Investigating the existing and emerging technologies, devices, and delivery platforms common to 3D games, simulations, and virtual reality.

September 29, 2006

The Center for Technology in Education
Johns Hopkins University
http://cte.jhu.edu

Jacqueline Nunn, Ed.D, Director

by

David Peloff

and

Samuel Abramovich

Introduction:

Many of the most successful video games, past and present, have utilized detailed and realistic graphics to visually represent the 'real world'. A quick review of the current best-selling video games (according to Yahoo! Games, September 2006) reveals that nine out of ten employ 3D graphics. (*The lone exception is the ever-resilient Super Mario Brothers*). Among school-age kids, games that visually simulate reality (albeit a *fantastical* reality in most cases) are historically among the most popular.

But what if the popularity of simulation-style games among kids has less to do with 'eye candy' and more to do with adolescent socialization and empowerment? In a video game that simulates reality, the gamer becomes an important figure in a virtual world, a world without the same social awkwardness, limitations, and repercussions for failure he lives in every day. An 8th grader playing the Sims 2 can experiment with new ideas, express himself in ways he probably wouldn't at the dinner table, and make decisions that are normally not his own to make. Even in the less 'cerebral' action genre, the virtual world might offer an outlet for overcoming the sense of powerlessness many kids feel or a chance to raise their self-image by demonstrating courage and strength.

In games that allow players to customize or even build from scratch their own virtual world, are they more engaged and invested in the outcome? Do they feel a sense of ownership and pride in what they have created? In other words, does a child's interaction with a simulated environment affect their 'real world' attitudes and mental health (positively or otherwise)?

If there is any truth in the speculations above, how might educators leverage these virtual environments to reach and engage kids in compelling, authentic learning experiences? Could the purposeful, educational use of 3D immersion and virtual reality lead to positive affects on retention and understanding of difficult concepts? Could simulations help teachers to put abstract concepts or skills into a real-world context, allowing the student to more easily fit the new information into the scaffolding of their existing knowledge? What, if any, are the physiological changes to the brain when kids are learning by interacting with a virtual environment, compared to a more traditional mode of instructional delivery? How might virtual environments provide new opportunities for students with physical disabilities or other special learning needs?

The Johns Hopkins Center for Technology in Education (CTE) believes there are enough compelling issues and questions in the paragraphs above to warrant further investigation and research. This white paper, which examines the existing and emerging technologies related to 3D games and simulations, is a first step towards contextually investigating the learning potential of virtual environments.

PART 1: VIRTUAL REALITY (VR)

VR: A Brief Overview

To many casual observers, Virtual Reality (VR) is seen as an unfulfilled promise, an area of technology that has not – at least as of yet - lived up to its hype. This perception of VR is probably the result of it's portrayal in television and film (i.e., the Star Trek 'Holodeck', the Matrix, etc.), as a near-perfect digital representation of reality. VR experienced a level of hype reserved for very few technologies through history, as the concept of a virtual world where seemingly all things are possible understandably took hold in the popular imagination. But the technology required to realize this fantastical view of VR has been slow to develop, especially when compared to the great leaps forward occurring in other areas of computer technology.

While VR has, in some respects, fallen off the popular radar, research and development on this potentially revolutionary technology has progressed on many fronts. Dramatic improvements in the design of computer and graphics chips have led to breakthroughs in VR that were technically impossible just a few years ago. Below is a brief look at the origin, current state, and projected future of Virtual Reality.

Some precursors to VR:

In 1956, decades before the term 'virtual reality' was popularized, an inventor named Morton Heilig created the *Sensorama*. A multisensory arcade-like device, the Sensorama booth combined projected film with sound, wind, smells, and vibration to add realism to the viewer's visual experience. Heilig's simulations included dramatic motorcycle and helicopter rides, as well as a virtual performance from a belly dancer.

In 1965, another visionary in the field that would later be called VR, Ivan Sutherland (MIT) conducted experiments using real-time video and Head Mounted Displays (HMDs). Sutherland created the first 'stereoscopic' HMD (each eye had its own display) as well as a mechanical head-tracking system that moved the source video camera in conjunction with the wearer's movements. Sutherland's work was funded in part by the military, who hoped that the HMD might allow for the remote examination of hazardous areas and enhanced capacity for helicopter pilots to land in difficult terrain.

The military's interest in simulation-related technologies has continued to grow. Recognizing the inherent danger & expense of training pilots with actual airplanes, the U.S. military began using computer-based graphics for flight training as early as the 1970's. By the early 1980's, advances in computers and 3D graphics allowed pilots to navigate detailed and highly realistic virtual environments. Joining the military in researching VR were the CIA and NASA, each of which developed their own HMDs for use in simulations, training, and remote operation of equipment.

