Lecture Notes in Artificial Intelligence 4650

Edited by R. Goebel, J. Siekmann, and W. Wahlster

Subseries of Lecture Notes in Computer Science

Yang Cai (Ed.)

Digital Human Modeling

Trends in Human Algorithms

Springer

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Library of Congress Control Number: 2008939130

CR Subject Classification (1998): I.2.1, I.2, H.5, J.3-4, I.6, H.5, C.2

LNCS Sublibrary: SL 7 – Artificial Intelligence

ISSN 0302-9743
ISBN-10 3-540-89429-2 Springer Berlin Heidelberg New York
ISBN-13 978-3-540-89429-2 Springer Berlin Heidelberg New York

Springer is a part of Springer Science+Business Media

springer.com

Printed in Germany

Typesetting: Camera-ready by author, data conversion by Scientific Publishing Services, Chennai, India
Printed on acid-free paper SPIN: 12568277 06/3180 5 4 3 2 1 0

Virtual Clinical Therapy

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Abstract. Virtual Reality (VR) is more than a fancy technology: it is an advanced tool for assessment and clinical therapy. On one side, it can be described as an advanced form of human–computer interface that allows the user to interact with and become immersed in a computer-generated environment in a naturalistic fashion. On the other side, VR can also be considered as an advanced imaginal system: an experiential form of imagery that is as effective as reality in inducing emotional responses. The chapter outlines the current state of research in this area. In particular, it focuses its analysis both on the concept of "presence" and on the main applications of VR in clinical psychology: anxiety disorders, eating disorders and obesity, pain reduction. The open source "NeuroVR" VR system (http://www.neurovr.org) and its potential clinical applications are also introduced.

Keywords: Virtual Reality, Clinical Psychology, Human Computer Interface, Anxiety Disorders, Eating Disorders, Obesity, Pain Reduction.

1 Introduction

Virtual Reality (VR) enables computer to synthesize a three-dimensional graphical environment from numerical data. Using visual, aural or haptic devices, the human operator can experience the environment as if it were a part of the world. This computer generated world may be either a model of a real-world object, such as a house; or an abstract world that does not exist in a real sense but is understood by humans, such as a chemical molecule or a representation of a set of data; or it might be in a completely imaginary science fiction world.

A VR system is the combination of the hardware and software that enables developers to create VR applications. The hardware components receive input from user-controlled devices and convey multi-sensory output to create the illusion of a virtual world. The software component of a VR system manages the hardware that makes up the VR system. This software is not necessarily responsible for actually creating the virtual world. Instead, a separate piece of software (the VR application) creates the virtual world by making use of the VR software system.

Y. Cai (Ed.): Digital Human Modeling, LNAI 4650, pp. 90–107, 2008.

Typically, a VR system is composed of [1]:

– The *output tools* (visual, aural and haptic) that immerse the user in the virtual environment;
– The *input tools* (trackers, gloves or mice) that continually report the position and movements of the users;
– The *graphic rendering system* that generates, at 20-30 frames per second, the virtual environment;
– The *database construction and virtual object modeling software* for building and maintaining detailed and realistic models of the virtual world. In particular, the software handles the geometry, texture, intelligent behavior, and physical modeling of hardness, inertia, surface plasticity, of any object included in the virtual world.

Fig. 1. Different VR systems: Immersive (top left), Cave-based (top right), Augmented (bottom left) and Desktop (bottom right)

According to the hardware and software included in a VR system, it is possible to distinguish between:

– *Fully Immersive VR*: With this type of solution the user appears to be fully inserted in the computer generated environment (Fig. 1). This illusion is produced by providing immersive output devices (head mounted display, force feedback robotic arms, etc.) and a system of head/body tracking to guarantee the exact correspondence and co-ordination of user's movements with the feedback of the environment.

