Adding intelligence to virtual reality

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Abstract. Virtual reality systems have reached a certain level of maturity in terms of visual and aural quality, but the sense of presence also requires believably behaving environment. A new field of adding intelligence into virtual environments is emerging. We describe shortly the field of virtual reality, and how AI can be applied there. We outline the possibilities of using AI to enhance existing applications, like a training environment for astronauts

1 INTRODUCTION

Creating an immersive Virtual Environment (VE) for a human user is an interdisciplinary challenge, which takes advantage of knowledge from human sensory system, psychology, human anatomy, electronics, measurement and sensor technology, computer sciences, computer graphics, display technologies, optics, physics, audio systems, acoustics and psychoacoustics, for example. Human senses are fooled to believe in computer-generated simulations, but the models of the real world can never be authentic if all the behavior and action encountered in reality are not modelled accurately enough. There is an increasingly growing interest in developing believably behaving actors in Virtual Environments to improve the immersion. Intelligent Virtual Environments (IVE) is an emerging research field; it merges Artificial Intelligence (AI) and Artificial Life (AL) technologies with Virtual Reality (VR). An IVE is a virtual environment resembling the real world, inhabited by autonomous Intelligent Virtual Agents (IVA) exhibiting a variety of behaviors. Examples of IVEs include simulations, where agents interact with each other in a virtual environment; training simulators, where the trainee cooperates or takes into account other agents (people or machines) acting in the scenario; and computer games, where the player interacts with many different kinds of characters. Real-time simulation of people and other autonomous agents makes the immersive experience of virtual worlds more realistic. Advanced modeling of believable human individual and group behavior takes virtual environments, real-time simulations, computer games, and computer aided training systems to the next level.

2 VIRTUAL REALITY SYSTEMS

Virtual reality is an old concept, yet arcane to major public even nowadays – most people have heard about it and have some sort of conception of data helmets, data gloves and term VRML.

2.1 Virtual reality

Virtual reality has two different common definitions. Firstly, virtual reality is a technique for interactive 3D visualization. Some current 3D games satisfy the definition – the user may move somewhat freely to any desired direction in a 3D-environment. A stricter definition requires having a powerful feeling of immersion – feeling of ”really being there”. In this view, VR is a technology to fool senses – in VR we try to tell human senses about simulated surroundings. These sensory stimulations are controlled by computer, thus creating a virtual environment. All in all, virtual reality may be defined as computer-generated interactive, immersive 3D environment [16].

Virtual Environment (VE) is a commonly used term in context with virtual reality. The differences between VR and VE are not big and the terms are sometimes used interchangeably. We consider VE to be the digitally generated environment that the user of VR occupies. In a sense, a VR system could be thought as an interface between the real world user and the virtual environment. Also, virtual environments can be observed with normal computers like regular programs with common PC-hardware. Yet this kind of setup has poor immersive capabilities and cannot be considered as a true VR system. It can be said that VE is a critical, but not the only part of VR. In addition to realistic sense stimulus, the level of immersion depends on the virtual environment and how believably it behaves and can be manipulated. Objects must fall, break and act like in the real world.

Augmented Reality is technically very close to VR. It differs from the latter in that 3D-visualizations are used to present only the desired 3D-objects, while everything else is real. In other words, augmented reality means that computer-generated 3D objects are added to normal field of view.

2.2 Motivation for using VR

VR has been studied for a few decades now, the early efforts being cumbersome and not so convincing. Fortunately during the last ten years VR technology has evolved considerably. Nowadays the possibilities of utilizing virtual reality are numerous especially in the fields of science and industry. Potentially VR can avail anywhere where the real environment is expensive, difficult, hazardous, or even impossible to occupy.

A good example is prototyping: until recently manufacturers of packaged and investment goods, e.g. car manufacturers have had to construct many prototypes per car series development. This is very expensive, time-consuming and wasteful. Using virtual prototypes instead of real ones would result in huge savings. At 2000 Volvo estimated that the cost benefit ratio of use of VR would be at least 40%. This means 10-20% reduction in costs (roughly 6 Million Euros) for one car series development, while the development process can be decreased from 60 to 40 months [23]. And all these figures were given 3 years ago – after that there have been huge progress in VR. Construction industry can also use VR for same kind of purposes: previously prototypes of houses and buildings were not viable. VR

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enables them to build prototypes and to sell buildings by letting people walk in them virtually (in natural size) before construction. This also aids companies in adapting new ways of doing business, like construction on-demand and designed-as-you-want-it –basis.

