ACM SIGGRAPH 89

COMPUTER ART IN CONTEXT

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SIGGRAPH '90 Art Show Chair
Dr. Thomas Linehan
Visualization Laboratory
College of Architecture
Texan A&M University
College Station, TX 77843
phone: (409) 845-3465
fax: (409) 845-4491
telex: (510) 892-7689

Association for Computing Machinery
11 West 42nd Street
New York, NY 10036
(212) 869-7440

SIGGRAPH '90 Conference Information
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(312) 644-6610

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Coordinating Editor
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Main Editorial Office
Leonardo
2030 Addison Street, Suite 400
Berkeley, CA 94704, U.S.A.

European Editorial Office
Leonardo
8 rue Émile Dunois
92100 Boulogne sur Seine, France

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WELCOME

I welcome you to the SIGGRAPH '89 Art Show on behalf of the SIGGRAPH '89 conference committee.

This year's show is the result of strong international response to SIGGRAPH's call for computer art. Jurors from Austria, Canada and the United States selected 80 pieces from a much larger group of entries. The works represent a broad range of styles and techniques and include two-dimensional works, sculptures, books, interactive installations and videotapes.

The essays included in this catalog consider the question of the context of computer art today. The authors hold a wide range of views and grapple with notions of computers and art from a broad perspective. Questions of the context of computer art remain.

The computer art community is a vital community, with varied interests, opinions and visions. I am pleased and excited to share works by members of this community. I thank all who have participated by volunteering labor, essays or artworks. Their contributions make the show.

Once again, welcome to the SIGGRAPH '89 Art Show.

MARK RESCH
SIGGRAPH '89 Art Show Chair

Im Namen des SIGGRAPH '89 Konferenzkomitees heisse ich Sie bei der SIGGRAPH '89 Kunstausstellung herzlich willkommen.

Die diesjährige Ausstellung ist das Resultat des starken Echos auf unseren Aufruf für Computerkunst. Jurys von Österreich, Kanada und den Vereinigten Staaten trafen die hier vertretene 80 Auswahl aus einer viel grösseren Zahl von Eingaben. Die Arbeiten sind stellvertretend für die Vielzahl von Stilen und Techniken einschliesslich zweidimensionaler Arbeiten, Skulpturen, Büchern, interaktiven Installationen und Videobändern.

Die in diesem Katalog abgedruckten Aufsätze behandeln die Frage des Kontexts von Computerkunst von Heute. Die Autoren vertreten ein breites Spektrum der Ansichten über Computer und Kunst. Fragen nach dem Kontext von Computerkunst bestehen nach wie vor.

Die Gemeinschaft von Computerkunstanhängern ist eine aktive Interessengemeinschaft, vertritt aber die verschiedensten Interessen, Meinungen und Visionen. Es freut mich deren Arbeiten hier vorzustellen. Der herzlichste Dank gebührt allen denjenigen, die Arbeit, Aufsätze und Kunst freiwillig zur Verfügung gestellt haben.

Herzlich Willkommen zur SIGGRAPH '89 Kunstausstellung!

MARK RESCH
Vorsitzender
SIGGRAPH '89 Kunstausstellung

SIGGRAPH '89 アート・ショーへようこそお越し下さいました．開催委員会を代表し，歓迎の言葉を述べさせていただきます．

今回のアート・ショーはコンピュータ・アートに対する国際的な関心が高まって来た事を背景に開催の運びとなったものであります．出展されております作品は，オーストリア，カナダ，アメリカの審査員が，世界各国から寄せられた応募作品の中から選りすぐったものです．作品のスタイル，手法も多様で，二次元作品から立体作品，書籍，機器，そしてビデオテープに及んでおります．

このカタログに収載されています多くの論文はコンピュータ・アートの概念を主題としています．そこでは各著者の方々が広い視野からコンピュータ・アートの概念をとらえ，将来を眺望しております．コンピュータによる芸術の概念そのものが問われているのです．

コンピュータ・アートの世界は今まさに激動期にあり，様々な関心，意見，期待が寄せられております．この様な状況にあって，今回皆様方と交歓の機会を持たせていただけることを大変嬉しく思っております．このショーの実現にあたって御協力戴きました方々，論文の著者の方々，作品の制作者の方々に厚く御礼申し上げます．

SIGGRAPH '89 アート・ショーの成功を祈って歓迎の言葉と致します．

マーク・レッシュ
SIGGRAPH '89 アート・ショー
開催委員長

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EDITORIAL

COMPUTERS, ART AND CONTEXT

Art evolves with and is influenced by the development of many technologies and many diverse media. While histories of specific media exist, we rarely consider art history in terms of the history of the technologies employed by artists. Rather, we consider the art tradition part of the cultural and historical moment. Until recently there has been a tendency to conceptualize the historical framework of computer art in terms of technology. This is understandable, since the history of computers must be a history of the evolution of technology, and a common view holds that computer artists find more acceptance from the computer community than from the art community. Recent discussion about the relationship between computer art and the mainstream artworld prompted the SIGGRAPH '89 art show committee to call for, and here to present, essays about the context of computers and art as well as reproductions of the artworks selected for the exhibition.

Artists have always participated in the activities of the Association for Computing Machinery's Special Interest Group on Computer Graphics (ACM/SIGGRAPH). SIGGRAPH has developed into a prominent forum for exchange of ideas about computer graphics. The SIGGRAPH annual meeting functions as an academic conference presenting technical papers and panel discussions, a place to continue education by offering tutorials in various aspects of computer graphics, a meeting place for special interest sub-groups, a large equipment and hardware exhibition, and a provider of various venues for presentation of artworks made using computer graphic techniques, including a juried art exhibition as well as animation and film screening.

SIGGRAPH has championed the cause of arts and artists using computers. But do not misunderstand the interest of 'technological' organizations like SIGGRAPH in artmaking. The support for artists is not just support for 'art for art's sake'. The changes in perception and communication that result from artists using computers are profound. The fastest system for information gathering and understanding is the human visual system. The path from the eyes to the brain is among the shortest and the most massively parallel in all of the nervous system. Throughout history, artists have been actively involved in accessing this powerful visual system for intellectual and aesthetic communication. Artists continually strive to develop techniques for manipulating large amounts of information in order to create works that allow the viewer an aesthetic experience. Communicating at the speed of the human visual system with tools like computers to sort through vast amounts of information will allow us to end the 'Information Age'.

"Computer Art in Context: The SIGGRAPH '89 Art Show Catalog" considers many of the questions of the context of computer art. It is clear that computer art will profoundly affect our art-historical and cultural contexts, as artists initiate the change from art-for-display to network participation. Artmaking is a serious activity, and *vision* is still the essential ingredient. New, fast machines or sophisticated algorithms, while impressive, do not substitute for vision in works of art. We must participate from within our context, not apart from it.

MARK RESCH
SIGGRAPH '89 Art Show Chair
Troy, NY
April 1989

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A Brief History of SIGGRAPH Art Exhibitions: Brave New Worlds

Patric D. Prince

In 1981, the Association for Computing Machinery's Special Interest Group on Computer Graphics (ACM/SIGGRAPH) sponsored its first exhibition of computer art in conjunction with the annual conference on computer graphics. The 1989 Art Show will be the ninth SIGGRAPH exhibition of computer-aided art. The present effort can not be understood fully without examining the background and scope of previous exhibitions. During this short history SIGGRAPH Art Shows have become important to computer artists since they are the major sites for the exhibition of new work.

The relationship between the visual research produced by artists and that produced by scientists has always been acknowledged by the computer graphics community. Even before the first SIGGRAPH conference in 1974, artworks were exhibited occasionally at ACM conferences. For example, the 1970 ACM conference held in New York included an exhibition of computer-aided works. Some of these early computer pieces were reviewed by John Canaday in the *The New York Times.* He found them interesting but not satisfying, as indicated by the title of his article: "Less Art, More Computer, Please" [1]. Animation festivals were held regularly at the conferences. The dynamics of motion, as exemplified by computer-generated animation, has always been admired and supported by the association. Animation was regarded as the most viable use of both the technology (the medium) and the synergy (the changes in perception due to use of the machine.)

Several art-related events preceded the organized art exhibitions at the SIGGRAPH conferences. In 1977 and 1978, Joseph Scala produced fashion shows of garments created from computer-printed fabric. The design and production of the garments were a collaborative effort among a surface pattern designer, a fashion designer and computer graphics students from Scala's art department at Syracuse University. The 1981 conference included a frame-buffer demonstration using AED frame buffers and Barco monitors to display art and research from the New York Institute of Technology (NYIT), and works by artist David Em. It was programmed and managed by Julian Gomez. Artworks have been displayed as photographs on the equipment, or alongside it, at various conferences to highlight technical innovations.

In 1980 the idea for a formal art exhibition for SIGGRAPH conferences was conceived. After observing photographs and a printed fabric installation in a manufacturer's booth, artist Darcy Gerbarg suggested to SIGGRAPH officers that an art exhibition be created for the next conference. Her proposal to the 1981 conference chairs resulted in the first formal SIGGRAPH art show, Computer Culture Art Show '81. Consistent with SIGGRAPH policy on all new projects, the first art show was intentionally limited in scope and budget. However, Darcy Gerbarg was able to obtain part of the High Art Technology show exhibited at the Library of Congress in April of 1981. It traveled from Washington to the Electro Arts Gallery in San Francisco, where Ray Lauzzana directed the installation. A version of the High Art Technology exhibition was then scheduled for the July 1981 SIGGRAPH conference. Darcy Gerbarg and J. J. Larrea put together the entire show, framing all of the pieces and hanging the works. The works shown were flat, two-dimensional pieces that were easily transportable from site to site. The exhibition was mounted in the new city hall close to the SIGGRAPH conference site in Dallas, Texas. The general consensus among SIGGRAPH Conference attendees was that show the was an excellent idea. From Dallas the show traveled to the Flavio Belli Gallery in Toronto, Canada. A black-and-white catalog listing the artists and titles was printed, sponsored by the Canadian Ministry of Culture and Recreation and by the Photo/Electric Arts Foundation.

The artists and scientists represented in the 1981 show included Rebecca Allen, Will Anielewicz, Bill Apgar, Michael Assante, Colette and Jeff Bangert, James Blinn, Loren Carpenter, Ephraim Cohen, David Cox, Joanne Culver, Robert Dewar, Frank Dietrich, David DiFrancisco, Tom Duff, John Dunn, David Em, Herbert Franke, Richard Frankel, Dan Franzblau, Darcy Gerbarg, Copper Giloth, Paul Heckbert, James Hockenhull, Jim Hoffman, KEEN (Fred Gaysek and John Tucker), Scott Kim, Ken Knowlton, Raymond Lauzzana, Ruth Leavitt, Mark Lindquist, Dick Lundin, Ron Mackneil, Robert Mallary, Aaron Marcus, Mike Marshall, Nelson Max, Robert McDermott, Leslie Mezei, Zsuzsa Molnar, Tom Moxon, Duane Palyka, Ronald Resch, John Roy, Laura Scholl, Lillian Schwartz, Alvy Ray Smith, Joan Truckenbrod, Ralph Turner, Stan Vanderbeek, Norman White, Turner Whitted, Lance Williams, Edvard Zajec and Steven D. Zins.

The SIGGRAPH '82 Art Show, proposed by Copper Giloth, was the first art show organized exclusively for SIGGRAPH. Copper Giloth chaired the 1982 Art Show Committee, along with Joanne Culver, Louise Etra, Darcy Gerbarg and Aaron Marcus. The exhibition at the Sheraton conference center in Boston, Massachusetts, consisted of 88 pieces. A "Frame Buffer Show" was also included.

With greater resources available for the project, it was possible to publish the first Art Show Catalog. This color catalog contained a complete listing of the artworks, 22 images and introductory essays by Cynthia Goodman, A. Michael Noll and Gene Youngblood. The exhibition was described as "an exhibition highlighting the recent achievements of artists working with computers . . . the SIGGRAPH '82 Art Show celebrates the increasing access to electronic technology

Patric D. Prince (computer graphics historian, independent curator), Fine Arts Administration, 901 Sixth Street, S.W., Number 914, Washington, DC 20024, U.S.A.

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available to artists today and the growing aesthetic awareness in computer graphics" [2]. A separate set of art show slides was also created.

Copper Giloth again chaired the art show for the 1983 conference at Cobo Hall in Detroit, Michigan. This show, entitled SIGGRAPH '83 Exhibition of Computer Art, was juried by Gene Youngblood, David Morris, Joanne Culver, Copper Giloth and Jessie Reid. Before the works were selected, arrangements were made for the show to travel, and the contracts for exhibition sites in Europe and Japan were complete. The work selected by the jury reflected a broader scope since it was chosen for an international audience. In 1983, the Art Show Committee included Joanne Culver and Jessie Reid. Cynthia Neal was the Art Show administrator. The exhibition of 91 works was divided into 'hardcopy', 'installations' and 'video' categories. The full-color catalog included essays by Lucinda Furlong, Gene Youngblood and Catherine Richards [3]. A slide set, postcard set and Japanese/English catalog were also produced.

Under the direction of Joanne Culver the 1983 Traveling Art Show was exhibited at 33 sites in America, Europe and Asia over the next 2 years.

The 1984 SIGGRAPH conference was held in Minneapolis, Minnesota. An exhibition devoted to design, entitled Computer Supported Design Exhibition, was organized. Patrick Whitney chaired the design show. The curatorial committee included Patrick Whitney, Del Coates, Muriel Cooper and William Mitchell. An advisory board, an editor, and several designers were appointed to work on the project. The exhibition, located at the Minneapolis College of Art and Design, consisted of graphic information reproduced in the catalog and a number of architectural and product exhibits. The catalog contained essays on design-related issues by Patrick Whitney, William Mitchell and Del Coates [4]. A design show slide set was also produced.

The 1985 conference art exhibition was chaired by Louise Etra with Rachel Carpenter as the Art Show administrator. The SIGGRAPH '85 Art Show jury consisted of Kathy Rae Huffman, Robin King, Margot Lovejoy, Beau Takahara and Woody Vasulka. The committee was larger, as the scope of the exhibition had become more complex. Stephen Beck, Marc Canter, Loren Carpenter, Donna Cohen, Joanne Culver, Darcy Gerbarg, Copper Giloth, Lucia Grossberger, Howard Gutstadt, Laurin Herr, Bob Holzman, Gen Katz, Joanne Kelly, Sherman Kennedy, Constance Lawrence, David Ledeen, Diane Leyland, Tony Longson, Ann Marion, Barbara Mones and Patric Prince contributed as members of the committee.

The SIGGRAPH '85 Art Show was based at the Moscone Convention Center in San Francisco, but held events at several San Francisco locations. Over 100 works were exhibited at the Moscone Center. These included environmental, interactive, on-line, and traditional works. The Student Poster Animation Competition and Exhibition (SPACE) took place at the Academy of Art College Gallery. A computer graphics festival entitled "Input/Output" was held in the North Gallery of the San Francisco Museum of Modern Art. Two installations were mounted at the Exploratorium, and a performance was staged at the Palace of Fine Arts.

The 1985 Traveling Art Show visited sites in Japan, Spain and the United States. The video component of the show traveled extensively. A full-color, 44-page catalog [5], a Japanese version of the catalog for the traveling show and an art show slide set were produced.

The Convention Center in Dallas, Texas was the site for the 1986 conference. The ACM SIGGRAPH '86 Art Show was chaired by Patric Prince, who curated the two-dimensional and three-dimensional works and the installations. Paul Allen Newell curated the animated works. Professional assistance was provided by Deborah Sokolove Colman. The 1986 Art Show Committee included Maxine D. Brown, Donna J. Cox, Paul Allen Newell, Sylvie Rueff, Gary Walker and Gayle Westrate. The SPACE Committee was made up of Darcy Gerbarg, Barbara Mones and John Olvera.

The 1986 Art Show was an international retrospective of computer art that covered over 20 years. It featured 6 hours of animation, two projected installations, and 18 interactive or online works. A total of 450 pieces were exhibited. A display of printed material covered the period from 1960–1986 and a 'Technical Gallery' exhibited milestones in technical achievement. A lecture entitled "Computer Art in the Mainstream" was presented by Patric Prince and artists Tony Longson and Barbara Nessim at the Dallas Museum of Art. A companion exhibition of computer art was held in conjunction with the SIGGRAPH Art Show at the Sheraton Gallery, at the Sheraton Hotel in Dallas. A smaller version of the exhibition, the 1986 Traveling Show, was shown at three other sites in the United States.

The 52-page catalog included essays by Herbert W. Franke, John Whitney, Ken Knowlton, Frank Dietrich and Patric Prince [6]. Computer typesetting was used, for the first time, in the production of the catalog. The 1986 catalog also received an ISBN number from ACM. An art show slide set that demonstrated the development and history of the medium was produced.

In 1987, the SIGGRAPH Art Show was chaired by Joanne Culver with Crimson Indigo as the administrative assistant. The 1987 jurors were Joanne Culver, Jeffrey Murray, Larry Shaw and Louise Ledeen. The Art Show Committee that year was composed of Joanne Culver, Crimson Indigo, Jeffrey Murray, Larry Shaw, Gay Graves, Laurin Herr, Louise Etra-Ledeen, Frank Dietrich, Terry Dowd, Darcy Gerbarg, Barbara Mones-Hittal and Patric Prince. The exhibition site was the Convention Center in Anaheim, California.

Artworks were exhibited in five categories: Abstract, Visual Research, Human Image, Graphic Design, and Landscape. An educational program that provided informative explanations and artists' statements was added. The 1986 Art Show was the first to have a live performance (held twice each day in the gallery), made possible by a corporate sponsor. The exhibition also incorporated a 3-D laser projector.

The 1987 Art Show catalog featured the first computer-generated and computer-animated "smooth, phong-shaded embossed reflection" hologram on its cover. Joanne Culver stated in the catalog, "The SIGGRAPH conference Art Show provides the opportunity to present ideas, images, and explorations not necessarily acceptable to a traditional museum environment. The scientific alongside the fine art. Interactive, static and performance works all investigating the development of the computer as an imaging aid to the mind" [7].

The Art Show Committee counted the number of visitors to the art exhibition at over 23,000 for the week-long conference. A traveling version of the

1987 SIGGRAPH Art show visited sites in North America and Europe.

The 1988 Art Show chair Lucy Petrovich and her committee were devoted to showing the best interactive works possible at the Conference held in Atlanta, Georgia. The ACM SIGGRAPH '88 committee members were Lisa Fremont (administrator), Kathleen Tanaka and Patricia Harrison. Two Art Show juries were formed in 1988. The jury for interactive works included Patricia Harrison, Sally Rosenthal, Sadowski, Kathleen Tanaka and Jane Veeder. The two-dimensional and three-dimensional works were juried by Frank Dietrich, Kenneth O'Connell and Edward Pope. The introduction to the artists list states, "The SIGGRAPH '88 exhibition of computer art highlights interactive computer installations, an artform unique and intimate to the digital medium. The viewer is transformed into a player, an explicit accomplice in creating the art work" [8].

The exhibition was designed around the interactive pieces and featured works from *The Interactive Image*, a group of installations directed by Tom DeFanti and Maxine Brown, designed by Vicki Putz and programmed by artists and faculty from the University of Illinois working at the Chicago College of Engineering and Electronic Visualization Laboratory. *The Interactive Image* incorporated 18 separate works by Sumit Das, Seton Coggeshall, Maurice Clifford, Fred Dech, Debra Herschmann, Stephan Meyers, Avrum Weinzweig, Dan Sandin, Mary Rasmussen, and Louis Kauffman, Harriet Lurie, and Donna Cox. *The Interactive Image*, an important exhibition wholly designed for interactivity, is now on permanent display at the Computer Museum in Boston. The 1988 Art Show included seven interactive pieces, 12 installations and 12 video works. The design and installation of the 1988 exhibition was very elegant, reflecting the changes in conference planning procedures, the amount of space allocated to the Art Show and the committee's dedication to excellence.

The catalog format was changed to reflect contemporary media. The committee published a list of 1988 SIGGRAPH Art Show participants. The 2-D and 3-D works were recorded in the slide set and the interactive pieces were recorded on videotape.

Mark Resch was selected as Art Show Chair for the 1989 SIGGRAPH Art Show to be held in Boston, Massachusetts. This year marks the 16th annual SIGGRAPH Conference and the ninth Art Show. Aesthetic communication in a wide range of styles and techniques will be represented in the 1989 exhibition. Deborah Williams is providing professional assistance. The committee consists of Rachel Carpenter, Philip Getto, Copper Giloth, Kathy Huffman, Oliver Strimple and Jane Veeder. The Jury includes Lorne Falk, Copper Giloth, Patric Prince (Traveling Art Show Chair), Mark Resch, Christine Schöpf and Dorothy Spencer. The animated video works will be juried by and displayed in conjunction with the Computer Graphics Theater Committee. The exhibition focuses on the aesthetic quality of the individual artworks presented as a continuum of twentieth-century art. This select exhibit includes 86 works in a variety of media.

The exhibition will be held at the Hynes Convention Center and at the Computer Museum in Boston. The works will be seen at the Computer Museum from 28 June–5 September 1989 before the 1989 SIGGRAPH Traveling Art Show tours to other sites.

The 1989 Art Show Committee solicited written essays for the catalog published by *Leonardo*. The 1989 Art Show catalog will be distributed to the full SIGGRAPH membership. The Art Show Chair believes that it is important for "computer art to be placed in the larger art-critical, art-historical tradition" within the catalog.

ACM/SIGGRAPH draws its membership from professional managers, technical developers, artists, designers, computer scientists and educators, all having an interest in using computers to create visual works. The entire conference, including the art show, is conceived of and run by volunteers. Each SIGGRAPH art exhibition has taken the vision of art and technology further by providing a venue for new art forms and expression. There has been a commitment to exhibit multi-dimensional artworks in the best possible circumstances. The Art Show Chairs are prepared to break with traditional gallery practices by using low-light environments in unusual spaces. The history of these exhibitions demonstrates the development of the art form as well as the vision.

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The Tao of Postmodernism: Computer Art, Scientific Visualization and Other Paradoxes [1]

Donna J. Cox

ABSTRACT

The author suggests that a paradigm shift must occur in art criticism to assimilate the nonlinear branching of aesthetic activities in our era. These activities include computer art and scientific visualization, and they reflect many issues addressed in postmodern dialogue such as our image-synthetic, "simulacrum" society. Postmodernism unexpectedly informs most disciplines, including the natural sciences, and is a cultural systemic norm that relates to our electronic information age. The Taoist concept of oneness is used as a metaphor for the interrelatedness of electronic-mediated societies, and this social connectedness explains the enfolding and complex nature of contemporary aesthetic activity. A cybernetic paradigm might provide a better model for criticism than modernism or postmodernism, since this paradigm presents a holistic view that concentrates on creativity and the organization of interrelated systems. The convergence of art with science is assumed as a logical interdisciplinary outgrowth of this electronic oneness.

All right, so you want a style out of America. Stick at it. but when it comes, it mayn't be where you are looking for it.

—Ezra Pound

The art that is coming will give formal expression to our scientific conviction.

—Franz Marc

Some enlightening philosophical and social ideas have emerged from postmodern art criticism. A brief review of the shift from modernism to postmodernism outlines some of the aesthetic consequences that include art market influence on artists. The second section of this paper elaborates critical issues that present problems to aesthetic activities such as the making of computer art and the production of photography. These issues include an unprecedented pluralism of artists' activities in this transition to postmodernism. The third section refutes the idea that postmodernism is merely a style; rather, it is a cultural norm that permeates many fields such as film, architecture and science. Finally, section four places postmodernism in a much larger context, based on Turchin's cybernetic approach to human evolution. Some contemporary cultural characteristics such as the recycling of aesthetic styles, interdisciplinary activity, and 'simulacra' are related to basic human creativity and the multiplicity of cultural systems.

From Modernism to Postmodernism

Artmaking since the beginning of the twentieth century has been recognized as a major break from artmaking prior to that time. Institutionalized, conventional analysis of art and its history proposes a kind of linear 'cause and effect', tracing lines of works and artistic styles'; this approach has provided a paradigm [2] to explain a transition that might cover trends from pre-renaissance to modern [3]. Art historical awareness and the age of mechanical reproduction are undeniable components in the development of modernism at the turn of the century; and this image production provides a gluttony for public consumption. "For inhabitants of industrialized societies (indeed, production and consumption of images serves as one of the distinguishing characteristics of advanced societies), it [mass produced image making] has become a principal agent and a conduit of culture and ideology" [4]. The suffering avant-garde, from Impressionists to Dadaists, were popularized in media and liberal arts education. During the twentieth century, the 'Shock of the New' was deformed into a lust for the avant-garde. Like alga and fungus that live symbiotically, the artist and the buyer have evolved a symbiotic relationship that must feed its soul and pocketbook with the new vanguard. This complex system of artists, galleries, museums, critics and art brokers has come to be known as the art market [5].

Fig. 1. Bea Nettles, *Metamorphosis*, altered and staged silver print, 7.5 × 7.5 in, 1988. The artist's fine art explorations have also involved alternative processes. This type of fine art photography was a radical change from traditional 'straight' photography.

Donna J. Cox (artist, educator), School of Art and Design, Adjunct Faculty for Supercomputing Applications, National Center for Supercomputing Applications, University of Illinois Champaign/Urbana, 605 E. Springfield, Champaign, IL 61820, U.S.A.

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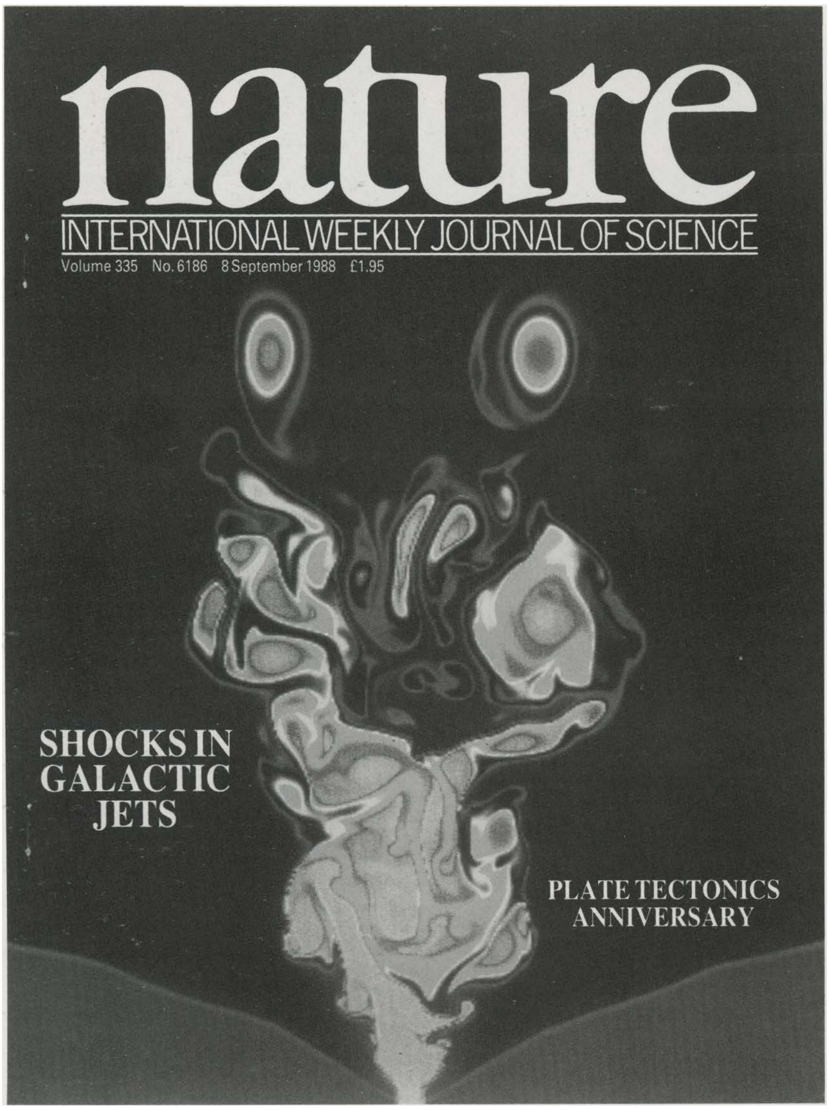

Fig. 2. Michael Norman, Jack Burns, Martin Sulkanen (scientists) and Donna J. Cox (artist), supercomputer simulation of a galactic jet used for the front cover of *Nature* magazine, 1988. This image is an example, developed in the hard sciences, of the 'simulacra' in our society. Such image 'simulation' is characteristic of our Postmodern electronically mediated culture.

By the mid-twentieth century, postmodern discourse exposed the art market search for the next avant-garde (the dog-seeking-its-avant-garde-tail). This convolution of thought has been called the 'transcendental historicism' of art. As Hal Foster explains: "No matter how 'transcendental' or radically new the art, it is usually recouped, rendered familiar by historicism. Late modernism only reworks the contradiction: art is avant-garde insofar as it is radically historicist—the artist delves into art historical conventions in order to break out of them. Such historicism (the New as its own Tradition) is both an origin and an end for the avant-garde; and one aim for postmodernism is to retain its radicality but be rid of its historicism" [6]. Thus, some refer to late postmodernism as post-historical.

Computer Art: An Orphan Child of 'High' Art Criticism

Historicism and the concept of 'style', reified from art-historical thinking, have led theorists to conjecture that artists tend to emulate older technologies with each new technology until they find a 'pure' form of expression. For example, historians and critics proposed that early nineteenth-century photographers emulated painting style with the camera [7]. Likewise, it is possible that computer artists are copying styles of older technologies as well [8,9]. However, if one closely analyzes the evolution of fine art photography from the Industrial Revolution into the postmodern era, one gains a different perspective.

In order to establish photography as a fine art, Alfred Stieglitz proposed that the artist exploit the camera for its unique qualities and create 'pure' photographs that did *not* resemble 'painterly' styles. He stated that the photographer should not manipulate photographs nor state allegories (as early photographers had done). Rather, he proposed, the pure photograph employs the camera for what it does best: capturing a slice of the real world from the personal viewpoint of the artist. Thus the artist's personal style and photography's pure form of expression emerged. Consequently, the pure photograph was completely divorced from painting by 1920. However, a transition to postmodernism resulted in the complete inversion of photographic 'purity' by 1970. Staged, altered (Fig. 1) and appropriated photographs have become the accepted market, not the adulteration that Stieglitz refuted with his 'straight' fine art photography [10]. As Abigail Solomon-Godeau has noted, "the properties of photographic imagery which have made it a privileged medium in postmodern art are precisely those which for generations art photographers have been concerned to disavow" [11]. Here we see a paradox that developed in fine art photography; such a paradox can also be found in the evolution of computer art.

> Virtually every critical and theoretical issue which postmodernist art may be said to engage in in one sense or another can be located with photography [and computer art]. Issues having to do with authorship, subjectivity, and uniqueness are built into the very nature of the photographic [and computer] process itself [12].

