CHAPTER 1

A Survey of Computer Graphics

A saguaro-entertainer scene from a computer-generated cartoon animation.
(Courtesy of SOFTIMAGE, Inc.)

1-1 Graphs and Charts
1-2 Computer-Aided Design
1-3 Virtual-Reality Environments
1-4 Data Visualizations
1-5 Education and Training
1-6 Computer Art
1-7 Entertainment
1-8 Image Processing
1-9 Graphical User Interfaces
1-10 Summary

Computers have become a powerful tool for the rapid and economical production of pictures. There is virtually no undertaking in which graphical displays cannot be used to some advantage, and so it is not surprising to find the use of computer graphics so widespread. Although early applications in engineering and science had to rely on expensive and cumbersome equipment, advances in computer technology have made interactive computer graphics a practical tool. Today, we find computer graphics used routinely in such diverse fields as science, art, engineering, business, industry, medicine, government, entertainment, advertising, education, training, and home applications. And we can even transmit graphical images around the world using the Internet. Figure 1-1 gives a compact summary of the many applications of graphics in simulations, training, and data plotting. Before we get into the details of how to do computer graphics, we first take a short tour through a gallery of graphics applications.

1-1 GRAPHS AND CHARTS

An early application for computer graphics is the display of simple data graphs, usually plotted on a character printer. Data plotting is still one of the most common graphics applications, but today we can easily generate graphs showing highly complex data relationships for printed reports or for presentations using 35 mm slides, transparencies, or animated videos. Graphs and charts are commonly used

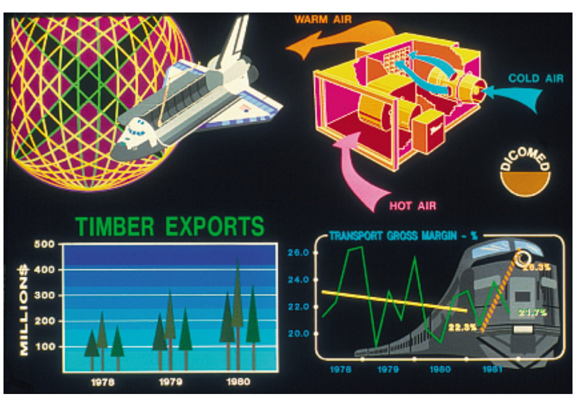

FIGURE 1-1 Examples of computer-graphics applications in various areas. (*Courtesy of the DICOMED Corporation.*)

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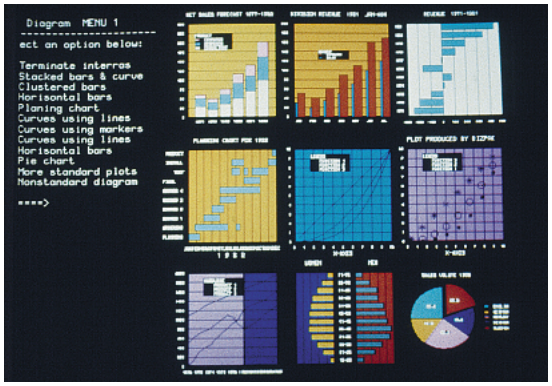

FIGURE 1-2 Two-dimensional line graphs, bar charts, and a pie chart. (*Courtesy of UNIRAS, Inc.*)

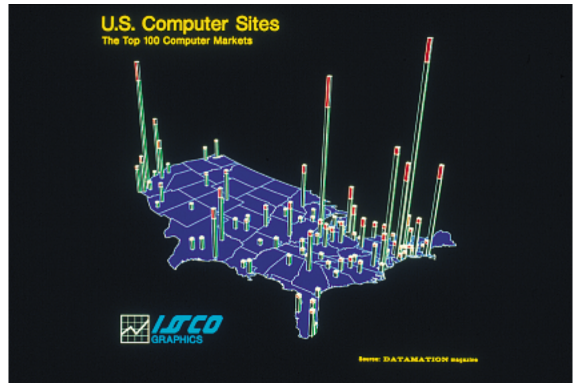

FIGURE 1-3 Two color-coded data sets displayed as a three-dimensional bar chart on the surface of a geographical region. (*Reprinted with permission from ISSCO Graphics, San Diego, California.*)

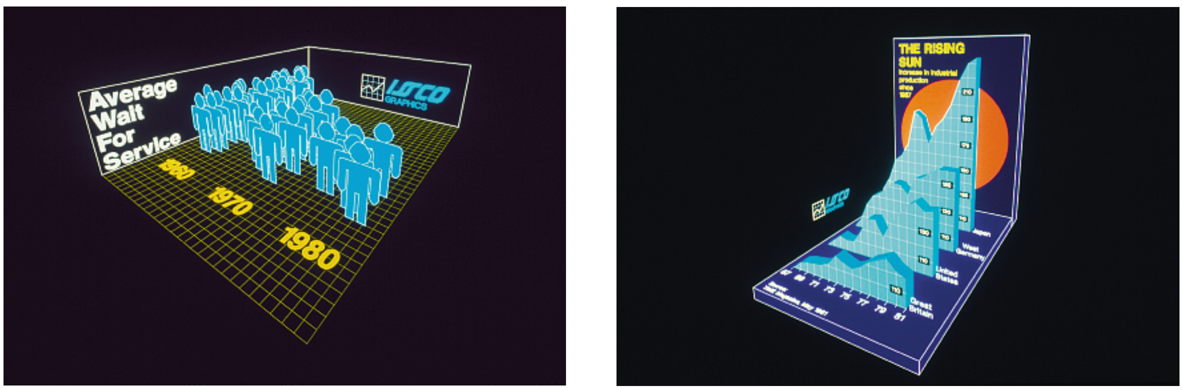

FIGURE 1-4 Two three-dimensional graphs designed for dramatic effect. (*Reprinted with permission from ISSCO Graphics, San Diego, California.*)

to summarize financial, statistical, mathematical, scientific, engineering, and economic data for research reports, managerial summaries, consumer information bulletins, and other types of publications. A variety of commercial graphing packages are available, and workstation devices and service bureaus exist for converting screen displays into film, slides, or overhead transparencies for use in presentations or archiving. Typical examples of data plots are line graphs, bar charts, pie charts, surface graphs, contour plots, and other displays showing relationships between multiple parameters in two dimensions, three dimensions, or higher-dimensional spaces.

Figures 1-1 and 1-2 give examples of two-dimensional data plots. These two figures illustrate basic line graphs, bar charts, and a pie chart. One or more sections of a pie chart can be emphasized by displacing the sections radially to produce an "exploded" pie chart.

Three-dimensional graphs and charts are used to display additional parameter information, although they are sometimes used simply for effect, providing more dramatic or more attractive presentations of the data relationships. Figure 1-3 shows a three-dimensional bar chart combined with geographical information. And Figure 1-4 provides examples of dramatic three-dimensional data

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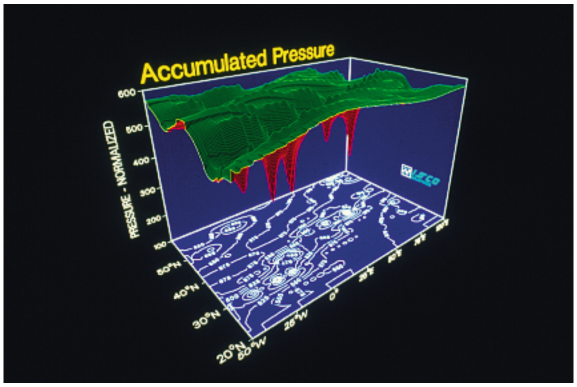

FIGURE 1-5 Plotting two-dimensional contours in a ground plane, with a height field plotted as a surface above the ground plane. (*Reprinted with permission from ISSCO Graphics, San Diego, California.*)

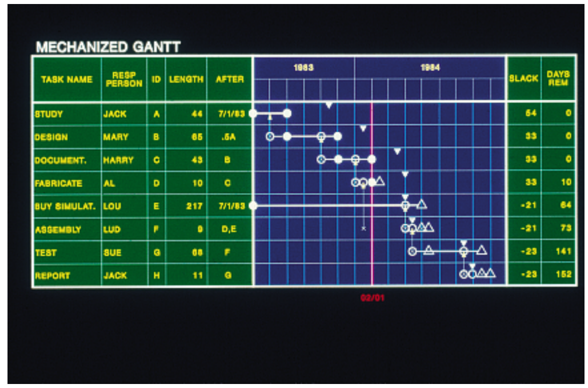

FIGURE 1-6 A time chart displaying scheduling and other relevant information about project tasks. (*Reprinted with permission from ISSCO Graphics, San Diego, California.*)

graphs. Another example of three-dimensional graphing is a surface plot, as illustrated in Fig. 1-5, which shows a height surface and its projected two-dimensional contour plot.

Figure 1-6 illustrates a time chart used in task planning. Time charts and task network layouts are used in project management to schedule and monitor the progress of projects.

1-2 COMPUTER-AIDED DESIGN

A major use of computer graphics is in design processes—particularly for engineering and architectural systems, although most products are now computer designed. Generally referred to as **CAD, computer-aided design,** or **CADD, computer-aided drafting and design,** these methods are now routinely used in the design of buildings, automobiles, aircraft, watercraft, spacecraft, computers, textiles, home appliances, and a multitude of other products.

For some design applications, objects are first displayed in a wire-frame outline that shows the overall shape and internal features of the objects. Wire-frame displays also allow designers to quickly see the effects of interactive adjustments to design shapes without waiting for the object surfaces to be fully generated. Figures 1-7 and 1-8 give examples of wire-frame images in design applications.

Software packages for CAD applications typically provide the designer with a multiwindow environment, as in Figs. 1-9 and 1-10. The various windows can show enlarged sections or different views of objects.

