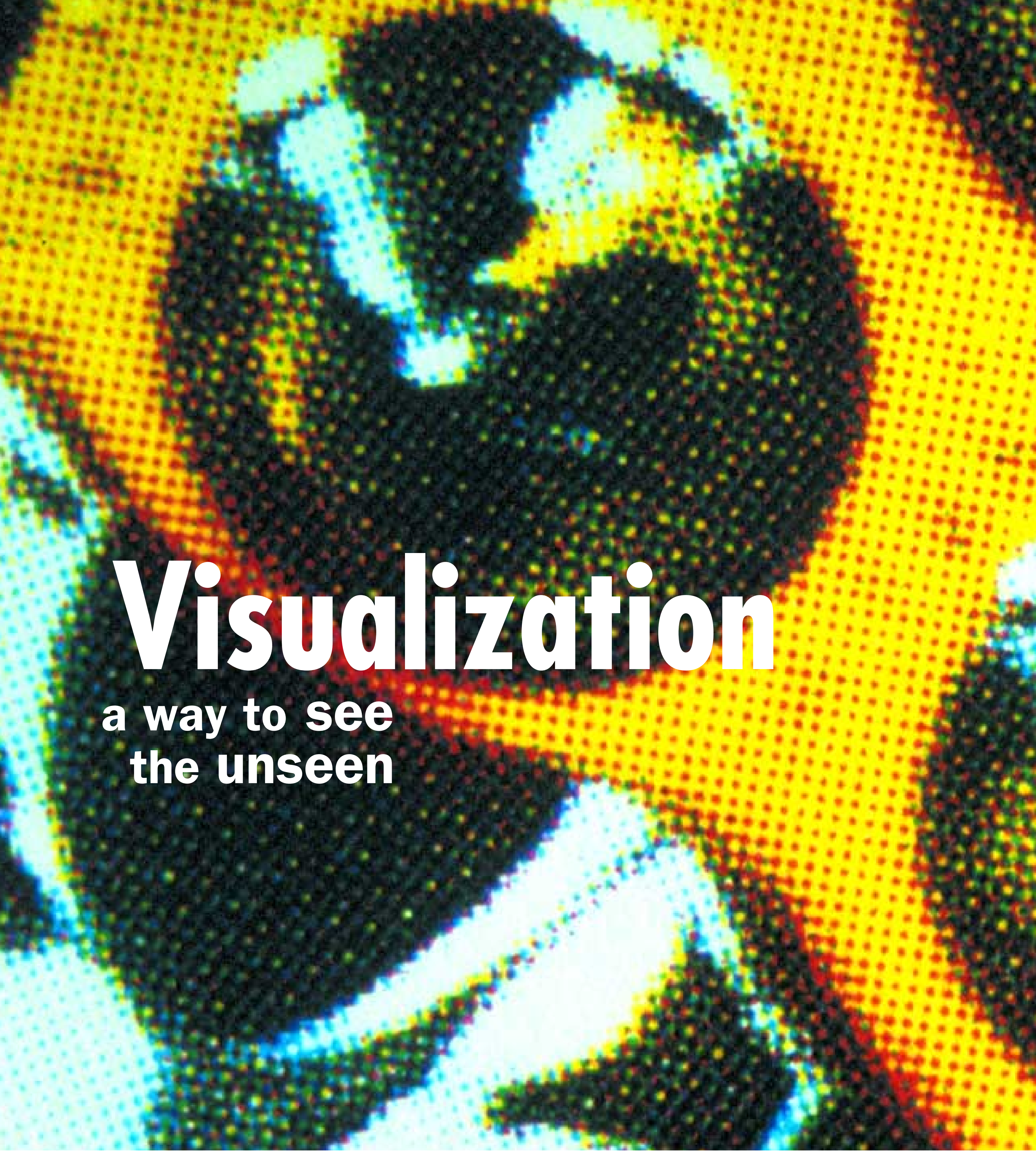
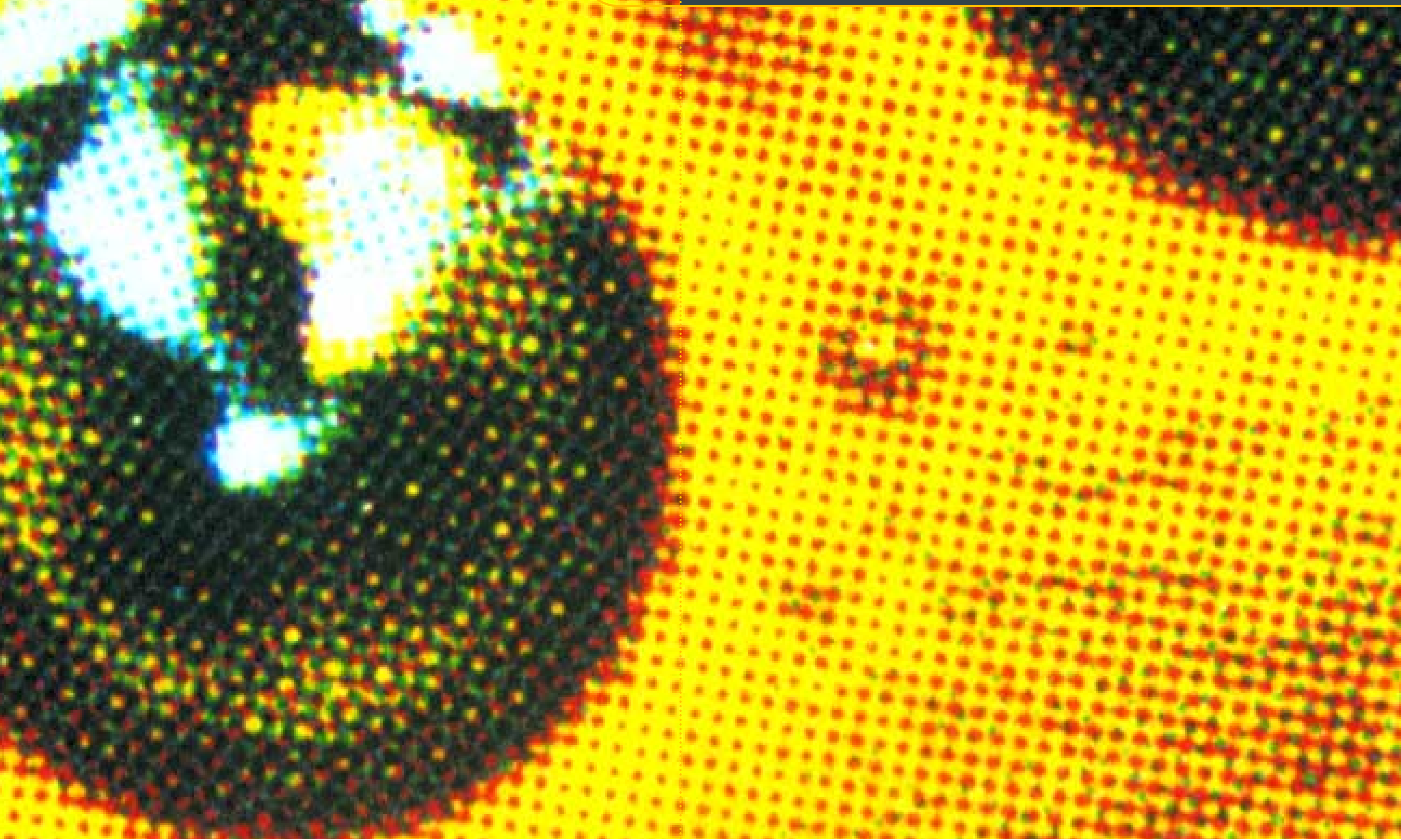


