

VIRTUAL REALITY SCIENCE CENTRE EXHIBITS

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Stuart Edward Ralston

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Acknowledgements

Writing a thesis is like constipation; it takes ages to get it out, but once it is you have no interest in it.

Tim Bell (1994)

Thanks must go to my girlfriend Delwyn who has put up with my late nights and “virtual” lifestyle for the last two years. I thank all the staff at *Science Alive!* for allowing me to work in such an exciting environment and with inspiring people. My final appreciation goes out to my supervisor, the afore mentioned Tim Bell, who was the only person who had the energy to tackle this new subject; both of us learning how to juggle for “real” through its development.

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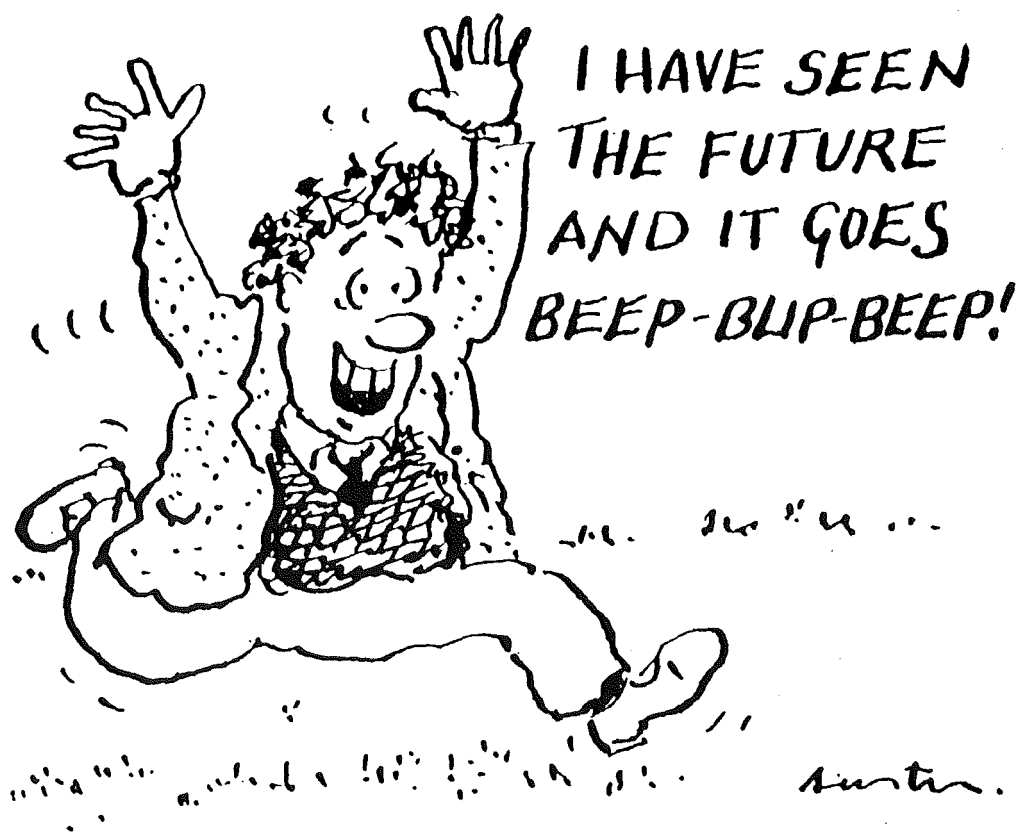
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Abstract

Virtual Reality (VR) systems have become widely recognised by the public as a result of media attention, but the cost of the underlying hardware has limited research in the field. Recent improvements in computing power, rendering software, and their availability have started to lower the price of personal VR system components, allowing VR to become an increasingly affordable technology. Science centre exhibits have traditionally been a starting point for high impact science products, presenting them directly to the public. VR technology is currently in a state where its introduction into a science centre is feasible.

This thesis describes three computer-based science exhibits that have been designed and introduced to the *Science Alive!* science centre in Christchurch, New Zealand. The first exhibit, called *Juggling In a Virtual Environment (JIVE)*, teaches the user to juggle virtual objects in VR. The exhibit was constructed using an IBM compatible personal computer, a modified Mattel *PowerGlove*, a data projector, a 2 metre by 1.5 metre fabric screen, and public domain rendering software. The main advantages of the system are that it is economical and it attempts to teach skills that are otherwise difficult to learn. Overall, the *PowerGlove* proved to be unreliable due to background noise, a restricted working angle of the ultrasonic tracking, and a high breakage rate of the finger sensors. The second exhibit, called *Cybertennis*, was constructed using the same hardware as JIVE, except for modifying the breakage-prone *PowerGlove* into a bat. A new virtual world was designed to allow the user to play a game of tennis with an artificial opponent.

The third exhibit, called the *Data Digester*, is an electronic questionnaire; consisting of a Macintosh personal computer, a touch screen device, and HyperCard developing software. The *Data Digester* gathers information for market research, demographic investigations, and exhibit evaluation.

Chapter 1

Introduction

We live in a physical world whose properties we have come to know well through long familiarity. We sense an involvement with this physical world which gives us the ability to predict ... where objects will fall, how well-known shapes look from other angles, and how much force is required to push objects against friction. A display connected to a digital computer gives us a chance to gain familiarity with concepts not realisable in the physical world. It is a looking glass into a mathematical wonderland.

Ivan Sutherland (1965)

Virtual Reality (VR) is an emerging field of computer science that uses interactive computer technology to create the illusion of being immersed in an artificial world. Currently a basic VR experience consists of a user placing a helmet over their head, and using a glove input device to interact with graphical objects that appear within their vision. Other senses can be added, such as sound or touch, but this configuration of vision immersion and hand interaction appears to be the current perception of a VR exhibit to a user. To date, most VR systems have been custom-built, and are generally very expensive, being used only by large companies who can afford them.

Although the implementation of VR is a recent development, researchers have been trying to create interactive systems since the “Link Trainer” in 1929 (Rheingold, 1991),

culminating in the official launch of VR to the public on “Virtual Reality Day”, 7 June 1989. This day heralded the first public demonstrations of VR systems by the companies VPL and Autodesk. As with any new technology, the longer it is available for, the better and cheaper it becomes. At present the main factor preventing many institutions from purchasing a high definition VR system is the high cost.

The general components of a VR system include a computer supporting a powerful graphics renderer; a visual display, either stereo- or mono-scopic, and of varying immersion; and an interface to the computer that can track the user and interpret the user’s motion as meaningful commands. A VR system can also interact with multiple users, either real or artificial, in real-time, and as a result the user can participate in a unique experience. Recent improvements and availability in computing power and rendering software, have started to lower the price of personal VR system components, allowing more people to research and experience it.

Through television programmes such as *Beyond 2000* and movies like *The Lawnmower Man*, the general public has been introduced to the role that VR may play in their lives. The programmes describe both factual and improbable forms of VR to the public. The “Hollywood” image of VR tends to be over-hyped; the photo-realistic computer graphics used in their movies are unlikely to be drawn in real-time, which is necessary for a VR experience. The scientific programmes project a more realistic image of what kinds of VR applications are being developed around the world and what they are capable of producing. Unfortunately, the general public tend to enjoy movies more than educational programmes, and as a result want to see what the “Hollywood” image is showing them. This demand from fictional VR is what is driving the VR market to produce experiences that match public expectations.

VR applications already designed and implemented include walking through potential building designs; molecule manipulation, to see the results of dangerous experiments without actually performing them; telesurgery, where a surgeon can operate on a patient

remotely, without the patient risking travel or the surgeon leaving other patients; solving crimes by being able to view a recreated scene from any angle (Sims, 1992); and leisure activities, such as virtual skiing (Coghlan, 1992).

By the year 2000, it is estimated that educational applications of VR and other new technologies will be commonplace in households and communities in the form of instructional programs, tele-education, teleconferencing, access to on-line databases, computer-aided instruction, and simulations (Miles *et al*, 1990).

An important potential application of VR is in the field of education, either at home, in the classroom, or for people with disabilities. Already computers are being used in these situations, for example a system was developed for the “Persons With Disabilities” conference in San Francisco, intended to teach seriously emotionally disturbed and learning disabled children positive and constructive mechanisms for dealing with conflict (Rothman, 1993). Current VR systems tend to be abstract in presentation, for example, having the user “fly” through spinning polygons. VR appears to be an improvement on television and other computer programs by encouraging user activity, rather than passivity. Through networks, a user can interact, via the computer, with other people, thus learning important social skills in addition to the skills taught by the VR program (Gale, 1993).

Currently there are no science centres in New Zealand that have VR exhibits, with the exception of *Science Alive!*, in Christchurch. A virtual music system has been developed at *Science Alive!* where virtual instruments are played in the air with a Mattel *PowerGlove* (Thomas, 1992). Capitol Discovery Place, a children’s science centre in Wellington, proposed building a VR exhibit, but implementation never occurred (Hart, 1991b). The only exhibits resembling VR systems in science centres, have been flight simulators. However, VR exhibits have been introduced overseas, such as in Paris, France where an exhibit called *L’Autre — The Other* — used ultrasonic tracking devices

to make an enormous computer-generated face follow the visitor's movements (Gale, 1993).

This thesis describes the design and introduction of three educational computer-based exhibits to *Science Alive!*, a children's science centre. The first exhibit, called *Juggling In a Virtual Environment* (JIVE), teaches the user to juggle virtual objects in VR. The second exhibit, called *Cybertennis*, invites the user to a game of tennis with a virtual dinosaur. The third exhibit, called the *Data Digester*, is an electronic questionnaire. The *Data Digester* gathers information for market research, demographic investigations, and exhibit evaluation for use by the science centre (software diskettes are included with this thesis, see Appendix G for installation instructions).

Existing juggling software does not allow the user to interact with the simulation of juggling patterns, and are not intended to "teach" juggling, only to "show" it. JIVE consists of two systems: the "public" JIVE system is a simple ball handling environment for an exhibit experience lasting between 3 to 5 minutes, while the "laboratory" JIVE system is a genuine attempt to teach juggling in a more controlled environment, with the experience lasting between 5 to 20 minutes. JIVE allows the user to use a *PowerGlove* input device to interact with virtual objects that can move slowly in a virtual world, and give the user feedback on their throws, being a computer-assisted learning system for juggling (Ralston, 1993). Being able to experience a real world physical activity, such as juggling, in a virtual environment may give the user the ability to learn that skill with more ease and understanding.

The *Cybertennis* exhibit was derived from the JIVE system, using the same hardware components, except for modifying the *PowerGlove* input device. The high breakage rates of the *PowerGloves* in the JIVE exhibit led to the design of a bat, that controls a virtual racquet, for use in a game of virtual tennis against a dinosaur.

The JIVE and *Cybertennis* VR systems use a large screen projection system, which is an unencumbering approach to computer visualisation that does not possess the problems faced with head-mounted displays for about the same price. While state-of-the-art VR hardware looks a bit like a scuba-mask and glove, the trend for the future will involve hardware that is less intrusive (Miller, 1992). The VR system in this study was purchased for about NZ \$14,000 — compared with around NZ \$250,000 for conventional “laboratory” systems.

Questionnaires and surveys have traditionally come in the form of pen and paper. Data collection was usually done by ticking boxes and filling in blanks; processing the assembled data was done by hand. Computers offer a new method of information gathering, because they possess the ability to gather and analyse information directly and quickly, with minimal human assistance. The *Data Digester* is an electronic questionnaire using touch screen technology, that gathers visitor and exhibit information for *Science Alive!*.

Both VR and touch screen technology are examples of computer science’s move away from the command line and keyboard paradigms, into a more natural and intuitive form of human-computer interaction.

Chapter 2

Virtual Reality

Computers have changed our lives; with Virtual Reality, they will change our very experience of life, recreating it in an image of our choosing.

Benjamin Woolley (1992)

VR was introduced to the public on “Virtual Reality Day”, 7 June 1989, at the San Francisco Civic Auditorium, heralding the first public demonstrations of VR by the companies VPL and Autodesk. Five years later, VR is still evolving and the public has become more aware of its developments, and it is gaining recognition as a result of media attention. What is this new field of computer science? Helsel and Roth (1991) have given separate definitions for the words *virtual* and *reality*. They define *virtual* as “being in essence or effect, but not in fact”, and *reality* as “a real event, entity, or state of affairs”. Thus, VR might be paraphrased as a “fact or real event that is such in essence, but not in fact”. VR is also synonymous with the phrase *artificial reality*; coined by a VR pioneer Krueger (see Section 2.1), although the phrase is sometimes associated with unencumbered approaches to VR. In fact, VR is really about an interface and an experience, and so from this point of view it could be defined as “The immersion¹ of a user or users in a computer generated world, interacting with virtual objects that do not physically exist”.

¹ Immersion can be of varying degrees

Some people reason that a virtual experience can simply be being “engrossed in a novel” or “watching a movie”. A feeling of being somewhere else is achieved by the user. Whether these activities are defined as a “virtual reality” is debatable. However, replicating as many senses as possible will make the virtual experience more “believable”. As senses are removed or become less accurate, for example the use of low resolution displays, the virtual experience may become confusing or difficult to use.

Currently a basic VR experience consists of a user placing a helmet over their head, and using a glove input device to interact with graphical objects that appear within their vision. Other senses can be added, such as sound, but this configuration of vision immersion and hand interaction appears to be the current perception of a VR exhibit to a user.

In this chapter, the history of VR will be reviewed, with reference to the important people involved, both overseas and in New Zealand. The options for each component of a VR system are also studied, and later in this thesis the elements chosen for two VR exhibits, designed for *Science Alive!*, are outlined.

2.1 History of Virtual Reality

VR can be considered as a combination of old technologies, with new ideas and applications. To view VR as a recent technology ignores the painstaking and innovative work of its developers over the last sixty five years. The main path-finders of this technology are Link, Heilig, Sutherland, Krueger, Gibson, Lanier, and Rheingold.

Henry Link

In 1929, Link, a pipe organ designer, created the first mechanical simulation of flight — the *Link Trainer* — which was seen as the start of the conceptual process that led to VR (Hart, 1991a). Link used bellows-like devices to pitch, roll, and yaw a cockpit as a World War II era pilot moved the controls. A primitive visual display showed a simple horizon line that shifted when the simulated aircraft turned (Rheingold, 1991).

Morton Heilig

Heilig, a Hollywood cinematographer, created an arcade game called the *Sensorama Simulator* in 1960 (Rheingold, 1991). The system used a stereoscopic film projection mechanism that allowed passengers to travel through the streets of bygone Brooklyn on the seat of a motorcycle. Thirty years later, the simulator is still in good working order (Rheingold, 1991). Heilig commented that, “When you watch television or a movie in a theatre, you are sitting in one reality, and at the same time you are looking at another reality through an imaginary transparent wall. However, when you enlarge that window enough, you get a visceral sense of personal involvement” (Rheingold, 1991).

Ivan Sutherland

In 1963, Sutherland created *Sketchpad*, for his Ph.D. thesis, from which modern day computer-aided design grew (Rheingold, 1991). *Sketchpad* was probably the first successful interactive graphics system ever devised. Users could create images in the most natural way possible, by using hands and eyes and a pen-like device to “draw” on a cathode-ray tube. In that respect, *Sketchpad* was a powerful model of a totally new way to operate computers (Rheingold, 1991). In 1970, Sutherland created the first head-

mounted display (HMD), which he called the *Sword of Damocles*; named to reflect the enormous size and weight of the equipment.

Myron Krueger

Krueger first started working with interactive art in 1969, when he created the *Glowflow* — a system that surrounded the user, without the use of gloves or goggles, as he preferred an unencumbered approach to virtual environments (Csuri, 1991). This was followed by *Videoplace* in 1970 — a system that provided telecommunications between remote locations, via fast video technology (Csuri, 1991). Krueger devised the “Duck” test; if a virtual object was thrown at a user, and they moved to avoid it, then the experience was perceived to be realistic (Rheingold, 1991).

William Gibson

Gibson (1984) coined the word *Cyberspace* in his science fiction novel *Neuromancer*, depicting huge virtual structures of data in the “consensual hallucination” that millions of people directly connected to. There are “cowboys” in Gibson’s cyberspace who “jack in” their nervous systems into the “matrix” via a “deck”. Gibson describes cyberspace as being experienced daily by billions of legitimate operators, in every nation, including children being taught mathematical concepts (Rheingold, 1991).

Jaron Lanier

Lanier invented the phrase *Virtual Reality*, and was the founder of the now disbanded company VPL, which created the first commercially viable VR glove — the *Data Glove* (Porter, 1992). The *Data Glove* was a light-weight lycra glove fitted with bundles of optical fibres along the backs of the fingers of the user (Sturman, 1992). In 1985 Lanier

developed *Mandala*, a visual programming language, which enabled non-programmers to command computers by creating diagrams with visual icons, via a glove input device (Rheingold, 1991). In 1992 Lanier set up a new company called VR Builder to continue his VR research and development (Webb, 1992).

Howard Rheingold

Rheingold (1991) has lectured on VR all around the world. In 1990 Rheingold started the Internet computer network discussion group for VR researchers, called *sci.virtual-worlds*, moderated at the Human Interface Technology Laboratory. Between 50 and 200 million people worldwide have access to the Internet (Wong, 1993). Rheingold is generally regarded as the world's foremost authority on VR research and development.

2.2 New Zealand Talent

VR systems have been available in the United States for the last several years, but interest in New Zealand has only been active over the last year or two. Interest in New Zealand is mainly due VR's recent television coverage on programmes like *Beyond 2000* and *Wild Palms*, as well as in movies like *The Lawnmower Man* (see Figure 2.1). These programmes bring both accurate and implausible perceptions of the current state of VR to New Zealand. The image of VR from "Hollywood" tends to be over-hyped by pre-processed photo-realistic computer graphics. Such images cannot be interacted with by a user, and as a result cannot provide a VR experience. Scientific programmes like *Beyond 2000* project a more realistic image of what kinds of VR applications are being developed around the world and what they are capable of producing. Unfortunately for VR developers, the general public tend to enjoy movies more than educational programmes, and as a result want to experience what the "Hollywood" image is showing them.



Figure 2.1 A scene from the movie The Lawnmower Man.

VR has also been made popular by several New Zealanders, who are further developing this new technology. There is a surprisingly large amount of work going on around the country, especially amongst New Zealand universities.

Hart (1991b) considered the issues of VR for a children's science centre; the exhibits have not yet been implemented. Hart (1993) has also explored VR in a fact-finding overseas tour, with the rationale that such a search might reveal the "lever to kick-start VR" in New Zealand. Thomas (1992) produced a *Virtual Maestro* science centre exhibit that allowed the user to play virtual musical instruments in the air with a *PowerGlove*. Owen (1993) developed a simulator for helping helicopter pilots to improve their flying skills; supported by a grant from NASA. The system allows control of the virtual environment to change flying conditions, such as wind disturbances, for research into the physical aspects of pilot training (Davis, 1993).

On the commercial side, Dennis has built flight simulators for networked combat experiences in an arcade environment. The cockpits allow complete rotation in all directions, with up to four people simultaneously experiencing the same virtual world (Davis, 1993). Barlow (1994) has promoted a road-show exhibit, called *Virtuality*, which has toured New Zealand shopping malls. *Virtuality* systems have been the first appearance of commercial VR exhibits for the public (Cook, 1992). Barlow is currently creating a “cyberspace standard” for VR developing environments, based on CD-ROM technology. The CD contains a library of “building blocks” that can be referenced by the rendering software (see Section 2.3.3) to create virtual objects.

2.3 Components of Virtual Reality

VR tries to stimulate as many of the five senses as possible with the technology available. A full VR system usually consists of a visual display, three-dimensional (3-D) body tracking, a renderer, tactile feedback, auditory feedback, a virtual world to interact with, and a fast computer architecture. The computer must be capable of screen refresh rates above twenty five frames per second, for smooth human perception. The VR designer must optimise the time each component requires for processing. Every delay in response time degrades the feeling of presence and reality in the virtual world. The interaction of these conceptual modules (see Figure 2.2), within the VR system will dictate the quality and usefulness of the virtual experience.