Circuits, such as the one shown in Fig. 1-10, and networks for communications, water supply, or other utilities are constructed with repeated placement of a few graphical shapes. The shapes used in a design represent the different network or circuit components. Standard shapes for mechanical, electrical, electronic, and logic circuits are often supplied by the design package. For other applications, a designer can create personalized symbols that are to be used to construct the network or circuit. The system is then designed by successively placing copies of the components into the layout, with the graphics package automatically providing

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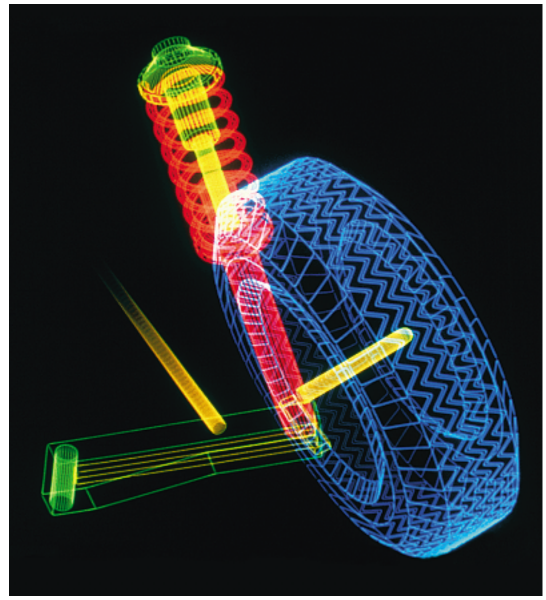
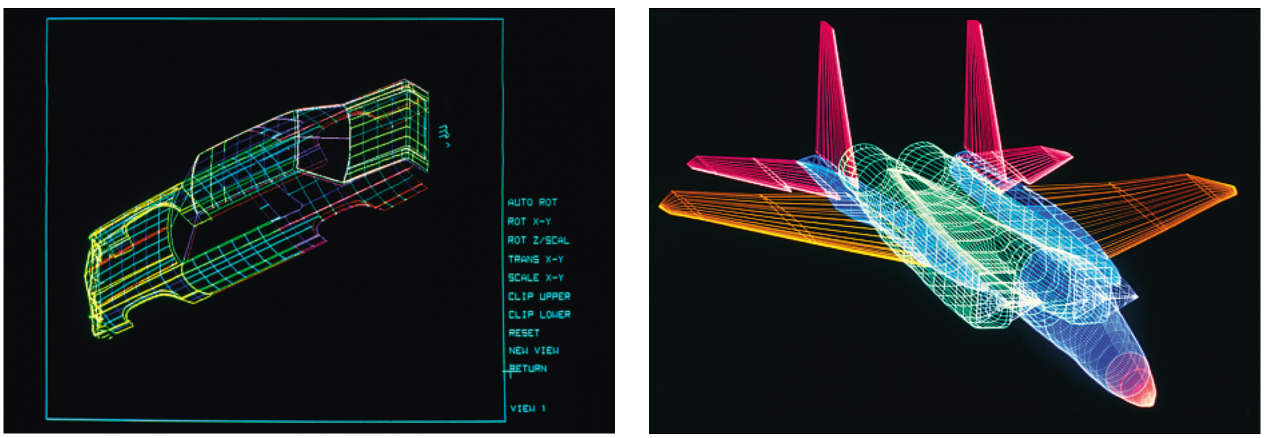


FIGURE 1–7 Color-coded, wire-frame display for an automobile wheel assembly. (*Courtesy of Evans & Sutherland.*)



(a) (b)

FIGURE 1–8 Color-coded, wire-frame outlines of body designs for an automobile and an aircraft. (*Courtesy of* (a) *Peritek Corporation and* (b) *Evans & Sutherland.*)

the links between components. This allows the designer to quickly test alternate circuit schematics for minimization of the number of components or the space required for the system.

Animations are often used in CAD applications. Real-time, computer animations using wire-frame shapes are useful for quickly testing the performance of a vehicle or system, as demonstrated in Fig. 1-11. Because a wire-frame image is not displayed with rendered surfaces, the calculations for each segment of the animation can be performed quickly to produce a smooth motion on the screen. Also, wire-frame displays allow the designer to see into the interior of the vehicle and to watch the behavior of inner components during motion.

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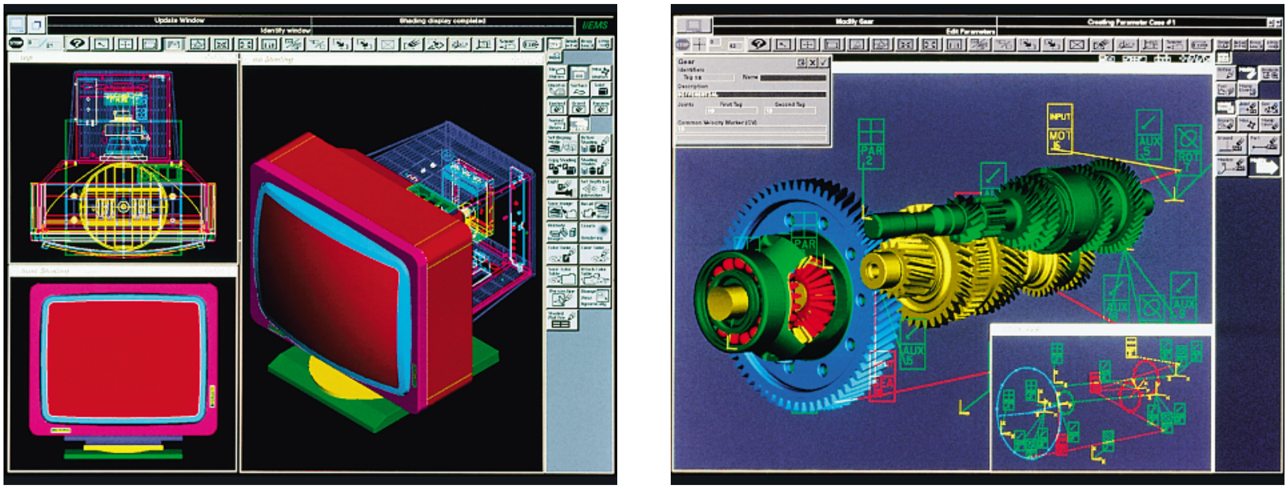

(a) (b)

FIGURE 1–9 Multiple-window, color-coded CAD workstation displays. (*Courtesy of Intergraph Corporation.*)

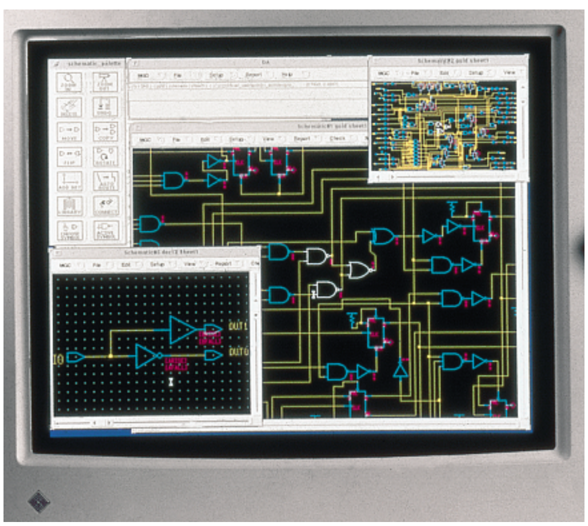

FIGURE 1–10 A circuit design application, using multiple windows and color-coded logic components. (*Courtesy of Sun Microsystems.*)

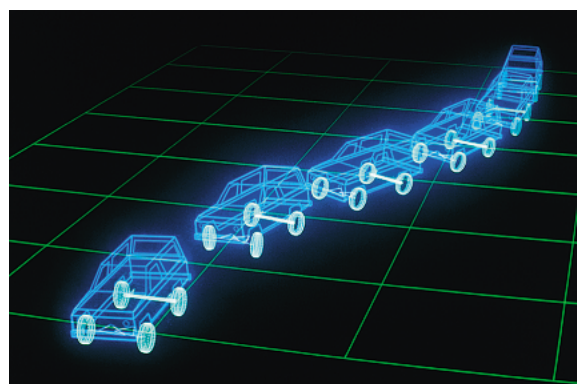

FIGURE 1–11 Simulation of vehicle performance during lane changes. (*Courtesy of Evans & Sutherland and Mechanical Dynamics, Inc.*)

When object designs are complete, or nearly complete, realistic lighting conditions and surface rendering are applied to produce displays that will show the appearance of the final product. Examples of this are given in Fig. 1-12. Realistic displays are also generated for advertising of automobiles and other vehicles using special lighting effects and background scenes (Fig. 1-13).

The manufacturing process is also tied in to the computer description of designed objects so that the fabrication of a product can be automated, using methods that are referred to as **CAM, computer-aided manufacturing.** A circuit

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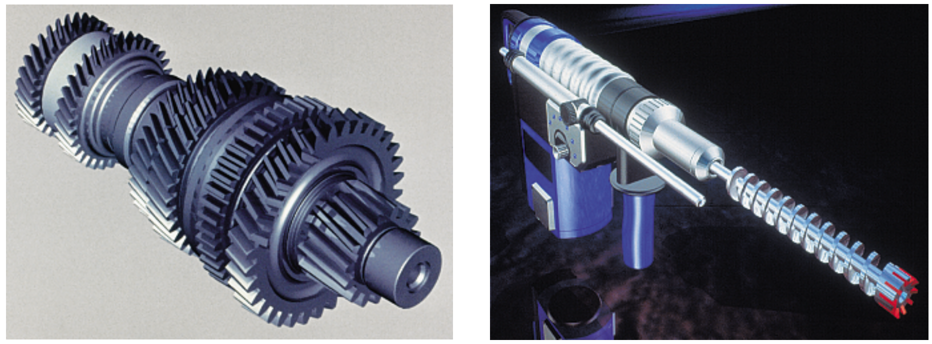

(a) (b)

FIGURE 1-12 Realistic renderings of engineering designs. (*Courtesy of* (a) *Intergraph Corporation and* (b) *Evans & Sutherland.*)

FIGURE 1-13 Studio lighting effects and realistic surface-rendering techniques are applied by computer-graphics programs to produce advertising pieces for finished products. This computer-generated image of a Chrysler Laser automobile was produced from data supplied by the Chrysler Corporation. (*Courtesy of Eric Haines, Autodesk, Inc.*)

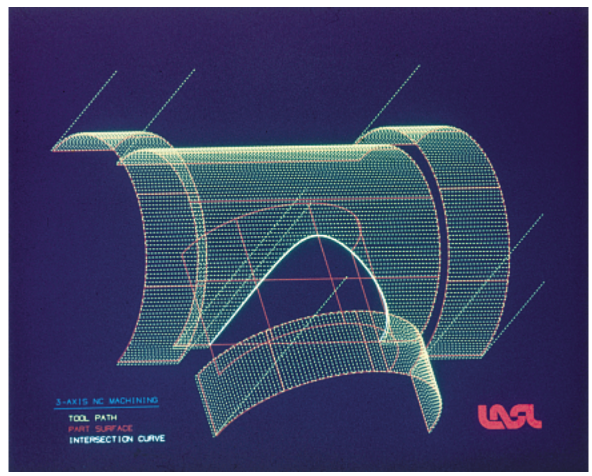

FIGURE 1-14 A CAD layout for describing the numerically controlled machining of a part. The part surface is displayed in one color and the tool path in another color. (*Courtesy of Los Alamos National Laboratory.*)

board layout, for example, can be transformed into a description of the individual processes needed to construct the electronics network. Some mechanical parts are manufactured from descriptions of how the surfaces are to be formed with the machine tools. Figure 1-14 shows the path to be taken by machine tools over the surfaces of an object during its construction. Numerically controlled machine tools are then set up to manufacture the part according to these construction layouts.