Visualization

a way to see the unseen

Computers help us answer questions about matters ranging from the future of the world's climate to the workings of the body's cells. Computer output, however, can seem to be little more than mounds of dry data, completely disconnected from the dynamics of the original event. To better connect the answers to the questions, we have come to use visualization techniques such as computer graphics, animation, and virtual reality—all pioneered with NSF support.



Scientists in many disciplines use sophisticated computer techniques to model complex events and visualize phenomena that cannot be observed directly, such as weather patterns, medical conditions, and mathematical relationships. Virtual reality laboratories give scientists the opportunity to immerse themselves in three-dimensional simulations, often with spectacular results such as those in the acclaimed IMAX film *Cosmic Voyage*. The field of computer visualization has developed rapidly over the past twenty-five years, largely because of NSF support. NSF has encouraged pioneering individual research, the development of supercomputing centers, wider-range applications being explored at science and technology centers, and far-reaching programs such as the Partnerships for Advanced Computational Infrastructure. NSF's commitment has helped computer visualization grow from its infancy in the 1950s and 1960s to the important scientific and commercial field it is today.

Visualizing Science in Action

A surgeon can repair a human heart, but like all living organs, the heart presents a host of problems to scientists who want to understand it in detail. X-rays, probes, and scans show only a partial picture—a snapshot—while often what is needed is a motion picture of how all the parts interact. In 1993, scientists at New York University came up with a solution. Working at the NSF-funded Pittsburgh Supercomputing Center, they created the first three-dimensional, animated model of a beating heart.

That first successful "heartbeat" required nearly a week of computing time and represented fifteen years of work by mathematicians Charles Peskin and David McQueen. Subsequently, the work has had broad influence in studies of biological and anatomical fluid flow.

Other simulations demonstrate the dynamics of much larger events, such as tornadoes. Scientists at the University of Illinois have traced air motion within and around tornadoes by introducing thousands of weightless particles into the flow. With that information, and with the computing power at the NSF-supported National Center for Supercomputing Applications (NCSA), also at the University of Illinois, they created a model that provides a closer look at updrafts, downdrafts, and strong horizontal changes in wind speed.

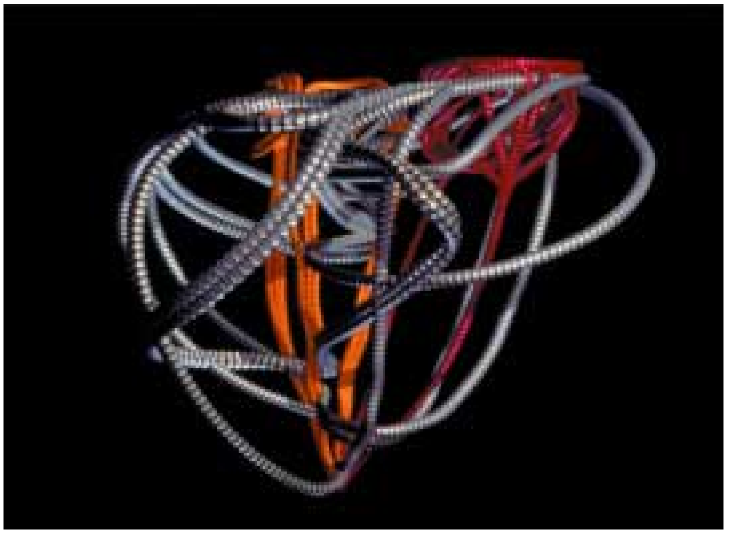
Robert Wilhelmson, an atmospheric computer scientist, began modeling storms almost thirty years ago in hopes of better predicting severe occurrences. One of the founders of NCSA, he wanted from the beginning to model how storms evolve. Wilhelmson and his research group have pushed storm visualizations from static two-dimensional images to three-dimensional animations at ever-greater resolution and over longer time spans.

All the sciences use the visual arts in some form or another, depicting everything from molecules to galaxies. Engineering, too, relies on detailed renderings. Over the years, NSF has funded the development of computer visualizations in many fields, while at the same time challenging computer specialists to go back to the basics and learn how to make these visualizations more accurate and more useful as scientific predictors.

