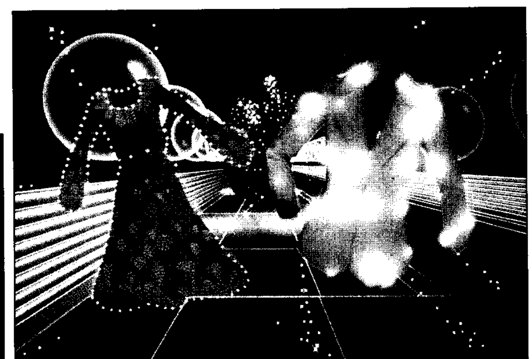
Falling costs for computer graphics hardware and software have improved access for artists and animators. They now face the challenge of successfully using technology in their art.

Art and Animation

Charles A. Csuri
Ohio State University



"Levi Commercial" by Robert Abel, Robert Abel and Associates (animation)

"Ray Tracing with Vases" by Shaun Ho, Cranston-Csuri Productions (still)

The early 1980s still found high-end computer graphics exceedingly expensive for artists, with multiple refrigerator-size cabinets for computers costing more than $100,000 and film recorders at $100,000-$250,000. This did not include the cost of custom software and devices such as one-inch videotape machines, scanners, and digitizers. Only production companies charging $3,000 per second for commercials and advanced university computer graphics research centers could afford the technology.

Even when artists and animators had access to equipment, it was very difficult for them to understand computer graphics and to use the software. Often the artists had the perception they were dealing with a mystical universe or an alien culture. Relatively few educational programs dealt with 3D graphics and animation. Moreover, computer graphics in the early 1980s was an elitist activity limited to those who had access to the high-end hardware, not artists and animators.

The issue of access began to change dramatically about the middle of the decade. We witnessed the introduction of lower cost workstations, which seemed to explode upon the scene with significant reductions in cost and greater CPU speed, memory, and disk storage space. Commercial software packages for art and animation began to appear, although still expensive. The improvements of personal computers with better software made it possible for more artists to have access to computer graphics. Siggraph and NCGA played a very important role, providing opportunities for the art community to learn about computer graphics with panels and courses. The film and video shows as well as the art exhibitions demonstrated the potential for the fine arts. Various publications, such as *IEEE Computer Graphics and Applications*, *Computer Pictures*, *Computer Graphics World*, and *Leonardo*, continue to provide a forum illustrating advanced methods and concepts applicable to the arts.

"Flock" by M. Girard and Susan Amkraut, Ohio State University (animation)

"Mandela" by David Sherwin, Berkeley, Calif. (still)

"Ductile Flow" by Craig Reynolds, Symbolics (animation)

"Tree" by Peter Oppenheimer, New York Institute of Technology (still)

Production houses lead the way

The legacy for art and animation, especially animation, for most of the decade came from commercial production companies. Artists, animators, and film makers brought an esthetic sensibility to the production of television commercials. Their imagination and intuitive grasp of the implications of computer control over motion, color, object synthesis, and rendering lent artistic value to the commercials. Outstanding companies included Magi, Robert Abel Associates, Information International, Pacific Data Images, Sogetec, Industrial Light and Magic, and Cranston-Csuri Productions.

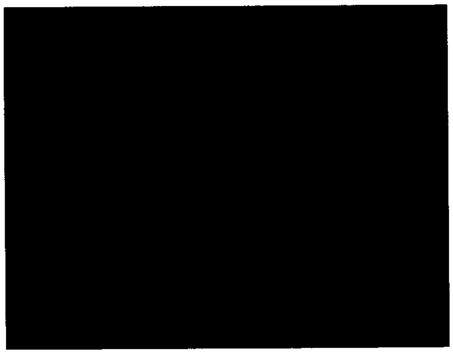
The creativity, excitement, and development in special effects were truly remarkable. Competition among these companies stimulated new techniques. Computer graphics software tools in the hands of visual artists clearly demonstrated the beauty and power of computer animation. The complexity of the creative task required incredible cooperation and communication among artists, computer programmers, video and film experts, and creative directors. The interaction of such groups within production companies encouraged new ideas and expanded everyone's understanding of this application of computer graphics.

