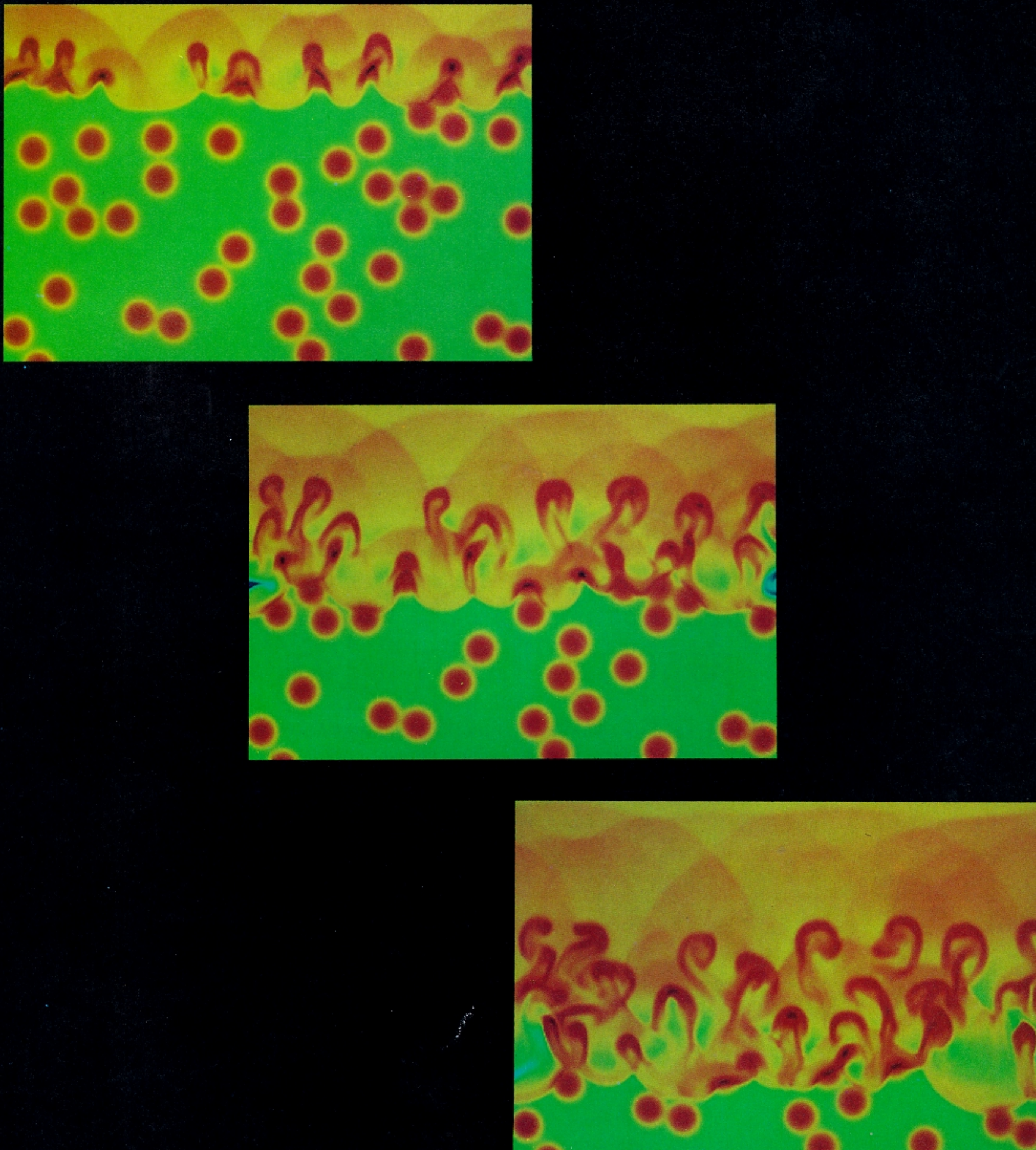


Numerical Simulation of Shock Propagation Through Interstellar Space

This time sequence shows how a shock wave progresses through a gas of non-uniform density, as found in interstellar space. Different density values are assigned different colors—high densities are indicated by red and low by chartreuse. The undisturbed medium consists of spherical regions of high density in a uniform background. Modeled numerically, the chaotic swirling patterns are the result of the shock wave's interaction with the dense clumps. Gas dynamical processes, such as those shown here, occur in a wide range of practical situations, like air flow over airplanes and gas flow in jet engines. This calculation was performed on a Cray X/MP with Zeus Code developed by Michael L. Norman, at the National Center for Supercomputing Applications, the University of Illinois, Urbana-Champaign. Zeus is a two-dimensional Eulerian gas dynamics code, which Norman is now applying to a variety of astrophysics problems.

THE ART AND SCIENCE OF VISUALIZING DATA

"I manipulate the laser," the artist said, having exploited laboratory equipment. "This is a parallel pipeline systolic SIMD engine we call the 'Jell-O Engine,'" the animator/straight man announced, but not until he had decimated the practice of ray tracing. And officials from supercomputer centers declared the visualization of scientific data would define a new field, a revolutionary way of doing science.

KAREN A. FRENKEL

The dancer slithered in front of a laser so that the beam writhed. An animator hilariously spoofed scientific papers. And there was the urgent drive for ways to visualize scientific information. Would Hollywood's special-effects people and laboratory scientists countrywide meet and share techniques? Would the right brain triumph over the left? At a late-night, bicoastal bash, a man told a woman, "Hey, like, you look like you're from New York," and then came the crisp counter, "You look like you're from L.A." People were consumed by images. This was SIGGRAPH 87—colorful, captivating, and abounding with curiosa—where, as one participant joked, "the hair gets shorter as the technology gets faster."

The range of themes at SIGGRAPH 87 (held in July in Anaheim, California) was broad, yet there was a confluence of ideas. Scientists, animators, and graphics and image processing experts acknowledged needing each other in order to advance their fields. But there was also divisiveness, as some participants suggested that SIGGRAPH splinter off into sub-SIGs for each group mentioned. With 30,000 participants, the conference seemed unwieldy, and some resented the push for visualization of scientific data. A facilities manager said that group was intruding and trying to tell the graphics community how to do its job better. Others said they had been presenting data graphically for years, but just did not have a name for it.

The "visualization of scientific data" theme rippled through many panels and technical sessions. Much of the Coons Award speech by Donald P. Greenberg (see p. 122 of this issue) was devoted to it, as was a well-planned, even carefully staged press conference, during which a National Science Foundation graphics panel report "Visualization in Scientific Computing" was released [1].