Architects use interactive computer-graphics methods to lay out floor plans, such as Fig. 1-15, that show the positioning of rooms, doors, windows, stairs, shelves, counters, and other building features. Working from the display of a building layout on a video monitor, an electrical designer can try out

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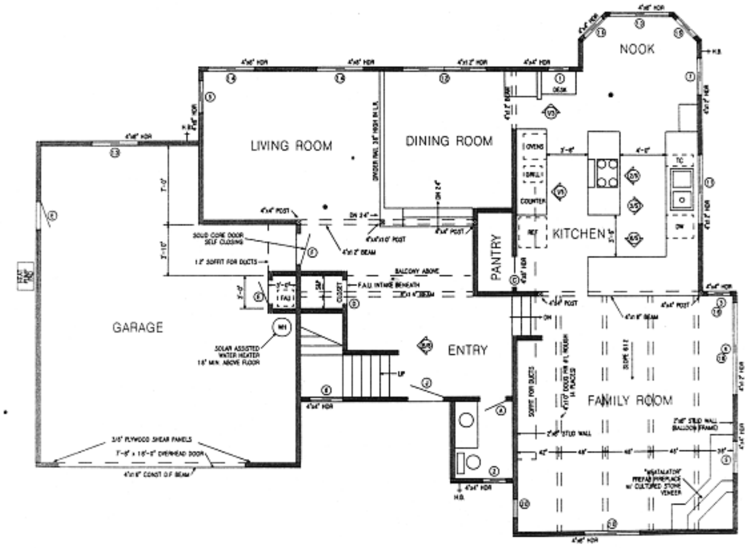

FIGURE 1-15
Architectural CAD layout for a building design. (*Courtesy of Precision Visuals, Inc., Boulder, Colorado.*)

(a) (b)

FIGURE 1-16 Realistic, three-dimensional renderings of building designs. (a) A street-level perspective for the World Trade Center project. (*Courtesy of Skidmore, Owings, & Merrill.*) (b) Architectural visualization of an atrium, created for a computer animation by Marialine Prieur, Lyon, France. (*Courtesy of Thomson Digital Image, Inc.*)

arrangements for wiring, electrical outlets, and fire-warning systems. Also, facility-layout packages can be used to optimize space utilization in an office or within a manufacturing facility.

Realistic displays of architectural designs, as in Fig. 1-16, permit both architects and their clients to study the appearance of a single building or a group of buildings, such as a campus or industrial complex. In addition to realistic exterior building displays, architectural CAD packages also provide facilities for experimenting with three-dimensional interior layouts and lighting (Fig. 1-17).

Many other kinds of systems and products are designed using either general CAD packages or specially developed CAD software. Figure 1-18, for example, shows a rug pattern designed with a CAD system.

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FIGURE 1-17 A hotel corridor that provides a sense of movement by positioning light fixtures along an undulating path and creates a sense of entry by placing a light tower at the entrance to each room. (*Courtesy of Skidmore, Owings, & Merrill.*)

FIGURE 1-18 Oriental rug pattern created with computer-graphics design methods. (*Courtesy of Lexidata Corporation.*)

1-3 VIRTUAL-REALITY ENVIRONMENTS

A more recent application of computer graphics is in the creation of **virtual-reality environments** in which a user can interact with the objects in a three-dimensional scene. Specialized hardware devices provide three-dimensional viewing effects and allow the user to "pick up" objects in a scene.

Animations in virtual-reality environments are often used to train heavy-equipment operators or to analyze the effectiveness of various cabin configurations and control placements. As the tractor operator in Fig. 1-19 manipulates the

FIGURE 1-19 Operating a tractor in a virtual-reality environment. As the controls are moved, the operator views the front loader, backhoe, and surroundings through the headset. (*Courtesy of the National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, and Caterpillar, Inc.*)

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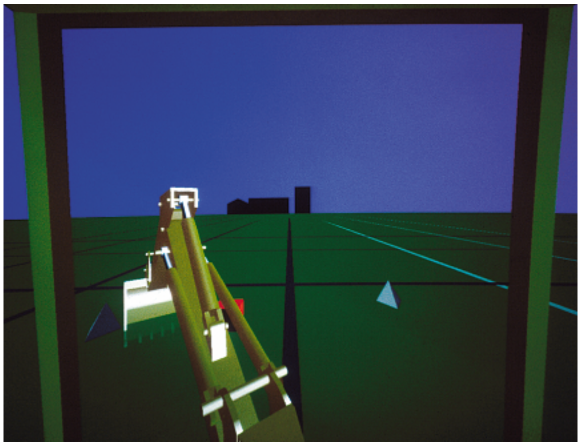

FIGURE 1-20 A headset view of the backhoe presented to a tractor operator in a virtual-reality environment. (*Courtesy of the National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, and Caterpillar, Inc.*)

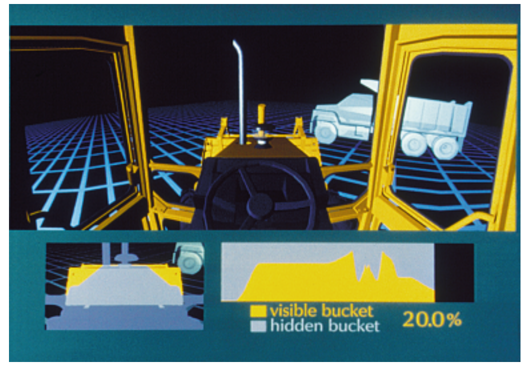

FIGURE 1-21 Operator's view of the tractor bucket, composited in several sections to form a wide-angle view on a standard monitor. (*Courtesy of the National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, and Caterpillar, Inc.*)

FIGURE 1-22 View of the tractor displayed on a standard monitor. (*Courtesy of the National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, and Caterpillar, Inc.*)

controls, the headset presents a stereoscopic view (Fig. 1-20) of the front-loader bucket or the backhoe, just as if the operator were in the tractor seat. This allows the designer to explore various positions of the bucket or backhoe that might obstruct the operator's view, which can then be taken into account in the overall tractor design. Figure 1-21 shows a composite, wide-angle view from the tractor seat, displayed on a standard video monitor instead of in a virtual, three-dimensional scene. And Fig. 1-22 shows a view of the tractor that can be displayed in a separate window or on another monitor.

With virtual-reality systems, designers and others can move about and interact with objects in various ways. Architectural designs can be examined by taking a simulated "walk" through the rooms or around the outsides of buildings to better appreciate the overall effect of a particular design. And with a special glove, we can even "grasp" objects in a scene and turn them over or move them from one place to another.

1-4 DATA VISUALIZATIONS

Producing graphical representations for scientific, engineering, and medical data sets and processes is another fairly new application of computer graphics, which is generally referred to as **scientific visualization.** And the term **business visualization** is used in connection with data sets related to commerce, industry, and other nonscientific areas.

Researchers, analysts, and others often need to deal with large amounts of information or to study the behavior of highly complex processes. Numerical computer simulations, for example, frequently produce data files containing thousands and even millions of values. Similarly, satellite cameras and other recording sources are amassing large data files faster than they can be interpreted. Scanning these large sets of numbers to determine trends and relationships is a tedious and ineffective process. But if the data are converted to a visual form, the trends and patterns are often immediately apparent. Figure 1-23 shows an example of a large data set that has been converted to a color-coded display of relative heights above a ground plane. Once we have plotted the density values in this way, we can easily see the overall pattern of the data.

There are many different kinds of data sets, and effective visualization schemes depend on the characteristics of the data. A collection of data can contain scalar values, vectors, higher-order tensors, or any combination of these data types. And data sets can be distributed over a two-dimensional region of space, a three-dimensional region, or a higher-dimensional space. Color coding is just one way to visualize a data set. Other visualization techniques include contour plots, renderings for constant-value surfaces or other spatial regions, and specially designed shapes that are used to represent different data types.

Visual techniques are also used to aid in the understanding and analysis of complex processes and mathematical functions. A color plot of mathematical curve functions is shown in Fig. 1-24, and a surface plot of a function is shown in Fig. 1-25. Fractal procedures using quaternions generated the object shown in Fig. 1-26, and a topological structure is displayed in Fig. 1-27. Scientists are also

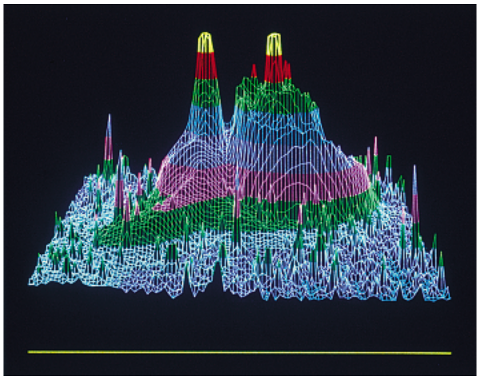

FIGURE 1–23 A color-coded plot with sixteen million density points of relative brightness observed for the Whirlpool Nebula reveals two distinct galaxies. (*Courtesy of Los Alamos National Laboratory.*)

FIGURE 1–24 Mathematical curve functions plotted in various color combinations. (*Courtesy of Melvin L. Prueitt, Los Alamos National Laboratory.*)

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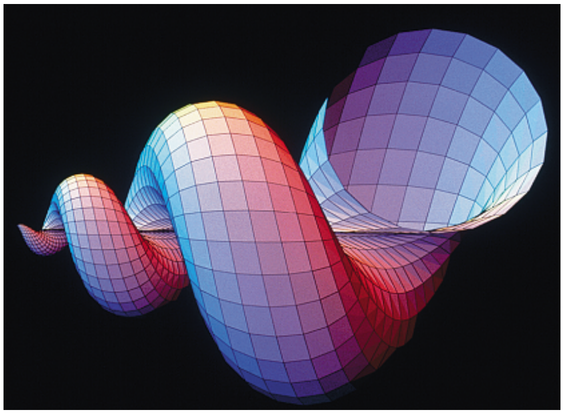

FIGURE 1-25 Lighting effects and surface-rendering techniques were applied to produce this surface representation for a three-dimensional function. (*Courtesy of Wolfram Research, Inc., The Maker of Mathematica.*)

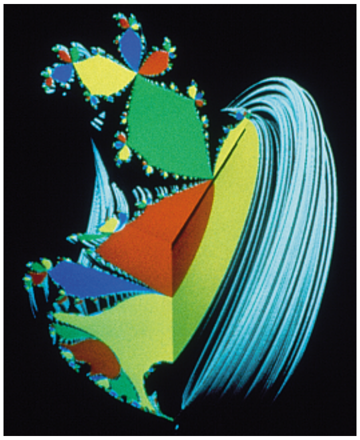

FIGURE 1-26 A four-dimensional object projected into three-dimensional space, then projected to the two-dimensional screen of a video monitor and color coded. The object was generated using quaternions and fractal squaring procedures, with an octant subtracted to show the complex Julia set. (*Courtesy of John C. Hart, Department of Computer Science, University of Illinois at Urbana-Champaign.*)

FIGURE 1-27 Four views from a real-time, interactive computer-animation study of minimal surfaces ("snails") in the 3-sphere projected to three-dimensional Euclidean space. (*Courtesy of George Francis, Department of Mathematics and the National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign.* © *1993.*)

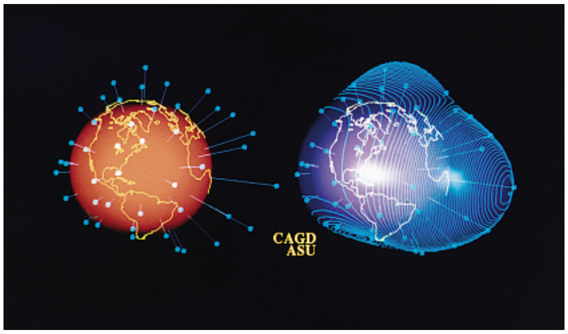

FIGURE 1–28 A method for graphing and modeling data distributed over a spherical surface. (*Courtesy of Greg Nielson, Computer Science Department, Arizona State University.*)

