Time Traveler

by Scott Stevens

Several months ago a series of posts to an electronic bulletin board at Carnegie Mellon University heralded a video game as the future of computing. It had impressive fluid graphics, was highly interactive, and had incredible, true 3-D images where, without the need for special glasses, you could watch actors standing up and walking around on a glass plate. There was a wide viewing angle of almost 180 degrees and you could put your hand through the image. Since interactive digital video is my principle area of research, I rushed to the mall to see the game, Time Traveler. It isn't the future of computing, but it is an intriguing example of the integration of mature techniques and technologies to create a new product.

The b-board contributors were wondering, as was I, what technologies were behind the game. The short answer is: analogvideodisc (15+ years old) and a concave spherical mirror (century+ old).

When I saw the game, it was immediately apparent that the system was using an analog videodisc, LaserDisc, and the image was a real image created by the projection of the monitor. The interesting questions were 1) was this a single or multiple disc player system and 2) was the image created by a concave spherical mirror or a holographic optical element (HOE). The design of the game suggested single disc player. The cost of good quality mirrors of the type used is high and the word "Hologram" appeared on the front of the game. Being a trusting soul, I thought there might actually be a HOE.

A few words may be useful on mirrors, lenses and the images they form. A real image can be made with concave mirrors or convex lenses. It is distinguished from a virtual image in that light actually passes through the image point; with a virtual image light diverges from the image point. A real image may be projected onto a surface and appears to float in space if

This and the following images show scenes from Sega's new interactive 3-D video game, Time Traveler.

viewed directly. An ordinary household mirror produces a virtual image.

One of the finest examples of the optical reality of a real image comes from an exhibit at the Exploratorium in San Francisco. A spring is sitting in front of you in a hole in a box. You see a flashlight, which you condude can be used to illuminate the spring. As you try to touch it, there is nothing there. Several museums around the country have similar exhibits. For around $45, Edmund Scientific sells a "floating coin optical mirage" that demonstrates the effect with a slightly different geometry.

Epcot Center uses virtual images to create an interesting exhibit. In their computer center small actors bounce from one console to another singing and dancing. Unseen by you and under your feet are multiple monitors that move on tracks. Between you and the computer center is a glass wall. You are actually seeing virtual images of the monitors in a partial mirror, the glass wall. The virtual image in a flat mirror is formed at a distance behind the mirror that is equal to the distance the object is in front of the mirror. Where the Epcot exhibit falls short is when the actor is moving with a component parallel to the window. It is sometimes apparent that he or she is not walking at precisely the same rate that the image is moving. The problem is due to the difficulty of timing the physical motion of the monitors with the gait of the actors. This problem is not a factor with Time Traveler since the actors' movements in the studio are intrinsically scaled on projection.

Using a HOE in place of a concave mirror would have been something of a breakthrough. HOEs are optically recorded mirror (or lens) elements that have imaging characteristics essentially identical to the original optical element. While HOES have drawbacks, they have some significant advantages. They are only as thick as the photographic plate/film plus emulsion, and the HOE does not have to be oriented at an angle that conforms to the geometry of the original optics. They are used in head-up displays, helmet-mounted displays, and supermarket bar-code scanners. Using a HOE for Time Traveler would be quite a trick; HOEs have peak efficiencies over very narrow ranges of wavelengths and Time Traveler offers a full-color image. Creating a HOE large enough is another problem. Holograms can record multiple, independent images. I thought Sega, the game's manufacturer, had possibly created a large HOE with three "mirrors," each tuned to one of the three RGB phosphors. No such luck. A second trip to the mall, flashlight in hand, helped to establish that there is simply a spherical concave mirror creating a real image.

Dragon's Lair, a videodisc game similar in design to Time Traveler, was popular briefly in the early 1980s. It used animation and no live actors, but the basic design paradigm was the same. At the time, it was hoped that Dragon's Lair would be the savior ofvideo arcades; arcades and home games were losing appeal. Dragon's Lair offered players limited control over the actions of characters. You could go left, right, up, down and shoot. After awhile with these control limitations, player interest waned (it turns out that Time Traveler's development was headed by Rick Dyer who worked to develop Dragon's Lair with Don Bluth, director of An American Tail and The Secret of Nimh).