While scientists claimed they were stymied for lack of supercomputer graphics capabilities, one computer scientist decreed a paradigm shift for graphics modeling. Tilting away from the "kinematics of motion" that have so far characterized the fantastical effects of much animation, the paradigm leans toward embedding the laws of physics in hardware. Not merely catching up with Newtonian dynamics, such "physically based modeling" calculates forces on an object due to its motion. The goal of using such inverse dynamics and also dynamic constraints would ultimately be to make modeling easier. (See "Physically Based Modeling *vs* 'Faking It,'" p. 116.)

Besides creating controversy within the graphics community, these calls for action raise questions for computer science: What impact will these calls, if answered, have on computer science? Will hardware and software be advanced? Along with the challenges of rendering two- and three-dimensional surfaces, the NSF report cited an emerging domain—*volume visualization*—the presentation of not just surface data so that it looks three dimensional, but of interior points in a structure. This new field is expected to require new languages and operating systems—entirely different computing environments. But generally, answers offered remain thin, and perhaps it is still too early to say just what the impact will be.

SIGGRAPH's Film and Video Show, courses, and

Curtains float off a rod and onto nearby furniture.

FIGURE 1. Fabricated Rhythm

papers on technical advances reflected the ricochet between the arts and sciences, and suggested applications as themes as well. One film sequence showing progress in modeling deformable materials depicted a pair of curtains floating off a rod and onto nearby furniture (Figure 1). To achieve this effect, the researcher incorporated algorithms taking into account such physical properties as gravity and mass on points of a mesh representing the cloth. Elasticity and stiffness described characteristics of the cloth itself, an application that may be important to the fashion industry. Another researcher's work showed facial expressions, an area that has been coming to fruition over several years. On a huge screen, computer-generated smiles, grimaces, dropped jaws, and bulging eyes confronted the audience (Figure 2). These animations were based on models of muscles that either pulled or squeezed to create the deformable topologies of faces. Progress in facial muscle modeling could facilitate teaching lipreading to the hearing-impaired, and help determine preoperatively the mobility that would remain after facial surgery, for example. And artificial intelligence had its day, when one researcher showed a video of flocks of birds whose positions were generated by rules. The computer program, not the animator, therefore determined where each bird ought to be in each frame.

VISUALIZATION OF SCIENTIFIC DATA

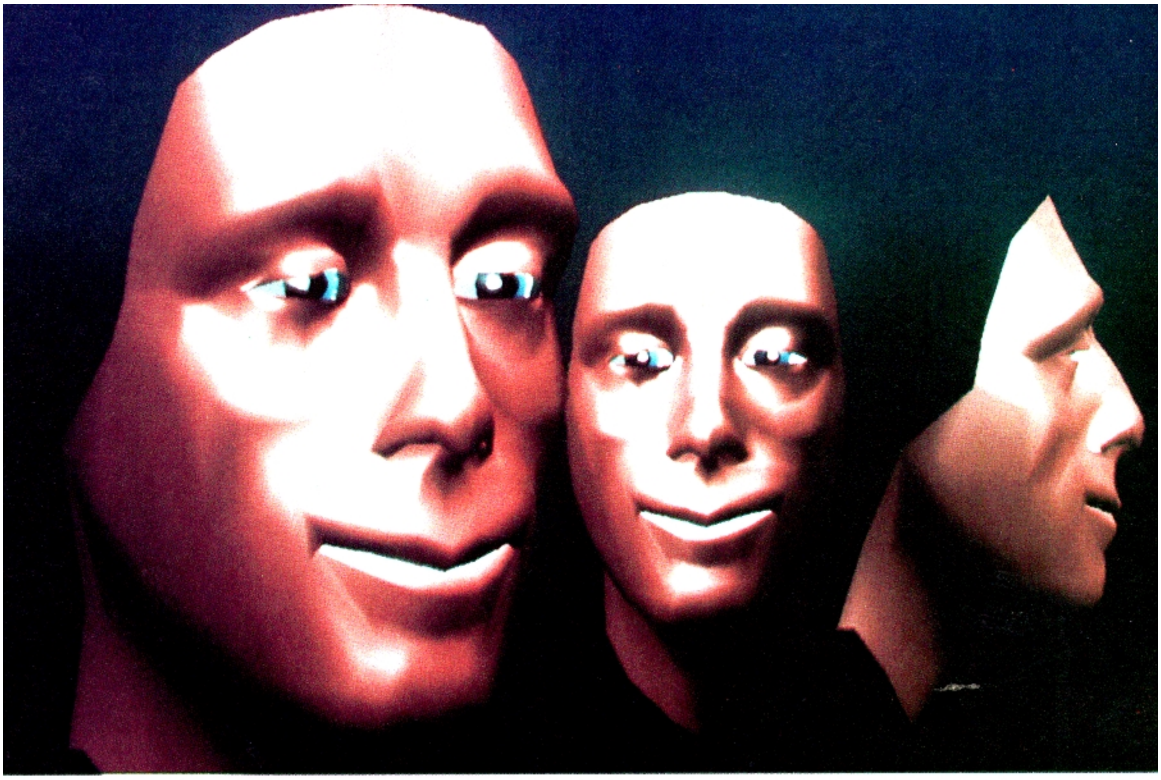
The July 1987 report "Visualization in Scientific Computing" was edited by Bruce H. McCormick, of Texas A&M University, and Thomas A. DeFanti and Maxine D. Brown, both of the University of Illinois, Chicago. All are members of an advisory panel on Computer Graphics, Image Processing and Workstations. Too lengthy to summarize here, we present the report's Executive Summary (see p. 121) and refer readers to SIGGRAPH's November 1987 newsletter, *Computer Graphics*, a special issue in which the report appears in its entirety. An accompanying videotape, which is a special edition of *SIGGRAPH Video Review*, is also available [2].