This user community also raised questions and challenges to computer graphics researchers that, at least indirectly, had an impact upon the field. The commercials shown on national television helped promote computer graphics as a medium for communication. Many of the commercials created during this period remain today some of the best examples of art and animation.

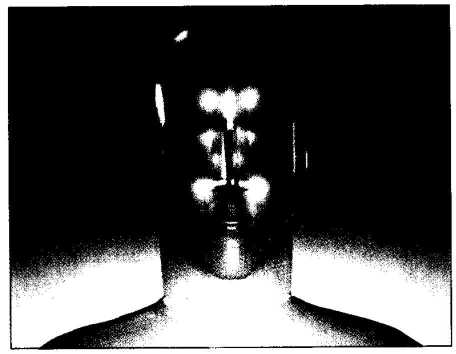
The rapid progress of computer technology and the development of commercial graphics packages has been rather amazing, and the rate of change in cost and performance, spectacular. We can only generalize and predict that this rate of change will continue, providing even greater CPU speed, memory, and disk space. Judging from the exhibition floor of the recent Siggraph conference, high quality rendering is commonplace, and numerous tools exist for motion control and image processing.

Many artists now have access to relatively low-cost hardware and software. Educational institutions and independent artists can acquire better software packages at low cost or even for free (e.g., Thompson Digital Images and Wavefront). The integrated software package APE (animation production environment) is available with tools for animation, image processing, and rendering, including the source code, simply for the cost of a distribution tape and postage.

While we have seen significant developments during the last decade in rendering, animation systems and motion control,



"Interactive Communication" by Myron Krueger, Vernon, Conn. (animation)



"Tron" by Magi Inc. (animation)

and image processing, software for geometric modeling lags far behind and continues to be a major problem. Sophisticated packages are available to create 3D data, but they tend to be quite expensive and generally awkward to use. In reality, requirements for objects with great detail and complex geometry still take patience and a long time to generate. Scanning hardware now available can digitize a human head or small objects, but it is expensive and has problems with small detail. Within a few years we will see scanners to digitize the entire human body. In fact, the government has put out an RFP (request for proposal) for such a device.

What will probably appear soon in the marketplace are libraries or databases of all kinds of objects, such as cars, ships, people, trees, buildings, landscapes, flowers, etc. You could purchase the entire database, but it will likely be exceedingly expensive. On the other hand, you might be able to purchase an individual object at a relatively low cost to obtain a savings in time and energy. We might also see databases for special surface properties, such as stucco, wood, plastic, plaster, cement, and a variety of fabrics, plus designs and icons or symbols.

Advances in animation

Computer animation for the most part has represented a synthetic reality exploiting advanced techniques in rendering and motion control. Computer graphics researchers continue to emphasize the imitation of nature with photographic realism as their primary objective. However, the representation of realistic creature motion continues to challenge research. To exploit a full range of imagery, artists will use more live action film with image processing techniques to modify the images. On the other hand, artists are not quite purists, because in the final analysis they want to make an artistic statement.

We will have technology to convert the video source into an RGB frame, compress the data with encoding techniques, and store many minutes of the live action onto a digital disk. This technology to convert to RGB will be relatively inexpensive, making longer films possible. We can also expect technology to transfer animation frames from disk to a frame buffer in real time.

Image processing can be applied to a live action sequence, making it appear, for example, like an impressionistic painting or a line drawing in motion. There are infinite possibilities, depending upon the creativity and imagination of the artist. The learning curve for artists to work with image processing is shorter than that for obtaining the knowledge and understanding required to work exclusively with 3D computer graphics. Of course, many artists who know 3D computer graphics and animation will combine live action and image processing with synthesized 3D objects and environments.