Virtual reality also offers a flexible platform for different kinds of training environments. It provides a safe and relatively cheap environment for training hazardous or expensive tasks. Flight simulators for fighter pilot training were actually the first applications of VR. The pilots were trained in custom made cockpits wearing helmets that did stereoscopic images. Since then technology has made it possible to widen the training to everything from medical to military applications. In astronaut training there has been no way for trainees to have hands-on training on earth. Mockups have been built but they are far from realistic zero gravity environment. Furthermore, while astronauts should be able to move realistically from one place to another, the moving of mockup is not a simple task. Now, with VR they can be trained on ground, while giving their senses a realistic feeling of being up in space

In addition to real world simulations, VR allows users to visualize micro- or macroscopic entities in a way that would not be physically possible in the real world. For example doctors and medical students can explore human tissue in nanoscopic scale. Another common application is visualization of scientific data in its original context. These types of applications add the virtual environment with visible representation of information that is usually invisible. For instance engineers can see the heat dissipation from a house structure at design phase.

2.3 Computing architectures

Virtual reality is an exceedingly demanding field for computer systems. It combines high quality rendering of graphics and sound to complex behaviour of the virtual environment and user interaction together with strict real-time requirements. Traditionally VR systems have been built utilizing a centralized architecture where expensive supercomputer is responsible for all calculations. Even today this kind of architecture is the most common design for VR systems. During the last few years PC-based cluster architecture has started to be a feasible alternative because the performance of low-cost PC hardware has grown exponentially especially in graphics and networking. Cluster architecture is based on distribution of computing between many normal PC computers. They are connected together via a high-speed network, resulting a single powerful unit. This way it's possible to create a unified high performance VR system that comes close to traditional centralized VR systems in performance but costs only a fraction of the price. More thorough discussion about VR architectures can be found in [19].

2.4 Interaction

Interaction is a critical element of VR systems. First of all the stimulus for user's senses, that is, the output of the system, must feel as real as possible. Intuitive and well designed interfaces for user interaction can also increase the level of immersion extensively.

2.4.1 Output devices

To create visually strong immersion, VR systems must give the user an accurate feeling of being in a 3D environment. Compared to normal monitors, VR display devices add the support for stereoscopic projection and the viewpoint changes caused by the users head movements. Stereoscopic projection is made by computing separate images from the virtual viewpoints of the users eyes, and showing a different image to each eye. There are two major paradigms of VR display devices. Head Mounted Displays (HMD) are constructed from small display devices that are attached to a helmet or some kind of glasses that the user wears. Spatial Immersive Displays (SID), commonly known also as projection-based displays, surround the user with large display screens with images projected on them. The first system using this kind of approach was called CAVE[3] [6].

After sight, hearing is the second most important sense to stimulate in VR systems. Current sound rendering systems are able to produce quite realistic 3-dimensional sound environments, see e.g. [3] for more details. Research on producing artificial stimulus for other senses has also been made. For example there are already devices that can create sense of touch or feeling of motion to some extent, but these are still expensive and rather seldom used.

2.4.2 User Interaction

The more easily user can manipulate the virtual objects and environment, the more believable the application probably is. Due to the nature of VR, user interaction has to be accomplished with special input devices. The VR interaction devices try to use more lifelike methods than the traditional computer devices. For example, a VR system can be equipped with speech recognition software so the user can issue spoken commands to the system. Data gloves are used to get information about the users fingers and hand gestures, and they can also give force feedback to the user. A tracker detects body part positions of the user, thus enabling the users movement in the virtual environment. Input devices for VR systems are presented e.g. in [16].

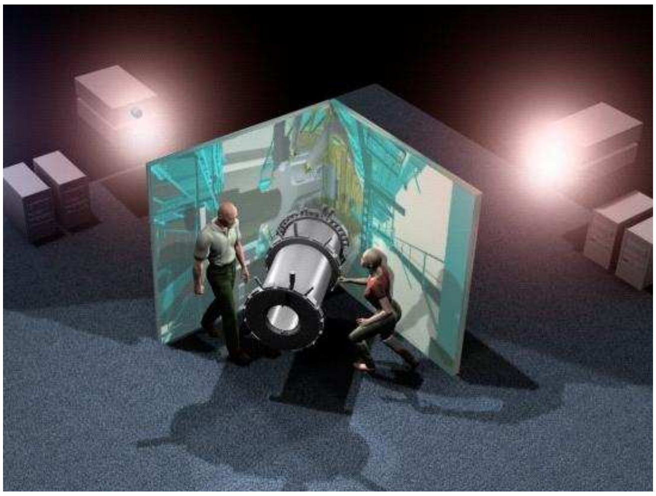

Figure 1. Lumeportti hardware configuration including two back projected screens and four rendering PCs and projectors for passive stereo.

