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Scientific Applications of Visualization, Virtual Reality and High Performance Visualisation Computers

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1 Introduction

Visual supercomputing combines high-performance graphics, computing, and data management technology to solve complex research problems that were unapproachable only a few years ago. More over large scale simulations are producing such large data files that the major research establishments are now using this technology to actively tackle "Grand-Challenge" problems in fields such as:

- *Computational steering*: enabling interaction with simulations and to direct the solution of biomedical, chemical, and engineering time-critical problems.
- *Medical*: investigate such complex systems as the human body with real-time, 3D computer images; visualising correlation between therapeutic targets and disease; surgical planning and simulation: virtual endoscopy; computer augmented surgery; FEM of bodily functions.
- *Geophysics*: interact with subsurface data to better understand geologic makeup and improve seismic interpretation; 3D GIS.
- *Astrophysics*: stellar fluid dynamics.
- *Engineering:* simulations; virtual prototyping of design concepts; advanced FEM.
- *Aeronautics*: real-time wind tunnel, fly-thru simulations, aero elastic simulations
- *Material Science*: nanotechnology research (Bucky tube interatctions).

These are just a few of the potential research areas. This briefing paper gives an overview of the current state-of-the-art technology that is driving this research. Case studies detailing specific application areas will be provided in a separate document.

2 Visualization

Visualization transforms data or information into images or graphs. It is primarily aimed at one of human's most dominant senses, the eyes. In modern times computers have been used for this transformation and with the use of computers other sensory representations have been included such as sound and touch. Modern visualization involves the user exploring, transforming and viewing their data as images to gain understanding and insight.

Visualization has been divided up into three main types, scientific visualization, data visualization and information visualization. Scientific visualization is the formal name given by computer scientists that all inclusively covers the user interface, data representation and processing algorithms, visual representations and any other sensual representations. Data visualization is a more general term than scientific visualization because it deals with data forms outside the realms of science and may include data analysis techniques. Information visualization attempts to visualize abstract forms of data such as directory or file structures on a computer, the information content of books, hyper-text documents on the web or other forms of abstract data. Data mining is sometimes used in connection with information visualization; data mining attempts to allow the user to investigate the relationships between large numbers of seemingly unrelated data. Interestingly all types of visualization may relate to data that has a fixed physical geometry although it is not necessary.

Virtual reality (VR) and visualization are converging fields. Virtual reality aims to be immersive and achieves this by having feedback on its sensory devices. On the other hand visualization is primarily aimed at vision, it is often interactive and may use feedback but this is not vital. Image production and interactive feedback are both computationally expensive so hardware renderers and other solutions that take advantage of high performance architecture have been developed to keep the update rate high. Initially this type of development was all kept within the realms of scientific computing. Now the games industry is providing much innovation and some consider it the killer application for VR.

3 Virtual Reality

Virtual Reality uses computer interface technology to enhance humans' natural capabilities. Today's familiar interfaces - the keyboard, mouse, monitor, and GUI - force us to adapt to working within tight, unnatural, two-dimensional constraints. VR technologies let us interact with real-time 3D graphics in a more intuitive, natural manner. This approach enhances our ability to understand, analyse, create and communicate. The greatest impact virtual reality will have on science is how it will change our thinking. Virtual reality encourages viewers to be participants immersed in the data rather than passive observers watching from a distance. In addition, it is not the shape of objects that is emphasised so much as the shape of the space that they enclose and how that space is filled. By thinking of some scientific problems as environments for the first time, new insights will be gained.

Some of the interfaces used to build a VR system are:

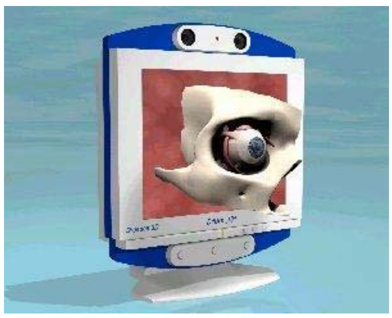
- Visual Displays
- Tracking systems
- Input devices
- Haptic devices
- Sound systems
- Graphics & computing hardware.

These technologies are described below.