While the military drove the advancement of 'serious' computer graphics, the film industry was pushing the technology forward from the entertainment side, using cutting-edge computer-based graphics in such films as *Westworld* (1973), *Star Wars* (1977), and *Alien* (1979). Also on the entertainment front, Atari gave birth to the modern video game industry in 1977 with Atari 2600 home console. For very different reasons, the military and entertainment sectors continued to pour millions into research and development to improve the capacity of computers to produce realistic 3D graphics. (The video game industry, perhaps more than any other force, has driven innovation in computer graphics.) In recent years, collaboration and knowledge-transfer between the military, entertainment, and education sectors has driven much of the innovation in VR and 3D simulation technologies.

What is Virtual Reality (VR)?

Virtual (or *Artificial*) Reality allows a person to interact with a three dimensional computer-simulated environment. Originally used almost exclusively to describe experiments with head-mounted displays, the term is now used more broadly to describe a variety of 3D simulation technologies, ranging from fully immersive VR to 3D environments displayed on the screen of a PDA.

In immersive VR, the user becomes fully immersed in an artificial, three-dimensional world that is completely generated by a computer (or a cluster of computers). The user's head movements are tracked, causing the visual display to change in real time, simulating actual change in visual perspective. A stereoscopic view provides a sense of depth perception and space. The illusion of being fully immersed in an artificial world can be improved through the use of directional (3D) sound and haptics (simulated sense of touch). A data glove or wand can allow for manipulation and control of elements within the virtual world.

Real-time tracking of movement is critical in providing compelling VR experience. Visual perspective on the world changes as the user physically moves his head or body. The system continually measures the physical position of the HMD (for head/eye tracking) or the wand/glove (for hand tracking). Full body suits with sophisticated motion tracking also exist for specialized usage (i.e. to create CGI characters in a film).

In shared VR environments, each person experiences the virtual world from their own unique visual perspective (each user is presented as a virtual character, or *avatar*, to the other participants). A shared environment allows for both teamwork and competition, or even competition among teams.

What is Augmented Reality (AR)?

Another area of research closely related to VR that shows great promise is Augmented Reality (AR). In AR, virtual elements are added to, or over-laid upon, the real world, resulting in a partially-virtual environment. A simple example can be seen on network television during Sunday football games, when a yellow stripe appears on the field, indicating the position of the first down marker. Only those watching at home on television can see the line, because it isn't present on the actual field. In another example, a see-through HMD could allow an electrical engineer to view the schematics of a complex circuit board, including virtual labels, superimposed onto the actual circuit board for reference. Or an Obstetrician could examine a patient with ultrasound images superimposed onto her body, creating the illusion of x-ray vision.

The educational implications of AR are only just being imagined, though the possibilities are intriguing. Imagine being able to pull up supplemental data using AR glasses on nearly everything you come across. And the ability to add virtual elements to the real world (buildings, people, objects) for simulation and training purposes could be extremely valuable. For now, however, AR is a relatively new concept that will likely take years to evolve into a practical tool for education.

For the sake of consistency, the term 'virtual reality' or VR will be used extensively in the paragraphs below. Most of the information, however, is also relevant to the growing field of augmented reality.

Head Mounted Displays (HMDs)

A typical head-mounted display (HMD) houses two miniature display screens and an optical system that translates the visual signal into stereoscopic images to simulate depth. A motion tracker continuously measures the position and orientation of the user's head and adjusts the images in real-time to believably represent the current view. As a result, the viewer can look around as they walk (or fly) through the surrounding virtual environment.

HMDs range widely in price and quality, from a $250 low-end PC gaming device to a $200,000 military, industrial or scientific device with the most sophisticated optics and a cluster of computers providing processing power and tracking. The more expensive, higher-quality HMDs provide a much higher visual resolution, more closely simulating the actual field of view capable by the human eye. Lower-end devices are simply small LCD monitors placed directly in front of the eye, with little or no peripheral vision and only a basic sense of immersion.

The Sensics PiSight display, initially developed at the Johns Hopkins Wilmer Eye Institute, uses an array of 24 small LCD monitors (12 per eye) to more closely simulate the human eye's natural field of view and sense of peripheral vision. Driving the display is a cluster of 6 computers, each with 4 video outputs, plus a 7th computer that controls what visual data is sent to each of the 24 eye panels. As a result of our close geographical proximity to Sensics, and our own affiliation with Johns Hopkins University, CTE will be using the Sensics HMD to conduct demonstrations and case studies with middle school age children and their teachers over the next 2 years.