2.5 An example system - Lumeportti and VEView virtual reality sofware platform

Lumeportti is an example of back projected stereo system, designed and implemented at VTT Information Technology. The hardware set-up is controlled by VEView, a software platform developed in the

[3] CAVE is a trademark owned by the University of Illinois, Board of Trustees and exclusively licensed to Fakespace Systems Inc.

VIEW EU project [5]. VEView is a modular, distributed system composed of several services running in different computers. The platform is also scalable so that the same software can be used on different types of hardware configurations, ranging from simple desktop applications to VR systems based on multiple projection walls. The software platform can be currently run on WindowsXP and Windows 2000 systems.

VEView software platform provides a programming API (Application Interface) and core system services to implement virtual reality applications. The applications can take advantage of stereo graphics, multimodal interaction services for data glove and speech input, head and hand tracking, audio feedback and physics based real-time simulation of object behavior.

Lumeportti installation, which is a two-wall setup described in figure 1, is currently in use at VTT Information Technology. The hardware set-up includes the following main components: four rendering PCs (2.0 GHz CPU, 512RAM, GeForce4 based graphics cards), a control PC (similar to rendering PCs), a laptop for data glove connections and speech recognition, an audio server PC, 5th Dimension data gloves, IS600 Intersense tracker or A.R.T. optical tracker and Gigabit switch for networking all the computers together. All in all, this hardware configuration costs one-tenth of a corresponding supercomputer-based VR system.

2.5.1 *Astronaut training application*

A virtual reality application prototype for astronaut training was designed, implemented and installed into Lumeportti system during the VIEW EU project [5] that studied the possibilities of VR and VE for industry use. The application provides a simulated zero gravity environment for the astronauts students to practise hands-on assembly sequences normally performed in space station. The application has a multimodal interaction logic that utilizes a combination of speech recognition, datagloves and tracking of the user's positions. A preliminary set of user tests were conducted and they implicated the necessary further development steps from the usability stand point of view for zero gravity training. On the other hand the test implicated that virtual reality simulation in this field can be beneficial.

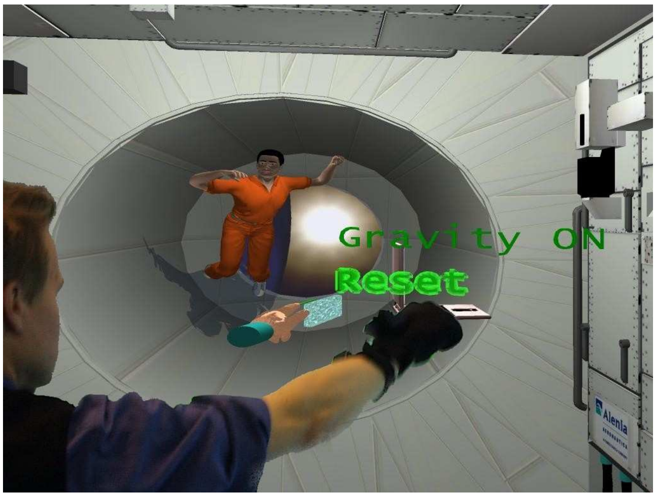

Figure 2. VEView astronaut training application is beign operated in the Lumeportti system.

2.5.2 *Architecture visualization application with walking characters*

We have implemented an architecture visualisation application for the Lumeportti platform. It utilises tools that can be used to export scenes from various 3D-modeling programs to the visualisation application. The user can navigate in the architectural models that are populated by virtual characters that walk inside the building under inspection. The characters give a sense of scale to the user and a better sense of presence in the virtual environment. The character animations must be generated beforehand either from motion capture data from real moving humans or synthetically with a character animation program. Currently the virtual characters do not have AI components to direct their actions and their behavior is determined by simple scripts. We foresee that capability of an interesting and necessary development step in future projects.