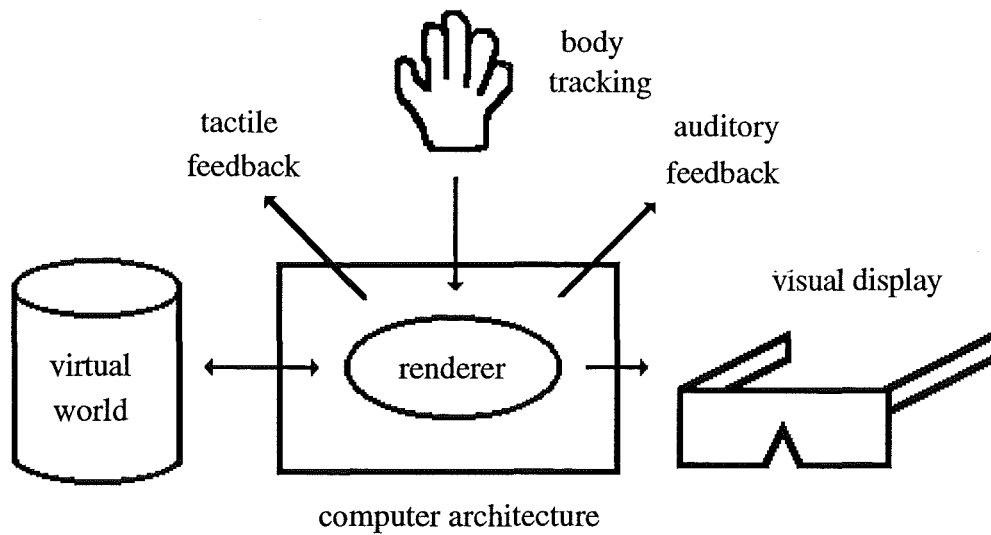


Figure 2.2 The conceptual modules of a VR system.

In the future it is hoped that the increase in availability of personal computing power will be correlated to the use of VR in the home. It is predicted that VR will follow the path of television, and be common in the homes of the general public around the year 2000 (Hart, 1991a; Rheingold, 1991). Currently 29.6% of the homes in New Zealand own a television set, comparable to 81.2% in the United States (Statistics NZ, 1994); and there are approximately one billion television sets worldwide (Beyond 2000, 1993).

Personal computing power has been increasing dramatically over the last few years (Forester, 1987). New Zealand households are purchasing more home computers than ever before (see Figure 2.3), the number having more than doubled in the last eight years (Statistics NZ, 1994).

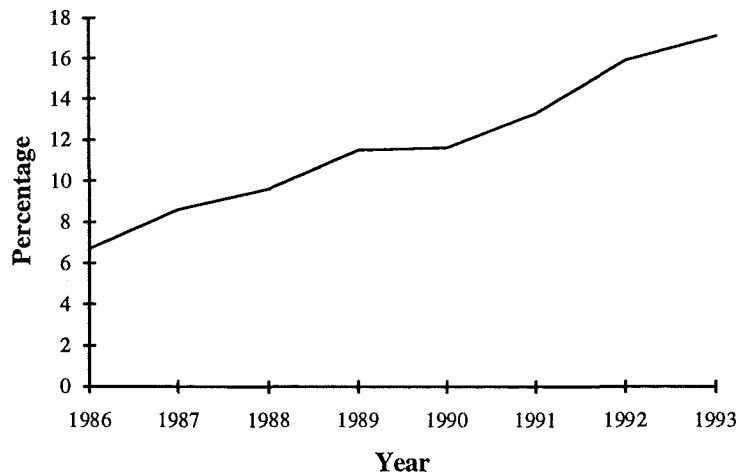


Figure 2.3 Percentage of households owning personal computers in New Zealand.

2.3.1 Visual Displays

The importance of visual feedback in VR worlds has been documented by Hart (1991a). For VR to be used as a tool for education, training, or entertainment, visual feedback is important to create a stimulating atmosphere. Visual cues, such as size, shape, and texture help a user to perceive objects in the virtual world, relating them to what they know in the real world. A young child, for example, with a mild learning disability may be enthusiastic to learn in such an environment. A poor visual display, however, may create disinterest or confusion in the user.

The types of displays available for use in a VR system include head-mounted displays (HMDs), cellophane and polarised 3-D glasses, liquid crystal display (LCD) shutter glasses, large screen monitors, projected image systems, and unencumbering 3-D displays.

Head-Mounted Displays

Several types of HMD units are currently available. The characteristics of an HMD are typically a visor covering the eyes, with one or two LCD screens whose images are presented by a series of mirrors and lenses. Some custom-made HMDs use high-resolution miniature cathode-ray tubes (CRTs) and fibre-optics to display the image. An HMD usually receives a phase alternate line (PAL), or national television standard committee (NTSC) signal, which needs converting from the basic computer signal; for example, a video graphics array (VGA) signal from an IBM compatible personal computer.

The main advantage of using an HMD is the ability to be fully immersed into a virtual world. HMDs have the ability show stereoscopic or monoscopic images, and have the potential to attach head tracking devices. Unfortunately, the disadvantages currently often outweigh the benefits. Purchase and associated maintenance costs of HMDs are high, currently costing around NZ \$10,000 to import from overseas. HMDs often have a fragile structure and are cumbersome to wear. Size restrictions on the LCD screens, caused by the physical dimensions of the helmet, limit the number of picture elements that can be displayed, thus producing low resolution graphics. Observers are prevented from watching the VR experience, unless a separate monoscopic monitor is provided. All the above disadvantages will improve with time, as the appropriate technology advances. Until then, VR developers will have to be innovative (Bricken, 1991). One important disadvantage which is not expected to improve is that HMDs in public use are unhygienic. A typical HMD is shown in Figure 2.4; notice that the HMD comes into contact with a large proportion of the user's head and face.

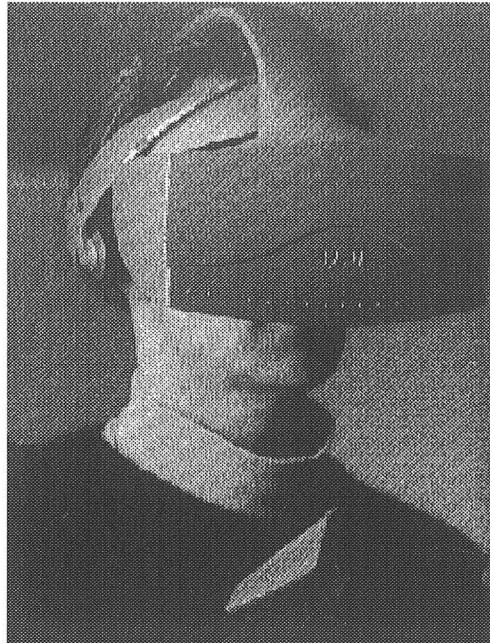


Figure 2.4 A user wearing a VPL head-mounted display.

Experience with the *Virtuality* road-show exhibit, has reinforced the benefits and drawbacks of HMDs, previously described.

Other HMD-like visual displays include binocular omni-orientational monitors (BOOMs), which use counter-balanced arms with high resolution displays that the users hold to their eyes. The BOOM requires no expensive 3-D tracking technology, and therefore has no time lag when moved through the virtual world (Brill, 1992). The user can withdraw from viewing quickly, if necessary. Unfortunately, the BOOM lowers the level of interaction by the user, because both their hands are used to control the display.

Cellophane and Polarised Three-Dimensional Glasses

Glasses made from cellophane and polarised glass work on the principle of using a single display to present stereoscopic images to the user. In both systems, two slightly differing images are displayed on the screen. Due to the filtering effect of the cellophane or

polarised glass, each image is seen by only one eye, thus giving the illusion of 3-D. Cellophane glasses filter the image by using different coloured cellophane, usually red and blue, over each eye. In the polarised glasses, each eye is covered by glass polarised perpendicular to each other. A special monitor is needed to produce the polarised images.

The advantages of using cellophane or polarised 3-D glasses include the lack of electronic componentry and are inexpensive; the purchase price of cellophane 3-D glasses are NZ \$1 each and are readily available and hence replaceable. The glasses do not require communications with a computer, although a head tracking device could be attached, if desired. Draw-backs for both types of glasses include extra processing required to draw two images compared with monoscopic viewing, the virtual world is non-immersive, and the glasses can be awkward for users with spectacles. In the case of cellophane glasses, colour use is restricted to the cellophane coloration and their combinations. Polarised glasses require the user to remain relatively stationary, because if the user's head is rolled, the 3-D image is lost.

Liquid Crystal Display Shutter Glasses

LCD shutter glasses work on the principal of synchronising alternately displayed stereoscopic images, usually on a CRT monitor, to create 3-D images. Generally, there is one LCD screen for each eye which alternately darkens and clears. Slightly different views of the same image are scanned on the CRT every 1/60 of a second, each eye seeing only the images appropriate to a left- or right-eye view of a 3-D scene (Rheingold, 1991). Advantages of LCD shutter glasses include their stereoscopic viewing capabilities and light-weight nature. LCD shutter glasses are relatively inexpensive, with a current purchase price of NZ \$200. Disadvantages include the additional requirement of a CRT or similar display screen. When surrounding light diffuses into the glasses, the LCDs do not darken fully, producing a "ghosting" effect. LCD shutter glasses are fragile

and need to be handled with care. Observers are prevented from watching unless a separate monoscopic display monitor is provided.

When the left- and right-eye images are swapped the resulting 3-D image appeared to be some distance “inside” the screen rather than the same distance “outside” the screen. For an interesting effect imagine a person “in” the screen running towards the viewer, then swapping the left- and right-eye images at the correct time, to create an “out” impression.

Large Screen Monitors

The use of large screen monitors provide relatively large and clear images with slightly more immersion compared to a normal 14" monitor. A person's field of view — the visual angle a viewer can see without head rotation — will be increased from 45° to about 60° using a large monitor. However, large monitors are expensive (a 21" monitor currently costs around NZ \$7,000), and heavy, making secure mounting in an exhibit environment difficult.

Data Projectors

Data projectors use light from a conventional over-head projector (OHP) to project a computer generated image onto a screen. The data projector is a transparent LCD screen that replaces the regular foil used on the OHP. Some high-end data projectors use thin film transistor (TFT) technology to enable them to recreate CRT quality images at the equivalent update rates. TFT technology employs a matrix of nearly a million transistors that act like high-speed shutters. The transistors selectively allow light generated from the OHP behind them to pass through the glass, then on through a corresponding red, green or blue filter, and then finally onto the screen (Wood, 1993).

Data projectors are readily available and can offer the user a high degree of immersion into the virtual world. Images of varying sizes can be viewed, depending on the screen size and the dimensions of the viewing area. The field of view of a projected image system is around 75°. The user does not have to wear anything on their head, and because the image is projected, observers can visually collaborate. However, for clear viewing of the projected image, a darkened area is required, and any obstructions can make shadows on the screen. Purchase price of a data projector is currently around NZ \$8,000, however an OHP is also required, costing around NZ \$1,000. The only way of achieving stereoscopic images using a data projector is by wearing cellophane glasses. Polarised glasses required a special screen to produce the polarised images, and the data projector does not synchronise with the LCD shutter glasses. Systems where the image is projected from behind the screen (back-projection) work in well lit areas, although they need a special screen material, as well as a reversed image. A new display technology called field-emission displays may solve the TFT's lighting problems; producing brighter contrast displays than LCDs (Baran, 1994).

An example of a fully immersive projection system is the *CAVE* (Cruz-Nelra *et al*, 1992). The system consists of a room whose walls, ceiling, and floor surround the viewer with projected images. The *CAVE* allows multiple users to interact with the system, without reproducing any hardware.

Unencumbered Three-Dimensional Displays

One visual system that has an unencumbered approach to VR, and also has the advantage of stereoscopic imaging has been developed in New Zealand by King (Davis, 1993). The system uses a spinning mirrored disk in a vacuum tube, to produce two stereoscopic images that can be seen without the user having to wear anything on their head or in front of their eyes. Another 3-D display system combines an optical stereo technique using lenticular lenses with LCDs and a head tracking device. The image appears to

“float” in front of a 14" screen without the viewer needing to wear a special visor (Rheingold, 1991).

2.3.2 Body Tracking

Efficient 3-D position tracking of the user's head and hands is vital to virtual reality technology (Meyer *et al*, 1992). In some systems the user's entire body might even be tracked. The main technologies that have been used for this are ultrasonics (acoustic), magnetic, mechanical, and real-time video (optical) tracking. A suitable tracking device needs to have the following features (Meyer *et al*, 1992):

- resolution and accuracy — the exactness of a reported position,
- responsiveness — data rate, sample rate, update rate and lag,
- robustness — accommodation of real world noise,
- registration — actual and reported position difference, and
- sociability — range of operation and multiple tracking.

Mechanical Position Trackers

Mechanical trackers measure change in position by physically connecting the remote object to a point of reference with jointed linkages, and therefore have no time lag when tracking the user. The mechanical positioner is usually very precise and largely free from errors induced by the real environment around it (Meyer *et al*, 1992). However, mechanical trackers have a sociability problem in that they restrict the user to a limited range of operations. A simple mechanical tracker can be built for under NZ \$50, although it does not possess high degrees of freedom of movement (Gradecki, 1994). The BOOM visual display (see Section 2.3.1) uses mechanical tracking to monitor the user's movements.

Magnetic Position Trackers

Magnetic trackers use alternating or direct current to generate magnetic fields in mutually perpendicular sensor coils (Meyer *et al*, 1992). The trackers, as a result, tend to have good accuracy in small working areas, but the accuracy diminishes with distance in open-room VR applications. The magnetic tracker is also prone to eddy currents, and hence position errors, produced by neighbouring metallic materials (Meyer *et al*, 1992). The system may introduce lag times to filter out these errors. The cost of a magnetic tracking system, such as the *Polhemus Isotrak*, is currently around NZ \$5,000.

Optical Position Trackers

Optical trackers use video cameras and real-time image processing to monitor the user's movements. Optical trackers have been implemented using a variety of techniques including fixed transducers, pattern and colour recognition, and laser ranging (Meyer *et al*, 1992). Optical trackers tend to need extra processing power to be able to deal with high band-width video images in real-time. They are also prone to ranging errors brought on by spurious light, and ambiguity of surfaces.

Acoustic Position Trackers

Acoustic position trackers have been implemented using two basic methods: *time-of-flight*, and *phase-coherent* techniques. *Time-of-flight* trackers determine distance by measuring the elapsed flight time of an acoustic wave, while *phase-coherent* techniques calculate distance by comparing the phase of a reference signal to that of an emitted signal. Inaudible pulses of ultrahigh frequency sound are emitted from two transducers on the user, and are picked up by three ultrasonic receivers; triangulation calculations determine the absolute position of the user. The accuracy of acoustic trackers can vary;

an acoustic system is well suited to small spaces, although vulnerable to spurious acoustic pulses at any range. Jingling a set of keys, for example, will cause a *time-of-flight* system to generate large errors. Readings can become inaccurate when anything obstructs linear transmission between the acoustic transducers and the receivers. Acoustic tracking technology is relatively inexpensive, seen commercially available in the Mattel *PowerGlove* (see Figure 2.5).

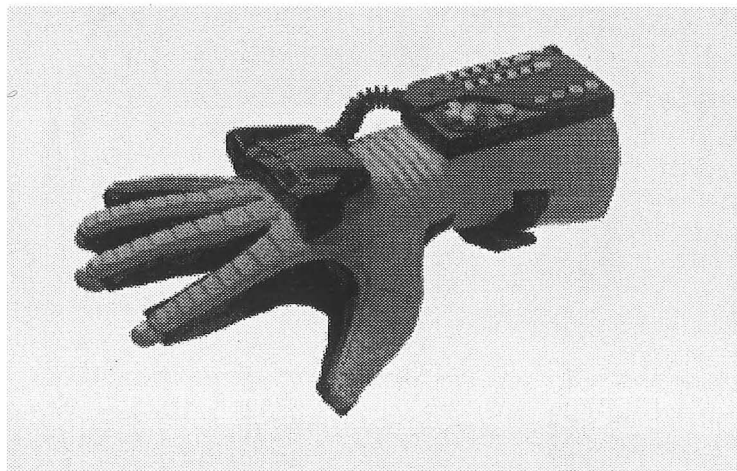


Figure 2.5 The Mattel PowerGlove.

The *PowerGlove* uses a *time-of-flight* position tracker, and will only perform when the transducers are pointed at the receivers (see Chapter 5). The acoustic tracker has a range of 3 to 4 metres from the receivers and an effective working angle of 45° off the centre axis. When the *PowerGlove* is within two metres of the receivers, the 3-D coordinate information is accurate to 6.5 millimetres (Meyer *et al*, 1992). The *PowerGlove* reduces in performance if the user is clenching a fist, since there are no analogue-to-digital converters in the finger gauges. The electronics in the *PowerGlove* use interrupts and timing to determine the degree of bending of each finger (Thomas, 1992). The cost of a *PowerGlove* is currently around NZ \$200.

2.3.3 Rendering

A renderer is the software component of a VR system with which the virtual worlds are created. Researchers and developers frequently express impatience with the current technological development of renderers (Rheingold, 1991); high resolution renderers are too slow, and low resolution renderers lack quality. Furness (1991) comments that the development of tool-kits containing pre-programmed virtual objects, are an important factor in constructing virtual worlds. The choice of renderers varies depending on the requirements of the system. The features typically needed in a renderer for VR are:

- fast drawing algorithms²,
- polygon manipulation,
- surface removal,
- interface to body tracking technologies,
- texture mapping,
- a coding language (ie. programmable),
- interface to visual display technologies,
- high resolution images,
- stereoscopic support,
- light sources and shading, and
- virtual world maintenance utilities.

An appropriate public domain renderer for a low-cost VR system is REND386. Although it does not have texture mapping, and it has a fixed resolution (320 by 200 pixels), it is fast and can produce realistic virtual worlds; realistic is the sense that a user can recognise the shapes being rendered. Most of the algorithms developed at the core of the REND386 renderer are written in assembly language to make them fast. The speed of rendering is not a straight forward variable to measure. The relationship between processor speed and the complexity of the scene, determines the number of

² 25 frames per second update rate is necessary for smooth human perception

frames drawn per second. For example, a virtual world containing 60 objects consisting of 100 polygons each, can be drawn at a rate of about 16,000 polygons per second (equal to 27 frames per second), on a 486/DX2-66 MHz IBM compatible personal computer.

Commercial rendering packages include *WorldToolKit*, *Lepton*, and *VREAM*. These renderers are high quality, and expensive, with current purchase prices around NZ \$1,500 to NZ \$5,000. However, the purchase of a commercial renderer with high quality VR equipment, may only be a fraction of the total cost of the system. In addition to commercial rendering software, expensive hardware, such as graphics accelerators, are sometimes needed to run the VR system at acceptable frame rates. Without such hardware assistance, the resulting rendered frame rate of the virtual world would be low and impractical to use. Some commercial renderers, such as *WorldToolKit*, that need a compiler for virtual world development, allow VR developers to add their own programming code to solve unforeseen situations. Other software packages, such as *VREAM*, have a visual programming interface that can simplify the task of virtual object creation and animation.

2.3.4 Computer Hardware

A range of hardware options are available for constructing VR systems. These include IBM compatible and Macintosh personal computers, Silicon graphics computers, Sun workstations, and Cray super computers. Cost, availability, and processing power are important factors in choosing the correct hardware for a VR system. Silicon graphics, Sun workstations, and Cray computers are very expensive, usually only used by large corporations or governments who can afford them. IBM compatible and Macintosh personal computers are less expensive, and are available at a reasonable cost to the general public or small businesses. However, more efficient software is necessary to run responsive virtual worlds on personal computers with low processing power.

Chapter 3

Learning In Virtual Reality

When there is much desire to learn, there of necessity will be much arguing, much writing, and many opinions; for opinions in good men is but knowledge in the making.

John Milton (1658)

The process of learning is not restricted to the years of formal education. It is involved not only in mastering a new skill or academic subject, but also in emotional development, social interaction, and even personality development (Atkinson *et al*, 1987). The early years of life is the time when children learn most of their fundamental skills and knowledge.

The notion of using computers as educational tools is not new. Educational VR environments could be created by using similar concepts to successful scholastic software. One of these conventional computer tools is computer-assisted learning (CAL).

3.1 Computer-Assisted Learning Systems

Computers are being used increasingly as learning tools in schools and the home. A computer-assisted learning (CAL) system is likely to include the use of computers to aid

or support the education or training of people. CAL systems test attainment at any point, provide faster or slower routes through the material for people of different aptitudes, and can maintain a progress record for the instructor or learner to review (Oxford University Press, 1990).

CAL systems have been used in classroom environments in the past, with considerable success. Atkinson *et al* (1987) researched CAL reading programs with primary school children aged 11 to 12 years old. The computer was programmed to present different types of materials and instructions to each student, depending on the difficulty a student was having at any point in the reading curriculum. CAL had the advantage of working with each student in a highly individualised way, concentrating on the areas that the individual found more difficult. A control group had no supplementary CAL for reading. At the end of one year, all students were given a standardised reading test. Students in the experimental group scored, on average, higher in the reading test than students in the control group, suggesting that CAL had been beneficial. CAL systems that make use of VR technology are beginning to be explored.