– *Desktop VR*: Uses subjective immersion. The feeling of immersion can be improved through stereoscopic vision (Fig. 1). Interaction with the virtual world can be made via mouse, joystick or typical VR peripherals such as Dataglove
– *CAVE*. Cave is a small room where a computer-generated world is projected on the walls (Fig. 1). The projection is made on both front and side walls. This solution is particularly suitable for collective VR experiences because it allows different people to share the same experience at the same time.
– *Telepresence*. Users can influence and operate in a world that is real but in a different location. The users can observe the current situation with remote cameras and achieve actions via robotic and electronic arms.
– *Augmented*. The user's view of the world is supplemented with virtual objects, usually to provide information about the real environment (Fig. 1). For instance, in military applications vision performance is enhanced by pictograms that anticipate the presence of other entities out of sight.

2 Virtual Reality in Clinical Psychology

The use of virtual reality (VR) in clinical psychology has become more widespread [2]. The key characteristics of virtual environments for most clinical applications are the high level of control of the interaction with the tool, and the enriched experience provided to the patient [3].

On one side, it can be described as an advanced form of human–computer interface that allows the user to interact with and become immersed in a computer-generated environment in a naturalistic fashion. On the other side VR can also be considered as an advanced *imaginal* system: an experiential form of imagery that is as effective as reality in inducing emotional responses.

These features transform VR in an “empowering environment”: a special, sheltered setting where patients can start to explore and act without feeling threatened [4, 5]. Nothing the patient fears can “really” happen to them in VR. With such assurance, they can freely explore, experiment, feel, live, and experience feelings and/or thoughts. VR thus becomes a very useful intermediate step between the therapist’s office and the real world [6].

Typically, in VR the patient learns to cope with problematic situations related to his/her problem. For this reason, the most common application of VR in this area is the treatment of anxiety disorders, i.e., fear of heights, fear of flying, and fear of public speaking [7-9].

Indeed, VR exposure therapy (VRE) has been proposed as a new medium for exposure therapy [2] that is safer, less embarrassing, and less costly than reproducing the real world situations. The rationale is simple: in VR the patient is intentionally confronted with the feared stimuli while allowing the anxiety to attenuate. Avoiding a dreaded situation reinforces a phobia, and each successive exposure to it reduces the anxiety through the processes of habituation and extinction.

VRE offers a number of advantages over in vivo or imaginal exposure. First, VRE can be administered in traditional therapeutic settings. This may makes VRE more convenient, controlled, and cost-effective than in vivo exposure. Second, it can also isolate fear components more efficiently than in vivo exposure. For instance, in

Fig. 2. The use of VR in the treatment of Obesity: A phase of the therapy (left) and a screen-shot of the virtual environment (right)

treating fear of flying, if landing is the most fearful part of the experience, landing can be repeated as often as necessary without having to wait for the airplane to take-off. Finally, the immersive nature of VRE provides a real life experience that may be more emotionally engaging than imaginal exposure.

However, it seems likely that VR can be more than a tool to provide exposure and desensitisation [2]. As noted by Glantz and colleagues [10], "VR technology may create enough capabilities to profoundly influence the shape of therapy." (p.92). Emerging applications of VR in psychotherapy include eating disorders and obesity [11, 12], posttraumatic stress disorder [13], sexual disorders [14], and pain management [15].

In fact, immersive VR can be considered an “embodied technology” for its effects on body perceptions [16-18]. First, VR users become aware of their bodies during navigation: their head movements alter what they saw. The sensorimotor coordination of the moving head with visual displays produces a much higher level of sensorimotor feedback and first person perspective (egocentric reference frame).

For example, through the use of immersive VR, it is possible to induce a controlled sensory rearrangement that facilitates the update of the biased body image. This allows the differentiation and integration of new information, leading to a new sense of cohesiveness and consistency in how the self represents the body. The results of this approach are very promising.