Ensuring this accuracy, according to Cornell University's Don Greenberg, a long-time NSF grantee, entails making sure that computer-generated visualizations obey the laws of physics. Researchers at Cornell, one of five institutions in the NSF Science and Technology Center for Computer Graphics and Visualization, address this issue by developing ways to incorporate the physics of how light behaves and how our eyes perceive it. Their renderings look like architectural photos—studies of light and space. And their research has been used by General Electric Aircraft Engines, Battelle Avionics, Eastman Kodak, and others.

Moving computer visualizations from what is acceptable to what is most useful from a scientific standpoint has taken a lot of work, says Greenberg. "It's easy to make visualizations believable; *Jurassic Park* and *Star Wars* did a fine job of that," he says. "But they weren't very accurate. It's much harder to make them accurate."

Mathematicians Charles Peskin and David McQueen laid the groundwork for visualizations that will allow physicians to better understand the inner workings of the human heart. The model may lead to more effective diagnosis and treatment of heart defects and diseases.



Worth at Least a Thousand Data Points

The increased ability of scientists and engineers to model complex events is a direct result of NSF's investment in supercomputing centers. These university-based research facilities, started in the 1980s, gave researchers around the country access to the computational power they needed to tackle important—and difficult—problems. Visualization, while not an explicit goal of the supercomputing centers, quickly emerged as a way to cope with the massive amounts of scientific data that had been pouring out of computers since the 1960s. "We became very good at flipping through stacks of computer printouts," recalls Richard Hirsh, a specialist in fluid dynamics who is now NSF's deputy division director for Advanced Computational Infrastructure and Research. "But we realized that, at some point, people needed to *see* their solutions in order to make sense of them."

Humans are adept at recognizing patterns, Hirsh says, especially patterns involving motion. One of the early visualization success stories was a model of smog spreading over Southern California, a model so informative and realistic that it helped to influence antipollution legislation in the state. As the cost of computer memory dropped and computer scientists began finding more applications for visualization techniques, the scientific community began to take notice.

The NSF Panel on Graphics, Image Processing, and Workstations published its landmark report *Visualization in Scientific Computing* in 1987. "ViSC [visualization in scientific computing] is emerging as a major computer-based field," the panel wrote. "As a tool for applying computers to science, it offers a way to see the unseen . . . [it] promises radical improvements in the human/computer interface." The NSF report was accompanied by two hours of videotape demonstrating the potential of the new tool.

"Before the publication of the report, the opinions and observations of many well-known and respected computer graphics experts were of little concern to the scientific and computing establishments," recalls Tom DeFanti, director of the Electronic Visualization Laboratory at the University of Illinois at Chicago and co-editor of the ViSC report. Today, he says, "their comments are sought after—to educate the public, to influence industry research, and to identify new scientific markets."

NSF earmarked funds for visualization at the supercomputing centers from 1990 to 1994. During that time, application of visualization techniques spread. Since 1997, NSF's Partnerships for Advanced Computational Infrastructure (PACI) program has stimulated further advances in areas ranging from sophisticated tools for managing, analyzing, and interacting with very large data sets to collaborative visualization tools to enable researchers from far-flung areas to work interactively on a real-time basis. Applications now span the whole of contemporary science. For example:

- Molecular biologists use modeling to depict molecular interaction.
- Astronomers visualize objects that are so far away they cannot be seen clearly with most instruments.
- Medical researchers use computer visualization in many diagnostic techniques, including the Magnetic Resonance Imaging (MRI) system that produces three-dimensional images of the body.

Art and Science: An Alternative to Numbers

DeFanti and his colleague Maxine Brown summarized reasons for the booming popularity of visualization in *Advances in Computers* (1991):

"Much of modern science can no longer be communicated in print; DNA sequences, molecular models, medical imaging scans, brain maps, simulated flights through a terrain, simulations of fluid flow, and so on all need to be expressed and taught visually . . . . Scientists need an alternative to numbers. A technical reality today and a cognitive imperative tomorrow is the use of images. The ability of scientists to visualize

Computer Graphics: A Competitive Edge

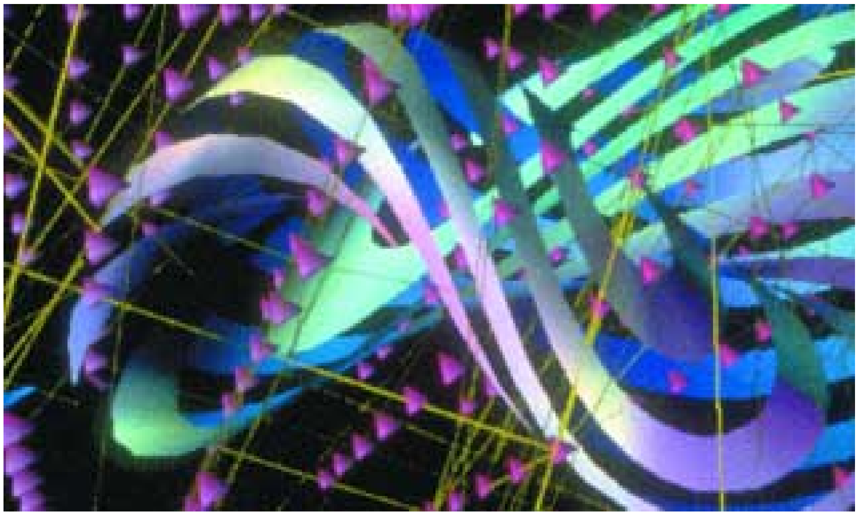
"Advances in computer graphics have transformed how we use computers . . . While everyone is familiar with the mouse, multiple 'windows' on computer screens, and stunningly realistic images of everything from animated logos in television advertisements to NASA animations of spacecraft flying past Saturn, few people realize that these innovations were spawned by federally sponsored university research.

