Three applications of virtual reality for brain injury rehabilitation of daily tasks

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ABSTRACT

Part of the process of rehabilitation after a brain injury is the relearning of various daily tasks such as preparing food, managing finances, getting from one place to another and so forth. These tasks require learning on all levels from physical to cognitive. Remembering a PIN code for a bank card, for example, can become automatic and 'in the fingers' after much repetition. However, other tasks require a certain cognitive process, for example, procedures must be followed, quantities estimated, numbers of items remembered or dangerous situations avoided. Even in these cases, repetition of the task many times can help fix the important aspects in the mind. This paper describes three applications of a Virtual Reality based method of rehabilitation which are a part of a larger project to investigate the potential and pitfalls of Virtual Reality technology as a complement to physical training in Brain Injury Rehabilitation. Virtual Reality has the advantage of providing a safe, controlled and highly repeatable environment that a patient can experience in a relaxed manner before having to encounter the potentially dangerous or stressful real environment. The three applications considered here are: kitchen work, an automatic teller machine (ATM) and finding ones way in a complex environment.

1. INTRODUCTION

The project 'Virtual Reality for Brain Injury Rehabilitation' at Lund University, Sweden is now entering into its third year and has produced many interesting results. The project has had three main goals:

- To investigate usability issues of VR technology for people with brain injury.
- To examine the issue of transfer of training.
- To develop three different applications of VR for training of daily tasks.

The initial stages of the first goal have been reported in Davies *et al* (1999) and Lindén *et al* (2000), however the final results are still being analysed. From this stage of the project, the most suitable input devices and methods of design of the Virtual Environments (VE) have been chosen. Further, implications for usability of those decisions have been assessed (if the reader is interested in further details and results from these studies, please contact the leading author; these results will be duly published once analysis is complete).

The second stage, that of transfer, is also still being investigated and is being considered separately for each of the Virtual Environments being developed in stage three. This paper is intended as an overview of the work and deals primarily with these Virtual Environments, the tools used, and summarises the studies so far performed and the results so far obtained. Comments are also made about usability and transfer as appropriate.

2. NAVIGATION AND INTERACTION

From the usability studies, the input device for moving around a VE (navigation) has been chosen to be a large programmable keyboard with arrows drawn on its surface to give three degrees of freedom (ie six possible directions of movement; move forward, move back, turn left, turn right, move left and move right). A joystick caused the subjects in the usability tests to become disorientated whereas a keyboard, though slower, provided better control. Two degrees of freedom was found to be adequate, three allowed for more precise movement in confined spaces, more causes confusion. Nevertheless, more complex navigation devices might be suitable for patients with experience using them, for example, from playing computer games.

Interaction with objects requires a separate device (to reduce cognitive load and device complexity). A touch-screen allows direct contact with the objects being moved or used, but not all people have sufficient dexterity. A mouse is cognitively more abstract, but physically easier for some, and other pointing devices may be necessary for people with physical disabilities. Our studies have suggested that people with very little computer experience manage mouse movement, clicking-to-activate, and even drag-and-drop without problem, in fact, they expect these capabilities and can be confused when such is not possible.

Furthermore, a 'carrying-hand' object (see fig. 1(a), bottom right of picture) that follows the viewpoint can be used to place objects on when moving from one part of a VE to another. This is expected to reduce cognitive load and physical dexterity requirements (having to hold a finger on the screen at the same time as navigating). Usability tests suggest that the concept is easy to understand and was in fact spontaneously used by some of the subjects without instruction into its function, but the form, size and location could be refined.

In the applications described in this paper, therefore, the primary navigation device, (where one is needed) is a large keyboard with three degrees of freedom and the primary object interaction device is a touch-screen and allows click-to-activate, drag-and-drop and a carrying-hand where appropriate. Exceptions to this are noted and are usually related to programming limitations.

3. THREE APPLICATIONS

Three representative training tasks have been chosen in consultation with Occupational Therapists for development into VE applications. The selection was based on usefulness in the rehabilitation process, suitability for implementation using VR, to give a range of task types and to test different forms of VR tool. These tasks are; kitchen-based training (eg. brewing coffee, laying a table); using a vending machine (in this case, an Automatic Teller Machine (ATM)); and finding ones way in a complex environment.