The report's presentation, complete with a catchy acronym, "ViSC," and the urgent tone at the press conference, prompted some to wonder why the hard sell? Why were members of SIGGRAPH, an organization known for its robustness during the recent computer industry slump, crying out for money now? Rumor has it that when the NSF supercomputer centers were formed, graphics tools were included in their budgets initially, but ultimately were not acknowledged. And that later, the NSF felt the demand for graphics and image processing tools from the centers' users. NSF scientists thought they had accomplished their goal since their mandate is to fund the *sciences*, which may or may not include computer science or computer graphics. Needing to know more, they established the graphics panel. In effect, a panel of computer scientists represented one scientific community to another. Lawrence E. Brandt, NSF Associate Program Manager for Supercomputer Centers, says the confluence of technology in advanced workstations and proliferation of supercomputer cycles are some of the reasons for the ripe climate for visualization. He also credits NSF-funded projects done on a Cray at Digital Productions, a now defunct special effects house, with exposing the benefits of visualization. "Between '84 and '85 (just as the centers were getting started) the NSF met all proposals, about 6 to 12. Before that, what you could do with visualization was not well-known," he says. Pointing out that research has never been an industry, Brown says, "Scientists do not constitute a market. [They] don't have big bucks. They get them from funding agencies to purchase equipment. And the commercial market area is not going to develop equipment for the scientists. The commercial area, [which accounts for] SIGGRAPH's growth, sells business and CAD/CAM graphics. Those are the two largest areas in graphics—that's where the money is—it's not science." There is also concern that the Japanese will recognize and usurp the workstation market. Laurin Herr, an analyst with Pacific Interface, New York, New York, cautions, "In '83 we saw the first wave of Japanese vendors, but they were second tier vendors." Although they did not penetrate the U.S. market then, they are now a threat and Japanese devices are already inside our workstations, he says.

The editors and panel members take care to point out that although the supercomputer centers were the impetus for the report, they are by no means the only reason for the visualization initiative. McCormick explains that the panel was formed to answer questions "precipitated by supercomputers" as they yielded numerical printouts that were inadequate for three-dimensional jobs. "But visualization is an immensely larger field than supercomputing and always will be," he says. Asked whether it was a way to fund graphics for parallel processors, some of which are supercomputers, McCormick says, "The visualization problem is not peculiar to supercomputers in any sense. In fact, I don't expect the bulk of [the visualization initiative] to be tied to them. Supercomputers are in many ways dinosaurs, a dying breed." Their costs indicate that that market will not be very significant within the computer market, he says, adding, "Basically, it supports one-and-a-half firms." The workstation market is much larger, and eventually number crunching and modeling will be delegated between supercomputers and workstations, McCormick predicts. Parallel processing will find its way into minisupercomputers, and "as more and more firepower" is needed, McCormick says, they will also serve as local graphics and image processing machines.

LOOKING AT SCIENTIFIC DATA TODAY

But right now, "Computing, and in particular supercomputing, without visualization, is like assembling a jigsaw puzzle in the dark," says Richard Weinberg, a



Simulated muscles and features yield facial expressions.

FIGURE 2. Happiness

computer science professor at the University of Southern California, Los Angeles. "If you can't see what you're doing, you're very likely to wind up with the wrong picture." Scientists say they are working with antiquated tools. Craig Upson, a research scientist in visualization at the National Supercomputer Center for Applications (NCSA), Urbana-Champaign, Illinois, says, "The graphics tools that scientists have are archaic—they date from the 1960s. It's one of the areas in high tech that has remained stagnant, so the state of the art for the masses in scientific animation is still vector graphics." Meanwhile, some scientists write their own application-specific software, an inadequate solution since others cannot benefit from the customized results, says Michael Keeler, manager of the San Diego Supercomputer Center's Graphics Animation Project.

Despite these hindrances, scientific data are being visualized with success, albeit with a great deal of effort. To simulate the evolution of a thunderstorm, for example, Robert Wilhelmson, professor of meteorology at the University of Illinois, is using the Cray X-MP at NCSA. For a decade, he and colleague Joseph Klemp have been refining software for a model based on flow equations that describe thunderstorm dynamics. Thunderstorms involve huge amounts of data—they are generally 30 km across, and formations within, like tornadoes, are 0.5 km. Past simulations of surfaces of storm structures on a Cray 1 were limited by a horizontal resolution of 1 km, which is too coarse for studying gusts and tornadoes. "The constraint is not in the equations. It's in the computing power and memory needed," says Wilhelmson. By using the Cray X-MP, he has improved horizontal and vertical resolutions by almost a factor of four to reveal some internal formations (Figure 3). Updrafts and horizontal shear appear, but tornadoes remain elusive.

Another project, in cerebral cartography, is yielding insight into Alzheimer's disease, as two neurobiologists and two pathologists collaborate in visualizing brain tissue. In the effort to explore outer and inner surfaces of neuronal structures, Mark Ellisman, professor of neurosciences, and Steven Young, Department of Psychiatry, both at the Univerity of California, San Diego, obtain slices of biopsy samples taken by pathologists Suzanne Mirra and Robert Terry, of the Emory University School of Medicine. These are studied under the high-voltage electron microscope at the University of Colorado, Boulder. Next, the images are digitized by manually tracing contour lines. Finally, entire neurons are reconstructed from "stacks" of 100 levels of contours. At first Young ran his specially created program (developed at Boulder) on a PC, but the team turned to a Cray X-MP in order to see surfaces across gaps between contour slices (Figure 4). The researchers are classifying these structures and the progression of changes in them as cells die, with the hope that a better understanding of this sequence will lead to the causes of degeneration.

If visualization is more than just the supercomputer user's problem, one might expect scientists using PCs to act as Elissman and Young did. Just the opposite is true, says Robert S. Wolff, a space physicist at Jet Propulsion Laboratory in Pasadena, California. Scientists in laboratories have a desktop orientation that he calls the "John Wayne approach to computing." When analyzing data ported from a Cray, their attitude is "'If I can't visualize data on my IBM PC, then it's not worth doing,'" Wolff complains. "That's just as ludicrous as saying 'Let me visualize 100 Gbytes of data on my PC' and 'Let me generate 100 Gbytes on my PC.'" A simulation that might take 24 hours on a Cray is equivalent to 240,000 hours on a PC, which is roughly equivalent to 80 years of 8 hour days, he calculates. Such resistance causes the data that these scientists are generating to go to waste, says Wolff.

THE MAINFRAME *vs* WORKSTATION MENTALITY

The balance of processing between a supercomputer and connected workstations and the connection itself is a matter for debate. At a panel, "Supercomputer Graphics," Donald P. Greenberg, professor of computer graphics at Cornell University, announced, "I am a bigot. I believe the future of visualization is going to depend on high-powered workstations, which are connected over high bandwidths to supercomputers." Unless software development and bandwidth transmission speeds are a priority for bringing visualization processes into scientists' laboratories, he believes, "we will miss the boat." "We should off-load all graphics onto workstations because it's the wave of the future," he said, adding that workstations provide linpacks two to three orders of magnitude cheaper than large-scale mainframes. Mainframe cycles should therefore not be wasted, and all graphics done locally. "We should be transmitting object data instead of image data," he said. Now, scientists are batch processing—they preprocess models and look at the results two weeks later. So that scientists can monitor simulations while they are occurring, "we have to change analysis techniques, change finite element grids, change parameters, or even change problem definitions. That's what will make supercomputer centers more cost-effective," he concluded.