Then came Nintendo. Users could now go left, right, up, down, shoot, and maybe kick. Not quite the advance that game buffs might have hoped. Time Traveler fits this model with the addition of real-life visuals and audio. The amount of control the user has is still very limited. Time Traveler is a single-sided analog videodisc, which means it holds 30 minutes of randomly accessible video. I estimate the average sequence is 10-15 seconds long, so there are about 150 sequences, some of which may be used more than once.

The game's design, one of simple branches, is such that inappropriate input is ignored. The user, for example, might input a left turn, but only a right turn is accessible. During most of the time, no input is permitted since no response is available. These limitations are masked by the fact that the typical user tries to be successful by making the appropriate input at the appropriate time.

The fact that Time Traveler has

its roots in a decade-old technology and that technology and design paradigms have surpassed it, does not detract from it at all. On the contrary, it is Time Traveler's good design-playing on the suspension of disbelief of the user and an understanding of user's expectations-that masks Time Traveler's limitations.

I believe one of the other lessons here is the captivating power of the story/fantasy. Good examples of this power from the linear world are the failure of Battle Star Galactica and the success of Dr. Who. Battle Star Galactica had the best special effects money could buy, but poor writing. Dr. Who captured its following on the basis of its stories, certainly not its special effects.

So what does all of this have to do with scientific visualization? A lot, actually. For one thing Time Traveler demonstrates the mileage that is yet to be gained from mature technologies. More important are the subtle lessons that can be applied to scientific visualization.

Much work in educational computing research has gone into what makes games captivating. Thomas Malone looked at why people spend hours playing them. He identified several motivating factors, such as challenge (goals with uncertain attainment), curiosity (sensory and cognitive), and fantasies (especially intrinsic fantasies where the fantasy depends crucially on the task). I believe these are the very attributes that make scientific visualization exciting, or for that matter all areas of inquiry. There is a fundamental belief that the universe is knowable. The unknown produces cognitive curiosity evoked by the need for completeness, consistency, and parsimony.

Decades ago, the pioneering film maker and theoretician Sergei Eisenstein used the work of Jean Piaget in the formulation of his theory of film. Malone's work is also closely tied to Piaget. For Piaget and Malone, learners assimilate new knowledge in terms of their existing mental schemes. If the new knowledge is too far removed from existing schemes, the learner, game player, or researcher cannot accommodate the knowledge.

One notable example of this phenomenon in research was the discovery of the positron. Carl Anderson, working under Robert Millikan, collected dozens of images of positron tracks. These objects were so unaccounted for by theories of the day that Anderson believed they were tracks of moving electrons (although the momentum of the collisions precluded this conclusion), and Millikan believed them to be protons (even though their experimentally deduced mass ruled out protons). It was not until Paul Dirac's theoretical work predicting anti-electrons was coupled with Anderson's experimental images that physicists at large accepted the results of both Anderson's experiments and Dirac's relativistic quantum mechanics. With scientific visualization, one of the challenges is to present researchers with optimum levels of information complexity.

What about fantasy? Work today in virtual reality is really about fantasy. Scientific visualization is virtual reality, taking us places we could not go by any other means. How much fidelity is enough? Michael Christel studied users of a program he and I created at the Software Engineering Institute, called "A Cure for the Common Code." The system creates a virtual world consisting of six sub-worlds. Two methods of navigating through the world were tested, one a direct-manipulation point and click map, the other a surrogate travel interface where the user "walks" through the space and into the desired sub-world. Both groups of users liked, or disliked, the interfaces equally and used them in equivalent fashion to navigate the world. Users with the surrogate travel interface, however, came away from the experience with more positive opinions about the subject under investigation. While the surrogate travel interface was more cumbersome and slower, its users were brought more completely into the fantasy.

Many models present their data through motion. Motion may be primarily under user control, such as rotating a three-dimensional model, or it may be under the primary control of the simulation, as in atmospheric models. Do differing levels of fidelity matter? Are four frames per second fast enough? 30 frames? 60 frames? The viewers of Time Traveler are captivated by the real-time motion in the game. Is this just because they are used to Nintendo-style arcade graphics?

There are compelling reasons to believe that high frame rates are more than frills. In the same experiment cited above, Christel presented one group of users with full-motion video and audio in the various sub-worlds. Another group had the same experience except sequential still images

were used with the audio. This was easy to implement with digital video; Christel simply displayed every nth video frame. The users with full motion video retained more information than did the others even though the information on which they were tested was contained only in the audio.