3.1 Task 1 – Kitchen, using WorldUp

A virtual kitchen has been developed as a test-bed for each of the three goals. This kitchen is a replica of a training kitchen in the same area. This has been chosen both as a suitable environment to test usability of input devices and programming methods and for investigation of transfer of training between the virtual and real kitchens. The tasks to be performed in the kitchen are; brew coffee, fry an egg, make toast and lay the table. These have been chosen from the standard suite of training tasks (Fischer, 1995) used by the Occupational Therapists in the real kitchen.

In the kitchen, it should be possible to perform the tasks in whatever manner the user chooses. Different learning strategies can be applied, both learning by trial-and-error and error-free learning. Assistance in performing the task in the correct way is provided by the Occupational Therapist though some in-built help may be available later. If the user becomes sufficiently confident with the tool, they may be permitted to use it independently, though a completely self-sufficient task environment is not presently the goal.

As previously mentioned, three degrees of freedom navigation is provided via a special keyboard and interaction via a touch-screen. Click-to-activate, drag-and-drop and the carrying hand are possible.

An important feature of this environment is the stereo sound effects. Not only should objects look more-or-less as in reality, but they should sound right also. Previously (Davies *et al*, 1999), we have found that realistic sound can compensate for less-than-realistic visual effects (for example, pouring liquid is complicated to model in VR, but playing a sound encourages the user to believe the liquid is flowing anyway when the visual effect is missing). Furthermore, sound provides clues to the user about the status of various objects. If the tap is on, running water is heard. One part of the procedure is to remember to turn off the tap, and attention to audio cues is thus vital. Or, when the toast is ready, it pops up with an appropriate sound. Thus, even when not in the visual field, the toaster notifies the user of its status and they must take appropriate action. Inclusion of olfactory feedback is also appealing, for example the smell of burning toast, but beyond the scope of this project.

(a) *(b)*

Figure 1. *The virtual kitchen (a) and the real kitchen from which it is modelled (b).*

The tools used in the development were: digital camera and scanner for obtaining textures of objects like packets, pictures on walls, outside the window and fronts of various kitchen appliances; Adobe Photoshop® for texture editing and refinement; digital camera with mpg recording capabilities for capturing sound effects; Adobe Premier® for isolating required sounds and saving in correct format (an advantage of using a digital camera for sound recording is that one has a visual cue as to what the sound actually is); AutoCAD® and 3DVis® for model building and Sense8 WorldUp® as the Virtual Reality design and visualisation tool. A special driver was also required for WorldUp for reading from a joystick with more than two degrees of freedom. For distribution, all that is required is the WorldUp Player, the joystick driver and the VE files.

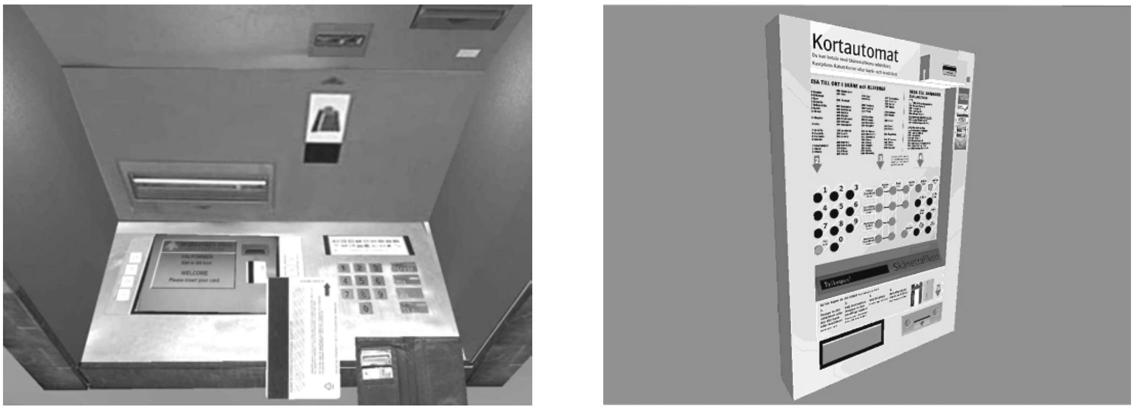
The main complication in this environment is the desire to make it as natural as possible so that the user can perform the required tasks in whatever manner they like. This necessitates an object-oriented programming approach with each object (such as a coffee pot) having certain attributes and behaviours – what is to happen when filled with water and heated, for example. One also needs to consider which behaviours are sensible to program. Should we program the outcome of boiling the coffee pot dry, for example? Decisions as to what effects to include are taken in consultation with the Occupational Therapists and in consideration of programming time.