"[For example] [h]ypertext and hypermedia have their roots in Vannevar Bush's famous 1945 *Atlantic Monthly* article 'As We May Think.' Bush described how documents might be interlinked in the fashion of human associative memory. These ideas inspired Doug Engelbart at SRI (funded by DARPA) and Andries van Dam of Brown University (funded by NSF) to develop the first hypertext systems in the 1960s. These systems were the forerunners of today's word-processing programs, including simple what-you-see-is-what-you-get capabilities . . .

"High-quality rendering has caught the public's eye and is having a vast impact on the entertainment and advertising industries. From *Jurassic Park* to simulator rides at Disney World and dancing soda cans in TV commercials, the world has been seduced by computer animation, special effects, and photorealistic imagery of virtual environments . . .

"One could continue with many more examples, but the message is clear: federal sponsorship of university research in computer graphics stimulated a major segment of the computing industry, allowing the United States to establish and maintain a competitive edge."

—Excerpted from *Computer Graphics: Ideas and People from America's Universities Fuel a Multi-billion Dollar Industry* by Edward R. McCracken, Former chairman and Chief Executive Officer, Silicon Graphics, Inc. © 1995-1997.



Through computer mapping of topographical surfaces, mathematicians can test theories of how materials will change when stressed. The imaging is part of the work at the NSF-funded Electronic Visualization Laboratory at the University of Illinois at Chicago.

complex computations and simulations is absolutely essential to ensure the integrity of analyses, to provoke insights, and to communicate those insights with others."

Over the years, two basic types of drawing systems have vied for the attention of both developers and users—vector graphics and raster graphics. Vector graphics systems are based on specifying the location of points on an X and Y coordinate system and connecting the points with lines. The basic drawing element of vector graphics is the line, created by an electron beam in the monitor as it moves directly from one set of coordinates to another, lighting up all the points in between. By contrast, the electron beam in the monitor of a raster graphics system scans across the screen, turning on specific picture elements (which came to be called pixels) in a predefined grid format.

While the precision of vector graphics was well suited to mechanical drawing, computer-aided design and manufacturing, and architectural computer graphics, raster graphics opened up possibilities in other areas and brought many more types of people into the world of computer graphics. It was perhaps the use of raster graphics in television advertising, including titles for network specials, that brought the public's attention to the potential of computer graphics. The low resolution of the television screen and the short viewing time—measured in seconds—called for relatively few calculations and was therefore less expensive in terms of power, speed, and memory. However, there was initial disappointment in the precision of raster graphics; the disappointment was largely offset with anti-aliasing techniques that minimized the disturbing effect of jagged lines and stair-stepped edges. Compression in the number of pixels in the predefined grid also improved the quality of raster images.

But high resolution has a price. A typical full-color computer screen with 1,000 rows and 1,000 columns of pixels requires 24 million bits of memory. That number multiplied by at least 60 is the amount of memory required for the rapid-fire sequencing of frames in a smooth, professional-looking animation. While not as costly as it once was, animation remains an exercise in allocating the supercomputers' massive resources to achieve the most effective results.

Today, scientific visualization embodies the results that NSF hoped to achieve in funding the supercomputing centers: to find answers to important scientific questions while advancing both the science of computing and the art of using computer resources economically.

In 1992, the four supercomputer centers then supported by NSF (National Center for Supercomputing Applications in Chicago and Urbana-Champaign, Illinois; Pittsburgh Supercomputing Center; Cornell Theory Center; and San Diego Supercomputer Center) formed a collaboration based on the concept of a national MetaCenter for computational science and engineering. The center was envisioned as a growing collection of intellectual and physical resources unlimited by geographical or institutional constraints.

In 1994, the scientific computing division of the National Center for Atmospheric Research in Boulder, Colorado, joined the MetaCenter. The five partners, working with companies of all sizes, sought to speed commercialization of technology developed at the supercomputer centers, including visualization routines. An early success was Sculpt, a molecular modeling system developed at the San Diego Supercomputer Center. It earned a place on the cover of *Science* magazine and has now been commercialized by a start-up company.

The concept of a national, high-end computational infrastructure for the U.S. science and engineering community has been greatly expanded since 1997, when the National Science Board, NSF's governing body, announced PACI as successor to the NSF supercomputing program. PACI supports two partnerships: the National Computational Science Alliance ("the Alliance") and the National Partnership for Advanced Computational Infrastructure (NPACI). Each partnership consists of a leading edge site—for the Alliance it is the National Center for Supercomputing Applications in Urbana-Champaign, while the San Diego Supercomputer Center is the leading edge site for NPACI—and a large number of other partners. More than sixty institutions from twenty-seven states and the District of Columbia belong to one or both of the partnerships. With access to an interconnected grid of high-performance computing resources, many researchers at these participating institutions are developing state-of-the-art visualization tools and techniques to address multidisciplinary challenges that range from creating roadmaps of the structures and connections within the human brain to producing astronomically accurate, high-resolution animations of distant galaxies.

Staking the Pioneers: The 1960s to the 1990s

The richness of computer visualization today can be traced back to pioneering work, such as Ivan Sutherland's landmark doctoral dissertation from the early 1960s. As an NSF-supported graduate student at the Massachusetts Institute of Technology (MIT), Sutherland developed a real-time line-drawing system that allowed a person to interact with the computer using a prototype light pen. While the research itself was supported in terms of both funds and computing resources by the Air Force through the MIT Lincoln Laboratory, the NSF fellowship helped make this graduate study possible. Sutherland credits NSF for the support it provided: "I feel good about NSF taking well-deserved credit for supporting my graduate education. Having independent NSF support was crucial to my ability to transfer to MIT from Caltech. MIT had seemed eager to have me in 1959, but was all the more willing to admit me in 1960 as a post-master's student because I brought NSF support with me."