3.2 Educational Software

Software that deals with educational themes are available to teach young children. They are popular due to their interactive realistic graphics, sound effects, and imaginative ideas. Most educational software tries to teach children skills that can be translated into the real world, providing another tool that teachers can use to teach in an attractive and interesting way.

Bailey's Book House is an example of a CAL program that combines a unique set of proven learning techniques with the power of interactive technology, to encourage two to six year-olds to develop early-reading skills (Cast, 1993). The program uses several ideas to teach the child. Every word is read aloud and highlighted as it is read, a word or sentence can easily be repeated by merely moving the mouse arrow and "clicking",

animated adventure characters motivate and engage the child as they play, and the child can learn and explore at their own pace due to its open-ended design.

Teaching new material through familiar concepts, may make learning exciting and more interesting. VR builds on this idea, by using concepts such as grasping and pointing to interact with the computer.

3.3 New Zealand Schools

At the School Certificate level³, in 1992, New Zealand schools had a failure rate (with normal scaling) of 42.9%, with up to 66.0% failing in some ethnic groups; a failure being a grade between 0% and 49%. Similarly at the Sixth Form Certificate level⁴ 39.5% of students received a grade of 6 to 9, and 58.1% in some ethnic groups. There has also been a drop of 13.2% in the number of students sitting School Certificate level examinations over the last twelve years, as well as a 39.6% drop in students continuing from the fifth form to the sixth form (New Zealand Qualification Authority, 1992). These trends seem to suggest that current teaching techniques may need to be reassessed to reach the struggling students.

An injection of the appropriate technology may be what is needed to reduce failure levels, and VR may be the answer to classrooms of the future. Progression from school to tertiary education currently needs a high level of academic achievement, and a positive attitude to learning. New rules of entry to New Zealand universities have changed to exclude 20% of students previously eligible for entrance into university (New Zealand Press Association, 1994).

³ Equivalent to a child 15 to 16 years old

⁴ Equivalent to a child 16 to 17 years old

New Zealand school rolls are falling, as well as their entitlement to funding. Low-cost educational aids are continuously being searched for. Declining school rolls, however, does not mean the student to teacher ratio is approaching the ideal of 20 : 1, because as the roll falls, so does the number of teachers permitted at the school. Computer aids, including VR, may help the teacher give each student the individual attention required. However, some educators are concerned that more technology that they are not trained to use will be dropped into the classroom, and that it will not help them to teach more effectively (Bricken, 1991). The time required to train the teachers to use new computer equipment is sometimes ignored. More positively, computers can have a self-motivating effect on children.

Currently computers in secondary schools are used for mostly instruction in computer programming, or as an introduction to computer science courses, whereas primary schools, being “experience” oriented, are more likely to use computers for adventure-type programs which can develop language, mathematical, or processing skills. New computer systems are being introduced into New Zealand schools. For example, Telecom New Zealand is supporting several schools in a new *Learning Link* program. *Learning Link* is a telecommunications system that allows classrooms to communicate with overseas schools in co-operative projects. Students can also access information from library and science centre databases, and interact with curriculum-based classroom projects, such as Edunet (Telecom Education Foundation, 1994).

3.4 The Role of Virtual Reality

Researchers at the Human Interface Technology Laboratory have been investigating the potential value of VR to education (Winn, 1993). Their research was conducted into the areas of cognition theory and psychological immersion processes, and how they relate to current proven techniques of learning. The study concluded that immersive VR furnishes first-person non-symbolic experiences that are specifically designed to help students learn

material, and cannot be obtained in any other way in formal education. In other words, learning the concept before learning the symbols or semantics of that concept.

VR may have important implications in schools of the future, by helping to educate children that are failing in the current system, as well as complementing the work of the more competent students. To help educate, VR offers teachers and students unique experiences that are consistent with successful instructional strategies: hands-on learning, group projects and discussions, field trips, simulations, and concept visualisation (Bricken, 1991). A VR learning environment can be experimental, intuitive, and provide a shared information framework that offers unique and natural inter-activity; being configured for individual learning and performance styles. A potential problem for a learner in VR would be the risk of learning relationships that might be incorrect in reality, and having to unlearn them (Osberg, 1993). To a child, the difference between VR and reality may become “blurred”, as the quality of VR systems improve.

Society has become more orientated to *visual-media*, and children nowadays are not reading as much and generally have shorter attention spans, than children twenty years ago (Forester, 1987). Television and video games can affect children by giving them more desire for instant gratification and a lack of the basic common sense appreciation of working to achieve rewards (Porter, 1992). The characteristics of VR are the same as those of good teaching. The teacher wants to create an environment that is programmable and flexible, in which the students can participate (Byrne, 1993). An important principle of classroom activity design is that the student’s actions and responses determine what will be learned. Learning comes after the student’s attention is focused; and learning is primarily action.

Learning in VR is a simple concept: in principle, everything done to educate with words and with pictures can be provided as a virtual experience. Location, scale, density of information, inter-activity and responsiveness, time, and degree of participation, are all variables could be altered from within the virtual world.

Ideally VR input responds to natural behaviour. In general a student should be able to command the system. There should be no command lines or “clicks”, but rather, walking, pointing, speaking, and grasping. Virtual environments are not restricted to only viewing. The student can also use VR tools to create new virtual environments, to modify old ones, to take immersive simulation exams, to fix errors, or to play. Byrne (1993) has documented a strong positive emotional reaction from VR participants. The users feel free and empowered, as if they are a “superman”; showing that VR is compelling. Children have also expressed a similar feeling of power in the classroom during interactive lessons (Byrne, 1993).

Rheingold (1991) comments that VR can help in the learning of a new a subject or skill, but it will never be a completely effective substitute for having physically worked on that subject or skill. The user needs to be reminded that a VR model is only a simplification of its real world counterpart. The designer must avoid teaching physical principles that do not apply in reality.

The use of VR as a learning environment requires an understanding of the shift from education as primarily a *text-based* experience, such as in secondary schools, to one that is *multi-sensory*. In developing practical educational applications of VR, Osberg (1993) has documented several issues that need more investigation. Osberg asks how learning in VR is different than that of traditional educational environments, and what aspects of multi-sensory learning may be of value in determining the effectiveness of VR. Osberg questions how individual learning styles may be enhanced or changed by VR, and what kind of research will be needed to assist instructional designers in developing effective VR learning environments in the future. Two additional questions developed during this study ask whether learning in VR can help an individual to learn a real world motor skill, and how the learner in VR can become the teacher.

Helsel and Roth (1991) comment that the capabilities of an educational virtual world should be able to produce an activity that is interesting and fun, as well as permitting

decision-making by the users. The virtual world should have potentially collaborative interaction, and allow the user to develop their own problems with a range of difficulties. The user should be able to engage in educational activities at the user's discretion, without the onus of surveillance.

Ferrington and Loge (1992) stated that learning using VR should be "less formal than traditional classrooms, perhaps more fun, and more realistic in terms of the wealth of experiences that might be generated". Research has showed that VR is a compelling creative environment in which to teach and learn. Students could create a "universe" of learning worlds that reflect the evolution of their skills, and the pattern of their growth of knowledge as they advance through the school system.

An early VR educator, Heilig, was aware of the educational content of his exhibit the *Sensorama Simulator*. Heilig's patent predates much of the psychological research that has since gone into the nature of learning, but noted in his patent that, "A basic concept in teaching is that a person will have a greater efficiency of learning if he can actually experience a situation as compared with merely reading about it, or listening to a lecture" (Rheingold, 1991). This concept expressed by Heilig is not new, viz the Chinese proverb, "I hear and I forget. I see and I remember. I do and I understand".

The *Juggling In a Virtual Environment* science centre exhibit, described in Chapter 7, attempts to extend work in the area of CAL and VR. JIVE meets the requirements for a good learning tool; containing realistic elements such as gravitational control on virtual objects, a virtual hand to throw with, and feedback on the form of the user's throws.

Chapter 4

The Exhibit Environment

If I wasn't meant to touch anything, what are these things on the ends of my arms for?

Science Alive! (1993)

The *Science Alive!* children's science centre in Christchurch, New Zealand, has a large collection of interactive educational displays in its main hall, as well as specialised equipment and experiments set up for school groups to visit regularly to provide experiences not usually available in schools.

People may visit a science centre for wide variety of reasons: to instruct or entertain themselves; to show off their knowledge; to have something to talk about to their friends; or even to get out of the rain. A high proportion of visitors may be attending for reasons that have little to do with the possibility of learning. Exhibits need to be built so that once a visitor has entered the main hall, they want to "have a go" at the exhibits, regardless of their initial reasons for attending the science centre. How and where the instructions for each exhibit are placed is important. Instruction labels should not be too long, should be not be placed above eye level, have large lettering, be colourful, and contain illustrations to orientate the user on the exhibit's functionality. A questionnaire, either "pen-and-paper", or computer-based at the end of the activity, or just before leaving the science centre provides good information regarding how well an exhibit was enjoyed (see Chapter 9). An exhibit should build upon knowledge thought to be

common to all users. For example, in the *Juggling In a Virtual Environment* exhibit described in Chapter 7, grasping and throwing objects by hand is an action that all the users would be familiar with.

4.1 Design Stages

The creation of a science centre exhibit usually requires several developmental stages. The stages of design which an educational exhibit usually follows are (Miles *et al*, 1988):

- initial concept and authorisation,
- planning,
- implementation,
- presentation and evaluation,
- maintenance, and
- updating and revision.

The initial idea or concept must be practical. A prototype exhibit is usually constructed to ensure that the initial concept is feasible, and trial runs are performed with a small number of volunteers. It must be remembered that the exhibit, once on the science centre floor, will have a higher breakage rate compared to the prototype or any subsequent exhibits constructed for supervised use. Redesigning of the exhibit then occurs, based on the feedback from the volunteers and observations made by the designers. Feedback and observations can be made via a questionnaire (see Chapter 9), in person, on video, or by self-analysis performed by the exhibit. Once the exhibit has proved itself to be fun, educational, attractive, safe, and robust, it is unveiled at the science centre. Tomlinson (1991) reports that educational systems that are good at teaching must not only have educational content, but must also be enjoyable. Video games, in particular, will keep users practising a single skill for hours. Individual exhibits must be able to withstand heavy and incorrect use. Therefore exhibits need to be robust.

The exhibit must be of interest to a wide range of the public, and hold their attention until the activity is finished. Science centre exhibits should aim to be stand-alone systems requiring minimal supervision. This not only can reduce the on-going cost of the exhibit, but allows the user the freedom to experiment and make their own mistakes during the learning process. By the end of the exhibit activity, the user should have learned something and come away with a feeling of accomplishment. Continual observations and feedback from the public are still required to allow the exhibit design to be perfected. Ideally, the cost of an exhibit should be kept as low as possible by the designers, in case complete replacement of the exhibit is required. Science centres often have tight budget constraints. The basic cycle of the development of an educational exhibit is shown in Figure 4.1 (Miles *et al*, 1988).

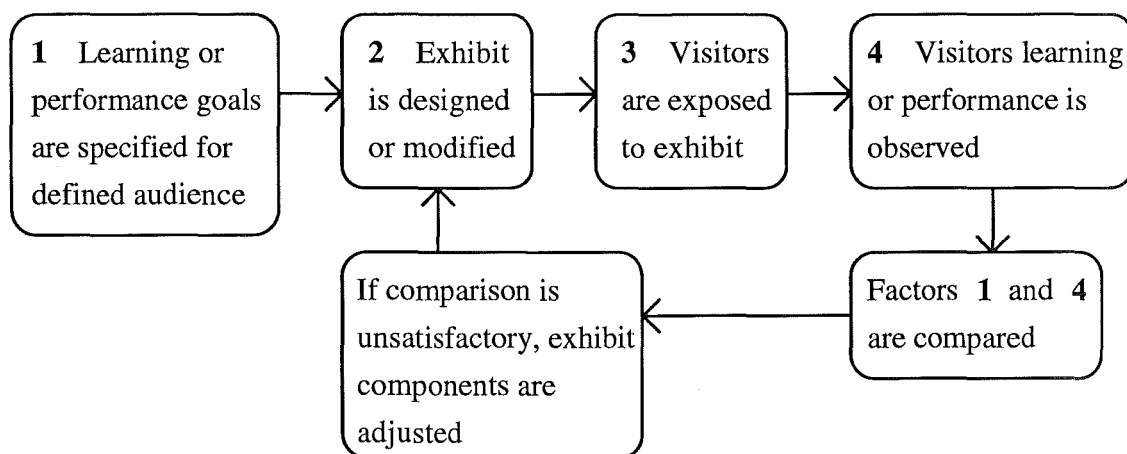


Figure 4.1 The basic development cycle for educational exhibits.

Interactive exhibits usually receive the most favourable feedback. VR provides a different form of human interaction with a computer, and incorporated into a science centre exhibit it may not only educate the user on the current theme of the exhibit, but also let them experience and understand the latest technology.

Video games provide a useful comparison for the success of VR as an interactive exhibit. Malone (1992) listed the characteristics of a good video game into three categories: challenge, fantasy, and curiosity. To be challenging, a game must have a clear goal but the outcome of each game is uncertain. To have an uncertain outcome, a goal must be neither too easy, so that it is certain to be reached, nor too difficult, so that it cannot be reached. Uncertainty can be added to the experience through the incorporation of random events occurring, or fixed events occurring at random time intervals. Fantasy can be incorporated into a game by setting the game in a foreign location, another planet, or in “cyberspace”, for example. The name and appearance of the exhibit should stimulate the user’s curiosity, thus drawing them to the exhibit to answer the questions they have formed in their minds.

Visitors often have a “What’s in it for me?” attitude — they weigh up the amount of effort, the likelihood of success, and magnitude of reward. It is unlikely that a visitor will spend much time on an exhibit, unless they feel the rewards will be worthwhile (Miles *et al*, 1988).

There are several reasons why an exhibit is unlikely to be successful in the eyes of the visiting public. A new concept is sometimes too vague, and can start beyond the visitors’ familiar knowledge. The exhibit should teach step by step, as well as the whole concept of the theme of the exhibit. Visitors can be confused if they are unable to see why something is introduced, because it has not been justified. The wording of instructions on an exhibit can sometimes be poor.

These common exhibit failings were kept in mind when implementing the exhibits described later in this thesis; *Juggling In a Virtual Environment* (see Chapter 7), *Cybertennis* (see Chapter 8), and *Data Digester* (see Chapter 9). The concept of VR is becoming increasingly common knowledge through media coverage. Initial knowledge required by the visitor for the Virtual Reality exhibits include putting on a glove, throwing and catching an object, or holding a bat to hit a tennis ball. In the two VR

exhibits, the system slowly makes the conditions more difficult as the user's skill improves. In the *Data Digester* exhibit, the concept of a questionnaire is well known. Initial knowledge required for *Data Digester* exhibit is to read the on-screen instructions and touch the screen in the correct area to give the answer. The introduction of on-screen objects in all three exhibits follows a logical progression as the user moves through the system. Instructions beside all three exhibits are complemented by on-screen instructions.

4.2 Educational Exhibits

An exhibit can teach concepts in several ways: by definition, demonstration, interaction, enactment, and analogy (Miles *et al*, 1988). The ways in which an exhibit can help a visitor to learn about a subject include:

- attracting the visitors,
- holding their attention,
- helping them recall knowledge (a level of background knowledge is assumed),
- presenting them with new information,
- activating their response, and
- by providing them with feedback.

One of the best ways to reinforce new ideas in an exhibit environment is to provide real-time feedback to the user indicating what they did wrong and how to correct their mistake.

4.3 Video Games and Science Centre Exhibits

In the future, VR will most certainly be popular in arcade systems, from the indication of their current popularity with most children. Concern has been expressed on whether VR will be better or worse than television or video games, for children. With television, there is “mode” of existence in which the watcher takes in a great deal of experience and information without moving (Rheingold, 1991). VR brings back physical and social activity, which television has taken away (Porter, 1992). Furthermore, if the VR system is programmable to the point where users can design their own virtual worlds, it may free them from the routine that video game producers like Nintendo or Sega have brought them into.

Computer games can play a significant amount of time in a child’s leisure activities, usually more than science centre visits. The games usually use small joysticks and large cathode-ray tube screens to interface with the player. In some cases guns or steering wheels are used together with large projected screens. Most arcade type games are oriented around repetitive learning. In other words, the user keeps on doing the same actions over and over until they progress. Most games available are based around violence. However, an advantage of using these types of games is that reaction skills develop quite quickly. The user can also obtain good skills manoeuvring with a joystick, or even have experience driving a car-like simulator. There are several similarities between an arcade game and a science centre exhibit. Most arcade games and science exhibits are:

- physically robust (or need to be),
- have robust software algorithms,
- deal with the general public (mainly children),
- are used for approximately 3 to 5 minutes at a time,
- are immediately appealing to the user, and
- involve varying levels of interaction.

The main difference between video games and science centre systems is that most science centre exhibits stand the test of time, particularly physical science exhibits. Van de Graaff generators, for example, have fascinated children for many years, and will continue to do so in the future. Arcade games usually only stimulate a few of the user's senses, whereas a well-designed science centre display can involve all five senses (Bell, 1992). Any proposed VR exhibit needs to appeal to as many of the user's senses as possible.

A good science centre exhibit needs to be flexible to allow change in its appearance and functionality. This will attract the user back to the exhibit, and the science centre. An exhibit that does not need any physical changes, only that of software, will have a lower down time at the science centre, because software can generally be modified faster and more economically than any major physical changes to an exhibit.

Chapter 5

The PowerGlove

Let each man render me his bloody hand. First, Marcus Brutus, will I shake with you.

Mark Anthony, The Tragedy of Julius Cæsar

There are several important factors involved in selecting a glove device that is appropriate for a VR system (Sturman, 1992). The degrees of freedom of the glove dictates how much independent information can be obtained from the glove. The *PowerGlove*, for example, has eight degrees of freedom; four fingers sensors, hand rotation, and three-dimensional positioning information. A fast sampling rate will improve tracking of the hand; this is dependent on the computation required to obtain useable data, from the raw sensor information. Cross-coupling of fingers can affect the accuracy of making gestures, for example, a glove's fabric may pull at other joints. The reported position of the glove needs to be steady; "noise" originating from the surroundings may affect the tracking system of the glove. The weight of the glove can cause user fatigue, and can be uncomfortable for the user to wear. Electronic limitations may reduce the usefulness of the glove, for example, the *PowerGlove* lacks information on the horizontal rotation of the user's wrist, and does not have a sensor for the fourth "pinky" finger. The glove needs to be reliable and robust to withstand repeated usage.

An ultrasonic hand tracking device, called the *PowerGlove*, originally developed for the Nintendo home video market, was the method of body tracking chosen for this study

(see Figure 2.5). The *PowerGlove* system consists of a glove that the user straps onto the back of their hand, with finger guides, and straps that go around the wrist and extend up the forearm. The finger guides contain plastic strain gauges painted with conductive ink, which can detect finger flexion. Two ultrasonic transducers are positioned across the knuckles, and produce controlled pulses of ultrasonic sound waves. A separate L-shaped bar supports three ultrasonic receivers. The time taken for the sound waves to travel from the transducers in the glove, to the receivers in the L-bar is recorded, and used in triangulation calculations to determine distance. The L-bar and the *PowerGlove* are both connected to a circuit board that collates the glove information. The circuitry is, in turn, connected to a standard Nintendo controller cable connector, that would normally connect to the Nintendo Entertainment System, and can replace a joystick. The *PowerGlove* can be connected to an IBM compatible personal computer by replacing the standard Nintendo controller cable connector with a printer port connector (see Appendix A for connection details).

The *PowerGlove* was designed by VPL, a company with experience in expensive VR systems, and Abrams-Gentile Entertainment, a company that deals in the toy industry. They merged their ideas, along with Mattel engineers, to derive the Mattel *PowerGlove* from VPL's *DataGlove* (Rheingold, 1991). The key to the price difference is the use of electrically conductive ink printed onto a strip of flexible plastic that follows each digit of the hand, in place of the far more expensive (and more accurate) fibre-optic bundles used in the *DataGlove*. Position of the *DataGlove* is calculated by the *Polhemus Isotrak* magnetic tracking system, which is more accurate than the ultrasonics used in the *PowerGlove*. The *PowerGlove* currently costs around NZ \$200, whereas the *DataGlove* currently costs around NZ \$10,000.