3.1 Visual Displays

Visual displays are the devices that present to the user's eyes the 3D computer generated world. There are six categories, each providing a different degree of immersion: desktop displays, head-mounted displays, arm-mounted displays, single-screen displays, surround-screen displays and now volumetric displays. Most are capable of producing wide-angle stereoscopic views of the scene, although monoscopic vision may also be used. Generally a head tracking device coupled with the displays provides the location and direction of sight of the viewer. This is used to compute the correct perspective view of the virtual world.

Head-Mounted Displays (HMDs) are, probably, the most broadly used visual displays in VR systems. These devices place a pair of display screens directly in front of the user's eyes. The screens are mounted on a helmet that viewers wear while in the virtual world. Alternatively, arm-mounted displays such as the BOOM, look like a pair of binoculars mounted on an articulated arm. The user looks at the virtual environment through the lenses, having his movements constrained by the arm's length and motion range.



There are two types of stereoscopic rendering developed for light projection onto a fabric screen, passive and active. Active solutions require shutter glasses; the shutters for each eye open alternatively and are coordinated with the projector. Each eye receives separate image to give the impression of stereovision. Passive solutions use polarizing or red/green glasses. Two sets of images are projected simultaneously so twice as many projectors are needed than the active solution. Each eye receives a different image because each lens of the glasses filters out one set of images. This type of passive solution does not work on desktop displays. New passive solutions have been developed for some liquid crystal screens e.g., Dresden3D as shown in the picture. These require no glasses to be worn so removing a substantial psychological barrier for the user. A layer of prisms lie over the liquid crystal display and detract different images into each eye, similar to "cereal box 3D pictures". These systems tend to be sensitive to the graphics card used and can use head tracking.

Single-screen projection displays include the Immersive Workbench products. Most of these displays use a tabletop metaphor, in which virtual objects appear to lie on the table's surface. Some other systems use a window metaphor, in which the display acts as a large window, opened into the virtual space. In general, single screen systems are good options for applications that require manipulation of objects directly located in front of the viewer for example engine design.

The CAVE is an example of a multiple screen projection system where stereoscopic images are projected onto a cube composed of display screens that completely surround the viewer. The viewer explores the virtual world by moving around inside the cube. The CAVE blends real and virtual objects naturally in the same space so those individuals have an unoccluded view of their bodies as they interact with virtual objects.

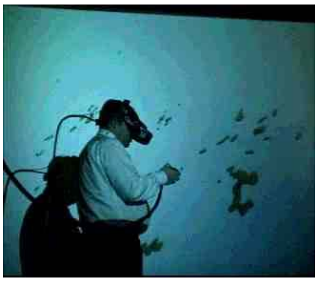
Whereas traditional technology flattens 3-D information onto a 2-D screen, Actuality's volumetric display makes 3-D data appear to float inside of a special viewing dome. The display acts as a "crystal ball" for the computer -- it accepts 3-D data from standard sources and converts it into volume-filling imagery that can be seen from any angle. Many aspects of the system's graphics processing architecture rely on the Spartan-II components. For example, the display contains a powerful graphics processing system and six Gb memory bank that computes and stores the 3-D data.

3.2 Tracking Systems

Tracking is a critical component of any immersive environment. The measurements of the user's head position and orientation is particularly important because it allows the correct perspective of the world to be calculated from the user's point of view. Computing a viewer-centred perspective lets users explore virtual environments in the same way they would explore real environments. Usually, one or both of the user's hands are also tracked to provide interaction. More sophisticated systems can track user's fingers and even the whole body.

There are six tracking technologies in use today: *electromagnetic* (e.g. Polhemus and Ascension systems); *mechanical* - rigid structures with several joints; *acoustic* – using ultrasonic sound; *optical* - a combination of markers such as light emitting diodes (LEDs), video cameras and image processing techniques; *inertial systems* – uses gyroscopes; *image processing* - using video cameras to capture the users.

3.3 Input Devices



Input devices allow you to interact with the virtual world, and there are a large variety of options available. Common examples include the data glove and its variants, three-dimensional joy sticks and wands, and even voice recognition systems. Many custom devices such as a steering wheel or a driving simulator are also in use.

3.4 Haptic Devices

Haptic devices are input and output devices that can measure the position and forces of the user's hand and other body parts when manipulating a virtual environment, and can apply forces back to the user to simulate the corresponding sensation of the feel of the objects being manipulated. Haptic device technology is still mainly experimental for two reasons. Firstly because the underlying technology is not well developed, for example pneumatic systems can be too powerful and could harm the user while a gyroscopic mouse may add feedback but may not be realistic.