Riva and his group [11] have recently conducted the largest randomised controlled trial to date with 211 morbidly obese patients (Fig. 2). This trial compared Experiential Cognitive Therapy (CT) - a VR-based treatment for obesity - with nutritional and cognitive-behavioral approaches along with waiting list controls. The 6 months follow-up Experiential CT, in contrast to the other approaches, resulted in improvements in both the level of body image, satisfaction and self-efficacy; and in the maintenance of weight loss. Riva and colleagues used Experiential CT also in the treatment of Anorexia, Bulimia and Binge Eating [12, 19, 20]. A similar approach was presented and tested by Perpiña and colleagues [21] in the treatment of eating disorders.

Apparently, a similar approach may be used in other pathologies. Lambrey and Berthoz [18] showed that subjects use conflicting visual and non-visual information differently according to individual ‘perceptive styles’ (bottom-up processes) and that these ‘perceptive styles’ are made more observable with the subjects’ changing their perceptive strategy, i.e. re-weighting (top-down processes).

Viaud-Delmon and colleagues [22, 23] showed that subjects with high trait anxiety, like subjects with symptoms of panic and agoraphobia, have a strong dependence on a particular reference frame in which the sensory information is interpreted and in which the subject remains anchored. A VR experience aimed at modifying the sensory reference frame may be useful in speeding up the process of change. Future studies are needed both to identify specific perceptive styles in different pathologies and to define the best protocols for changing them.

Another medical field in which VR has been fruitfully applied is neuropsychological testing and rehabilitation. Here, the advantage of VR on traditional assessment and intervention is provided by three key features: the capacity to deliver interactive 3D stimuli within an immersive environment in a variety of forms and sensory modalities; the possibility of designing of safe testing and training environments, and the provision of "cueing" stimuli or visualization strategies designed to help guide successful performance to support an error-free learning approach [24-26].

Beyond clinical applications, VR has been revealed to be a powerful tool for behavioral neuroscience research. Using VR, researchers can carry out experiments in an ecologically valid situation while still maintaining control over all potential intervening variables. Moreover, VR allows for the measurement and monitoring of a wide variety of responses made by the subject [27].

3 From Presence to Transformation of Flow

Why is VR effective both as advanced imaginal system and as empowering environment? Typically, the clinicians’ answer is: because the patient is “*present*” in the virtual world.

Here we argue that the key feature of VR is that it offers an effective support to the activity of the subject [28] by activating a higher sense of “*presence”*. But what is presence?

To answer this question, the European Community has been funding, since 2002, the “Future and Emerging Technologies - IST” research program (http://www.cordis.lu/ist/fet/pr.htm).

If we check the outcomes of the funded projects, we can find two different but coexisting visions of presence [29]. A first group of researchers describes the sense of presence as a function of our experience of a given medium [30-38]: the *perceptual illusion of non-mediation* [33], produced by the disappearance of the medium from the conscious attention of the subject (*Media Presence*). The main advantage of this approach is its predictive value: the level of presence is reduced by the experience of mediation. The main limitation of this vision is what is not said. What is presence for? Is it a specific cognitive process? What is its role in our daily experience?

For this reason, a growing group of researchers considers presence a neuropsychological phenomenon (*Inner Presence*), evolved from the interplay of our biological and cultural inheritance whose goal is to increase emotional fidelity and perceptual accuracy to produce a strong sense of agency and control [39-51].

According to this vision, presence has a simple but critical role in our everyday experience: the control of agency (enaction of intentions) through the unconscious separation of "internal" and "external" [52, 53]. Within this view, *presence is defined as the non mediated (prereflexive) perception of successfully transforming an intention into action (enaction)* [54]. In the next paragraphs we will discuss deeply the main features of the psychology of "presence".

3.1 The Layers of Presence

From an evolutive viewpoint, the sense of presence allows the nervous system to *differentiate between "internal" and "external" states*.

As infants develop, they learn that some aspects of their perceptual worlds are part of the "self" (such as the movements of their arm) and that other aspects of the environment are "not self" (such as the movements of their mother's arm). Were it not for the development of the sense of presence, it would be impossible for the nervous system to reference perceptions to an environment beyond our boundaries.