The computer artist represents a double risk to the art market, because the work is often twice removed from a personal style, authorship or uniqueness: first the art is made with a computer, then documented with a photograph. The computer art purist might argue that the 'interactive' mode or the 'artist-as-programmer' mode of the computer aesthetic is *sine qua non* [13,14]. That is to say, the pure form of expression from the computer is realized through interactivity or through the artist's personal software. However, interactive computer works

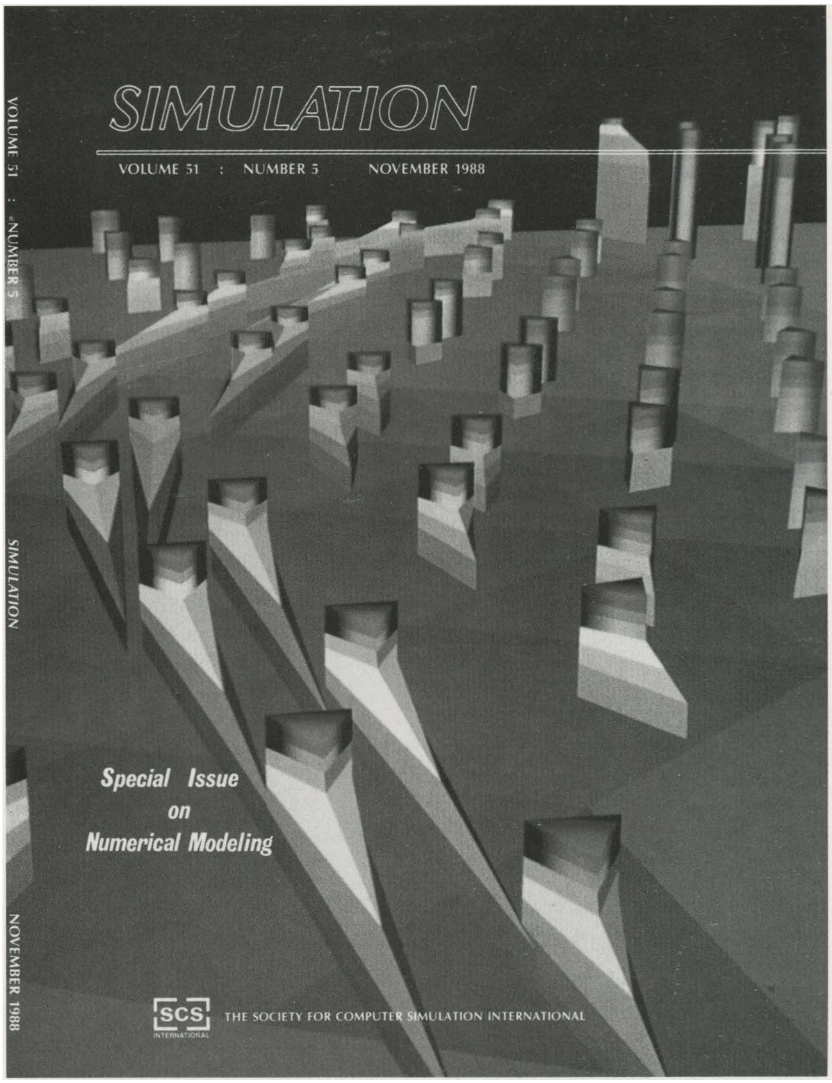

Fig. 3. Richard Ellson, Donna J. Cox and Ray Idaszak, cover image of a contemporary science journal, *Simulation*, 1988. This cover image, illustrating scientific simulacra, shows the use of computer techniques to visualize abstract numerical information from a supercomputer simulation of hot plastic polymer.

and electronic installations are intrinsically difficult to show and sell in the art marketplace [15]. These types of issues have left art curators and critics in a quandary and have contributed to computer art being outside the mainstream of 'high' art criticism. Interesting out-of-the-art-mainstream publications, such as SIGGRAPH [16] art show catalogues, *Leonardo* or articles from technical publications such as Prince's reviews of computer art [17,18], present critical information that cannot be gleaned from the art market coffers; because "artistic practices employing film or photography [or computer], as well as those using found objects, processes, or systems where creative labor is apparently absent, continue to problematize the transcendental imperatives which predominate in critical and historical literature on art" [19].

In addition to the above, interdisciplinary activity has become a key descriptor in the postmodern era and it prohibits the classification of works merely by the medium. Photography as well as traditional painting and sculpture experienced a radical realignment during the 1960s [20]. Painting and sculpture merged to create new hybrid forms. And, like photographers, many artists cast aside the purity of the medium [21]. Douglas Crimp states,

> the ease with which many artists managed, some ten years ago, to change media—from sculpture, say, to film (Serra, Morris, et al.) or from dance to film (Rainer)—or were willing to 'corrupt' one medium with another—to present a work of sculpture, for example, in the form of a photograph (Smithson, Long)—or abjured any physical manifestation of the work (Barry, Weiner) makes it clear that the actual characteristics of the medium, per se, cannot any longer tell us much about the artist's activity [22].

Other scholars submit that art based upon technology is just one possible mode of expression and that the medium should not claim to have any special status [23]. Alas, many late modernist or postmodern critics would be dismayed at the fact that computer art segregates itself via the medium rather than concentrates on the artist's 'aesthetic activities'. Here we see the computer art paradox: many computer artworks are shunned by the modernist for lack of purity, authorship or originality at the same time that they are shunned by postmodern dialogue for computer art's 'media/technology identification'. Thus, computer art is like an orphan child to most current art criticism. In addition to analyzing these problems, the next section delineates other negative social criticism surrounding the making of computer images.

POSTMODERNISM IS A NEW SYSTEMIC CULTURAL NORM

It must be made clear here that postmodernism is *not* a so-called style; rather it is a "new systemic cultural norm" that informs other disciplines, including science fiction film, music, poetry, architecture [24] and the natural sciences (as I will later demonstrate). Postmodernism is like a force field in which very different kinds of impulses and forms emerge from cultural production [25]. Postmodernism is not a style; rather it points to a social and technological mechanism from which styles are being generated. Critics note the development of a society that has experienced a technological transformation of the social world where electronic artifacts such as computers, television and video constitute and symbolize the radical alteration of our culture's time and spatial consciousness [26]. Computer graphics and electronic image generation are viewed as contributors to the removal of the individual from direct experience of reality, resulting in a society of simulacrum, image simulation of the real world. Real space is distorted into an electronically mediated space, a weightless polygonalization, as in *Tron, Star Wars* or *Star Trek II: The Wrath of Khan.* Real time is deformed in an electronic culture of televised instant replays, generic pastiche and interactive mouse control. Postmodern architecture and fine art are characterized by de-historicized collections of recycled aesthetic styles [27]. In the classic postmodern film *Bladerunner,* scenery resembles recycled international junk and costumes rehash fashions spanning many decades. In this film, genetically engineered replicants, artificial simulations of real people, have become more human than human.

Physics and other natural sciences have been affected by this electronically mediated postmodern milieu of simulacra. Scientific visualization is the use of computer graphics to visualize 'simulations that model reality'. Scientific observations of real data have been transcended in this electronic age where supercomputers can solve numerical equations that represent real physical models. These simulations are visualized with computer graphics to represent such natural phenomenon as an astrophysical jet (Figs 2, 3) that might be 100,000 light years in length [28]. While most of these models of reality cannot be experienced directly by human beings, they can be computed, digitally stored, recorded and electronically replayed on a VHS video tape deck, providing a vicarious view of invisible phenomena. Scientific simulations and computer-graphic visualizations can compress geophysical time from tens of billions of years to a millisecond and shrink a blackhole deformation to the width of a television screen [29]. Humans have technologically warped time and space and documented every possible visual image. "Now, more than ever before, different strata in our society have converged in their passionate interest in the image, in representation, in the very process of mediation and simulation" [30].

Thus, postmodernism is a dynamic, systemic cultural condition that informs most disciplines in electronically mediated societies and can be characterized primarily by the following:

1) *Historical hypersensitivity*—workers in many disciplines, media and art have an increased historical awareness, and their works reflect historical elements that have been recycled and recombined into new aesthetic forms

2) *Cross- and Interdisciplinary Activity*—in art, science and philosophy, people have dissolved many boundaries between traditional modes of behavior, expressions and concepts

3) *Simulacra* in society, our age of mechanical reproduction and electronic media have collapsed time, space and matter into image synthesis, representation, simulation and electronic models of natural phenomena.

The Cybernetic Paradigm

The postmodern characteristics noted above can be related to cybernetics, the theory of information control in living organisms; this theory is based on the concept of systems and subsystems that are organized into hierarchies [31]. Cybernetic processes include use of memory, free association, visualization, but most importantly, the construction of new mental models of reality. Humans build mental models of reality through the association of representations. This modeling allows humans to create. When we re-associate concepts or representations, the models undergo reorganization or change; thus humans create and re-create models by this type of free association. Members of human society communicate on the highest level of their individual organization through this process. In this way, *people have contact by brain* because these models become a continuation of each individual brain [32,33]. Social systems and subsystems in culture are natural extensions of shared models and paradigms within our society. And people will utilize whatever technology is available to continue this creative process.

Twentieth-century technological advances in electronic communication and image production have resulted in an accelerated contact of the individual with an external world through television and other media. If people have contact by brain, then people are having more brain contact more rapidly than ever before. We are constantly bombarded with changing images and information that model the external world through media. Today, artmaking and other creative disciplines increasingly reformulate models, due to this efficient information flow and exposure of artists to a broader range of cultural associations. Thus, intense exposure to historic styles inevitably stimulates artists to produce re-associations and sometimes to recycle these styles in their aesthetic production. A natural outcome of this electronic information flow is more interdisciplinary activity. Simulacra, images synthesis, and the electronic production of visual models of reality are social extensions of individual creativity resulting from our electronic age.

Cybernetics provides a model of society as well as a model of individual thought that explains the complex dynamic systems in which culture itself is rapidly evolving. The whole of these social systems is like one big brain that moves toward greater complexity from which new levels of organization and creativity emerge. The evolution of collective consciousness takes place through the natural selection of the models that humans create [34].

> The necessary selection of variants for increasing the complexity of the organization of matter by trial and error now takes place in the human head. This process differs fundamentally from the process of [Darwin's] natural selection and takes place incomparably faster, but in both its function (constructing and using models of the environment) and in its results (growth in the total mass of living matter and its influence on nonliving matter) it is completely analogous to the earlier process [Darwin's natural selection] and is its natural continuation. The human being becomes the point of concentration for Cosmic Creativity. The pace of evolution accelerates manyfold [35].

This holistic interrelationship as a basis for creativity and life is evinced in other areas of twentieth-century science. The old simple mechanistic outlook has given rise to a holistic approach, a view that treats "the organism as a whole, a view which, incidentally, echoes the old Chinese picture of the universe itself as a self-dependent organism" [36].

Summary

People think, understand and create by building mental models of the world about them. These models often develop into complex social systems that interact and influence others. For example, when Alfred Stieglitz proposed his pure photography as the appropriate modus operandi, he created a model that integrated fine art photography into the existing system of the art market. His rationale provided an acceptable model for fine art photographers until a new model was adopted.

Another example of modeling is presented here regarding the transition from modernism to postmodernism. The first section proposes that an interaction among the cultural systems of art history, the art market, and mass media resulted in a hypersensitive art historical awareness, and this awareness influenced artists in their attempts to transcend history and create an avant garde. This simple analysis provides a model of an interaction among several cultural systems and its effects upon art. Such an analysis reflects the cybernetic approach and recognizes the major influences that social systems and paradigms have upon artmaking.

The point here is that artists are inextricably immersed in culture; they are constantly attempting to operate within a multiplicity of social systems including the art market, mass media and academia. The complete analysis of an art object would recognize and include the multiplicity of systems within which the artist works. Artists have contact by brain with all parts of the world in today's electronically mediated culture. And to simply say that 'the art work speaks for itself' is to ignore the whole from which the work evolves.

The shift from modernism to postmodernism has been a transition from one paradigm to another. Postmodernism is more general than modernism because it subsumes many modernist concepts (e.g. aesthetic purity and lineage of styles) and re-evaluates them in a new context. It proffers a schema that clarifies interdisciplinary aesthetic activities. Likewise, postmodernism generalizes across social criticism and incorporates many aspects of our high-technological, electronic culture through such concepts as simulacra.

However, many postmodern critics, in their languid historicism, fail to recognize the 'real' 'new', and this period where the old is dying and the new cannot be born results in many morbid symptoms [37]. Many view electronic/computer media as evil, as a primary contribution to the negation of humanism. This technophobic attitude handicaps any emerging technological aesthetic. Unfortunately, computer art was born in the transition between modernism and postmodernism. While both paradigms broach computer art issues, for the most part these issues have been relegated to technological biases.

If one agrees that computer art is treated like an orphan child by mainstream art criticism, then one would also agree that a model is yet to be born that will assimilate scientific aesthetic activity such as scientific visualization. This type of artistic exploration attempts to cross an even greater chasm between two disparate social systems—that of science and that of art. Technological art is often viewed suspiciously enough, but art delving into both science and technology is too distant from the current imperatives of the art world. A shift in criticism must occur to assimilate such alien aesthetic activities as scientific visualization.

The cybernetic paradigm subsumes computer art, scientific visualization and other art paradoxes into a model of human evolution where technology, simulacra, historicism and eclecticism characterize intense cultural creativity. This approach encourages analysis of the complex network of systems and subsystems in an evolving, dynamic society. Artmaking crosses many of these subsystems, and this type of analysis might prove to be very enlightening. For example, a comparison between the current art market and SIGGRAPH might reveal interesting influences that these two economic systems have had upon computer art production. Likewise, this comparison might reveal the tensions and frustrations of those artists who attempt to operate between these two systems. This type of analysis—where the whole social organism is considered integral to individual artmaking—is characteristic of a cybernetic approach to art criticism.

Criticism should address art production within all aspects of culture, including economics, mass media, science and the whole interrelatedness of our heterogeneous cultural life. Jameson has negatively characterized current cultural production as schizophrenic and randomly heterogeneous. However, none of these eclectic features should be seen as random; rather they confirm one another in an intricate network of social systems and historical meaning that can be understood within the context of human creativity [38]. Electronically mediated societies are rapidly and collectively re-creating new models of reality because of the increased exposure to image and information. Metaphorically speaking, this continually evolving re-creation and modeling of reality can be symbolized by the "*Tao* . . . the one ultimate, tireless activity . . . it inevitably retains the impression of an unlimited past and as surely moulds the ceaseless future, but is itself unconditioned by time, space, or matter" [39].

Glossary

association—in thought or information processing, association is the connection of concepts, images or models. When the brain 'associates' it brings together representations into a new association, and this process results in a new association of representations, a recombinant association. The latter is at a higher level of hierarchy in the organization of thought processes. Associating is a primary function in the process of modeling.

appropriation—in postmodernism fine art photography, this term refers to artworks exemplified by Sherrie Levine or Richard Prince, where the artists copy and exhibit other artists' works. Levine and Prince intended to make an artistic statement about authorship and originality and attempted to dismantle subjectivity in the art works. However, the art market, with its innate ability to commodify almost anything, has also marketed these plagiarized photographs as art.

art market people, businesses and institutions who have an interest in normalizing and benefiting from avant-garde art (this category includes dealers, collectors, museum officials, directors of cultural programs, critics, artists).

art world a term that is inclusive of the art market as well as university and other art educators, non-professional art students, artists who do not participate in the art market, public art exhibit attendees who do not generally buy art.

cybernetics—Norbert Weiner's cybernetics is the study of relationships and information control in the living organism. This term has come to mean a study of human control functions and of the mechanical and electric systems designed to replace them. This theory is based on the concept of systems and subsystems that are organized into hierarchies. Turchin outlines human cybernetic processes that include use of memory or history, free association, visualization, playfulness and the creation of models of reality; and he applies these ideas to society as a whole.

modeling the creation of models is simply the mental interconnection of associations or representations that have a time coordinate and a resultant capability to foresee the future; this is the idea of constructing a model of the environment. For example, concepts such as 'season' or 'taxes' provide simple models that retain a sense of time and regularity and allow one to predict a continuation of the phenomenon. In this sense, a model both provides a mental representation and allows one to plan the future. Knowledge is the presence in the brain of a certain model of reality. In our brains, this model of reality is at a high level in the hierarchy of associations that enables us to foresee the results of our actions (Turchin, p. 73). A model that is shared among many people as a system of belief is a paradigm.

modern—characteristic of contemporary styles that reject traditionally accepted or sanctioned forms and emphasize individual experimentation and sensibility. Modernism is thought to have begun around the end of nineteenth century and to have peaked during the first half of the twentieth century.

paradigm—a model or standard; in this paper, paradigm refers to Thomas Kuhn's meaning (see Ref. [2]). At any given time, a discipline or specialty will disclose a set of recurrent and quasistandard illustrations of various theories in their conceptual, observational and instrumental applications. These are the community's paradigms, revealed in its textbooks, lectures, and laboratory exercises (Ref. [2] p. 43). Paradigm is used in two different senses: on the one hand, it stands for the entire body of beliefs, values, techniques and so on shared by the members of a given community. On the other, it denotes a single concept that is employed as a model or standard (Ref. [2] p. 175). Paradigm also refers to a model of reality that is shared by many people and that has evolved into a system of belief.

postmodern—an art and social-criticism term that originated in fine art photography and that describes the art that followed modernism; postmodernism developed during the mid-twentieth century. Postmodern criticism reveals a hypersensitive historical awareness, recognizes the print/electronic media as central to the conduit of culture and suggests that electronic media have created an isolation of the individual from direct experience of reality; critics observe that art from the postmodern era involves a pastiche of recycled styles.

simulacra artifacts, images and cultural production that are created by electronic simulation to produce an artificial space and time or are produced in any synthetic manner to give the appearance of or represent some other thing, possibly from some other time or place. This type of cultural production often appears as a pastiche or collage of recycled historic styles. Also, simulacrum is any reproduced synthetic form that is made to give the appearance of some other thing or represent something else. Electronic simulacra often remove the individual from direct experience of reality (e.g. television, video, etc.).

Taoism—'the way' or perhaps 'the order of nature'; ancient Chinese religion and philosophy proposed the unity of nature and oneness of the universe. The universe was seen as an organism made from an interrelated network of hierarchical systems; nature must be studied as a whole, not reduced to its parts. The Taoists were among the first great scientists and artists of China; this philosophy began around the same time as ancient Greek science, fifth century B.C.

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1. The title of this article is in the spirit of *The Tao of Pooh* by Benjamin Hoff and *The Tao of Physics* by Fritjof Capra, who is doing research in theoretical high energy physics at Lawrence Berkeley Laboratory and is a lecturer at the University of California at Berkeley.

2. T. S. Kuhn, *The Structure of Scientific Revolutions*, 2nd Ed. (Chicago: University of Chicago Press, 1962, 1970). Kuhn explains that science progresses through major paradigm shifts (e.g. from Ptolemy's geocentric solar system to Copernicus's heliocentric solar system; from Newton's classical physics to Einstein's Theory of Relativity). In art, from Kuhn's point of view, the shift from premodern to modern might be considered a paradigm shift. He notes that, in the past, scholars have shown the tendency to see the history of science as a linear or cumulative process. However, contemporary historiography raises serious doubts about this linear approach (pp. 2–3, pp. 138–139). I might add here that postmodern critics also question the validity of historical linear progression of aesthetic styles.

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30. V. Sobchack [24] p. 236.

31. V. F. Turchin, *The Phenomenon of Science* (New York: Columbia University Press, 1977) pp. 4, 315. The author is a physicist who outlines the way humans model reality in this book on the cybernetic approach to human evolution.

32. V. F. Turchin [31] p. 95. Language—seen as an extension of thought—comprises a system or model. Larger metasystems such as art, science, and philosophy are also viewed as systems or models that people create through thought and language. Language is not only a continuation of each individual brain but also a general, unitary continuation of the brains of all members of society. It is a collective model of reality on whose refinement all members of society are working, one that stores the experience of preceding generations.

33. V. F. Turchin [31] p. 92. Turchin notes that art is not a formalized linguistic language, like science; however, art does have a complex organization of concepts and objects that form cultural systems and subsystems, that are linguistically demarked, and that provide contextual models.

34. T. de Chardin, *The Phenomenon of Man* (London: Wm. Collins Sons & Co., Ltd, 1959). Matter and life have constantly moved toward greater complexity, and it is this observation that characterizes our biosphere.

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The Wizard of Ethereal Pictures and Virtual Places

Timothy Binkley

ABSTRACT

Renaissance artists constructed pictorial space using algorithms based on Euclidean geometry. Computer artists use algorithms based on the analytic geometry of Descartes to compute pictures as well as the subjects in them. An examination of the workings of these two different types of algorithm reveals that the computer offers a radical new approach to making art, which is not yet well understood. Postmodern algorithms for picturemaking are more evanescent than their Renaissance counterparts because computers process information conceptually instead of storing it physically. The computer is neither a passive medium nor a pliant tool, but an active creative partner.

. . *the computer is a 'metaphysical machine'* [1].

—Sherry Turkle

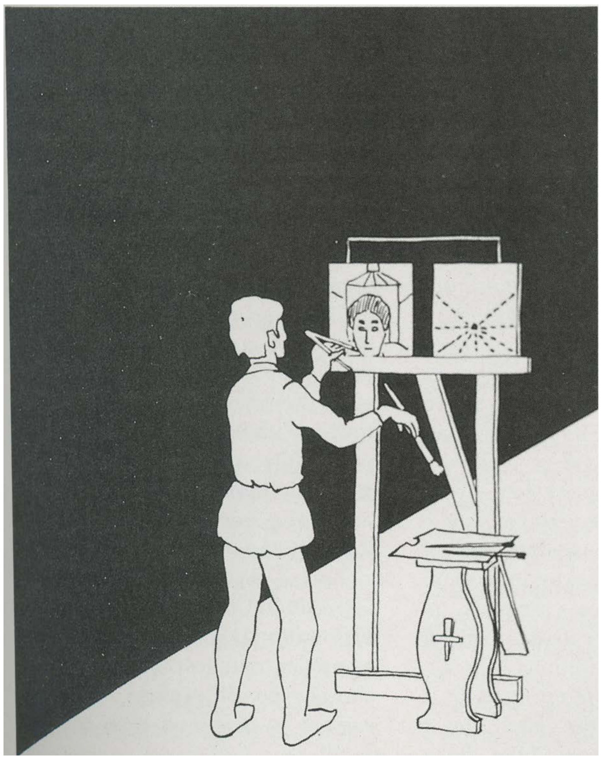
The Artistic Computer: A Protean Enigma

Computers are protean. Gamboling from the churning high seas of Postmodernism, they disturb the cultural waters even further with their enigmatic and plastic visages. Like the Greek god of the sea, they are facile with disparate guises—pretending to be now a pencil, then a spreadsheet, a design studio, an airplane, a chess partner, a paintbrush, a raconteur, and most certainly a sorcerer—all the while remaining nothing other than hyperactive dervishes spinning out myriad illusions by proficiently manipulating numbers. Add to this that their sometimes obstreperous mischief makes them seem more demons than deities, and it is no wonder that critics and the artgoing public alike are suspicious of computer art in addition to being baffled by it. What is the computer's role in art? Does it have a legitimate claim to artistic respect? Or is it simply a technological charlatan, recalcitrant to acculturation and slippery as Proteus when we try to grasp its essence?

Efforts to navigate these troubled waters sometimes liken the computer to a medium as a way of explaining its role in art [2]. But upon examination, I believe we will find the concept of the computer as a medium to be more misleading than useful. Computer art will be better understood and more readily accepted by a skeptical artworld if we acknowledge how different it is from traditional tools. The computer is an extension of the mind, not of the hand or eye, and, unlike cinema or photography, it does not simply add a new medium to the artist's repertoire, based on a new technology. The role of media in artmaking is fundamentally altered by 'thinking machines'.

It will help clarify the confusing rubric 'Computer Art', which congregates a multitude of disparate objects and events, by looking at the art-historical context. Let us begin by studying differences between picturing techniques used by Renaissance artists and those employed more recently by computer artists. By comparing the alternative ways perspective drawings are rendered, we can begin to understand in a familiar context the radical new approach to artmaking introduced by computers. The computer does much more than assist imagemaking, but once we understand its novel approach in familiar territory, we will be better able to chart its wild and woolly antics. So, taking a lesson from the old myth, let us grasp this protean creature relentlessly until it gives us some answers.

Fig. 1. Samuel Edgerton's rendition (from Ref. [3]) of how Brunelleschi constructed his first perspective picture. The Baptistry is situated behind the artist. The easel holds a mirror on the left and a painted panel on the right. Measurements are taken from the mirror by caliper and then transferred to the panel.



Constructive Algorithms: The Transparent Window

Circa 1425 A.D., Filippo di Ser Brunellescho made a revolutionary pilgrimage to the Baptistry of Florence to develop what we now call an 'algorithm' for making pictures. His

Timothy Binkley (academic administrator), Institute for Computers in the Arts, School of Visual Arts, 209 East 23rd St., New York, NY, 10010, U.S.A.

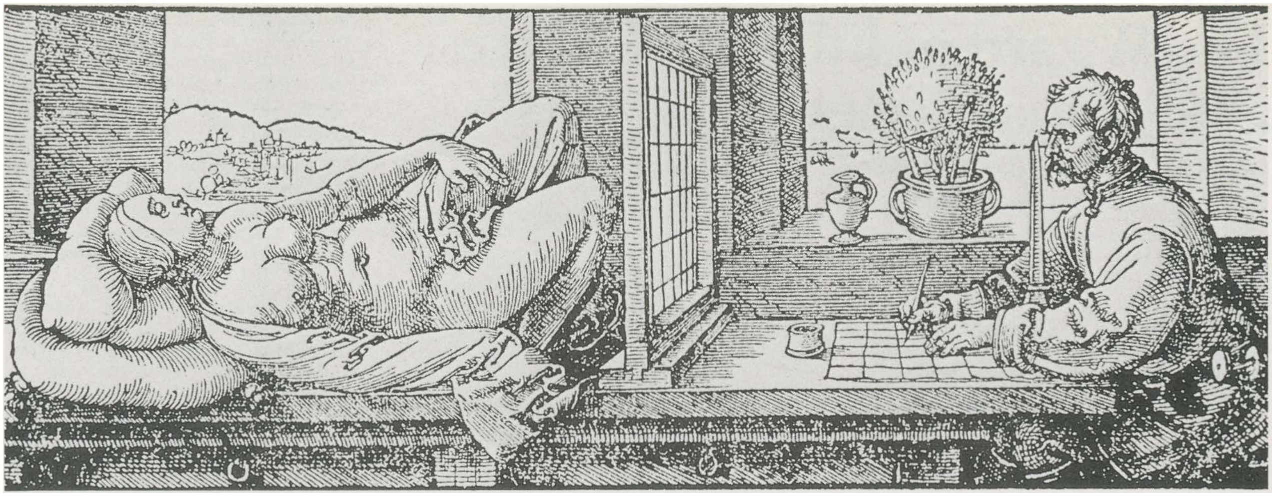


Fig. 2. Albrecht Dürer, *The Designer of the Lying Woman.* In this version of the Constructive Algorithm, the point of view is fixed by a small obelisk marking the place where the artist moves his eye to take readings. The picture plane is the framed grid of strings. A matching grid is drawn on the paper and used to transfer points from the picture plane.

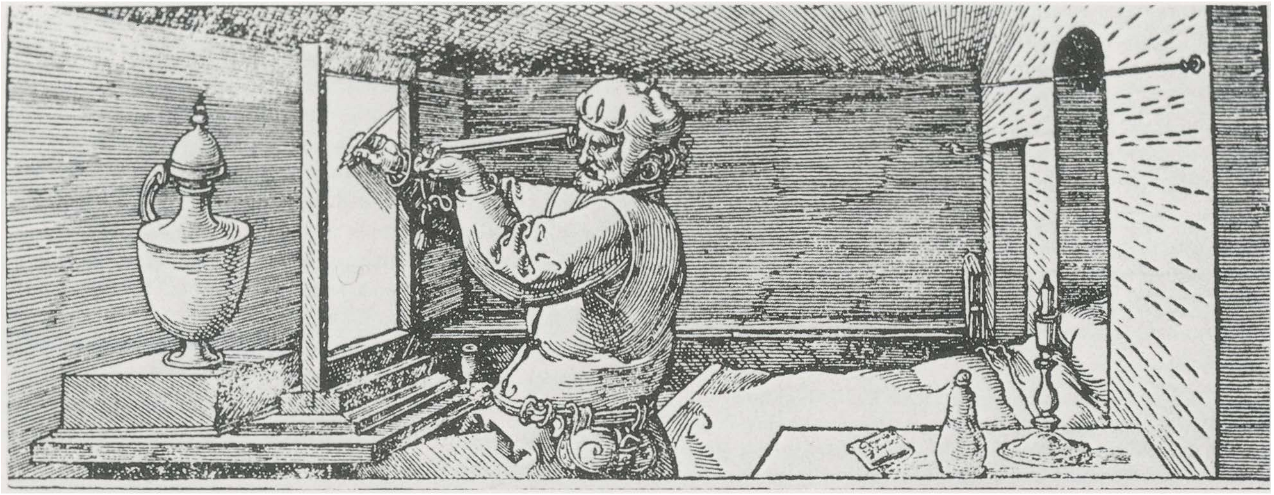


Fig. 3. Albrecht Dürer, *The Designer of the Can.* In this version of the Constructive Algorithm, the artist draws directly on the picture plane, which is transparent.

achievement changed the history of art. Perspective had apparently been used in ancient times, but there existed no records of any formulae that might be applied systematically to construct a perspective picture. By using a mirror to ascertain picture elements, Brunelleschi essentially delineated a process that can be described with a set of step-by-step instructions for transferring the appearance of the everyday three-dimensional world to a convincing two-dimensional image on a panel [3]. According to Samuel Edgerton's hypothesis (Fig. 1), the artist placed a mirror on an easel next to the panel to be painted. With his back toward the Baptistry and his own reflection partially obscuring the view, Brunelleschi transferred magnitudes of reflections in the mirror onto the panel by means of a caliper. His algorithm spawned others that were codified by Alberti 10 years later and were embraced by many artists of the Renaissance who used them to create spectacular works of art with heretofore unseen depth and startling points of view [4]. The illusionary panoramas these algorithms produce have become so much a part of our culture that we no longer feel the astonishment they provoked in fifteenth-century Florentines.

Brunelleschi's algorithm, like its progeny, is based on the constructive geometry of Euclid. Its essential parameters are fixed in the pictured setting: a *point*—the point of view—from where the scene is seen, and a *plane*—the picture plane—determining where the image will be cast onto a surface [5]. These elements are more apparent as well as easier to use in one of Albrecht Dürer's renditions (Fig. 2), where the point is determined by a small obelisk and the plane by a framed grid of strings. Like many great discoveries, Brunelleschi's seemed obvious once articulated, and the rules of the algorithm are simple to follow. Its purpose is to correlate points on the image with points in the represented setting. This is done by repeatedly connecting the point of view to points in the scene (using light rays in Figs 1 and 2 and a taut string in Fig. 3). Lines so constructed will intersect the picture plane at a point that represents the corresponding point in the world. With this sort of algorithm, the perspective picture is actually *constructed* following Euclid's classic principles of geometric construction with straightedge and compass. The conviction of the apparition so fabricated is grounded in Euclid's Twenty-First Proposition (Fig. 4), which guarantees by similar triangles that proportions in the picture will preserve those in its subject as perceived from the viewpoint.

Once his algorithm became known, industrious artists found many ways of implementing and modifying Brunelleschi's insight. Dürer made a number of woodcuts depicting different methods. In yet another of his constructive algorithms (see Fig. 3), the artist again fixed the point of view with a screw eye mounted on a wall, but the picture plane was a transparent sheet and the lines of sight were intersected with the picture plane by aiming them through a viewing tube attached to a string tied to the screw eye. All of these algorithms involved geometrical constructions that are accomplished with manual tools such as pens, strings, rulers and calipers and were carried out in the actual presence of the depicted setting. Related techniques were developed by Alberti and subsequently by others for designing perspective images of simple geometrical shapes without needing a real physical subject to work from. The *locus classicus* of strictly two-dimensional constructive algorithms is the checkerboard ground plane Alberti used as his paradigm (Fig. 5). By turning the line of sight 90 degrees, one can place it in the same plane as the picture and, with a straightedge, construct the receding horizontal lines. Although capable of assisting the construction of pictures of imaginary settings by adumbrating geometrical outlines, even these methods require the manipulation of real physical tools on a desktop, tools that constitute the necessary hardware for any geometrical construction. The achievements of Renaissance artists promoted the development of an abstract theoretical branch of mathematics called Projective Geometry, but the applications of its theorems to picture-making always rely upon the concrete manipulations of constructive geometry.