Usability studies have been performed to investigate the best way to navigate and interact with the VE, as mentioned above. These were performed on people at the hospital with little computer experience. The level of usability for people with brain injury has yet to be assessed. This environment will be the main test-bed for transfer of training studies since it is a controlled environment with the real version close by. Patients will be asked if they wish to take part; each will form an individual case study. Training in the VE will be prior to training in the ordinary kitchen and not as a substitute for obvious ethical reasons.

3.2 Task 2 – Service and Vending Machine, using WorldUp

The virtual kitchen is a large and complex environment where the user must move around between different places in order to carry out the tasks. Thus an input device for navigation must be used (and be usable). Another situation where VR was expected to be useful (Davies et al, 1999) is in training to use an Automatic Teller Machine (see also Wallergård *et al*, this volume). Normally, this task is carried out at a local machine, but this is not practical for repeated training. Modelling the task in VR allows for repeated training before the real machine is encountered. Codes can be learnt and exceptional circumstances experienced (such as entering the wrong code three times causing the machine to swallow the card). For this task, the user need not move around, they must simply operate the machine. The view zooms in and out as appropriate (so no navigation device is required) and interaction with the machine is with a mouse or touch-screen.

Two prototypes have so far been developed (fig. 2). The first to investigate the feasibility and complexity of developing an ATM in VR and for testing aspects of usability with people with brain injury (Wallergård *et al*, 2001). The second to extend the concept to other forms of service machine and to develop a more general framework to allow the construction of almost any such machine from a number of base components. This would allow service machines from the patient's own environment to be quickly constructed thus ensuring greater usefulness and situational training with those machines the person will actually encounter.



(a) *(b)*

Figure 2. *Two functional prototype Service Machines modelled in Virtual Reality. (a) is an Automatic Teller Machine, and (b) is a local train ticket machine.*

The tools used in the construction of the VE are the same as for the kitchen. One problem that occurred was in obtaining realistic texture-photographs of an ATM as this takes time and can annoy people actually trying to use the machine. Furthermore, many surfaces are made of shiny metal which gives poor quality textures with reflections. The first machine developed using the second prototype (fig 2(b)) uses textures obtained from the website for the service machine owners. This gives a much better quality object, though with a somewhat matt look, but avoids the above problems.

Further details and results from usability tests can be found in Wallergård *et al* (this volume).

3.3 Task 3 – Way finding, using Halflife

Both of the previous tasks involve single rooms or single devices. For the third application, it was decided to increase the scale and consider an entire building. A problem that many people have is finding their way from one place to another. Standard training involves travelling the route and committing to memory key features in order to remember which way to go. It was thus decided to develop an environment that patients would need to learn and of a sufficient complexity to be non-trivial.