The *PowerGlove* can supply information to the computer quantifying the user's hand movements into four positions of the thumb and first three fingers, twelve positions of rotation of the wrist, and a three-dimensional coordinate of the hand, at a sampling rate of 15 Hz.

5.1 Background Noise

Acoustic tracking is susceptible to interference from external sound waves in the environment, which may introduce spikes to the user's movements in the virtual world. The *PowerGlove* cannot distinguish between a spike from surrounding interference and a fast moving user, resulting in the virtual hand moving independently from the user's real hand. Filters, hysteresis, and deglitching in the rendering software help to keep the position of the *PowerGlove* stable. These methods involve removing any obviously large movements of the glove and reusing the last identified position of the glove instead.

To investigate the level of background noise in an exhibit environment the *PowerGlove* was placed in the science hall, at waist height and 1.5 metres from the ultrasonic sensors. Any change in position was recorded using the rendering software for a period of thirty minutes, and the results averaged (see Table 5.1). Excess or uncontrollable background noise adversely affects the precision, positioning, and response of the glove for the user. Table 5.1 shows that over time the *PowerGlove* can give reliable results, but occasionally produces incorrect position data; this can result in the virtual hand moving unpredictably, causing frustration for the user.

Direction of Movement	Maximum Movement (% of dimension length)	Mean Movement (% of dimension length)
x	31 %	0.4 %
y	27 %	0.2 %
z	20 %	0.1 %

Table 5.1 The PowerGlove's positioning information from background noise test.

Since VR is a real-time system, any sudden movements to the user's position will reduce the reliability of the system. Soft fabric, such as towel, around the receivers can reduce the noise and reflections that can produce irregular positioning.

5.2 *PowerGlove* Gesture Recognition

The gestures performed by the user can be calculated from the four sensors in the finger guides of the *PowerGlove*. Each sensor has two bits of information, representing a maximum of four detectable positions of each digit. The following technique was used to recognise a gesture from the combination of the sensor values, implemented in the VR exhibit. Figure 5.1 shows part of an array, *Gestures*, of bounding sensor values that represents each gesture. For example, a 0 means the digit is fully extended, and a 3 indicates the digit is fully bent. The first pair of each tuple of the array represents the bounding sensor values for the thumb, the second pair for the index finger, the third pair for the middle finger, and the fourth pair for the ring finger.

```

Gestures[] = {
    0,1, 0,1, 0,1, 0,1,  /* OPEN */
    2,3, 0,1, 2,3, 2,3,  /* POINTING */
    2,3, 2,3, 2,3, 2,3,  /* CLOSED */
    2,3, 0,1, 0,1, 2,3,  /* PEACE */
    ...
}

```

Figure 5.1 An array of bounding finger sensor values.

To determine the gesture of the *PowerGlove*, the algorithm compares the current flexion values of each finger with the bounding sensor values in the array. If all sensor values

fall on or between their corresponding bounding value, then the gesture is asserted into the system. Any gestures that are not found in the array are asserted as “unknown”.

The order in which the gestures are placed into the array dictates the order in which the system will find the gesture in. A gesture that is similar to another may not be found. For example, a “ring” gesture defined as $\{1,2, 1,2, 0,3, 0,3\}$ describes the thumb and first finger being slightly bent (between positions 1 and 2), and any position is acceptable for the other two fingers (between positions 0 and 3). This would conflict with a gesture, say “ring2”, defined as $\{1,2, 1,2, 2,3, 2,3\}$ which is similar to the “ring” gesture except the second and third fingers need to be bent fully.

Normalisation or calibration of finger sensors occurs when the JIVE exhibit (see Chapter 7) asks each new user to “Put on the glove and point your hand towards the screen. OPEN and CLOSE your hand slowly to start VIRTUAL JUGGLING”. This procedure allows the *PowerGlove* to measure the extreme values of each of the finger sensors.

5.2.1 User Defined Gestures

The range of finger flexion varies between people. For example, a pointing gesture for a young child may involve two or three extended fingers. Also, as a result of high breakage rates of the strain gauges (see Section 5.4) some finger sensors may not be working to their full potential. A system to allow for the frailty of the *PowerGlove* would let the user input their versions of the gesture presented to them on screen. However, some users may find it physically difficult to create the gestures required for an absolute angle system⁵. For example, users attempting to create a pointing gesture, that cannot bend their thumb flat against their hand while keeping their index finger straight, may have problems. The tip of their index finger would bend and the pointing gesture be misread. The user would have to hold their index finger straight with the other hand.

⁵ In this system the gesture is recognised via a fixed-range deflection of the strain gauge

A programmable system that allows the user to customise the glove gestures would not be suitable for an exhibit environment since it would involve extra attention from science centre staff and would be prone to human errors. User defined gestures would be ideal for a system which is used regularly by a limited number of people, like in a classroom situation. Some systems use dynamic calibration techniques, which monitor the extreme movements of the user's fingers, adjusting to the capabilities of the user more readily (Thomas, 1992).

5.3 The Mouse versus the *PowerGlove*

Both mouse and *PowerGlove* input systems were implemented for the JIVE and *Cybertennis* VR exhibits. Assuming y , and z represent the directions up and forward; to move the mouse cursor in the z direction the right mouse button is held down, disabling the y direction at the same time. To simulate an "open" and "close" gesture, while using the mouse, the left button is pressed; limiting the number of gestures it can perform. The *PowerGlove* has a reputation for inaccurate three-dimensional positioning, due to interference from its surroundings and the necessity of having to always be directed towards its receivers. However, it gives the user a more natural approach to mastering on-screen graphics, such as juggling virtual objects, rather than operating a mouse in a horizontal plane. Users of laboratory JIVE (see Section 7.5) seemed to have more difficulty in using the *PowerGlove* than the mouse, this may be due to the user already being familiar with the concept of mouse operations. The *PowerGlove* represents a new computer interface which the users were not familiar with at first, and because of its inaccuracy, it did not always react to a users movements as they would have expected.

The mouse gives the user more freedom and precision of control of the cursor, which in the case of the JIVE exhibit, is the virtual hand. The mouse relates its horizontal movements directly to the movements of the virtual hand, in one vertical plane on the screen. A mouse may be preferred in a VR application where accuracy and low-cost is

important. In some cases, such as using VR to learn a motor skill, a glove input device would be needed to integrate the movements of the user's hand with the virtual objects in the VR application. Once the user has mastered the input device, they can focus on the application at hand. In a way, getting "used to" the device is necessary, which may take a few sessions of practise.

5.4 Strain Gauges

In the early 1980s, engineers developing the Koala touch-pad needed a tough, flexible plastic with a constant resistive surface (Eglowstein, 1990). During development, there were a number of rejects — one of which changed resistance as it was bent. That material forms the basis of the sensor technology that is used in the digits of the *PowerGlove*.

The *PowerGlove* sensors are 9 cm strips of polyester, each coated with 0.6 mL of a specially formulated ink. The resistance changes as the sensor bends over the normal range of finger movement. One sensor in each digit of the hand (except the fourth "pinky" finger) measures a single value representing all the joints at once. Following initial trials of the JIVE system, it was found that the *PowerGloves*, were not as robust as previously thought. The strain gauges were breaking at an alarming rate after only two to three weeks of usage. The breakage rates of the *PowerGloves* were beyond what had been budgeted for by the science centre. From examination, it was found that the strain gauges were splitting at the point of contact between the resistive paint and the soldered joint (see Figure 5.2) that connects to a cable leading to the glove's 8-bit processor.

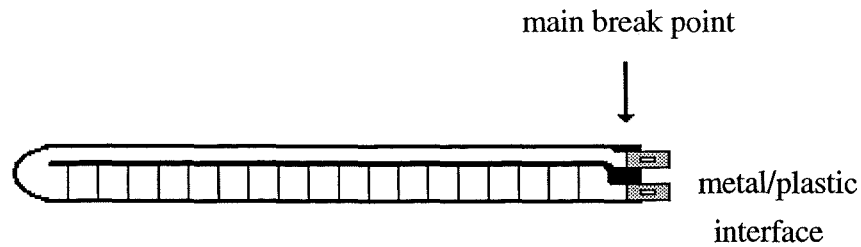


Figure 5.2 A strain gauge from the PowerGlove.

The main reason for this breakage is the way the strain gauge is mounted into the glove itself. The strain gauge holders themselves are too small for the sensors; being tight at both ends of the sheath. When a user puts on a glove the strain gauge cannot move around smoothly, and thus stretches. Visitors at the science centre using the *PowerGlove* have differing hand sizes, and can get rough with exhibit equipment — the science centre advertises that everything in the “hands-on” science hall is made to be touched. There have also been breakages found in the middle of the strain gauge, again due to the lack of movement allowed by the strain gauge holders.

The only strain gauge that did not break was in the thumb of the glove. The design of this particular strain gauge was different to the other finger sensors, being bent in two places along its length, following the shape of the human thumb. This shape has redistributed the strain of the flexing of the user to stronger parts of the strain gauge along the length of the plastic, rather than at the plastic/metal interface. The sheath of the thumb strain gauge was also wider and allowed more freedom of movement for the sensor. A VR application’s rendering software can use the fact that the thumb sensor is usually robust, and render all the other fingers as if they had the same flexion — ignoring their actual strain gauge sensor values. Although this would somewhat limit the gestures that can be performed by the user, in practice an “open” and “closed” gesture is sufficient to catch and throw objects.

The strain gauges need to have a looser sheath to prevent breakages, as well as reinforcement of the fragile plastic/metal interface with possibly a flexible soldering joint, protecting the joint from strain and friction. At *Science Alive!*, the gloves have been opened, and a velcro flap added to allow easy replacement of the broken strain gauges, when necessary, from spare parts created by older broken gloves. Unfortunately, Amtech, the company that manufactures the strain gauges, will not sell them separately to individual institutions. The *PowerGlove* is getting hard to purchase, so repair or replacement is not practical for the science centre in the long term.

Chapter 6

Juggling In The Real World

“The narrower pattern of the fountain”, said one careful voice, “makes it intrinsically more difficult than the cascade, though the flight-to-dwell ratio is the same.” “But having two independent feedback loops”, said a second, “accommodates minor variations more easily. Rastelli preferred the fountain”. The two were debating, not hydrodynamics or some obscure branch of mathematics, but the analysis of juggling.

Joe Buhler (1984)

Juggling is a complex motor skill, although once learned, the fundamentals are not easily forgotten. To learn to juggle the would-be juggler has to overcome the challenges and constraints of the real world, with gravity being the main factor. Most people can follow a single ball thrown back and forth between two people. But add another ball or two and at once the game becomes magical — the juggled balls take on a life of their own. It becomes difficult to tell whether the balls or the jugglers are in command, where the catches end and the throws begin, or even how many balls there are. Suddenly, simple motions and common objects blur into one stunning display after another.

Recently, jugglers and observers have begun to analyse juggling not only as a game, but as a phenomenon within the bounds of physical laws. Most jugglers, even those who are highly talented, do not think analytically about their juggling. For most of its four-

thousand-year history, juggling has been considered as an intuitive art. The earliest known evidence of juggling comes from an Egyptian tomb, dating from about 1900 B.C., which contains a painting of a woman juggling three balls (Buhler and Graham, 1984). The Greeks and Romans looked upon juggling as a form of entertainment, along with gymnastics and magic tricks. Their interest in juggling is reflected in relics from that era (see Figure 6.1).

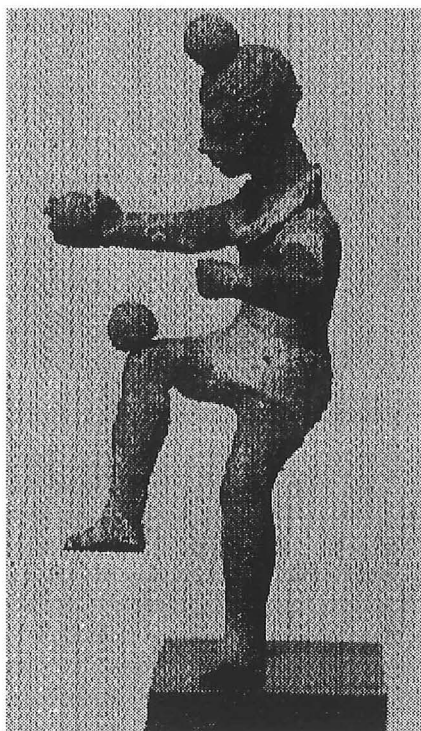


Figure 6.1 A Greek terra-cotta figure of a juggler, third century B.C.

Juggling can be analysed mathematically in at least two ways: through dynamics, the study of objects in motion; and through combinatorics, the study of the way objects and groups of objects can be combined (Buhler and Graham, 1984). Practising jugglers have an intuitive sense of the constraints of juggling patterns, such as the “cascade” or the “shower”. In the cascade, each object travels from one hand to the air, to the other hand to the air, and back again, following a looping path that looks like a figure eight on its

side. The cascade is typically the first juggling pattern learned by a new juggler. For this reason the cascade juggling sequence is first introduced to the user in the VR display designed in this study. The shower is a more difficult manoeuvre than the cascade; the objects in a shower follow a circular path as they are thrown upwards by the right hand, caught by the left, and quickly passed back to the right.

6.1 Algebra and Acrobatics

The constraints faced by the juggler, can be expressed with mathematical precision, using algebra and combinatorics. In mathematical terms, juggling involves five variables (Buhler and Graham, 1984). They are the number of objects (o) being juggled; the number of hands (h) being used to juggle with; the flight time (f) of each object between the hands; the length of time that a hand is empty (e) between catches; and the length of time that an object dwells (d) in a hand between throws.

These variables can be combined to calculate (see Equation 6.1) the period (p) of an object. The period of a thrown object is the time it takes the object to travel between each hand and can be looked upon from two perspectives — that of each object, and that of each hand. From an object's point of view, the duration of its journey will increase by $(d + f)$ for each hand it meets. Thus, one period equals $h(d + f)$. From the hand's perspective, the length of one period is based on each hand holding and being empty of each object; the duration will increase by $(d + e)$, for every object a hand meets. For each hand, one period equals $o(d + e)$. The time it takes for each hand to meet each object, is equal to the time it takes for each object to meet each hand, therefore:

$$p = o(d + e) = h(d + f) \quad (6.1)$$

Equation 6.1 is derived from the research of Claude Shannon, formerly of Bell Laboratories and the Massachusetts Institute of Technology (Buhler and Graham, 1984).

In his retirement, Shannon has worked towards a machine that juggles steel balls, using steel drums.

Gravity is the most confining physical affect on a juggler. The strength of the Earth's gravitational field (g) and the initial throwing conditions rigidly define how long an object will stay in flight once thrown. If a juggler throws an object with one hand to a height (H) and catches it with the other in the same horizontal plane, then the object's total flight time (t) on its parabolic path can be described as,

$$t = 2 \sqrt{2 H / g} \quad (6.2)$$

On Earth, g is about 9.8 metres per second squared. This gives the novice juggler a seemingly short time to catch and throw one object before another drops in their hand. In fact, the object is in flight for just over one second for a cascade-type throw.

From Newton's laws of motion the following equations can be derived to calculate the final velocity (v) of an object after t discrete time units of flight, with an initial velocity (u), travelling a distance of d units:

$$v = u - (g t) \quad (6.3)$$

$$v = d / t \quad (6.4)$$

$$d = (u t) - \frac{1}{2} g t^2 \quad (6.5)$$

Equation 6.3 calculates the final velocity of an object in conditions where gravity is operating, whereas equation 6.4 calculates the final velocity where gravity is not being opposed. Equation 6.5 calculates the height of an object at time t , when moving under gravity.

6.2 Relating a Real World to a Virtual World

Equations 6.2 to 6.5 can be used to simulate and predict the motion of an object under gravity, from one hand to another. A computer juggling program needs to throw an object from one hand to another, under given gravitational conditions, and in accordance with the juggling pattern being learned. The Virtual Juggling system includes two computer generated hands, one that is operated by the user and the other computer controlled (see Chapter 7). The computer is also able to calculate the trajectory of an object, allowing the user to focus on the timing of catches and throws only.

During software design, equations 6.6 to 6.8 were utilised to calculate the position of the thrown object at time t measured in discrete time units of the simulation.

$$x = x_o + (u_x t) \quad (6.6)$$

$$y = y_o + (u_y t) - \frac{1}{2} g t^2 \quad (6.7)$$

$$z = z_o + (u_z t) \quad (6.8)$$

The object's coordinates in three-dimensions are x , y , and z ; x_o , y_o , and z_o are the initial coordinates of the object; u_x , u_y , and u_z are the initial velocity of the object; and g is the downwards acceleration of the object.

To predict the initial velocity (u_x , u_y , and u_z) an object needs to be thrown at to produce a desired juggling throw, involves the use of equations 6.9 to 6.11.

$$u_x = s_x / T \quad (6.9)$$

$$u_y = \frac{1}{2} g T \quad (6.10)$$

$$u_z = s_z / T \quad (6.11)$$

The time of flight (T) of the object can be calculated by substituting equation 6.2 into equations 6.9 to 6.11, where u_x , u_y , and u_z are the initial velocities of the object in the x ,

y, and z directions; s_x and s_z are the separation distances between hands in the x and z directions; and g is the downwards acceleration of the object. An example of the calculations of the initial velocity required by the computer to throw an object in a *cascade* motion of height 1000 units; hand separation of 1500 units in the x direction, and 0 units in the z direction, and gravity of 9.8 units per discrete time unit squared, is:

$$\begin{aligned} u_x &= 1500 / (2 \times \sqrt{(2 \times 1000 / 9.8)}) && = 52.5 \text{ distance units per time unit} \\ u_y &= 0.5 \times 9.8 (2 \times \sqrt{(2 \times 1000 / 9.8)}) && = 140.0 \text{ distance units per time unit} \\ u_z &= 0 / (2 \times \sqrt{(2 \times 1000 / 9.8)}) && = 0 \text{ distance units per time unit} \end{aligned}$$

The object's path, after being thrown, is described by equations 6.6 to 6.8. The sign of each component of the velocity of the object dictates the direction in which the object will move. In the y direction case, positive is up and negative down, while in the x direction case, positive is right and negative left. In the z direction case, positive is forward and negative is back.

The ability for the computer to predict the trajectory of an object means that it can act as a computer assistant and provide a kind of decision support system for the user, on how to change their throwing style. Knowing the initial velocity required for an object to travel a given horizontal distance (s_x) and to reach a particular height (H), range checking can be applied to the user's throw and subsequent feedback given. Equations 6.12 and 6.13 have been derived from equations 6.2, 6.3, and 6.9 and can be used to compare the distances thrown with the correct distances.

$$s_x = (2 u_x u_y) / g \quad (6.12)$$

$$H = u_y^2 / (2 g) \quad (6.13)$$

Feedback can include an on-screen informative comment, if the user has not thrown the object correctly, or a positive comment when a good throw is achieved. Sound could also be used as an indication of how well an object was thrown. Other forms of textual

feedback implemented here include an indication on what type of throw to execute, and information on changing virtual world conditions, such as gravity.

6.3 Real Juggling

For the novice juggler, objects seem to move too quickly for their hands to respond. Difficulties in learning to juggle include coping with gravity bringing the objects down too fast, prediction of where each object is going to land while not watching the last part of the object's flight, peripheral vision to see as much of the object's pathway to accurately predict where it will be caught without losing track of the other objects in the air, and tactile feedback to give the feeling of catching the object. An ideal juggling pose would have the juggler catching objects at about navel level. Objects would be caught about 10 cm to the side of the body, with a further downwards movement following catching, and rising up to the navel throwing position, with the accumulated momentum.

The JIVE system has replaced tactile feedback with auditory feedback — a “thud” as the object is caught. Ideally juggling occurs in a vertical plane, but a new juggler may find themselves throwing slightly away from themselves. JIVE restricts the z dimension of the virtual objects, making throwing and catching easier. The juggling system also encourages timing training, by controlling the speed and direction of the object, and letting the user focus on just catching and throwing. Timing is important to ensure that an empty hand is available to catch an object at the appropriate moment.

In the JIVE system objects and hands all have shadows directly below them on the virtual floor, to help the user gauge their position in the z dimension, if it is configured to be unrestricted. Prediction is part of the juggling process; a juggler should only be looking at the peaks of the objects, predicting where they will fall, and adjusting their hand accordingly. This effect can be confirmed by throwing an object with the juggler closing their eyes before the flight's peak, and then after; and comparing the rate of

successful catches. When the eyes are closed after the flight's peak catches are more frequent than before the flight's peak.