Input Devices

Many input devices, such as data gloves, joysticks, and hand-held wands, allow the user to navigate through a 3D environment and interact with virtual objects. Some of these devices including advanced 'forced-feedback' (haptics) which simulate the sense of touch, shape, texture, etc., to further enhance the realism of the VR experience.

Wands: Essentially a hand-held joystick device with buttons and a motion tracker, a wand can come in many different sizes, shapes, and configurations. Usually represented in the 3D world by an object 'avatar' (wand, weapon, tool, etc.) for interacting with the virtual environment (i.e. selecting and moving objects) and for navigating through the VR world (for example, pointing the wand skyward and pushing a button would cause the user to 'move' upwards in that direction).

Data Glove: Like a VR wand, a data glove can be used in a variety of ways to navigate through and interact with the virtual environment. Exactly how the glove is employed depends on the software, but could include assigning actions to specific hand gestures (pointing, making a fist, waving, touching two fingers together, etc.), or controlling a virtual hand 'avatar' within the simulation for selecting or manipulating objects. Many gloves also include joystick-like controls similar to a wand (buttons, toggles, etc.). Higher-end data gloves include SDKs (software development kit) that allow programmers to customize how the data glove is utilized within a particular simulation.

Haptics

In virtual reality, visual and auditory information is relatively easy for the computer to generate. But how can the computer let someone know when they've bumped into a virtual wall? How might a surgical simulator teach a medical student what it feels like to cut into muscle? When a pilot-in-training runs her fingers over a virtual instrument panel, how could VR help simulate when her finger touches the contours of a button? *Haptics* in VR deals with the sense of touch, and how a computers & devices can provide physical feedback to allow for more realistic interaction with virtual objects.

Cutting edge studies with haptics have proven that computers can trick the body's senses into thinking a flat surface is actually bumpy, sharp, hard, soft, spongy, etc. The goal is to simulate any shape, texture, or sensation. Future devices could simulate many tactile sensations, including temperature, hardness/softness, weight, and shape. A virtual handshake while wearing a haptics-capable data glove might one day feel like a real handshake, complete with body heat and perspiration. Some speculate that haptic devices will eventually also simulate physical pain (a potentially controversial new aspect of video game play).

The study of haptics is also closely related to the field of robotics. Much like a data glove controls the movement of a virtual avatar in a VR environment, it can also control the movements of an actual robotic arm. Such research is proving valuable in space exploration (the remote control of robotic arms in space or in other hazardous environments), medicine (the ability of doctors to perform physical exams and procedures on patients across long geographic distances), and particularly for individuals with physical disabilities.

The CAVE System

While immersive VR typically involves the use of an HMD, a CAVE (Cave Automatic Virtual Environment) system can also provide the sense of full immersion on a virtual world. The CAVE was developed at the University of Illinois at Chicago and provides the illusion of immersion by projecting stereo images onto the walls and floor of a room. Unlike an HMD, a CAVE is not limited to one person at a time; a typical CAVE can accommodate several people at the same time, each wearing special stereoscopic glasses (though the person wearing the glasses containing the head-tracking device will have the most visually realistic experience).

Disadvantages of CAVEs include their expense, difficulty in setting up and maintaining, and their immobility. On the positive side, a well-constructed CAVE running a compelling 3D simulation is a truly immersive experience, without the hindrance of a heavy HMD and its attached cables.

The Geo Wall:

The Geo Wall is a fairly low-cost projection system originally developed to give scientists – and science educators – an inexpensive platform for projecting 3D earth science images. Created at the Electronic Visualization Lab at the University of Illinois at Chicago (UIC), Geo Walls can now be found at universities, museums, and even public schools, illustrating 3D models related to astronomy, geology, biology, paleontology, and medicine, as well as to visually represent abstract mathematical concepts.

To observe the 3D effect on a Geo Wall, observers simply put on cheap polarized glasses and watch the screen. The effect is near-holographic, with the 3D image appearing to float in the room directly in front of the screen. The authors of this report observed a demonstration at the University of Michigan, in which the skeleton of a prehistoric fish seemed to float in the middle of the room as an instructor described the characteristics of the extinct fish before us.

Construction of a Geo Wall requires 2 DLP projectors with passive polarizing filters on the lenses, and a special screen that preserves the polarization. The 3D effect works with both front and rear projection; rear projection is somewhat more effective but requires more physical space to setup. A Geo Wall can be constructed for under $10,000 with educational pricing discounts, making it a realistic teaching technology for universities and K12 schools. The effect is similar to commercial 3D projection systems (such as the 3D Imax films), but made affordable by dropping prices and technological improvements in LCD projectors and PCs.