Brunelleschi's ingenious insight has been likened to cutting a window in the Medieval fresco wall [6]. His predecessors used a motley assortment of practical rules of thumb to indicate depth; these had been gradually worked out over the centuries, including such principles as occlusion, foreshortening, terracing, and locally convergent lines in architecture, which were usually developed in response to particular types of subject matter. Artists of the Middle Ages struggled to make plaster and pigment adhere to a wall while amalgamating dissimilar methodologies in an effort to concoct a convincing representation of what was outside. Brunelleschi and his peers broke through the barrier of the wall and instituted a completely systematic method of projecting three dimensions into two to reveal a pictured world so clear and refined that it appears as if viewed through an open window. Easel painting was born on moveable framed panels.

Computational Algorithms: The Luminous Screen

Two hundred years after Brunelleschi's discovery, Descartes built the foundation for a rather different kind of picturing algorithm based on analytic geometry. Although such algorithms were not widely used until the advent of computers, they can be described without any reference to hardware. Instead of working directly with manual tools in the real world, a computational algorithm relies upon algebra applied in an abstract coordinate system. It is an example of the kind of problem treated in a new branch of mathematics that has recently been christened 'Computational Geometry'.

Computational algorithms for picturing do not require placement in any real setting; indeed if one wants to depict an actual object, the first step is to abstract its shape from the real world and place it in the imaginary world of a selected coordinate space (see Fig. 6). The object must be described using numbers to fix its characteristics ($X0$, $Y0$, $Z0$). The picture plane is similarly determined with points or an equation ($z = ZP$), and the point of view simply becomes an ordered triple (XV, YV, ZV). A computational algorithm functions not by manually or optically tracing out lines connecting an object to a point, but rather by using equations to calculate algebraically the depicting points of intersection in the picture plane. Once the points are calculated, they need to be reified in some medium to make an actual image out of them. As such algorithms are used today, this medium is typically the screen of a video monitor connected to a computer that performs the calculations and sends the results to a cathode ray tube (CRT).

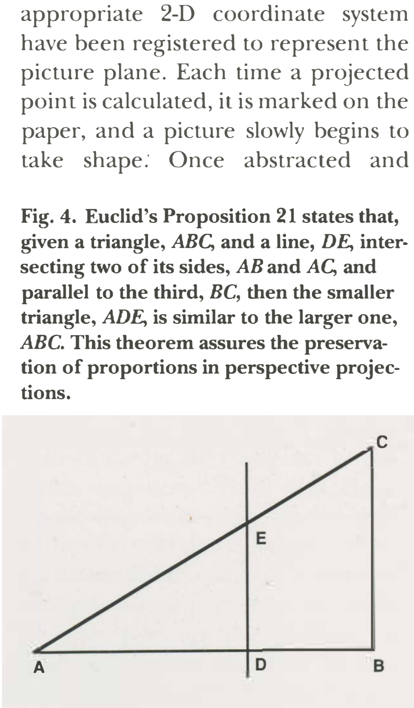
Before examining the computer's contribution, let us look more closely at how the two types of picturing algorithms differ.

The underlying frameworks are similar: beginning with an object, a plane, and a point, we create a representation of the object in the plane by scrutinizing lines connecting the object and the point. Perspective projections using the two algorithms may sometimes have similar appearances, but they are quite different and can yield rather different-looking results. In order to highlight their differences, let us step up to the easel beside Brunelleschi and compare 'manual' executions of both.

As Brunelleschi deftly gleans the outlines of his picture by casting glances at his mirror, we laboriously begin setting up a coordinate system by arbitrarily (but we hope conveniently) locating an origin and three perpendicular axes. The next step is to use a tape measure to take readings of the positions of the main features of the Baptistry and record them as coordinate triples in reference to our axes. Similar readings are taken for the picture plane and the point of view. So far, we are doing only preparatory work. Brunelleschi has probably already completed at least a sketch of his picture before we even finish taking readings.

Brunelleschi must use his algorithm while standing in the square before his subject, whereas the real work on ours begins after we leave the site. As we slowly sift through our data and process them, a piece of graph paper is kept on the side where the axes of an appropriate 2-D coordinate system have been registered to represent the picture plane. Each time a projected point is calculated, it is marked on the paper, and a picture slowly begins to take shape. Once abstracted and

Fig. 4. Euclid's Proposition 21 states that, given a triangle, *ABC*, and a line, *DE*, intersecting two of its sides, *AB* and *AC*, and parallel to the third, *BC*, then the smaller triangle, *ADE*, is similar to the larger one, *ABC*. This theorem assures the preservation of proportions in perspective projections.



processed, the information arising from the depicted setting needs to be reconcretized to convert it into a pictorial—as opposed to merely a numerical—format. The image surface has become once again opaque, like a Medieval fresco wall, and we never have the sense of making an image by peering through a window.

Recent technological developments turn the picture plane of computational algorithms into the luminous screen of a CRT, which replaces the Renaissance window and emanates a vibrant image after it has been quickly calculated by a computer. Despite its comparatively humble appearance, the computer is actually more critical than the vibrant screen to a successful career for the new algorithms, since our thought experiment clearly demonstrates the impracticality of trying to execute them 'by hand'. Yet maybe we should say 'by brain' since mental processes are more important then manual ones in executing computational algorithms. The practical difference is one of the first things that strikes us about the two algorithms: one can be executed manually, the other cannot. But the reason for this goes deeper than matters of convenience, since the two algorithms manipulate different kinds of entity and take place in quite different realms. The former works with objects in the real world; the latter works with concepts in an imaginary one [7]. One I do primarily with my hands, the other primarily with my mind (although I do, of course, use both mind and hand in either case). The reason the computer revolutionizes picturing by computation is because of its speed and precision in performing calculations. But this is a mental, not a physical, prowess.

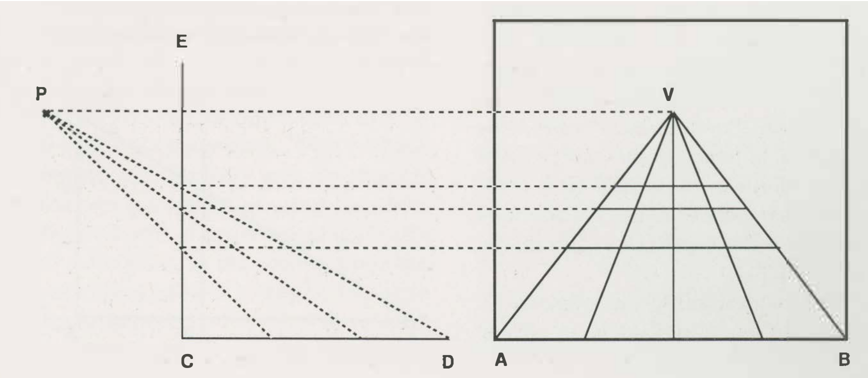
It is important to notice what happens at the onset and culmination of the computational algorithm. At both ends conversions occur, from concrete to abstract and back again. These transformations are unnecessary in constructive algorithms since their execution stays concrete from beginning to end. In constructions, information is taken from the world and processed in an *analog* format. It is continuous, smooth and transferred directly from the world to the picture by physical processes using physical magnitudes. The computational algorithm, on the other hand, processes information as numbers whose magnitudes are indicated not by physical size but by symbols in a conceptual framework. It treats information in a *digital* format, which is discontinuous, discrete, and extracted from the real world by an indirect process that converts physical magnitudes into numbers. The tape measure is a primitive analog-to-digital converter that delivers numbers for computation, and graph paper is a crude digital-to-analog converter that turns numbers into physical magnitudes on paper. Both are grounded in a Cartesian coordinate system that supplies the frame of reference for making the conversions. Thus, while constructive algorithms are bound to record information from the real world, computational algorithms can be used to generate pictures of fantasy worlds just as readily: coordinates do not by themselves betray whether they represent any real object or event.

The major difference between the two types of algorithm lies not in technology, but in ontology. Constructive algorithms have been automated as well—by cameras, which can often take pictures quicker than computers can make them. But cameras cannot take pictures of fantasies since they automate manual chores, not mental ones. Computers using computational algorithms, on the other hand, can conjure up images of any world that is mathematically describable. This is because the computer is an extension of the mind, not of the eye or hand.

Because they deal with numbers instead of objects, computational algorithms can encompass a greater breadth of information than their constructive counterparts. The original Renaissance algorithms projected only shape and location; there were no resources for dealing with color, lighting, transparency, elasticity and a host of other parameters that are grist for the computational mill. Even cameras, which often do a good job with color, do not permit independent control of variables and cannot depart from what is presented by the panoramas and laws of nature.

One algorithm works with physical tools and materials, the other with conceptual structures and numbers that have no preferred or canonical material expression. Nowhere is this distinction more apparent than when we look at dimensions greater than three. Although constructive algorithms can be used to project three dimensions into two, there is simply no way to stretch a string into the fourth dimension to construct a projection of its inscrutable denizens. Computational algorithms, on the other hand, can readily be devised to project images from higher dimensions into the lower ones we inhabit. The work of Thomas Banchoff and his colleagues at Brown University offers unprecedented glimpses into the fourth dimension that help us visualize what it is like, much more vividly than we are able to do simply by thinking about it or making sketches by hand. Our understanding of the hypercube (a four-dimensional analog of the cube) is greatly increased by viewing his animated film that shows different views

Fig. 5. One of Alberti's methods for constructing, entirely on paper, a perspective picture of a checkerboard floor. A side view of the projection is drawn on the same piece of paper as the picture, adjacent and aligned. The principal vanishing point, *V*, is located in the picture, and lengths of the floor tiles are marked off along the line, *AB*, where the ground plane and picture plane intersect. Receding lines in the floor are constructed by connecting *V* with the points marked on *AB*. The lateral floor lines, which are more difficult to position and came later historically, need to be constructed in reference to the side view. Lengths of the floor tiles are again marked, but this time on line *CD* in the side view. Line *CE* is the side view of the picture plane. By connecting the point of view, *P*, to the points on *CD*, the correct position of the orthogonal floorlines can be found at the intersections with *CE*.



of it as it rotates. This is accomplished by calculating the projections from four- into three-dimensional space and then from three-dimensional space into the two-dimensional space of the film. Just as the constructive algorithm gave rise to projective geometry, the computational algorithm is opening up vistas on new mathematical worlds. It is a boon to mathematics and science, as well as art, because it yields to our purview a wide variety of rich new abstract worlds including such things as cellular automata, chaos and fractals.

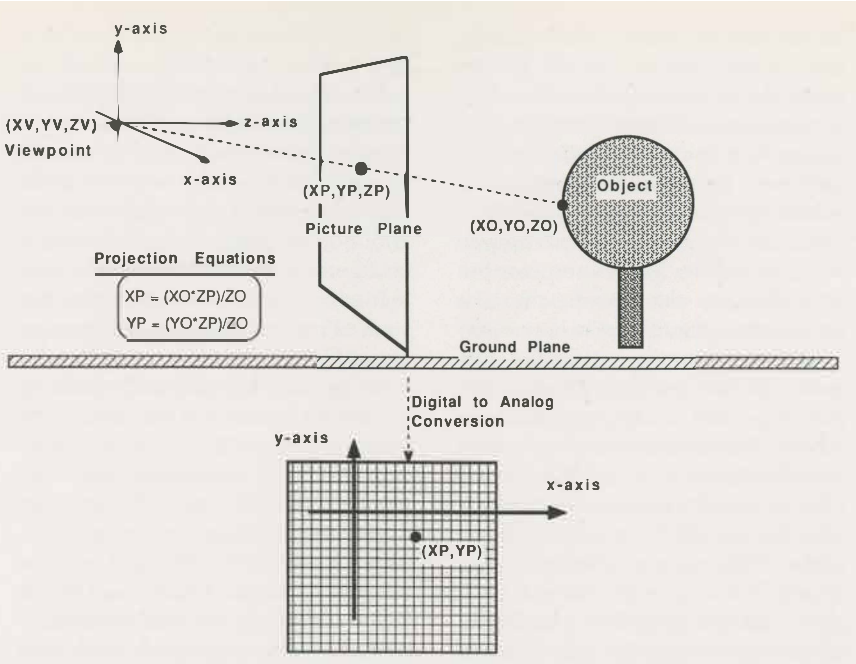


Fig. 6. The Computational Algorithm. Projected points, such as (X_p, Y_p), are calculated using equations. Once their values are determined, they can be plotted on graph paper representing the plane of the picture.

THE COMPUTER'S ROLE: CREATIVE PARTNERING

Let us first consider the role of a medium in constructive algorithms. In a Renaissance painting, the medium of paint serves several functions. (1) It is the physical repository of pictorial information. The projection is constructed in the plane of the painting. (2) It passively embodies this information in an analog format existing in an inseparable union with paint. It is deposited directly on the canvas, so to speak, and does not exist in another form that can be freely moved from one medium to another. (3) It is the locus defined by a set of manual tools and techniques for articulating imagery. In order to make a constructed picture, the artist manipulates a physical material and hence must learn how to do such things as mix paint and wield a brush. (4) It is a channel for communicating cultural information from one person to another. We learn of Renaissance art by looking at paintings made at that time or by looking at reasonable photographic facsimiles of them. (5) This channel is culturally defined. It is according to a set of cultural conventions that the artistic message is read from the front of the painting and not the back, or that it stops where the frame begins and does not continue onto the adjacent wall.

The artist stands amidst media creativity. One element the artist contributes, which is not part of the medium per se, is the imaginative thinking that gets expressed in the work of art. This thinking activity is absolutely essential in order to construct a picture: the artist figures it out using manual tools, but without the mental process nothing happens. So the artist's mind is allied with the physical material of a medium to procure the creative result.

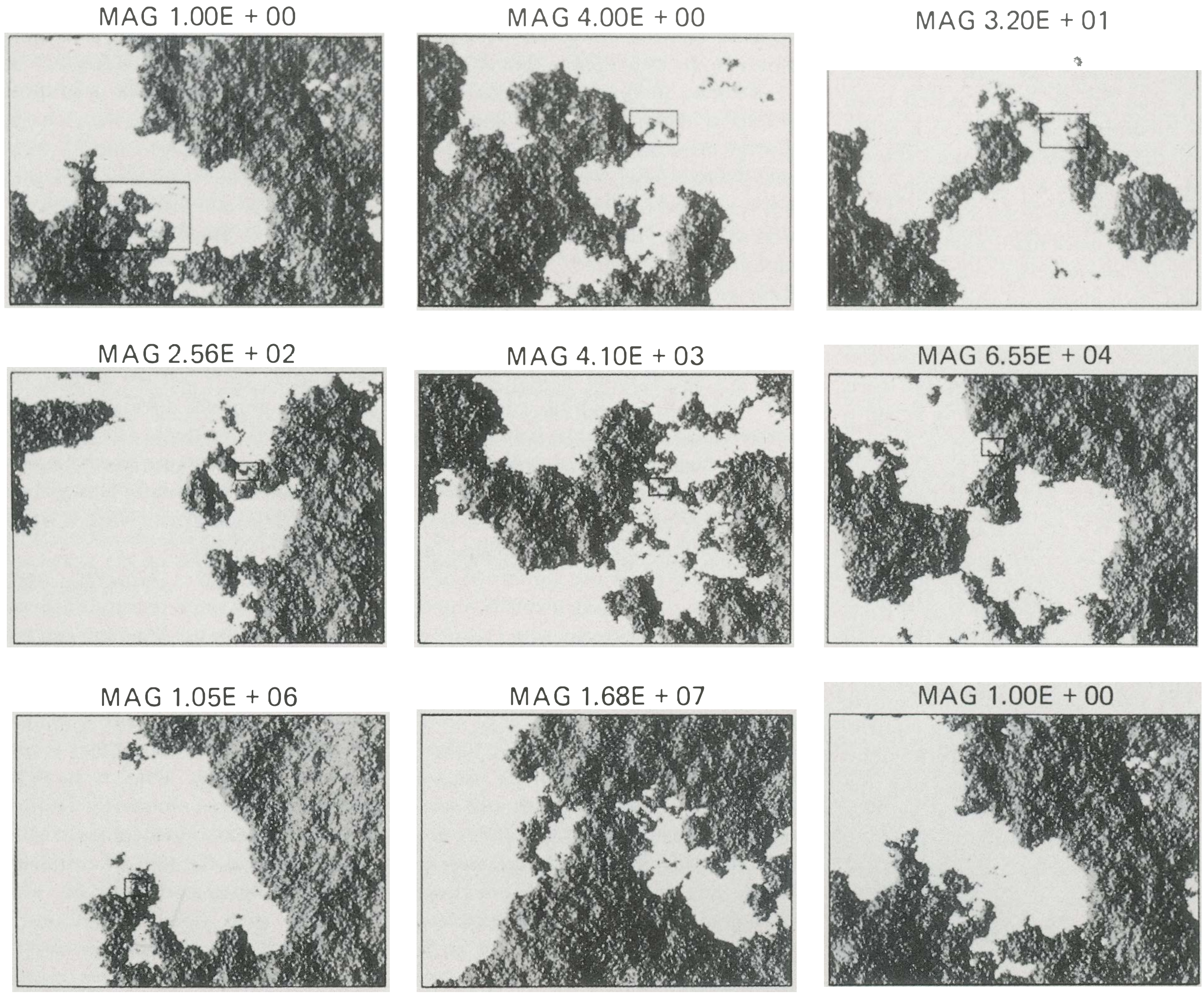
Now if we look at what a computer does for computational algorithms, it appears that its function is much closer to the conceptual contribution of the artist than to the physical contribution of the medium. Computers diverge from media on each of the five points listed above. (1) Computers are not very good places to store information since they do not have very large memories and tend to forget everything when turned off. Furthermore, stored information is conceptually coded in a digital format, not physically embodied in an analog one; this (2) makes the machine capable of actively manipulating it. It is immaterial to digital pictorial information whether a computer is made of silicon chips or vacuum tubes since these substances are not constitutive of that information the way the substance of a medium is. (3) Mental dexterity supercedes manual dexterity when using a computer, and no fixed tool-based skills are prescribed. (4) Computers are not themselves channels of communication, although they are linked to such channels in much the way we are. (5) The computer deals with concepts, numbers, and bits, which are not culturally defined and dependent in the way a medium is. From these considerations, I think it is apparent that the role of a computer in art is more that of an active creative partner than a passive medium [8]. Comparing the benefits of a computer to a pencil is not like comparing the advantages of a backhoe to a shovel when one is searching for buried treasure. Rather like a seismic detector, the computer does not promise to shovel more dirt faster to get to the rich nuggets of creative insight more quickly but rather avails itself of a little intelligence to obviate the need to move a mountain to find a pot of gold. In computational algorithms executed by computer, some of the thinking burden carried by the artist using a constructive algorithm is shifted to the computer. Here we see clearly that what the computer does is quite unlike what a medium does. The computer 'thinks'—it calculates. Media cannot do this since they are physical and passive; the computer can since it is conceptual and active.

The computer, however, needs media for the same reason our brains need sense organs. A person can execute a computational algorithm in the mind, but it requires eyes and hands to convert the data into a picture. Without media, the computer is completely impotent. Thus it is always functioning in a symbiotic relationship with at least one medium to which it is interfaced through an automated analog-to-digital converter. So, while we may give up the medium of graphite for page layout in desktop publishing, we nevertheless transfer its function to another medium, the laser printer. Computers are so integrally bound up with media that they are starting to be built into the tools of media, such as cameras and videotape recorders. Putting them closer to the media they work with is a trend likely to continue and intensify as computers grow smaller and more powerful. This may be one reason why it is tempting to assimilate computers into media and try to win a place for computer art in the gallery alongside paintings and sculptures. But this strategy is dangerous since it obscures the computer's true role and is more likely to put off than to convince critics who are skeptical that the computer has any valid role to play in making art. The promiscuity with which a computer can interface with a variety of media underscores the fact that it is not one of them. If we hope the computer will eventually become accepted as a new medium, we may have a long wait.

Although it must use media, the computer is not best understood as a new medium tool, whether it is in the gallery as an interactive installation or in the studio as a creative partner. It is a metamedium and a mental tool. It can add intelligence to tools by working cooperatively with them. Its contribution is made by establishing a relationship between hardware and software that does not exist for the tools of media. The computer is more versatile than a camera, but it can do nothing without software to guide its cognition. A camera is not directed by software because it is 'hardwired' to do one job only; it is physically based and cannot think for itself [9]. Software supplies the computer's affect, its 'personality', which is what makes these machines able to interact and think. The computer is not a single-minded tool: it can be taught new tricks with new software. It can 'learn', unlike traditional media-based tools that are unable to modify the structure of their behavior based on any software fed into them. Even though a video cassette recorder can play any tape, it can do nothing other than play it out (unless, of course, it has a little computer inside).

In his renowned essay, "The Work of Art in the Age of Mechanical Reproduction", Walter Benjamin claims that mechanical technologies remove the aura from one-of-a-kind artworks produced using traditional methods [10]. The *Mona Lisa* loses some of her mystery when the image of Leonardo's painting is subjected to profligate replication in books, magazines, posters and post cards. The computer can reproduce imagery even more faithfully than mechanical devices can, since it processes information digitally; but its effect on art is unlikely to be similar. Its information technology is more metaphysical than mechanical, which makes it capable of generating novelty and responding uniquely to different situations. Its legacy need not be the impersonal tedium of assembly-line culture emanated from physical dynamos conceived in the Industrial

Fig. 7. A sequence of zooms into a fractal landscape by Richard Voss. Magnification ranges from 1 to more than 16 million.



Revolution. Although the computer will never reclaim the lost aura of art from an earlier age, it does invite new personality onto the art scene.

The Myth of Resolution: Metaphysical Imagery

Some artists are drawn to the computer (or repulsed by it) because of what they perceive to be a characteristic look of the art created with it. This is, however, just another byproduct of the effort to domesticate these intractable machines by assimilating them into media. Even a cursory examination of the varied work in exhibitions reveals that computer art in itself has no representative physiognomy. Computers are bound to media, but to no particular one, and hence work done with them can project all the different appearances of media currently in use. The myth of the look is fostered by the fact that, due to historical circumstances, the canonical medium for working with computers has been the CRT connected to image memory in frame buffers that have until recently been rather limited in size. Yet since their role is conceptual, not perceptual, any new appearances that computers introduce must reside in the structure of their interfaces to media, and not in the substance of media, in the way that certain looks are characteristic of watercolors, oil, pastels or charcoal.

One of the paradigmatic differences between computers and media is that the former usually process information in digital form while the latter store it in analog form. Because of this difference, imagery created with computers can still look discrete when interfaced to an analog medium and give the impression that the computer has its own peculiar 'digital' look. Yet in the process of converting digital computer information into analog medium information through an interface with an analog-to-digital converter, the discreteness of digital information can be hidden and completely assimilated into the analog medium.

One feature that has until recently been commonly associated with computer art is the low resolution for which it was often ridiculed in its infancy. But it is important to recognize that the computer per se is resolution-independent in a way no medium can be. This is at first difficult to comprehend, since we constantly talk about the resolution of computer graphics systems and compare them on this basis. Yet this concept of resolution has more to do with interfaced media than with digital information. Media has resolution; computers do not. The resolution of video or film is rather apparent, based on the number of scan lines of a video system or the size of grains on film. Even paints and pencils have a definite resolution, refined although it may be. The computer, on the other hand, does its calculations with numbers whose results can be delivered to an output device at any desired resolution. The precision of floating point arithmetic does impose limits, but these limits are flexible and permit the reiterated zooms of Richard Voss (Fig. 7), which would produce grainy pictures very quickly if done photographically. Even a tunnelling electron microscope possesses a quite definite—albeit extremely high—resolution, while computerized magnifications of virtual worlds can seem to go on forever without losing definition. Resolution is not defined by the computer, but by the output device—a medium.

Interaction in a Postmodern World: Experiencing Virtual Reality

The era of Modernism was the age of new media: photography, cinema, video, acrylic paint and fiberglass sculpture. The self-conscious exploration of artistic expression that was characteristic of Modernism provided the spawning ground for new media as artists experimented with newness and highlighted the foundations of their expressive channels. Banners of the avant-garde charted a progressive course through exhaustive investigations of the possibilities of media.

Conceptual art marked a watershed between the progress of Modern art and the pluralism of Postmodernism [11].

Due to its conceptual orientation, the computer should not, I believe, be placed in a Modernist context as a new medium, but rather in the context of an increasingly conceptual Postmodern art that, while reverting to the use of media, remains aloof from them. The computer is Postmodern not only temporally but theoretically. By working with formal properties, computers can simulate anything specifiable with numbers or mathematical formulas. They thereby demonstrate something of Proteus' prescience by being able to foretell the future—or at least play it out—in a virtual world. These computer simulations should be allied with the Postmodern work of such artists as Sherry Levine or Michael Graves and not with the media they sometimes simulate. The recent history of art has witnessed the breakdown of distinctions between traditional media, and artworks have become generally less media bound (happenings, performance art, multi-media, conceptual art, etc). It is retrogressive to try to justify computer art as the advent of yet another medium when in fact its real import is much more closely allied with the conceptual thrust of recent art than the physically based media delimited in the past as separate disciplines. Even when it emulates them and uses them, the computer etherealizes media and makes them evanesce in the spirit of a tradition inspired by Marcel Duchamp's readymades. Although his amusing work *In Advance of a Broken Arm* is a physical object (a snow shovel), its artistic meaning is not expressed in physical material the way a sculpture by Rodin or Calder is. The import of the computer as a creative partner is similarly conceptual. The computer is more than a fancy picture maker; its powers are versatile enough to carry us into the virtual worlds it conjures up with its computational algorithms. The window of Renaissance perspective is a barrier keeping us away from the depicted world at the same time it unveils it to us. But the luminous screen under computer control can transport us—like Alice through the looking glass—into the virtual worlds it displays. We can, in a sense, live in these created environments and interact with them.

The unique element computers add to art is interactivity. This happens in two stages. First, the computer transcends the passive physicality of media to become conceptually active. The art itself has assumed the ability to manipulate conceptual objects; this has heretofore been the exclusive domain of the artist. The second step takes place as the artwork becomes almost anthropomorphized so that we can interact with it. It is not simply active, putting on a performance of entertaining wizardry, but it recognizes us as sentient beings with whom dialogue is possible. The paradigm by which to comprehend computer art is not the medium or the medium simulation, but the interlocutor. The computer rises from the sea of Postmodern culture not as a new Venus promising more beautiful art, but as a wily sorcerer taunting us with its cleverness. This wizard is not easy to work with [12], but commands an intriguing repertoire of artistic resources.

References and Notes

1. Sherry Turkle, *The Second Self* (New York: Simon & Schuster, 1984) p. 16.

2. See, for example, Arielle Emmett, "Computer and Fine Arts", *Computer Graphics World* (October 1988) pp. 68–75. See also Cynthia Goodman, *Digital Visions* (New York: Abrams, 1988). Her book and the exhibition "Computers and Art", on which it is based, provide ample documentation of the diversity of art created with computers. Other examples of the medium paradigm can be found in *The Art of David Em* (New York: Abrams, 1988) and Stephen Wilson, *Using Computers to Create Art* (Englewood Cliffs, NJ: Prentice Hall, 1986). Wilson does admit, however, that "it is a concept . . . that may have outlived its usefulness" (p. 21).

3. Brunelleschi left no record of the precise rules he followed, but Samuel Y. Edgerton, Jr. has done an admirable job of reconstructing them in his book *The Renaissance Rediscovery of Linear Perspective* (New York: Basic Books, 1975).

4. Leon Battista Alberti, *Della Pittura*, L. Mallè, ed. (Firenze, 1950).

5. Edgerton [3]. See also my article "Computed Space", *Proceedings of the National Computer Graphics Association* (1987) pp. 643–652.

6. Edgerton [3]. See also John White, *The Birth and Rebirth of Pictorial Space* (New York: Harper & Row, 1972) and Dan Pedoe, *Geometry and the Liberal Arts* (New York: St Martin's, 1976).

7. Jean Baudrillard dubs this computational realm 'hyperreality' to distinguish it from the real world of constructions. See his *Simulations* (New York: Semiotext(e), 1983).

8. Arguments for this view are presented more fully in my essay "The Computer Is Not a Medium", *Philosophic Exchange*, forthcoming. See also "Medium Nor Tool?", *Computer Graphics World* (February 1989).

9. I explore some of the differences between ways cameras and computers make pictures in "Camera Fantasia", *Millennium* **20/21** (Fall/Winter 1988/1989).

10. Walter Benjamin, "The Work of Art in the Age of Mechanical Reproduction", in *Illuminations* (New York: Schoken Books, 1969).

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Fractals and an Art for the Sake of Science

Benoit B. Mandelbrot

ABSTRACT

A new form of art redefines the boundary between 'invention' and 'discovery', as understood in the sciences, and 'creativity', as understood in the plastic arts. Can pure geometry be perceived by the 'man in the street' as beautiful? To be more specific, can a shape that is defined by a simple equation or a simple rule of construction be perceived by people other than geometers as having aesthetic value—namely, as being at least surprisingly decorative—or perhaps even as being a work of art? When the geometric shape is a fractal, the answer is yes. Even when fractals are taken 'raw', they are attractive. They lend themselves to 'painting by numbers' that is surprisingly effective, even in the hands of the rank amateur. And the true artist's sensibility finds them a novel and attractive support.

The artist and the artisan are often hard to tell apart. For example, objects that were in principle meant to be utilitarian—be it folk architecture, religious imagery, or drawings and photographs of flowers, birds or water eddies—often end up being regarded as genuine works of art. It may become hard to distinguish them from works in which science was used almost as an excuse for artistic creativity. Thus, art faces us with broad possibilities. We are presented with innumerable works of art for the sake of commerce: objects have been commissioned under precise specifications to be useful—to decorate, to educate, to flatter, to entertain, to impress or to persuade. We are also presented with a few works created strictly as art for art's sake. And we also know of many possibilities that lie, so to say, in-between.

Does mathematics relate in any way to these familiar forms of plastic art? The classic shapes of geometry are hailed for their conceptual beauty, but they seem mostly to reside in the imagination of skilled practitioners. Although the popular poet Edna Saint Vincent Millay proclaimed that "Euclid Gazed on Beauty Bare" and although Euclid's geometry was of central importance to painters of the Italian Renaissance during the brief period when perspective was being 'invented', to the eye of those unschooled in mathematics, the beauty of Euclid's geometry is bare and dry to a fault. At the least it lacks scope and visual variety when compared with those excesses of either nature or the fine arts, which everyone seems tempted to call 'baroque' or 'organic'.

Today, however, there is more to geometry than Euclid. During the 1970s it was my privilege to conceive and develop fractal geometry [1], a body of thoughts, formulas and pictures that may be called either a new *geometry of nature* or a new *geometric language*. And the reason why it is worth discussing here is that I have discovered that, most surprisingly and without any prodding, this new geometric language has given rise to a new form of art. I propose here to make a few disjointed comments on its account. Many readers are bound to be familiar with fractal art, and the volume in which this paper appears may well contain some new examples from the 1989 SIGGRAPH show; nevertheless, close familiarity with the subject is not expected from the reader.