"I am a bigot. I believe the future of visualization is going to depend on high-powered workstations, which are connected over high bandwidths to supercomputers."

Donald P. Greenberg

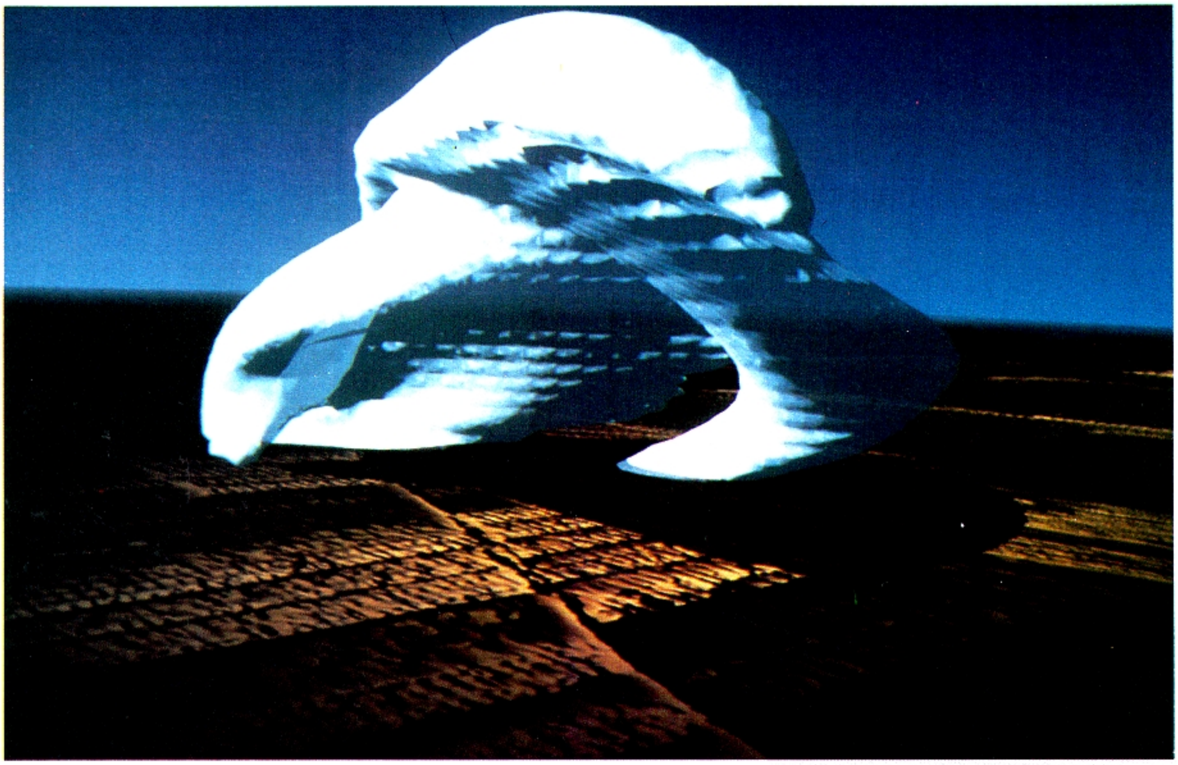


FIGURE 3. Simulation of a Tornadic Storm Development

Temperature and moisture structures of the atmosphere during a storm formation on May 20, 1977 in Del City, Oklahoma are the real data. To trigger the storm, data of a small artificial cumulus cloud were added.

FIGURE 4. Volume Visualization of a Neuron

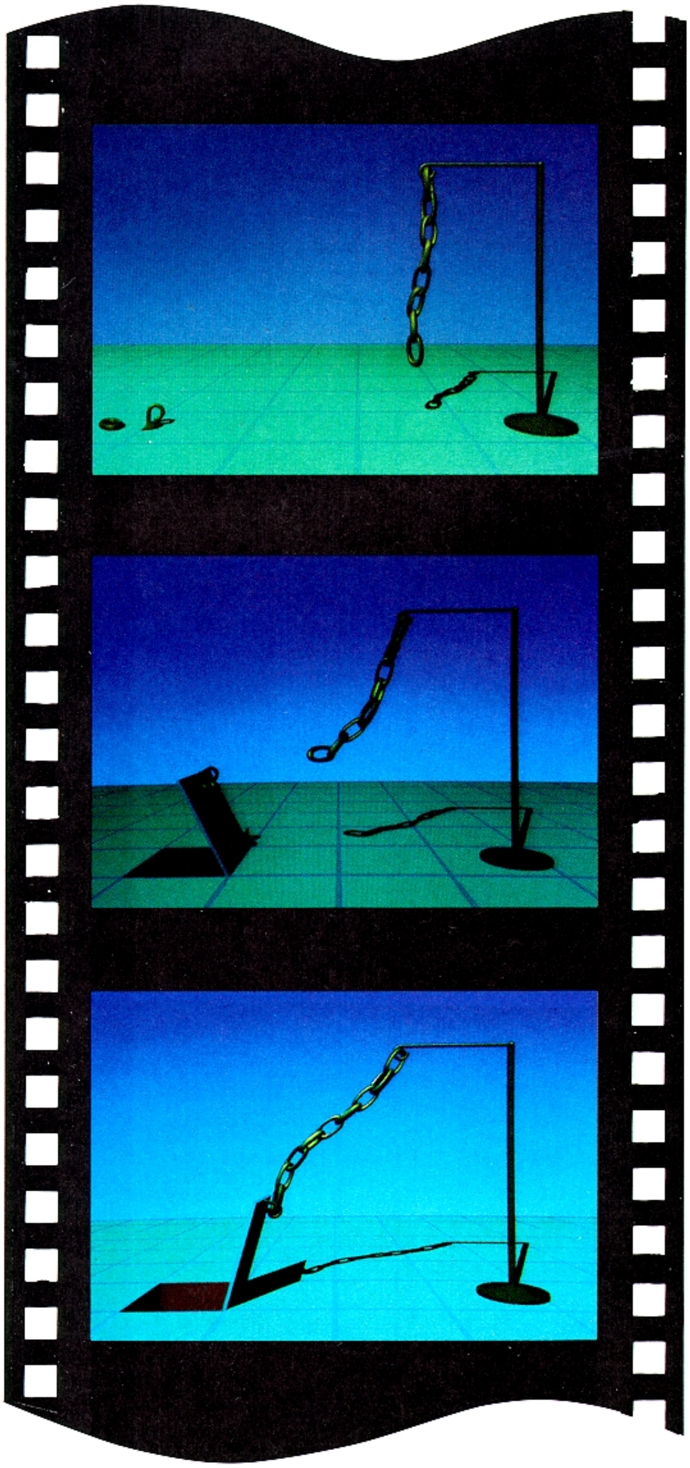
Yielding clues into the causes of Alzheimer's disease, this neuron's surface membrane was rendered using polygons to connect the slices. Surfaces of interior structures, whose distribution in the cell is also being studied, can be rendered similarly.