Further, presence progressively evolves into the ability to distinguish external, perceived events from internal, imagined or otherwise internally-modeled events. From an evolutive viewpoint an organism must be able to answer these questions:

1. Is this happening to me, or to someone else? ("internal" vs. "external")
2. Is this true/acted or is it fiction/planned? ("imagined" vs. "perceived") and
3. Is this good or bad for me? ("relevant" vs. "non relevant")

It is important to note that the meaning of these questions progressively evolves in time: in early infancy it is related to the body only; in adulthood it also includes the social and cultural space (situation) in which the self is included.

In fact, even if presence is a unitary feeling, recent neuropsychological research has shown that, on the process side, it can be divided into three different layers/subprocesses (for a broader and more in-depth description see [53, 54]), phylogenetically different, and strictly related to the evolution of self [55]:

- *proto presence* (self vs. non self; Fig. 3);
- *core presence* (self vs. present external world; Fig. 4);
- and *extended presence* (self relative to present external world; Fig. 5).

More precisely we can define "*proto presence*" as the process of internal/external separation *related to the level of perception-action coupling (self vs. non-self)*. The more the organism is able to couple correctly perceptions and movements, the more it differentiates itself from the external world, thus increasing its probability of surviving. Proto presence is based on proprioception and other ways of knowing bodily orientation in the world. In a virtual world this is sometimes known as "spatial presence" and requires the tracking of body parts and appropriate updating of displays.

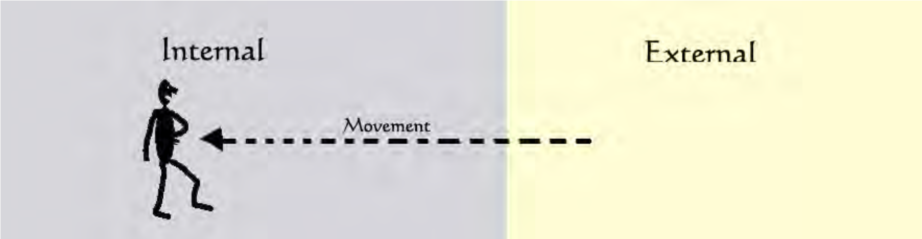

Fig. 3. Proto presence (reprinted with permission from Riva et al., 2004)

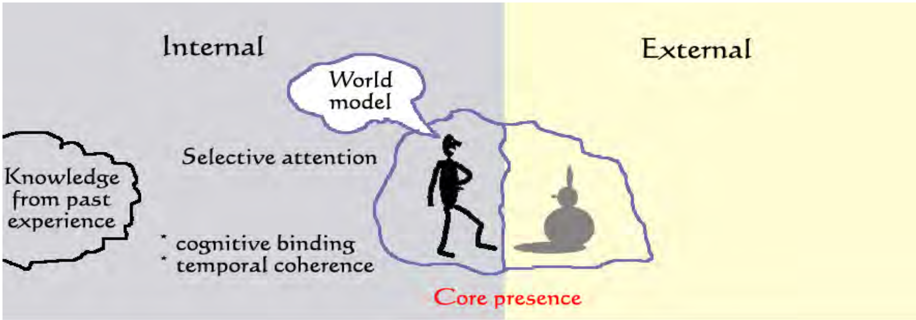

Fig. 4. Core presence (reprinted with permission from Riva et al., 2004)

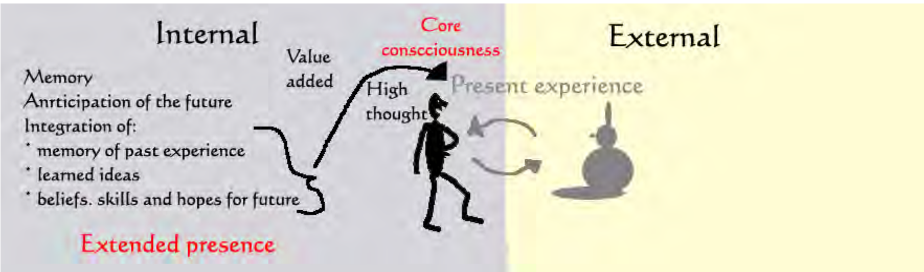

Fig. 5. Extended presence (reprinted with permission from Riva et al., 2004)