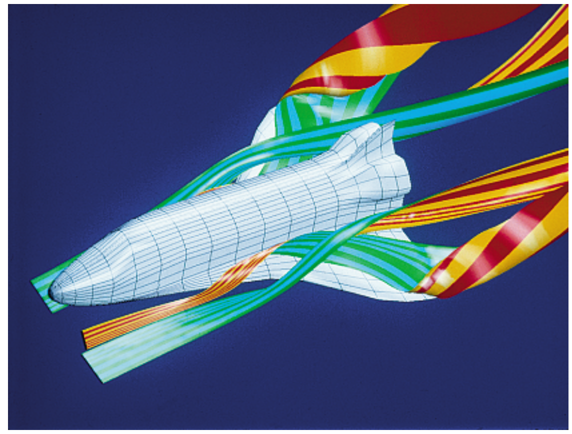

FIGURE 1–29 A visualization of stream surfaces flowing past a space shuttle, devised by Jeff Hultquist and Eric Raible, NASA Ames. (*Courtesy of Sam Uselton, NASA Ames Research Center.*)

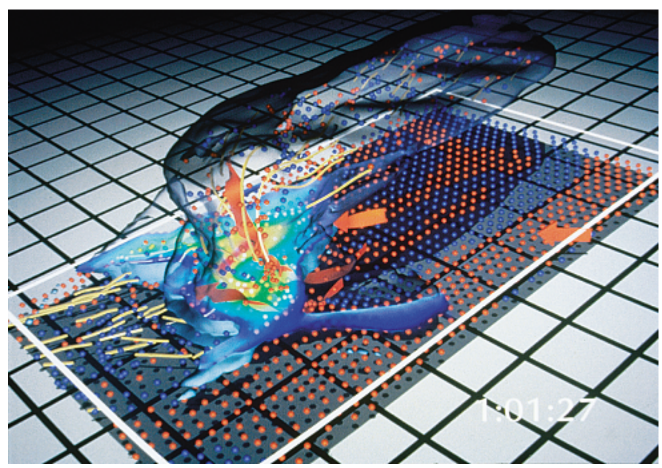

FIGURE 1–30 Numerical model of airflow inside a thunderstorm. (*Courtesy of Bob Wilhelmson, Department of Atmospheric Sciences and the National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign.*)

developing methods for visualizing general classes of data. Figure 1-28 shows a general technique for graphing and modeling data distributed over a spherical surface.

A few of the many other visualization applications are shown in Figs. 1-29 through 1-42. These figures show: airflow over the surface of a space shuttle, numerical modeling of thunderstorms, a display of the effects of crack propagation in metals, a color-coded plot of fluid density over an airfoil, a cross-sectional slicer for data sets, protein modeling, interactive viewing of molecular structures within a virtual-reality environment, a model of the ocean floor, a Kuwaiti oil-fire simulation, an air-pollution study, a corn-growing study, reconstruction of Arizona's Chaco Canyon ruins, and a graph of automobile accident statistics.

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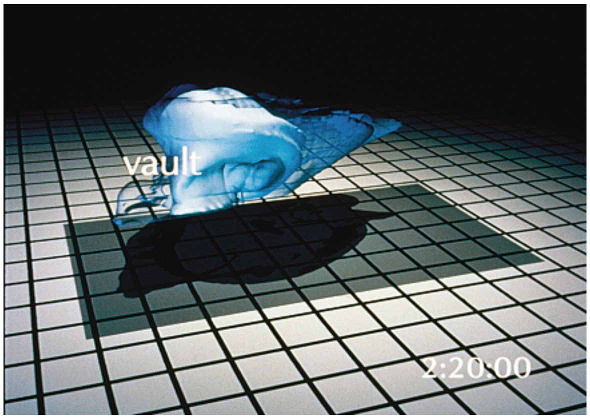

FIGURE 1-31 Numerical model of the surface of a thunderstorm. (*Courtesy of Bob Wilhelmson, Department of Atmospheric Sciences and the National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign.*)

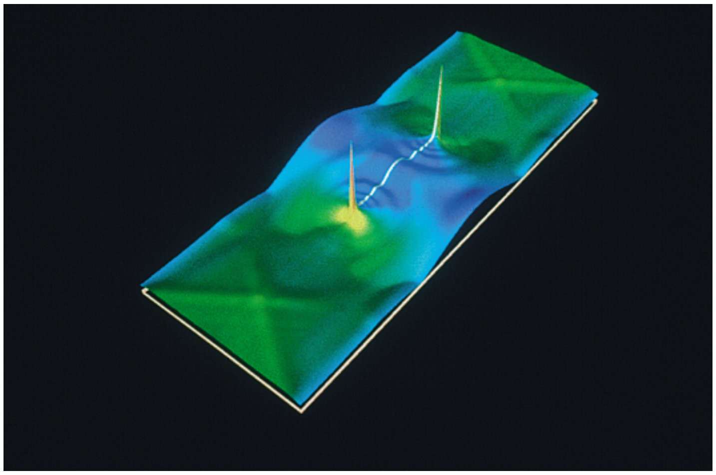

FIGURE 1-32 Color-coded visualization of stress energy density in a crack propagation study for metal plates, modeled by Bob Haber. (*Courtesy of the National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign.*)

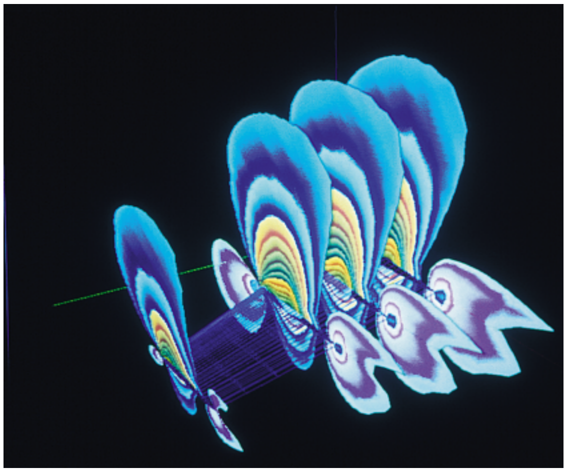

FIGURE 1-33 A fluid-dynamic simulation, showing a color-coded plot of fluid density over a span of grid planes around an aircraft wing, developed by Lee-Hian Quek, John Eickemeyer, and Jeffery Tan. (*Courtesy of the Information Technology Institute, Republic of Singapore.*)

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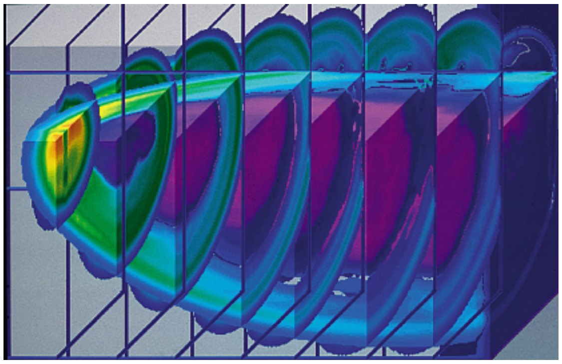

FIGURE 1-34 Commercial slicer-dicer software, showing color-coded data values over cross-sectional slices of a data set. (*Courtesy of Spyglass, Inc.*)

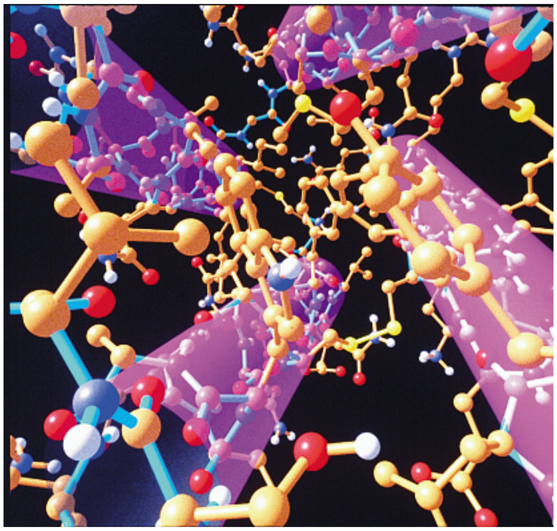

FIGURE 1-35 Visualization of a protein structure, created by Jay Siegel and Kim Baldridge, SDSC. (*Courtesy of Stephanie Sides, San Diego Supercomputer Center.*)

FIGURE 1-36 A scientist interacting with stereoscopic views of molecular structures within a virtual-reality environment called the "CAVE". (*Courtesy of William Sherman and the National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign.*)

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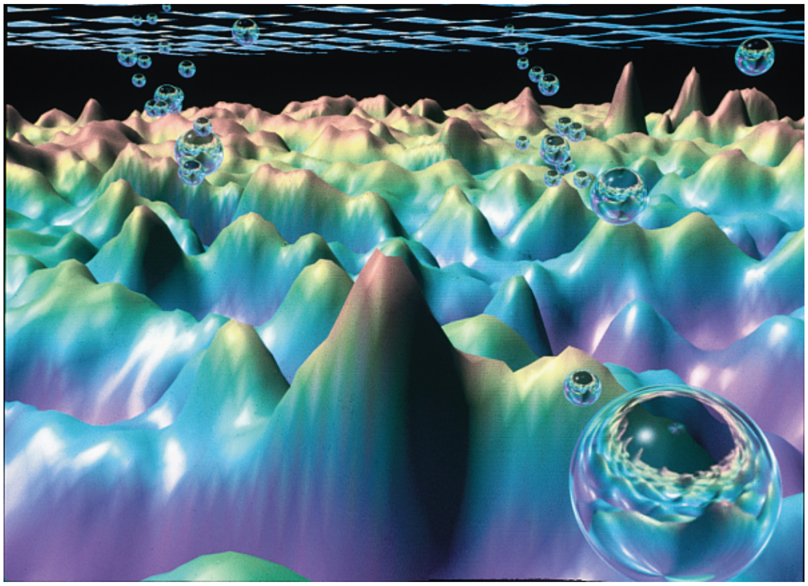

FIGURE 1-37 One image from a stereoscopic pair, showing a visualization of the ocean floor obtained from satellite data, created by David Sandwell and Chris Small, Scripps Institution of Oceanography, and Jim Mcleod, SDSC. (*Courtesy of Stephanie Sides, San Diego Supercomputer Center.*)