Physically Based Modeling *vs* "Faking It"

One of the highlights of SIGGRAPH '87 was the panel debate on the "Physical Simulation and Visual Representation of Natural Phenomena." The forum pitted graphics experts who see the technology as an effective tool for scientists against those who quench Hollywood's thirst for special effects. The principal players were Alan H. Barr, assistant professor of computer science at the California Institute of Technology, Pasadena, and William T. Reeves of Pixar's Animation R&D group, in San Rafael, California.

If modeling were an easy process, we would not put this teapot on a pedestal . . .

Alan H. Barr



Pandora's Chain

Barr delineated the elusive search for realism and announced a new paradigm for graphics modeling—"physically based modeling." Realism, he said, involves rendering the interaction of light with matter, modeling static shapes, as well as making objects move. But computer graphics is at a point in its history analogous to the early days of audio, when Thomas Edison played his first scratchy recording and was told, "Oh, that sounds like the real thing," Barr said. Similarly, upon finishing his or her work, the graphics expert often hears statements like, "Oh, that's a nice computer picture of a tree." But, "if modeling were an easy process, we would not put this teapot on a pedestal," Barr quipped, referring to the 13-year-old model of a teapot created by Martin Newell. Because modeling is quite difficult, people use old models over and over again to create different images.

Until now, motion has seemed fantastical because animators have followed rules antithetical to nature, Barr said. Three tenets previously adhered to describe what Barr calls the "kinematics of motion:"

Rule 1. An object at rest stays at rest irrespective of any force that may act on an object.

Rule 2. An object will move only under the influence of an interpolation spline.

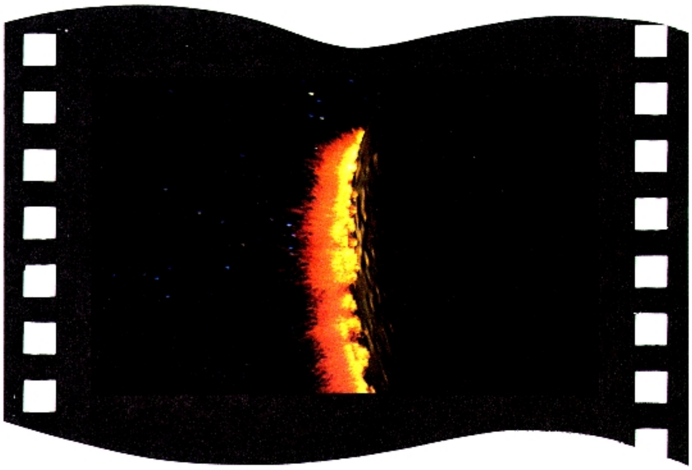
Rule 3. For any action, there is no reaction, whatsoever.

Yet, if these rules are so bad, Barr asked, why do we use them? And, in fact, they have not served animators ill. The problem is that animators have to specify all the action and all the details.

To achieve realistic motion, geometric constraints between objects must be maintained, and the object must move in accordance with Newtonian physics, Barr says. But this does not mean that the computer graphics community is now merely moving from the classic Greek solids to the 17th century and discovering freshman physics, Barr said. In a physical simulation, objects interact as they will, from which we derive forces of interaction, Barr explains. But there is another causal layer—"a teleological layer." In this new approach, "We wish the objects to interact in a particular manner, and we calculate the forces that would, and finally do, achieve the desired effect." In

Pandora's Chain, one example of such inverse dynamics, the goal was to connect the links, calculate the forces that the chain *would* exert in order to lift a trapdoor, and *then* connect it to the chain (left). The methods that make the chain snap together in the video pave the way for studying the self-assembly of molecular structures and planning robotic assembly lines, for example. In general, such a computational environment will make modeling easier, Barr says. Eventually it would exist in hardware since the software implementations now are too slow.

Representing those in special effects, Reeves took exception to Barr's suggestion to move beyond the Greek aesthetic. We shouldn't ignore what is simple, he noted, since solving the physics of some phenomena can lead to complexities that no computer is capable of handling. To illustrate the enormity of past projects, he noted that the code for the fire in *Star Trek II: The Wrath of Khan* (right) took three person-months to write, two more to refine, and four hours per frame to compute. Physical simulation yields correct results, but you risk falling into a "computational black hole," he said. "You can dump cycles in, and you'll get your answer someday," but there are deadlines to meet. One way to avoid the chasm, he suggested, is to use a model as long as is practical. To create the waves in *Flags and Waves* (right), for example, Reeves began with ocean wave models, but did not go as far as oceanographers might by looking at the behavior of individual particles. His motto is, use a model to the point where it is computationally practical and approaches the desired visual effect. Then, if necessary, augment the results by filling in detail using stochastic or texture map processes that have nothing to do with the reality. "You do what you can, and then fake it," he said. "That's nothing to be ashamed of. I enjoy fooling you." Just don't get caught, he cautioned colleagues. Concentrate on the visual aspects that the audience will be watching. You can fake the background if the audience is distracted by the foreground.



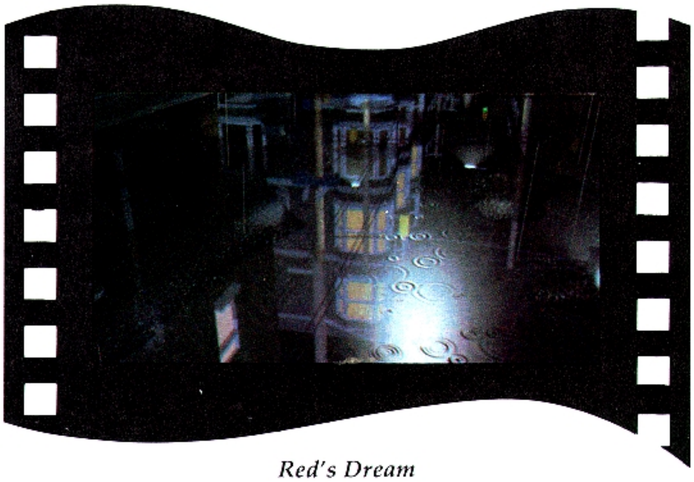
Star Trek II, The Wrath of Khan, **Genesis**

You do what you can, and then fake it. That's nothing to be ashamed of. I enjoy fooling you . . .