In reality, a simple juggling pattern taught by a professional takes around 20 minutes to learn. The goal of the JIVE system is to reduce this learning time, by allowing the user to experience juggling in a virtual world, where the physical constraints of the world are controlled by the computer. The user experiences the advantage of learning a juggling pattern in low-gravity, and feedback from the computer on the accuracy of each throw and the user's cumulative performance.

Chapter 7

The “Juggling In A Virtual Environment” Exhibit

Since gravity imposes such sharp constraints, mathematically minded jugglers often daydream of the feats they could accomplish if the acceleration due to gravity were not so great.

Ron Graham (1984)

Techniques that have been used to experience low-gravity juggling include underwater juggling, juggling while in free-fall, and juggling light objects such as balloons. Some jugglers have even imagined venturing onto the surface of the moon to juggle. Galilean jugglers, mimicking Galileo’s experiments in Pisa, used inclined planes and rolling balls to help fight gravity (Buhler and Graham, 1984). The introduction of a virtual environment where gravity can be controlled would allow users to experience low-gravity juggling without some of the inconveniencing of the above methods. The user could alter gravity in the virtual world in which they are juggling, and experience realistic conditions in a safe and controlled environment. VR may make a difficult skill, like juggling, easier to learn.

This chapter describes the design and functions of the *Juggling In a Virtual Environment* exhibit, built for a children’s science centre, *Science Alive!*. Juggling, as explained in Chapter 6, is often perceived as a complex skill; VR may be able to help users learn this skill. The system components chosen for this exhibit are discussed (see Chapter 2 for broader description of VR system components), then two types of virtual juggling

systems — the “public” JIVE system, and the “laboratory” JIVE system — are described. The public JIVE system is a simple object handling environment for an exhibit experience lasting from 3 to 5 minutes, while the laboratory JIVE system is a genuine attempt to teach juggling in a more controlled environment, with the experience lasting from 5 to 20 minutes. Each system is investigated for its merits and draw-backs.

7.1 JIVE Components

The components used in the JIVE exhibit are suitable for most exhibit VR applications, not specifically for a juggling exhibit (for example see the *Cybertennis* exhibit in Chapter 8). However, not all VR systems can be constructed from generic components. Some systems may need specific hardware, for example, a musical VR application (Thomas, 1992).

The software and hardware chosen for JIVE resulted from investigations into different systems that currently are available in the VR arena. Components were selected that best met the requirements of the proposed public VR exhibit, outlined in Chapter 4. The components need to be robust, have inexpensive initial and replacement costs, and be available locally. As *Science Alive!* relies heavily on donations to finance exhibits, all costs must be kept to a minimum. The chosen JIVE components are:

- Infocus TFT 7600WS colour data projector,
- 486 DX2-66 IBM compatible personal computer,
- Kodak Econolux 113 over-head projector,
- tiered glass case with cooling fans, power supply, and a large reset button,
- wooden frame with fabric screen (2.0 metres by 1.5 metres),
- modified Mattel *PowerGlove* and ultrasonic receivers, and
- REND386 public domain rendering software.

The JIVE exhibit, in Figure 7.1, shows the user standing about one metre away from the large screen, which is made of a wooden frame and white cotton fabric. There is a two-tiered glass cabinet to the right of the user, oriented at an angle of about 70° from the screen, containing the data projector, over-head projector (OHP), computer and monitor, cooling fans, and power supply to all units. A holster on the wall next to the screen holds the *PowerGlove* that is connected to the computer via cables behind the screen, across the ceiling and down to the cabinet and the computer I/O port. The *PowerGlove* receivers were placed behind the fabric screen. The long cables required to connect the *PowerGlove* and the receivers to the computer did not deteriorate the tracking signal quality of the *PowerGlove* received by the computer. Instructions on the glass cabinet give the user background information on the exhibit and its use. The glass case also has a large red reset button on one side, which is connected to an I/O port of the computer. The reset button allows each new user to reset the system at the beginning of their experience. The OHP automatically turns off after five minutes of use, terminating the session.

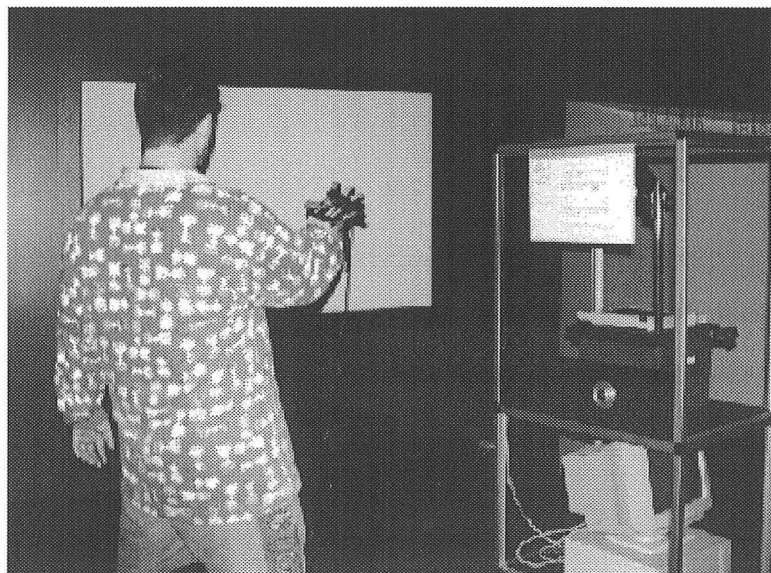


Figure 7.1 JIVE as set up at Science Alive!

The *PowerGlove* and reset button are theoretically the only exhibit components to be handled by users. Unfortunately, users tend to touch most parts of an exhibit due to the nature of the “hands-on” science centre, including the screen. The exhibit’s down time for maintenance needs to be minimised so visitors will not be disappointed if they are expecting it to be operating.

The large screen of the JIVE exhibit was chosen because it allows medium immersion⁶ and visual collaboration. The field of view of the large screen is about 75°, compared with 45° for a 14" monitor, and 140° for an HMD.

The 3-D cellophane and polarised glasses technologies were not considered suitable for the VR exhibit. Cellophane glasses were not used because of the colour limitations in the filters, and the need for extra processing power to render stereoscopic images. The need for an illusion of three-dimensions was not justified, and the shutter glasses, like the HMD are fragile and cannot be used for a public exhibit, unless strengthened in some way.

The data projector and OHP system is relatively inexpensive, and is a more reusable technology for the science centre than VR specific helmets. The side projection system introduces a slightly skewed image to the user (see Figure 7.2), but generally this was not noticed. Boff and Lincoln (1988) have found that small distortions of an image according to projective geometry will not affect the user’s perception of the image. A projected system removes the possibility of motion sickness; this is a phenomenon where the user’s eyes perceive movement, while their ears say that they are not moving.

⁶ Full immersion would cover the user’s entire peripheral vision

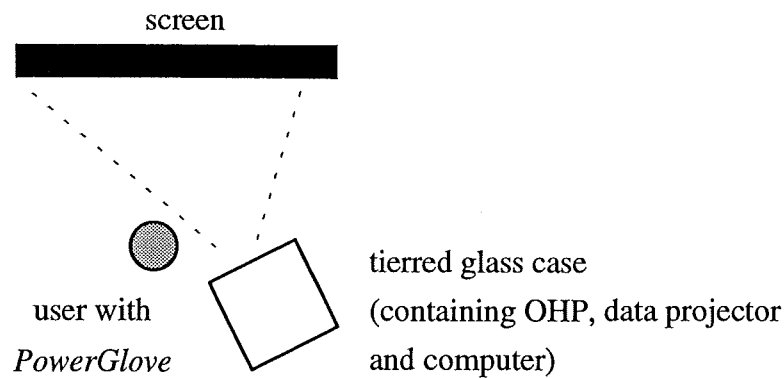


Figure 7.2 Over-head view of the JIVE exhibit.

The fabric used for the large screen allows the ultrasonic sound waves to pass through unaltered. The fabric is 469 μm thick, with 210 μm between threads, so 9.57% of the fabric was space.

The life of the light-bulb in the OHP was an unforeseen maintenance cost of this equipment. Approximately NZ \$100 was spent on replacing bulbs per month on the exhibit, as bulbs were NZ \$50 each. Hardware actions have been taken to secure the life of the bulb, by using a five minute automatic time-out mechanism that cuts out the power supply to the OHP. The data projector gives the best robust, public display correlated with the best immersion factor. However, shadow problems occur with the projected system, by the user waving their arms in front of the line of projection.

The *PowerGlove* was chosen for its apparent robustness (see Chapter 5), and its low-cost. Although made for the Nintendo Entertainment System, the *PowerGlove* can be connected to a PC (see Appendix A). The *PowerGloves* were, at the time of exhibit development, available locally, but have since gone out of production commercially, making them hard to replace.

A public domain rendering package called REND386, was used to create the virtual worlds. REND386 has the capability of loading in a description of a virtual world, and provides the object manipulation functions used in coding the juggling system. The

parameters of the world are defined in the virtual world file, such as the initial viewing angle, where objects should be placed in the world, lighting intensities, and colour definitions. Each object referenced in the world is described in a separate file, with descriptions of every point in the object, how they are joined into polygons, and the colour used on each face of the polygon. Appendix B shows a sample object file. REND386 does not have texture mapping or true surface removal support, but it is sufficiently fast to use in this VR application. The renderer provides device driver routines that make it compatible with the *PowerGlove* and it is freely available, being public domain software.

7.2 Juggling in Virtual Reality

VR may help the user learn new skills, including juggling (Geake, 1992). Some researchers have discussed virtual juggling systems that handle various objects, but none have implemented a learning system. Furness (1991) imagines learning to juggle in a virtual world with one-twentieth of the Earth's gravity, and then gradually increasing the gravitational force. Furness comments that the ability to alter parameters of a virtual world is an important tool of teaching such basic laws as gravity or time. JIVE implements learning to juggle in VR with a conventional, readily available, low-cost system.

There is existing software that teaches the patterns and principles of juggling, and allows users to explore new patterns. Public domain PC software such as *JugglePro* allows the user to vary the number of hands and to see the pattern being juggled from a variety of angles. *JugglePro* unfortunately does not have interactive participation; the user is not in the processing loop. A juggling program for Sun workstations, called *xjug*, produces a two-dimensional image of a specified juggling pattern, and has the ability to change the simulation speed in real-time. However, a prior knowledge of the structure of juggling patterns is necessary to use the program.

A number of features have been developed during this thesis that may help the user to learn to juggle in a virtual environment. Features of JIVE that aid juggling in VR include:

- controlling gravity (automatically and manually),
- control of throwing space (especially the z-axis),
- sound replacing tactile feedback,
- automatically calculating the speed and direction of throws for timing training,
- controlling the pace of the system,
- assist throws via feedback with “pop-up” text windows,
- allow the grasping of objects that are “close” to the hand,
- computer-generated hand throws back to the user in the correct way,
- using a *PowerGlove* as a natural input device,
- shadows to improve perception of objects’ positions, and
- multiple objects introduced into the virtual world.

7.3 Two Juggling Systems

JIVE consists of two integrated systems that both incorporate a level of learning and comprehension of both juggling and VR. The user in a public exhibit situation only has around 3 to 5 minutes of contact with the system, and will react differently to a user in a laboratory situation. The public JIVE user may not fully read the instructions given to them that so any instructions should not vital to the operation of the exhibit and their performance. The first system is an introduction to interacting with a virtual environment and being able to change the parameters of that world. The second system is a genuine attempt to teach the user a motor skill. Under laboratory-type conditions, the user is be able to obtain feedback from their actions in a longer experience (5 to 20 minutes), using the *PowerGlove* or mouse input devices.

7.4 The Public JIVE System

The main aim of the public JIVE system is to introduce the user to the experience of interacting in a virtual world with virtual objects; in this case throwing them around a room of fixed dimensions, and being able to change characteristics of the world via a pointing gesture and their own hand movements (Ralston, 1992). The user can learn how gravity affects the behaviour of objects within the virtual room.

The first screen instructs the user to don the glove, open and close their hand slowly to calibrate the finger sensors, and keep their hand pointed towards the screen. They are then presented with a virtual room shown in perspective with different objects on the floor. A virtual hand mimics the movements of the user's own hand, as they are asked to "grab an object" from the floor (see Figure 7.3). The objects include a giant chess piece, a fir tree, a giant doughnut, a banana, a pterodactyl, and a spinning globe. A library of objects is available for the science staff to change the selection on a regular basis, through an ASCII script file.

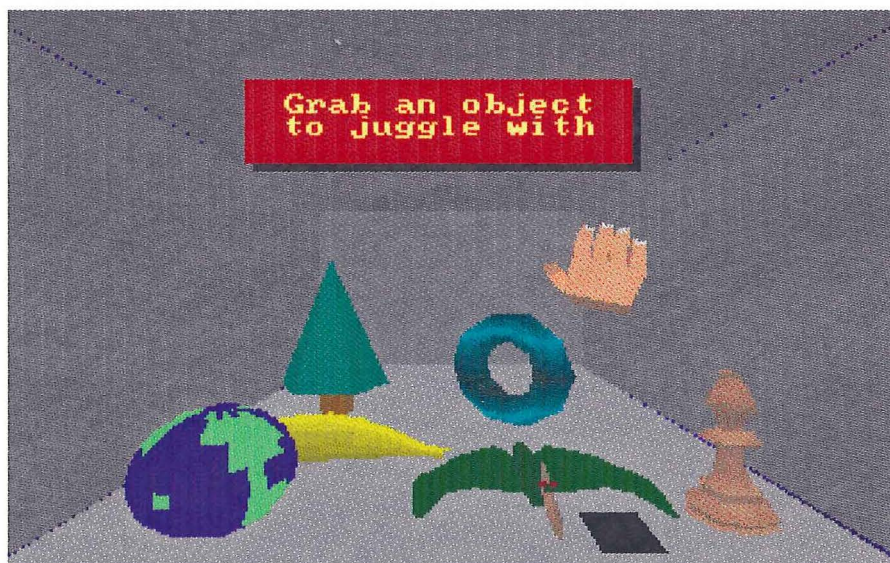


Figure 7.3 Selecting a virtual object in JIVE.

With the other objects automatically removed, the user is now able to throw the object around the room and catch it. Shadows are shown below both the hand and the object chosen. Gravity can be changed by creating a pointing gesture. This gesture reveals a gravity selection menu, overlaid onto the virtual room (see Figure 7.4). Moving the glove up or down moves a highlighted bar up and down the menu, as long as the pointing gesture is held. As the *PowerGloves* deteriorated, the pointing gesture became more difficult to perform and keep steady. To allow for this, the scheme was changed to a toggle function, using just one pointing gesture to reveal the gravity menu, and another to remove the menu. The problem associated with holding the pointing gesture for too long, was removed by accepting pointing gestures in succession by the user as a single point.

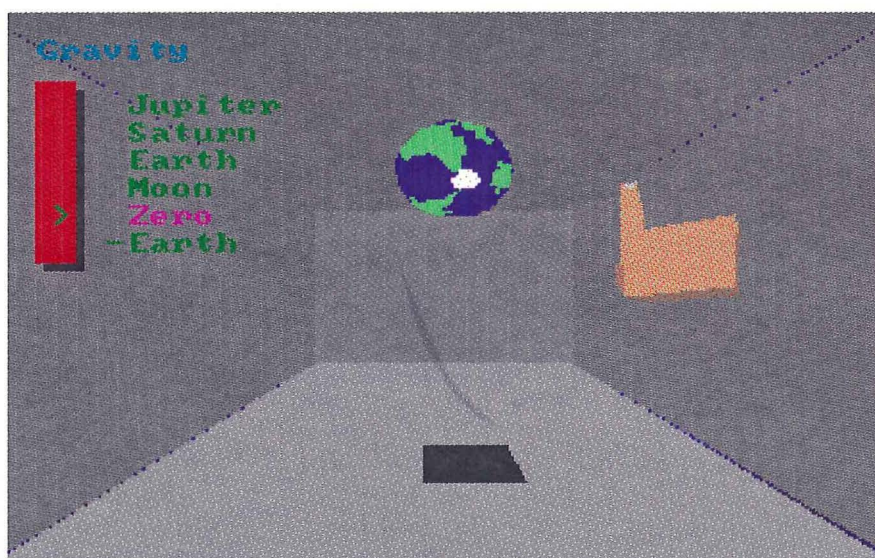


Figure 7.4 Changing gravity on a virtual globe in public JIVE.

The user can set the environment's gravity to that of a different planet, or reverse it so that the object floats to the ceiling. The object is kept within reach, with the walls of the room limiting its movement. The hand movements were amplified in all three dimensions to allow the user to only move a little to reach the bounds of the virtual room. This was

useful with restricted space in the exhibit hall. The large reset button returns to the object selection screen.

7.5 The Laboratory JIVE System

The laboratory JIVE system is designed to allow users a longer experience to learn to juggle different juggling patterns. The juggling features described at the start of this thesis are investigated in more detail.

The main feature is a computer-generated left hand present in the environment to catch and throw back objects to the user. The goal was to attempt to teach the user to juggle under controlled VR conditions and see how they were able to juggle in reality afterwards. The system gives the user feedback and advice on their throwing form.

Observations were made of user's who had not juggled before, as well as some with juggling experience. The experienced jugglers liked the system, but wanted a more complex, or faster means of juggling more objects, whereas the new jugglers liked the pace of the system — the system felt individualised to their skill level.

7.6 Juggling Patterns

Juggling in reality requires control of the way the objects are juggled. A pattern configuration system was produced to allow the computer and the user knowledge of some real juggling techniques based on what is called *siteswap* notation. This enables the user to be more prepared for juggling in reality. Most people can juggle one or two objects, either from one hand to the other or up and down to the same hand. This simple skill is a starting point for the user and the computer to extend the knowledge into something more complex and challenging for the user. A pattern configuration file is

used to inform the computer of the number of objects in the arrangement, and the repetitive sequence for the actual pattern.

The *siteswap* notation of juggling via plain ascii files has been adapted from a public domain PC package called *JugglePro*. An example of a three lined ASCII file for the *cascade* sequence is shown in Figure 7.5.

```
# Classic cascade juggling pattern
3
3
```

Figure 7.5 File format for the cascade juggling pattern.

The first line of the cascade juggling pattern file is a comment describing the file. The second line indicates the number of objects in the pattern; in this case three objects. The last line is the *siteswap* notation for the pattern, each number in the list representing the throw type for each hand. The full *siteswap* notation in this case is simply 3. The hand sequence for this pattern is: right hand throws a 3-type, left hand throws a 3-type, right hand throws a 3-type, and so on; producing a *siteswap* notation of 3 3 3 3 recurring. This is simplified to 3, since the repetition is implicit. More examples are given in Appendix C.

7.7 Types of Throws

The type of throw refers to how an object is expected to be thrown, and ultimately analysed by the computer juggling system.

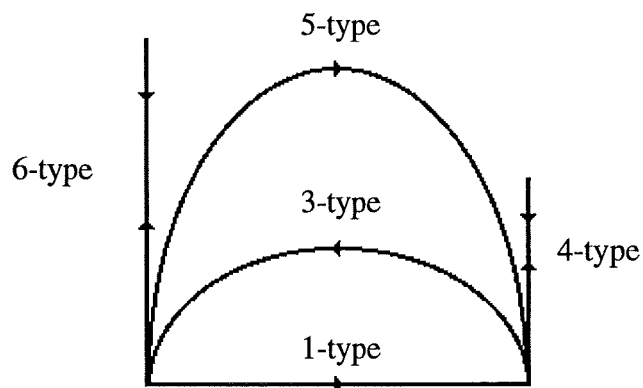


Figure 7.6 Throw types used in siteswap notation.

The period between the start of each throw is termed the “beat” of the sequence. There are several possible types of throws shown in Figure 7.6, represented in *siteswap* notation they include:

- *0-type* means there is no object in the hand to throw
- *1-type* means a throw (one beat) horizontally to the other hand
- *2-type* means hold the object in the same hand for a beat
- *3-type* means throw a *cascade* throw to the other hand
- *4-type* means throwing the object vertically and back to the same hand
- *5-type* is similar to a *3-type* except about twice as high
- *6-type* is similar to a *4-type* except a higher flight

The types of throws possible continue to about an *8-type*, due to the physical limitations of the human body. An example in *siteswap* notation of a shower pattern is *5 1*. All sequences start with the right hand and then alternate with the opposite hand; this is called *asynchronous* juggling. The JIVE system shuffles objects equally into both hands at the start of a juggling session. If there is an odd number of objects, the extra object is placed into the right hand, which starts the sequence.

From the nature of the *siteswap* notation, odd number throws go to the opposite hand, and even number throws to the same hand. Averaging the throw numbers gives the number of objects that can be juggled. This acts as a check to the validity of the juggling pattern. For example, *5 1* is a valid three object pattern since the throw numbers average to 3, while *4 3* is not valid.