Geo Wall 2, a next-generation 3D solution, is being developed for applications that require a much higher image resolution. One of the first of these systems at UIC utilizes 15 LCD panels driven by a cluster of computers, providing screen resolution of 8000 x 3600 pixels. Smaller and larger versions are also being designed, with some stretching hundreds of feet in length. Such systems could be used to display high resolution images such as aerial photography from the U.S. Geological Survey or astronomical images from the Hubble telescope.

3D Scanners:

Using software alone, skilled 3D graphic artists can create models and virtual environments completely from scratch. This approach is necessary for objects & places that don't actually exist in the real world. But what about objects and places that do exist in reality, but need to be represented digitally in a VR environment? Devices called '3D Scanners' make translating reality into a VR format relatively simple. One common type of 3D scanner uses small synthetic dots that are placed on the surface of an object, area, or person. By tracking the physical position of these dots, even as the object is turned, the scanner can accurately create a 3D digital representation. This technology could allow someone to create a realistic digital representation of their self for use within a video game, or allow a pilot to interact with an exact virtual replicate of the cockpit she will be flying in.

Virtual Reality and Mobile Devices

The large amount of graphical data and processing power required to render high-fidelity 3D simulations has limited the usefulness of handheld devices in VR. But in the foreseeable future the processors and graphics capacity of mobile devices should begin to catch up to their PC counterparts. Handhelds will eventually be capable of smoothly rendering high-quality 3D graphics.

Another area where handheld devices will likely experience rapid development is in high-speed wireless connectivity. While most new mobile devices are able to connect wirelessly to the Internet, the bandwidth of the available connections is currently not robust enough to transmit and receive the large amount of graphical data required by VR. But there are several promising wireless technologies that may eventually remove this obstacle as well. Wireless phone providers are beginning to roll out networks with speeds of 3.1 megabits per second (significantly faster than the typical 144 kilobits per second connections that most cellular phones currently have). Worldwide Interoperability for Microwave Access (WiMax) is a network standard that allows for high speed data connections (up to 70 megabit per second) over large distances. It will be some time, however, before the WiMax standard becomes official and manufacturers produce consumer equipment that uses it. Finally, the Optemax Corporation, has developed a prototype point-to-point wireless network called *BeamNet* that promises speeds 18,000 times faster than WiMax.

The availability of high speed wireless networks, combined with improvements in the graphics and processing power of mobile devices, should result in handhelds becoming popular platforms for running sophisticated, graphics-intensive games, VR simulations, and augmented reality experiences.

The Future of Virtual Reality:

To understand where VR is going, it’s important to look at some of the key limitations and challenges facing the field today. Common problems with VR include:

a) Motion Sickness: Even a miniscule time lag caused when the computer or motion tracker struggles to keep up with the changing visual perspective of the user can cause nausea and eye strain. Improvements in graphical processing power and greater accuracy of motion tracking devices will help reduce or eliminate this discomfort. (‘Natural’ motion sickness, caused by the realism of the VR experience, will still affect those who would experience motion sickness naturally).

b) High-Cost of Equipment: The truth is that low - and even mid-range - VR devices, typically sold for gaming and entertainment purposes, are far from compelling. The low sense of immersion provided by the optics will impress only the most easily impressed among us. Until higher-quality devices become affordable, VR will remain a training and research tool for the military and scientific communities.

c) Lack of Mobility: Most VR equipment is heavy and non-mobile, usually involving a multitude of cables and plugs. In higher-quality VR system, racks of computers often provide the required processing power. Advances in high-bandwidth wireless technologies, the invention of lightweight, less cumbersome VR devices and the increased capacity of mobile computers will eventually make VR technology more mobile and accessible, widening it's appeal and applicability for as-yet unexplored uses.

d) Lack of Compelling, Interactive Content: The difficulty and expense of creating compelling applications of VR, particularly when few high-end systems are accessible to the general public, have limited its growth. As VR becomes less costly and accessible, a larger community of developers will likely emerge to provide compelling new applications of the technology. While the entertainment and gaming applications will probably come first, the learning potential of VR will also emerge as educators and programmers work together to develop compelling new content and applications. Another factor that would greatly contribute to the growth of compelling VR content would be easier-to-use 3D development tools and simulation-creation tools that do not require a high level of programming skill to master.