The bulk of fractal art has not been commissioned for any commercial purpose, even though all the early work was done at IBM. And it has not necessarily been touched by esthetic sensibility. Therefore, we shall argue that fractal geometry appears to have created a new category of art, next to art for art's sake and art for the sake of commerce: art for the sake of science (and of mathematics).

Fractal art for the sake of science is indissolubly based on the use of computers. It could not possibly have arisen before the hardware was ready and the software was being developed; that is, before the decade of the seventies. What a profound irony that this new geometry, which everyone seems spontaneously to describe as 'baroque' and 'organic', should owe its birth to an unexpected but profound new match between those two symbols of the inhuman, the dry, and the technical: namely, between mathematics and the computer.

Before we describe the peculiarities of fractal geometry in more detail, it is good, for the sake of contrast, to comment on examples of similar matches that have arisen in areas such as the study of water eddies and wakes. In these cases, the input in terms of reasoning and programs is extremely complicated, perhaps more complicated even than the output. In fact, one may argue that, overall, complication does not increase but changes over from being purely conceptual to being partly visual, a change that is important practically and interesting conceptually. Fractal geometry, however, gives us something quite different. In fractal geometry, the inputs are typically so extraordinarily simple as to look positively simple-minded. The outputs, to the contrary, can be spectacularly complex. Again, while a contribution from an artistic sensibility is not necessary, it is well rewarded.

Let us hasten to raise a question. Since the inputs are so simple, why is it that fractal art failed to appear earlier and in more traditional ways? The answer lies in a 'Catch 22' situation. To draw the simplest fractal picture 'by hand' would have been feasible in principle, but would have required many person-years and would have been ridiculously expensive. Consequently, no one would have considered undertaking this task without having a fair advance knowledge of the result; yet the result could not even be suspected until one actually had performed the task. And a sure way of being discouraged from ever undertaking it would have been to begin with any one of the various definitions of fractals. Here is one informal definition I often use:

Fractals are geometric shapes that are equally complex in their details as in their overall form. That is, if a piece of a fractal is suitably magnified to become of the same size as the whole, it should look

Benoit B. Mandelbrot (mathematician, research fellow), Physics Department, IBM T.J. Watson Research Center, Yorktown Heights, NY, 10598, U.S.A.; Mathematics Department, Yale University, New Haven CT 06520, U.S.A.

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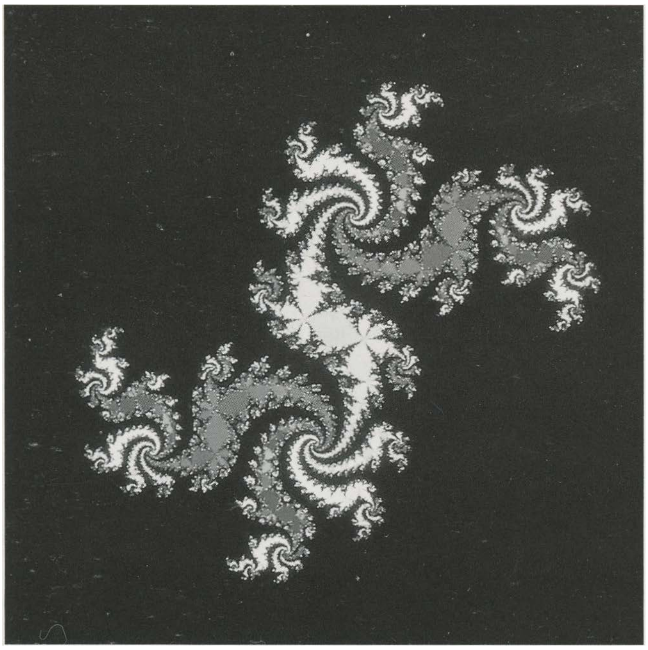


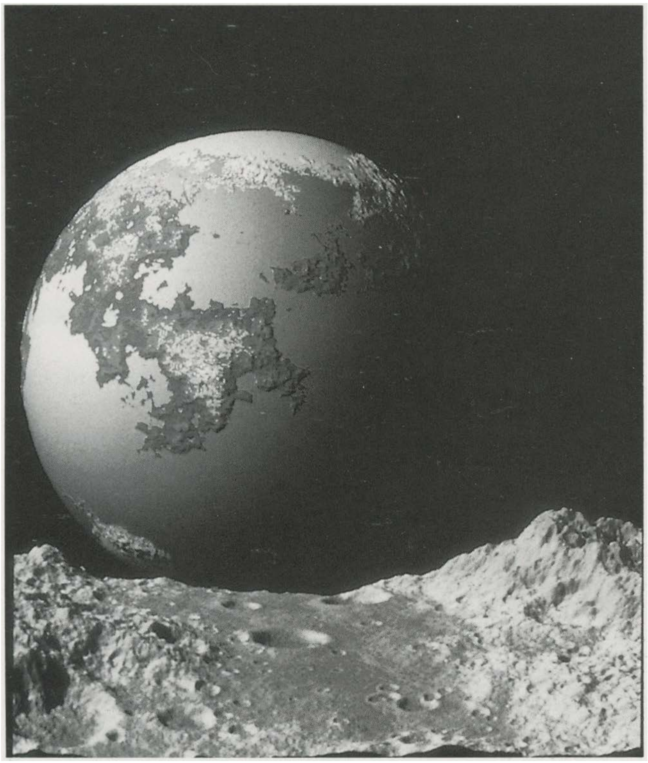


Fig. 1. The two faces of fractal art. (above) M. R. Laff and A. V. Norton, *Fractal Dragon*, 1982. (below) R. F. Von, *Fractal Planetrise*, 1982. This *Fractal Dragon* and *Fractal Planetrise* may be the best known of all fractals, since they appear on the two halves of the jacket of *The Fractal Geometry of Nature* (Ref. [4]). Their being set as neighbors is meant to illustrate the basic fact that fractal art straddles the boundary between art that is, and is not, representational.

like the whole, either exactly, or perhaps only after a slight limited deformation.

Are we not right in the middle of dry geometric principles? An artist could expect nothing from fractals defined in this fashion, hence no one attempted to draw them carefully. The few old fractals that had been known under various names (and depicted for at least a century) are also the least interesting esthetically because one glance shows that everything about them has been obviously put in by hand; they are orderly to excess. These images, however, began to grow in number and in variety after they were picked up and made into the first few 'words' in the new geometric language of fractals. This happened with my first book in 1975 [2].

What were the needs that led me to single out a few of these monsters, calling them *fractals*, to add some of their close or distant kin, and then to build a geometric language around them? The original need happens to have been purely utilitarian. That links exist between usefulness and beauty is, of course, well known. What we call the beauty of a flower attracts the insects that will gather and spread its pollen. Thus the beauty of a flower is useful—even indispensable—to the survival of its species. Similarly, it was the attractiveness of the fractal images that first brought them to the attention of many colleagues and then of a wide world.

Let me tell how this started happening. In the 1960s, the basic idea of the theory of fractals was already present in my mind, having been devised to study such phenomena as the erratic behavior of stock prices, turbulence in fluids, the persistence of the discharges of the Nile, and the clustering of galaxies, which manifests itself with the presence of great intergalactic empty spaces. But society seemed to think that my theories, their mathematical techniques and their goals were strange, as opposed to simply new. As a result, my attempts to make my thoughts accepted as sound seemed always to encounter a wall of hostility that words and formulas failed to circumvent.

One day it became necessary to convince Walter Langbein, the editor of a water resources journal, to accept a paper I had co-authored. He was a skilled and able scientist, but not one to gamble on wild, unproven ideas. I decided to resort to a tactical detour, presenting him with two images in the hope that Langbein would find it impossible to distinguish between reality and 'forgeries' that were based solely upon an early fractal theory. If this were to happen, he would no longer be able to view this theory as irrelevant to his work, he could not and would not reject our paper outright, and he might eventually accept fractals. This is indeed what happened: the detour through the eye turned out to be successful, and its offspring grew beyond expectation.

What happened next to fractal art as it evolved brings us to the traditional dichotomy between representational and nonrepresentational art. In the well-recognized forms of art, this dichotomy no longer seems so strongly etched, and fractal art straddles it very comfortably. The earliest explicit uses of fractals gave me the privilege of being the first person to tackle in a new way some problems that must be among the oldest that humanity had asked itself: how to obtain 'figures' that represent the shapes of mountains, clouds and rivers? It turns out that, when the representation of nature by fractal is perceived as successful, it also tends to be perceived as beautiful. Unquestionably, the fractal 'forgeries' of mountains and clouds are examples of representational art.

The skeptic will immediately raise another question. Is it not true that the colors used to render these mountains and clouds are chosen by rules that have nothing to do with any geometry? If this is so, these 'forgeries' are not purely fractal. What precise role, then, does color play in the acceptance of what you call 'fractal art'? This may sound like a very strong objection, but in fact it is easy to answer.

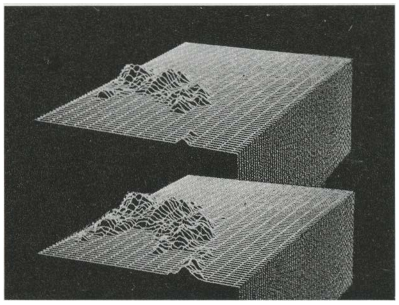
First of all, the question did not and could not arise with the first fractal pictures, simply because they were in black and white. I might also add that in many cases this supposedly obsolete palette is the one I continue to favor.

When the use of color did arise, Richard Voss and I worried that it might detract from our primary concern with the geometry. Thus, initially he decided to color his art simply, as in the *London Times World Atlas*; but in landscapes viewed from an angle instead of the zenith, this proved to be visually unacceptable. However, we continued to avoid excessive artistic intervention, and Voss kept his esthetic urges under the tightest of control. This, in my opinion, helped fractal geometry make its intended point. Once that point was achieved, however, a completely different situation was created in which reserve was no longer an overriding obligation. In the recent crop of pictures by F. Kenton Musgrave, 'SIGGRAPH tricks' are allowed, but one *absolute* constraint remains. Every surface that is depicted must be a fractal surface, and all commands that are used to improve the rendering must be global commands. To 'fix' an unsatisfactory corner of a piece by a local patch is not permitted. Many computer artists would find this constraint to be quixotic, but it is essential if fractal art is to preserve its integrity.

While dealing with fractals intended as forgeries of nature, we found that cases soon began to multiply in which this intent failed. The result, however, remained just as beautiful, and occasionally even more so. Happy errors! Furthermore, a person fascinated by shapes could not avoid forgetting on occasion the original goals of the fractal geometry *of nature* and would play on with fractal algorithms just to find where they might lead. Thus as a fractal model of mountains is deformed by changing the values given to one or a few numbers that characterize the fractal's form, the picture becomes less and less 'realistic' as a mountain and gradually becomes altogether 'surreal'.

Even more striking surrealism prevails within the second major aspect of fractal geometry. Fractal 'dragons', of which the 'oldest' is reproduced here (see Fig. 1)—and of which millions seem to have been drawn since—have never been meant to represent anything in nature. Their intended usefulness concerned mathematics, since they helped me investigate a process called the 'dynamics of iteration'. Early in the century, the mathematicians Pierre Fatou and Gaston Julia had found that this process presents a deep and surprisingly intellectual challenge. Then for 60 years hardly anyone touched the problem because even the most brilliant mathematicians, when working alone with the proverbial combination of pencil-and-paper and mental images, found that its study had become too complicated to be managed. My fresh attack on iteration could rely upon the help of the computer, and it was effective: the new mathematical order was spectacular. For the purposes of this discussion, this does not matter at all, of course; but a side result does matter a great deal: the resulting balanced co-existence of order and chaos was found almost invariably to be beautiful.

As in the case of the fractal mountains, the new iteration-generated fractals were already perceived to be



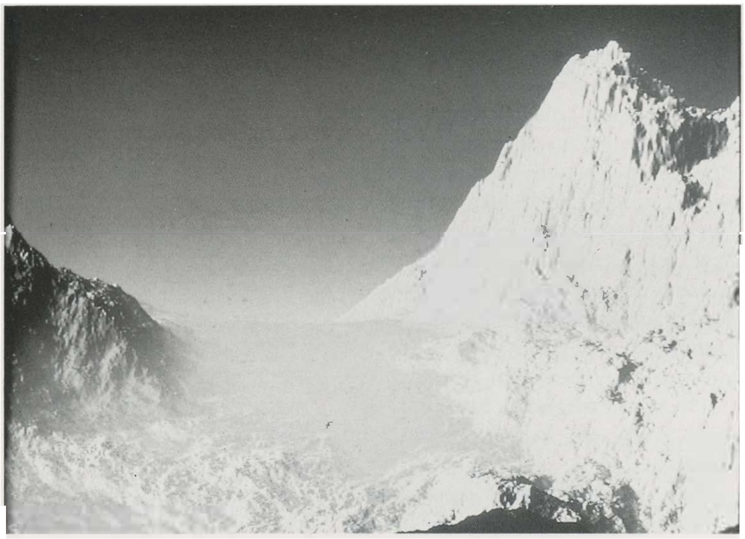


Fig. 2. Fractal landscapes. These illustrations exemplify three of many successive stages in the development of fractal landscapes. One may call these stages, respectively, 'archaic', 'classic' and 'romantic'.

The archaic wire model illustration (above) was done by S. W. Handelman (1974), who was then my programmer at IBM at a time when our work was dominated by the extreme crudeness of the tools.

The classic illustration (below) is by Richard F. Voss of IBM (1985). It is an improved form of one in a series he prepared for my book of 1982 [4]. By then, the computer tools had become less obtrusive, and allowing fancy to take over was a genuine temptation. But fantasy had to be resisted because these pictures were primarily tools of scientific discourse. The wonder is that these extreme constraints should have allowed the emergence of Voss's masterpieces of subdued elegance.

The romantic illustration (see back cover) is by my present Yale student, F. Kenton Musgrave, and myself (1989). Today, wire models that are better than the archaic one take 1 second to be computed and drawn on a workstation, and the number of available colors has changed from being unmanageably small to being unmanageably large. The most innovative use of fractals now is to serve as support for an artist's inspiration and skill.

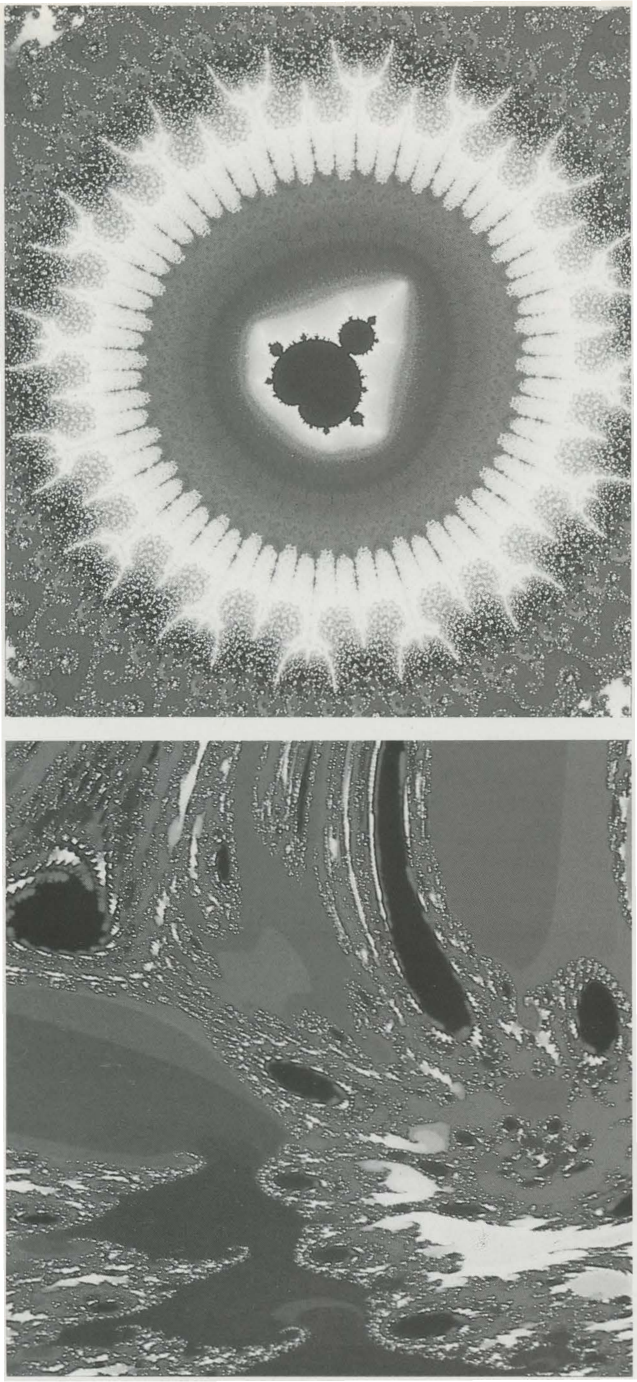


Fig. 3. Two fragments of the Mandelbrot set. The Mandelbrot set is explained in Refs [4], [7] and [8]. The first fragment (above; R. F. Voss, 1988) was selected so as to include, near its center, a small replica of the whole, with its obvious symmetries and repetitions, and even to include additional symmetries that are not present in the whole set. This fragment, therefore, leans too far towards orderliness. The second fragment (below; B. B. Mandelbrot), which is from a generalized, not the 'ordinary', Mandelbrot set, was selected to provide contrast since it is devoid of obvious symmetries.

beautiful in their original black and white. More precisely, the output of my work was a collection of numbers that in the early stages had to be reduced to two possibilities, to be represented by black and white. After color became involved, these numbers were first represented by colors chosen more or less at random by color-blind hackers. (An awful case of painting by numbers!) Yet even these fractals were, in a way, beautiful. But when the coloring was placed in the hands of a true artist, we began to see true wonders.

Our skeptical critic will come back at this point to remind us that fractals should share the credit for this art with both the computer and the programmer artist who frames the object and selects the colors. These last two factors are the ones usually considered central to computer art; hence the critic's point concerns the significance of the fractal's additional input. In some cases (as in one of the illustrations of this paper) fractals' most obvious contribution is an obtrusive symmetry that may in fact be found to be very objectionable. In other cases, however, when the symmetry is hidden we see an interplay between strong order and just enough change and surprise. My readings on the meaning of art suggest that such an interplay is one of the basic prerequisites of plastic beauty.

To summarize, the altogether new feature brought in by fractal art is that the proper interplay between order and surprise need not be the result either of the imitation of nature or of human creativity, and it can result from something entirely different. The source of fractal art resides in the recognition that very simple mathematical formulas that seem completely barren may in fact be pregnant, so to speak, with an enormous amount of graphic structure. The artist's taste can only affect the selection of formulas to be rendered, the cropping and the rendering. Thus, fractal art seems to fall outside the usual categories of 'invention', 'discovery' and 'creativity'.

All this seems to have happened long ago, and today fractal geometry is so well established that young people are astonished to find that the 'father of fractal geometry' (as I am delighted to be called) is still alive. But I hope to live long enough to really understand what has happened.

References and Notes

1. The first three books on fractals are Refs [2], [3] and [4]. Among later books, I recommend Refs [7] and [8], which are of higher graphic quality than mine, though of narrower focus. Of the approximately 40 books that have by now been written on fractals, nearly all are for mathematicians and/or physicists, and Refs [4], [7] and [8] are the only books written in English for a broad audience. Ref. [5] belongs here because of the journal in which it appeared and because it is my earliest statement on the issue of fractals and esthetics, and Ref. [6] can be viewed as a commentary on the present paper.

   A quandary and an Apology. It would have been nice also to recommend works with which I am less closely associated, but this would be very hard. Each quote creates one happy person and many unhappy ones. The time when my close associates were the only people involved with fractals passed years ago, and to write a balanced survey is not a task I enjoy.

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Mathematics As an Artistic-Generative Principle

Herbert W. Franke

ABSTRACT

The author defines a mathematical discipline that is devoted to the generation of artistic images. The practical implementation of the underlying theory is possible today with the aid of computer graphics systems.

Interconnections between mathematics and art are manifested for the most part in the form of principles of order that can be observed in works of art. Especially in the works of classical art, symmetry was explored by Hermann Weyl [1]; he used mathematical methods for analysis and description of various types of artwork. Up until now other mathematical characteristics of artistic pictures—for example those of combinatorics (Karl Gerstner, Richard Paul Lohse, Shizuko Yoshikawa), of the theory of numbers (Rune Mields, Anton Stankowski), of aleatorics (Gerd von Graevenitz, Herman de Vries), and others were stated but not considered more deeply from the point of view of general theoretical relations [2].

A further area of common ground can be seen in the fact that the visualization of mathematical relationships often leads to aesthetically pleasing results. A good illustration of this is the computer graphics work with fractals begun by Benoit B. Mandelbrot and continued by the Bremen-based "Working Group on Complex Dynamics" headed by Heinz-Otto Peitgen and Peter H. Richter [3]. In these and similar cases, the beauty of the pictures obtained is regarded as a pleasant side effect that can be enhanced further by selection of appropriate sections and colors. This represents an initial, still hesitant step towards artistic creativity; it yields results which can still be treated as mathematical documents in pictorial form, but for which its practitioners claim artistic value, as is expressed in the term 'map art' coined by the Bremen working group. Visually attractive pictures can also be achieved using other fields of mathematics, such as field theory, the theory of complex functions, Fourier transformations [4] and—most recently—topology [5]. In all these cases the fascinating visual results are more a subordinate effect, but they prove that this method shows a yet-widely untouched field of interesting forms and shapes. Enormous possibilities lie in mathematical research conducted with artistic rather than mathematical goals.

In the past, there have been only few indications in this direction; the most important work—a systematic investigation in the fields of algebra and analysis—was conducted by Maurice El-Milick in 1936 [6]. Also remarkable are the publications of Hermann von Baravalle [7], who devoted his work to a series of geometrical shapes.

The development of artistic computer graphics implies a strong impulse to use sophisticated mathematical relations for artistic creations. In particular, those working with mathematical plotters—from Frieder Nake, Georg Nees and A. Michael Noll to Collette and Jeff Bangert, Harold Cohen and Edward Zajec [8]—used mathematics in pretentious fashion to produce new structures, unknown in art up to this time; but unfortunately, they did not theoretically systematise their methods. On the other side, utilisation of menu-controlled computer-aided design (CAD) and paint systems is a step backward to conventional picturemaking and a corresponding renunciation of innovations coming from mathematics in this field. There are, however, some artists using sophisticated mathematics—for example Jeffrey Ventrella uses fractals [9] while Donna Cox employs physical research with supercomputers [10].

As a logical consequence of these developments and in order to clarify the situation, it is appropriate at this point to name and define the procedure that underlies these attempts: *Generative mathematics is defined as the study of mathematical operations suitable for generating artistic images.*

Following are some suggestions for some of these goals:

(1) One of the focuses of generative mathematics is the derivation of functions that, when graphically displayed and viewed, yield aesthetically interesting results. These can be either graphic elements suitable for composing images, or configurations that can be used as the basis for further processing. The functional relations that deserve particular attention are not those that are the expression of any scientific discoveries (perhaps for this very reason have been ignored in the past), but those that bring forth new and fascinatingly beautiful forms.

Yet another fundamental activity of generative mathematics is the development of transformations that can be applied to images; no longer of relevance here are the mathematical attributes on which interest previously focused, but rather the possibilities they offer for aesthetic optimization.

(2) One important concern in the field of generative mathematics is the concern with the description of image structures, a process analogous to the transcription of music. This line of study concentrates on aspects of mathematical formalism and on the algorithms used by the computer programs.

(3) An interesting aspect of generative mathematics is its link with rational aesthetics. This has to do, for example, with the extent to which mathematically expressible

Herbert W. Franke (scientist, artist), Puppling, Haus 40, 8195 Egling, Federal Republic of Germany

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principles can be correlated with aesthetic effects. Quantifiable image description also provides a useful basis for statistical studies of the aesthetics of information.

(4) Historical questions (particularly those belonging to the recent past) are relevant to generative mathematics. For example, it would be desirable to compile an inventory of all of the computer graphics methods that have yielded aesthetically interesting results during the last 25 years. These include the use of random number generators, which has been practiced right from the start and still plays a significant role in connection with depiction of fractal geometry. A collection of earlier publications dealing with connections between mathematics and art would also be very useful.

(5) Finally, generative mathematics also includes procedural issues related to the hardware and software problems associated with computer graphics. For example, the method of 'experimental mathematics' that is currently being discussed avidly in specialist publications can be readily tied in with aesthetic issues. It would also be worthwhile to discuss questions related to instruments and methods in connection with the concept of the 'aesthetic laboratory' introduced by Georg Ness.

CONCLUSIONS

Many artists are opposed to theoretical considerations such as those discussed here. The question arises: Do aesthetic experiments with mathematical relations need in fact a theory? I think the answer is yes, in order not to overlook all the possibilities and consequences in the utilisation of complicated mathematical methods and their application in a highly sophisticated tool, the computer. It is not simply a question of how to produce beautiful pictures; in this context, the question arises as to whether generative mathematics could not also open up new possibilities for representation and expression. A parallel to this can be found in music, where the development of instruments combined with the theory of harmony has given rise to an extraordinary artistic development.

The use of instruments and other aids results in new techniques, and new techniques in turn inspire new ways of thinking. For example, the mathematical method of image generation leads to a departure from the classical way of composing a picture. In the conventional approach, the picture is changed only where the artist directly intervenes (with a brush or pencil, for example). This approach can therefore be described as 'punctual'. The advent of a mathematical way of thinking, by contrast, makes available the possibility of altering the entire picture with each intervention (e.g. by means of a transformation). This approach can thus be characterized as 'integral'.

In principle, any image can be constructed using either of these two approaches, but apparently certain visual structures exist that lend themselves more readily to implementation by the punctual method and others that are better suited for integral composition. In the past, those in the latter category have all too often been neglected—predominantly those that do not consist of arbitrarily placed elements, but instead obey a uniform principle (even though this may be a complex one). In this respect, they are more closely related to music than to the classical visual arts.

The rapid switch from one image to another made possible by computer graphics systems facilitates the transition from still images to moving pictures. In other words, the mathematical method is, in a manner of speaking, inherently suited for depiction of dynamic processes. This yields interesting possibilities for putting into practice the old idea of a dynamic play of graphic forms. If this can be described with the aid of mathematical formulas, then it is particularly easy to implement it with a computer program. Even the idea of 'graphic improvisation' in realtime can be achieved in this way without difficulty.

It is of course also possible to use mathematical methods for image generation without having a theoretical background—as has already been shown by the work of various individuals. But if the aim is to exploit the gigantic potential that exists for the creation of mathematically describable images, then 'generative mathematics' is capable of making a vital contribution.

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Cinema and the Code

Gene Youngblood

ABSTRACT

The author and his colleagues suggest a criterion for evaluating artistic achievement in the medium of the digital moving image as distinct from other forms of cinema. This criterion is the extent to which the formal possibilities of digital imaging are employed as syntactical or linguistic elements, not simply as 'special effects'. Four digital imaging techniques are discussed as possibilities for a new syntax and, hence, for the expansion of cinematic language.

What are the implications of digital imaging for the evolution of cinematic language? Since 1986, Peter Weibel, Steina and Woody Vasulka and I have been meeting to discuss that question [1]. We thought our talks might become a book, whose subject Weibel conceived as "the evolution of the image through the digital image". What follows is an outline of our conversations, assembled for this publication from 200 pages of transcript. It is in every sense a first draft, a working paper. We are quite aware of the problematic nature of our discourse, especially in the cursory form presented here. Every conclusion is vulnerable to criticism, which we welcome. We are certain of only one thing: that these questions are important and need to be explored.

The subject of 'digital imaging', we agree, exists in the context of both video and the computer (different only in the source of the image and the possibility of real time operation) and covers the generic areas of image processing, image synthesis, and writing or organizing digital code in a procedural or linguistic fashion [2]. But in every case when we refer to the phenomenology of the moving image, we call it cinema. For us it is important to separate cinema from its medium, just as we separate music from particular instruments. Cinema is the art of organizing a stream of audiovisual events in time. It is an event stream, like music [3]. There are at least four media through which we can practice cinema—film, video, holography and structured digital code—just as there are many instruments through which we can practice music. Of course each medium has distinct properties and contributes differently to the theory of cinema, each expands our knowledge of what cinema can be and do. Each new medium modifies and extends the linguistic possibilities of the moving image, subsuming the syntaxes of previous media without negating them.

Thus, the basic phenomenology of the moving image—what Vasulka calls "the performance of the image on the surface of the screen"—remains historically continuous across all media. Digital code, for example, has radically altered the epistemology and ontology of the moving image but has not fundamentally changed its phenomenology. There are no digital images that have not been prefigured in painting, film and video. With the code we can only summarize them, elaborate and unfold them or exercise modalities. Vasulka calls the code a variation machine. There are no new classes of images, there are only new variations and new epistemological and ontological conditions for generating and witnessing those variations. Each new medium of the future, says Vasulka, can only "play host to the phenomenology of the moving image", which will evolve through that medium to the next, accumulating the language of each.

Gene Youngblood (author, critic, educator), Communication Arts Department, The College of Santa Fe, St. Michael's Drive, Santa Fe, NM, 87501, U.S.A.

Weibel puts it this way: a medium is "a corpus of aesthetic strategies" inherited from previous media. In the 1920s mathematicians attacked the problem of foundations: What was pure logic? What was an axiom? Today the answers to those questions are implemented in the computer. Logical concepts have become instrumental, they have become parts of machines. And any machine element, says Weibel, is nothing but a physical implementation of a formal device. It implements mental strategies into something physical. (This is what Buckminster Fuller meant when he defined technology as "instrumented or documented intellect"). Similarly, aesthetic strategies invented 100 years ago in photography and cinema—scaling, perspective, positive/negative reversals, wipes, mattes—have now become machine elements whose operations are trivially invoked through the preset button. It is a question of primitives. The code is a metamedium: through it, high-level aesthetic constructs from previous media become the primitives of the new medium. This influences which aesthetic strategies will be emphasized. When a strategy that was possible but difficult in film becomes a preset button in video or a command in computer graphics, it tends to be used more frequently. But that does not make it more meaningful. The challenge is to turn 'effects' into expressions, into syntactical units of meaning.

This raises the question, How has the corpus of aesthetic strategies inherited in a medium like photography or film transferred over to electronic media and especially to the code? Things are possible in the code that were not possible, or at least not easy, in film and video. Only by comparing formal devices developed in one medium to other devices developed in other media can we arrive at criteria for evaluating artistic achievement. Have the syntactical and linguistic possibilities of the digital image been identified and elaborated in practice? We think not—at least, not very often. We rarely find them in the work that is otherwise admired in the name of the medium. People praise a particular work of 'video' or of 'computer art', and yet we find in this work no definitory elements of video or of the code. It may be great cinema but it is not great *electronic* cinema. We are not arguing for exclusivity or essence. We are not trying to be the Clement Greenberg of the code. The phenome-

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nology of the moving image remains constant across all media, but each new medium brings about a shift of emphasis or accent. Through the code, we can unfold the potential of formal strategies that were possible but limited in previous media, thereby expanding the richness of cinematic language.

Vasulka asks, "Who creates the language of a medium?" Weibel responds by quoting Heidegger: "Man is but a guest in the house of language." Vasulka agrees. All possibilities of a system, he says, are contained within that system. We are not free to invent the language of film, video or computer. The language already exists in the system. Our task is to discover it, identify it, draw it out and name it, put a nomenclature on it. Vasulka has built his machines in order to discover 'the language' in them, which could be found only through dialogue with the machines. He points out that this is not unique to electronic cinema. Film language also arose from a similar systemic understanding. As a syntactic device, the cut, the edit, is machine-bound. It is the only way to splice film. The most important figures in the history of film are those who elaborated its syntactic or linguistic potential. This is our criterion for artistic achievement in the new medium: to what extent does the artist articulate and develop the formal possibilities of the system as syntactical or linguistic elements? To what extent does the artist transform effects into expressions?