"Core presence" can be described as *the activity of selective attention made by the self on perceptions (self vs. present external world)*: the more the organism is able to focus on its sensorial experience by leaving in the background the remaining neural processes, the more it is able to identify the present moment and its current tasks, increasing its probability of surviving.

The role of "*extended presence*" is to *verify the relevance to the self of experienced events in the external world (self relative to the present external world)*. The more the self is present in relevant experiences, the more it will be able to reach its goals, increasing the possibility of surviving. Following the Sperber and Wilson approach

[56], an input is relevant when its processing yields a positive cognitive effect: a worthwhile difference to the self's representation of the world.

The experience of presence is maximized when the three layers are focused together on the same *external* events and actions.

3.2 The Feeling of Presence: From Breakdowns to Flow

On the other side, presence *provides the self with feedback about the status of its activity*: the self perceives the variations in the feeling of presence (*breakdowns* and *optimal experience*) and tunes its activity accordingly [54]. Subjectively, a higher level of presence is experienced by the self as a better quality of action and experience [44, 57].

The possible mechanism is outlined by the Embodied Cognition theories [58]: during self-produced actions a sensory prediction of the outcome of the action is elaborated along with the actual motor command. The results of the comparison (which occurs at a sub-personal level) between the sensory prediction and the sensory consequences of the act can then be utilized to track any possible variation in its course. If no variations are perceived, the self is able to concentrate on the action and not on its monitoring.

Winograd and Flores [59] refer to presence disruptions as *breakdowns: a breakdown* occurs when, during our activity, an aspect of our environment that we usually take for granted becomes part of our consciousness. If this happens, we shift our attention from action to the object or environment to cope with it. To illustrate, imagine sitting outdoors engrossed in reading a book on a pleasant evening. As the sun sets and the light diminishes, one continues reading, engrossed in the story until one becomes aware that the light is no longer suitable for reading. In such conditions, before any overt change in behavior, what we experience is a breakdown in reading and a shift of attention from the book to the light illuminating the book.

It is interesting to consider why we experience these breakdowns. Our hypothesis is that breakdowns are a sophisticated evolutionary tool used to control the quality of experience that ultimately enhances our chances of survival. As a breakdown occurs we experience a lower level of presence. This reduces the quality of experience, and leads us to confront environmental difficulties through an attentive shift.

On the other side we have optimal experiences. According to Csikszentmihalyi [60, 61], individuals preferentially engage in opportunities for action associated with a positive, complex and rewarding state of consciousness, defined as "optimal experience", also defined as "flow." There are some exceptional situations in real life in which the activity of the subject is characterized by a higher level of presence. In these situations the subject experiences a full sense of control and immersion. When this experience is associated with a positive emotional state, it can create a flow state. An example of flow is the case where a professional athlete is playing exceptionally well (positive emotion) and achieves a state of mind where nothing else matters but the game (high level of presence). For Ghani and Deshpande [62] the two main characteristics of flow are (a) the total concentration in an activity and (b) the enjoyment which one derives from the activity. Moreover, these authors identified two other factors affecting the experience of flow: a sense of control over one's environment and the level of challenge relative to a certain skill level.

Following this vision, it is possible to design mediated situations that elicit optimal experiences by activating a high level of presence [28, 63-65]. Optimal experiences promote individual development. As underlined by Massimini and Delle Fave, [66] "To replicate it, a person will search for increasingly complex challenges in the associated activities and will improve his or her skill, accordingly. This process has been defined as *cultivation;* it fosters the growth of complexity not only in the performance of flow activities but in individual behavior as a whole." (p. 28).