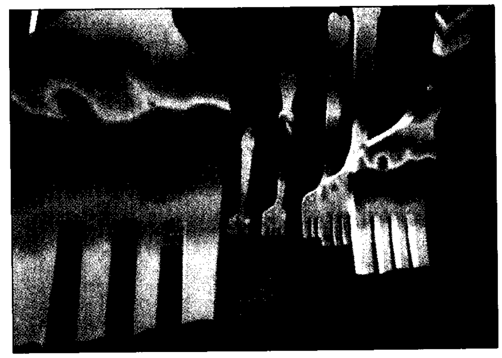
During the past decade the graphics community has made major progress with rendering, animation systems (some of which have forward and inverse kinematics as well as dynamic simulation), and to a certain extent with geometric modelers. Systems are better integrated with improved interfaces that exploit the use of icons, sliders representing a broad spectrum of functions. We are moving in the direction of real-time interaction, which allows artists to work with software tools and algorithmic models at an intuitive level. Since researchers have reasonably solved many of the difficult lower level issues, we have a framework that can provide a higher level of control, offering more customized tools for the artist's individual aesthetic. Each artist will need manipulation of objects and motion in a special way, expressing stylistic differences.

Algorithms for animation

The state of software development might be in a good position to deal with such concerns. This means the layering of higher level control upon lower level software, which is certainly not a new idea, but programming requirements made it difficult to build such systems. We do have examples of the algorithmic control of data generation or motion control. Various researchers have simulated natural phenomena such as trees, water, and mountains using fractal geometry and procedural models. Especially notable is the work of William Reeves and Alain Fournier with waves and Alvy Ray Smith with plants.

In the film *Eurythmy*, Susan Amkraut developed Flock, a system using vector force fields to control the motion of a flock of birds. Basically, a vector force field can be seen as a space in which each point in the space is assigned a directed arrow or "vector." A moving organism can be "given directions" about

"Everglade" by Darcy Gerbarg, Graheamsville, N.Y. (still)



"Broken Heart" by Joan Stavely, Ohio State University (still)

where it should go at every point it passes through. The family of all paths, taken together, constitute the flow of the vector field.

The Flock system provides the animator with a set of vector fields classifiable by the type of flow lines that result. The animator's choice of field will, therefore, direct the population's overall pattern of movement. The fields produce flows from linear differential equations, which can be elegantly classified by their "shapes of movement" in space. The classes include flows that repel, attract, and spin organisms about different axes in their own coordinate systems.

John Fujii and Tom Benoit in their film *Coredump* used algorithms that utilized large groups of vector-controlled entities focused on common flight objectives. Attributes such as directionality, velocity, freedom of rotation, color, and spatial distribution were all designed for easy accessibility, with additional emphasis placed on organizing stochastic methods and natural life models to achieve more organic expressions of form.

The *Ductile Flow* video by Craig Reynolds demonstrated a technique for visualizing flow fields in three dimensions. Polyhedral objects move with the flow and trace its motion through space. Flow patterns are created by iterating nonlinear spatial transformations. Polyhedral objects placed in the flow move with it. Adaptive subdivision provides sufficient ductility. The polyhedra are made as flexible and yielding as necessary. When an edge or face becomes larger than a certain maximum size, it is subdivided.

Then we have behavioral animation, which goes beyond simulations based solely on the physical behavior of objects. Instead of acting under the laws of physics, we take into account the neurological and psychological laws that govern a creature's behavior.

These anticipated changes will result from the integration of better lower level systems with the use of object-oriented programming languages. Artists will more routinely use these capabilities.

Further opinions expressed

The following from my earlier works further explain my opinions and definitions of art. I encourage interested readers to consult them.

"Art, Computers, and Mathematics," *Fall Joint Computer Conference*, AFIPS Conf. Proc., Vol. 33, Thompson, Washington, D.C., 1968.

"Real-Time Film Animation," *9th Ann. UAIDE Proc.*, 1970.