Our perception of motion is obviously affected by slow frame rates. 24 film frames and 30 video frames per second seem adequate to produce the effect of flicker free motion (flicker caused by 30 frame-per-second, high-resolution interlaced monitors is a separate problem). But what happens at higher frame rates? About ten years ago, Douglas Trumbull invented a film technique that used a larger format than 35mm film. It ran at 60 frames per second. When I sat in a ShowTime theater to watch one of Trumbull's films, there appeared to be a technical problem. The lights dimmed and then a stage light came on behind the screen. A workman was moving around behind the screen and then seemed to notice the audience. At that point, he put his face to the screen and pressed on it to look at us. The screen noticeably bulged and I thought it was ruined. With a scene change it became clear that it was all part of the film. The three-dimensional illusion was impressive.

On reflection, a ten- or twelve-inch displacement aimed directly toward a viewer at typical theater distances would produce very little parallax change. The eye is almost completely accommodated so there would be little change in focus. In any case, at that distance and with a relatively small pupil size depth of focus is a couple of feet. So, for certain images and movements the principal optical cues are essentially the same in a movie as the real world. The real question is why do other movies not appear three-dimensional? One reason is that objects are often at an unnatural size for screen distance. A close-up of a face, a wide shot of a boat the relative sizes are wrong. But not always. It is not just the size of the image either. Trumbull's screen was actually smaller than a typical theater, and often unnaturally sized objects showed the effect. Overly large screens are not the answer. Imax films are impressive because of their size, but they do not exhibit the same three-dimensional effect as Trumbull's technology. The real difference is the frame rate. The visual system simply has to fill in too much at lower frame rates.

Three-dimensional imaging systems that depend solely on binocular stereopsis create a cardboard cutout effect and create eye fatigue. The eye must maintain focus on the screen, yet the binocular information is telling us that focus should change. Time Traveler achieves a very different 3-D effect. When viewing it, you think objects move toward and away from you. It seems as though there is a natural perspective when objects occlude one another. Yet the image is actually planar-a real image of a flat monitor projected in space. The illusion is enhanced by the addition of real objects, blocks and the rear of the kiosk, located behind the optical image. Your eyes are continually focusing at different points. Eye fatigue is minimal. The illusion of three-dimensionality is striking. Experiments are being proposed at the Robotics Institute here at Carnegie Mellon University to test whether combining binocular stereopsis with an optical arrangement such as Time Traveler's will significantly increase fidelity.

Three-dimensional effects sometimes occur unintentionally. Color stereopsis is a three-dimensional effect caused by a combination of axial chromatic aberration and the fact that the optical and visual axes of the eye are not the same. Most observers see red light as nearer than green light even when both lights lie in the same plane. Color stereopsis may be observed in the image of the inside of a single cubic ice lattice on page 10 of the March/April 1991 issue of Pixel. While the perspective is direct, the blue on top and the red on the bottom give the impression that the lattice is rotated. If we are concerned with radiation minimums, color stereopsis may lead to an unconsciously skewed perception. The film industry has learned much about color, even not to "colorize" the first ten minutes of *The Wizard of Oz*

All right, so maybe frame rate and color do affect our perception, but surely with perspective, what we see is what we get. After all, in 3-D to 2-D projections the equations cannot lie. Let's look at some examples.

In Dudley Andrews's book, The Major Film Theories, Rudolf Arnheim points to the fact that we see a rectangular table as nearly rectangular even when the front edge is pushed quite dose to our eyes. Despite the fact that the retinal image of the table is trapezoidal (as would be any photograph of it taken from this perspective) our mind compensates for the distortion. Our vision, in other words, is not a mere result of retinal stimulation, but involves an entire "field" of perceptions, associations, and memory. In this case we aren't seeing badly; we are actually seeing more than our eyes can tell us. Vision is a complete mental operation of which retinal stimulation comprises but a part. Objects diminish in size by the square root of their distance from us. Our mind compensates for this to a large extent. But a photograph does not so compensate. "It can give us an image of a man's foot larger than his head," Amheim says, "if it is stretched out in front of him. When examining a photograph, our mind fails to compensate for this effect, since the photograph is a two-dimensional object. Being true to the mathematically real, photography is false to the psychologically real."

A related, but inverse effect is the rotation of a real three-dimensional trapezoidal window in a Ganzfeld (empty field). While you may have full knowledge that you are looking at a rotating trapezoid, you see a rectangular window going back and forth.