3 AI IN VIRTUAL REALITY

Creating an immersive virtual experience for a human user is an interdisciplinary challenge, which takes advantage also of AI technologies to improve the user interfacing, the virtual reality system and the believability of the contents of virtual worlds. Aylett et al. call the merging of AI and VEs Intelligent Virtual Environment (IVE) if it concerns the virtual world itself, and Intelligent Virtual Reality System (IVRS) if it concerns the system that creates and renders the world [1].

Figure 3 depicts a reference model for a virtual reality system, and illustrates how AI research areas relate to its subsystems. Through the user interface a user observes and takes part in a virtual world simulation, where virtual agents interact with the environment and each other. The simulation is responsible for all the change and behavior in the environment, and contains also domain knowledge for describing the simulation scenario. The content production subsystem creates contents for the virtual world off-line.

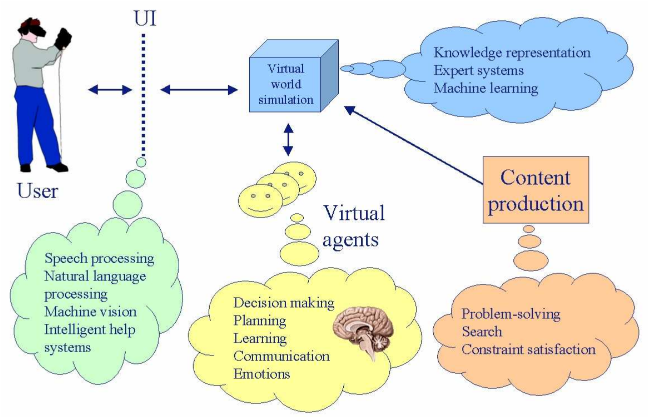

Figure 3. A reference model for a virtual reality system.

Machine vision can be used in human-computer interfacing to recognise a users position, pose, movements and actions (see [14] for an example), and speech recognition and natural language processing can be used in controlling the system or giving commands to virtual agents operating in the world. A user interface can provide the user with some intelligent help services that guide the user in the virtual world simulation (see [10]) or teach him to use the VR system (see [22]).

When simulation is introduced in a VE, a graphical presentation is not enough anymore, and more knowledge must be attached to the objects taking part in the simulation. Their physical extensions need to be defined for collision detection, as well as their masses, friction coefficients, strength, etc. One of the issues AI researchers have been tackling over the years is how the facts of the world, objects and their relations are described. The research on knowledge representation should not be neglected when VR developers manipulate objects at the knowledge level [18]. Simulation requires processing power, and it is not always possible to include the finest resolution simulation model in a real-time VR system. An expert system, such as a rule-based system, could be used to approximate the simulation of the world. Also a qualitative reasoning approach [4] could be used. Machine learning techniques can be used to map the actions to physical behavior of objects. Learning can be done off-line using a fine resolution simulation model, and then the learned mapping can be used to approximate the behavior of the objects in the real-time simulation.

Modeling the behaviour of machines (computers, robots etc.) is also of relevance. Often it is impractical to simulate machine operations accurately, but a well-crafted expert system might reproduce the machines behaviour accurately enough.

Problem-solving is needed when contents for a VE simulation is produced. Many constraints must be solved when objects and graphical components are attached together as a realistic virtual representation of a certain environment.

3.1 Virtual agents

However visually appealing a VE is, or however intuitive VR system is used to render it, the immersive experience is limited if the world is static, and empty of change and behavior [1]. To improve the sense of presence the first thing to do is to simulate the interactions between objects by introducing the laws of physics in the virtual world. This is not enough if we consider creating virtual worlds resembling our world, where all kind of autonomous agents, humans, animals, and machines, interact with each other. There is an increasingly growing interest in developing believably behaving actors in virtual environments in many fields, like computer games [17], training simulators [11], animation [12] and film industry [9], and new methods are being developed for modeling complex interactions and behavior experienced in the real world.

3.1.1 Believable behavior

Believable behaviour is a difficult term to define properly, but considering for instance animation we can easily tell the difference between an animated and a real human walking, even though we may be unable to give an objective reason why a motion is unrealistic [8]. The same applies to higher levels of virtual agent control. By going around in a virtual world, we can easily tell whether the actors plan their moves and react to our presence believably or not.