William T. Reeves

Flags and Waves

Sometimes, models do not exist or cannot be found in the literature, Reeves added. Occasionally, models can lead to false assumptions; for example, weather data usually do not address the color of a pixel in a cloud, and so that must be inferred. Sometimes, accuracy is not effective; code for the rain in *Red's Dream* (right) was the most faked, looked the most realistic, and took only one person-month to write, one to refine, and only 25 minutes per frame to compute, he said. And, sometimes, as in caricature, you just don't want accuracy, Reeves said. "There's something that an animator does that no differential equation will ever do." Nevertheless, he said, the way to bring the entertainment industry and science community together is for people to sit across the table and talk.



Red's Dream

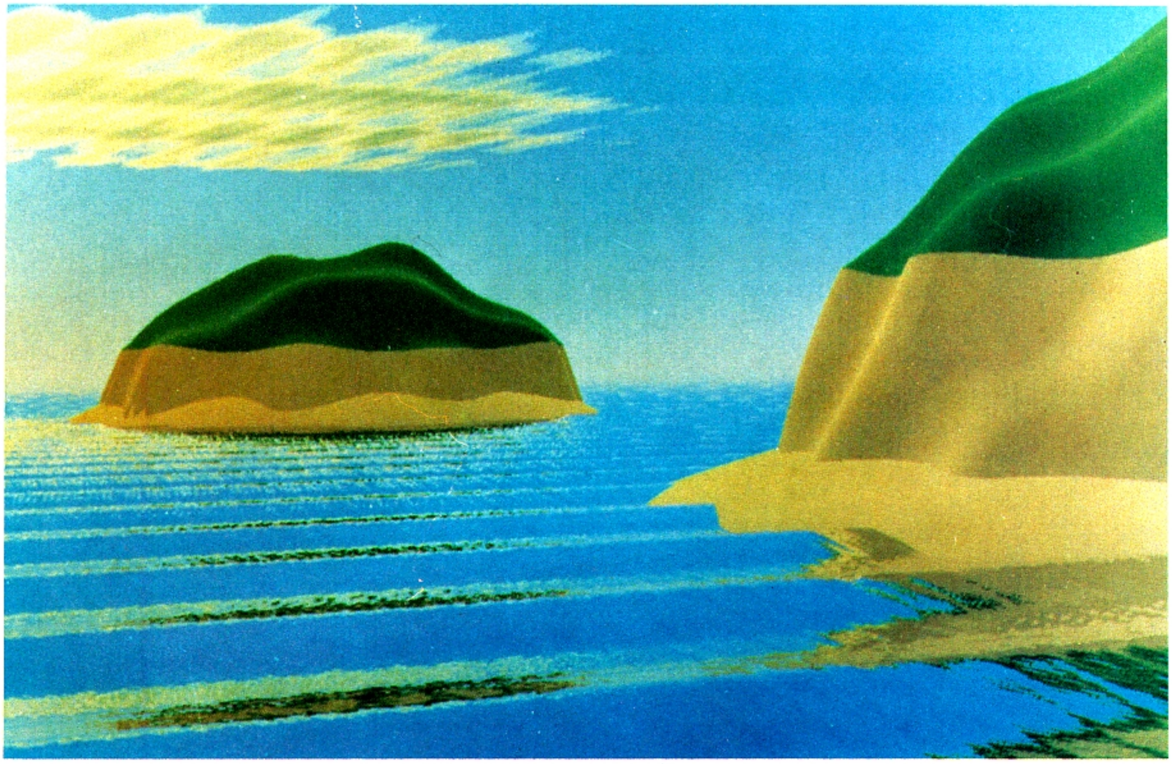
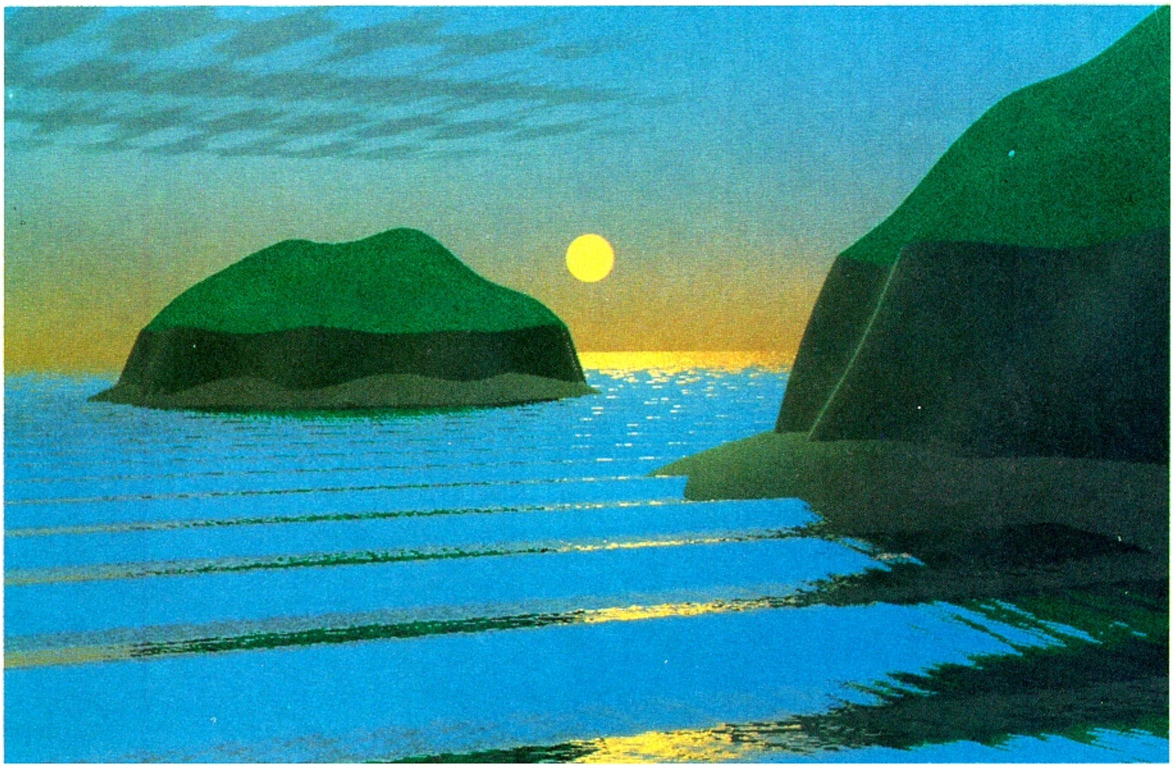


FIGURE 5. Carla's Island, Daytime and Dusk

Only 256 colors per frame (normally there are 2^{24}) appear in these stills. Forty horizontal bands of colors for the sky gradually change according to translation tables that assign colors to these bands. This results in changing midday sky colors to sunset colors. The same 40 colors were used for rays reflected from the ocean to the sky, so water colors changed accordingly.