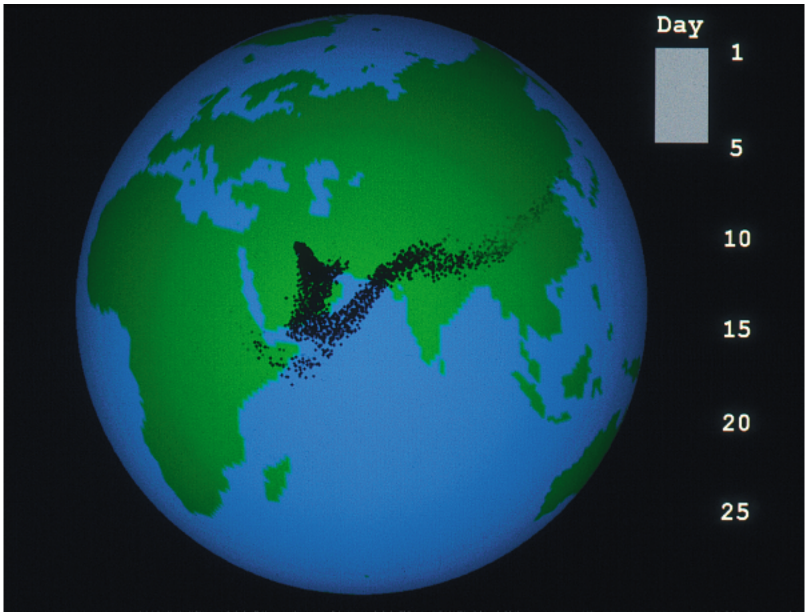

FIGURE 1-38 A simulation of the effects of the 1991 Kuwaiti oil fires, developed by Gary Glatzmeier, Chuck Hanson, and Paul Hinker. (*Courtesy of Mike Krogh, Advanced Computing Laboratory at the Los Alamos National Laboratory.*)

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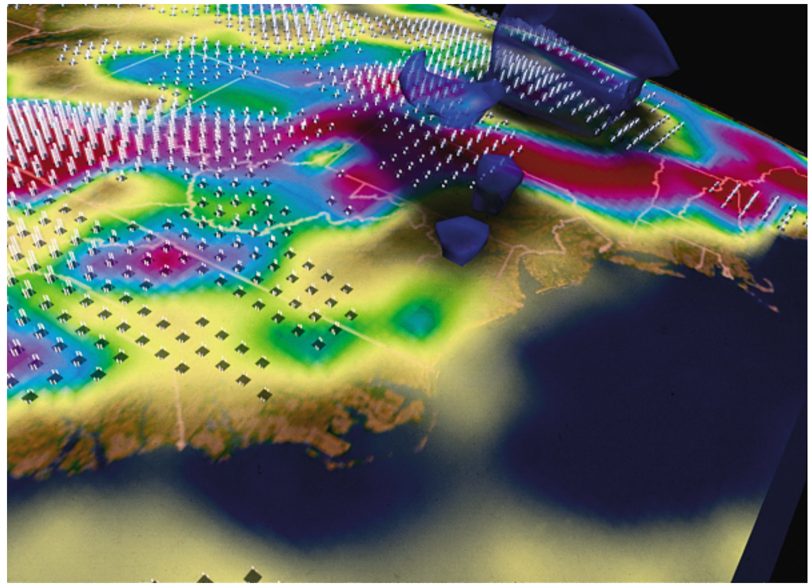

FIGURE 1–39 A visualization of pollution over the earth's surface, devised by Tom Palmer, Cray Research Inc./NCSC, Chris Landreth, NCSC, and Dave Bock, NCSC. Pollutant SO_4 is plotted as a blue surface, acid-rain deposition is a color plane on the map surface, and rain concentration is shown as clear cylinders. (*Courtesy of the North Carolina Supercomputing Center/MCNC.*)

FIGURE 1–40 One frame of an animation sequence showing the development of a corn ear. (*Courtesy of the National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign.*)

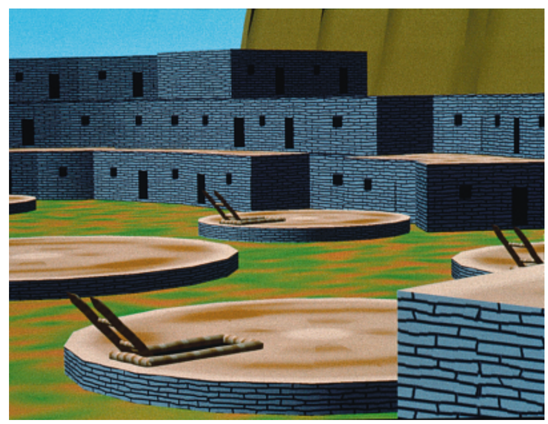

FIGURE 1–41 A visualization of the reconstruction of the ruins at Chaco Canyon, Arizona. (*Courtesy of Melvin L. Prueitt, Los Alamos National Laboratory. Data supplied by Stephen H. Lekson.*)

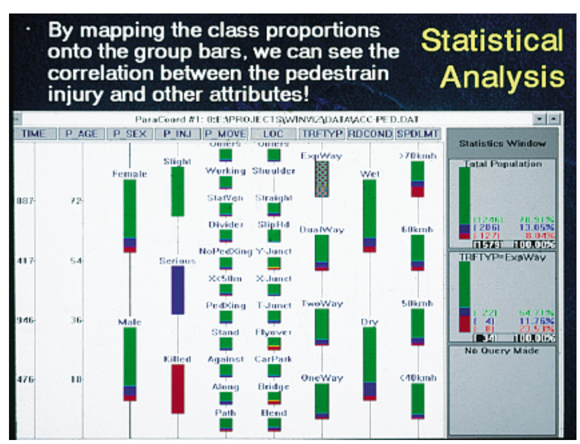

FIGURE 1–42 A prototype technique for visualizing tabular multidimensional data, called WinViz and developed by a visualization team at the Information Technology Institute, Republic of Singapore, is used here to correlate statistical information on pedestrians involved in automobile accidents. (*Courtesy of Lee-Hian Quek, Oracle Corporation, Redwood Shores, California.*)

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1-5 EDUCATION AND TRAINING

Computer-generated models of physical, financial, political, social, economic, and other systems are often used as educational aids. Models of physical processes, physiological functions, population trends, or equipment, such as the color-coded diagram in Fig. 1-43, can help trainees to understand the operation of a system.

For some training applications, special hardware systems are designed. Examples of such specialized systems are the simulators for practice sessions or training of ship captains, aircraft pilots, heavy-equipment operators, and air traffic-control personnel. Some simulators have no video screens; for example, a flight simulator with only a control panel for instrument flying. But most simulators provide screens for visual displays of the external environment. Two examples of large simulators with internal viewing systems are shown in Figs. 1-44 and 1-45. Another type of viewing system is shown in Fig. 1-46(b) and (c). Here a viewing screen with multiple panels is mounted in front of the simulator, and color projectors display the flight scene on the screen panels. Figure 1-47 shows the instructor's area that can be situated behind the cockpit of a flight simulator. The keyboard is used by the instructor to input parameters affecting the airplane performance or the environment, and the path of the aircraft and other data is viewed on the monitors during a training or testing session.

Scenes generated for aircraft, naval, and spacecraft simulators are shown in Figs. 1-48 through 1-50. An automobile simulator and associated imagery is given in Fig. 1-51. Part (a) of this figure shows the interior of the simulator and the viewing screen visible through the windshield. A typical traffic street scene is shown in Fig. 1-51 (b). Although automobile simulators can be used as training systems, they are commonly employed to study the behavior of drivers in critical situations. Driver reactions in various traffic conditions can then used as a basis for optimizing vehicle design to maximize traffic safety.

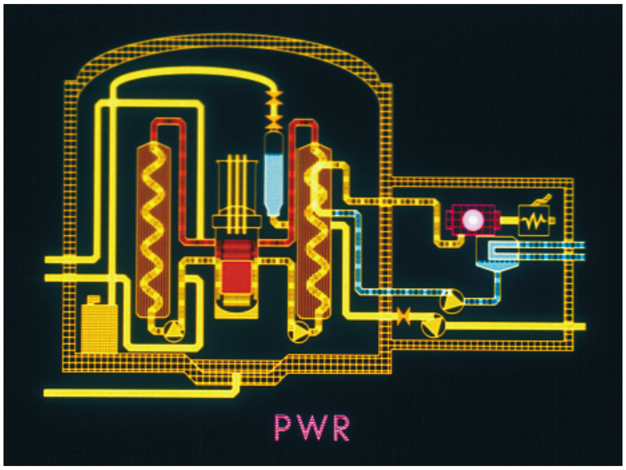

FIGURE 1-43 Color-coded diagram used to explain the operation of a nuclear reactor. (*Courtesy of Los Alamos National Laboratory.*)

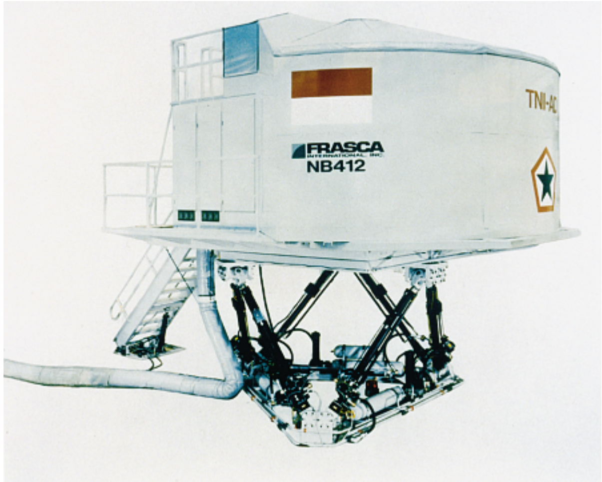

FIGURE 1–44 A large, enclosed flight simulator with a full-color visual system and six degrees of freedom in its motion. (*Courtesy of Frasca International.*)

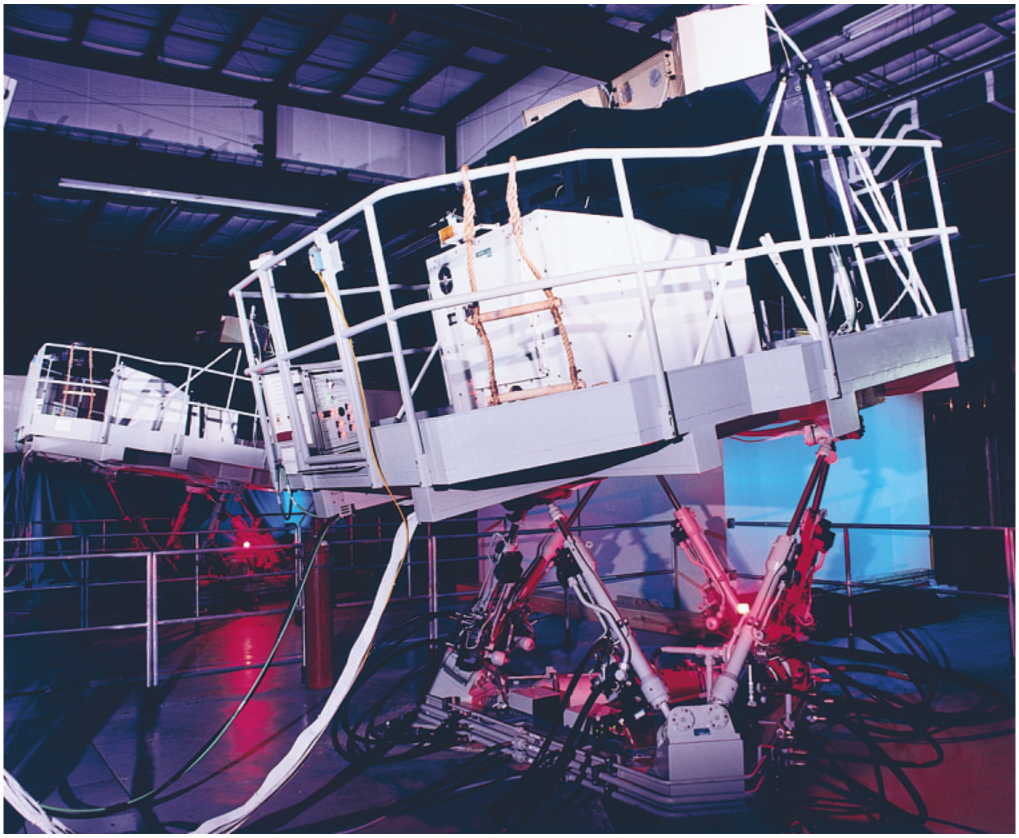

FIGURE 1–45 A military tank simulator with a visual imagery system. (*Courtesy of Mediatech and GE Aerospace.*)