PART II: 3D GRAPHICS and VIDEO GAME HARDWARE

More than any other force, video game graphics have driven improvements in consumer computer hardware, and provided one of the most critical incentives for computer owners to upgrade their equipment. As the hardware improved, so did the realism and capabilities of virtual reality and computer-based simulation. Examining the hardware and graphics technologies common to the video game industry is crucial to understanding the current state of 3D, high-fidelity graphics that drive VR and simulation development.

An Overview of Video Game Hardware

Most games and simulations are played on either a personal computer or a video game console. There are additional, specialized electronic devices for games (usually found in the toy section of stores) but the usage level is insignificant compared with personal computers and consoles.

Consoles can be divided into two categories: non-portable and portable. There are three big companies in the game console market. Sony has the largest amount of non-portable gaming consoles in the marketplace with the Playstation and Playstation 2 (currently the most-used game console). The Playstation 3 is expected before the end of the year*.* Microsoft has the Xbox and the more recent Xbox 360 (currently the most technically advanced console on the market). Nintendo has a long history in the non-portable gaming console market including their current entry, the Gamecube (Nintendo's next console, the Wii, is expected in late November of 2006). The portable gaming console market is almost entirely dominated by Nintendo's DS (Dual Screen) and, at a distant second, Sony's PSP (PlayStation Portable).

Video game consoles and personal computers share many of the same technologies and design elements but differ drastically in purpose. Personal computers are not designed solely for gaming, or even for entertainment, but instead are multi-purpose devices designed to accomplish a variety of tasks. Game developers have successfully exploited the technical capabilities of home computers for gaming, and in the process created thriving game market on the PC platform. Video game consoles, on the other hand, are solely home entertainment devices whose primary (and sometimes only) purpose is to play video games.

Gaming Hardware: Personal Computers vs Consoles

Most personal computers are comprised of a *CPU* (central processing unit) that executes commands and performs actual binary computations, a *motherboard* that primarily governs communication between various hardware components, *RAM* (random access memory) that stores and retrieves active data, and a *hard drive* for storing programs, data, and files even when the computer is powered off. Modern gaming consoles, such as the Xbox 360, have these same components, but each part is optimized for game playing and cannot typically be repurposed to perform other tasks. The hard line between consoles and computers blurred somewhat with the Xbox 360, as Microsoft incorporated several PC-like features (such as live messaging and support for various home multimedia formats) into their current console.

Personal computers are built with interchangeable parts, reflecting their multi-use design. It is relatively easy for a computer owner to replace older components with newer ones, improving performance and alleviating the need to upgrade the entire computer. The hardware within a console is rarely, if ever, altered during its lifespan. But consoles are expandable, allowing owners to add additional devices (steering wheels, data gloves, dance pads, etc.) that are specifically designed for their console type. Similarly, personal computers have industry-standard slots and inputs for switching or adding components, controllers, and other devices.

Another major difference between computers and consoles is the method of user input (how the game is controlled). Though other options do exist, most gamers use the keyboard and mouse to play games on a personal computer. Conversely, video game consoles include handheld controllers that are unique to each individual system. A typical controller consists of a directional device to control movement and an assortment of buttons whose function depends on the game being played. One notable exception, the Nintendo DS, uses a stylus for inputting data on a touch-screen (in addition to a directional device and buttons). Adding an innovative twist, the upcoming Nintendo Wii will include a controller with motion and direction sensitivity (i.e., a swinging motion made with the controller could equate to a swing of a bat within the Wii). A variety of other controllers and joysticks can be found for both video game consoles and personal computers.

Video Graphics

Most commercial video games & simulations released in the past 5-10 years are extremely graphics-intensive. In other words, it takes a lot of video memory and graphics processing power to keep the game running smoothly. Gaming consoles are built with heavy graphics in mind, and the games themselves are designed carefully so as not exceed the capabilities of the console. On the personal computer side, things aren't so simple. Even a newly purchased PC workstation may have difficulty running a modern video game. The reason lies in the computer's graphics hardware, which varies widely from one computer to another.

The graphics capacity of a personal computer defines whether or not it will be useful as a gaming platform. Even though entry-level PCs purchased today are capable of reproducing high-fidelity graphics for most purposes, games and simulations typically require a dedicated, modern graphics card in order to run properly. While many computer components have been successfully integrated into the PC's motherboard (modems, ethernet ports, sound, hard drive controllers, etc.), a computer that will run graphics-intensive programs, games, or simulations should be equipped with a separate graphics card with a modern chip and at sufficient graphics memory. In fact, those who use PCs to play video games typically consider the specifications of the graphics card to be of equal or greater importance than that of the CPU itself.