Nelson Max, a computer scientist at Lawrence Livermore National Laboratory, Livermore, California, disagreed on the matter of down-loading all graphics to workstations. "As an algorithm developer, I cannot use a workstation that has specific rendering algorithms already built into it," he said. "I want to create new algorithms, and to do this, I need a general-purpose computer rather than specialized hardware to speed up old algorithms." He wants to do computation on a supercomputer, but cites I/O bandwidth as the main hindrance. Max described several tricks for using a supercomputer effectively while competing with other users for time. In 1981, to make his film, *Carla's Island*, which shows a sun rising and setting beyond ocean waves, a Cray 1 ray traced every pixel (Figure 5). To use as little memory as possible, however, Max kept his data arrays small by ray tracing only pixels on one vertical scan line at a time. He also reshuffled arithmetic to achieve vectorization—the calculation for a ray's reflection due to a wave, for example, was vectorized for all rays in a vertical scan line. Max also took advantage of the film's periodic theme by processing only one cycle of the wave motion on the Cray. He also economized by using a minicomputer and film recorder to assign less than the usual color choices. So, if motivated because of competition, supercomputer users can be frugal. Acknowledging that he is not the typical Livermore user, Max described the needs of those working on nuclear weapons simulations. "They want a movie in the morning," he said, "They run the simulation over night, and then they want to see animation of the results the next day." As matters stand now, the quickest turnaround is 48 hours—after data are crunched for 24 hours, the film of the simulation can be processed overnight.

Objecting to Greenberg's conviction that sending raw data to workstations is the way to go, Larry Yaeger said, "The raw data of 3-D information are more of a problem to transmit than when they're in graphics form." The I/O problem persists, and just as Max indicated, "You [end up with] an I/O problem in order to save supercomputer time," Yaeger said. Formerly with Digital Productions and now working for Apple Computer, in Cupertino, California, Yaeger described the enormity of special-effects jobs like the planet Jupiter in the movie *2010*. Keeping in mind the cost constraint of two minutes of Cray time per frame and the fact that film moves at 24 frames per second, Yaeger noted that for a typical application you would require 65 MFLOPS sustained, assuming 500 operations per pixel-color and a resolution of 2,560 by 2,048. As even well-vectorized applications tend to average more like 24 MFLOPS sustained, it is clear that vectorizable code cannot always take advantage of the Cray's peak rate of 300 MFLOPS per processor, he said. For Jupiter, he said, "We pushed 5 to 10 million particles around [each frame]. You can't remotely approach this on a workstation." Although massively parallel neural networks are his current area of investigation, and parallel architectures are promising for improving the speed of workstations, Yaeger said that Amdahl's Law still holds.

The best way to visualize data interactively is a religious matter rather than one of prejudice for Gray Lorig of Cray Research, in Minneapolis, Minnesota. He says the claim that the Cray is a batch machine no longer applies. "Cray's operating system is being superseded by UNIX®," he says, "so the batch argument can no longer be made." The originator of Oasis, Cray's graphics package, Lorig explains that the software was designed to be interactive in some, but not all, respects. "Once you have the data, you can look closely at it," he says. "The rendering process is not interactive. Modeling is." Oasis was designed with the expectation that simulation data would be rendered by the supercomputer, modeling—meaning integrating the simulation data into a scene—would be done on a workstation, the supercomputer would then calculate the images per frame, and finally that would be sent back down to the workstation to create raster images. Oasis has been on the market for two years and has 20 users. Cray is working on both increasing bandwidth and ways to further distribute processing.

ETA Systems, in St. Paul, Minnesota, a subsidiary of Control Data Corporation, has also been tackling the supercomputer-workstation problem. "Users are screaming for graphics," says Steve L. Telleen, manager of Applications Technical Marketing. "But how do you deliver that cost-effectively? There are no standards for super high-speed bandwidths, and you can get boxed in by that." As he sees it, both the bandwidth and work-

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Nelson Max

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"[Those in AI] loved the left side of the brain, and [those in graphics] loved the right. And what we've done is fund the left, but not the right."

Bruce H. McCormick

station solutions are problematic. Bandwidth demands can be insatiable—increasing bandwidth will make users crave Gbit throughput, which no one has yet, Telleen says. And once they get that, they will want higher resolution. In the meantime, this solution is best applied to coarse animations. One way to "do it smarter" is to generate an image partly on the supercomputer and do the rotations on the workstation. Another way is to down-load an image onto the workstation. Although it takes a while to paint the first time, as changes are made in the simulation on the supercomputer, only those changes are sent down, he explains. The drawback here is that workstation code can become so complicated that images dribble across the screen. Of the standards so far, Telleen believes PHIGS (Programmer's Hierarchical Interactive Graphics System) is most amenable to such distributed processing, which will make supercomputer graphics cheaper.

A BATTLE FOR FUNDING?

Since its release, the visualization report has been interpreted in too "narrow a sense" by DARPA, as a supercomputer and scientific computation matter, according to McCormick. A key issue for him is the "enormous imbalance" he perceives in government funding of visualization and AI research. Indeed, rivalry causes other computer scientists in graphics to dub AI as "artificial stupidity" and they refer to the "rock star quality" of AI researchers. Projects like the autonomous vehicle, which was supposed to be sufficiently intelligent without a human in the loop, have not panned out, McCormick says. In contrast, having a person in the loop is just what visualization is concerned with. Although DARPA has always supported computervision image analysis, and many graphics researchers were trained at DARPA-funded projects at the University of Utah, the government decided that graphics was not respectable on the basis of cultural tastes, McCormick charges. Those in AI are verbal—they "like strings and formal language"—whereas those in computer graphics love imagery. "One [group] loved the left side of the brain, and one loved the right," he says, "and what we've done is fund the left, but not the right." What about the robotics vision people? This group is presenting its work less and less at AI conferences, he says, and machine vision has never been happy under the AI label. But "there is coupling," he acknowledges, "particularly in object-oriented programming styles, but it's not central." DARPA's Robert Rosenberg says that all projects compete with one another for funding and there is "no graphics for the sake of graphics." Funds might be granted to a mathematician who needs graphics, for example, and that work might be thought of as "good research in mathematics," he explains.