Secondly because haptic devices are often application dependant, medical VR simulation is an area of active research that offers some good examples. Medical VR often involves the user manipulating a tool to complete a task. The most realistic tools will be the ones that feel like the tool and attaching a real tool to the haptic device can do this. There is a relatively new tool on the market, the **phantom** that has “realistic” feedback, many degrees of freedom, a reliable API and is reasonably priced. Information about the manufacturer of the **phantom** can be seen at http://www.sensable.com/haptics/products.html while a company that has used the **phantom** in an augmented reality system is http://www.reachin.se/DevelopmentPlatform/DesktopDisplay.htm.

3.5 Sound Systems

Sound systems in VR require localisation i.e. the ability to generate three-dimensional sound. Localised sounds can be attached to objects or can be used to enhance the sense of immersion within the environment. Sonification greatly enhances the sense of immersion provided by the visual displays, since humans use audio cues to acquire information about our surroundings, beyond what it is provided by the visual channels.

4 The Reality Centre

Silicon Graphics developed the Reality Centre concept in the mid 1990s. It provides a collaborative immersive environment for groups of up to 30 people. It requires the integration of many of the VR technologies described above: high-brightness projectors and display screens (flat, spherical, and cylindrical); edge-blending and colour correction electronics; central data, audio, and lighting control systems; stereoscopic viewing devices; advanced output devices (such as headsets and haptic devices); and, of course, software applications. At the core of the Reality Centre is a visual supercomputer – typically a Silicon Graphics Onyx2 configuration.

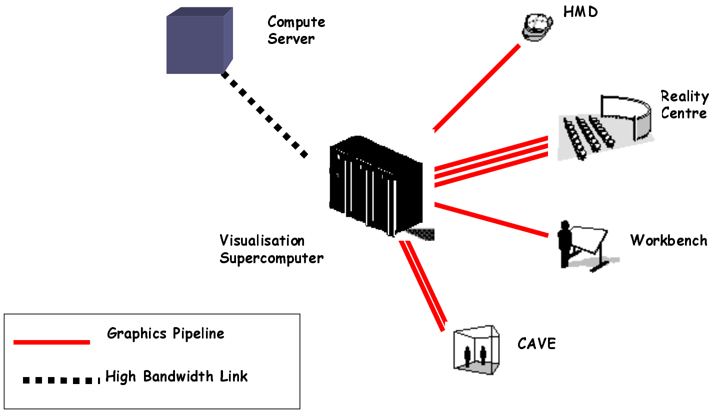
The result can be a highly realistic and sophisticated interactive simulation environment, useful for understanding spatial dynamics and interrelationships among objects, people and places. The potential benefits are the ability to enable multidisciplinary work teams to deal easily and efficiently with complex data sets, and the ability to visualise and interact with models and processes without the attendant danger, impracticality, or significantly greater of using physical models.

5 Visualisation Supercomputers

The computer hardware has to handle several tasks: the generation of the graphics for the scene, the computation of the state of the environment, and the control of input and output devices. In a virtual reality environment, all these tasks have to be integrated and synchronised, usually every frame. Although many VR and visualisation applications can be run today using desktop PCs, the “Grand Challenge” problems require Visualisation Supercomputers i.e. computer hardware with multiple processors, and multiple graphics engines.

A remote high performance computer e.g. the Cray T3E, can be used to run applications that require intensive computations – see diagram below. The results are then shipped to the graphics computer for rendering. This type of environment is still under investigation, but it is proving to be extremely useful to include complex behaviours in virtual environments. For real time visualisation, however, it may be necessary to have the graphics hardware and supercomputing power integrated in the same visual supercomputer. Another problem is the difficulty in distributing real time graphics applications across a network. Even with fibre optic solutions, the maximum limit of the visualisation console from the graphics engine is 3 km. There are also APIs that can be used such as RGL (Remote OpenGL), but these are still experimental.

Commercially, Silicon Graphics dominate this area with their Onyx2 graphics workstations, and the Origin 2000 and Cray range of compute servers.



Appendix A

UK Example Sites – Some of The Leading Player's

University College London

Computer Graphics and Virtual Environments Research Group

http://www.cs.ucl.ac.uk/research/vr/

Main interest is academic research into VR including lighting, realistic clothing, tele-VR and treatment of phobias.