In the early 1990's, PC video cards were separated into two categories: two dimensional (2D) and three dimensional (3D). All computers had video cards capable of producing what most people think of as standard 2D computer graphics (menus, icons, the Windows desktop, photographs, etc) while a relative minority of personal computers included an additional video card for rendering 3D graphics. The reason that a special card was needed was that the processing requirements to render 3D graphics are exponentially higher than those required to render 2D images. Video cards that were capable of producing beautiful 2D graphics and even video playback were not powerful enough to display true 3D.

Those who purchased a second video card dedicated for 3D graphics were primarily video gamers and graphic artists. The invention of the 3D card drove the development of more 3D, graphics-intensive games. And as more games became available, more gamers upgraded their computer's video capacity with a second card for 3D. By the end of the 1990's, advances in graphics technology eliminated the need for two separate video cards, allowing 2D and 3D to finally coexist on a single, multi-purpose card. The result was a boom in the video game industry and the market for video card upgrades. It was also the beginning of the tension between the ever-expanding graphical requirements of newly released video games, and the ability (or inability) of the average personal computer to play them.

Before 3D graphics cards became easily available to the average computer user, virtual reality (VR) and simulations were relegated to custom-designed computers with specialized video cards. As 2D/3D graphics cards became ubiquitous in personal computers, the development tools needed to create high fidelity 3D graphics for VR and simulations also began to emerge. Programmers and graphic designers suddenly had a platform on which to develop compelling, 3D environments that could be shared with a large audience of personal computer users. The new prevalence of 3D graphics cards fueled enormous growth in video game industry and significantly furthered the development of virtual reality and simulation technologies.

The Details Behind 3D Graphics

The video card industry is dominated by two corporations: Nvidia and ATI Graphics. The companies vigorously compete for the entire market range of graphics cards for personal computers. While both companies use different computer chips on their graphics cards, the results are similar. When Microsoft develops communication standards for Windows, both Nvidia and ATI cards are compatible. The same holds true for 3D graphics. Microsoft has its DirectX line of applications programming interfaces (APIs) and there is an open standard API for 3D called OpenGL. The end result is that the consumer can select a graphics card without worrying if the card will be compatible with the software or games they purchase. An important note is that while both API's are used extensively for game development, simulations and VR content tends to rely more heavily on OpenGL.

Because of the intensive graphics requirements of VR, 3D simulations, and (most) video games, innovations in the way graphics cards communicate with computer hardware can have major effects on performance and quality. Nvidia and ATI are regularly improving their GPUs (graphical processing units) and creating new cards constructed with the latest advances in graphics hardware. One feature of the most powerful cards is the ability to access its own reserved memory, integrated into the card and separate from the rest of the computer. Memory capacity that was once considered large for an entire computer can now be found on the graphics card alone. The highest-end video cards currently come with 512 MB of video memory.

Originally graphics cards would plug into a standard PCI (Peripheral Component Interconnect) slot on a computer's motherboard. To streamline communication with the graphics card and increase performance, motherboard manufacturers created the Accelerated Graphics Port (AGP) slot. AGP significantly increased communication speeds between the graphics card and the rest of the computer. Today, the AGP slot is being phased out in favor of another graphics-specific motherboard slot with even faster communication speeds, PCI Express.

The latest trend in maximizing the performance of personal computer graphics is to use multiple cards for what is traditionally handled by a single card. With multiple cards, the work load can be and throughput can be increased by factors of how many cards are being used (i.e. two cards can double the performance). Nvidia calls this technology Scalable Link Interface (SLI) and ATI refers to it as CrossFire.

These improvements in technology have had a dramatic effect on VR and graphics-intensive simulations. Personal computers have always struggled to smoothly and realistically render high-fidelity, virtual environments. As the graphics quality of video games has increased, the same hardware and techniques that produced the games has been leveraged to create significantly improved, realistic VR environments. In addition, while graphics cards have had the largest impact on advancing virtual reality and 3D immersive environments, other video game technologies, devices, and input mechanisms have also contributed significantly.

The Flow between Video Game and VR Technologies

Some console and computer game control devices have a technology called either Force Feedback or Rumble Packs. Motors are embedded into items such as control pads, joysticks, and steering wheels and based on instructions from the game are able to provide resistance or movement to simulate tactile feedback. An example would be resistance on a steering wheel when guiding a vehicle through a tight turn or feeling the controller shake every time your character in a game is damaged. This technology was developed to create a more realistic, immersive experience for a player. Consequently, the technology has found a natural role in VR and simulations. Many of the same technological advancements occurring in Force Feedback and Rumble Packs have found their way to different haptic technologies. (see *Haptics* section in Part 1).