3.3 Transformation of Flow in Clinical Psychology

According to this vision, existing professional treatments should include positive peak experiences because they serve as triggers for a broader process of motivation and empowerment. Within this context, the *transformation of flow* can be defined as a person's ability to draw upon an optimal experience and use it to marshal new and unexpected psychological resources and sources of involvement.

We hypothesize that it is possible to use VR to activate a transformation of flow to be used for clinical purposes [28]. The proposed approach is the following: first, identify an enriched environment that contains *functional* real-world demands; second, use the technology to enhance the level of presence of the subject in the environment and to induce an optimal experience; third, allow cultivation by linking this optimal experience to the actual experience of the subject.

To verify the link between advanced technologies and optimal experiences, the "V-STORE Project" recently investigated the quality of experience and the feeling of presence in a group of 10 patients with Frontal Lobe Syndrome involved in VR-based cognitive rehabilitation [67]. On one side, the project used the Experience Sampling Method [68] for repeated on-line assessments of the external situation and the emotional, cognitive and motivational components of daily experience during one week of these patients, including traditional cognitive rehabilitation and sessions of exposure to V-STORE VR environment. On the other side, after the VR experience the ITC-Sense of Presence Inventory [69] was used to evaluate the feeling of presence induced by the VR sessions. Findings highlighted the association of VR sessions with both positive effects and a high level of presence. In particular, during the VR sessions, the "spatial presence," the first scale of the ITC-Sense of Presence Inventory, significantly correlated with the positive psychological feelings of "being free" ($r = 0.81$, $p < 0.01$) and "being relaxed" ($r = 0.67$, $p < 0.05$).

The transformation of flow may also exploit the plasticity of the brain producing some form of functional reorganization [70]. Recent experimental results from the work of Hoffman and his group in the treatment of chronic pain [71-73] also might be considered to foster this vision. Few experiences are more intense than the pain associated with severe burn injuries. In particular, daily wound care - the cleaning and removal of dead tissue to prevent infection - can be so painful that even the aggressive use of opioids (morphine-related analgesics) cannot control the pain. However it is well known that distraction - for example, by having the patient listen to music - can help to reduce pain for some people. Hoffman and colleagues conducted a controlled study of the efficacy of VR as an advanced distraction by comparing it with a popular Nintendo video game. The results showed dramatic reductions in pain ratings during VR compared to the video game [74].

Further, using a functional magnetic resonance imaging scanner, they measured pain-related brain activity for each participant during conditions of virtual reality and without virtual reality in an order to randomized study [73]. The team studied five regions of the brain that are known to be associated with pain processing: the anterior cingulate cortex, primary and secondary somatosensory cortex, insula, and thalamus.

They found that during VR, the activity in all the regions showed significant reductions. In particular, they found direct modulation of pain responses within the brain during VR distraction. The degree of reduction in pain-related brain activity ranged from 50 percent to 97 percent.

4 VR in Clinical Psychology: From Theory to Practice

Although it is undisputable that VR has come of age for clinical and research applications, the majority is still in the laboratory or investigation stage. In a recent review, Riva [2] identified four major issues that limit the use of VR in psychotherapy:

- The lack of standardization in VR hardware and software, and the limited possibility of tailoring the virtual environments (VEs) to the specific requirements of the clinical or the experimental setting;
- The low availability of standardized protocols that can be shared by the community of researchers;
- The high costs (up to 200,000 US$) required for designing and testing a clinical VR application;
- Most VEs in use today are not user-friendly; expensive technical support or continual maintenance are often required.

To address these challenges, we have designed and developed NeuroVR (http://www.neurovr.org), a cost-free virtual reality platform based on open-source software that allows non-expert users to easily modify a virtual environment (VE) and to visualize it using either an immersive or non-immersive system.