3.1.2 Controlling agents

The spectrum of techniques for controlling virtual characters is wide, and range from those that handle individuals not as separate units, but as flows, to those that represent each individual as being controlled by a virtual brain. Computer game and animation industries have used flow models to create large crowds of characters, especially because of their low computing cost per character. Advanced computer games and VR systems use agent-based models to create believable individual characters in virtual worlds. The difference between games and VR is that a computer game must usually run on a single computer, whereas a VR system can be built on a distributed processing architecture, which enables more processing power reserved for the behavior simulation. This does not necessarily mean that VR systems have more believable agents, but more complex methods in terms of memory consumption and processing time can be studied within VR systems. Bosnia Mission Rehearsal [15] is an example of a VR system, where a virtual brain architecture was developed for controlling virtual humans in a military simulation. Another example of a virtual brain architecture can be found in [7], which was demonstrated in controlling virtual dogs.

3.1.3 Sense, plan, act

Agents operating in virtual worlds can be understood as physically embodied agents, and they face the same kind of problems as robots do in the real world. They have to use their virtual brains to sense the world, model their surroundings, and plan their acts in order to achieve their goals, possibly using some mechanisms for learning and improving their performance. The complexity of a virtual brain depends on the complexity of the physical model of the virtual body the brain is controlling, on the complexity of the interactions between the body and the world, and on the complexity of the goals the virtual body is supposed to achieve.

3.1.4 Sensory honesty

Unlike with the case of real robots operating in the real environment, the agents in a virtual world could be programmed to have access to the world model, i.e. to all the information there is available without any overhead coming from mechanisms for sensing and world modeling. However, it appears that omniscient agents are not ideal for modeling believable characters, since real world agents do not see around corners, and do not have access to other agents brain models. Sensory honesty means that a virtual agent does not know what it has not perceived and memorized. Agents build up their own individual models of the world around them, and interesting features emerge, as explained in [10]. Agents can make honest mistakes and be surprised, because their world models might not be correct in every sense. Agents can find rules of behavior that generalize across many objects, including ones it has never seen. For example, if some eatable thing was red and small, an agent may try to eat a new thing it finds, if it is also red and small enough.

3.1.5 Emotions

Evolution has equipped animals with emotions, which affect the behavior and help to survive in situations where their purely instinctual or limitedly rational behaviour would not help. Emotions are a very clever brain mechanism to cope with all the information and uncertainty there is in the environment, and they cannot be neglected from believable virtual character modeling. Integration of emotions in virtual environments needs knowledge from psychology and models for determining how the state of the world affects the emotions, and how emotions affect the actions of a virtual character. The use of emotions has been demonstrated for example with virtual dolphins [20], included in a computational mind model [2], and used in training simulations like in the Bosnia Mission Rehearsal Exercise [13]. Emotions affect the character modeling in all levels of control from animation to the highest level of cognition. The way a character moves, communicates, plans its actions, and acts are all affected by an emotional state the character is experiencing. Emotions are also included in human face modeling, as real humans use their faces subconsciously to communicate emotions and attitudes non-verbally. Personality modelling goes hand in hand with the emotion modelling. A persons reactions to different events in the environment are defined by her personality, but the reactions are produced through the emotional states she will go through.

3.2 Future trends

Laird et al. stated that computer games are the application that will need human-level AI [17]. Computer game industry is definitely forced to put more and more resources on game-AI research, as the audience is ranking games not only based on the graphics, but also based on the believability and variability of the behavior of actors in the games. Laird et al.s ideas can be extended to comprise also other types of VEs like virtual reality systems. All VEs will need human-level AI, not only computer games. All kinds of training simulations, where the trainee co-operates or otherwise has to take into account other people operating in the environment, would benefit from realistic virtual humans.

Today researches of VR, AI and computer gaming have different standpoints and perspectives, and the field of intelligent virtual environments is still very immature. But the field is anyhow very active, and we can expect that in the future there will be methodologies and toolkits, which help developers to add autonomous believable characters to virtual environments. Especially, the success in creating virtual humans, so called avatars, with advanced human behavior modeling opens up unparalleled possibilities for applications. There is no need to pass the Turings test [24], but still virtual humans may appear very natural in restricted cases, and constitute the basis for many systems for training, education and entertainment where interactions between humans play an important role. There could be tools for architects to add virtual people in the virtual models of buildings, shopping centres, and urban areas they are designing, and to see how real people would live, work and feel in the environment. Policemen could rehearse handling different kinds of people with different temperament and character in different training scenarios in virtual reality. Peacekeepers could be trained to get along with people coming from different cultures with different personalities. Rescue teams could learn how to treat wounded and calm down panicked people in simulated accidents and terrorist attacks. Flight personnel could rehearse serving the customers on a flight in a virtual training simulator.