Sutherland's Sketchpad introduced new concepts such as dynamic graphics, visual simulation, and pen tracking in a virtually unlimited coordinate system. The first computer drawing system, DAC-1 (Design Augmented by Computers), had been created in 1959 by General Motors and IBM. With it, the user could input various definitions of the three-dimensional characteristics of an automobile and view the computer-generated model from several perspectives. DAC-1 was unveiled publicly at the 1964 Joint Computer Conference, the same forum Sutherland had used in 1963 to unveil Sketchpad, which had the distinguishing feature of enabling the user to create a design interactively, right on the screen. His achievement was so significant that it took close to a decade for the field to realize all of its contributions.

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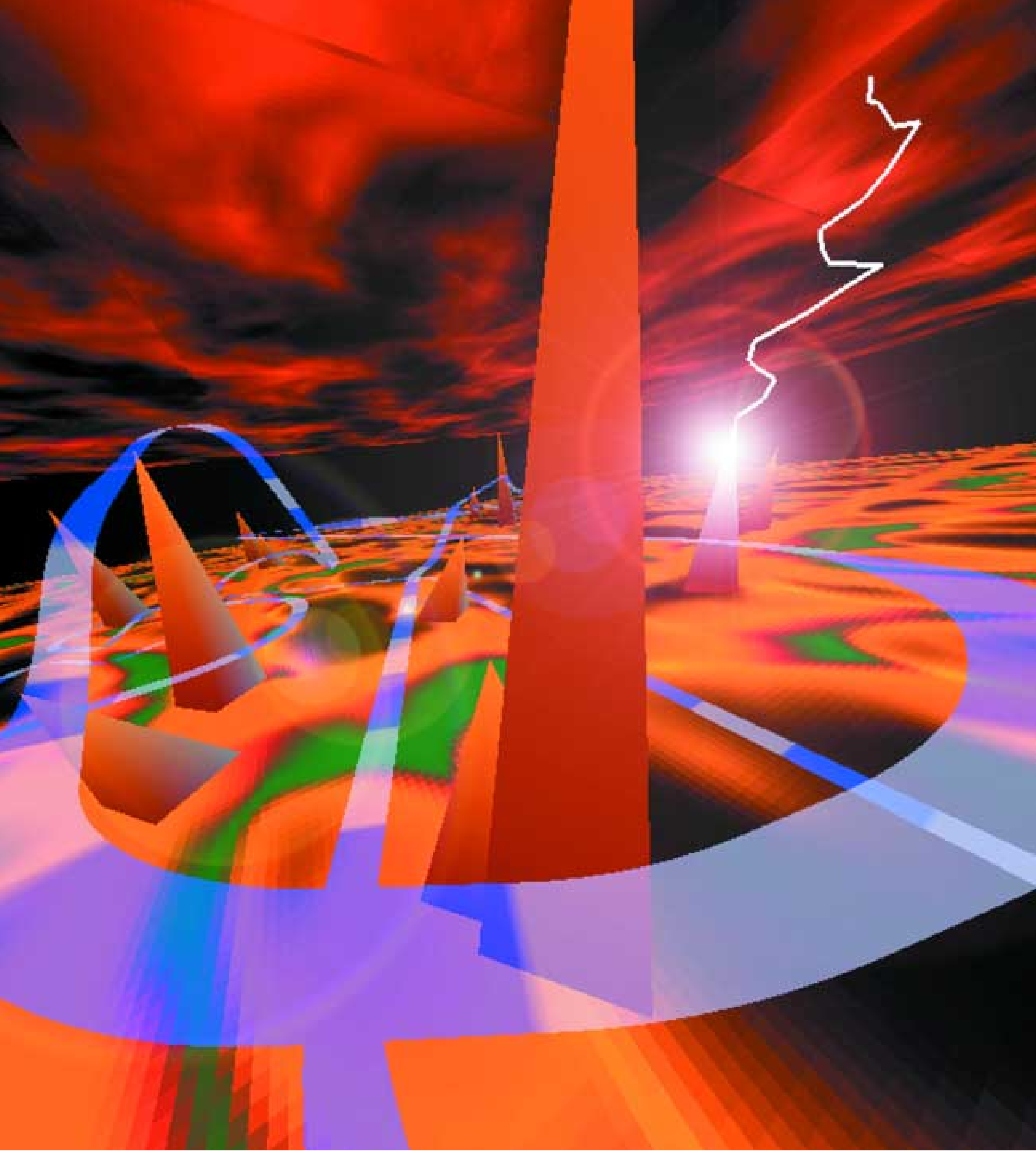
The NSF-funded National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign has long been a source of innovation in the field of visualization. One product of NCSA-based research is Virtual Director, created by Robert Patterson and Donna Cox. This application provides an easy-to-use method to control camera action for playback or animation recording.



A Panoply of Applications

Computer graphics has entered just about every aspect of modern life. The information age has become an age of images — a new hieroglyphics containing more content and promising greater understanding than ever before. Among the key areas of modern business, industrial, and academic activity that have been revolutionized in the last forty years are those listed here.

ARCHITECTURE & ENGINEERING Building design, space planning, real estate analyses, interior architecture and design, construction management, cost-estimating integrated with design and drafting, procurement, facilities management, furniture and equipment management, and needs forecasting.

BIOMEDICAL APPLICATIONS Surgical and radiation therapy planning, diagnostic aids, prostheses manufacturing, studies of morphology and physiology, molecular modeling, computerized tomography (CT scans), nuclear magnetic resonance (NMR, MRI), and teaching of surgical techniques.

BUSINESS & MANAGEMENT GRAPHICS Decision-making systems, graphical data displays, presentation graphics systems, visual information systems, C^3I (command, control, communication, and information systems), financial graphics systems, and business and scientific charts and graphs.