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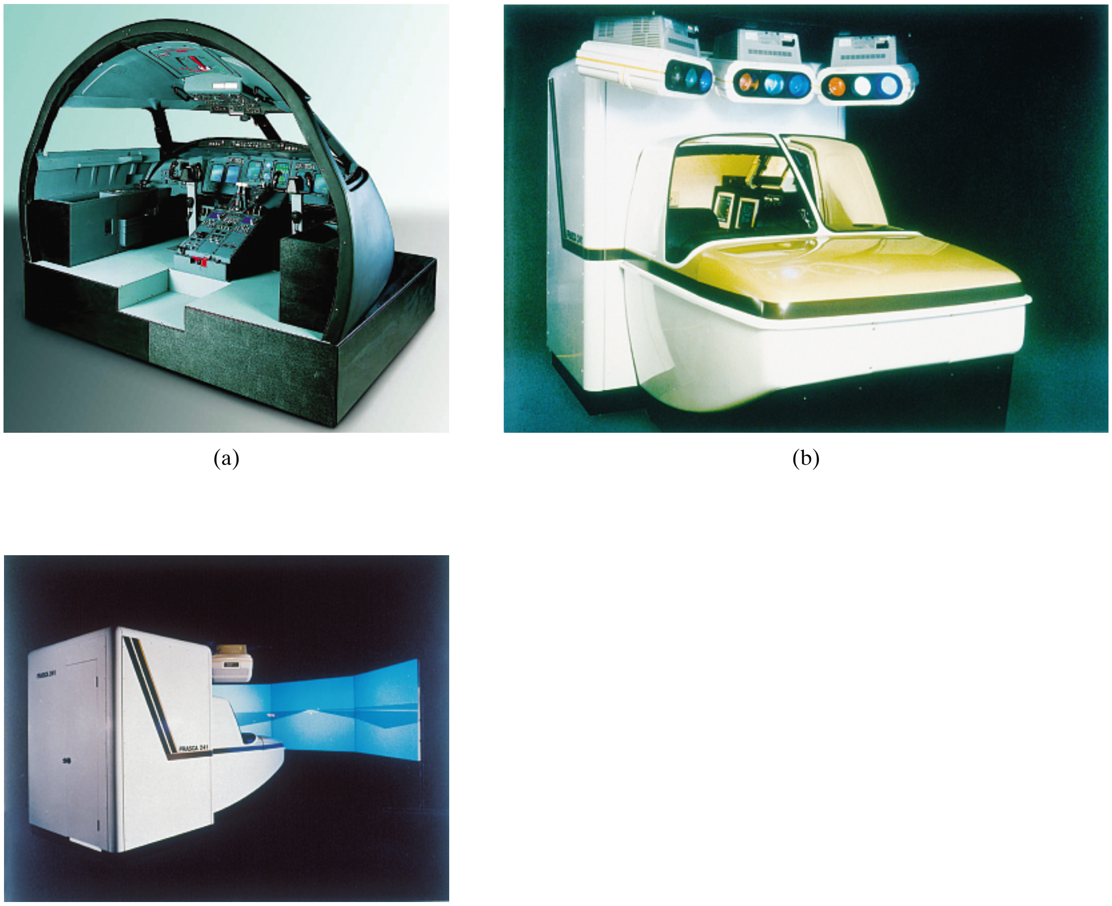

(a) (b)

(c)

FIGURE 1-46 The cabin interior (a) of a dual-control flight simulator, and an external full-color viewing system (b) and (c) for a small flight simulator. (*Courtesy of Frasca International.*)

FIGURE 1-47 An instructor's area behind the cabin of a small flight simulator. The equipment allows the instructor to monitor flight conditions and to set airplane and environment parameters. (*Courtesy of Frasca International.*)

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FIGURE 1–48 Flight-simulator imagery. (*Courtesy of Evans & Sutherland.*)

FIGURE 1–49 Imagery generated for a naval simulator. (*Courtesy of Evans & Sutherland.*)

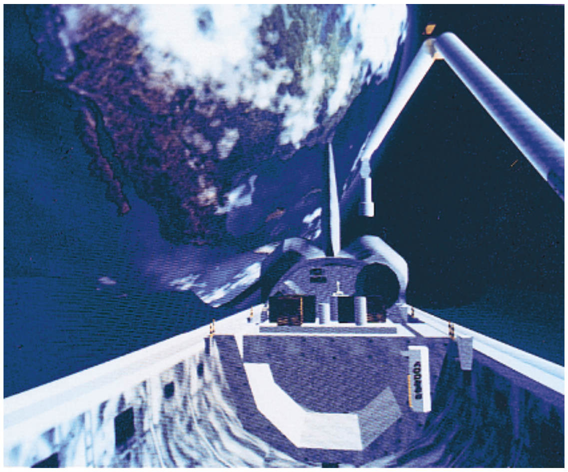

FIGURE 1–50 Space-shuttle imagery. (*Courtesy of Mediatech and GE Aerospace.*)

(a)

(b)

FIGURE 1-51 The interior of an automobile-simulator (a) and a street-scene view (b) that can be presented to a driver. (*Courtesy of Evans & Sutherland.*)

1-6 COMPUTER ART

Both fine art and commercial art make use of computer-graphics methods. Artists now have available a variety of computer methods and tools, including specialized hardware, commercial software packages (such as Lumena), symbolic mathematics programs (such as Mathematica), CAD packages, desktop publishing software, and animation systems that provide facilities for designing object shapes and specifying object motions.

Figure 1-52 gives a figurative representation of the use of a **paintbrush program** that allows an artist to "paint" pictures on the screen of a video monitor.

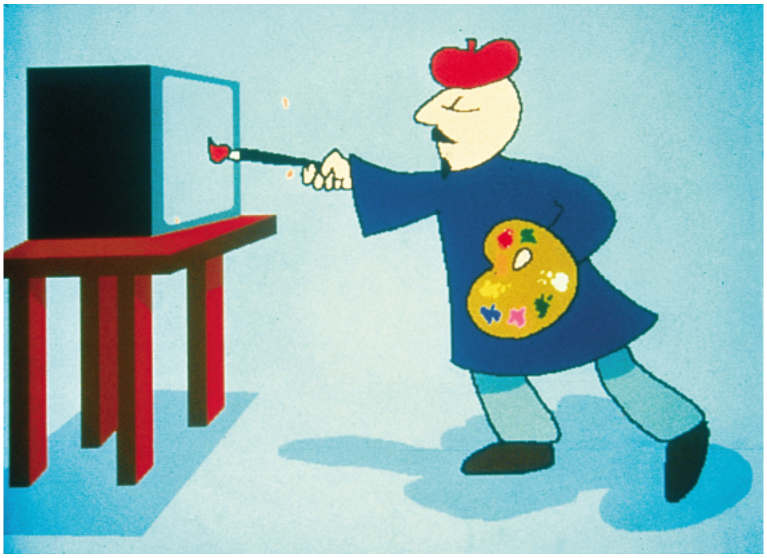

FIGURE 1-52 Cartoon drawing produced with a paintbrush program, symbolically illustrating an artist at work on a video monitor. (*Courtesy of Gould Inc., Imaging & Graphics Division, and Aurora Imaging.*)

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(a) (b)

FIGURE 1-53 Cartoon demonstrations of an "artist" creating a picture with a paintbrush system. In (a), the picture is drawn on a graphics tablet as elves watch the development of the image on the video screen. In (b), the artist and elves are superimposed on the famous Thomas Nast drawing of Saint Nicholas, which was input to the system with a video camera, then scaled and positioned. (*Courtesy of Gould Inc., Imaging & Graphics Division, and Aurora Imaging.*)

FIGURE 1-54 A Van Gogh look-alike created by graphics artist Elizabeth O'Rourke with a cordless, pressure-sensitive stylus. (*Courtesy of Wacom Technology Corporation.*)

Actually, the picture is usually painted electronically on a graphics tablet (digitizer) using a stylus, which can simulate different brush strokes, brush widths, and colors. Using a paintbrush program, a cartoonist created the characters in Fig. 1-53, who seem to be busy on a creation of their own.

A paintbrush system, with a Wacom cordless, pressure-sensitive stylus, was used to produce the electronic painting in Fig. 1-54 that simulates the brush strokes of Van Gogh. The stylus translates changing hand pressure into variable line widths, brush sizes, and color gradations. Figure 1-55 shows a watercolor painting produced with this stylus and with software that allows the artist to create watercolor, pastel, or oil brush effects that simulate different drying times, wetness, and footprint. Figure 1-56 gives an example of paintbrush methods combined with scanned images.

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FIGURE 1-55 An electronic watercolor, painted by John Derry of Time Arts, Inc. using a cordless, pressure-sensitive stylus and Lumena gouache-brush software. (*Courtesy of Wacom Technology Corporation.*)

FIGURE 1-56 The artist of this picture, entitled *Electronic Avalanche,* makes a statement about our entanglement with technology, using a personal computer with a graphics tablet and Lumena software to combine renderings of leaves, flower petals, and electronics components with scanned images. (*Courtesy of the Williams Gallery. © 1991 Joan Truckenbrod, The School of the Art Institute of Chicago.*)

Fine artists use a variety of other computer technologies to produce images. To create pictures such as the one shown in Fig. 1-57, the artist uses a combination of three-dimensional modeling packages, texture mapping, drawing programs, and CAD software. In Fig. 1-58, we have a painting produced on a pen plotter using specially designed software that can create "automatic art" without intervention from the artist.

Figure 1-59 shows an example of "mathematical" art. This artist uses a combination of mathematical functions, fractal procedures, Mathematica software, ink-jet printers, and other systems to create a variety of three-dimensional and two-dimensional shapes and stereoscopic image pairs. Another example of electronic art created with the aid of mathematical relationships is shown in Fig. 1-60. The artwork of this composer is often designed in relation to frequency variations and other parameters in a musical composition to produce a video that integrates visual and aural patterns.

Commercial art also uses these "painting" techniques for generating logos and other designs, page layouts combining text and graphics, TV advertising spots, and other applications. A workstation for producing page layouts that combine text and graphics is illustrated in Fig. 1-61.