Just as video game technologies and innovations have influenced virtual reality, VR research has impacted the video game industry. Head mounted displays (HMDs) have historically been extremely expensive and only used for serious research on specialized VR systems. As breakthroughs in video technology have progressed, low cost HMDs have become viable consumer electronics. While they might not offer the same fidelity as their more expensive counterparts, low cost HMDs offer a relatively inexpensive way to add immersive VR elements to a video game. These new low-cost HMDs are also used in low fidelity VR implementations. The maker of low cost HMDs can market both to the VR industry and those that are using them to play games on their personal computers.

The Near Future: Presently Emerging Hardware and Devices

“Moore’s Law” states that the power of computer chips will double every two years, a projection that has basically held true since originally stated by Gordon E. Moore (co-founder of Intel) in 1965. The strength of the video game industry, fueled by consumer demand for innovative equipment and games, has led to similarly rapid improvements in video games technologies, particularly as related to graphics quality and performance. These innovations have directly impacted 3D software development (including video games, VR and simulation content, and 3D development tools), as enhanced capacity of computers and consoles greatly expands what is possible from a graphic design perspective.

Mobile gaming: Mobile phones, which have been able to play low fidelity games for some time, will soon leverage advances in color screens, memory, and CPUs to play games that were once regulated to portable consoles. (One only needs to examine the Nintendo DS and the Sony PSP to understand just how much gaming power and graphical fidelity can be squeezed into a small package.) The same is true for portable MP3 players, such as Apple Computers' Ipod. The latest generation Ipod comes standard with several graphic-rich games. And since games and VR are driven with similar technologies, it is probably a matter of time before VR and simulation content is also available for portable devices.

Physics Cards: In a recent example of graphics card innovation, the AGEIA Corporation has created a chip called the PhysX that is being marketed as a physics processing unit (PPU). Such a card would allow games and simulations to offload the calculations needed to reproduce physics (i.e. gravity, motion, force of impact) to the PPU, freeing up the regular CPU for other critical calculations. The result would be a much more realistic game or simulated environment. An example would be the ability to simulate and display breaking glass. The PPU would control the graphics required to realistically display the glass breaking into hundreds of small shards, a job that would normally place a heavy load on the CPU and graphics card (probably requiring the game or simulation designer to settle for a few shards of glass and decrease the level of realism).

Artificial Intelligence Chips: Another potential breakthrough is the Intia Processor by the AIseek Company. What the PPU will do for physics, the Intia would do for artificial intelligence (AI). When a player interacts with virtual, non-player character (NPC) in a game or simulation, AI is responsible for all actions for the NPC. AI algorithms that govern a NPCs movement, interaction, and speech require many cycle of a computer's CPU. The Intia could also free the CPU for other processes by handling the complicated calculation required by AI algorithms.

Though they are designed for games, both the PhysX and the Intia could dramatically improve the realism and graphical fidelity of a VR simulation. Physics and AI are critical aspects affecting the quality and believability of a VR experience or other 3D immersive environment. Freeing up the CPU resources required for physics and AI in virtual reality would greatly expand what is possible, allowing developers to include additional graphic detail, animation, avatars, etc., to further enhance the realism of the experience.

Movement Pads: A current crop of popular music-themed games (including Dance Dance Revolution, or DDR) come with their own floor mat for registering dance moves. In DDR, players match movements of their feet with signals on the screen while staying in time with the music. (The state of West Virginia has even used dance pads in school physical education programs.) VR simulations could take advantage of similar technology, mapping a user's movement and translating the movements to a virtual avatar in the simulated environment.

Motion Tracking: Inexpensive webcams can now, with assistance of more powerful CPUs, track a user's head and body movements, integrating that data into a game or simulation. The EyeToy for the Playstation 2 allow players to interact with objects in a game based on body movement alone. The forthcoming Nintendo Wii will have a controller (the *Wiimote*) that is both wireless and motion sensitive. Devices such as these that integrate natural body motion seem to add a sense of realism and immersion to the experience.

Playing games online is not a new phenomenon, but the online communities that have arisen around the most popular games have also begun to appear in VR applications. Multiplayer games such as *World of Warcraft* (WOW) have inspired numerous communities (known as *guilds* in WOW). Members of these communities interact socially and provide help to each other in numerous online pursuits. The computer program *Second Life*, the closest thing in the gaming world to a true VR simulation, is a virtual world where users create their own 3D environments that are inter-connected and shared with the creations of other Second Life users. A member of Second Life can create their own avatar (digital representation of themselves), build a virtual home, organize virtual social events, and even setup a business offering services in the virtual world. And much like WOW's guilds, Second Life users have formed their own online communities for socialization and support.