EDUCATION & LEARNING Techniques for developing visual thinking skills and creative abilities in both children and adults; science and mathematics instruction; architecture, engineering, and design instruction; arts instruction; and development of the electronic classroom based on research findings on the cognitive, motivational, and pedagogic effects of computer graphics.

ELECTRIC CAD/CAM Printed wiring board and integrated circuit design, symbol construction, schematic generation, knowledge-based systems in electronic design and simulation, advanced systems for chip and circuit design, circuit analysis, logic simulation, electronic fabrication and assembly, and test set design.

HUMAN FACTORS & USER INTERFACES Advances in the visual presentation of information; graphical software development tools and visible language programming; improvements in screen layout, windows, icons, typography, and animation; and alternative input devices, iconographic menus, improvements in color graphics displays, and graphical user interfaces (GUIs).

MANUFACTURING Computer-aided design (CAD), manufacturing (CAM), and engineering (CAE); computer-integrated manufacturing (CIM), numerical control (NC) in CAD/CAM, robotics, and managing the flow of manufacturing information from design to field services; manufactured parts, buildings, and structures; and integrating CIM with CAD.

MAPPING & CARTOGRAPHY Geographic information systems (GIS) and graphical databases; computer-assisted cartography; engineering mapping applications in transportation and utility fields; computer-assisted map analysis; 3-D mapping techniques; management systems for industrial, office, and utility sites and cross-country facilities such as transmission lines; military and civilian government facilities management; natural and man-made resource mapping; and land planning, land development, and transportation engineering.

PATTERN RECOGNITION & IMAGE PROCESSING Feature selection and extraction; scene matching; video inspection; cartographic identifications; radar-to-optical scene matching; industrial and defense applications; analysis and problem solving in medicine, geology, robotics, and manufacturing; computer vision for automated inspection; and image restoration and enhancement.

PRINTING & PUBLISHING Integration of text and graphics in printed documents, technical documentation created from engineering drawings, technical publishing systems, online documentation systems, page layout software, scanning systems, direct-to-plate printing capabilities, and computer-assisted design systems for publication design and layout.

STATISTICAL GRAPHICS Graphical techniques for rendering large masses of data to increase understanding, graphical techniques for data analysis, graphical display techniques, graphical interaction techniques, and multivariable data analysis.

VIDEO & MULTIMEDIA TECHNOLOGY High-definition television; computer-generated video for entertainment and educational applications; electronic video-conferencing; broadcast applications for news, weather, and sports; and CD-ROM and Web graphics.

VISUAL ARTS & DESIGN Computer graphics applications for graphic design, industrial design, advertising, and interior design; standards based on design principles relating to color, proportion, placement, and orientation of visual elements; image manipulation and distortion for special effects; systems for computer artists involved in drawing, painting, environmental installations, performance, and interactive multi-image systems; computer animation in film, television, advertising, entertainment, education, and research; and digital design of typography.

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Computer graphics was still too obscure a field to be a cover story in 1972 when Bernard Chern, who later retired as director of NSF's Division of Microelectronic Information Processing Systems, began a program to support the development of computer systems for representing objects in three dimensions. Chern assembled a stable of grantees, including many of the country's leading researchers in automation and modeling.

Among them was Herbert Voelcker, who recalls the state of the technology when he launched the computer modeling program at the University of Rochester: "Major advances in mechanical computer-assisted design were not possible because there were no mathematical and computational means for describing mechanical parts unambiguously . . . There were no accepted scientific foundations, almost no literature, and no acknowledged community of scholars and researchers . . . These early explorations were unsettling, but also challenging because they led us to try to build foundations for an emerging field."

Voelcker and his team were among the pioneers in computer-assisted design (CAD), which, for most of its history, had relied primarily on wireframe systems. Mimicking manual drafting, these computer programs build either two- or three-dimensional models of objects based on data supplied by users. While useful, the programs frequently result in ambiguous renderings—a rectangle might represent either a flat side or an open space—and are fully capable of producing images that resemble the drawings of M.C. Escher, where continuous edges are a physical impossibility. Solid modeling, on the other hand, is based on the principles of solid geometry and uses unambiguous representations of solids.

In 1976, Voelcker's group unveiled one of the earliest prototype systems, called PADL, for Part and Assembly Description Language. For the next two decades, PADL and other solid modeling systems were constrained by heavy computational requirements, but as faster computers have come into their own, PADL descendants are now displacing wireframe modeling and drafting in the mechanical industries.

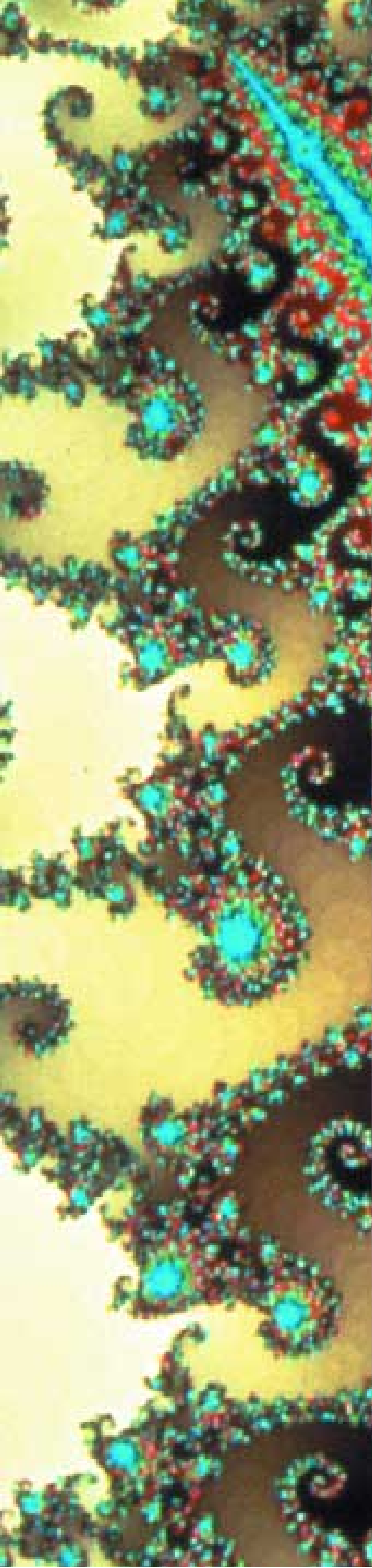
NSF-funded researchers at the University of Utah are taking computer drafting techniques even further, all the way to what is known as "from art to part." That is, they are creating a system that generates a finished metal product from a sketch of a mechanical object, bypassing the prototyping stage all together.