Immersive virtual reality equipment:

- A four-walled immersive VE system which is similar to a CAVE
- Various Head-mounted displays: VR8, VR4 and Sony Glasstron
- An Onyx Infinite Reality 2, mainly used to drive the immersive VE system
- An Onyx Infinite Reality 1, mainly used for HMD systems
- A range of other SGI machines including several O2s and a High Impact.

Imperial College London

Visualisation Centre

The centre's main interest is in scientific visualization of both experimental and simulated data. They have diversified into VR to increase data analysis. They have a strong interest in medical applications but also have active research in reaction kinetics, thermo-dynamics and computational fluid dynamics.

- A 44-processor Silicon Graphics Reality Monster supercomputer and Trimension Virtual Reality (VR) system.
- 2 Onyx2 Reality Deskside Servers
- A Octane/ MXE Power Desktop Workstation and 19 O2 Workstations

Loughborough University

AVRRC: the Advanced VR Research Centre

http://sgi-hursk.lut.ac.uk/~avrrc/index.html

AVRRC aims to provide a state of the art human-computer integration research centre exploring VR applications, especially areas of human interaction including usability analysis, human cognitive processing, augmented reality and mobile computing.

Laboratories and equipment:

- Immersive VR Lab is configured to support detailed investigations into helmet mounted display based VR systems, various HMD's are available
- The Dynamic Motion VR Lab incorporates a hydraulically actuated moving base system that can faithfully reproduce certain motion cues.
- The Panoramic Reality Centre comprises two reconfigurable display surfaces that can support wide field of view (in excess of 150 degrees 3m high) semi-immersive displays.
- The High Performance Computing Resource is mainly SGI based and is configured to support parallel research and development. Systems range from SGI Infinite Reality, Maximum Impact, O2, and Indy etc. Other platforms such as PC and MacIntosh are available.
- Projection equipment in the laboratory has been provided by a special SEOS high-resolution wide field of view projection system. A four processor Silicon Graphics Infinite Reality computer or six-processor three pipe Onyx drives this device.

University of Manchester

Manchester Visualization Centre

http://www.man.ac.uk/MVC/

The centre's original interest was in scientific visualization but while maintaining it's research interest in the application of visualization and in developing the visualization pipeline it has diversified into medical VR. It has a sister department CSAR that supplies high performance services to UK academics and is keen on high performance VR.

Equipment:

- A 40 processor Silicon Graphics Onyx II with six graphics pipes powers a 30-seat immersive projection theatre.

Nottingham University

The Mixed Reality Laboratory

http://www.mrl.nott.ac.uk/

The MRL is an interdisciplinary research initiative at the University of Nottingham. It consists of three groups: Communications Research group (CRG), VIrtual Reality Applications Research Team (VIRART) and Centre for Research in Development, Instruction and Training (CREDIT). MRL has much VR equipment but VIRART is the group that works most with high performance VR kit.

VIRART: Virtual Reality Applications Research Team http://www.virart.nottingham.ac.uk/

VIRART is a multidisciplinary, independent, research and development group with expertise in ergonomics, manufacturing engineering, computer systems, psychology, operations management and computer aided design. Primarily their interest is that of academic research.

VR Systems

- Division Provision 100VPX
- IBM/Virtuality Elysium
- 6 PC based VR systems with enhanced graphic and sound capability

University of Salford

Centre for Virtual Environments

http://www.nicve.salford.ac.uk/

The centre consists of three associated groups an agents group, an advanced virtual prototyping group and a physical modelling group. They work together to improve the take up of virtual technologies by industry, in doing this they conduct research into VR in construction the engineering industries, medical applications (tissue modelling) and adding artificial intelligence to these systems.

Equipment and Laboratories:

- Three major virtual reality installations include an Immersive workbench, a Silicon Graphics Reality Centre and a CAVE.
- An SGI Onyx Infinite Reality machine powers these. They also host an array of workstations for small scale VR.

University of Strathclyde in Glasgow

Virtual Environments Laboratory (VEL)

http://www.strath.ac.uk/Departments/Architecture/VEL/

VEL focuses on visualisation research in virtual reality, especially the building industry, for research, industry and education.

Equipment:

- The VR laboratory consists of a 15 seat theatre with a large curved screen, a Silicon Graphics Reality Centre. The VR system is driven by a graphics super computer (a Silicon Graphics Onyx II) with three advanced Barco projectors.