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FIGURE 1-57 From a series called "Spheres of Influence", this electronic painting (entitled *Whigmalaree*) was created with a combination of methods using a graphics tablet, three-dimensional modeling, texture mapping, and a series of geometric transformations. (*Courtesy of the Williams Gallery. © 1992 Wynne Ragland, Jr.*)

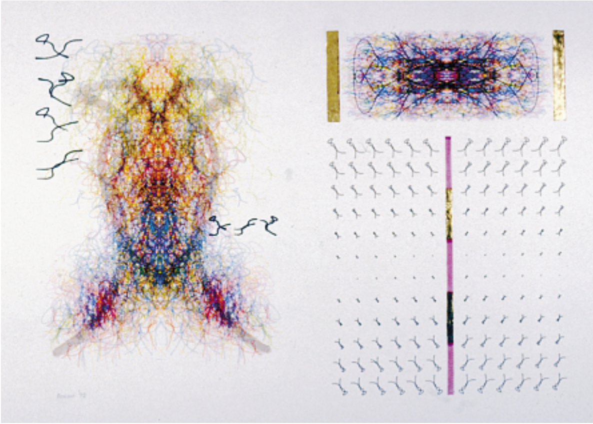

FIGURE 1-58 Electronic art output to a pen plotter from software specially designed by the artist to emulate his style. The pen plotter includes multiple pens and painting instruments, including Chinese brushes. (*Courtesy of the Williams Gallery. © Roman Verostko, Minneapolis College of Art & Design.*)

FIGURE 1-59 This creation is based on a visualization of Fermat's Last Theorem, $x^n + y^n = z^n$, with $n = 5$, by Andrew Hanson, Department of Computer Science, Indiana University. The image was rendered using Mathematica and Wavefront software. (*Courtesy of the Williams Gallery. © 1991 Stewart Dickson.*)

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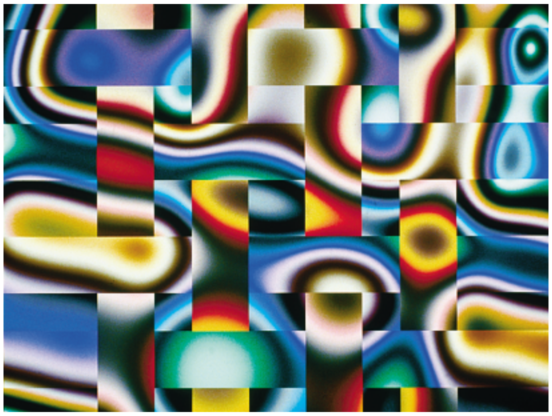

FIGURE 1-60 Using mathematical functions, fractal procedures, and supercomputers, this artist-composer experiments with various designs to synthesize form and color with musical composition. (*Courtesy of Brian Evans, Vanderbilt University.*)

FIGURE 1-61 Page-layout workstation. (*Courtesy of Visual Technology.*)

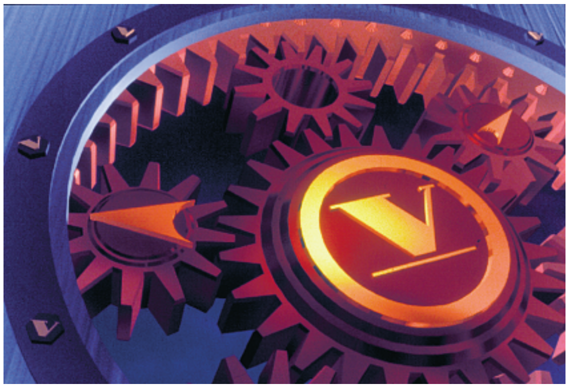

FIGURE 1-62 Three-dimensional rendering for a logo. (*Courtesy of Vertigo Technology, Inc.*)

As in many other computer-graphics applications, commercial-art displays often employ photo-realistic techniques to render images of a design, product, or scene. Figure 1-62 shows an example of three-dimensional logo design, and Fig. 1-63 gives three computer-graphics images for product advertising.

Computer-generated animations are also frequently used in producing television commercials. These advertising spots are generated frame by frame, where each frame of the motion is rendered and saved as a separate image file. In each successive frame, object positions are displaced slightly to simulate the motions involved in the animation. When all frames in the animation sequence have been rendered, the frames are transferred to film or stored in a video buffer for playback. Film animations require 24 frames for each second in the animation sequence. If the animation is to be played back on a video monitor, at least 30 frames per second are required.

A common graphics method employed in many television commercials is *morphing*, where one object is transformed (metamorphosed) into another. This method has been used in TV commercials to turn an oil can into an automobile

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(a) (b) (c)

FIGURE 1-63 Product advertising using computer-generated images. (*Courtesy of* (a) *Audrey Fleisher and* (b) *and* (c) *SOFTIMAGE, Inc.*)

engine, an automobile into a tiger, a puddle of water into a tire, and one person's face into another face. An example of morphing is given in the next section (Fig. 1-69).

1-7 ENTERTAINMENT

Television productions, motion pictures, and music videos routinely use computer-graphics methods. Sometimes graphics images are combined with live actors and scenes, and sometimes the films are completely generated using computer-rendering and animation techniques.

Many TV series regularly employ computer-graphics methods to produce special effects, such as the scene in Figure 1-64 from the television series *Deep Space Nine*. Some television programs also use animation techniques to combine computer-generated figures of people, animals, or cartoon characters with the live actors in a scene or to transform an actor's face into another shape. And many programs employ computer graphics to generate buildings, terrain features, or other backgrounds for a scene. Figure 1-65, shows a highly realistic computer-generated view of thirteenth-century Dadu (now Beijing) for a Japanese television broadcast.

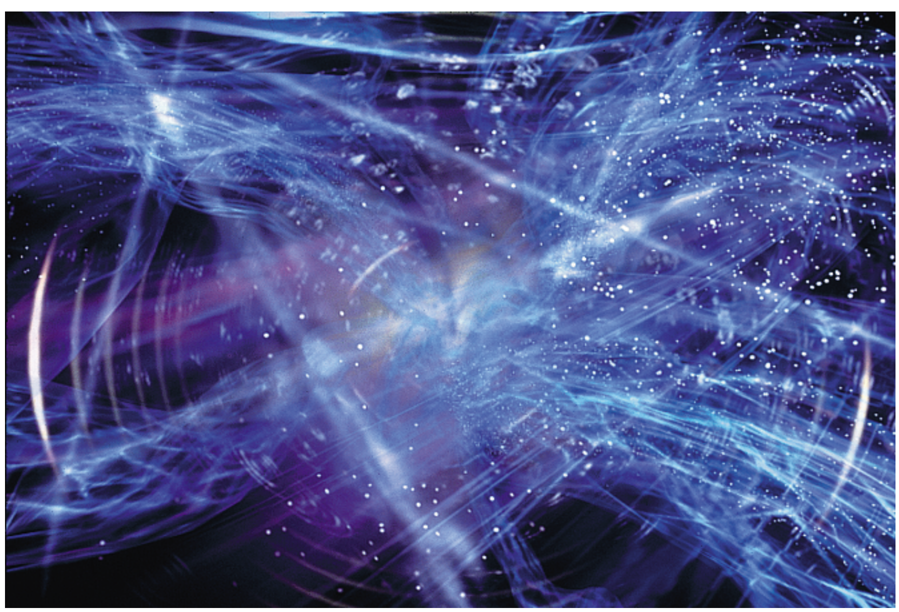

FIGURE 1-64 A graphics scene from the TV series *Deep Space Nine*. (*Courtesy of Rhythm & Hues Studios.*)

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FIGURE 1-65 An image from a computer-generated reconstruction of thirteenth-century Dadu (Beijing today), created for a Japanese broadcast by Taisei Corporation (Tokyo, Japan) and rendered with TDI software. (*Courtesy of Thomson Digital Image, Inc.*)

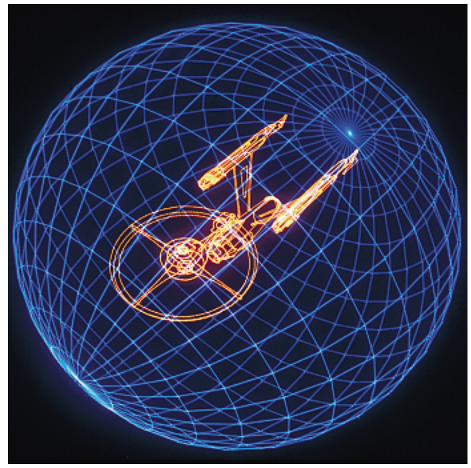

FIGURE 1-66 Graphics developed for the Paramount Pictures movie *Star Trek—The Wrath of Khan*. (*Courtesy of Evans & Sutherland.*)

(a) (b)

FIGURE 1-67 Computer-generated film scenes: (a) *Red's Dream*, (*Courtesy of Pixar.* Copyright © Pixar 1987.), and (b) *Knickknack*, (*Courtesy of Pixar.* Copyright © Pixar 1989.)

Computer-generated special effects, animations, characters, and scenes are widely used in todays motion pictures. Figure 1-66 illustrates a preliminary computer-graphics scene generated for the movie *Star Trek—The Wrath of Khan*. Rendering methods are then applied to the wire-frame forms for the planet and spaceship in this illustration to produce the final surface appearances of the objects that are shown in the film. Advanced computer-modeling and surface-rendering methods were employed in two award-winning short films to produce the scenes shown in Fig. 1-67. Other films employ computer modeling, rendering, and animation to produce an entire human-like cast of characters. Photo-realistic techniques are employed in such films to give the computer-generated "actors" flesh tones,

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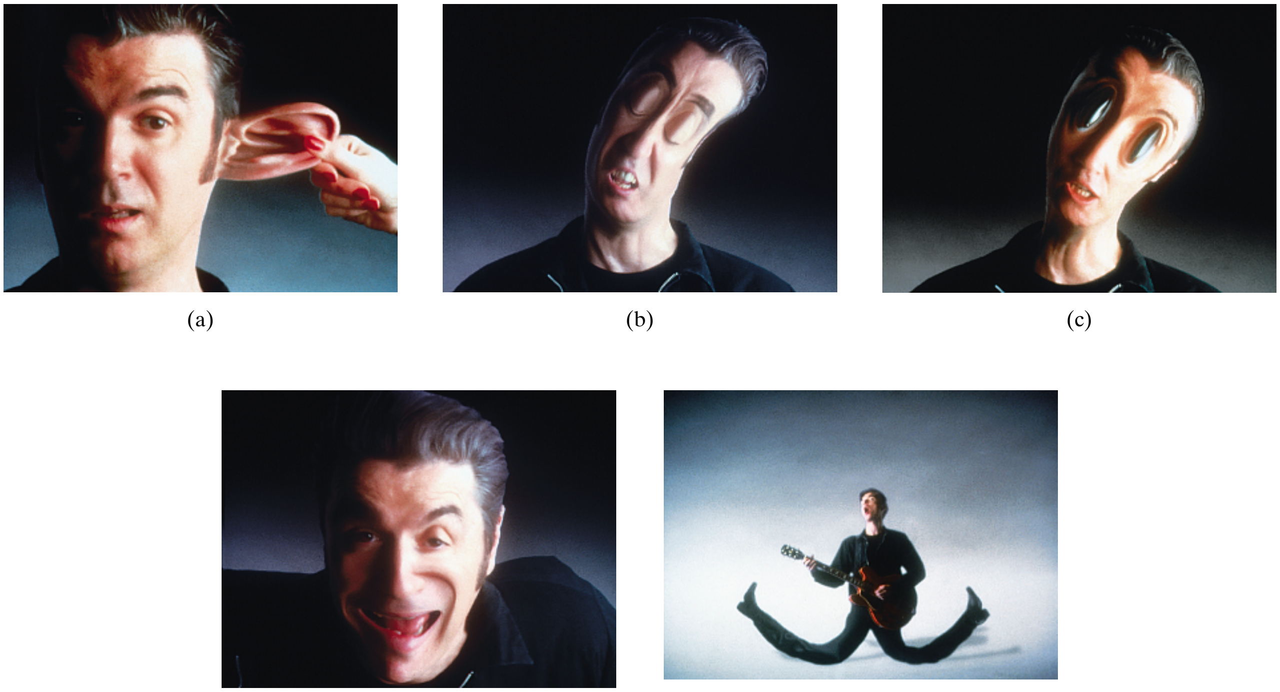
FIGURE 1-68 A scene from the film *Final Fantasy: The Spirits Within*, showing three of the animated characters in the cast: Dr. Aki Ross, Gray Edwards, and Dr. Sid. (*Courtesy of Square Pictures, Inc.* © *2001 FFFP. All rights reserved.*)