Visualization: Back to the Future

By 1991, the field of computer visualization was exploding. "The field had gotten so big, with so many specialties, that no one could know it all. No single research lab could do it all. Graphics hadn't just become broad—it was increasingly interdisciplinary," explains Andries van Dam of Brown University. Van Dam is the current director of NSF's Science and Technology Center for Computer Graphics and Scientific Visualization, which was established both to help deal with the interdisciplinary needs of the scientists and to expand the basics of computer graphics.

The center is a consortium of research groups from five institutions—Brown University, the California Institute of Technology (Caltech), Cornell University, the University of North Carolina at Chapel Hill, and the University of Utah—all of which have a history of cutting-edge research in computer graphics and visualization.

In addition to collaborating, each university focuses on a different part of graphics and visualization research, studying such fields as novel user interfaces, hardware design for visualization and graphics, the physics of the interaction of light with its environment, and geometric modeling for mechanical design.



Computer Graphics: Into the Marketplace

The advances that built on Ivan Sutherland's ground-breaking Sketchpad work at MIT would bring computer graphics out of the laboratory, off the military base, and into the commercial marketplace, creating a steadily growing demand for computer-generated images in a variety of fields.

Continuing technical developments and the widespread commercial adoption of the personal computer — both the IBM PC and the Apple computer—helped spur a demand so strong that computer graphics ceased to be an add-on to a computer's capability and became an integral feature of the computer itself. Today, entire generations are growing up with an exclusively graphics-based experience of computing.

Some of the advancing techniques along this route to the future were:

WIREFRAME DRAWING PROGRAMS AND BOUNDARY REPRESENTATION SYSTEMS depict structures in three dimensions showing all the outlines simultaneously from various perspectives. These programs can recognize surfaces, erase hidden lines, and add shading.

SOLID MODELING SYSTEMS define the interiors, edges, and surfaces of an object.

CONSTRUCTIVE SOLID GEOMETRY SYSTEMS provide a library of preformed shapes that can be combined in additive and subtractive ways to create solid objects.

FRACTAL GEOMETRY uses self-similar forms—where the structure of a small section resembles the structure of the whole—to geometrically simulate the intricacies of nature, such as patterns in tree bark, cracks in the mud of a dry riverbed, or the edges of leaves.

RAY-TRACING ALGORITHMS simulate the effect of light rays bouncing around a scene—illuminating objects, creating reflections, and defining areas of shadow. Ray-tracing often produces strikingly realistic images.

IMAGE MAPPING, also known as texture mapping, is a technique for wrapping two-dimensional patterns and images around three-dimensional models.

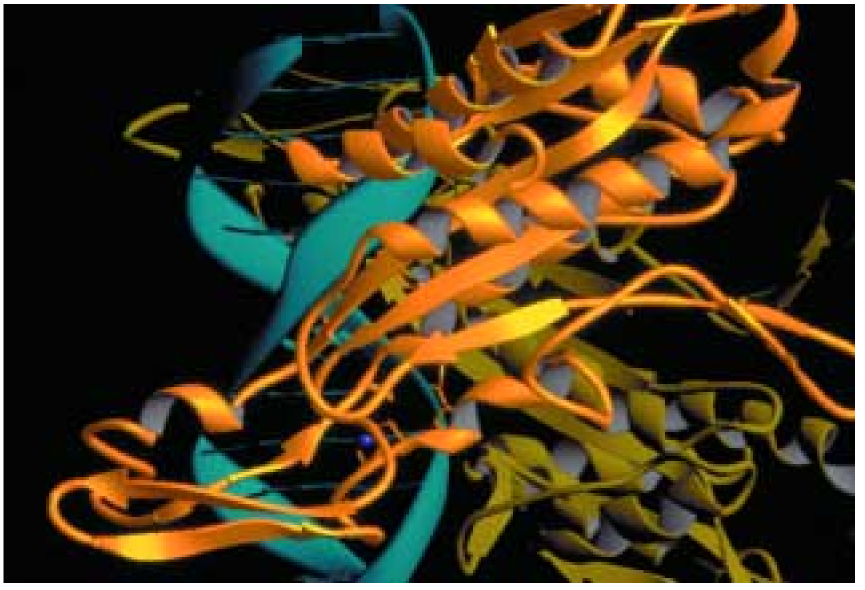
SPATIAL TEXTURING uses an automatically created three-dimensional pattern that is defined for a three-dimensional volume rather than a two-dimensional plan. With spatial texturing, also known as solid textures, you can cut a model of a block of wood in half and see the wood grain inside.

ELECTRONIC PAINT SYSTEMS include tools that imitate the use of brush, oil, and canvas and provide a menu of choices for type of paint brush, color hue and intensity, and type of stroke.

IMAGE PROCESSING PROGRAMS enable users to edit and manipulate photographs and other images to create different effects.

ANIMATION introduces the dimension of time and creates the illusion of motion.

VIRTUAL REALITY SYSTEMS create the illusion of real three-dimensional space through the use of three-dimensional graphics and head or body tracking that changes the view when a user moves.



For more than fifteen years, University of Pittsburgh researcher John Rosenberg and his colleagues have studied how protein-DNA recognition works in the case of a particular protein, Eco RI endonuclease. This detailed model shows that the DNA-Eco RI interaction creates a kink in the DNA's structure.