It is a question not only of the evolution of cinematic language, but of human perception itself. Human vision, Weibel points out, has always been 'machine-assisted'. The invention of perspective, for example, was machine-dependent. It was derived from optical instruments. Dürer's boxes were in this sense 'machines'. They implemented physically what then became formal strategies. With the help of this machine we could invent perspective. (Weibel thinks this curious. Why did it take so long?) Similarly, Vermeer, under the influence of Spinoza and the science of optics in the seventeenth century, created paintings that were not initially seen as poetic. They were regarded more as scientific research. (In the nineteenth century, Proust, influenced by photography, 'rediscovered' Vermeer, now regarded as a poet. The computer is to the artist of today as the lens was to Vermeer.) The Impressionists, too, were following theories, not subjective experience. Impressionism was based on color theory: three different colors produce a fourth impression. An optical theory of color, says Weibel, is also a machine, a mental machine, like a Turing machine. Thus we have substantial evidence that the evolution of vision is dependent on machines, either mental or physical. It has come to the point that it is no longer possible to suppress the machine part of it: first there was the camera, now the computer. This is significant, Weibel thinks, because art always tries to suppress the influence of the machine element in the work itself. It is not art if the technology is too apparent. But the issue here is not art, it is language and perception. They co-evolve only to the extent that the syntactic possibilities of technological systems are made the subject of aesthetic inquiry.

The following formal possibilities of digital imaging are available for articulation as syntactic elements or linguistic primitives: (1) image transformation, (2) parallel event-streams, (3) temporal perspective and (4) the image as object.

Image Transformation

If mechanical cinema is the art of transition, electronic cinema is the art of transformation. Film grammar is based on transitions between fully formed photographic objects called frames. It is done primarily through that collision of frames called the cut, but also through wipes and dissolves. In electronic cinema the frame is not an object but a time segment of a continuous signal. This makes possible a syntax based on transformation, not transition. Analog image processing is one vehicle of this particular art—for example, scan processors. But it becomes even more significant in digital image synthesis, where the image is a database. One can begin to imagine a movie composed of thousands of scenes with no cuts, wipes or dissolves, each image metamorphosing into the next.

A cut is a cut, but a transforming or metamorphosing operation is open-ended. There are infinite possibilities, each with unlimited emotional and psychological consequences. Metamorphosis is not unique to digital imaging; it is a familiar strategy in hand-drawn animation. What is unique is the special case of *photoreal* metamorphosis. It is one thing for a line drawing or fantasy painting to meta morphose, quite another for a photographically 'real' object to do so. This is theoretically possible in mechanical cinema and has been prefigured (but never fully realized) in hand-drawn animation, where it is so difficult and time consuming that it is, for all practical purposes, impossible. It is possible digitally, because the code allows us to combine the subjectivity of painting, the objectivity of photography and the gravity-free motion of hand-drawn animation.

Steina points out that there are two kinds of transitions based on the cut, and these require different kinds of metamorphoses. One moves us to a different point of view in the same space/time, the other moves us to a different space and/or time. In flashbacks (cinematic memory), either a matte is used within the frame or the whole frame dissolves. With the code, a part of the frame can metamorphose. This implies an expanded cinematic language of simultaneity.

Parallel Event-Streams

With the arrival of electronic cinema it became apparent that film grammar was limited in what might be called its vocabulary of tenses—for the most part it was 'meanwhile' or 'after'. For example, simultaneous events are traditionally signified through cross-cutting, or what is known as parallel montage. But, Weibel notes, there was never a formal distinction between a cut to a different position in space/time (say, between people in conversation) and a cut between different spaces or time. The distinction has always been logical or inferential (as in parallel montage), never formal. Digital code offers formal solutions to the 'tense' limitations of mechanical cinema. Past, present and future can be spoken in the same frame at once.

There are at least three possibilities: superimpostion (overlay), or simultaneous but spatially separate event-streams that are either framed or unframed. Superimposition has been explored extensively in experimental film, notably by Stan Brakhage. His work is the closest cinema has come to the Joycean text. In such work it is not always possible to identify consciously each image-stream, just as it is often impossible to distinguish every voice in a musical composition. One is disturbed by this only if one is unfamiliar with it. Once one learns to read it, the dense text is a pleasure. Digital code offers possibilities of image-overlay whose linguistic potential we have not begun to explore.

The second possibility is more familiar: framed parallel event-streams, such as split screens in film (optical printing) or floating imageplanes in video, done with digital effects devices such as ADO or Quantel. But there is also the possibility of *unframed* parallel events occupying different areas of a single image. This can best be seen in the work of the Vasulkas, for example, where pointillist textures move independently in separate areas of the frame. Different zones of the image are activated in different ways in parallel. The Vasulkas accomplish this through digital image processing. But image synthesis, through a variation on metamorphosis, would provide unlimited possibilities for unframed but separate parallel event-streams in a single frame.

Below, in a discussion of the image as object, I shall have more to say about parallel event-streams. Meanwhile, consider that simultaneity enlarges our concept of a cinematic event. Weibel puts it this way: whereas first we had the industry of the moving image, today we have the industry of the accelerated image. If there are three image-planes instead of one, the information conveyed within the overall frame is tripled, and, furthermore, each succeeding image destroys the meaning of the previous one. The information is accelerated so much in perspective and in all other ways that the value of 'the image' is replaced by the value of the image-gestalt or image-field.

Temporal Perspective

"The history of every art form", wrote Walter Benjamin, "shows critical epochs in which a certain art form aspires to effects which could be fully obtained only with a changed technical standard, that is to say, in a new art form" [4]. Weibel pursues this logic in reverse, working backward from the digital image to find desire for its powers in art history. He begins by noting that Renaissance perspective was always at eye level with one point of view and one vanishing point. By 1850, photographers were climbing onto Parisian rooftops and shooting down into streets. Twenty years later, Odilon Redon painted a balloon-suspended eye moving up into the sun. Perspective as no longer bound to a static point of view. It had become free-floating. In the same period, the German Romantic painter Kaspar David Friedrich painted mountain shadows falling at an angle different (that is, displaced in time) from that of the impinging sunlight. Other examples are found in the work of El Lissitsky and the Cubo-Futurist movement. Painting, influenced by photography and cinema, introduced multiple points of view and implied time.

And what did cinema do with perspective? Not much. Bound to psychological realism, it exploited it only spatially, mainly through deep focus (Eisenstein, Welles, Renoir), never temporally. Only in experimental cinema was temporal perspective explored in any serious way at all—the outstanding example being the work of Michael Snow, such as *La Region Centrale* and *Back and Forth.* But with the advent of the code, the emphasis on perspective returns. Moving-image art can now embrace it in an emphatic way. When the image is a three-dimensional database, perspective becomes a temporal as well as spatial phenomenon. It is a strategy that is intrinsic to the code. Painters, photographers and filmmakers could not realize the full potential of this desire. But now we can unfold and elaborate that which could only be indicated in earlier media.

Vasulka notes that, if we remove the two cinematic vectors from earth to space and establish the principle of a point in space, we arrive at two possibilities: first, cinema looks from one point to infinity in a spherical point of view. That is one vector, we shall say. The other is the opposite: one looks from each point in space towards a single point. If all these points are in motion around one point, that is the space in which ideal cinema operates. But as long as we are talking about psychological realism we will be bound to an eye-level cinema.

The Image as Object

There are three technologies through which the image can become an object: image processing, image synthesis, and three-dimensional display—either binocular (stereoptic) or holographic. The code is responsible for the first two and may be partially involved in the third. This is another aspect of parallel event-streams. We recognize cinema as frame-bound and frame-unbound. Mechanical cinema is characterized primarliy by its reliance on the frame. It cannot leave the frame unless a special effort is made through optical printing. But with code it becomes a trivial matter to remove the image from the frame and treat it as an object, an image-plane, because those tools have no capacity to deal with the geometry of the image itself: they deal only with its location or position (its 'address') within the larger frame. The use of framed parallel events points to new narrative possibilities, new semiotic strategies—for example, the possibility of a previous or future event appearing spatially behind or in front of a current event within the same frame. There is always a pending image. Editing can be avoided entirely—as Vasulka did in his 1987 work *Art of Memory.* He points out that, through hierarchies of image planes in particular arrangements 'in a mental space', future and past tenses may be suggested. As already mentioned in the discussion of parallel event-streams, conventional film language is rather inarticulate in this respect. There is no temporal eloquence in film. But digital video suggests the possibility of establishing one image-plane as 'present' with other time-frames visible simultaneously within the frame. This would extend the possibility of transfiguration (metamorphosis) into a narrative space composed of layers of time, either as moving or still images. Ed Emshwiller's *Sunstone* was one of the first works to explore these possibilities. In it the image becomes object, and it has both framed and unframed parallel event-streams.

When image becomes object in a stream of parallel events, the realm of psychological realism or photographic truth is abandoned. The frame-bound photographic image brings us truth. But three image-planes within a frame lose what Vasulka calls "the aura of truth". We detach ourselves from them psychologically. Will it be possible to construct a psychological space in a language of frame-unbound parallel event-streams?

For Weibel, all this raises a

fundamental challenge to the metonymic nature of cinematic language. He invokes the name of Roman Jakobson, who argues that there are only two fundamental operations in language: metaphor and metonymy. And the language of cinema is not metaphoric, it is metonymic. It is the language of the part for the whole. All cinematic images are contingent. The frame, said Jakobson, is always part of an unseen whole. At its fundamental syntactic level—the level of cutting, of editing, of bringing spaces together—the filmic language game is metonymic. In the service of psychological realism, conventional editing reconstructs 'real' time and 'real' space, following logical causal chains by metonymic association. Experiments like *Last Year at Marienbad* were attempts to transcend that limitation within psychological narrative. But in the electronic image there is no need to make a *Marienbad*, because it is clear that we no longer have that constancy of time and space. Once an image-object is set against a reference, the metonymic tension is lost. Objectifying the image within the frame puts it in a different time zone. Metonymy becomes problematic. On the one hand, such constructs are not metonymic because the space they occupy is not 'natural'. The image-object is not part of the whole; it is no longer contingent. But it is not metaphoric either. It is something new. We do not know what it is. It might still function metonymically, but in a different way. This is an important area that is wide open for aesthetic exploration.

The second level of the image as object is achieved through digital image synthesis. Here, because it is a three-dimensional database, we can control not only the location of the image-object within the frame but also its perspective, its angle of view, its geometry. As a result, the synthesized image becomes truly an object, the witness becomes a 'user', and the relation between them becomes not observation but interaction. Jean-Louis Baudry argues that, in the cinema of psychological realism, the primary identification of the spectator is not with the characters but with the camera itself [5]. But in interactive image synthesis, the spectator *is* the camera. Since it is not separate from the scene it surveys, the virtual camera is neither a voyeur nor an instrument of surveillance. "It is a point of view that is active *within* the scene", writes Catherine Richards. "Not only can this camera (the user) direct its own looking, it can be sensed, responded to, and represented in the scene: it sees and is seen" [6].

The third level of the objectification of the image is realized through three-dimensional display. Whether through holography or binocular (stereoptic) technology, cinema is moving from the two-dimensional image on a screen to the three-dimensional object in space. Today cinema represents reality; tomorrow it will *be* reality. Already with stereoptic technology the image becomes an object. And in Scott Fisher's virtual environment project of the U.S. National Aeronautics and Space Administration (NASA) (combining a three-dimensional database with stereo vision in a wraparound head-mounted display), cinematic space becomes a place to live. An unframed image is not an image, Vasulka points out, it is an object in space: "It forces you to deal with air." It is no longer a representation but the thing itself. Vasulka notes that different understandings of reality and truth are implied by the representational image and by an object in space, no matter how insubstantial that object may be. Three-space cinema, he suggests, is more like theatre. In two-space cinema there it truth but no reality. In theatre there is reality but no truth.

References and Notes

1. Peter Weibel is a videomaker, mathematician, art historian, writer and professor of art and electronic media in Austria and the U.S. Steina and Woody Vasulka are internationally known video artists who founded The Kitchen in New York City in 1970 as one of the world's first presentation centers for electronic art. Gene Youngblood is author of *Expanded Cinema* (1970), the first book about video as an art medium.

2. Both real-time video machines and computers operate on the same structure of digital code. ADO, Quantel and Fairlight are digital computers. The only difference is that they take their 'model' from camera input and they operate in real time. With the exception of extremely fast computers, most digital image systhesis, or 'computer graphics', is not done in real time. Other than this we make no distinction between them, except in reference to the source or model of the organization of the image—one through camera input, the other through algorithms. Also, we regard the process of writing or structuring the code as part of the digital-imaging procedure. It is the craft of digital imaging in computer graphics. You do not 'write the image' in video.

3. My colleagues have found the concept of the 'event-stream' problematic. Vasulka defines it as "every scheduled change". He points out that there is always an invisible technological level to every perceived event, like the event of line-forming in video, or computations and logical operations in image synthesis. The key is to realize that the event does not have to be consciously perceived. In music, for example, a listener would be incapable of naming each sonic event, but music is nevertheless a system of parallel event-streams.

4. Walter Benjamin, "The Work of Art in the Age of Mechanical Reproduction", in *Illuminations* (New York, 1978) p. 237.

5. Jean-Louis Baudry, "Ideological Effects of the Basic Cinematographic Apparatus", *Film Quarterly* **28**, No. 2 (Winter 1974–1975). Quoted in Christian Metz, "History/Discourse: A Note on Two Voyeurisms", in *Theories of Authorship*, John Caughie, ed. (London, 1981) p. 231.

6. Catherine Richards, "Virtual Worlds, Digital Images", in the catalog of the 1987 American Film Institute Video Festival (Los Angeles, CA, 1987).

Computer Imagery: Imitation and Representation of Realities

Beverly Jones

ABSTRACT

Contemporary theory in philosophy, aesthetics and cognitive/social sciences stresses the embedment of cultural and historical conventions in art and technology. Computer imagery for aesthetic/artistic or technical/scientific purposes have these conventions embedded in them and consequently reflect larger models of humanly constructed cultural reality. Careful analyses of the form, content and practice of computer graphics are proposed to reveal views of reality embedded in technology and in models generated by the technology.

Computer-generated images, objects and events have existed a short time relative to theoretical stances that are embedded in them. This paper will explore the views of traditional and contemporary philosophers and art theorists that

(1) appear related to the form or content of computer-generated or -processed images, objects or events

(2) bear some relation to imitational and representational theories of art and/or reality

(3) illustrate the embedment of historic and representational theories of art and/or reality.

These conventions may have been intentionally embedded or may have been unconsciously employed by the person or group who generated the computer creations. The broad definition of computer art that will be used here is "any aesthetic formation which has arisen on the basis of logical or numerical transposition of given data with the aid of electronic mechanism" [1]. This definition allows for inclusion of the greatest variety of forms. Generated or processed screen graphics, computer-controlled environments and sculptures, three-dimensional artifacts designed or executed with the aid of the computer, conceptual art displays including computer programs, and interactive performances are included within this definition. Also included are computer images and objects that have been created for nonartistic purposes by individuals who may or may not have any formal artistic training. Consequently, works included in SIGGRAPH slides and tapes in either technical or artistic categories would be included as potential candidates for analysis.

Background of the Study

Media and Theory

Computer related imagery is facing some of the same theoretical controversies and dilemmas that photography, film and video have faced. For example, Galassi described one point of view as follows: "The object here is to show that photography was not a bastard left by science on the doorstep of art, but a legitimate child of the Western pictorial tradition" [2]. In contrast Sekula's work [3,4] in the history of photography stresses the need to study the photographic archive, the set of practices, institutions and relations to which photographic practice belonged, rather than reassembling the archive in categories constituted by art and its history. Rosler extends Sekula's concerns to the world of video:

> It is the self-imposed mission of the art world to tie video into its boundaries and cut out more than passing reference to film, photography, and broadcast television, as the artworld's competition, and to quash questions of reception, praxis, and meaning in favour of the ordinary questions of 'originality' and 'touch' [5].

She states her disapproval of separating video art from the other ways that videotechnology is used. To do so, she believes, is to accept the idea that the transformations of art are formal, cognitive and perceptual. Gouldner describes the relation between art and media in terms of the separation of cultural and technical facets of modern culture [6]. He sees those who are surrounded by the most powerful, advanced, expensive hardware as optimistic technicians and contrasts this with pessimistic, politically impotent representatives of the cultural apparatus. All of these views, except Galassi's, express concern for the larger cultural context.

Lucas studied evolving aesthetic criteria for computer-generated art via the Delphi strategy. He chose eight prominent computer artists as participants. In the conclusions of phase one of his study, he states, "If there is a hidden quorum here, it may be the commonly held belief that regardless of innovative properties which may or may not require new aesthetic models about computer imaging, traditional criteria remain an integral part of the aesthetic evaluation of this art form"; in phase two of his study, he raises the question, "Are there traditional aesthetic criteria which are adequate for evaluating computer art?" [7]. In response, five of eight experts agreed that visual basics of harmony, symmetry and balance were applicable, six of eight agreed that computer art had roots in traditional fine arts considerations and five of eight agreed that computer art has not elicited the need for new aesthetics. However, in the course of the study, interactivity was mentioned several times as a potential source of need for new aesthetic criteria.

In this paper I advance the view that computer imagery should not be separated into aesthetic/artistic formations and technical/scientific formations. Embedded in computer imagery are cultural and historical conventions which affect both aesthetic/artistic and technical/scientific formations. In addition, these conventions reflect larger models of cultural reality. Both art and technology are affected by these models of reality. This view is in accord with post-

Beverly Jones (art educator), School of Architecture and Allied Arts, University of Oregon, Eugene, Oregon, U.S.A.

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structuralist theory. For example, M. Foucault discusses archeological analysis of archives as revealing "the set of conditions in accordance with which a practice is exercised, in accordance with which that practice gives rise to partially or totally new statements, and in accordance with which it can be modified" [8]. In other words there are rules operating which were not invented or formulated by the participants, relations which provide their practice with support but which may remain invisible to some, if not all, of the participants because they have not been consciously articulated. Members of the Yale school of literary criticism, especially de Man, stress the ways in which texts containing these rules may be seen as deconstructing themselves (as these rules are revealed and demystification follows from close examination of the text) [9,10]. Norris describes de Man's later work as revealing a stance that "equates right reading with the power to demystify forms of aesthetic ideology" [11]. Post-structuralists, such as Foucault, as well as some neo-Marxist and feminist critics, stress the political and social consequences of ignoring the existence of these rules.

The view that such models or rules exist may be found to some degree in various traditional and contemporary theories. For example, the art historian Wölfflin [12] claimed that style could be detected in areas that escape attention, stating that the whole development of world views might be found in the relationship of gables [13–15]. Kaplan describes two post-modern theories that stress cultural relationships in context rather than stressing decontextualizing fragmentations and binary oppositions. According to Kaplan both "involve a thinking that transcends the very binarisms of Western philosophical, metaphysical and literary traditions which have been put into question by poststructuralism and deconstruction" [16]. The literary and feminist theory, labeled by Kaplan as utopian, involves a search for a liberatory new position. This position may be found in the work of Bakhtin [17], Derrida [18], Lacan [19], Cixous [20], Kristeva [21], and Barthes [22,23]. The discourse, labeled by Kaplan as commercial or co-opted, warns about the psychological effect of new technologies in the service of consumer culture. This position is held by Baudrillard [24–28] and Kroker and Cook [29].

This paper describes a position related to those described above. I hypothesize that selections of images and modes of presentation are made by the creator, and these selections are inherently related to aesthetic and technological conventions established within the culture of the creator whether or not the creator is consciously aware of these conventions. The creator may be acting in accord with these conventions, critically examining, them, or reacting against them. In all cases, the work reflects the historical cultural setting in which it is created. This position is supported by recent literature stressing the contextual character of art and other aspects of culture. It appears in sociology of knowledge, anthropology, archeology, history, art history, folklore, literary criticism and psychology. From this stance, the work of individuals creating computer images can be examined as expressing cultural conventions. This holds true whether the training of the creators is entirely in the sciences, entirely within the arts or in both arts and sciences.

In the early days of computer graphics, systems were built primarily for scientific and practical purposes. Few artists had access to them. However, their users, primarily scientific or technical personnel with no formal art background, made images that expressed conscious or unconscious aesthetic conventions. Currently computers are much more accessible to artists. Teams of artists and programmers collaborate in advertising, film companies and government projects utilizing state-of-the-art technology. Artists frequently use software that includes algorithms developed for technical scientific purposes. Consequently their work may express reality constructs from technical/scientific areas of which they may or may not be aware.

Development of hardware and software usually originates in research done by government and large corporations. Over time and with amortization of research and development costs they are simplified first for mid-sized- and later for microcomputers. Simplified versions of the originals become available to smaller companies and individuals at lower and lower costs. End users, for example individual artists with no institutional or industrial affiliations, frequently use microcomputers—as the credits for the SIGGRAPH art slides makes evident. Hardware and software that have been simplified remain influenced by their origins, although they are frequently referred to as 'degraded'. It is to these origins, practices and embedded conventions that theorists such as Sekula, Rosler, Foucault and I refer.

Aesthetic Theories

Art as imitation is one of the oldest and most varied of theoretical purposes. Plato [30,31] discussed imitation of the Ideal, preferring it and contrasting it to literal imitation of physical reality. Aristotle [32] and Plotinus [33] discussed imitation of essences. Further variations of imitational theory have been discussed by Sir Joshua Reynolds [34] and others. The two classical traditions of Idealism and Realism are most commonly associated with art as imitation. Idealism eschews literal representation of physical reality and Realism seeks essential or scientific correspondence with physical reality. Contemporary art theorists continue to examine questions of imitation and representation of art and reality. Their concerns are with 'the new realism', simulation, simulacra, reproduction and appropriation. The generation of modernists that preceded contemporary theorists was concerned with nonliteral representation, i.e. representing that which could not be literally imitated. As technology changed and traditional media such as painting and sculpture were joined by printmaking, photography, film, video and computer imagery, new concerns evolved in art theory. Contemporary theorists are concerned not only with the image, but with its role in the broader context. They frequently stress the cultural embedment of art. The edges between art and philosophy, criticism, politics and social theories have become less distinct.

Art as Imitation

Platonic Idealism

The writings of Plato, Aristotle and Plotinus present early versions of imitationalism or mimesis. Their views, like those of contemporary theorists, are concerned with the function of art in its cultural context. Acknowledging the power of art to influence the citizenry, especially the young, Plato cautioned against art that literally imitated the physical world or that could overly excite the emotions.

Consequently, he approved art that would represent the Perfect Idea of an object, that is, the ideal representation of an object, rather than attempt to imitate a specific physical object in the physical world. Being an Idealist, Plato regarded specific physical objects as inferior copies of their ideal counterpart in the world of ideas. A literal representation of these would represent a copy of an inferior copy. However, he approved the work of artists who, through intuition, were capable of representing images of the Perfect Idea of an object. In his view this work would represent perfect harmonies intuited from the Ideal world of ideas. These forms would have perfect proportions; consequently they would embody *Kalokagathia*, that is, goodness, truth and beauty. Analyses of Greek architecture and statuary, which some believe attempted the physical embodiment of Plato's theory, reveal consistent proportions. Most commonly cited is the golden rectangle. Both the Pythagoreans and the Platonists were concerned with the relation of number, proportion and harmony to beauty. They also assumed a relationship between beauty, truth, and goodness.

Among later writers, Spengler provided a 40-page historical review of the relationships between the arts and mathematics [35]. L. von Bertelanffy [36] cites Spengler in his *General System Theory*. G. D. Birkhoff [37] contributed mathematical analysis of visual art, especially that of the Greeks, in *Aesthetic Measure*. J. Hambidge [38] in his work on Dynamic Symmetry also examined mathematical constructs underlying Greek aesthetics. The influence of these theorists on later work involving information science and cybernetics as related to aesthetics may not be readily evident. However, Hill states, "Nevertheless, more than an echo of Birkhoff's work is found in the ideas proposed by, for example, N. Rashevsky, H. J. Eysenk, A. Moles, M. Bense, H. W. Franke and F. Nake" [39–41]. It is my belief that these individuals and others are not necessarily influenced by Birkhoff. Rather they and Birkhoff are engaged in a search for a formulation of universals in terms of mathematics that may be applied to aesthetic objects or responses to aesthetic objects. The work of Moles and Bense are responsible for the formation of information theory aesthetics and exact aesthetics [42]. Eysenk searched for universals in experimental aesthetics [43,44]. Early computer artists Franke and Nake utilized computers in attempting to create aesthetic forms [45]. The work of Stiny and Gips in algorithmic aesthetics is a contemporary link to the underlying belief that beauty, form and number may be linked [46–48]. Plato's concept of intuition of perfect form may be applied to an interpretation of the discussion in Clive Bell's [49] book of 'pure form'. Bell's discussion has been important to modernist art, especially that of the formalists. Many examples of early computer art bear resemblance to the work of modern formalists, emphasizing purely formal relations of elements and principles of design. Many works of early computer art may be considered to express a concern for the relations of pure form, possibly ideal forms, generated with a concern for the beauty and based in numerical relations.

Modern artists who utilized mathematics in their work include Duchamp, Arp, Lissitzky, Pevsner, Naum Gabo, Vantongerloo, Bill, Lohs and Gerstner. Some of these may be considered influenced by imitation of ideals or essences. For example, Duchamp's piece, *Large Glass* is based upon the golden rectangle, which is prominent in Greek art and in Birkhoff's analyses. Many of the other artists are considered Constructivists, whose art consists of mathematically based explorations of the relationships of plastic rhythms to aesthetically pleasing form.

Many individuals working with computers in the 1960s were not artists, but scientists. However, they had seen and were influenced by modernist artworks. Consequently, they were conscious of the similarities in form between the geometric shapes generated by the computer and the gallery art with which they were familiar. An interesting project would be an analysis of this early computer art in terms of its appropriation of aesthetic structures and conventions.

Aristotle's Imitation of Essences

Aristotle, considered the originator of realism, posited that works of art should not be literal copies of nature but should express the essence of the subject portrayed. Plotinus, a neo-Platonic idealist, also stressed imitation of essences. The underlying geometric forms in nature have served to recall the essences of some forms. D'Arcy Thompson [50] has explored these underlying structures. An example of recent computer graphics that could be regarded as imitation of essences would be the work of Kawaguchi [51], who, by studying Thompson and Izuhara [52], has written computer programs that describe the growth and form of plants, shells, coral, tusks and claws. He generates these forms using algorithmic structures based on the laws of nature. Consequently he generates images of forms that have never existed but follow natural laws. These may be considered imitation of essences, if we consider that underlying structures are essential to these forms. Examples of other work imitating the essential structural patterns in nature are found in Prusinkiewiscz, Lindenmayer and Hanan's [53] developmental models of herbaceous plants and de Reffe et al.'s [54] plant models of botanical structure and development. Other computer graphic techniques that may be considered to imitate patterns of regularity and irregularity to create underlying structural or visual patterns constituting the essence of natural forms use concepts that include fractals, particle system modeling, chaos theory, and fourth dimensional (time) modeling. Visual essence rather than the structural essence is involved in these techniques. An overview of visual simulation techniques was presented in 1985 by Doenges [55]. These techniques are most frequently utilized in entertainment, educational, commercial and aesthetic applications.

Probably the most widely known of visual simulation techniques are fractal curves that may imitate the visual essence of natural forms such as planet surfaces, mountain ranges, clouds and trees. The originator of this procedural model is Mandelbrot, a French mathematician [56]. According to Tucker, "Fractal geometry provides simple mathematical descriptions for highly irregular or fragmented structures, finding a deeper order in the bewildering complexity of natural forms. . . . A unique characteristic of fractal curves is that they have detail at all levels of resolution" [57].

Reeves' work on particle systems [58–60], Gomez' on chaos theory and Hunter's algorithms that model phenomena in time provided models for representation of such nebulous dynamic events as wind, fire and explosions. The discussions of Papathomas, Schiavone, and Julesz [61] focus on application of computer graphics to the visualization of meteorological data. They describe computer graphics animation sequences representing weather episodes. These models can represent motion, changes of form and dynamics. Techniques that model literal surface representations of objects would require too much computer time and memory if applied to dynamic phenomena. Papathomas et al. describe Gardner's work [62] in which he sought to resolve the conflict between realistic images and computational time by adopting the impressionists' approach of representing the essence of natural scenes as simply as possible. Gardner achieved remarkable results using textured quadratic surfaces bounded by planes to portray clouds and trees; his work is an example of visual simulation. Gelberg and Stephenson [63] created *SuperSeer*, a cloud prediction and display system that presents and interacts with data from earth and planetary science. This work attempts simulation that is both visual and based upon physical laws.

Do the computer models described in this section imitate, model or simulate the phenomena involved or do they provide approximate visual or conceptual correspondence because of correspondences in underlying belief systems of the creators and observers? The answer depends upon whether reality is seen as a set of conventions and constructs *invented by humans* or whether it *exists independent of human understanding*.

Realist Imitation: Objective

Basic philosophical realism involves belief in some sort of link between human conceptual systems and other aspects of reality. In the objective realist's view, reality is structured in such a way that it can be modeled by set theoretical models. That is, the world consists of entities, the properties of those entities and the relations holding among those entities. In the corresponding version of imitational theory, it is assumed that the relationships of objects depicted on a three-dimensional grid (a conceptual system) can depict areal view of phenomena. it is assumed that this structure exists as *real in itself, independent of human understanding*. Consequently, it is *the correct* way to portray reality. It requires that artists who wish to portray an object or event realistically utilize the conventions common to Western Europe. These are in turn assumed to be based upon the best scientific knowledge of the time, which also is assumed to correspond to the structure of reality. These ideas dominated European art criticism from the mid-fifteenth to the mid-eighteenth centuries [64].

Sir Joshua Reynolds articulated this view, claiming that the artists must derive his ideal of beauty from the physical world through direct observation, thereby discovering the ideal, which is true nature. In his Discourse Two, Reynolds discusses the mastery of painting. He insists that mastery necessitates that comparison should not be between performances of art with each other, but that by examining "Art itself by the standards of Nature, he [the artist] corrects what is erroneous, supplies what is scanty and adds by his own observation what the industry of his predecessors may have yet left wanting to perfection"; he also states, "Invention, strictly speaking, is little more than a new combination of those images which have been previously gathered and deposited in the memory: nothing can come of nothing: he who has laid up no materials can produce no combinations"[65]. In Discourse One he advocates a method of instruction that requires students to draw exactly from the appearance of the model before them, stressing exactness and precision in representation. He further states that students should not change the form according to vague and uncertain ideas of beauty. He also castigates those whose drawing resemble the model only in attitude.

These remarks coincide with the scientific realist's orientation to imitation that contrasts sharply with both imitation of ideals and imitation of essences. In traditional artworks this view may be said to appear in Roman portraiture and Roman illusionism. It informed the work of Renaissance artists as they explored the creation of illusions of space on the flat surfaces of paintings. Brunelleschi is usually accorded the honor of its rediscovery or invention. All of the underlying rules of three-dimensional rationalized space are given in Alberti's *De Pittura* and later treatises by Viator, Dürer and others. Dürer's work depicts an artist drawing upon a surface with a grid imposed between it and the scene to be drawn. In effect, he is creating an illusionary z axis upon an x y planar surface. He is attempting an isomorphic representation of reality. This is the *visual version of scientific objective realism.* A belief that symbolic representations may form an objective, one-to-one, value-free correspondence to reality is the basis for scientific objective realism. The symbols utilized may be mathematical or graphic.