The equations in Chapter 6 were used to create a throw with a given height, hand separation distance, and gravitational force.

7.8 The Learning Control File

As in learning most subjects, the student juggler starts from basic facts and skills, and is led step by step to new and ever more complex permutations. The learning control file dictates the sequence of actions that the user will experience, as they learn juggling step-by-step. This file can be restructured to suit a different set of users — from the less experienced to the more advanced.

Start	Cascade	Demo				
1	5	TIMING	FIXED	1.0	1.0	OFF
1	5	TIMING	FIXED	1.0	9.8	OFF
1	5	OPEN	FREE	1.0	1.0	OFF
2	5	OPEN	FREE	1.0	9.8	ON
Start	Shower	Demo				
3	5	TIMING	FREE	1.0	1.0	OFF
3	5	TIMING	FREE	1.0	9.8	OFF

Figure 7.7 An example of a learning control file.

Figure 7.7 shows a file format that lets the user practise the cascade juggling pattern, and then the shower pattern, with a demonstration of the each pattern showed at the start of the practise, indicated by the key word “demo”. The first column indicates how many objects to juggle and the second how many catches in a row the user needs to make on each object before progressing to the next level. The third column shows the nature of the throw. The key word “TIMING” indicates that the computer will calculate the correct throw speed and direction for the user, with the user concentrating on timing of catches and throws. The key word “OPEN” means the users movements of the virtual hand will dictate the speed and direction of the thrown object. The fourth column shows how the hand can move; the key word “FIXED” leaves the hand on one spot, and the key word “FREE” allows free movement in the virtual room. This is particularly useful when using the *PowerGlove*, which is prone interference and sporadic movements. The fifth and sixth columns indicate the initial and final values for gravity. Gravity will be gradually increased over the number of throws indicated by the value in column two. The seventh column indicates whether the z axis is restricted, indicated by the key word “ON”, or free indicated by the key word “OFF”.

The learning control file gives the user or experimenter the flexibility to adjust the learning program to allow for their improvement over time. For example, the number of objects can be increased as the proficiency of the user improves. An expert in the system may want to skip straight to high gravity juggling, for example. After leaving the laboratory JIVE system, a file can be recorded on how each user performed throughout the experience.

7.9 Lending a Virtual Helping Hand

To portray the skills involved with learning to juggle, a second virtual hand was needed to catch the user’s throws. The virtual hand acts “behind the scenes” to helping the user achieve the correct juggling style. This is done by catching the user’s throws and

throwing them back correctly. The user can learn by “example” and by “trial and error” at progressive levels of achievement. In a sense the second virtual hand helps the user by giving advice as they juggle, especially as the number of objects increases. Figure 7.8 shows the virtual hand on the left and the user controlled hand on the right. The feedback system is suggesting to the user to throw a *3-type* throw for the next object.

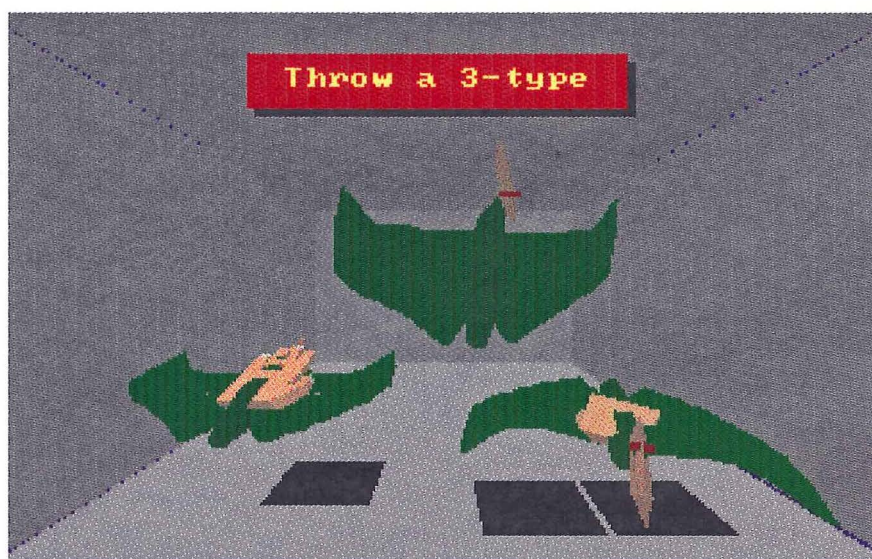


Figure 7.8 Juggling three pterodactyls in a cascade pattern.

A method of controlling the hand’s movement that reflected a natural activity, were developed. The pseudo rules for the virtual hand’s actions include:

*if hand is empty and object approaching⁷ within grasping distance then
grab the object*

*if hand is full and object from the other hand is at top-of-flight⁸ or beyond⁹ then
throw object from the hand*

⁷ As opposed to objects just thrown by the hand

⁸ The top-of-flight is when the y-value of the object’s velocity is zero

⁹ If an object is past its top-of-flight peak and is near the vicinity of the other hand

The left virtual hand movements are governed by sampling the right virtual hand's position, controlled by the user, at regular intervals. The left virtual hand's location moves slowly to a given offset in the x -axis away from the right virtual hand.

Initially more than one object may be in a hand. This is treated as a special case for the start of the pattern. Objects are automatically placed back into the user's hand when a restart is necessary; for example, when a surface is collided with or an object is dropped.

7.10 Moving Objects in a Virtual World

The equations for Newton's laws of motion from Chapter 6 are used to calculate the position at any time of any object thrown by a hand, virtual or real. Pseudo rules for object movements are:

if object just thrown from a hand then

set the initial velocity of the object to the final velocity of the hand

if object collides with a wall in the virtual room then

reverse the velocity vector of the object that opposes the wall and lose energy

if object not in a hand then

move object according to Newton's laws of motion

if object is in hand then

follow the hand

An object does not have to be actually "on" the hand before it can be grasped into the hand. An invisible sphere surrounds each object, and if a hand is within this distance and in a grasping gesture, then the object is automatically placed into the hand. A shadow is rendered for each object, to help users identify relative positions of objects. This is a new feature was developed during this study as an addition to the REND386 rendering

software. Shadows are implemented as black rectangular polygons positioned under the object at the level of the floor of the virtual room.

7.11 The Execution Cycle

The cycle of the rendering loop needs to be executed quickly, to produce a reactive real-time system for the user. Each function of the cycle performs specific tasks related to juggling virtual objects, and are listed below.

- Retrieve the latest glove or mouse information
- Set gestures
- Process user keyboard actions
- Move hands
- Move objects
- Process hand collisions
- Process object collisions
- Feedback messages to the user
- Refresh the display

The computer displays feedback messages on what to throw next, just as the user grabs an object, and information about the form of the throw, as the object has leaves the user's hand. Each object stores its own information relevant to its current state in the virtual world (see Appendix D).

Controlling juggling speed is dependent on the number of polygons each object contains. Smaller objects, composed of a low number of polygons, will be rendered faster. Calibration is performed to ensure the correct speed of flight for each object. The time of each throw in a normal cascade, in reality, takes on average about one second to achieve. At the start of a session, a short calibration process using gravity of 9.8 units

per time squared, is applied. The system tries to calibrate to the proper speed after the first throw. The differing speeds depend not only on the number of polygons that make up the object, and the speed of the computer architecture, but also on the number of objects within the virtual world. The calibration could be a continual process if accuracy was important, but a high level of accuracy was not required, and was only performed on the first throw in the system.

7.12 Software

The software was designed with different platforms in mind. The JIVE system should be able to move platforms with only minor changes to the software. Being written in C++, it is reasonably portable. As *Science Alive!* can afford more expensive computers, displays, gloves, or body tracking devices, these should be easily upgraded, improving the exhibit with minimal effort or down time.

7.13 Analysis of the JIVE Exhibits

Feedback from the exhibit was obtained by the *Data Digester* exhibit (see Chapter 9) for the public JIVE system. This gave an idea on what some visitors thought of the exhibit.

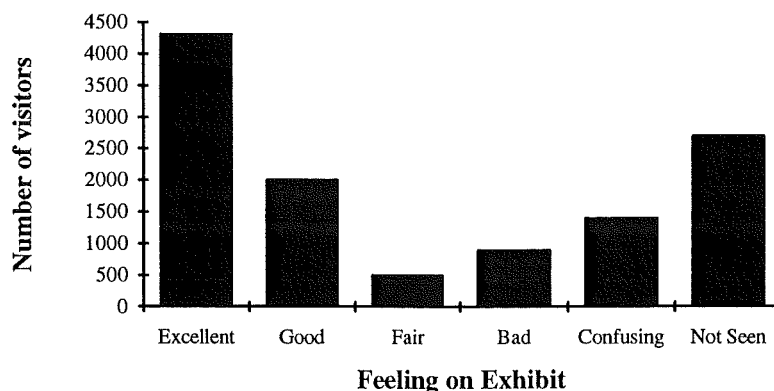


Figure 7.9 Results from the *Data Digester* electronic questionnaire for JIVE.

Figure 7.9 shows a graph of the results collected by the *Data Digester* exhibit. Most visitors that used the electronic questionnaire and saw the exhibit thought that it was “excellent”. A large number also never saw the exhibit. This may be due to the down time of the JIVE exhibit when the *PowerGloves* were broken.

During prototype testing of the public JIVE exhibit, video cameras were used to capture a classroom of children, aged between 10 and 12 years old, engaged in the JIVE system. The video was able to show how children were using the system. The video showed that the *PowerGloves* were difficult for young children to put on correctly without supervision, and they tended to frequently point the glove away from the receivers. The children were keen to create new ideas for the exhibit. Suggestions were made for juggling objects such as fire and different kinds of animals. Ideas for VR applications were encouraging with suggestions such as “I’d like to talk to and touch aliens from Mars”.

Computer monitoring from within the JIVE software has shown that most visitors choose the object that is closest to the front of the virtual room. This may be because the user does not realise that moving slightly forward will move the hand to the back of the room, until later in the exhibit. Tracking of the user’s movement was attempted, but getting any movement trends was made difficult by the sporadic movements of the *PowerGlove*.

The laboratory JIVE system was not able to be placed onto the exhibit floor, due to the *PowerGlove* failure and the move to the *Cybertennis* exhibit (see Chapter 8). The system was trialed with a selection of adults, with mixed results. Users found that the mouse was easier to control when grasping and throwing objects than the *PowerGlove* because it was more precise. However, when the “TIMING” key word was used with the “FIXED” key word in the learning control file, the users could use the system effectively with the *PowerGlove* because it gave them the hand gesturing experience when several objects were being juggled. Users found that this helped them

“understand” a juggling pattern more, rather than teaching them “how” to juggle. One user commented that keeping in mind how the virtual pattern was juggled, helped them approach real juggling with a different point of view.

Feedback includes several local newspapers which have mentioned the JIVE exhibit. One newspaper writes, “You can measure your electrical potential, build your own dinosaur in the Boneyard, or try your hand at one of the most challenging exhibits — computer-based Virtual Reality Juggling” (Killick, 1994). Whether calling it a “challenge” is positive is open to question, but there is little doubt that the idea of a VR exhibit is popular with the press.

Chapter 8

The “Cybertennis” Exhibit

The ultimate goal of the study of artificial life would be to create “life” in some other medium, ideally a virtual medium where the essence of life has been abstracted from the details of its implementation in any particular model. We would like to build models that are so life-like that they cease to become models of life and become examples of life themselves.

Chris Langton (1986)

Problems encountered in the running of the VR exhibit called *Juggling In a Virtual Environment* (JIVE) were overcome with the creation of a new virtual world called *Cybertennis*. This exhibit invites the user to a game of virtual tennis with a dinosaur.

The major problem encountered with the JIVE exhibit was the high breakage rate of the finger strain gauges in the *PowerGlove*. An interactive virtual environment was required where the degree of finger flexion was not important. A good way to achieve this was to build a bat, with the ultrasonic transducers imbedded inside. A prototype bat was constructed by removing the strain gauges from the *PowerGlove* and replacing them with 200 Ω resistors that simulated the effect of closed fingers. The bat was built that resembled a large table tennis bat with the transducers of the *PowerGlove* surrounded by foam padding in the middle of the “flat” of the bat. This design proved too awkward for

many users, as the position of transducers required keeping the bat facing towards the screen. Users tended to misread the instructions and use the bat back-handed, which pointed the transducers away from the receivers. This made the virtual bat, on the screen, move unpredictably, making the user frustrated with the exhibit. A second bat design was built that required a “punching” motion from the user to hit the tennis bat to keep the transducers facing the receivers (see Figure 8.1). This bat was easier for the users to operate successfully. A large white arrow on top of the bat helped the user keep the transducers correctly faced towards the screen in front of them.

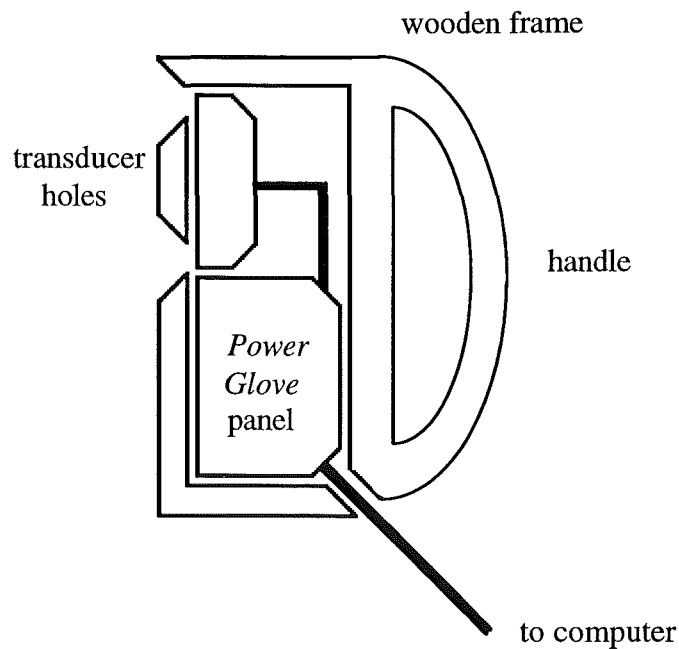


Figure 8.1 Cross-section of the VR “punch” bat design.

The virtual world was created using the REND386 renderer. The world consists of a tennis court suspended in “cyberspace”, with a dinosaur wearing sunglasses at the opposite end of the court, a tennis ball shaded to represent the Earth, and a computer-generated hand holding a tennis racquet that mimics the user’s bat movements. The virtual world is shown in Figure 8.2.

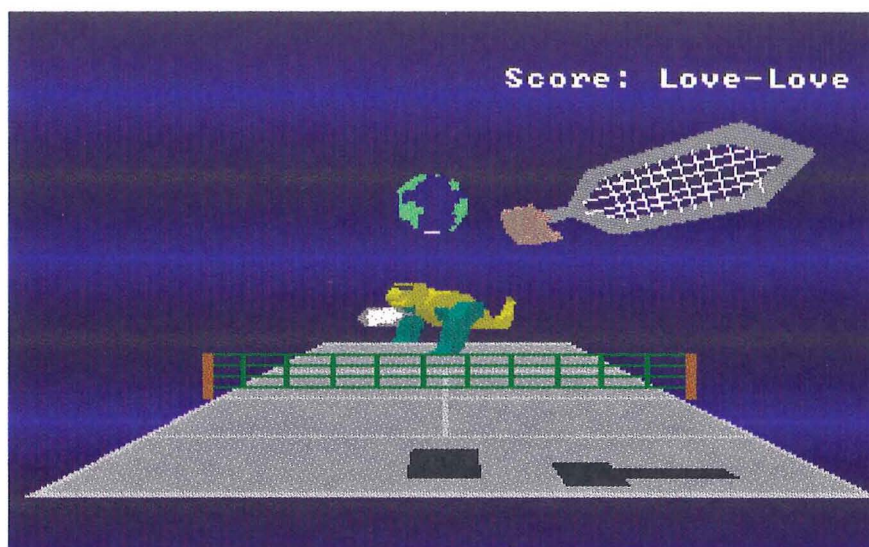


Figure 8.2 A view of Cybertennis.

The hardware from the JIVE exhibit remained the same, with the exception of modifying the *PowerGlove* into the bat. The dinosaur has the ability to return every ball hit to it by the user, except when the dinosaur is moving towards the net. When the ball is in the dinosaur's side of the court, it follows the x coordinate of the ball's position and returns it. At random times the dinosaur jumps over the net, towards the user then returns to its position, or walks up to the net and jumps up and down; giving the user an opportunity to score one or more points. The dinosaur varies the strength of ball return to the user in a random manner, making it more challenging for them. The virtual hand and tennis ball, both have shadows to help the user perceive the depth of the virtual world.

The virtual world of *Cybertennis* includes invisible walls surrounding the tennis court, ensuring that the ball does not leave the court. If one player misses the ball, the score is adjusted and the ball is kept in play, until a game is won. The score then resets to "love-love" and the tennis ball is moved to the front of the court, ready to be volleyed by the next user. This ensures the continuous nature of the exhibit. The renderer is programmed so the virtual racquet is kept vertical regardless of which angle the actual bat is at. The user must, however, ensure the ultrasonic transducers in the bat always

face the receivers which are behind the screen; otherwise the virtual bat can “freeze” and not update positions.

Design of the virtual world eliminates the need for the *PowerGlove*'s finger sensing functions, while still using its three-dimensional positioning system. The result is a new exhibit within the hardware framework of JIVE that requires less attention from the science centre attendants than the JIVE exhibit.

8.1 Bringing the Dinosaur to Life

The virtual dinosaur was modelled after a drawing of a *Tyrannosaurus rex* dinosaur. A cross-section of the dinosaur was plotted by hand, and segmented into several simple polygons. The virtual dinosaur was given depth using a DOS utility developed during the study, called *MAKDEPTH*. The utility takes a file that contains the description of the flat object and the required thickness, to produce the new object file. The virtual dinosaur and its virtual tennis racquet, currently consist of 202 flat-shaded polygons. The dinosaur theme was chosen largely because of the success of the movie *Jurassic Park*, at that time it was constructed. The science centre was also planning to present a new series of robotic dinosaurs to the exhibit hall.

Virtual paths were used to give the dinosaur movement patterns. The paths are simply defined by two three-dimensional points in virtual space, the speed of movement, and the action performed during the movement along the path. For example, an action may be the rotation of a part of the dinosaur's body. The dinosaur can be in one of several states, which include following the tennis ball, swinging its racquet at the tennis ball, moving randomly around the court, running up to the net, jumping over the net, jumping up and down, and moving back to the court's base-line (see Figure 8.3 below). The renderer was found to be sufficiently fast to draw the movements of the dinosaur, the virtual tennis racquet, the spinning globe, and to process their interactions.

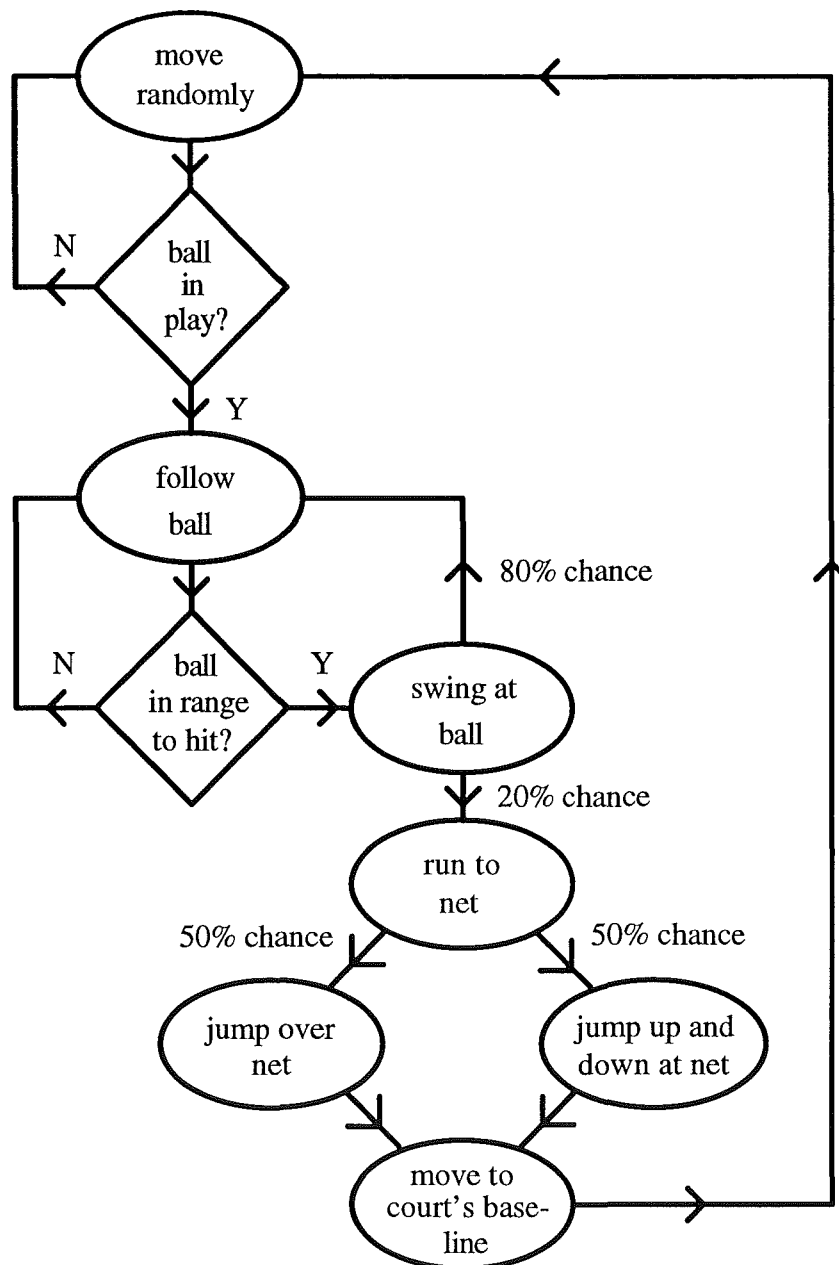


Figure 8.3 Dinosaur state diagram.