VR and Assistive Technology

Many of the previously described technologies have also contributed to the development of improved assistive technologies (AT) for special needs populations. More powerful processors allow software to perform real-time text augmentation and voice recognition. Technology similar to Force-Feedback allows for a user who can't rely on visual output to feel a computer's response. Digital cameras with sensitive motion tracking can allow a user to control a PC with body movement alone. Such technologies show great promise for alleviating some of the barriers that historically exist in cutting-edge technology applications. The AT potential of input devices such as haptic gloves, the sensitivity of which can be calibrated based on the special abilities of the wearer, could allow for a full range of movement and interaction within a virtual environment for a physically disabled user. As the realism and graphical fidelity of virtual reality improves, the medium could provide special needs populations with a variety of experiences and opportunities that are difficult or impossible for them to achieve in the physical world.

CONCLUSIONS

Like most technologies, virtual reality will undoubtedly become more technically sophisticated, less expensive, and more accessible over time. The quality of the visual graphics will eventually approach near-realism. Motion tracking will become so sophisticated as to allow free movement within a room or even a geographic area. New applications of the technology will emerge in both entertainment and education as the cost comes down and availability goes up. Stunning graphics, 3D sound, and the application of haptics and other sensory data will combine to provide truly compelling and realistic virtual environments.

Looking even further into the future, some imagine that VR could eventually involve the direct manipulation of the brain, 'implanting' sensory data in a way that would replicate the feeling of a vivid dream. Studies have shown that the non-invasive transmission of ultrasonic waves directly into the brain can recreate all five senses. *While purely conceptual at this stage, Sony has actually filed for (and received) a patent for the idea and intends to develop the concept further*.

As a potential learning tool, the combination of VR technology with well-constructed simulations could offer exciting possibilities for tomorrow's students. It would be fascinating to learn if immersion in an authentic, graphically realistic learning environment makes any difference in a student's understanding of difficult concepts, retention of what they learned, or ability to connect information to existing knowledge. We suspect there may be great educational potential in VR and simulations that has yet to be realized, at least in part because of the current state and expense of the technologies involved. But things are changing fast, as evidenced by the quantum leaps forward in video game graphics technologies over the past decade. Applying virtual reality as a learning tool, sooner rather than later, may prove to be more 'realistic' than many of us thought.

REFERENCES

3-dimensional scanners can aid museums and archaeologists, May 1, 2006, http://www.maya-archaeology.org

A Critical History of Computer Graphics and Animation, Section 17, Virtual Reality, Ohio State University, http://accad.osu.edu/~waynec/history/lesson17.html

A Brief, Early History of Computer Graphics in Film, http://www.beanblossom.in.us/larryy/cgi.html

Case, Loyd, *A Personal History of 3D Graphics*, Extreme Tech, January 16, 2006, http://www.extremetech.com

Electronic Visualization Laboratory, the University of Illinois at Chicago, http://www.evl.uic.edu

Fisher, Ken, *PlayStation 2 outselling Xbox 360 in US*, Ars Technica, June 11, 2006, http://arstechnica.com/news.ars/post/20060611-7030.html

Herman, L., Horwitz, J., Kent, S., and Miller, S., *The History of Video Games*, http://www.gamespot.com/gamespot/features/video/hov

Horsnell, Michael, *Sony takes 3-D cinema directly to the brain*, Times Online, April 7, 2005, http://www.timesonline.co.uk/article/0,,2-1557733,00.html

The Corewall Suite project, University of Illinois at Chicago, http://www.evl.uic.edu/cavern/corewall

The Geo Wall Consortium, http://geowall.geo.lsa.umich.edu/home.html

The University of Michigan Virtual Reality Lab, http://www-vrl.umich.edu

The University of Michigan 3D Laboratory, http://um3d.dc.umich.edu

The Video Game Revolution, Public Broadcasting System (PBS), http://www.pbs.org/kcts/videogamerevolution

The Wedge Virtual Reality Theater, Australian National University, http://wedge.anu.edu.au

Virtual Reality: History, 1995, The University of Illinois, http://archive.ncsa.uiuc.edu/Cyberia/VETopLevels/VR.History.html

Wikipedia entries:

Jaron Lanier, http://en.wikipedia.org/wiki/Jaron_Lanier

Virtual Reality, http://en.wikipedia.org/wiki/Virtual_reality#_note-0

Handheld Device, http://en.wikipedia.org/wiki/Handheld_devices