Western European cultural conventions for depicting visual reality have influenced the development of camera and video technology. They also have influenced the development of computer algorithms and hardware that are now being used extensively in countries outside Western Europe. The historical development of computer imagery in Japan, for example, appears influenced by these conventions. A review of the images presented at international computer graphic conferences prior to the development of sophisticated three-dimensional solid modeling and lighting techniques reveals greater variety; for example, depiction of space and designed surfaces in Japanese computer graphics of this period show more similarity to traditional Japanese artworks than do Japanese computer graphics shown after the development of these techniques. After introduction of algorithms that portray illusory space, a greater international homogeneity in computer graphic imagery seems apparent.

Early computer graphics were primarily geometric and planar. In the 1960s three-dimensional wire frame graphics were developed. With the consequent development of hidden line algorithms, solid modeling, and lighting and texturing techniques it was possible to attempt depiction of illusory three-dimensional 'reality' in computer graphics. Hardware development, including sufficient memory and speed, was also necessary for this depiction. To a large extent these developments were funded by federal defense-related research. Consequently, the changes in international imagery may be viewed as a form of cultural colonialism.

Foster [66] states, "The critique of perspectivalism, the concern with corporeal vision, the analysis of the gaze . . . are not new. Decades have passed since Panofsky [67,68] pointed to the conventionality of perspective, and Heidegger [69] to its complicity with a subject willed to master; years since Merleau-Ponty [70] stressed the bodiliness of sight, Lacan [71] the psychic cost of the gaze, and Fanon [72,73] its colonialist import." Other scholars including Ivins [74], Krautheimer [75], Edgerton [76,77], White [78] and Kubovy [79] have investigated technical, aesthetic, psychological, religious, economic and political impacts of perspectivalism. Heidegger [80] postulates that the natural world was transformed through the technological world view into a 'standing reserve' for the surveillance and manipulation of a dominating subject. The latter view serves as background to the postmodern aesthetic positions of Baudrillard [81] and Kroker and Cook [82].

Digitized imagery derived from conventional art media, or newer media such as photography, film, and video, may be used to generate computer graphic images that fall into the category of realist imitation. Artists may also utilize digitizing devices for drawing images based upon realist conventions. Photographically derived data (digitized or non-digitized) may be combined with algorithmically generated computer graphics. For example, in the film industry, *Tron*, produced in 1982, used computer-generated imagery as a backdrop for live actors. In 1984 *The Last Starfighter* included 27 minutes of computer-generated effects that were intercut with live action. A spokesman for Digital Productions claimed that the computer-generated images were so lifelike that when they were intercut with live action the audience would not be able to tell the difference [83]. Digital recording and alteration of photographic and video data that is virtually undetectable has led to ethical controversies in law and journalism. In effect, the problem or the opportunity exists of making images that appear real but have no correspondence to phenomenal objects and events. In the pessimistic or commodity postmodern view, film, photography and television constitute technologies of domination and spectacle. A less pessimistic view is that we may create illusory or virtual realities with current aesthetic, educational, commercial or entertainment value or we may create 'utopian' models for future cultural constructs. *However, conventions of cultural reality embedded in hardware, software, and mental constructs of human participants may inhibit or preclude development of some models.* Conscious awareness of these conventions and constructs reduces their power to influence human behavior.

Computer graphic algorithms based upon laws of optics for depiction of light sources, reflection, transparency, etc. and upon laws of physics for force and motion and upon medical and biological research for depiction of living forms are based upon the philosophical premises underlying scientific realism. Early solid modeling and ray tracing algorithms made use of memory storage and calculating ability to describe the way a surface would look as it moved in relation to a light source and view point. Techniques allowing changes in light quality, atmospheric quality and textural surfaces all improved realist imitation in computer graphics. A complaint that the images generated are too real and too perfect (that is, hyperreal) has caused recent attention to be focused on introduction of small irregularities to make computer-generated imagery look more naturally real (i.e. simulate literal portrayal of individually imperfect instances). Some form of randomization, or stochasticism, is introduced in the surface quality, movement or boundaries of images. This would correspond to the visual differences between Greek statues, which attempted portrayal of perfect models with no counterpart in the phenomenal world (imitations of Ideals or Essences), versus Roman portraiture, which portrayed a single living individual, warts and all (isomorphic representation of physical reality). Simulations and representations of reality are made by traditional artists by drawing, painting, sculpting and so forth. Simulations and representations of reality are made by humans using computers by digitizing images and by inventing algorithms that imitate images and events. Both of these may be based upon scientific realism, a view of the world that derives information from scientific research to make the most perfect representation of the world based upon the best information to date. They may also be based upon visual modeling. The SIGGRAPH '87 panel on natural phenomena addressed this issue in terms of science and entertainment applications. Springmeyer [84] states, "The goal of the entertainment researcher is the simulation of visual reality, whereas the goal of the physical scientist is the accurate simulation of physical processes" and, further, *"The two approaches have begun to reach the limits of their ability to work without each other" (italics mine). Reeves [85] phrases this difference as "simulation vs. faking it"* (italics mine). This phrasing in the first instance points to a necessity for both kinds of simulation and in the second to the culturally embedded valuation of scientific simulation over visual simulation.

Jackson [86], an early optimistic researcher in artificial intelligence stated, "By suitably programming a fast enough digital computer, one can simulate any finitely describable phenomenon." In effect this means that various aspects of reality or concepts of reality can be simulated on the computer and displayed graphically if they can be sufficiently defined. Putnam [87–89] is credited by some as being among the first philosophers to offer a computational or functionalist model for human reality. In his most recent work *Representation and Reality*, he renounces his earlier certainty that any phenomenon can be so represented. He describes why he found the realist view so appealing: "What I used to find seductive about metaphysical realism is the idea the *the way to solve philosophical problems is to construct a better scientific picture of the world"* (italics mine). In a sense, computer graphics that simulate or model natural phenomena consider their success dependent upon a better scientific picture of the world. The portrayed model may look too perfect or appear too abstract, as, for example, in imitation of ideals (dependent upon numerical harmonies) or as in imitation of essences (dependent upon natural laws which may be represented mathematically). Note that both of these positions involve a belief in aesthetic universals. When images appear too perfect, the appearance of isomorphic visual realism may be sought and small imperfections added so that a more natural or literal imitation of reality may be attempted. The crux of the problem that Putnam has recognized and that contemporary artists and scholars in many disciplines have explored is that the definitions of the parameters of what is real are based upon human definitions; that is, objective realism has no basis. Objective realism claims the existence of a structure of reality independent of human belief, knowledge, perception and modes of understanding. This position is not supported by contemporary research in the cognitive sciences, especially anthropology, linguistics and psychology [90].

Contemporary Problems in Imitation

Human cognition and human social and cultural structures are important in the determination of beliefs about reality and hence what may stand for a model, simulation, imitation or representation. Emphasis is placed upon the human role of definition. In some works of art and in some philosophical work, self-reflexive studies occur. That is, by examining previously executed work, human participation and underlying belief systems are made evident. Artists create self-conscious art: art about art, art institutions, relations of gallery art to mass media, and relations of contemporary art to historical art. Photographers are engaged in rephotography, painters are engaged in appropriation of historical works of art. Literary critics stress the conventionality of texts. Texts are demonstrated to have deconstructed themselves, revealing the conventions embedded in them.

Simulation, Simulacra and Appropriation

Deleuze [91] discusses Plato's critical description of literal imitation as a copy of a copy. However, he claims, "The factitious is always a copy of a copy, which must be pushed *to the point where it changes its nature and turns into a simulacrum* (the moment of Pop Art)" He views this as a destruction of models and copies that set up a creative chaos rather than as a Platonic destruction of models that conserves and perpetuates the established order. Warhol's imitation of a Campbell soup can is an initial example of this. Acceptance came to the copy of a copy, which served as an ironic comment upon the production of mass culture and mass production and especially upon the technology of reproduction.

Considering Deleuze, deBord [92] and Baudrillard's [93] descriptions of simulacra in light of the discussion of realistic simulations (both visual and scientific) in computer imagery in the previous section of this paper, it may be posited that the hyperreal simulations of reality and some of the artistic works based upon the algorithms involved in these may be examined as constituting simulacra. This requires disregarding the conscious intentionality of the artist or creator from the perspectives discussed in the first part of this paper or from the more commonly employed modernist aesthetic perspective of Wimsatt and Beardsley [94]. From these perspectives the hyperreal imagery may be seen as simulacra (critical artistic comments on the insufficiency of the model of reality embedded in scientific realism from a *human* perspective). It may account, in part, for the appropriation of artistic techniques drawn from traditional animation and employed in computer graphic imagery, for example those described by Lasseter [95] and Pixar's 1986 film, *Luxo, Jr.*, and Zeltzer's animation of a human skeleton [96]. In some cases, 'faking it' improves the human perceptual and cognitive reality of computer graphics.

Another quite different example of 'faking it' that may be considered a simulacrum is the construction of the character Max Headroom. In this case, digitized imagery of an actor utilizing extensive makeup is subjected to picture processing to imitate computer-generated imagery. That is, the appearance of computer-generated imagery is appropriated for use. This may be considered a simulacrum from two perspectives: (1) In spite of work in computer graphics such as that of Waters [97], computer generation of human facial expression is laborious, is expensive and lacks human reality. Consequently this may reveal the insufficiency of current models from a human perspective in the same manner as the hyperreal simulations involving scientific laws in examples above. (2) Berko [98] assumes a position congruent with Baudrillard's postmodern view of technological consumer culture. She offers "Max Headroom as a case study of the high concept image, the site upon which the codes of simulation have been able to produce, 'by dint of being more real than the real itself' [99] the absolute image of the process of consumption, the hyperreal Max Headroom". Berko further states that in the United States today "the image seems unreal, unclean, impure, i.e. unsimulated, if it has not been video-enhanced, digitized, and processed" [100]. Although Berko uses hyperreality in a way seemingly contrary to the utilization in example one above, both examples stress insufficiency or negativity of hyperreal models in human terms. Both examples accent and make apparent the conventions used in reality construction. The difference between the examples lies in the use of 'reality'. Examples of hyperreal ray traced surfaces accentuate human constructs of perceptual cognitive reality. The Max Headroom example accentuates human constructs of social, political and economic reality as they impact cognitive perceptual constructs.

As is illustrated above, appropriation may involve computer imagery borrowing from the artistic/aesthetic or from the technical/scientific realm. An early use of artistic appropriation is the plotter image of the *Mona Lisa* produced as an advertisement to legitimate technologically produced imagery. This is quite different from Duchamp's or Warhol's appropriation of the same image. Relatively transparent uses of appropriation involve early simulations of artistic style by Nake and Nolls [101] and current stylistic simulations by Kirsch and Kirsch [102,103]. Appropriations of stylistic conventions of earlier art forms, especially modernist formalism, Op art and Renaissance perspective, are in evidence throughout the early history of computer graphics. Extensive use of digitally scanned images of paintings, photographs, film and video assure that many creators of computer imagery deal directly with issues such as appropriation, blurring of authorship, dematerialization of the art object and questioning the relation of 'original' to copy.

Conclusions

This paper has raised questions that a much longer study must address more fully. It has pointed to the need for a multidisciplinary approach to computer art. It may be no coincidence that Greenberg's 1987 Steven A. Coons Award Lecture [104] called for cross-disciplinary education of students in computer graphics. Belting [105], an art historian, has cited the need for studies of newer media. Post-structuralist theory is not bound by disciplinary boundaries, considering them remnants expressing an earlier conceptual scheme that is no longer appropriate. All of these issues are embodied in problems faced by artists, technicians and scientists involved in producing computer imagery. As Brook states, "Pictures are the most potent of those nonverbal representations by means of which we ambivalently seek to open and close the gap between what is actual and what is only possible, and to discover in the space what our values are" [106].

This paper is an attempt to begin analysis of the form, content, and practice of computer imagery. It has pointed to the embedment of previous aesthetic theories and reality constructs in historical and recent computer graphic imagery. It has advocated the necessity of viewing computer imagery in a holistic manner rather than dividing it into disciplinary applications. Deconstructionists object to disciplinary divisions as arbitrary, valueless, falsifying and obscuring. Post-structuralists, especially feminist and neo-Marxists, object to disciplinary divisions because of their political and social ramifications. This paper posits that ignoring human participation in the creation and utilization of cultural conventions has important implications. The conventions embedded in the hardware, software and imagery of computer graphics limit the models that may be generated. Is it possible for consciously generated cultural goals to affect the development of technology and consequent models generated? A necessary step in that direction is careful analysis of the conceptual forms already embedded in the technology.

This paper posits that computer imagery is an excellent ground for contemporary multidisciplinary work that will include thoughtful analysis of form, content and practice. These analyses are important to larger philosophical questions involving the nature of reality, human-reality relationships, and roles of art and technology in representing these relationships.

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Beyond Computer Art

Brian Reffin Smith

ABSTRACT

'Computer art' and its systems of production are criticized, and some suggestions given to make it better.

Let us first agree that most 'computer art' is old-fashioned, boring, meretricious nonsense; and then that most of it is done by people whose knowledge of contemporary art and its problems is more or less zero; and then that most of this 'art' is actually a demonstration of the power of a few companies' graphics systems; then that most of the 'art' is really graphic design, produced for graphic design-like (and thus not art-like) reasons; and finally that there is a sort of 'mafia' of people who produce, teach, write about, judge at competitions and generally celebrate and curate this 'art' (the present author not excluded).

Let us then not be surprised that most 'proper' art galleries will not show it; that most critics will not even notice it, or if they do tear it to shreds; that even when it *is* shown or written about, it comes in scare-quotes; that it is almost always talked about in a sort of 'whatever-will-they-get-up-to-next' tone of voice; that most of the sponsorship for it comes from well-known 'art'-lovers whose publicity tends to portray all the values of a glossy brochure on hand-held missile launchers; and that, although computer art has been around for 38 years, it has virtually no place in the archives of contemporary art, not even in the interstices reserved for phenomena such as video or 'technological' art.

Let us, though, not be too negative: the 'art' has improved from the days—the 1970s when students in the fine art department of some college, hearing that the place had computers and wanting to explore computer art, would step timidly across the threshold of the computer room:

"Er . . . we're artists, and we've heard that you've got some . . . you know . . . computers . . ?"

The computer scientists and the programmers, some of whom have resolutely voted never to work on projects that actually kill people, and others who spend long hours boldly going with Star-man, Pac-wars and Nerd-trek, weep with gratitude.

"We're so glad," they say. "We thought you'd never come. Yes, we already make computer art. THERE IT IS!"

They point to where, Blu-tacked above the coffee-Mate, the terrified artists see—what? Snoopys, Mona Lisas, nudes and Santa Clauses, printed (or as we say 'output') from a printer as if typewriter art; symmetrical whirls and spirals as if from a supermarket drawing toy; random-number, mock-Mondrians that seem to lack a certain something; and stuff like their mothers used to make by banging nails into a piece of wood and stretching thread in between to make patterns or boats—and all of it justified as 'computer-art' because it was done with a computer and one day someone will frame it and hang it, well, if not in a proper gallery, then at least in a side room of a polytechnic where there will be real wine at the opening (or as we say 'vernissage') and their mothers will come and be totally mystified but really proud.

The art students, seeing all this, flee wailing and puking back to their studios. The computer people call them names, and realise with a little shiver of anticipation that other . . . artists . . . have been rejected—sometimes for days at a time—and *they* got famous.

Of course we can laugh at this now. How times have changed! One even finds artists employed by computer companies, just to make art! And computer art, still or animated, is seen every few minutes on television screens *even in Communist countries.*

This art is very sophisticated. It has also become much better. Not long ago, screen resolutions of 200 by 300 points, with only eight colours, were seen as the latest thing. Now, with 512 by 512 dots of up to 4096 colours seen as laughably minimalist, we have an art that is quite clearly approximately 2237 times better. Few other art forms are able to be quite so quantitative about their progress. At conferences from Berlin to Bratislava, from Paris to somewhere famous in America beginning with P, audiences thrill as they zoom into impossible universes populated by exciting teapots, cubes, spheres, and triangles; they gasp as they are told that next year the same amount of artistic creativity will go into machines whose resolution is greater than that of the human eye, with soundtracks created on the very latest Yamaha synthesisers, by people who only hours before were musically stupid.

The computer artists, often from California, bear many traces of genius. Bleary-eyed from jet-lag, they manifest that unquiet spirit of artists through the ages. Golden birds in the gilded cages of soft- or hardware companies, they find themselves so far sideways from other artists that they inhabit a kind of conceptual desert island, trudging round and round its fractal perimeter, desperately seeking SIGGRAPH. These latter-day Crusoes see tracks—they are not alone! They dream of constructing epistemologies and holding oceanic conferences; but it is only their old footsteps they are seeing, and it is not a Friday, and the artworld has sent no boats.

But perhaps we should be more serious, when faced with the fact that what might have been the most revolutionary artform ever, what could have advanced art so far that it

Brian Reffin Smith (artist, educator, author), Stettiner Strasse 59, 1000 Berlin 65, German Democratic Republic.

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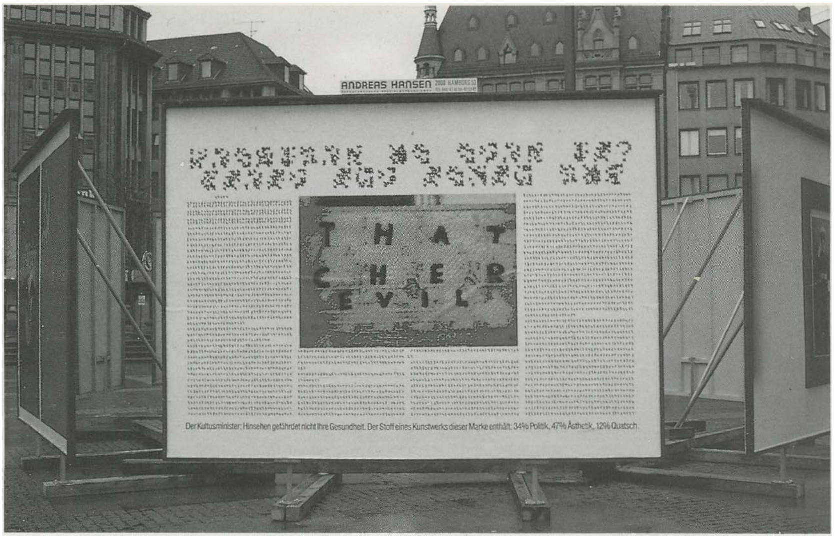

Fig. 1. Brian Reffin Smith, *That Cher Evil*, photographic reproduction of plotter drawing, 3 × 4 m, 1988. An attempt to combine several levels of representation and discourse in one piece, the work was shown in 'Public Concepts' on the streets of Hamburg, outside the town hall. For 'That Cher' read Thatcher. The 'headline' and 'text' are just representations. The lower text mimics a German smoking health warning: 'The Culture Minister advises: looking at this won't hurt your health. A work of this brand contains 34% politics, 47% aesthetics, 12% bullshit.'

actually began to answer some of the questions posed in the last 40 or so years, has been hijacked by people for whom self-delusion goes along with Thatcherite opportunism as they transform banal nonsenses into value-added insults to the intelligence.

It has been said that film is the truth 24 times a second, and video the truth (in Europe) 25 times a second. Computer art shows and conferences tend to be lies and humiliation once a year.

It is not surprising that many critics, artists, students and so on believe that computer art is only about impossible objects doing impossible things according to the impossible physical laws of impossible universes. It is impossible to believe their creators' defence that they are expanding art, or our consciousness, or something. These superficial 'impossibilities' are shackled—by chains of cynicism, delusion and real lack of imagination—to the most banal of realities. As if the worst of good art could not, at the drop of a hat, conjure multiple 'impossibilities', dimensionally so rich as to make computer graphics look like the table cloth after a chimps' tea-party, interestingly post-fractal though the latter may be.

Because they often are, or are linked to, commercial concerns, producers of 'computer art' have been able to push ideas of technological determinism (the idea that what is technologically possible is therefore desirable, even along other cultural dimensions) and of commercialism, and of spurious, meretricious representation, into the minds of those critics, artists and curators who should have known better.

Images are celebrated and justified just because they were done with a computer. (See also the trend in desktop publishing which often produces layout, typography and design of such an appallingly low standard that the only publications willing to accept it as advertising artwork are . . . computer magazines!)

In the 1960s and early 1970s, it was thought that ideas, techniques and metaphors of cybernetics and computers would transform art and culture generally into something wonderful and perhaps revolutionary. In fact, in general, computer art is the most conservative, dull, un-innovative artform of the 1980s. One would have to go back many years to find anything quite so isolated from current problems and questions of art theory, criticism and practice; so removed from any genuine cultural practice; so—as was said above—*old-fashioned*.

These things have to be repeated. Have we all gone mad? The present computer graphic systems are VERY GOOD! Thank you! Now for god's sake let us have a few ideas and do something with them. Who disagrees with this? We do not need better systems! Who does? Only the sellers of the systems or their clients from the Ministry of Peace.

Now all the above is not to suggest that there has not been, is not and cannot be any good art done by, with, or in spite of a computer. Of course there are (a few) wonderful exceptions. But it is to suggest, paradoxically, that for real progress in computer art, we must, as the title of this piece proposes, go beyond computer art. Then we may find, in the real world of art, real art problems to be tackled—and some of these may benefit from the use of a computer. Meanwhile, those who want to make graphic design, animated cartoons and so on are of course perfectly entitled to do so (we can admit through clenched teeth, not really meaning it), though it is hoped that they will not claim that they are addressing problems of contemporary art by so doing.

So . . .

1. Let us be honest and realistic and declare that graphic design and demo-reels from soft- or hardware companies are not, except under very special and rare circumstances, to be confused with art. They have different problems and are produced for different reasons according to different rules. They are (or should be) determined by different factors. They represent (or should do) different things.

2. Then let us be clear, in art schools, what we are teaching, and to whom. If it is true that ideas in art are at *least* as important as technical considerations, then let us teach computer art on that basis. We must demystify the technology, not deify it.

3. Let us acknowledge that to produce hyper-realistic models of objects often costs much time and money and computing power, but to effectively model the relations *between* representations of objects can be much cheaper. Luckily, most contemporary art recognises that it is on this meta-level that things become interesting. Computer art has much to learn from, for example, conceptual art (and, eventually perhaps, vice versa).

4. Let art schools buy 50 small computers in the place of one large one, and let the teachers be those with good art ideas, who are not scared of computers, rather than computer specialists. Do we teach painting using acrylic chemists, or video by television repair persons?

5. Let us try to make a form of computer art that companies like I.B.M., Nixdorf or Siemens would not want to buy (this is quite difficult). Let us have

shows of computer art that companies would find too dangerous to fund.

6. If we are artists who use computers, or their helpers or educators, let us try to make and encourage a new kind of computer art. It should be one that refers to quality rather than quantity. It is the pattern that connects that must be explored, not what is connected. A good idea will be good even if realised on a cheap computer, using a bad printer, monitor or graphplotter as output. A bad idea will remain bad, even when portrayed on a million-colour ultra-high resolution display. Are some people so stupid that they cannot see that it is the idea and the metaphor and the interactive capability of the computer that can make art, not having finer lines or more colours? Would Picasso have been 20% better an artist if he had 120 instead of 100 colours to use? Would Peter Greenaway make better films if film ran faster or grain were finer? Who cares, except Kodak?

7. Finally and most importantly, if the critics are mystified and the cura tors sometimes blind; if the teachers are confused and if the cost of the medium means that only certain messages are economically viable, let us make an art that defies all mis-representation, acting on a meta-level to avoid category mistakes. Let us include critical discourse and contextual and productive references *in the artwork itself* (Fig. 1). Let us make artworks that interact and provoke communication or that stimulate, because they contain the seeds of it, their own analysis and perception in new ways. Let us have a computer art that Walter Benjamin would have loved, that Wittgenstein would have appreciated, that would have turned Descartes into a Holist. Let us make an art that does not need the computer to justify it.

This is very difficult. Fortunately, we have the tools at hand. They cost much less than a package holiday to utopia. Do we have the courage, and the ideas?

(Technical note: this article was written using Textcraft 1.1 running on an Amiga 1000 computer connected to a Philips CM8833 colour monitor. It was output onto acid-free DIN A4 continuous perforated paper by a Star SG10 9-needle monochrome printer, but was collated by hand. The author apologises for the lack of style, content, creativity and literary skill, but in 1990 hopes to begin using a second-hand Cray, at which point we expect real literature to emerge. This article was sponsored by the Naval Ordnance Laboratory of the German Democratic Republic under grant number T44/jf4511. Any opinions expressed in this article are those of the author alone, and should not be taken to be representative of the above laboratory, the German Democratic Republic nor of the Socialist countries in general.)

Emergent Aesthetics—Aesthetic Issues in Computer Arts

Mihai Nadin

The production of art, as much as any other production, takes place in the context of human interaction—with others, with nature, with tools, with artifacts, and with ideas from times passed. Artistic work, more than any other, is probably a projection of the experiential structure of the act of producing artifacts (or events) with qualities socially acknowledged as artistic and values culturally celebrated as aesthetic. Throughout history, the patterns of human interaction have continuously changed, and so has art. Nonetheless, changes like the ones we experience today are unprecedented, requiring that we understand that the condition of art is probably more dependent than ever on the condition of humanity in general, and of science and technology in particular.

The age of information processing implies networking and interactivity. In a broad sense, this age can be understood as one of a generalized electronic medium against whose background digital and non-digital activities take place. It is not that, in the age of information processing, tradition or tradition-rooted forms of human practice cease; they are complemented by new forms, some impractical or even impossible in previous paradigms of thinking and creating. Two lines—one of continuity that establishes itself as an implicit reference and another of uncompromising revolution/radical change—could represent the topology of the space of artistic or scientific exploration as it results from the integration of the information-processing paradigm and the computer associated with it in our culture. These two lines follow various directions, which sometimes meet, run in parallel directions, and at some time diverge. I am suggesting this visual representation to make clear from the outset that the process is not of exclusion, but of diversification.

This said, it is time to examine what we address as computer art and to try to understand why, despite expectations (some very high) and tedious work, despite major investment (easily approaching the billion dollar mark and exceeding any other investment made in art), and despite enthusiasm, the results have been rather minor. This judgment can be questioned and contradicted, unless and until the perspective from which it is justified is defined. Indeed, if we include in our notion of computer art computer graphics in general, modeling, desktop publishing, simulation, image processing, and animation, as well as sound and image synthesis (I have not mentioned everything that might qualify), the argument of economic success, novelty and cultural impact will be impossible to refute. Moreover, the invisible participation of the computer in photography, film, video, music and graphic design technologies will definitely challenge the notion that the results achieved are minor. This is where the two lines of development—tradition and renewal—meet. New technologies are integrated into established forms of artistic practice and make possible a rationalization of previous work and a wider dissemination through channels of mass communication. The photographic camera controlled by a chip achieves what Eastman made the program of his house. Computer-supported graphic design, especially typesetting, has introduced means of increased productivity, quality control and variation unknown before. Nevertheless, once these and other examples are acknowledged, a feeling of dissatisfaction lingers. Computer-generated art and electronic music are interesting, and some works are provocative in their novelty. But once we have seen a computer graphic image or listened to a computer generated piece of music, it seems that we have seen and heard them all. In animation, after an initial period of surprise and hope, we now know that not much progress has been made from the first flying logos to the most recent (and ridiculous) flying flame of the NBC-televised Olympics, although technology has matured quite a bit and we have accumulated more than a fair share of experience. As opposed to works of art that look better the more we look at them, electronic art seems to exhaust itself at the first encounter.

These critical remarks describing the current state of computer art would not be more than an expression of disappointment and even subjective evaluation were it not for the need they trigger to go beyond these weaknesses and to approach basic issues as they pertain to the new aesthetic experience with the computer. These include the following:

1. the relation between a traditional notion of art and the emergent aesthetics of new forms of artistic practice
2. the relation between explanatory models of art and the generative power of explanations
3. the relation between technology and art, with special emphasis on digital technology
4. the relevance of an aesthetic consciousness for diversified artistic practice

In approaching these questions, and keeping in mind their implications and ramifications, I am aware that no simple answers can be given; furthermore, while any discourse about individual works of art can take place only *after* the work, nothing precludes a discussion of art as a form of participation in the process through which the artwork becomes possible. My own involvement with art and computers extends over 20 years. Although the fact that I have written programs and produced images or musical pieces does not necessarily make me the bearer of truth, my experience reflects an understanding of the subject and guarantees that my views will be accessible even to those who disagree with

Mihai Nadin (educator, consultant), Fashion Institute of Technology, School of Art and Design, 7th Avenue at 27th Street, New York, NY 10001-5992, U.S.A.

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them, because we share in the language of the technology and in the commitment to research its potential.

Context of Conflict

It is a commonplace that new forms of art emerge in a context of conflict with established art. As with many other patterns of human interaction, artistic activity is prone to establish its own power base and to exercise it economically, politically, ethically and in other ways. This happens through institutions and through reified moral values as reflected through laws, religions, schools and universities. Computer art is probably the best example of the attempt made by established art to appropriate and limit the efficiency of the new technology. In actuality it is the fight between that which is old, respectable, valuable, significant, progressively integrated into culture and tradition, and the new promise, challenge, and hope—the beginning of a new civilization. I certainly doubt that the plethora of mediocre images in continuation of the traditional realistic, surrealistic, expressionistic, etc. art can be attributed to imitation as an obligatory phase in every new development. It is more than an imitation phase—which we all resignedly accept as a given (children imitate adults, don't they?)—and different from mimesis. My thesis is that, in the process of appropriating this particular new technology—which is fundamentally changing the nature of human praxis—traditional artists, technologists and scientists have acted to preserve modes of expression they believe in, like or have tried to explain. Patterns of human interaction, in particular those pertinent to work, social existence, artistic activity and communication, are so deeply ingrained that uncertainty about and unpreparedness for the new explain the opposition to everything that does not preserve prior experiences wholly or at least in part. Symptomatically, we have tried to convert the revolution into an evolution, to see it as a cycle in a dynamics of progress, not as a dislocation of rigid and exhausted forms of thinking, working or creating. In the arts, probably more than in any other field of human interaction, one notices how encompassing the change can be. While traditionally open to experiment, renewal and innovation, and often assuming social roles of exemplary activism, artists did not oppose the technology, but hoped that it would not affect their studios and ways of working; some even hoped that it would go away. Since this has not happened, those who wanted to give it a chance have discovered that the issue is one of change—in the technology or in themselves. Since the latter requires more than good will and investment into what we know today as user-friendliness, they opted for the former. The programs we use—rendering, image mapping, ray tracing, to name a few do not contradict previous modes of expression but actually capture them in some computational form and make them available in ever-friendlier forms to 'Sunday painters' (as Negroponte once aptly called them [1]). We simply took the new tool and forced it to solve old problems, whose answers we knew ahead of time. With each work produced with the help of the machine that matched the answer, we became more emphatic.