(a) (b) (c)

(d) (e)

FIGURE 1-69 Examples of morphing from the David Byrne video *She's Mad*. (*Courtesy of David Byrne, Index Video, and Pacific Data Images.*)

realistic facial features, and skin imperfections such as moles, sunspots, freckles, and acne. Figure 1-68 shows a scene from the film *Final Fantasy: The Spirits Within*, which employed these photo-realistic techniques to closely simulate the appearance of a cast of human actors.

Computer-graphics methods can also be employed to simulate a human actor. Using digital files of an actor's facial features, an animation program can generate film sequences that contain a computer-generated replica of that person. In the event of an illness or accident during the filming of a motion picture, these simulation methods can be used to replace the actor in subsequent film scenes.

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Music videos use computer graphics in several ways. Graphics objects can be combined with the live action, or graphics and image-processing techniques can be used to produce a transformation of one person or object into another (morphing). An example of morphing is given in the sequence of scenes in Fig. 1-69, produced for the David Byrne video *She's Mad*.

1-8 IMAGE PROCESSING

The modification or interpretation of existing pictures, such as photographs and TV scans, is called **image processing.** Although methods used in computer graphics and image processing overlap, the two areas are concerned with fundamentally different operations. In computer graphics, a computer is used to create a picture. Image-processing techniques, on the other hand, are used to improve picture quality, analyze images, or recognize visual patterns for robotics applications. However, image-processing methods are often used in computer graphics, and computer-graphics methods are frequently applied in image processing.

Typically, a photograph or other picture is digitized into an image file before image-processing methods are employed. Then digital methods can be used to rearrange picture parts, to enhance color separations, or to improve the quality of shading. An example of the application of image-processing methods to enhance the quality of a picture is shown in Fig. 1-70. These techniques are used extensively in commercial-art applications that involve the retouching and rearranging of sections of photographs and other artwork. Similar methods are used to analyze satellite photos of the earth and telescopic recordings of galactic star distributions.

Medical applications also make extensive use of image-processing techniques for picture enhancements in tomography and in simulations of surgical operations. Tomography is a technique of X-ray photography that allows cross-sectional views of physiological systems to be displayed. *Computed X-ray tomography* (CT), *position emission tomography* (PET), and *computed axial tomography* (CAT) use projection methods to reconstruct cross sections from digital data. These techniques are also used to monitor internal functions and to show cross sections

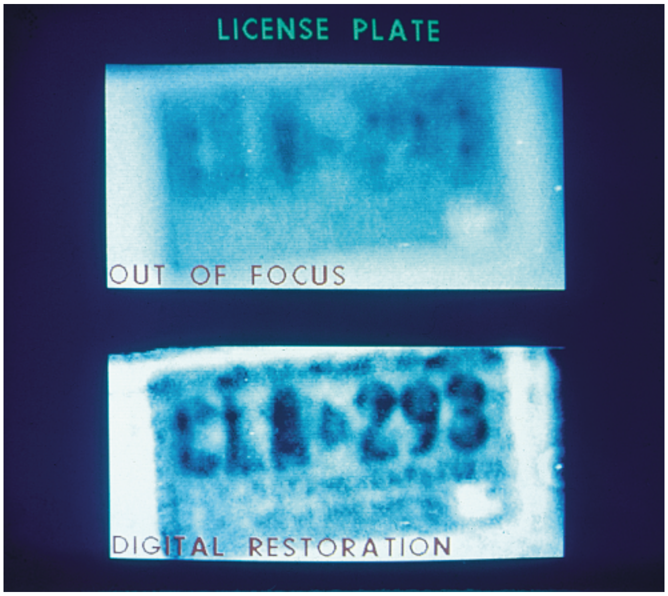

FIGURE 1-70 A blurred photograph of a license plate becomes legible after the application of image-processing techniques. (*Courtesy of Los Alamos National Laboratory.*)

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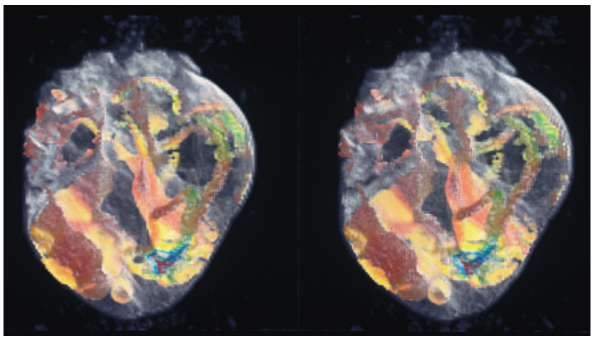

FIGURE 1-71 One frame from a computer animation visualizing cardiac activation levels within regions of a semitransparent volume-rendered dog heart. Medical data furnished by William Smith, Ed Simpson, and G. Allan Johnson, Duke University. Image-rendering software provided by Tom Palmer, Cray Research, Inc./NCSC. (*Courtesy of Dave Bock, North Carolina Supercomputing Center/MCNC.*)

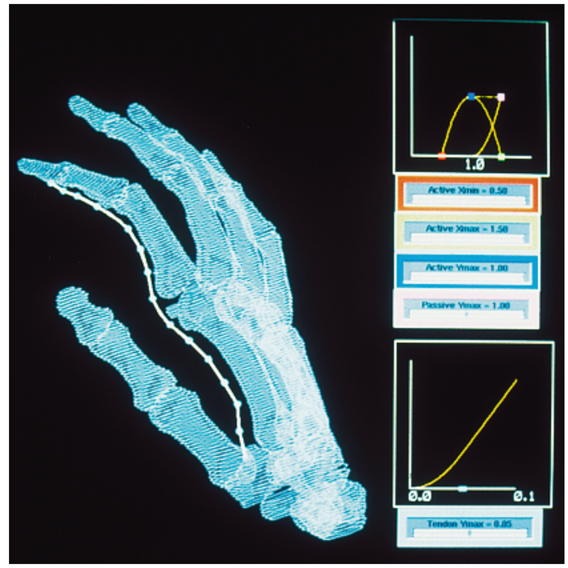

FIGURE 1-72 One image from a stereoscopic pair, showing the bones of a human hand, rendered by Inmo Yoon, D. E. Thompson, and W. N. Waggenspack, Jr., LSU, from a data set obtained with CT scans by Rehabilitation Research, GWLNHDC. These images show a possible tendon path for reconstructive surgery. (*Courtesy of IMRLAB, Mechanical Engineering, Louisiana State University.*)

during surgery. Other medical imaging techniques include ultrasonics and nuclear medicine scanners. With ultrasonics, high-frequency sound waves are used instead of X-rays to generate digital data. Nuclear medicine scanners collect digital data from radiation that is emitted by ingested radionuclides, and the data is then plotted as color-coded images.

Image processing and computer graphics are often combined in medical applications to model and study physical functions, to design artificial limbs, and to plan and practice surgery. The last application is generally referred to as *computer-aided surgery*. Two-dimensional cross sections of the body are obtained using imaging techniques. Then the slices are viewed and manipulated using graphics methods to simulate actual surgical procedures and to try out different surgical cuts. Examples of these medical applications are shown in Figs. 1-71 and 1-72.

1-9 GRAPHICAL USER INTERFACES

It is common now for applications software to provide a **graphical user interface** (GUI). A major component of a graphical interface is a window manager that allows a user to display multiple, rectangular screen areas, called display windows. Each screen display area can contain a different process, showing graphical or nongraphical information, and various methods can be used to activate a display window. Using an interactive pointing device, such as a mouse, we can active a display window on some systems by positioning the screen cursor within the window display area and pressing the left mouse button. With other systems, we may need to click on the title bar at the top of the display window.

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FIGURE 1–73 A graphical user interface, showing multiple display windows, menus, and icons. (*Courtesy of Image-In Corporation.*)

Interfaces also display menus and icons for selection of a display window, a processing option, or a parameter value. An **icon** is a graphical symbol that is often designed to suggest the option it represents. The advantages of icons are that they take up less screen space than corresponding textual descriptions and they can be understood more quickly if well designed. A display window can often be converted to or from an icon representation, and menus can contain lists of both textual descriptions and icons.

Figure 1-73 illustrates a typical graphical interface, containing multiple display windows, menus, and icons. In this example, the menus allow selection of processing options, color values, and graphics parameters. The icons represent options for painting, drawing, zooming, typing text strings, and other operations connected with picture construction.

1-10 SUMMARY

We have surveyed many of the areas in which computer graphics is applied, including data graphing, CAD, virtual reality, scientific visualization, education, art, entertainment, image processing, and graphical user interfaces. However, many other fields were not mentioned, and we could have filled this book with examples from the many other applications areas. In the following chapters, we explore the equipment and methods used in the applications discussed in this chapter, as well as various other applications.

REFERENCES

Applications of graphical methods in various areas, including art, science, mathematics, and technology, are treated in Bouquet (1978), Yessios (1979), Gardner and Nelson (1983), Grotch (1983), Tufte (1983 and 1990), Wolfram (1984), Huitric and Nahas (1985), Glassner (1989), and Hearn and Baker (1991). Graphics methods for visualizing music are given in Mitroo, Herman, and Badler (1979). Detailed discussions of computer-aided design and manufacturing (CAD/CAM) in various industries are presented in Pao (1984). Graphics techniques for flight simulators are presented in Schachter (1983). Fu and Rosenfeld (1984) discuss simulation of vision, and Weinberg (1978) gives an account of space-shuttle simulation. Graphics icon and symbol concepts are presented in Lodding (1983) and in Loomis, et al. (1983). For additional information on medical applications see Hawrylyshyn, Tasker, and Organ (1977); Preston, Fagan, Huang, and Pryor (1984); and Rhodes, et al. (1983).