Another of the center's focuses, explains van Dam, is tele-collaboration. "We are building tools that will make it seem like you're looking through a glass window and seeing your colleagues in the next room working on objects you're designing. We want to create an immersive environment. In my lifetime it won't be quite real, but it will be close enough."

Visualizing a Virtual Reality

While van Dam and his colleagues are moving people into a virtual design shop, other researchers outside the center are creating virtual realities—computer-driven worlds where everything is interconnected, allowing exploration on a level so extraordinary it approaches science fiction.

In previous studies of the Chesapeake Bay, scientists had to measure the wind, current, salinity, temperature, and fish populations separately. But with a virtual reality model, all the elements come together. Glen Wheless, a physical oceanographer at Old Dominion University, worked with William Sherman, a computer scientist at the National Center for Supercomputing Applications, to create a dynamic model of the Atlantic Ocean's saline waters converging with fresh water from more than 150 creeks and rivers that flow into the bay.

The model has given scientists new insights into the ways in which fish larvae are transported around the estuary; scientists are learning, for example, that they had previously underestimated the influence of wind, tides, and runoff.

The Chesapeake Bay virtual reality model is different from a computer animation in that it is interactive. Researchers can continually update the data and re-run the model. Computer animations, for all their explanatory power, cannot accommodate this demand; once completed, they are not easily changed.

Virtual environments are presented to the viewer through wide-field displays. Sensors track the viewer's movements through the data and update the sights and sounds accordingly. The result is a powerful mechanism for gaining insight into large, multidimensional phenomena. The Chesapeake Bay simulation was designed in one of the country's leading virtual environments for science, CAVE, which was pioneered with NSF support by the Electronic Visualization Lab at the University of Illinois at Chicago. CAVE is an acronym for Cave Automatic Virtual Environment, as well as a reference to "The Simile of the Cave" in Plato's *Republic*, which explores the ideas of perception, reality, and illusion through reference to a person facing the back of a cave where shadows are the only basis for understanding real objects.

CAVE is a darkened cubicle measuring 10 by 10 by 9 feet. Sound and three-dimensional images derived from background data are projected onto three walls and the floor. Wearing special glasses, visitors get a sensation of stepping inside the simulation.

CAVE's technology has been used for many simulations, perhaps the most famous of which is *Cosmic Voyage*, an IMAX film that made its debut in 1996 at the Smithsonian National Air and Space Museum in Washington, D.C. The museum cosponsored the film project with NSF and Motorola. *Cosmic Voyage* includes a four-minute segment of research-quality scientific visualization. The segment tells a story that begins shortly after the Big Bang, continues through the expansion of the universe and the formation of galaxies, and ends with the collision of two spiral galaxies. The segment is the result of the collaborative efforts of NCSA scientific visualization experts, NSF-supported astronomers, two movie production companies, and numerous high-performance computing machines at multiple centers.

Donna Cox, professor of art and design at the University of Illinois, Urbana-Champaign, choreographed the various parts of the simulation segment. For the camera moves, she worked with staff at the Electronic Visualization Laboratory to create a voice-driven CAVE application called the Virtual Director, a virtual reality method for directing the computer graphics camera for real-time playback or animation recording. Approximately one-half of the sequence—the collision and the merging of two spiral galaxies—is based on a simulation carried out by Chris Mihos and Lars Hernquist of the University of California, Santa Cruz, on the San Diego Supercomputer Center's CRAY C90 system. As the galaxies merge and then draw apart, tidal forces and galactic rotation cause the galaxies to cast off stars and gas in the form of long, thin "tidal tails." The compression of interstellar gas into the merged galaxies fuels an intense burst of star formation. Mihos and Hernquist found that increasing the resolution of their simulation led to new science, "particularly," says Mihos, "the large number of small, condensing gas clouds in the colliding galaxies that could be related to the formation of young, luminous star clusters or small dwarf galaxies, which are seen in many observed galaxy collisions."

In February 2000, *Passport to the Universe* debuted at New York's Hayden Planetarium to critical praise. The digital film, made using Virtual Director software and other high-end computing and visualization resources from both the Alliance and NPACI, combines images of actual astronomical objects with simulations made by cosmology researchers to provide audiences with an unparalleled depiction of intergalactic travel.

Real Support, Real Time, Real Value

While galaxies are merging and drawing apart—at least virtually—there is realism in the value of NSF's support of the basic scientific explorations that have fueled developments in computer visualization over the past fifty years. As one voice in the complex community of this field, Ivan Sutherland reflects on the value of this support. "I have now reached an age where the Association for Computing Machinery (ACM), the Institute of Electrical and Electronics Engineers, Inc. (IEEE), and the Smithsonian Institution have seen fit to honor me in various ways," he says. "Such retrospective honors are not nearly so important as the prospective honor NSF did me with an NSF fellowship. The prospective honor made a giant difference in my ability to contribute to society."

To Learn More

NSF Directorate for Computer and Information Science and Engineering
www.cise.nsf.gov

NSF Science and Technology Center for Graphics and Visualization
www.cs.brown.edu/stc

Caltech Computer Graphics Research
www.gg.caltech.edu

University of North Carolina Graphics and Image Cluster
www.cs.unc.edu/research/graphics/

Cornell Theory Center
www.tc.cornell.edu

Cornell University Vision Group
www.cs.cornell.edu/vision

National Computational Science Alliance
http://access.ncsa.uiuc.edu/index.alliance.html

National Partnership for Advanced Computational Infrastructure
www.npaci.edu

SDSC Tele-manufacturing Facility
San Diego Supercomputer Center
www.sdsc.edu/tmf/

Pittsburgh Supercomputing Center
www.psc.edu

National Center for Atmospheric Research
www.ncar.ucar.edu/

Electronic Visualization Lab at University of Illinois at Chicago
www.evl.uic.edu/