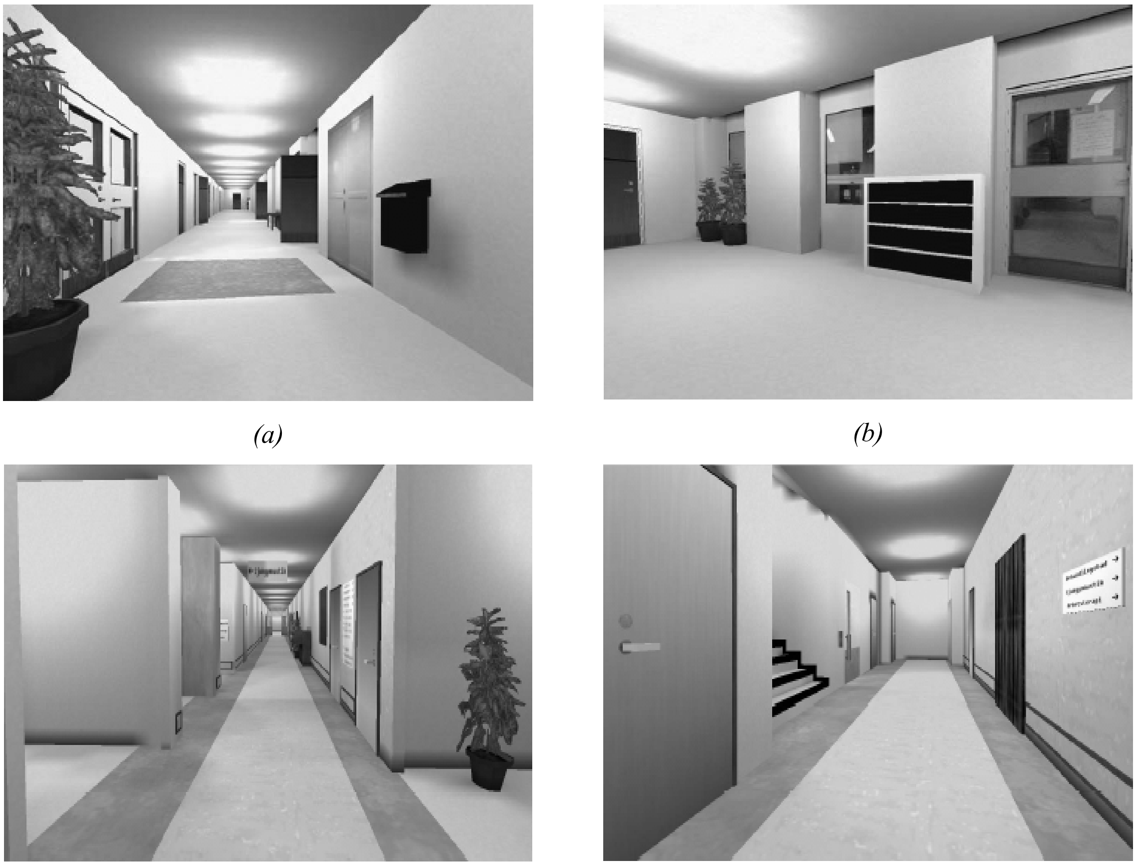
The environment chosen was the rehabilitation hospital itself, and the route from the Occupational Therapist's area to the family hotel. The hospital is spread over two buildings built on a hill with interconnections resulting in confusing changes in levels. The route is one that is not often traversed by the patient, but may be of interest. It also requires moving along several corridors, turning at the correct points and moving between floors (either by elevator or stairs).

Two prototypes have been developed using the tools Worldcraft, for environment design, and Wally, for texture management to produce a VE that runs in Halflife® (Löfgren, 2002). Textures have been obtained with a digital camera and modified in Adobe Photoshop®. Early in the project, it was decided that a tool other than WorldUp should be used, partly to give experience, and partly as 3D Game Engines are particularly well suited to the building of long corridor interior environments. The construction tools can be obtained online and are standard for the development of 3D games using the Halflife engine. They are of a professional quality and similar in many ways to standard VR development tools.

The environments generated have something of a game-like quality, however, various effects make the environment seem quite realistic, such as; automatic collision detection with walls and objects, realistic lighting effects (with shadows), walking action – including climbing stairs and object collision detection, and truly surround-sound effects. Many other features, such as monsters and guns typically found in 3D games are optional for a hospital setting.

In the design, several usability goals were made:

- The VE must be relevant, that is, the person must be able to use it to find their way and remember it. It should help the Occupational Therapists to notice what the patients observe in the environment.
- The VE must be efficient, that is, movement should flow easily and the user should not become stuck on unseen obstacles (such as door jambs). The Occupational Therapists should be able to easily follow what the patient is doing.
- A positive attitude to the VE is desired since this would make the patient want to try the VE, and benefits should be apparent to the Occupational Therapists so they see some purpose in using the tool.
- The tool should be easy to learn. Short-term memory problems could mean that the patient may not easily remember how to use a complex interface, thus it is ideal if they can simply sit at the computer and walk through the VE without any significant difficulties.



(a) *(b)*

(c) *(d)*

Figure 3. *Virtual Environments for learning to find one's way. (a) and (b) are from prototype one – a corridor at the university, (c) and (d) from prototype two – a corridor from the hospital.*

The task of way-finding is complex and depends on subconscious and conscious cues for a person to establish both where they are and the direction to take. In the development of a VE, it is important to include enough cues (objects, colours, signs, etc.) so that the person can recognise the real environment after using the virtual one. The problem is knowing which cues to include; it would be prohibitive to include everything, but it can be difficult to know what people will actually notice. Furthermore, different people will notice different things, depending on interest. For these studies, as many conscious cues as possible are included such as signs and objects that the Occupational Therapists usually point out. Colours, floor and wall materials, lighting, and of course, general shape of the environment are made to be as close to the original as possible. Other objects of significant size are included, but many small or mobile objects are not.