8.2 Analysis of the *Cybertennis* Exhibit

From observations, most people who used the *Cybertennis* enjoyed the experience. However, a small percentage of the users were frustrated when the virtual bat would not work correctly, when pointing it away from the receivers behind the large screen. As a

result, more informed instructions were created, that explained the ultrasonic tracking technology used in the bat.

Feedback from the exhibit was obtained by the *Data Digester* exhibit (see Chapter 9) for the *Cybertennis* system. This gave an idea on what some visitors thought of the exhibit (see Figure 8.4).

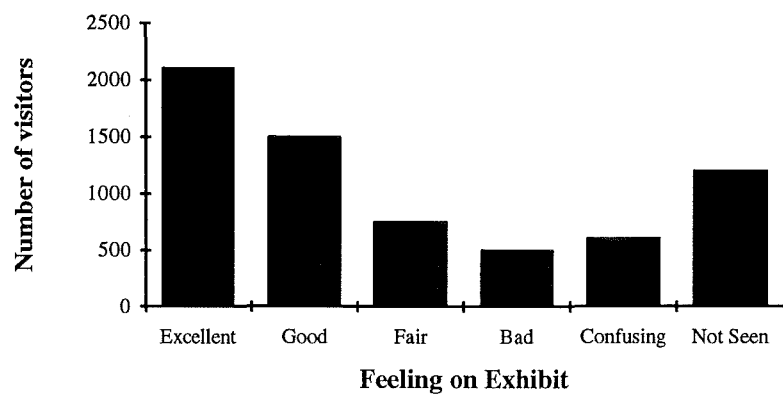


Figure 8.4 Results from the Data Digester electronic questionnaire for Cybertennis.

Most visitors that used the electronic questionnaire thought that the exhibit was “good” or “excellent”, although a large number also never saw the exhibit. This was mainly due to the removal of the exhibit to make room for a new series of robotic dinosaur exhibits throughout the science hall, for several months.

Chapter 9

The “Data Digester” Exhibit

*“I have answered three questions, and that is enough”, said his father;
“don’t give yourself airs! Do you think I can listen all day to such stuff?
Be off, or I’ll kick you downstairs!”*

Lewis Carroll (1898)

Questionnaires and surveys have traditionally come in the form of pen and paper. Data collection was usually done by ticking boxes, and filling in blanks, and processing the assembled data was done by hand. Computers offer a new method of information gathering, because they possess the ability to gather and analyse information directly and quickly, with minimal human assistance.

The *Data Digester* exhibit is a touch screen electronic questionnaire, written in the HyperCard system for the Apple Macintosh. The *Data Digester* is an on-line system that prompts visitors, as they leave *Science Alive!*, with questions about themselves and their experience at the science centre. Visitors respond by touching the appropriate graphical cue on the touch screen. The exhibit is used to gather meaningful visitor information for *Science Alive!*, and allows staff to have the data collated and interpreted in a graphical form.

Existing electronic questionnaires have several problems. For example, the *Excite* science centre in Hamilton, New Zealand has an electronic questionnaire that has not

been particularly successful, for various reasons. The exhibit is slow because it performs disk I/O at each user input, and uses an outdated, low powered computer. Monochrome screens and text-based displays interfaces have made the exhibit uninteresting for the visitor, with little or no feedback. The data collected by the exhibit is information solely based on individual characteristics, avoiding more useful information, such as the visitors origins for market research. Kiesler *et al* (1990) mention a university group carrying out what was believed to be the first controlled experiments using computers to collect survey data in 1984.

The last three decades have seen a rapid development of information technology, spearheaded by advancements in computer technology. More recently, cheap microelectronics have permitted the diffusion of this technology into almost all aspects of daily life, such as electronic libraries, travel booking, and life-support systems (Miles *et al*, 1990). Systems like the *Data Digester* are likely to become more available, and integrated into the public lifestyle. Data processing is independent of technology, taken to mean “the process of collecting and manipulation of data to produce meaningful information” (Haynes, 1990).

Touch screen devices are beginning to appear in public areas because they provide a more natural computer interface than a keyboard or mouse. For example, a system known as *The Note Station* uses a touch screen device and an IBM compatible personal computer (PC) to let customers in a music shop select, modify, play, and print music of their choice (Beyond 2000, 1994). The system allows the user to easily change the key, musical instrument, and tempo used in each chosen compilation. Touch screen devices have been integrated into new electronic note-pads, called personal digital assistants. The pen-based *Newton MessagePad* uses touch screen technology to improve data entry and information analysis, using a “pen-and-paper” paradigm (Apple Computer, 1993). The *Newton MessagePad* contains communications capabilities to help the user organise notes, share information, send faxes, and tap into on-line services or electronic mail. An another example, touch screen technology can be seen at the main railway stations in

Italy, where touch screen devices interact with users in four different languages, giving details of train times and fares (Haynes, 1990). The system contains up-to-date train information, and allows users to obtain details in their own language without the drawbacks of communicating with another person in a foreign language.

9.1 Designing the Exhibit

The *Data Digester* exhibit was designed in accordance with exhibit design procedures given in Chapter 4. The purpose of the electronic questionnaire was first established, then the aesthetics, screen format, and screen hierarchies developed. The goals of the *Data Digester* exhibit from a designer's point of view were to:

- evaluate exhibits on the science centre floor,
- obtain a profile of the user,
- ensure straight-forward data entry,
- allow editing, addition, and removal of questions by staff,
- provide multiple languages,
- provide individualised feedback information, and
- to create an appealing exhibit in its own right.

Data gathered from *Data Digester* is used in three main areas: market research, scientific investigation, and exhibit assessment. As a market research tool, the types of questions that may be asked include where visitors come from, their age, sex, and the type of group they came with. This helps *Science Alive!* to target their advertising. As a scientific investigator, *Data Digester* allows the participant to enter their personal characteristics, such as eye colour, with the program providing feedback to where they lie in comparison to other visitors, or on a normal distribution. As an exhibit assessor, *Data Digester* provides feedback relating to the success of each exhibit, which is used to help investigate any possible problems with an exhibit on the floor.

9.2 Touch Screen Devices

Touch screen devices use of a number of different technologies that are overlaid onto a cathode-ray tube (CRT) display to allow users to make selections by touching predesignated areas of the screen. In general, touch screen devices operate by producing x and y position data whenever a touch event is detected by the system. Touch events can be initiated by pressure sensors in the screen. Pressure touch screens use two transparent resistive sheets with spacers between them, that touch at the point where pressed. A new touch screen device has been developed, based on pressure pads underneath the computer monitor (Beyond 2000, 1994). The system works on the principle that a push onto the computer screen at one unique point, induces an equally unique pressure point on the sensor pads. This removes the need for the touch screen device to overlay the screen.

Boff and Lincoln (1988) outlined several advantages and disadvantages that are commonly associated with touch screen techniques. The advantages of touch screen devices include direct visual-to-tactile control, fast data entry, minimal training, restricted input options, minimal hand-eye coordination problems, and symbolic graphic representation. The draw-backs of touch screen devices include the potentially high initial cost, increased programming time, they are not as flexible as other input devices having fewer degrees of freedom, parallax errors affecting touch locations, physical fatigue from reaching to the screen, finger visually blocking the screen, and the new methods of programming interface software required.

The touch screen device was used instead of a mouse because there was a limited amount of space available for the exhibit, as well as the touch screen is a more natural computer interface for the lay computer user.

9.3 HyperCard

HyperCard is an interpreted language and programming environment for the Apple Macintosh computer, created by Bill Atkinson in 1987 (Goodman, 1990). HyperCard is widely available because it is part of the standard configuration for the Apple Macintosh line of personal computers.

An application written in HyperCard comprises of a collection of *cards* that make up the screens of the application. Each screen, or card, may contain any number of buttons, fields, and other designed graphics. The assortment of cards is called a *stack*. HyperCard is an event driven environment, with scripts that can be attached to any objects within each card, such as, the actions to take when a button is touched. The script language, known as *HyperTalk*, is often expressed by computer scientists to be a design disaster. However, Version 2.1 of HyperCard is sufficiently powerful to implement the goals of the electronic questionnaire outlined at the start of this chapter.

HyperCard has been widely used for educational purposes. For example, a HyperCard stack called *Southern Skies* helps identify stars, planets, and other night-time objects that are visible to the naked eye. The stack is designed for use at school or home and is simple enough for young children to use with adult guidance, limited only by the reading ability of the child (Van der Molen, 1992).

9.4 The Exhibit

Users of *Data Digester* are likely to be people with little or no computer knowledge. A touch screen device ensures that they do not need to learn how to use a keyboard or memorise commands. Furthermore, the physical limitations of the exhibit prevents space for keyboards and mice, making a touch screen device ideal.

The touch screen device chosen was an Edmark *TouchWindow*, currently costing NZ \$700. The touch screen device attaches to a monitor using adhesive strips, and to the computer via the communications port. *TouchWindow* is compatible with Apple computers and PCs. Device driver software allows the touch screen device users to pull down menus, make selections, and otherwise operate the computer like a mouse, using just their fingers. The touch screen device can also be detached from its strips and used as a conventional graphics tablet.

HyperCard programming was undertaken in a modular style to avoid lengthy reprogramming time for maintenance. The system is based around a dialogue style that guides the user through each screen. Each card has a “carry on” button which moves to the next appropriate screen, as well as the *Science Alive!* logo to guide the user through and ask questions. Each card also contains a hidden field of text for each language supported, which represents the question to be asked from the card, as well as any textual feedback information. Adding a new language is just a matter of creating a new field for each card, with the appropriate text in the new language. Each answer is stored in a HyperCard *global variable*, which is saved to a file at the end of the questionnaire, as part of a record tuple.

Parallax errors were reduced by using large buttons. Biff and Lincoln (1988) recommend that a minimum diameter of 22 mm be used in touch screen device button design. Physical fatigue was reduced by minimising the amount of data entry; hence the user touches the screen less. Cards were designed to prevent the user from blocking important parts of the screen with their finger. HyperCard interfaced to the touch screen easily with finger touches appearing as *mouse up* and *mouse down* events in the system.

The *Data Digester* was run on a Mac LC II. The exhibit's computer is cased in a wooden wall mounting, exposing only the touch screen and computer monitor (see Figure 9.1). An *AppleTalk* network system has been used to gain access to the exhibit's information, so physical access to the computer is not required.



Figure 9.1 Data Digester as set up at Science Alive!

The touch screen device needs to be aligned with the monitor, and the monitor strapped in to reduce any movement. The touch screen device needs constant cleaning, mainly due to the high usage, and dirt carried from other “hands-on” exhibits at the science hall.

9.5 The Questions

Science centre management wanted the questionnaire to give them feedback from their visitors. With an electronic questionnaire, there is flexibility in how the questions are presented, what sounds are produced, what colours to use, real-time feedback, and brevity to keep the visitor interested. *Science Alive!* wanted specific questions asked of their visitors, including:

- where they live,
- their sex,
- their age,
- had they been there before,
- did they enjoy the visit,
- how long did they stay,
- what kind of group they came with, and
- their feelings on three randomly selected exhibits.

First name, year of birth, and eye colour was collected as personal information, and used as part of the exhibit feedback mechanism. For example, after a visitor gives their first name, they are told how many of other visitors have the same name as them (see Figure 9.2).

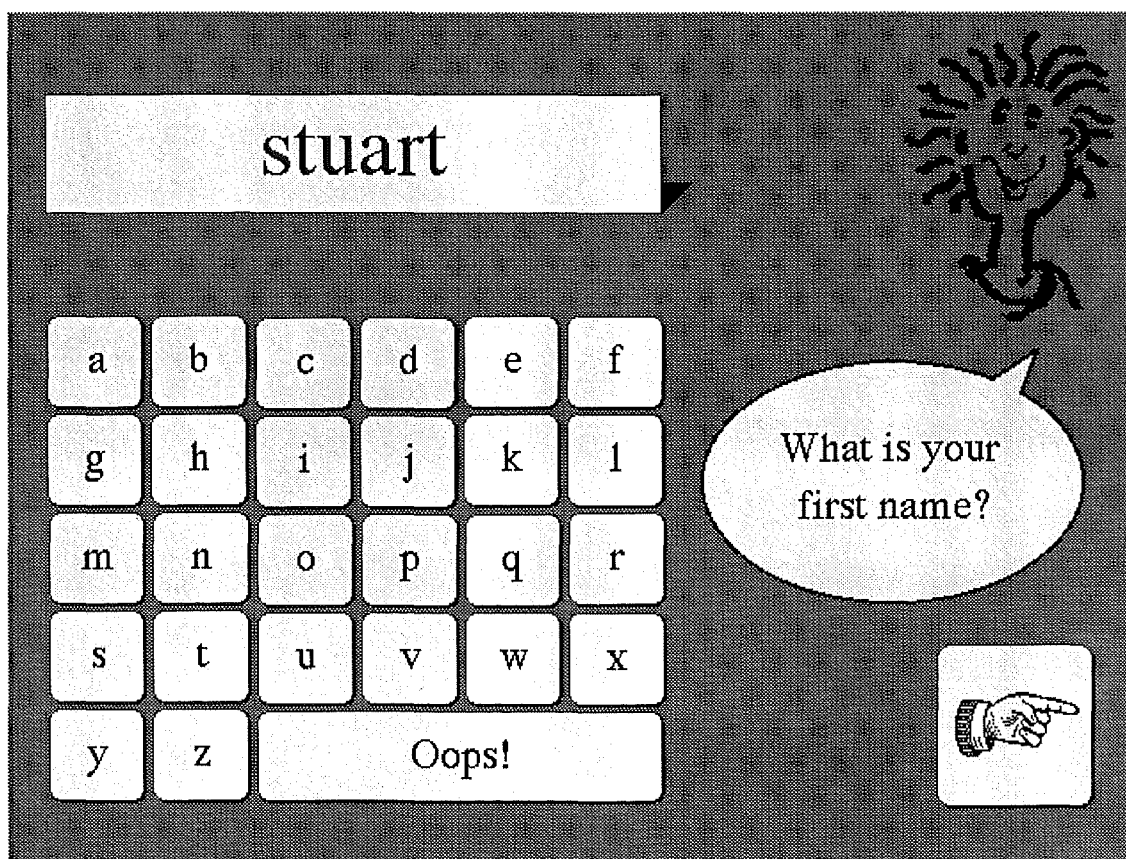


Figure 9.2 Asking a visitor for their first name.

9.6 Software

The system was designed so that each card in the stack can be moved within the stack with minimal changes required to the system. The system allowed the modification, addition, and deletion of exhibits, in the question regarding how the user liked three randomly chosen exhibits. Figure 9.3 shows the exhibit evaluation screen for the *Blower* exhibit. A bit map of the exhibit is shown, along with which “zone” it is to be found in at the science centre. There are six possible answer buttons covering the expected “feelings” of the visitor towards the exhibit.

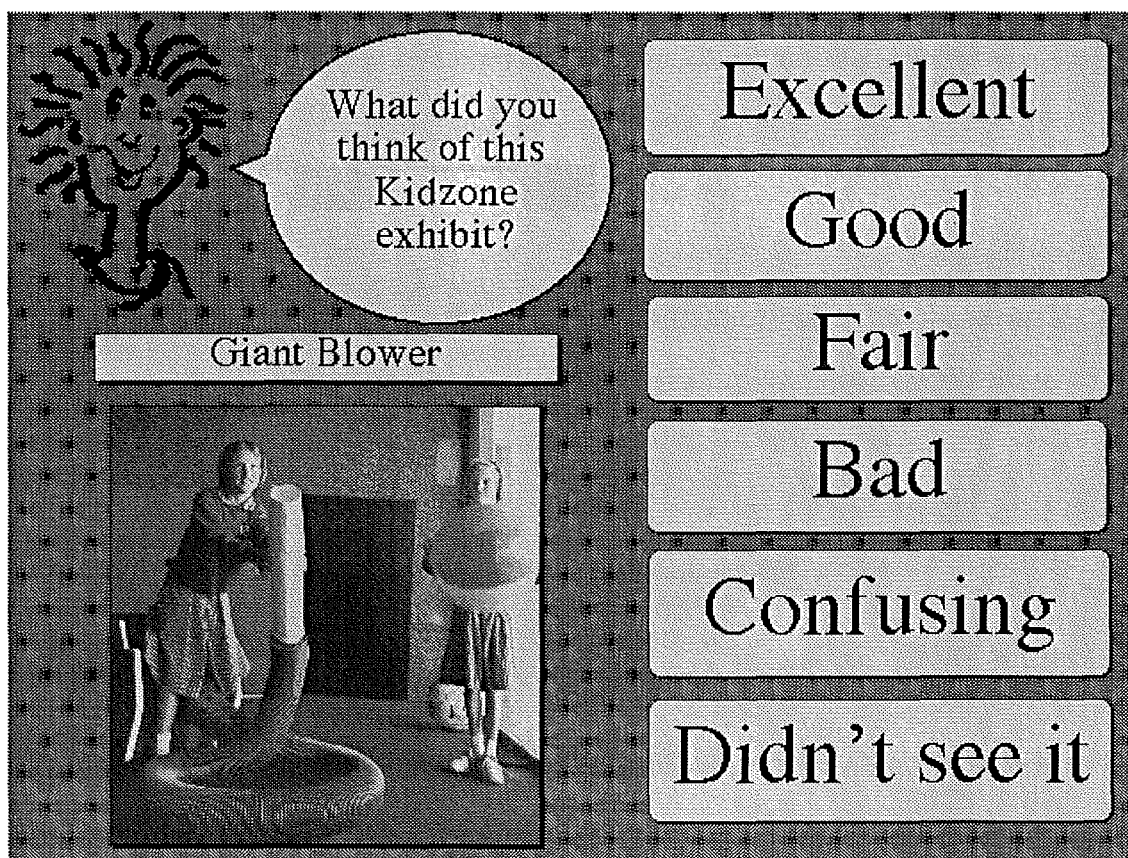


Figure 9.3 The exhibit evaluation screen of the *Data Digester*.

A hidden HyperCard text field contains the exhibit area names, the number of exhibits in that area, and the particular names of each exhibit in the area. A maintenance screen allows the *Science Alive!* staff to modify the field as exhibits are changed.

Adding new questions requires moving to the appropriate card and inserting a new card. The new card inherits the background information of the stack, which includes a “go on” button. This can be removed for questions that do not require it. Drawing tools are used to design the screen layout, and the text added to each language field necessary for that card. The variable being captured is then added to the output file record (see Figure 9.4). The record contains all the information gathered from the current user, as well as identifying the computer and when the questionnaire was used. This information is appended to the current day’s information file for later analysis by the science centre staff.

Computer node, Date, Time, Language, First name, Eye Colour, Sex, Been before, Age, Area from, Exhibit name 1, Exhibit feeling 1, Exhibit name 2, Exhibit feeling 2, Exhibit name 3, Exhibit feeling 3, Enjoyed visit, Group type, Time spent in science centre

Figure 9.4 The structure of the output file record.