The Group has a partner group, the Transparent Telepresence lab, who are interested in remote and collaborative VR.

http://telepresence.dmem.strath.ac.uk/

Warwick University

There is collaboration between the University of Warwick's Warwick Manufacturing Group and the virtual reality company VR Systems UK. Their main interest is in producing high-end VR systems.

They have designed a proto-type Cybersphere which mounts a large (3.5 metres in diameter), hollow, translucent sphere on a ring of bearings with additional low-pressure cushion of air allowing the sphere to rotate in any direction and the observer to walk around the virtual world.
They are also currently building, in partnership with PTC, and Sun Microsystems, a 3D visualisation theatre that will employ the largest 3D capable screen ever installed by VR specialists Trimension.

Glossary

actuator: Usually mechanical (hydraulic) or electric means used to provide force or tactile feedback to a user.

artificial reality: Simulated spaces created from a combination of computer and video systems. Coined by VR pioneer Myron Krueger in 1974.

assistive agents: Artificial intelligence algorithms developed to guide participants through a VR world, and to coach on available choices within the world.

augmented reality: The use of transparent glasses on which a computer displays data so that the viewer can simultaneously view virtual and physical objects.

avatar: A participant's graphical persona inside a virtual world.

bi-ocular: Displaying the same image to each eye. Sometimes done to computing resources when depth perception is not critical. See also: stereoscopic.

biosensors: Sensor devices that monitor the body's electrical activity for the purpose of computer input.

convergence: Occurs in stereoscopic viewing when the left and right eye become fused into a single image.

data sonification: Assignment of sounds to digitised data which may involve filtering to give illusion of localised sound.

data spatialisation: Assignment of orientation (yaw, pitch) and position coordinates (x,y,z) to digital sounds assigned to data.

DataGlove: A glove wired with sensors and connected to a computer system for gesture recognition and navigation through a virtual environment. Known generically as a "wired glove".

digital prototype: Simulation of an intended design or product to illustrate the characteristics before actual construction. Usually used as an exploratory tool for manufacturing designers/engineers or as a communications tool for persons reviewing proposed designs.

effectors: Interfacing devices used in virtual environments for input/output, tactile sensation and tracking. Examples are gloves, headmounted displays, headphones, and trackers.

eye tracking: Measurement of the direction of gaze.

force feedback: Output that transmits pressure, force or vibration to provide VR participant with the sense of resisting force, typically to weight or inertia. This in contrast to tactile feedback, which simulates sensation (e.g., texture) applied to the skin.

gesture: Hand motion that can be interpreted as a sign, signal, or symbol.

haptic interfaces: Use of physical sensors to provide users with a sense of touch at the skin level, and force feedback information from muscles and joints.

head tracking: Monitoring the position and orientation of the head through various tracking devices.

heads-up display: A display device that allows users see graphics superimposed on their view of the real world.

head mounted display (HMD): A set of goggles or a helmet with tiny monitors in front of each eye to generate images seen by the wearer as three-dimensional.

immersion: The observer's behavioural (subjective) reaction to the virtual world as being part of it, or virtual model as being actual.

motion platform: A controlled physical system that provides real motion to simulate the displayed motion in a VR world.

position sensor: A tracking device that provides information about its location and/or orientation.

presence: A feeling of being immersed in an environment, able to interact with objects there. A defining characteristic of a VR system.

refresh rate: The frequency with which an image is regenerated on a display surface.

shutter glasses: Glasses that alternately block out the left and right eye views in synchrony with the computer display of left- and right-eye images to provide stereoscopic effect.

six degrees of freedom (6DOF): Ability to move in three spatial directions and orient about three axes passing through the centre of the body. Thus six coordinates specify the location and orientation.

tactile displays: Devices that provide tactile and kinaesthetic sensations.

telepresence: Virtual reality experienced from remote locations. Remote control gives enough sensory data to give the illusion of being at that remote location.

tracker: A device that provides numeric coordinates to identify the current position and/or orientation of an object or user in real space.

virtual environments: Realistic, interactive, immersive simulations of places and scenes.

virtual surgery: Use of computer models and specialised interaction devices that mimic surgical tools to allow medical personnel to practice surgical procedures.

voxel: A cubic volume pixel for quantising three-dimensional space.