3.3 Adding synthetic characters to VR applications

We are interested in putting more behaviour into the contents of applications for architectural design and virtual astronaut training. The implementations of avatars have so far been based on scripted behaviour and walking animations with no higher level cognition or interaction between the user and the avatars. Also simple control mechanisms for navigation have been developed to prevent avatars from bumping into walls or each other.

[5] Model of the building is courtesy of Adactive OY, Finland, `http://www.adactive.fi/`.

Figure 4. Avatars walking scripted paths in an architecture[5] visualization application running on the Lumeportti system.

More advanced behaviour is needed before virtual humans can be utilised in simulations and their presence would improve the immersion significantly. Using scripts and animations is a conceptually simple but quite laborious solution for building versatile behaviour. The believability of characters depends on the ingenuity and hard work of the animators and script developers, who make the computer create the right behaviour.

Scripting is suitable for predefined static scenarios, but not for dynamic and unpredictable environments, where a user has more degrees of freedom to interact with the characters. Mechanisms for acting as a function of triggered events could be used to improve the autonomy and reactivity of the characters. Anyhow, we believe that only with interactive virtual brain processes that control character's actions the believability can be improved significantly. Virtual brains determine how avatars sense and model the world around them, plan their acts to achieve their goals, control the animation layer fluently, interact with the user and react to unexpected changes in the simulation. Virtual reality systems built on cluster architectures could, in principle, handle the computational complexity of many virtual brains in the simulation

In architectural applications the avatars should be aware of their surroundings, so that they could navigate using doors, stairs, escalators, and lifts taking into account other people and possible dynamic changes in the environment. This kind of avatar behavior could be used to visualise the buildings with people living and working there, and to figure out the scale of different structures and the applicability of the construction design for humans. With advanced physics modelling avatars could be used in crowd simulations, for instance evacuation simulations. When an alarm goes off the avatars stop their daily tasks, and start to move towards the outer doors and assembly areas. The purpose of the simulation is to find out where the possible bottlenecks are, are the corridors and pathways too narrow, how fast people can get out, and are there possibly dangerous structures in the architectural design considering the movements of large crowds.

In astronaut training applications the system could provide the user with assistance and help in a training scenario to learn the right procedures for using devices in a space station. The assistance system's user interface could be presented as a synthetic tutor character that would provide help and hints to the trainee during the training session. Steve is an example of an intelligent tutoring system [22] and it has also been applied for example in a human simulation tool for planning and simulating maintenance tasks in nuclear power plants [21].

Another way of applying AI in astronaut training would be the use of virtual astronauts in team work training. The training time of astronauts is expensive, and it is difficult to allocate a common training session from their calendars. Therefore, it would be preferable if astronauts could also rehearse the right procedures by themselves with virtual astronauts, instead of always having all the real astronauts gathered together in a virtual training session. Assemblage or maintenance of large satellites requires accurately coordinated actions, so virtual astronauts participating in the simulation would be very complex to design. They would need a lot of domain knowledge, they should learn to move objects and themselves in zero gravity, and they should give and take orders both verbally and non-verbally. They could also be equipped with emotions, which undoubtedly play an important role in space, where astronauts work long hours in inhuman and dangerous conditions. Mental representations of virtual astronauts could be used to train situations, in which someone becomes very frustrated and angry, or even experiences a temporal mental disorder and puts the whole operation in danger.

4 CONCLUSIONS

Virtual reality fools human senses to believe that computer-generated, synthesised environments are part of the real world. Artificial intelligence can be applied to virtual reality in many ways. In the user interface, we need systems that behave rationally, e.g. recognise speech and user movements as accurately as possible. Content production needs tools for optimising the layout of virtual worlds, and virtual world simulation needs methods for approximating the behavior of the environment. It seems that the strongest trend in current VR research is adding believability to virtual agents, both physically and behaviourally. Artificial intelligence is being applied in the area extensively, but due to the immaturity of the field, there is still plenty of room for more AI applications.

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