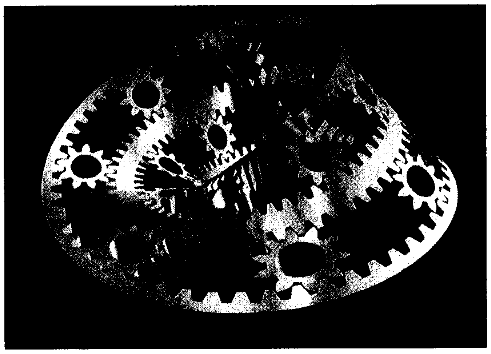
"Interactive Sound and Visual Systems," catalogue from the exhibition, Ohio State University, May 1970.

"Computer Graphics and Art," *Proc. IEEE*, Vol. 62, No.4, April 1974.

Moving into virtual reality

Interactive art objects as an art form have been around since the late 1960s. Today, they form a category at Ars Electronica, an international computer art and music competition. The Siggraph art show and the Artec Bienalle in Japan also recognize this as an important direction for the arts. Because it indicates a new dimension for the arts, artists are increasingly becoming interested in interactive art. Interactive art objects and some of the issues associated with this direction could easily be the subject of an extensive article. Perhaps my descriptions of art and interactive, real-time art objects (see the sidebar) are still appropriate, since we have the same conceptual problems about this art form today:

> Real-time computer art objects are an intellectual concept which can be visually experienced rather than a finalized material object. This kind of computer art exists for the time the participant and the computer with the CRT display are interacting as a process. The art object is not the computer or the display, but the activity of both interacting with the participant. In addition to its artistic parameters, the content of this art form is dependent upon the dynamics of a real-time process which give vital-



"Gears" by Thomas Longtin, Cranston-Csuri Productions

ity and life to the visual display through animation and user interaction. The participant becomes acutely aware of three-dimensional space as images are changed dynamically, and this perception represents an important parameter in the aesthetic experience.... Real-time computer art objects are designed so that the aesthetic experience is realized by the user through participation. The passive "viewer" must become an active "participant" in the actual context proved by the system. A case can be made for the idea that art can alter perception, and that since perception is an active organizing process rather than a passive retention-of-image causation, only by actively participating with the art object can one perceive it—and thus, in perceiving it, change one's reality structure.... One should conceive of this art form as a kind of aesthetic process which includes basic images, the man-machine interface, and the strategies used by the artist to design the art system. The constraints the artist establishes with the software determine the kinds of options he can offer the participant and the options determine the way the participant is to interact with the art object.

Virtual realities have sparked the imagination of researchers and artists alike. Consider head-mounted displays, electronic gloves, and even body suits. At the same time, we should realize that the notion of virtual reality has been around ever since 3D computer graphics. The idea of virtual reality with interfacing hardware, although an important extension, does not differ in kind from the 3D graphics of the mid 1960s (e.g., Evans and Sutherland's head-mounted stereo display). At Siggraph 1990 the topic interested many people in the graphics community who see it as a major research challenge and direction.

Continuing improvements in computer graphics hardware and a reduction in costs yield the prospect of interactive art objects with head-mounted displays and electronic gloves becoming a serious direction in art. The idea of virtual realities as a dynamic art object will develop more slowly because of difficult technical problems with hardware and the high cost. Some people believe commercial interests will drive the development of virtual realities as a new kind of Nintendo game for the 1990s.

Artists working with these special devices face a major challenge: to transcend the novelty of technology and achieve high-quality aesthetic results. A pioneer in this direction, Myron Krueger, has presented his work at many conferences and exhibitions. (See also "Displays on Display" in this issue.) "Videoplace," his best-known work, was conceived in 1969 and simulated in an exhibit called "Metaplay" in 1970. According to Krueger in his artist's statement:

> There were many motivations underlying its invention. One goal was to discover a true computer art form in the sense that it would be impossible without a computer. Another was to explore the ways that man and machine might interact, independent of any practical considerations. One intellectual outcome of this effort was the concept of an "artificial reality," which people can enter in order to experience a world in which the laws of cause and effect are composed by the artist. Ultimately, "artificial reality" will be more than an art form. It will be a new form of human experience, as rich in its way as movies, novels, and theatrical plays. It is not the goal of this work simply to make old art forms interactive, but rather to discover a new aesthetic which will allow us to create experiences that uniquely focus on the new opportunity provided by interactivity.