Obviously, at the beginning, power relations specific to artistic praxis were exercised gently. The maturing of the technology and its gradually higher price—I refer not to components, which became cheaper, but to the more complex configurations required by the complexity of the task, which require considerable investment—give these power relations aggressive, even brutal aspects. Although the new paradigm refers to and applies a reality different from the physical matter involved in previous forms of artistic practice (i.e. clay, cameras, marble, pigment-based colors, etc.), we stubbornly try to rediscover the old (assumed to be not only good, but also universal and eternal) and to preserve it. It should not be a surprise that fraud and ignorance have often played important roles in this practice of preservation. In order to make the new available, we have enrolled everyone willing to support it. The result is not unexpected: almost without exception, computer art classes are taught by those who never succeeded in their art. The new talent exhibited by technologists, scientists and self-made artists is met with suspicion and typically 'brought into line'. Even the new possibilities opened up by technology have been reduced to acknowledged procedures. Visualization of highly diversified spaces, 3D (virtual space) explorations and color explorations are still treated according to the aesthetics of white paper or canvas. This is why, although formally correct, some of the new imagery is expressively inadequate. Technical ignorance and aesthetic limitations explain the success of paint box programs, drawing programs and illustration software. Through such programs, previous forms of artistic practice are maintained, though at a qualitative level far below that of traditional tools and media. Thus, while trying to preserve a familiar mode, we in fact have preserved only the appearance of the previous mode, since the machine was no longer *being used* ("I will do what you want me to do") but started *using the user* ("Do what I can do, and how I do it")—the artist in particular. We knew that the hardware was not conceived for such creative work, but we hoped that some programs would do the trick. To a certain extent, this has been accomplished. But if art, at least in the romantic sense we still cling to, is the expression of personality, emotion, experience and the like, then the computer does not necessarily help the artist to bring it about more freely. Quite often, what is produced on the computer can be generated more easily, quickly and cheaply with a pencil or other traditional means. There are numerous instances in which the computer controls the artist and 'signs' the work. This is what I have called—and my formula has been widely adopted—'canned art'. There are also instances where the machine offers a fast substitute for art. This is what I called 'MacDonald art' [2].

Is the Artist a User?

Obviously a paint program, a drawing program, an image renderer, a ray tracer, etc. are computational models that capture knowledge about how aspects of images generated in the past can be replicated. Whereas the artist working in traditional media invented new forms of expression, the computer program gives a prefabricated, general solution. Such programs are the *how* of art and as such are quite impressive in their performance. As explanatory models, they rely on physics (the laws of reflection, refraction, etc.), linear mathematics (linear perspective, sectioning, solid modelling) and logic (mainly Boolean operations). To what extent a good explanatory model is also a generative procedure is a question raised again and again during the history of art and in epistemology. As it turns out, each explanation is incomplete. The perspective from which the explanation is given defines the level of incompleteness. Within the perspective assumed, a good description can become a generative scheme [3]. The golden section, the Fibonacci series, the formalism of the metaphor (logical or mathematical) can be used to generate artifacts with expected or desired formal qualities. Based on this limited notion of generativity, various descriptions were used at the outset of computer art and experiments were performed in order to generate families of images or sound sequences. The so-called intuitive element, i.e. variations within a given frame, was ensured (rudimentarily I should add) by the use of random number generators. What resulted was a whole family (infinite, in principle, or with a degree of infinity comparable to the degree of randomness achieved) from which an 'artist' selected what seemed aesthetically relevant. My own evolution went through this stage [4], which I actually enjoyed because of the unexpectedness that randomness sometimes led to. It was a form of aesthetic lottery whose winners attracted public attention, although it was not certain what was won. Nevertheless, the major question of whether a person (or machine) who describes art also creates art continued to obsess us. It seems that throughout the history of art the act of doing and the act of contemplating (i.e. what is known as *theory*) have been complementary rather than equivalent, and the hope of breaking this pattern enthused many.

Things became more complicated once the instrument of explanation and the instrument of production became the same. Indeed, the same mechanism can be used to analyze and to synthesize. Data resulting from analysis (output from a process) can become the 'matter' of the act of obtaining new artifacts (input of a reverse process). However, the logical laws governing the function of the machine require observation of stringent conditions for computability. Completeness and consistency, to which a fundamental logical law applies (Gödel), are not, by any stretch of our willingness to acknowledge logic and rationality in art, characteristics of the art process. Thus, the machine is intrinsically adapted to a universe of experience in which only partial artistic practice is possible. Indeed, the very structured nature of the typographic art makes it a good target for computer-based praxis—a theoretic idea that I expressed long before desktop publishing was made into an available key-system technology [5].

Since any description—in the philosophic form of discourse or in mathematical-logical formalism—is, after all, incomplete and thus subjective, once such descriptions become generative tools in the form of procedures or programs, they act upon the data (the 'matter' of electronic art) as a mold. The fingerprint of those who designed them gets marked in the image or the sounds generated. The 'artist', consequently, is actually the machine, while the human being becomes the operator working for the programmer(s). The uniformity of images and musical compositions that strikes anyone who has gone beyond the initial moment of surprise and even exaltation is the result of the limited number of programs and procedures available. Such programs, while deserving in many respects, were transported from machine to machine (sometimes losing efficacy compared to their initial characteristics, other times being improved) and became available in the broader market. There is no difference between a ray tracer in a sophisticated research or computer art center and the ray tracer we can buy for our PCs.

Being such high performance machines, computers are used to generate incredible numbers of images produced in all kinds of environments. However, we must make some distinctions. We look at images on screens in various contexts. Each context has its own requirements. Computer-aided design (CAD) images are, in virtue of their goal, supposed to be exact. Tools for achieving precision are continuously created. From CAD, we move towards computer-aided manufacturing (CAM), which implies precision as well but also some other characteristics, such as versatility for driving complex machines, precise time sequencing, even parallelism. Communication and entertainment applications (such as advertisement, mass communication, show business) have still different requirements, including realism. Simulation, by its very nature, suggests the need for convention based on mapping procedures from the realm of simulated phenomena to the realm of knowledge. Dynamics, as characteristic of simulated complex phenomena, requires integration of movement. In addition, the code of simulation (as it applies to colors, visual rhythms, shapes, topological changes) has to be conveyed together with the simulation, which raises issues of communication. In each of the fields mentioned, software tools (indeed, *the computer is not a tool—only programs qualify as tools*) were built, tested and improved according to the specific requirements of the work.

Artistic images are defined by their aesthetics; and the need for aesthetic characteristics is acknowledged. Yet while the aesthetic component is a structuring component that facilitates better usage, it is in fact only partially pursued. What those interested in the art did not understand about the tools was that it is not the precision of CAD that will make for art, not the sophistication of an integrated processing package that will make art programs out of CAM programs (even when used to drive a milling machine in order to create a 'sculpture'), nor the enticing commercial 'art packages'. Because the explanations used were explanations pertinent to any other class of artifacts but the artistic class, the result was contorted images, very technical, precise but not expressive, flashy but not convincing. In these images, a world of plastic, metal, even of gelatin [6] was constituted because CAD, CAM and simulation programs required the texture mapping of plastic, metal and other materials that our factories process, not because it was aesthetically relevant. Instead of allowing us to see whether explanations of works of art can become generative procedures, those who use explanations pertinent to engineering, modelling, communication, entertainment and simulation made us understand that their generative power is not relevant to art and not equivalent to an aesthetic perspective.

Aesthetic Consciousness

It goes to the credit of the industry, however, that it recognized the need for aesthetics in tools for practical activity other than art. But while I credit the visionaries—Alan Kay, Ivan Sutherland, Nelson Max, et al.—with this understanding of the formative role of the aesthetic component, I must add that it is difficult to say whether the aesthetic component was viewed as a marketing tool, an alibi or an intrinsic part of the design of new tools. Nevertheless, in the databanks of the characteristics of artifacts generated with the aid of computers and aspiring to the status of art, one will find the characteristics commissioned/required by those who supported computer graphics research for flight simulators, radar installations, satellite observation, space exploration, oil exploration, design of new machines (cars and trucks, in particular), etc.

It is comforting to see that money invested in such non-artistic areas trickles down into the hands (and products) of those interested in art. But the inadequacy of such tools for artistic practice remains. The question of precision in art is different from the precision of engineering. The combative nature of art is different from that of the military. An artistic artifact requires a different manufacture than that of mass production. Against the background of the digital (i.e., of the information- and symbol-processing paradigm), we arrive at the realization of the need to consider art in its interrelations with all other products of human activity. The digital computer is the carrier of information and a means of maintaining simultaneous levels of information exchange. It already supports unprecedented forms of human interconnection and makes available new types of interaction. Whatever an artist can do using traditional means will not become more valuable once it is computer generated. It is in the realm of what was not before possible that one can see the assets of this artistic involvement with technology. Digital carriers allow for interactive modes, for integrated environments, for mixed media.

Nevertheless, all this does not come for free. Since more people can participate in making the work, chances are that, in the process, authorship and quite a number of characteristics related to it will change. The digital medium is one of instant replication and perfect fidelity; therefore, the notion of the original, the aura of uniqueness, and the attraction of ownership will have to undergo reinterpretation and change. Our understanding of the artist-public relation changes as the distinction between artist and public gradually disappears. Indeed, in the electronic medium, everything done by an artist can easily be re-processed by the public. Variations become a matter of interaction with the work. The change is from a one-to-many relation to a sequence of one-to-one relations. Even the functions assigned to art change in the sense that an active relation rather than passive contemplation emerges. As I see it, digital art permeates the environment of existence as a neverending process, at levels of quality perhaps far below those celebrated in previous stages of human practice, but reaching far more people (in principle, the entire population). Intensity is converted into extension.

Based on some of these considerations, we should now consider the relation between the *possible* and the *desirable* because *first*, in the age of computer technology, the space of possibilities increases exponentially, and *second*, in the past, people desired new forms of expression and pushed the technology and the medium of expression to its possible limits. Today, technology leads and actually offers more possibilities than we are able or even qualified to use. Consequently, *desirability* starts shaping us in our way of expressing convictions, ideals and values. Is it indeed desirable to use a paint program without ever seeing a painting or preparing a canvas, mixing colors, mastering a real brush? Is it acceptable to synthesize sound without knowing what is culturally acknowledged as harmony or tonality? Is it possible to conceive of an electronic sculpture independent of the context of the world for which such a sculpture is produced? I can go on and on with even farther-reaching questions as to the significance of color not only as a component of art, but also with biological implications (its symbolism, its role in memory processes, the effect of the eye's color sensor on each person's well being, the behavioral implications of color in a given culture). Indeed, art is far more than the mere physical presence of an artifact; and this is why the digital approach to art must consider the human being, society and its evolution under new circumstances of life and work [7].

The digital computer made possible an accelerated integration of aesthetic characteristics in non-artistic artifacts. This has contributed to a dissemination of better taste through objects of daily life and in communication. Moreover, the digital computer, together with other electronic and non-electronic technologies, made possible and necessary patterns of human interaction that affect the primacy of language and language-oriented work. We are already entering an age of varied means of expression and communication in which taste, smell and touch as well as images and sounds play ever-increasing roles. Once the dominance of language ceases, we start living in a civilization of several modes of expression and communication. This in turn affects the relation between art and technology as new arts appear and new forms of interaction with art become possible. It is probably worth the effort to understand this diversification as an expression of a new relation between what we call the tools of the artist and the medium.

TOOL OR MEDIUM?

One question is frequently raised: Is the computer a tool or a medium? The easy answer is: both. But easy answers will not do. In the strictest sense of the word, the computer is neither a tool nor a medium; that is, the programs are the tools, the peripherals (such as printers, plotters, CRTs, sound synthesizers, loudspeakers, etc.) are the medium/media. In creating a sculpture by driving a milling machine, the artist has to understand the relation between the 'virtual' object as it results after data processing and the 'real' artifact that will (or will not) embody desired qualities. Many changes accumulate between the plotted image on the screen and the Cibachrome print; there is a change in quality and quantity between the sound synthesizer and the final tape. This profoundly *mediated* process, which results in removing the artist from the 'matter' on which he or she acts, requires skills different from those of the traditional craftsperson. It is not that thinking replaces the craft, but it diminishes the importance of craft in the actual making. I feel comfortable with the notion that, in the age of digital technology, *the program is the work of art*, although I am not quite sure how such a work realizes its meaning. It is probably, because I do not want to discard the thought, through the infinite use of the program, in which case all of us using programs are actually interacting with the art object called 'the program' and thus with the artist as author of the program. Whether or not this view is accepted, we still need to make clear that, due to the intrinsic characteristics of digital technology, there is no such thing as a computer artist who is not the author of his or her program. The very few successes we know of are the result of authentic mastery of the programming and the result of the attempt to create a legitimate alternative medium. Harold Cohen created not only the best computational theory of Harold Cohen's art, but also a tool of tremendous flexibility and respectable integrity. For those who want to be Harold Cohen followers, the use of AARON can be rewarding. But whether or not it is Harold Cohen who actually turns on the machine and makes sure it runs, the work is already signed by Harold Cohen; it projects his notion of art, his sensitivity and his particular aesthetic point of view. (AARON does not yet encode Cohen's aesthetics of color, so at least the color component is left to the artist.)

Art is not possible without technology. Nevertheless, art does not reflect how powerful technology is, but how powerfully it serves the artist's artistic means. The need for the 'disappearance' of the technology, for its 'invisibility', has to be put in the perspective of the *why* of art, as opposed to the *how* and even the *what*. In general, when the computer is visible, we are given an indication that the technology is not yet appropriately assimilated in the activity supported. Manfred Mohr and John Pearson are good examples for understanding the implications of this principle. Their work, so different each from the other, is the result of integrating the computer in their thinking about and making of art. Both artists recognize the need for a powerful planning procedure, for an instrument adequate to the research of a personal aesthetic set of possibilities in which geometry plays an important role without becoming a goal in itself. John Pearson confesses that the computer influenced his process of thinking: thus he felt encouraged to look at the many facets of an artistic idea and discovered that some relevant avenues explored in his work would have been overlooked had he relied only on intuition. He typically starts his creative work where the computer ends in generating the shapes that will constitute the invisible support of the final image. Manfred Mohr discovered that his aesthetic interest in multidimensional spaces could not be efficiently supported without an adequate instrument for visualization. He does not continue the tradition of literary descriptions of such higher-order spaces such as Abbot's *Flatland* [8], but uses a constructive perspective. Curvature, as evidenced in sections of this space, thus transcends the realm of topology and becomes artistically relevant.

Neither Mohr nor Pearson identifies his art as computer generated; and for someone who does not know what goes on in their studios, this is not relevant. At the opposite end of the spectrum are Lillian Schwartz and probably Frieder Nake. There is a strong computer component, almost a declaration of computer identity, that is quite misleading. Actually the computer trademark is a diversion. The expression is not the result of the hardware, but of an analytic effort. Nake's variations on Paul Klee and Lillian Schwartz's *Mona Leo* (juxtaposing half of the celebrated *Mona Lisa* and half of Leonardo da Vinci's self-portrait, suggesting that he was the model) are works with a precise aesthetic condition resulting from the integration of the computer in the creative act. The analytic effort does not necessarily become art. Ending with a formal description of a work (like my applications to Brancusi's body of sculpture), the analytic effort constitutes a computational explanation, not a new, original, artistically relevant expression. I give my own work as an example to clarify that the mastery of the computer and the mastery of art are related but still quite different. One does not automatically result from the other.

Can users, the vast majority of those interested in computer art, also succeed? Depending upon what it means to succeed, the answer may be 'Yes'. Provided that we are able to adopt a different notion of art and a different notion of the artist, many arguments speak in favor of an increased interpretive approach, of more performances and larger audiences, and of aesthetic products new in their condition, impact, and cultural and social implications. For all these things to happen, we have to gain access to the technology in each of its various aspects while we simultaneously start—and I mean *start*—thinking about possibilities, about what is desired, and about what it takes to prepare the creative 'quantum leap' promised by the progress of technology and the experience we are acquiring. My position is that, instead of refusing theory, historical reference, and culture—because some believe that these can obstruct the new and will subtract from our preparedness—we should involve them in our efforts. This becomes so much more critical today since there are very good computational models (i.e., theories) that, while keeping close to the practice, also put this practice in a digital perspective and thus turn out to be instruments of creative understanding [9].

Diversified Aesthetic Practice

At various professional meetings, seminars, workshops and classes during my involvement with computers, I have suggested artistic experiments and new ideas for a creative approach. I have tried some and am still involved in others. Of these, several can be mentioned along the line of the ideas pursued here.

1. Given the integrative power of the technology and the possibilities of combining sound, movement, images, etc., we can create an environment for play that documents itself in the data stored. Eventually a game can be conceived with events taking place both in sequence and in parallel, the outcome being the score for the next game, i.e. participatory performance.

2. Using the networking power of the technology, we can access people in their homes and challenge passivity and complacency by making possible the interaction of all those connected through the cable systems.

3. We can transform those major events of a democratic society—election debates, congressional debates and votes, referenda, etc.—into major artistic events, not only by recording a vote in a booth, but by making the act of voting an occasion for creative expression.

4. We can make private art part of the community ceremony; we can make possible the display of what people draw, write or compose within a community and allow interactive changes.

5. We can form our relation to what is already established by 'pumping' into people's homes high-resolution images of museum art; we can allow for interactive programs that will enable the viewer to reframe the work,

alter it, associate it with other works. These electronic copies will give people a better understanding of both art of the past and new art.

6. . . . more to follow, much more.

Obviously, I am not suggesting that these are the only possible ideas, but that some of them and others, many others, will bring us to a more promising domain than the current use of limited paint programs or sophisticated keyframe electronic animation. But none of these notions is meaningful if we do not build an aesthetic self-consciousness. Terribly engulfed—and justly so—in the technology of computer art, we meet and talk about pixels, megabytes, and call-up color tables. This language is necessary if we want to understand *how* we do what we do, but not *what* we do and *why* we do it. Aesthetic consciousness means the acknowledgment of aesthetic goals and the sharing of aesthetic experience. Frequently, in the absence of such an aesthetic consciousness, we fail to understand our own work. This should make us reflect on our own standards with respect to the work and our discourse about it. The diversity that is possible today will become reality only if we challenge our own prejudices as they have accumulated from prior modes of expression or from recent experiments with technology [10]. It is good that we share programs, that those of us with more resources are willing to disseminate our programs and experience. But this will not lead to more diversity. An animation pipeline used in several universities and abroad will remain uniform unless it is delivered with the firm commitment that it can be altered, that it can and will be creatively redesigned.

And this brings up the final issue: how programs written for particular applications determine the output of so-called artistic attempts. My claim, admittedly expressed in radical language, is that art is made by artists and that a truly creative approach can take place only if we can give the artist an 'empty' computer. What does this mean? Computers are cycles, storage and operating systems, input and output devices, compilers and/or interpreters, utilities, procedures. When an artist receives a machine, even with the most basic configuration, the machine already has its pixels defined, its geometry and logic programmed. Whether Boolean logic and art logic are equivalent, reducible to each other, or at least compatible has not been sufficiently researched. But no matter what the answer is, the nature of the machine as predetermined makes it a poor substitute for the empty canvas of the painter, the block of marble of the sculptor, or the blank lined sheets of the composer. We all understand why the computer industry maintains that, for reasons of competition and security, certain limitations (the notion of 'proprietary information') are necessary. But art is 'hacking' and 'viruses', not databank management or increased production. The industry is also preoccupied with providing tools for efficient work, not with the exotic realm of somebody's art. Consequently, the major creative effort of someone really wanting to use this technology for artistic purposes probably involves finding ways to strip the machine and reinvent it in each detail, going into language, interactive modes, and input and output devices. Scientists as well as artists express the same need. "As an algorithm developer, I cannot use a workstation that has specific rendering algorithms already built into it," stated Nelson Max [11]. My own program, as it applies to aesthetic performance, is definitely extreme—an empty computer. But given the background against which it is formulated, chances are that it will be implemented. Small steps in this direction (such as the generalization of associative modes of computation, supported by the hypermedia model) are already noticeable and have encouraged creative applications. Moreover, it may turn out that while the notion of processing is all right, digital formats are not the only type to consider. Binary representation is powerful but, as we know, not necessarily expressive. A compromise between precision and expressive power seems more appropriate and will result not in a computer (the digital machine), but in a family of machines (triadic, tetradic, etc.) that we should be able to interconnect while giving the analog a fair chance in the process.

There are many reasons to be optimistic and, although the quality of previous and current work is not among them, I would like to restate my respect for those who have failed. It takes failure, more than success, to open new avenues. In view of the implications of the entire process, it should come as no surprise that a discussion of the emergent aesthetics cannot start with self-delusive value judgments. After all, to discuss aesthetic issues is to discuss the future.

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The Image in Art and 'Computer Art'

Richard Wright

ABSTRACT

In this essay the author takes a cursory look at the increasing range of applications of computers to art and design practice and questions some of the assumptions that have been made about their use. The proliferation of computer imagery in society as part of the video culture and its effects on our attitudes towards digital representation are emphasised. This leads to a redefinition of the intimacy of the relationship between artist and art object. Such issues contribute to the comparative study of digital media and physical/mechanical media and the computer's impact on the creation and apprehension of imagery.

DOES 'COMPUTER ART' STILL EXIST?

The term 'computer art' has begun to drop out of usage in recent years to be replaced by phrases such as 'computer-aided art' or 'computers in art'. This must partly be because the computer is now used for so many different purposes that it can no longer form a basis for comparison by itself. Early 'computer art' of the fifties and sixties was based mainly on ideas drawn from the European Constructivist tradition—that of system, precision, geometry and structure—and the rigours of computer programming lent themselves easily to this approach [1]. The term 'computer art' seemed to imply that the content of this art was the computer itself, or rather the computer's symbolic processing abilities. Since then, computer power has increased and methods of communication and interaction between human and machine have widened. New uses have mushroomed—image digitising and processing, animation, 3-D modelling, paint systems, digital video editing, computer-aided sound synthesis and editing, and even word processing. And artists that choose to take advantage of these facilities undoubtedly see their work as coming under such varied headings as conceptual art, video art, installations, or as some symptom of the Post-Modernist pluralism. One may now ask whether it still makes sense to talk of a 'computer art'. Can the computer be a medium that can help define a new art form, or is it only a tool?

Painting is a medium that has embraced many different subjects, forms and art 'movements' in its history: it has been used as decoration (Rococo), as experiments in light and colour (Impressionism) or fragmentary form (Cubism), as something akin to psychoanalysis (Surrealism) and simply as a record of the act of painting itself (Action Painting). But it is still possible to talk of an *aesthetics* of painting, the unique visual qualities of pigment applied with a brush, the dynamics of the physical effort it demands from a painter, its function as a wall hanging. Such descriptions are especially apparent in the early days of a new medium, for instance Van Eyck's development of oil painting, whose slow drying time and variability of consistency enabled him to produce finely crafted images rich in surface detail and finish. Though today any attempt to show an exhibition of painting as a medium would include such a variety of aesthetic and conceptual approaches as to render it a pointless exercise, it is still possible to talk of 'pure' painting—that is, painting that exploits the properties of paint itself, even if it is part of a much larger intention.

If we compare painting with art made with a computer, however, it is not inevitable that we should conclude that the term 'computer art' is equivalent to 'paint-brush art'. Art that uses computers is still at an early stage—is it possible to elucidate the aesthetics of the computer as a medium before its products become too diverse to submit to analysis; is it possible to define it as a separate mode of cultural production aside from its appearance as a subject, tool or accomplice of other arts?

Fig. 1. Adrian Wilson, *Perspextive IV*, paintbox image frame-grabbed through Perspex, hand tinted and filtered, 1988. Reproduced by kind permission of the artist. All rights reserved.

THE ECLECTIC IMAGE

I will first try to elucidate some subtle but significant differences between digital and physical media in an area where

Richard Wright (artist, educator), Computer Graphics Department, Sir John Cass School of Art, City of London Polytechnic, Tower Hill, 100 Minories, London EC3N 1JY, United Kingdom.

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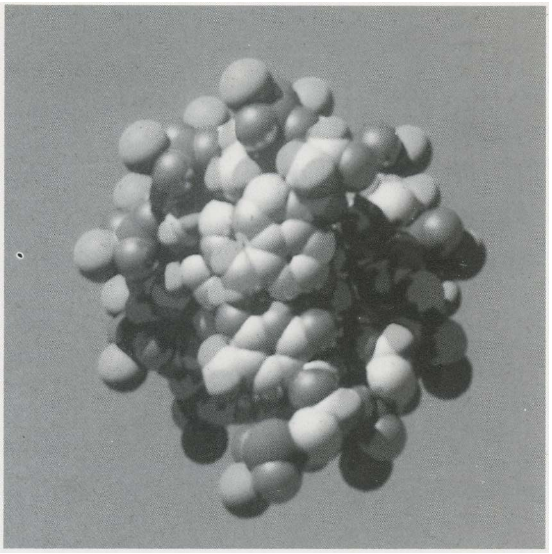

Fig. 2. Richard Wright, *DNA Molecule*, digital image, 1986. Data provided by Jane Burridge, Software Technolgy, IBM UK.

the computer is used toward apparently similar ends and exploits familiar skills—the use of electronic systems for painting and drawing. Apart from having fast graphic output in a form convenient for electronic reproduction and broadcast, the electronic paint system has the advantage of being able to sift through layers of menus to find, ready to be applied, almost all the graphic techniques one could think of. Paints, washes, delineated shapes, graduated shapes and typography can all be combined in rapid succession. Cutting and moving areas of the image, distorting, changing coulour and merging all contribute to the impression that the picture is an infinitely malleable entity.

An electronic image has a 'reproduced' quality to it—it seems to float behind the glass of the screen, seems to be unlocated at any unique point in space. The image itself is displayed on the monitor at a certain distance from the operator, emphasising its separation from the operator who labours on the touchpad and keyboard. A graphic designer does not have to wash his or her hands before beginning work on a paint system. Electronic images are *limited* by the screen but are not *on* the screen. In turn, the surface of the screen is often covered in smears, tends to accept distracting reflections from any light source in the room, and is prone to the adjustment of brightness, contrast and saturation control that we are accustomed to in our television sets. These all help to give any electronic image (not just images created by paint systems) a synthetic and transitory character, resulting in a loss of respect for the integrity the image would have had as a crafted object [2]. This effect is greatly increased in the case of digital media by the ability to store and retrieve previous versions and stages of work in a picture.

In the same way that the final image is viewed as flexible and immaterial, the drawing and painting functions of a system are all instantly available without regard to the practical difficulties normally associated with them. The operator can be a painter, draughtsperson, or typographer as the need arises. To use an airbrush to its optimum effect, for instance, would suggest heretofore the need to call in a professional airbursh artist, but its almost casual inclusion in the menu reduces its value to that of an 'option', to be employed as and when the mood takes us. And the loss of specialised craftsmanship carries over to a loss of 'aura' in the image itself.

The eclectic approach to image-making engendered by the varied available functions expands to include a vast collection of pictorial raw material that can be pressed into service. Many paint systems are exploited for their image digitising and processing potential, for photo-montage and collage as well as retouching (Fig. 1). A digitising camera is pointed at some area of interest in the visual world and made to take in what is confronting it. Once inside the electronic hardware, the information stored from the image is reduced to a range of digital symbols. Whether the source of the image is photographic, a thermal emission or live action, it is all converted to a single uniform representation. Even the terminology of the practice—'frame grabbing'—emphasises the visual world as being a storehouse of pictorial data, of 'frames', that is ready to be plundered and consumed. The special editing abilities of digital systems—such as squash and stretch, and shrink and expand—combine with the traditional tools of cut and paste to allow a high degree of visual 'violence' to be perpetrated on the original subject. One could not imagine slicing up an authentic Van Gogh canvas, or even an expensive reproduction of one, to provide material for an experiment in collage. But when the image is inside the 'library' of the paint system, it is downgraded into visual fodder; this in turn must affect the way in which we view the original, resulting in a serious loss of signification [3].

All the materials of the paint system user, whether digitised images or pixellated brush shapes and area fills, assume the same status and can be freely mixed and matched. Individual pixels can become the constituents of nearly any observable marks, lines, tonal graduations, patterns or textures [4]. Each element of the image can be processed equivalently with no respect for its semantic or perhaps even formal qualities. With all these graphical modes of expression available, the artist can become a style compositor, the author of a pluralism that is as mannered as it is evocative.

Synthetic Photography, Realism and Surrealism

It seems as though it has always been necessary to have some branch of the plastic arts devoted to reducing our experience of the three-dimensional world to a flat surface. The short history of computer graphics has been no exception. Engineers first used computer graphics to visualise new designs, as did scientists to evaluate, interpret and conceptualise large amounts of data (Fig. 2) [5]. Although synthetic photography has been used by methodical research as well as commercial graphics, its perception depends partly on the way photographic images are regarded in general. Computer graphics takes on a function similar to that of providing photographic evidence, the image being almost identified with the subject itself. In the case of work involving the exploration of abstract mathematical structures, the computer assumes the role of an 'abstract camera', giving an intuitive representation of a mental object that is essentially of a different nature.

Like photographs, this kind of computer imagery can take on the status of being records of the world, but this does not mean that they are equivalent to our ordinary way of looking. If we look at the progress in image synthesis from the late seventies to the mid-eighties, it is quite startling how relative the perception of improvements is. During the early eighties a computer graphics 'naive' could easily be impressed by the finely highlighted and smoothly shaded geometry of colour rendered frames generated on the recently available frame-stores. Yet all this suddenly paled into insignificance once ray-tracing algorithms appeared; their clear reflective surfaces were like a new pair of spectacles to a near-sighted person—they revealed unsuspected visual delights in the surrounding world. Ordinarily, the closer one looks at an object the more sharply focused it becomes, but in a scene rendered by a computer each object can be as crisply defined as any other. One gets the impression that this kind of picture has a greater clarity than an ordinary photograph, as each object projects itself on our retina as forcibly as the next. With no depth of field or selective focusing functions our eyes can wander aimlessly over the pristine surface, unable to find any differentiated subject to catch our attention. Many pictures like this exist in the computer graphics universe. Sometimes they are a result of limitations in the software, but it is difficult to resist the feeling that the artist has tried to insist upon the superior reality of the computed image by giving all the elements in the scene an equal, idealised definition, that this is how things really look without the limitations of the human eye. It is of course a mistake to chastise the eye for failing to correspond to a mathematical model; the perception of a synthetic image is still only the beginning of an understanding rather than the acceptance of a definitive account.

Although the pursuit of realism in computer graphics was originally for the purposes of providing a more easily evaluated simulation of a computer-modelled industrial product or architectural scheme, by the early eighties synthetic photography had invaded the world of graphic design and advertising. Few fine artists have been attracted to this kind of imagery, however—not even those remnants of seventies hyper-realism who were more concerned with reproducing and editing rather than creating. Three-dimensional image synthesis simply did not seem to present or solve any artistic problems.

The perception of computer imagery by the design companies that provide the briefs that the production houses work to (as well as the perception of other artists who have avoided involvement with such techniques) is that this imagery is one of faultless presentation, accuracy, and a commitment to the myth of self-justifying technological progress. The objects in a computer-generated picture are crisply delineated, one *trusts* these images and feels sure one 'knows'—has knowledge of what one is looking at, even though one might not actually recognise what it is. It is not naturalism that these images seek, nor is it what architectural simulations might aim for. What they seek is a kind of 'realism' of an ideal sort, a realism that tries to describe the world with an insistent, even authoritarian, accuracy that is overwhelming. It is as though the corporate power of the media had joined up with the methodological rigour of the mathematicians and scientists to create some final, definitive and coercive depiction of the visual world [6].

The Japanese artist Yoichiro Kawaguichi is one of the artists who tries to use this power of synthetic photography, in a manner reminiscent of the *trompe l'oeil* style of Surrealism, to make vivid fantasy creations that compete with more familiar images of everyday scenes [7]. Another Surrealist technique, that of juxtaposing domestic objects in unfamiliar combinations and situations to release unsuspected associations, has become a stylistic theme of computer graphics (though often it is little more than a license for various forms of gimmickry).