The NeuroVR platform is implemented using open-source components that provide advanced features; this includes an interactive rendering system based on OpenGL which allows for high quality images. The NeuroVR Editor is realized by customizing the User Interface of Blender, an integrated suite of 3D creation tools available on all major operating systems, under the GNU General Public License; this implies that the program can be distributed even with the complete source code. Thanks to these features, clinicians and researchers have the freedom to run, copy, distribute, study, change and improve the NeuroVR Editor software so that the whole VR community benefits.

4.1 The NeuroVR Editor

The majority of existing VEs for psychotherapy are proprietary and have closed source codes, meaning they cannot be tailored from the ground up to fit specific needs of different clinical applications [2]. NeuroVR addresses these issues by providing the

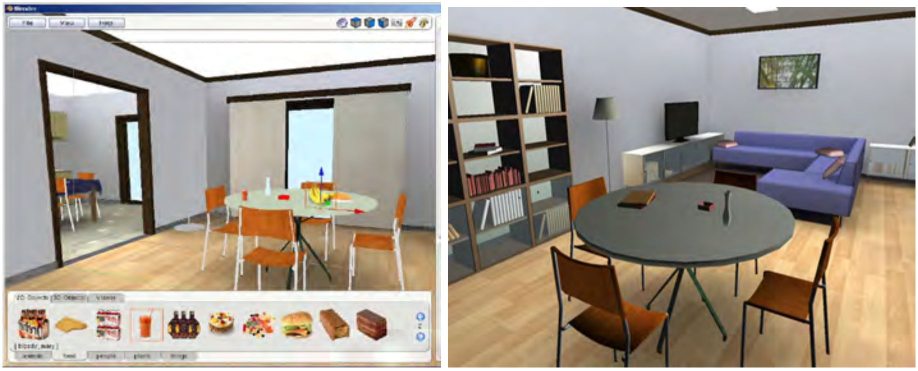

Fig. 6. The NeuroVR Editor (*left*) and Player (*right*)

clinical professional with a cost-free VE editor, which allows non-expert users to easily modify a virtual scene, to best suit the needs of the clinical setting.

Using the NeuroVR Editor (see Fig. 6), the psychological stimuli/stressors appropriate for any given scenario can be chosen from a rich database of 2D and 3D objects, and easily placed into the pre-designed virtual scenario by using an icon-based interface (no programming skills are required). In addition to static objects, the NeuroVR Editor allows overlay on the 3D scene video composited with a transparent alpha channel. The editing of the scene is performed in real time, and effects of changes can be checked from different views (frontal, lateral and top).

The NeuroVR Editor is built using Python scripts that create a custom graphical user interface (GUI) for Blender. The Python-based GUI allows hiding of all the richness and complexity of the Blender suite, and therefore to expose only the controls needed to customize existing scenes and to create the proper files to be viewed in the player.

Currently, the NeuroVR library includes different pre-designed virtual scenes representing typical real-life situations, i.e., the supermarket, the apartment, the park.

These VEs have been designed, developed and assessed in the past ten years by a multidisciplinary research team in several clinical trials, which have involved over 400 patients [75]. On the basis of this experience, only the most effective VEs have been selected for inclusion in the NeuroVR library.

An interesting feature of the NeuroVR Editor is the option to add new objects to the database. This feature allows the therapist to enhance the patient's feeling of familiarity and intimacy with the virtual scene, i.e., by using photos of objects/people that are part of the patient's daily life, thereby improving the efficacy of the exposure [75]. Future releases of the NeuroVR Editor software may also include interactive 3D animations controlled at runtime. A VRML/X3D exporter and a player for PocketPC PDAs are planned Blender features, as well.

4.2 The NeuroVR Player

The second main component of NeuroVR is the Player, which allows navigation and interaction with the VEs created using the NeuroVR Editor (Fig. 6).

NeuroVR Player leverages two major open-source projects in the VR field: Delta3D (http://www.delta3d.org) and OpenSceneGraph (http:// www.openscenegraph.org). Both are building components that the NeuroVR player integrates with ad-hoc code to handle the simulations.