McCormick does, however, see a cultural shift toward visual information, as exemplified by CT scans for medical diagnoses, currently the most common application for volume visualization. And, at a workshop last spring, representatives from the National Institutes of Health, the Central Intelligence Agency, the Department of Defense, the Defense Mapping Agency (DMA), and NASA expressed interest. This year NIH has allocated several million dollars for graphics research. Other agencies are asking how they can use graphics. The DMA's interest is in detailed topological simulations so that flyers can train on 3-D rather than 2-D maps. The CIA, on the other hand, would like to incorporate graphics into database management. A representative from the National Library of Medicine raised questions about trust, however, wondering about verification of data under circumstances where things can be made to appear and disappear so easily. Brown replies that this is an ethical problem not specific to graphics; "You can lie with statistics," she says.

REALITY AND ILLUSION

And then there is the problem of illusions, points out Robert Parslow, senior lecturer in computer graphics at Brunel University and president of New Management Strategies in England. In its effort to produce realism by accurate presentations using depth clues, computer graphics is mistakenly assuming that these clues are sufficient for correct pictures of reality, he says. In his study of 2,000 subjects, 96 percent were unable to visualize simple 3-D objects, he reports. These "victims of spatial illusion, or 3-D blindness," failed at such exercises as the spinning cube. If spinning while hanging from one corner, a wire frame cube will suddenly seem to reverse directions when viewed from 3 m away. The illusion can be maintained by moving closer and shutting one eye. Next, the cube seems to distort, so that a near face appears expanded and distant while a far face apparently shrinks and comes close. Parslow found some variation of spatial ability among his sample: "Of 110 APL programmers, 80 percent showed 3-D blindness, and the best performance groups consisted of CAD workers, over 30 percent of whom were capable of visualization. This means that nearly 70 percent of this group, whose main work is in 3-D design, are 3-D blind!" he wrote in "A New Direction for Computer Graphics" [3].

Given such illusions, long familiar to those in the field of visual perception, Parslow asks, "Why try to get an accurate picture when we don't see reality right?" If we successfully get data on the screen, he says, we will see illusions. And programmers have already produced faulty algorithms based on a false 3-D view, he says. Insofar as he emphasizes visual retraining because of the danger of illusions, Parslow goes further than the NSF report. The report does call for a "major educational reform on two fronts," but it is not very specific about training: visualization technologies must be used by both tool makers and users, and computational scientists must have access to such technology and learn to think visually. But generally, the consensus is that to "teach people to see," we must learn from those in the fine arts. As Parslow puts it, "If we listen to artists, then we can go into a new phase with our pictures."

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This issue's cover and **Figure 2** appear in *Computer Graphics 21*, 4, (July 1987).
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Carla's Island, by Nelson Max, Lawrence Livermore National Laboratory.

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Executive Summary: Panel Report on Visualization in Scientific Computing*

Visualization in Scientific Computing (ViSC) is emerging as a major computer-based field, with a body of problems, a commonality of tools and terminology, boundaries, and a cohort of trained personnel. As a tool for applying computers to science, it offers a way to see the unseen. As a technology, Visualization in Scientific Computing promises radical improvements in the human/computer interface and may make human-in-the-loop problems approachable.

Visualization in Scientific Computing can bring enormous leverage to bear on scientific productivity and the potential for major scientific breakthroughs, at a level of influence comparable to that of the supercomputers themselves. It can bring advanced methods into technologically intensive industries and promote the effectiveness of the American scientific and engineering communities. Major advances in Visualization in Scientific Computing and effective national diffusion of its technologies will drive techniques for understanding how models evolve computationally, for tightening design cycles, integrating hardware and software tools, and standardizing user interfaces.

Visualization in Scientific Computing will also provide techniques for exploring an important class of computational science problems, relying on cognitive pattern recognition or human-in-the-loop decision making. New methods may include guiding simulations interactively and charting their parameter space graphically in real time. Significantly more complexity can be comprehended through Visualization in Scientific Computing techniques than through classical ones.

The university/industrial research and development cycle is found to be inadequate for Visualization in Scientific Computing. The programs and facilities are not in place for researchers to identify and address problems far enough in advance, even though the emerging discipline of Visualization in Scientific Computing is found to be critically important to a portion of the country's domestic and export trade threatened by foreign competition. At the present rate of growth, the capabilities of networks, displays, and storage systems will not be adequate for the demands Visualization in Scientific Computing will place on them.

The gigabit bandwidth of the eye/visual cortex system permits much faster perception of geometric and spatial relationships than any other mode, making the power of supercomputers more accessible. Users from industry, universities, medicine and government are largely unable to comprehend or influence the "fire hoses" of data, produced by contemporary sources such as supercomputers and satellites, because of inadequate Visualization in Scientific Computing tools. The current allocation of resources at the national supercomputer centers is considered unbalanced against visualization, in competition with demands for more memory and disks, faster machines, faster networks, and so forth, although all need to be improved.

The Panel recommends a new initiative in Visualization in Scientific Computing, to get visualization tools into "the hands and minds" of scientists. Scientists and engineers would team up with visualization researchers in order to solve graphics, image processing, human/computer interface, or representational problems grounded in the needs and methods of an explicit discipline. The expectation is that visualization tools solving hard, driving problems in one computational science would be portable to problems in another. Proposals would be peer reviewed, and awarded for both facilities and projects at national supercomputer centers and elsewhere. Other agencies of government are encouraged to recognize the value of Visualization in Scientific Computing in their missions and support its development accordingly.

* Executive Summary reprinted from Ref. [1].

FRONTISPIECE. A Simulated Steel Mill

This image was created using a modified version of the hemi-cube radiosity algorithm, computed on a DEC VAX 8700 and displayed on a Hewlett-Packard Renaissance Display. The environment consists of about 55,000 elements and is one of the most complex environments computed to date. To reduce the calculations, the improved algorithm concentrates its effort on the surfaces emitting or reflecting the greatest radiosities. The image demonstrates that the radiosity approach can be extended to complicated scenes (produced by Stuart Feldman and John Wallace, of the Cornell Program of Computer Graphics).