Two prototypes were created. The first, a corridor at the university, was designed with the purpose of establishing both the most usable and visually pleasing means of constructing the VE within the technical limitations of the Halflife environment. Issues such as means of navigation (with mouse, keyboard, or both), the level of realism required for surfaces and objects, and how to represent non-modelled spaces in a realistic manner were investigated. Further, we were interested in whether people familiar with the real environment would recognise the computerised version, and if not, why not. This was tested on members of the university department familiar with the real corridor and people unfamiliar with the environment from the hospital. They were instructed to go to certain places in the corridor, observed during the tests and interviewed afterwards.

The second prototype was of the route at the hospital described above and included elevators which could be used if desired. This was tested with five subjects from the hospital with experience of people with brain injury and varying computer experience. They had to find their way in the VE, thinking aloud and making observations on the way and were recorded for later analysis. Afterwards, they were interviewed. More exact details of the tests, subjects, interviews and analyses can be found in Löfgren (2002).

4. A USER-CENTRED DESIGN METHODOLOGY

The overall method for the project has had the user needs at the centre – ultimately, the tools developed must be usable by people with brain injuries in the rehabilitation process and be useful for the people working with them (such as Occupational Therapists and family).

Each application has been developed with a user-centred design approach. In each case, there are two primary user groups; the person with a brain injury who is to use the tool, and the Occupational Therapist(s) responsible for the rehabilitation program. The former must be able to use the equipment without undue cognitive loading, and the latter must be able to set-up and run the VE as well as gather meaningful data about how the rehabilitation is progressing.

In all the applications, step one has involved gathering information and learning about the task to be programmed. This has meant extensive discussions with Occupational Therapists and visits to the rehabilitation hospital wards. At this stage, the Occupational Therapists act as expert representatives for the people with brain injury. Much of the fine-tuning to the VEs is performed on-site to give easier access to patient expertise and the real environments. Furthermore, staff at the hospital have been used often as subjects in early testing stages, and their comments are always welcomed and provide useful insight into whether we are on the right track or not.

In step two, low-fi or simple computerised prototypes have been made and tested with members of each user group. Again, the Occupational Therapists act as expert representatives for people with brain injuries. This is due to the difficulties involved in using standard testing methods with people with brain injury who may have difficulty concentrating on multiple tasks (such as using a program and thinking aloud), cannot easily abstract from a low-fi prototype, have trouble following instructions or find it hard to manage an interview or questionnaire. The current kitchen tool was preceded by a simple coffee-making environment (see Davies *et al*, 1999), the ATM by paper prototypes and the hospital corridors by a simpler corridor at the University.

From the results of steps one and two, successive computerised prototypes have been developed and tested with real users (Occupational Therapists and people with brain injury) resulting finally in tools which can be said to be usable by the intended users for the intended tasks.

5. RESULTS

5.1 Task 1 – Kitchen

The virtual kitchen has been extensively tested as part of investigating usability issues of the VR technology. Results indicate that a specially designed keypad is most understandable for navigation, though a joystick can be beneficial for expert users. Furthermore, two degrees of freedom can make navigation complicated, but three degrees (being able to walk sideways as well) can make it easier to become lost. Both mouse and touch screen have been considered for interacting with objects; results are still being analysed. Moving objects by drag-and-drop was spontaneously understood by most subjects, though almost all expected objects such as cupboards and drawers to be activated also by a click-and-drag action (in fact, only a click was required). For some, having a hand to carry objects in was considered obvious, others managed without. The tasks to be performed within the environment (brewing coffee, making toast, frying an egg and laying the table) are still being programmed and thus no further results can be presented here.

5.2 Task 2 – Service and Vending Machines

The virtual ATM built on results from the virtual coffee machine tests (Davies et al, 1999) and is similar in that the user need not worry about navigation – the computer determines from the current state of the task which view is most suitable. In the evaluation, some of the subjects had problems with the interaction method, some misunderstood the virtual representation of the ATM interface and visibility of small objects such as buttons was problematic. However, for some, the virtual representation was so encapturing that they unconsciously tried to grab the money – this suggests a high degree of presence.