Computer art of the common man

The 1990s will also see the emergence of computer folk art, that is, the art of the people or what is known in traditional media as the art of the unschooled or the primitive. We will have low cost and more powerful home computers with improved graphics software and user interfaces. An older, retired, affluent, and better educated population and other groups will become involved with computer graphics as a hobby. Unlike the problems of training in traditional art media, drawing and painting in perspective within a virtual reality is a non-issue. Image processing techniques make trivial problems of digital collage and the pixel manipulation of photographic images. You can acquire 3D objects off networks or purchase them from a library of common objects. The mythology, icons, and popular symbols of the culture in general offers an interesting potential for creative expression.

Virtual reality for a changing universe

We are likely to find that virtual reality as a descriptor for art with the computer will replace the notion of computer art. As computers become more integrated and accepted in society, the words "computer art" may disappear. From a philosophical point of view, the words "virtual reality" have many advantages, including calling attention to the need for cultural changes. Virtual reality is a new metaphor representing the complexity and ambiguity in the contemporary world. This is a world full of fragmented and mixed messages about human values. Our institutions and modern art in particular are unable to respond to new needs and cultural values. This world is one of great contradictions, with traditional institutions and artistic forms unable to assimilate and represent our changing physical, cultural, and scientific universe. We have reached the stage where, as artists, we must begin the journey, searching for these new forms and alternate views of reality, art, and esthetics.

Computer technology has become a dominant force in our society, introducing new potentials for the creative processing of information. This force is redefining our world, expanding our knowledge, and requiring a new level of visual literacy and syntax that will affect our lives at a fundamental level. New ideas exploiting computer graphics and visualization methodology and networks have rapidly changed the nature of scientific research. Other fields and institutions will soon be affected by imaginative models of visualization expanding our knowledge and how we communicate.

The challenge for the artist is to make contact with these changes and use technology to give form to perceptions that can become a meaningful statement about our lives. Computer technology is redefining our world, and art should reflect these changes. By the year 2000—less than 10 years—I predict that artistic activity with the computer will begin to have an important impact on educational institutions and culture in general. ❑

Business looks good for computer graphics companies in the 1990s. This enabling technology should continue to thrive.

The Business of Computer Graphics

Carl Machover
Machover Associates

When *IEEE Computer Graphics and Applications* was established in 1981, American computer graphics vendors shipped world-wide more than $3.6 billion worth of hardware, software, systems, and services. Today, computer graphics is a major industry. Over the past three decades, it has moved from "being a cure for no known disease" to "being a cure for every known disease"! In 1990 US computer graphics companies shipped about $19 billion worth of goods and services. I expect that the market can sustain at least 10 percent per year dollar volume growth over the next five years. This means that shipments of American suppliers should reach at least $30 billion by mid-decade (1995). In fact, my company forecasts that shipments by 1995 will exceed $40 billion.

On what do I base this optimistic forecast? Essentially, on low market saturation. I believe that, even after three decades of computer graphics, less than 10 percent of the people who could use computer graphics in established applications do use computer graphics. For example, *Computerworld* reported in the September 25, 1989 issue that only about 1 percent of end users store their information on electronic media (magnetic and optical). They stored 4 percent in microforms and 95 percent as paper!

The American computer graphics industry employs about 150,000 people. About 50,000,000 workstations, personal computers, and terminals have been installed in the US in the last decade. While not all are used for computer graphics, I suspect a respectable percentage are. In the next decade, I estimate that 125,000,000 such units will be installed, with an increasing percentage offering some kind of graphics capability.

Just before *CG&A*

As the 1970s came to a close, a vast number of changes occurred in computer graphics. Display memory got cheaper,