The whole player is developed in C++ language, targeted for the Microsoft Windows platform but fully portable to other systems if needed. When running simulation, the system offers a set of standard features that contribute to increase the realism of the simulated scene. These include collision detection to control movements in the environment, realistic walk-style motion, advanced lighting techniques for enhanced image quality, and streaming of video textures using alpha channel for transparency.

The player can be configured for two basic visualization modalities: immersive and non-immersive. The immersive modality allows the scene to be visualized using a head-mounted display, either in stereoscopic or in mono-mode; compatibility with head-tracking sensor is also provided. In the non-immersive modality, the virtual environment can be displayed using a desktop monitor or a wall projector. The user can interact with the virtual environment using either keyboard commands, a mouse or a joypad, depending on the hardware configuration chosen.

5 Conclusions

The basis for the VR idea is that a computer can synthesize a three-dimensional (3D) graphical environment from numerical data. Using visual, aural or haptic devices, the human operator can experience the environment as though it were a part of the world.

The key characteristics of virtual environments for most clinical applications are the high level of control of the interaction with the tool, and the enriched experience provided to the patient [3]. For these features, VR is described as a “simulation technology” with, and within which, people can interact. In summary, VR provides a new human-computer interaction paradigm in which users are no longer simply external observers of images on a computer screen but are active participants within a computer-generated three-dimensional virtual world [76].

In this chapter we also suggest the possibility of using Virtual Reality for a new breed of clinical applications based on a strategy defined as “transformation of flow.” The vision underlying this concept arises from “Positive Psychology” [77]. According to this vision, existing professional treatments should include positive peak experiences because they serve as triggers for a broader process of motivation and empowerment.Within this context, the *transformation of flow* can be defined as a person's ability to draw upon an optimal experience and use it to marshal new and unexpected psychological resources and sources of involvement.

We identify the feeling of “presence,” the feeling of being in a world that exists outside the self, as the theoretical link between the technology and transformation of flow. The technology is used to trigger a broad empowerment process within the flow experience induced by a high sense of presence.

VR can facilitate these processes: by inducing a feeling of presence, VR may support a person's actions, allowing a greater subjective sense of personal efficacy.

Even if the potential impact of VR in clinical psychology is high, the majority of the existing clinical VR applications are still in the laboratory or investigation stage. In a recent review, Riva [2] identifies four major issues that are limiting the use of VR in psychotherapy:

- The lack of standardization in VR hardware and software, and the limited possibility of tailoring the virtual environments (VEs) to the specific requirements of the clinical or the experimental setting;
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To address these challenges, we have designed and developed NeuroVR (http://www.neurovr.org), a cost-free virtual reality platform based on open-source software that allows non-expert users to easily modify a virtual environment and to visualize it using either an immersive or non-immersive system.

Currently, the NeuroVR library includes a limited number of VEs addressing specific phobias (i.e. fear of public speaking, agoraphobia), obesity and eating disorders. However, these pre-designed environments can be easily adapted for targeting other clinical applications. Moreover, it is envisioned that the 250,000 people worldwide Blender user community will contribute to extend the NeuroVR library, developing new VEs which can be tailored by the clinical professionals for a range of clinical and experimental needs.

A future goal is also to provide software compatibility with instruments that allow collection and analysis of behavioral data, such as eye-tracking devices and sensors for psychophysiological monitoring. Beyond clinical applications, NeuroVR provides the VR research community with a cost-free, open source "VR lab", which allows creation of highly-controlled experimental simulations for a variety of behavioral, clinical and neuroscience applications.

Acknowledgments. The present work has been supported by the Italian MIUR FIRB programme (Project "Neurotiv - Managed care basata su telepresenza immersiva virtuale per l'assessment e riabilitazione in neuro-psicologia e psicologia clinica" - RBNE01W8WH) - and by the European Union IST Programme (Project "INTREPID - A Virtual Reality Intelligent Multi-sensor Wearable System for Phobias' Treatment" - IST-2002- 507464).

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