The image of the inside of a single, cubic ice lattice is a won-derful image. But if a three-dimensional physical model were sitting on your desk, I doubt that it would ever look like this image. There may well be compositional forms of the two-dimensional image that would psycho-physically look like the physical model. Having both views available may add a new dimension to scientific visualization.

Mars Navigator is an analog videodisc that most readers will agree is scientific visualization. Derived digital terrain data and a 250MB Viking Orbiter image was used to create over five and a half minutes of an animated 3-D fly-over of the Mars surface. Users may interactively change the speed of flight and direction of travel. Much like Time Traveler, the user decides which path to travel. Also, as with Time Traveler, input can only be responded to at specific points. Mars Navigator uses two identical videodiscs. Seamless transitions from one section to the next are achieved by cuing up the secon videodisc in anticipation of user needs. This device actually simplifies some aspects of design (disc geography requirements are relaxed) while it provides much more flexibility.

Mars Navigator makes impressive use of audio. Using both the videodisc's audio tracks and digital audio stored on a hard disk allows for continual audio, even during presentation of still images. The overall effect would be greatly diminished without audio. Could sound correlate to some parameter, say vibration or temperature, in images that are already overloaded with information? Of course, vibrating molecules don't create sounds. But since they are smaller than the diffraction limit of light they don't look like anything either. They surely do not possess the attribute of color. Multimedia hardware of today is giving us the opportunity to ask new questions about what scientific visualization is.

In the program mentioned earlier, "A Cure for the Common Code," the digital video design paradigm is an extension of work done by both Piaget and by Malone. One of the sub-worlds is a digital video simulation where a user can carry on a conversation with three personae. These personae react to the user and to one another in both a content domain and an affect domain. For example, the personae may become defensive, aggressive, shy, or even humorous in response to the ongoing discussion.

The program has two hours of digital motion video split into 450 pieces (files), 10 hours of audio in 4,500 files, and several thousand still images on a single CD-ROM. There is no notion of branching. The simulation is controlled by a rule base that determines what video, images, and audio to display and how to display them. The user may take different roles.

Depending on the choice of role, different actors will be used. The system composes the video on playback, creating a single screen from five different video pieces, and concatenates multimedia objects to create the perception of a single presentation.

Is "A Cure for the Common Code" scientific visualization? I would argue yes, but not too strongly. **After all,** we have created a model of behavior. The investigator can interact with the model and then view the results of the interaction. If what is seen-and in this case also heard-departs from the expected, experiments can be

devised to see if we have discovered new knowledge of the phenomenon, or if our model needs revision.

Video can be data for many scientific visualization applications. It may be as simple as comparing the video of an actual tornado to a computer model; the ability to synchronize the two, present them side-by-side, or digitally superimpose them. It may be intelligently abstracting information from digitized aerial photographs, processing the images, and then presenting them from a new viewpoint. Mars Navigator includes a multimedia database of Mars that is associated with the flyby. Wolff and Volotta, the developers of Mars Navigator, suggest extending the model so "instead of different visual paths to fly on Mars, you can switch filters and fly through a model of the Martian magnetosphere." Applying multiple analog videodiscs, digital video, or rule bases may be overkill in an arcade-where customer throughput needs to be high-but in scientific visualization, emerging technologies will truly afford us an exciting future.

Scott Stevens is a senior member of the technical staff of the Software Engineering Institute and an adjunct senior research scientist in the Center for Design of Educational Computing at Carnegie Mellon University. The Software Engineering Institute is funded by the Department of Defense.

Bibliography

Josef Albers. *The Interaction of Color.* Yale University Press, New Haven, 1963.

Dudley Andrew. *The Major Film Theories* Oxford University Press, London, 1976.

Michael G. Christel. *A Comparative Study* ofDigital *Video Interactive Interfaces in the Delivery* of*a Code Inspection Course.* Doctoral dissertation, Georgia Institute of Technology, June 1991.

Thomas W. Malone. "Toward a Theory of Intrinsically Motivating Instruction." *Cognitive Science,* Vol.4, 1981, pp. 333-369.

Scott M. Stevens. "Intelligent Interactive Video Simulation of a Code Inspection," *Communications of the ACM,* Vol. 32, No. 7, July 1989.

Rob Wolff Tom Volotta. "Mars Navigator: An Interactive, Multimedia Exploration of the Red Planet." *Computer Graphics, Vol.* 24, No. 3, July 1991, pp. 145-146.