5.3 Task 3 – Way finding

Testing the first prototype produced the following results:

- The corridor was not immediately recognised by a couple of the subjects.
- Textures from photographs were considered indistinctive.
- The most effective way for showing a non-modelled room was to past a picture from the real room on a flat block placed in the doorway, though odd viewing angles can mean strange perspective views.
- Windows can be mistaken for mirrors or paintings..
- The plants were considered good, as well as an extension of the corridor that was not modelled, just photographed.
- The mouse for navigation was difficult. Navigation with just the keyboard was considered much easier.
- The overall attitude was positive.

The tests with the second prototype produced the following:

- The first part of the corridor was recognisable, though some subjects thought it narrower than in reality.
- The paucity of objects was commented (the real corridors are much more cluttered).
- The interaction with the elevator was difficult and lacked feedback (the user has to wait till the door opens, enter the elevator before it closes again, face the button panel, and then press a key on the keyboard – this is standard for games, but not very intuitive).
- The elevator doors could open when it was in motion, and opened and closed too quickly. One of the elevators in reality doesn't have self-opening doors but did in the VE. Two of the subjects experienced some dizziness in the elevators.
- The second floor was mostly unrecognisable near the entrance way to the building. This was thought due to the fact this area is glassed-in with views of the outside, which were not present in the VE.
- Some landmarks were missing, such as 'the janitor's coat', and some colours were not correct. Lighting was not considered realistic.
- Navigation was complicated by the viewpoint becoming stuck on some door openings.
- The signs were useful for people not used to the hospital (though inadequacies in the sign-posting in the real hospital were discovered in the studies).
- Overall, the attitude was positive, and the subjects thought that a remade version might be useful for rehabilitation.

Further work is now being performed to produce an improved prototype based on these results which can be tested with people with brain injury in real way-finding situations. Of particular interest will be what visual cues are required by these users, and whether they experience the virtual corridors as being the same as the real ones. Furthermore, the users will not already be familiar with the real environment, so may not be as critical to level of realism so long as the cues they have learnt in the VE actually exist and are recognisable in the real world.

6. DISCUSSION

Different tools have been used in the different applications. The more ordinary VR development tool WorldUp has been found to be useful for general purpose VEs and the development of complex systems which require interaction from the user. Halflife and associated tools has produced pleasing results for large environments which one can wander around in, but is difficult when interaction with objects is required. However, the future Virtual Reality systems may well be based on such game-engine technology, since the rate of development is very rapid whilst the price is very low.

The work reported in this paper is still in progress and aspects about usability and transfer of training are still being analysed or are yet to be tested. However, the development of these applications has progressed well, and the various tools chosen have been found to be adequate for the design of VEs for rehabilitation.

Nevertheless, the time required to develop a new task from scratch could well be prohibitive for long term usage in rehabilitation contexts. The main difficulty is the programming of object behaviours; every minute reaction to an action taken with an object has to be considered, modelled and programmed. One possible solution to this is to make reusable modules, as is being done for the service and vending machines part of this project. Even so, considerable remodelling and programming of the executive functions must still be performed. In the kitchen, it may also be possible to work with predefined modules to build up any kitchen layout, however, making an exact replica of, say, a patient's own kitchen will still require much time and expertise. Similarly, creating objects that look realistic (and are recognisable) can take much time, either in the modelling of the object in a CAD package, or in taking pictures from reality, modifying these to improve quality and using these as textures on simpler objects.

It can be concluded that VR will very likely become a valuable training technique, and many others have also found it to be beneficial in various cognitive training tasks. However, it has always been maintained that it can, at best, be a complement to existing rehabilitation methods. This view is repeatedly reinforced by discussions with Occupational Therapists and other medical experts since VR by itself misses a vital physical component of the training. Plans are being made, however, to couple Virtual training with real training in so-called Mixed Reality systems. Similarly, further work is required to speed up the development process, and perhaps even make it possible for Occupational Therapists and care-givers themselves to develop new virtual training environments, or at least adapt existing ones to local conditions. It may even be worth considering the development of a standard for interconnection of virtual object modules and the creation of an open-source library of objects available to all.

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