A time-out dialogue appears after thirty seconds of inactivity, asking “Is anyone there? Press here to continue”. After another thirty seconds of inactivity the system resets without saving the visitor’s data, but recording which screen they were currently on for analysis of the questionnaire.

Some problems were encountered during the development of the exhibit. Picture loading and some search routines were slow, which encouraged the user to press several times on the touch screen device. As a result multiple touch events were produced, which

overflowed onto the next card, selecting incorrect options. To solve this problem, a "Please wait" message was shown to the user during long pauses between cards, as well as flushing the touch event buffer before continuing to the next card.

9.7 Analysis of Data

Data from the *Data Digester* is transferred to a PC for developing graphical representations of the gathered information. The accuracy of the information gathered can be improved by filtering out erroneous data. For example, any answers that used swear words for their first name, were filtered out; all the answers given by that visitor were ignored. An average of 4.1% of data was filtered out using this method of quality control.

A separate file of data is stored for each day of the exhibit is automatically placed into an appropriate month folder. The file is appended to after each visitor has finished the questionnaire. A month's worth of data uses about half a megabyte in hard drive space. At the end of each month the appropriate folder is removed from the *Data Digester* hard drive over the AppleTalk system. This process is done either after hours or when the centre has a low number of visitors. Downloading the data while a visitor is interacting will slow down the *Data Digester* system. The data is transferred onto an IBM compatible personal computer via a *Macintosh to PC* transfer utility, such as *Apple File Exchange*. Once on the PC, the data is processed.

Data in the *Data Digester* records have had a *linefeed* character appended, to be compatible with PC file reading standards. Two utilities for the PC were developed to help prepare the *Data Digester* data for analysis on the PC; they are *DDFILTER* and *DDCOUNT*. Figure 9.5 gives a specification for these two utilities.

```
Data Digester Filter -- by Stuart Ralston -- Version 1.0
```

```
Filters a file that contains comma delimited tuples, into  
a file (comma delimited) with the specified columns.
```

```
Usage : ddfilter inputfile outputfile column[s]
```

```
Example: ddfilter TEST.DAT OUT.DAT 1 4 8
```

```
Data Digester Count -- by Stuart Ralston -- Version 1.0
```

```
Counts unique occurrences of tuples in a file, outputting  
a comma delimited file with each unique tuple and its  
count.
```

```
Usage : ddcount inputfile outputfile
```

```
Example: ddcount TEST.DAT OUT.DAT
```

Figure 9.5 The usages of DDFILTER and DDCOUNT utilities.

First each month's data was concatenated into one file using the DOS command *COPY*. The *DDFILTER* utility is then used to extract the appropriate columns of data required, such as the exhibit name and visitor assessment columns. The *DDCOUNT* utility reads the resulting file, and counts each unique occurrence of a record tuple. The DOS command *SORT* was then used to sort this result into alphabetical order. Appendix E shows script runs using these commands. The data was graphed using a PC program called *Quattro Pro*, which imports comma delimited ASCII files. The *DDFILTER* and *DDCOUNT* utilities were written using C++.

Queries can be made on the data by using the *DDFILTER* and *DDCOUNT* utilities. For example, the question may be asked, "How many females thought the Virtual Juggling exhibit was excellent?". This would be accomplished by using *DDFILTER* to capture

the *sex* column and the *exhibit assessment* columns from the initial data. Using *DDCOUNT* over the resulting file would give the correct counts.

A problem with data analysis is changing a question and therefore the output record structure. This can be confusing during the collation of a particular month's data, with columns of mismatched data. *Science Alive!* was encouraged to make changes at the end of the month, but few changes were made anyway.

From the analysis of door sales during the running of the *Data Digester* exhibit, 32.9% of visitors had used the electronic questionnaire. Figure 9.6 gives an example of a resulting graph from the *Data Digester* exhibit.

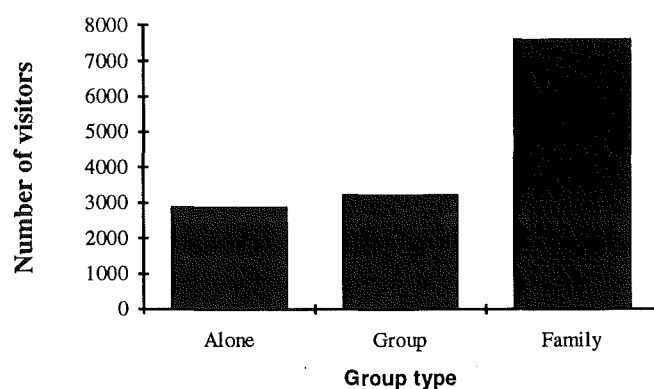


Figure 9.6 A graph showing how visitors came to Science Alive!

Figure 9.6 indicates that most visitors come to *Science Alive!* as part of a family. About the same number of people who come to the science centre alone or with a group. Appendix F shows some more results collected from the *Data Digester* information.

9.8 Analysis of the Data Digester Exhibit

During the running of the *Data Digester* exhibit, some analysis information was gathered to get an indication of its performance. The analysis was performed over one month on the science centre floor. Table 9.1 shows the factors recorded.

<i>How long to do the questionnaire?</i>	On average 1.3 minutes
<i>Time between Data Digester usage?</i>	On average 14.2 minutes
<i>Leave before completion?</i>	21.0%
<i>Erroneous data?</i>	On average 4.1% removed
<i>Gender?</i>	44% male, 56% female
<i>Data Digester usage by visitors?</i>	32.9%

Table 9.1 Data collected from the analysis of Data Digester

These results show that the *Data Digester* exhibit may need to be shorter, because 21.0% of the visitors left before completing the questionnaire. There also seems to be a bias with females using the electronic questionnaire more than males. If the time between usages of *Data Digester* drops dramatically, then *Science Alive!* will need to think about getting another computer to cope with the extra visitors. Further analysis into the collected data shows that on slow days, a greater percentage of visitors use the *Data Digester* than on the busier days. This is possibly because of the long lines in front of the exhibit acting as a deterrent. On busy days (mainly weekends), the *Data Digester* can have on average a visitor every 4.5 minutes, compared with an overall value of a visitor every 14.2 minutes.

Chapter 10

Conclusions And Future Work

*O! That a man might know the end of this day's business, ere it come;
But it sufficeth that the day will end, and the end is known.*

William Shakespeare (1610)

The three science centre exhibits discussed in this study have been designed and introduced to *Science Alive!* with varying success.

The JIVE and *Cybertennis* exhibits showed the potential for using conventional technology to produce working VR exhibits for public use. VR has proved to be a technology that was popular with both old and young visitors alike, and to people with no computer knowledge. Both VR exhibits were popular with the visitors of the science centre, with some coming in to experience them specifically.

The public JIVE exhibit introduced the concept and technology of VR first hand to the public. Visitors enjoyed interacting with realistic immersive three-dimensional graphics and were responsive to their interactions. The exhibit allowed the user to change the parameters of the virtual world, such as gravity, by using simple gestures. An important feature of a VR system is the ability for the user to change the virtual environment to test the result.

A public exhibit is very demanding on equipment, and most VR components available around today are not strong enough to withstand hundreds of uses per day. The *PowerGlove* used in the VR exhibits was not as robust as originally thought, with the finger sensors breaking after two to three weeks of public usage. Spare parts were only obtained by purchasing more *PowerGloves*, which became increasingly hard to find. The life of the strain gauges can be increased by improving the amount of movement within the finger guides of the *PowerGlove*, and protecting their interface to the *PowerGlove*'s circuitry with a flexible joint. The finger strain gauges could be extended further up the arm to reduce the strain on the solder joint, and reduce the frequency of breakage.

The *PowerGlove* has limited inputting capabilities and is not appropriate for all low-cost VR applications. Mouse input was found to be more responsive, reliable, and easier to use. The *PowerGlove* is prone to background interference which affects its three-dimensional positioning accuracy. Visitors who either did not read or forgot the exhibit's instructions tended to become frustrated with the virtual hand's sporadic movements. The movements spikes were due to either the users not keeping the transducers of the *PowerGlove* facing the receivers behind the screen, or background noise from the science hall. The laboratory *PowerGloves* had a lower breakage rate than the publicly used *PowerGloves*, due to the controlled conditions.

The *PowerGlove*, being an inexpensive 3-D tracking system, was not designed for precision work. A glove that is a combination of VPL's *DataGlove* and Mattel's *PowerGlove* would solve the instability problems experienced with the *PowerGlove*. The precision of the *DataGlove*, needs to be coupled with the inexpensive price and relative ruggedness of the *PowerGlove*. A more responsive system with magnetic tracking may improve the learning curves of users.

The large screen projection system used in the VR exhibits has advantages over a full immersion helmet, including collaborative visualisation, and not requiring the repetition of hardware for an extra user to visualise the virtual world. The data projector is based

on current conventional technology and was suitable for a public exhibit, without the need for fragile and cumbersome head-mounted displays. Although, it was the most expensive individual item in the VR system, over time it would not only be more cost effective than an HMD which may need frequent maintenance or replacement, but can also be used by the science centre for other purposes.

REND386 is a suitable public domain renderer for a low-cost personal computer-based VR exhibit. The frame rates on the IBM compatible personal computer, used in the exhibits, were sufficiently smooth to permit real-time interaction. The development of perceptual cues, such as shadows under the virtual objects, helped the user identify each object's relative position in the virtual world.

An exhibit experience is generally too short to teach a motor skill like juggling. The public JIVE system implemented a simple object handling environment appropriate for a public exhibit. The laboratory JIVE system attempted to teach the user juggling, at their own pace.

Does experience with virtual juggling help to learn the real thing? The answer is "maybe". Users found that the JIVE system helped them "understand" a juggling pattern more, rather than teaching them "how" to juggle. Laboratory JIVE was designed to aid the learning of real juggling, but cannot teach juggling, without the users practising in reality. Although a person can learn to juggle without using JIVE, the use of JIVE seems to improve their approach to juggling patterns.

Without a more precise tracking system, the user's learning process in VR has been limited. On-going monitoring of reactions to the exhibit may provide more information on how well it is working as a learning tool. The results may indicate whether this concept can expand the application of computers into teaching a difficult perceptual motor skill.

The *Cybertennis* exhibit has proved more robust than the JIVE exhibit, the main reason for this improvement was the modification of the *PowerGlove* into a bat. The software development of *Cybertennis* was performed on a separate computer, therefore the down time to change the exhibit was kept to a minimum.

The *Data Digester* has provided *Science Alive!* staff with useful information on the profile of visitors and their views on exhibits in the science hall. *Data Digester* has been used as a tool to help investigate any possible problems with an exhibit on the floor.

Several changes can be made to the JIVE, *Cybertennis* and *Data Digester* exhibits to improve their value as science centre exhibits.

Improving the realism of the three-dimensional objects in the virtual worlds, could be achieved by introducing texture mapping to give the effect of realistically shaped objects, and improving the shape of the shadows. Texture mapping is available in renderers like *WorldToolKit*, but hardware accelerators are required to enable real-time rendering. Shadows could be created by cross-sectioning each object and projecting that shape onto the virtual floor below the object. The shadow would need to be recalculated on every rotation of the object to produce a realistic effect. However, this would slow the renderer down because the analysis of object shape is a complex task.

Using two gloves to use both hands for juggling would allow the removal of the left virtual hand. The system would still be able to provide feedback for the user on throws from either hand. As more affordable and accurate VR gloves become available, these may be used with the JIVE learning system.

The problem of users obstructing the projected image could be overcome by using a back-projected system. The material for a back-projected screen is an opaque, waxy canvas that loses only 10 to 15% of its brightness, but is expensive currently around NZ \$1,000. New liquid crystal technology could be used in place of the data projector,

producing pictures up to five times as bright as conventional projection systems, and with a resolution that matches high-definition television (Fox, 1992). Fox claims that this projection system will produce bright images, up to ten metres across, in normally lit rooms. This would solve the problem of needing a darkened area for the JIVE and *Cybertennis* exhibits.

Tactile feedback technology may improve the user's response to the juggling system. The sensation of touch in the real world provides important information for juggling several objects at once.

Multiple ultrasonic transducers or multiple receivers could improve the *PowerGlove* tracking system, allowing the user to point the glove in any direction and still be tracked. To implement this, the problem of filtering out multiple sound waves will have to be overcome.

The science centre could make its own VR gloves. From experience in using the *PowerGloves*, ultrasonic tracking technology would be replaced with more accurate techniques, such as magnetic systems. This would mean that any replacement gloves could be quickly incorporated into the exhibit with minimal down time.

This thesis has described how two VR exhibits and one electronic questionnaire were constructed. It lays some solid groundwork of what low-cost VR components are currently available, and the analysis of how the chosen components fared. Exhibit construction theory is also reviewed and implemented in both VR exhibits as well as the *Data Digester*. VR seems to have potential in education, but the cost and fragility of the components at present is inhibitive. The public VR exhibits were enjoyed by most visitors to *Science Alive!* and the laboratory JIVE helped users to understand juggling theory, which they could then practice in reality. VR may never replace the first-person experience of a physical activity, but its use as a complementary tool in an educational computer environment looks promising.

Appendix A

PowerGlove to PC Connection

This describes a method employed to connect the Mattel *PowerGlove* to a bi-directional parallel port of an IBM compatible personal computer (Eglovestein, 1990). The *PowerGlove* components include an L-bar with a black circuitry box, which the *PowerGlove* connects to. Out of the black box is a standard Nintendo controller cable seven-pin connector. This cable was removed the circuit board within the box, and the circuit board was connected to a DB-25 male connector (see Figure A.1).

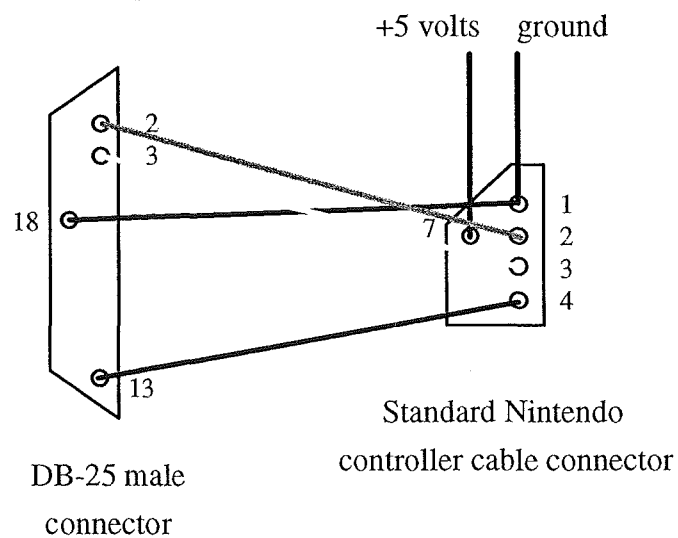


Figure A.1 Connecting the PC printer connector to the PowerGlove.

Power to the circuit board (+5V) can be supplied from the computer's keyboard by creating a short keyboard extension cable, with a pair of male and female five-pin DIN connectors, that contains all five lines (see Figure A.2).

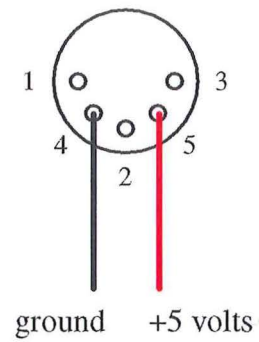


Figure A.2 Connecting a power supply to the PowerGlove.

The final set up includes the DB-25 male connector in the parallel port of the PC, that contains power from the short keyboard extension cable, with the other end of the cable connected to the black box. The *PowerGlove* also attaches to the black box via a male nine-pin connector.

Appendix B

Object Description File

The first line of each object file contains the object's name, the number of points in the object, and the number of polygons. Following this line is the list of the points and the list of the polygons. Each point has the format *x y z*, while each polygon has the form *colourNumberInHex numberOfPoints pointA pointB ... pointZ*. The points start numbering from zero. Figure B.1 shows the file format of a blue cube of size 100.

```
aBlueCube 8 6

0 0 100
0 100 100
100 100 100
100 0 100
0 0 0
0 100 0
100 100 0
100 0 0

0x1bff 4 0 1 2 3
0x1bff 4 1 5 6 2
0x1bff 4 5 4 7 6
0x1bff 4 0 3 7 4
0x1bff 4 4 5 1 0
0x1bff 4 7 3 2 6
```

Figure B.1 Object file format for a blue cube of size 100 units.

Appendix C

Siteswap Notation Examples

Some more *siteswap* notation pattern files for three and four ball juggling include:

```
# Box juggling pattern  
3  
4 2 3
```

```
# Columns juggling pattern  
3  
4 2
```

```
# Shower juggling pattern  
3  
5 1
```

```
# Half-shower juggling pattern  
3  
5 3
```

```
# Four ball arch juggling pattern  
4  
5 5 2
```

Appendix D

Virtual Object Information Structure

The C code structure of a virtual object's juggling information is:

```
typedef struct JIVE_OBJECT {
    SEG      *objectSeg;    /* Points to the object in question */
    SEG      *shadowSeg;   /* Points to the object's shadow   */
    long     x;            /* Object's current x coordinate   */
    long     y;            /* Object's current y coordinate   */
    long     z;            /* Object's current z coordinate   */
    long     time;         /* Time count into current movement */
    long     xo;           /* Initial x coordinate             */
    long     yo;           /* Initial y coordinate             */
    long     zo;           /* Initial z coordinate             */
    long     speedX;       /* Speed in the x direction         */
    long     speedY;       /* Speed in the y direction         */
    long     speedZ;       /* Speed in the z direction         */
    double   gravity       /* Gravity value on this object     */
    long     rotation;     /* X-axis rot. speed during flight */
    BOOL     attached;     /* Is object attached to a hand?    */
    long     destHand;     /* Hand ID the object is heading to */
    BOOL     topOfFlight;  /* Has this object been TOF tested? */
    float    tofTime;      /* Time for TOF of the object       */
    long     disabTime;    /* Time until object can be caught  */
    long     disabHand;    /* Hand ID that cannot touch object */
} JIVE_OBJECT;
```

Appendix E

Script Run For DDFILTER And DDCOUNT

Assume that the file *TEST.DAT* contains the commas delimited tuples from the *Data Digester* exhibit, and that the column *11* in the tuple is the information for how visitors came to the science centre. Figure E.1 shows the DOS commands to use *DDFILTER* to extract the visitor information to a file *OUT.DAT*, and then *DDCOUNT* to count each occurrence uniquely into a file *FINAL.DAT*.

```
DDFILTER TEST.DAT OUT.DAT 11
DDCOUNT OUT.DAT FINAL.DAT
```

Figure E.1 Extracting how visitors arrived at Science Alive!

Figure E.2 shows the format of the resulting file *FINAL.DAT*. The first column of this file is the category name, and the second is the count of that category. In this case, *A* means “alone”, *F* means “family”, and *G* means “group”.

```
A,2860
F,7605
G,3212
```

Figure E.2 The resulting file format for how the visitors arrived at Science Alive!

Appendix F

More Results From Data Digester

Extended results from the *Data Digester* exhibit include:

- Visitors from the South Island 59%
- Visitors from the North Island 20%
- Visitors from overseas 21%

- Visitors that enjoyed *Science Alive!* 71%
- Visitors that thought the centre was “okay” 13%
- Visitors that did not enjoy *Science Alive!* 16%

- Visitors that have come before 36%
- Visitors that had their first time there 64%

- Visitors staying for less than 30 minutes 18%
- Visitors staying for an hour 24%
- Visitors staying for two hours 30%
- Visitors staying for three hours 11%
- Visitors staying for more than three hours 17%

Appendix G

Installing The Diskettes

The diskettes accompanying this thesis are used to install *Data Digester* onto an Apple Macintosh computer, and to install *JIVE* and *Cybertennis* onto an IBM compatible personal computer.

To install and run *Data Digester*:

- insert the first diskette into the floppy drive
- copy contents onto hard drive
- copy the contents of disk 2 and 3 into the *Pictures* folder
- double-click on the *Data Digester* icon

To install and run *JIVE* and *Cybertennis*:

- insert the diskette into the floppy drive a :
- type `a:install`
- this will create three directories on the `c :` drive called *DD*, *JIVE*, and *CT*
- the *DD* directory contains the *Data Digester* related utilities
- the *JIVE* directory contains the *JIVE* system
- the *CT* directory contains the *Cybertennis* system
- move to each directory and type the following commands
- type `pubjive` or `npubjive` (no coprocessor) for the public *JIVE* system
- type `labjive` or `nlabjive` (no coprocessor) for the laboratory *JIVE* system
- type `ct` or `nct` (no coprocessor) for the *Cybertennis* system

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