Although as a graphic tool it was further developed for different purposes by other Surrealists such as Tanguy and Magritte [8], photo-Surrealism was first introduced by Salvador Dali when he joined the Surrealist movement in 1929. For Dali it was important as a way of realising the obsessive quality of his dreams and fantasies in a vivid and concrete way, of making them as 'real' as possible. It is this ability to create convincing

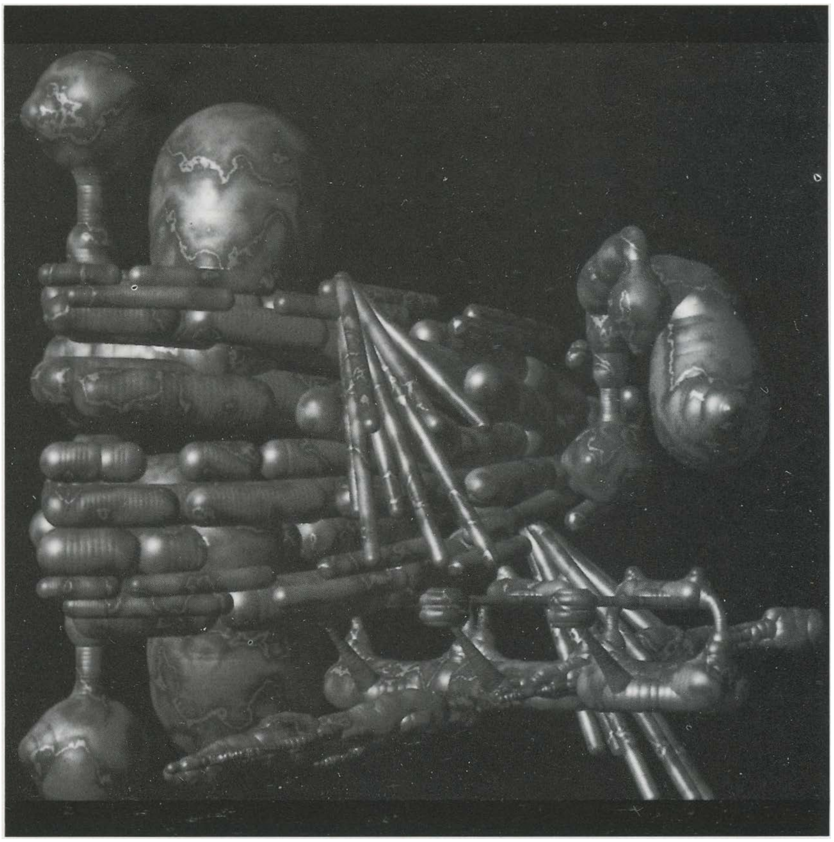

Fig. 3. Mike King, *Dock 1*, digital image, 1988. Modelling software: SCULPTOR, Mike King, City of London Polytechnic. Rendered by Ian Currington, Amazing Array Productions. Reproduced by kind permission of the artist. All rights reserved.

depictions of objects and scenes that computer graphics has sometimes been exploited for; it lends credence to the bizarre—seeing is believing. But an intrusion of the imagination into commonplace imagery was not the only aim of the Surrealists.

Surrealism was also a heavily political movement; it actively sought social reform and even upheaval and was intent on using art as a weapon. The Surrealists desired to break down art practice as an elitist activity by developing new techniques which would 'democratise' it. Artists like Miro, Masson and Matta tried to relinquish as much conscious control over their painting techniques as possible, aiming for a trance-like state of extreme physic sensitivity, in which it was hoped that the hand of the artist would be able to record instantly each random, irrational urge of the subconscious, the source of all creativity, without the ego intervening to censor the process. This technique was called 'automatism', or automatic painting. The point was that a method like this did not rely on mastering skills that could only be acquired by spending years at the traditional institutions; thus the average person would no longer need to feel excluded by the world of art. In the libertarian Surrealist world everyone could be an artist. The 'democratic' methods of the Surrealists were mostly dependent on their *physicality*—to be an automatist artist one needed only a piece of paper and a pencil; no training or preparation was required. Most importantly, it was an essentially organic process; the marking of the pencil on the paper was the result of unconscious spasms being transmitted directly through the physical body of the artist itself.

The contrast of this latter Surrealist practice with computer-graphics techniques is obvious and illuminating. Not only can the process of modelling and rendering be arduous and demanding, both in terms of the mental effort and the basic knowledge required, but the expensive hardware may, apart from its forbidding aura of technological insensitivity, be unaffordable.

Still, the hope of some writers on computers in art was that the boom in home-computing during the seventies would democratise art by transferring the burden of skills from the manual dexterity of the painter to the cerebral skills of the programmer and general computer user [9]. But it is naive to think that programming is an ability any less daunting than painting, and the arrival of the user-friendly, menu driven systems of the eighties has led to less rather than more intimacy between the computer user and the medium. Only by teaching formal computer language skills at the same time as basic reading and writing might we avoid this new form of illiteracy and create a new generation of informed and critical users.

The Creative Process in Symbolic Space

The idea that computer graphics can give an accurate visual interpretation of a 3-D computer model has given rise to the notion of 'computer sculpture' or 'sculpture simulation' (Fig. 3). Instead of using naturalistically shaded study drawings of projected sculptures, some artists now use graphics systems to help them visualise the final result. Some sculptors have been so impressed by the power of this approach that they simply leave their 'sculpture' in digital form and do not bother to build it. This of course means that they are now working in a different medium. It is not true that all the sculptor has to do is to express his or her concept in digital form, which can then be rendered physically: artists do not conceive of their work in its entirety before setting pencil to paper. The process of visualisation, whether on computer or with traditional tools, is also a process of further conceptualisation and development. Sculpture is, after all, a visual and tactile art form, not a cerebral one. Because of this the method of visualisation that the artist chooses will also determine the creative process: it will always control the kind of work produced.

It is widely considered that future computer graphics modelling tools will be so modified—to increase the ease of interaction, flexibility and precision and in general widen the whole domain of accessible forms—that their limitations will be the exception rather than the rule. But even then there will be subtle effects on the working practices of artists or designers that may not be appreciated immediately. These effects are due to the digital nature of the information stored in a computer, the symbolic form of all its constructs freed from the constraints of any physical manifestation, and its infinite reproducibility and storability as utilised by a creative process. One of the main advantages of computer-aided engineering (CAE) systems is that any rough 'sketch' or provisional draft can be analysed and a considerable amount of detailed information can be determined (information such as dimensions, weight, cost, compatibility with other components). Many alternative designs can be generated quickly, stored in the computer's memory and then compared to each other. The designer can—apparently—*explore alternatives* more efficiently, testing and perhaps perfecting the final answer to the problem in a sympathetic environment. This kind of activity has sometimes implied that designers are progressing in an orderly fashion towards a unique solution to their brief, that designing consists in searching for a 'solution space' for the correct answer. Yet it has been pointed out that this is a misleading view of the way designers work. It does not make sense to discuss the process of designing in terms of its final outcome [10]; designs are invented rather than discovered, and there can be many different solutions to the same problem.

Artists do not see themselves any more than designers as being presented with a problem that they then proceed to 'solve'. But much more importantly, where designers essentially communicate ideas, artists are concerned with generating meaning, with revealing the nature of their medium and their relationship to it. This is quite crucial when considering the effects of the computer on each of their working methods. A designer still tends to work *towards* something, however dimly perceived, while an artist works *out from* something. Many artists today have a preference for computer-'aided' art in terms of its helping them to 'try out' different variations, to explore alternative compositions and their 'effect'. This is in contrast to the aims of the Systems artists who like to fully work out and display a whole group of combinations and permutations for their own sake (a kind of symbolic action painting). These artists carefully store each stage of their work ready for instant recall should something 'go wrong' with the current process they are applying. But in what sense can a work of art 'go wrong'? Apart from the trivial case in which one might knock a pot of paint over one's canvas (or suffer the contribution of a 'chance' occurrence), mistakes can simply be seen as a record of the process of getting from where one was to where one is now. They can be seen as 'wrong' only if the artist is pursuing a preformed vision, performing a task whose goal is the perfecting of an ideal form or the creation of the right 'effect'.

The knowledge that one can go back and start again, can redo or undo something, reduces tension and gives art practice a ceratin reliability. It provides a cushioning from the responsibility of having to perpetrate some irreversible act upon a physical object such as a canvas or block of marble. On the other hand, with all these different experiments and versions floating around in symbolic space, it becomes unclear as to where the work of art is actually located. When one adopts this way of working one creates many different works of art, and a decision to chose one of them above the others loses much of its meaning and significance. Like choosing a red candy bar instead of a blue one, the criteria of artistic merit can become trivialised. In addition, the artist is now released from the need to make decisions with commitment. As the computer reduces the 'risk' in making art, so it reduces the need for conviction in the creative process. But here the artist is in danger of floundering helplessly. An artist might revert back to an earlier stage in the work at the first sign of a problem rather than try to 'rescue' the picture, to struggle on and perhaps reach something that provides a new insight. Such an artist may become a timid creature indeed.

A painter who has made the decision to change part of a work, without knowing beforehand exactly in which direction he or she is heading, has to move forward and so is much more aware of art as a process of getting from one place to another. This can be reflected in the painting itself. By discarding as irrelevant the many formative stages experienced on the way to the final image, an artist using a digital medium will end up presenting a work that exists in a wholly artificial context. This artist will present a work as though it 'just happened like that', a work isolated from its artistic roots.

The effects described above are all consequences of the nature of the computer as a medium, in particular its non-physicality and the status of its symbolic processing functions. Until quite recently the activity of making things was always a manually based task, but now it can be a cerebral one instead, a more rationalistic activity that seems to come from a different place in our experience. Even with the most versatile interactive graphics, the dynamics of working in an electronic space would mould the nature of the result. The issues raised here can only be resolved by recognising and coming to terms with the computer's influence, however subtle, on the minds of those who use it. Computer practices will likely not improve art practices nor 'aid' them, but will create completely different practices and lend more shape to our growing notions of what a 'computer art' might be.

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4. This unified expression in a digital language is also an attractive property to those practising algorithmic aesthetics who seek a universal notation for pictures and who choose to ignore their identity as tangible objects.

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6. The perception of computer imagery is affected by its relationship with television images, particularly for computer animation. A still picture like a painting or photograph is inspected and pondered as an object meriting special interest. When we use our eyes to get around in our daily lives we tend to scan whatever is in front of us, pausing to concentrate only on the things that break through our apathy and impress themselves upon us. When we watch moving images such as those on television we are even less likely to notice the subtler but possibly still important features in what we see, willing as we are to allow ourselves to be guided by what the camera shows us. Computer graphics, whether still or animated, are electronic images of quality similar to television images, and it is unclear to what extent our perception of them is affected by the visual habits carried over from our passive response to broadcast pictures and entertainment. A related area is the possible conflict between the use of the computer as a tool for representation, such as in scientific visualisation, and as a tool for hermeneutics—as a generator of a multiplicity of interpretations and pragmatic conventions—which will also become increasingly problematic.

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The Proceduralist Manifesto

Judson Rosebush

ABSTRACT

Computer art' has become a meaningless term, because soon virtually all art will be computerized in some way or another. The author introduces the concept of proceduralism as a label to represent a special class of art, one that constructs images using abstract qualitative and quantitative parameters, rather than simulates classical drawing and painting. This approach to making art differs radically from drawing and painting approaches because the picture-making process is detached from the picture. The net result is that an entirely new area of creativity has been unveiled for the artist. As such, proceduralism is a logical successor to conceptual/process art; it is a major art movement and a new medium.

The complexities of defining computer art have confused artists and institutions alike. Many art critics, galleries, museums and educators display attitudes similar to those of their peers 100 years ago who failed to understand that photography is art. On the other hand, when computer art is in vogue, even the most prestigious and computer-illiterate artists are prepared to join the ever-swelling ranks of computer artists. Just what is computer art anyway? And is the computer a new medium or just another tool to aid the artist?

Once upon a time it may have been possible to assert that a person who used a computer in the generation of artwork could claim to be a computer artist. Of course, when 'only scientists' could use computers, many art critics were quick to observe that, since scientists were not artists, obviously they could not be making art. Once computers became friendly enough that artists could interactively paint pictures, many critics asserted that computers were simply an alternative canvas. Luckily we have reached a point where almost all media are computer processed in some way or another if not by an electronic pre-press system then by a time base corrector. Now everybody is a computer artist whether he or she wants to be one or not.

In retrospect, it is not surprising that we have been failed so miserably by the art industry. Galleries have used little imagination in marketing new work and critics have had no concept of the germane aesthetic issues. Part of the problem may result from our own failure as computer artists to state the issues of our artistic agenda clearly. Much as we might like to think that work stands on its own, virtually all the major art movements of this century have been accompanied by a dynamic manifestoism explaining to the art community and to the public what the new work really is all about. This was true for impressionism, pointillism, cubism, expressionism, minimalism, conceptualism and, in the moving arts, for film and television.

In the case of computer art, the aesthetic is integrally related to the computer itself—how it works, how we use it, and how it stimulates our creative processes. But if indeed 'computer art' has become everything to everybody, as a term it lacks the precision required to describe those aspects of this new medium that make it a unique movement in the world of art. A suggested label for this movement is *proceduralism*, a term Isaac Kerlow and I developed 2 years ago to describe art made by employing scripted, notational directions that specify processes and parameters [1]; the picture is produced by executing these directions, rather than by drawing it directly. To borrow a term from Robert Rivlin, proceduralism is 'the algorithmic image' [2]. The procedures used by the artist may be relatively concrete, for example determining the position and color of synthetic spot lights, or they can be abstract concepts, like the constraints imposed in a Harold Cohen drawing. Like a scientific visualization, the resulting drawing is the graphical result of an experiment, the difference being that it is an art experiment dealing with the fabrication of graphic form. Proceduralism does not claim to embrace all computer art; its aesthetic issues are a subset of the aesthetics of computer art as a whole. Nor does proceduralism need to involve a digital computer; its focus is on how an artist approaches and manipulates a medium and not on any particular medium itself.

In terms of art movements, proceduralism represents a natural, historical evolution from conceptual process art, with the advancement that it actually scripts and enacts concepts, producing tangible personal property as the result—typically a drawing or image. In a very real way, proceduralism breaks through barriers inherent in the often-paralyzed, self-contemplative conceptual art process because it extends the definitional process to allow the production of real pictures and not simply conceptual ones. The results of proceduralism include graphical matrices such as Leslie Mezei's *Bever Scaled*; abstractions such as fractals; manipulations such as blockpix; realistic landscapes and still life interiors; portraiture; and surrealistic transformations such as Carl Sims' *Waterfall* that mix realism with novel procedural approaches.

There are several key tenets of the procedural movement, and they have vital implications for the art world. First, proceduralism implies art that is made using a command and control structure. Of course, all art made on a computer, even using an interactive paintbox, uses a command and control structure. The proceduralist initiative lies not simply in using predefined tools to simulate classical painting methods, but in the innovative use of new tools and procedures in order to expand the procedural possibilities of the art. In other words, simulating the cel animation process on a computer is not a proceduralist breakthrough—it is an automation. Programming fractals on a computer and producing fractal images are procedural breakthroughs because they introduce an entirely new class of parameters and an entirely new class of images.

Second, proceduralism almost always involves modeling.

Judson Rosebush (author, artist), Rosebush Visions Corporation, 25 West 45th Street, New York, NY, 10036-4902, U.S.A.

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The subject matter may be abstract (e.g. distributions of random points) or it may be concrete and realistic (e.g.the simulation of cloth). Whichever the case, the construction process used to generate the image is dramatically different from any approach used in the past. The proceduralist approach does not attempt to create the image directly, for example by drawing. Rather, it approaches the creation of the image indirectly, in fact by a most circuitous route—the formulation of commands and procedures that describe the behavior of a conceptual model. The image is determined as a result of these rules. The drawing is manipulated by manipulating the rules and the arguments. This abstraction of the drawing process is a profoundly different way of doing things, and its implications lead us to the third point.

The proceduralist approach affects the very essence of the creative process. The computer is itself an extremely plastic medium and a computer generated image can be composed in a very incisive manner. Problems inherent in overpainting to change detail do not exist. Composition, colors, perspectives, lighting—indeed the very contents of the picture—can be previewed and independently adjusted. The picture is not manipulated tactily, it is manipulated conceptually, procedurally. Fundamentally, the picture is conceived procedurally, and thus the aesthetics of the medium are intimately concerned with the definitions and domain of these procedural variables. Much of our aesthetic is about how these variables are developed. The evolution of algorithms to create images of hair, cloth or haloes are as significant a portion of art history as the evolution of methods to represent hair, cloth, or haloes in sculpture and painting during the last 4000 years.

Once discovered, many of these notationally mediated variables reveal combinations and domains that are simply absent from our normal experience. It is true, of course, that an illustrator could conceptualize a woman with leopard skin or a polyhedra turning itself inside out, but in practice it is the practice of exploring what one can do with texture mapping or transformation geometry that prompts many of these kinds of realizations. In other words, the very process of manipulating the image procedurally invokes a type of creativity that would not be present if the problem were approached in a different way. Invention does not always happen intellectually; it also happens by solving real problems. Our tools shape our thinking.

During the past 100 years, painting has dismembered realistic classical environments. In the early part of this century, impressionism and cubism challenged classical understandings of color, composition and perspective; by the middle of this century, abstract expressionism had abandoned any sense of physical reality in order to imprint the field with the emotive feelings of the artist. Minimalism and conceptualism sought to sterilize the process further, producing not only the all-white painting but also the conceptual painting that has no physical manifestation. Proceduralism simultaneously extends the reductionist, conceptual, process idiom further, except that it may actually produce an image or object.

Given that the art establishment has managed to understand the disintegration of painting and to reduce conceptual art to the Goedel paradox, one suspects that its continued failure to misunderstand 'computer art' may lie more in ignorance than in the complexity of the issues involved. The problem may simply be that the establishment is better equipped to gurgle on about rehashed abstract expressionism, color field theory and the implications of neo-realism. It is regrettable that some critics are still waiting for 'computer art' to mature, because it is clear that its major aesthetic themes already exist. Critics who are blind to the fact that computer art reflects the reality of the information era deserve comparison to the French Academy in the impressionist era—out of touch with the contemporary world and possibly with vested interests in establishment art. In practice, proceduralist computer art is among the most contemporary products of our culture and will increasingly be appreciated as a major art movement by this and future generations.

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Dataism

Tom DeWitt

ABSTRACT

Dataism is a term coined to designate computer art. In contrast to the iconoclasm of Modernism, in general, and Dadaism, in particular, Dataism restates traditional aesthetics through formal practices. Dataist works are not singular *objets d'art*, but algorithmic procedures and digital data bases that have a symbolic description. They can be perfectly duplicated and widely distributed. Dataist artworks can appear to exist in three dimensions and move in the time dimension, but they may be entirely synthesized, that is, a manifestation of imagination.

Dizzyingly rapid changes in the fine arts during the past century have induced a measure of exhilaration. When Dadaists promulgated a Manifesto, their critical attack on the mystique of illusionist art was bracing and refreshing [1]. Defiance of tradition was liberation, and the arts again brimmed with raw creative energy. Much as a log fire can be stoked to burn with renewed vigor until its last fuel is exhausted, each emerging art movement was excoriated long before it could impose its nascent discipline on an entire generation of artists. The twentieth century has given us little to build upon other than an institutionalized iconoclasm. Now this process has run its course. Today the dead embers of modern art may be feverishly stirred by contemporary cognoscenti, but there is no new light. Those who have championed Schnabel are fully worthy of the double entendre implied by his assemblages of cracked pots [2].

What has happened? The twentieth century obsession with novelty for its own sake is reviewed in Robert Hughes' study of Modern art, *The Shock of the New* [3]. Contemporary artists fly in the face of established aesthetics, reasonable expectations, conventional wisdom, or other constraints forced upon them by social norms and art history. Theirs is an Age of Outrage; they have a compulsion to offend. Hughes pronounces Modernism moribund. This sentiment is seconded by critic Suzi Gablik, whose treatise, *Has Modernism Failed?*, raises the specter of a self-perpetuating art market in which aesthetic base metal is transformed into gallery gold through an arcane curatorial alchemy [4].

Central to the alchemical formula of successful art marketing is the purveyance of unique collectible objects. Original *objets d'art* are distinguished from copies by a broad divide. The premier scandal of the collector's world is to be defrauded by a copy. Since the singularity of an object becomes a measure of its worth, the emergence of reproducible media such as lithography and photography creates a dilemma. This dramatic shift from painting, a technology little advanced since the Stone Age, seems to intimidate even the unflappable Robert Hughes:

> Because nothing could be retrieved or reproduced . . . the pre-technological eye was obliged to scrutinize—one thing at a time. Objects and images could not, except at the cost of great labor, be reproduced or multiplied. . . . Today, the object splits into a swarm of images of itself, clones, copies. Mass production strips every image of its singularity [5].

One solution to the marketability of reproducible media, actually practiced in lithography, has been the deliberate destruction by the artist of a master template after it has produced a finite number of copies. While this approach might satisfy the craven dictates of the marketplace for *objets d'art*, the consequences are regressive to the culture as a whole. The evolution of literature from handwritten manuscripts to printing press reproductions illustrates my point. Hughes' protests notwithstanding, the availability of books sharpened appreciation for the written word, even among collectors. To have limited the number of copies for the sake of enhancing the market worth of each copy would have ill-served our civilization, to say nothing of how it would have limited the circulation of John Hughes' thesis.

The issue of duplicable visual art media will not go away. With the advent of computers, the problem has resurfaced. Digital copies are identical to their masters. Scratching an original plate does not work here. Since each digital copy is itself a perfect master, the artwork is the data that describes it. For the purpose of this inquiry, I will call computer art Dataism and its proponents Dataists. A contrary allusion to Dada is deliberate.

FOUNDATIONS

Our cultural heritage has been transmitted to us, and the arts have played a key role in the transmission. A dynamic culture such as ours has accommodated change. Constructive or destructive, the changes are premised on a knowledge of precedent, for it is knowledge that is evolving. A broad foundation of precedent offers many choices for artists seeking expression, because they enjoy a broad set of aesthetic premises.

How do visual artists formalize an aesthetic so it can be transmitted? Obviously the works of art themselves embody aesthetic intent, but is there a detailed formalism expressing the process of creation? Certainly art historians have been able to identify cultural periods that produced works sharing a common aesthetic. However, these analyses have proceeded without the benefit of a specialized language that was invoked by the artists during the creative act. A clear contrast exists with Western music. It has compositional formalism complete with a notational system.

The role of notation in the development of Western music has been significant. Without the compositional score, the evolution of now-familiar harmonies and orchestrations would have been stunted. The notational system reflects an aesthetic, a system of discrete sound frequencies

Tom DeWitt (artist), Ancramdale, NY, 12503-0083, U.S.A.

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and temporal progressions. From this foundation rose musical creations that rank among our culture's greatest intellectual achievements. The transmission of these works from their composers to our ears depends largely on the acceptance of a formal abstract language and its notation.

There is some precedent for abstract formalism in the visual arts, particularly in architecture. The rigorous mathematical discipline of geometry gave artists and artisans notational and computational tools for designing buildings and decorations. During the Renaissance the formalism of perspective drawing was introduced, and this procedure has been employed by many subsequent generations of visual artists. But for the large part, image-making has been an intuitive pursuit, carried out by talented individuals whose inspirations are manifest in their work but whose methods are subjects of conjecture.

Dataism brings with it an innate formalism, because computers are machines programmed using procedural languages. In order to create images on a computer, the artist must invoke specific processes that are expressed in a defined notation. Images that are themselves very large data bases may be created from compact and manageable algorithms that automatically calculate complex images point by point. Even so-called 'paint' programs, which mimic the tactile application of color on canvas, are precise, detailed programs. Computer art calls upon the mathematics of geometry, including perspective rendering, linking Dataism with the extant foundation of visual formalism. Future developments promise to be much broader than any precedent, because mathematics has broadened enormously since it last played a role in the arts.

Mathematics is not a visual art. The void that separates the creative artist from the creative mathematician rarely has been bridged, the Renaissance being a period of notable exceptions. Yet recently, collaborations have spontaneously formed around the computer screen. In the sciences, the flood of data pouring from engines of calculation has been dammed up behind the CRT, triggering a need for visual thinkers. Artists stand at the ready, for they have already been drawn, moth-like, to the flickering light.

These Dataists will now build a foundation for aesthetic structures. Their work will enjoy an integrity that is possible only when a common language is used to communicate the processes of creation from generation to generation.

PRACTICES

When photography was invented, the status of representational painting began to wane. The camera produced realistic images with such facility that, by the turn of this century, the talent of a draughtsperson could be eclipsed by any rank amateur toying with his Kodak box camera. Photography, a triumph of technology, precipitated a diversion in the fine art mainstream away from illusionism.

Photography may have diverted some artists from traditional practices to forms of expression beyond the reach of technology, but many artists embraced the emerging image-making technologies. These artists then had the challenge of bringing the traditions of art to technology. Photographs intrinsically possess much of the realism found in representational painting, but there is a catch. Commonplace reality is not necessarily as beautiful as the ideal imagery depicted in the great classics. In fact, photography may have proven better at capturing the banal, the pathetic, the comic, and the ugly than ideal beauty. Ideals exist only in the mind. The photograph documents reality, not fantasy.

To reach the ideal, an attempt was made to place fantasies in front of the camera. This invoked the appearance of other arts as the subject for the photographer, particularly theater with its retinue of writers, players, directors, set designers, costumers, cosmeticians, puppeteers, et al. When motion pictures were invented, so was the 'fantasy factory' of the film industry. The camera operator became primarily a technician serving at the pleasure of other creative artists who preconceived the work and took primary credit for its success.

Limitations aside, moving pictures altered a basic assumption about visual art—that images were static. The manipulation of time gave the filmmaker an awesome new power of expression. The camera operator could dynamically change the window of view with a mere twist of the camera. Armed with no more than a pair of scissors and a pot of glue, the editor could alter time and place. As in music and theatre, deep emotions could be evoked by artificially changing images. This artifice was an art. It was visual art. It was new art. However, it remained dependent upon what was placed in front of the camera for initial recording.

The ultimate cinematographic technique for the manipulation of time is animation. For fine artists dedicated to bringing aesthetics to technology, stop action photography provided a path to outwit the uncompromising realism of photography. Since the audience could not see what was going on while the camera was not looking, media magicians were able to practice the sleight of eye, the *trompe d'oeil*, that makes imagination manifest.

Painters and draughtspersons were attracted to animation, but the price exacted in toil and treasure tended to compromise artistic integrity. An individual practicing creativity in the tradition of the solitary artist was faced with the Herculean task of feeding a medium that consumes up to 24 images a second. Pioneers such as Oskar Fischinger and Len Lye made heroic efforts, but both artists ultimately returned to the creation of objects: paintings and sculptures [6].

When the resources of the industrial fantasy factories were summoned to provide armies of draughtspeople, creative inspirations were diluted to conform to the economies of the mass audience. Fischinger tragically encountered this dilemma during the production of *Fantasia* [7]. Moreover, industrial factories were not capable of producing images of classic beauty. The term 'cartoon' came to imply a reduced standard of finesse in visual art. Characters were reduced to caricature, and stylization was often the forced by-product of an economy of means.

I do not wish to dismiss the sincere efforts of creative artists working in the media of photography and filmmaking but rather to identify a critical weakness in practice. There is a litmus test to assay the practical limits of a medium; namely, does it *make the imagination manifest?* In photography and film, so much depends on reality, i.e. the objects being recorded, that there is an unavoidable verisimilitude in style among all works in these media. Animation offers the potential for greater variety in visual style, but primarily through the intervention of the classical plastic arts: drawing, painting and sculpture. Painting and sculpture are versatile art media, accommodating virtually any visual preconception. Artists of every stripe have expressed their divergent visions through these ancient art forms. Can photographs and films accommodate such diversity?

Consider this archaeological paradigm. To decorate their caves, Cro-Magnon artists used silhouettes deposited by objects held against a surface and sprayed with smoke or pigment. This process created permanent negative shadows, suggestive of photographic contact printing [8]. The creative horizons of such an art are limited. Although contact printing allows anyone to make some kind of image, it prohibits the making of most images. The medium that survived these Paleolithic times was another contemporaneous invention: painting. Over 10,000 years of practice have shown that, with painting, imagination alone is the primary limit of expression.

The visual similitude among films, at least in comparison with the varied styles found in painting, may partially explain the slow acceptance of cinema as fine art. Television seemingly would have fared no better, since it was originally conceived of as instant cinema. However, the translation of camera-recorded images into an intermediate representation as electronic signals presented artists with some, perhaps unanticipated, possibilities: processing and synthesis.

Most video effects are not far removed from process photography and have ample precedent. Superimposition, split screen, matting, blue screen recording, contrast enhancement, edge enhancement, and pseudo-colorization have photographic equivalents. However, video processing permitted the instantaneous production of these 'special' effects, restoring some of the creative spontaneity of painting that film had removed. Photographers work in the dark, both literally and figuratively, due to the delay between exposure and processing.

Video synthesis, the creation of images without cameras, has virtually no precedent in photography and filmmaking. An electronic signal is generated to fit the technical specifications of a camera signal, but the point of origin is within the electronic circuits themselves. Synthesis demands formalism both in the design of circuits and the resultant imagery. Typically, synthesizers produce two-dimensional geometric shapes, reminiscent of traditional decorative arts.

Video synthesis opened a new realm of expression—visual music. The visual vocabulary in video synthesis is relatively small, if carefully selected. Synthesizers are the kind of specialized, well-defined instruments that lend themselves well to communications protocols. Both traditional music and contemporary electronic music offer instruction on appropriate practices to formalize the new art. However, video synthesizers cannot begin to encompass the entire realm of visual imagination. The promise of visual music is that within its defined vocabulary of expression will be found an aesthetic of the same universality that makes aural music so emotionally evocative [9].

Whatever the limits of video synthesis, the production of images from nothing more than electrons is reminiscent of painting's startling economy—illusions formed from little more than colored mud. With the inception of the computer, a single electronic tool stands between the preconception and the conception of a visualization. The correctly programmed computer can synthesize virtually any image.

Taming electrons to produce pictures presents challenges, especially as the technology passes through early stages of development. For some artists the technology may seem forbidding; but if the Renaissance is an instructive precedent, artists will submit contributions that fall outside scientific intuition. Making imagination manifest requires imagination. During the Renaissance, artists posed the problem of perspective and provided key intuitive solutions [10].

Dataists must engage in the process of reducing concepts to practice. One process is a recapitulation of the hand/eye coordination of the painter, carried out in the three-dimensional world of the sculptor. The artist grasps a stylus and draws in three-space—touching nothing, but imagining everything [11]. Another avenue is three-dimensional image acquisition, an extension of photography distinguished by the treatment of real objects as volumes rather than flat surfaces. Holographers have already pointed the way, but for Dataists the volumes must be captured numerically. Just as artists recognized the value of the *camera obscura*, their experimentation with range finding cameras will catalyze needed engineering developments.

Another major preoccupation for Dataists must be the display of their works. If they are three-dimensional, should they not float in space? Artists have already contributed to inventing these display technologies, such as filmmaker Lenny Lipton's electronically shuttered stereopticon [12] and the work of Dan Sandin, Mark Resch et al. in the field of parallax-barrier panoramagrams [13]. Artist holographers have developed their medium in the face of technical challenges that have tempered the enthusiasm of scientists. Today holography is best explored in museums specific to the process as an art [14].

Much of the three-dimensional work of Dataists is remarkable in that, unlike sculpture, its physical mass is that of the medium rather than the mass of a real object. The display itself is a real object, but the art is the image representation as data. With many implementations, one display can serve countless artworks, much as a television set exists as an entity separate from the videotapes it displays. This does not exclude a Dataist from making a solid sculpture based on the three-dimensional model, but such manufacture can postdate the formative creative process.

The dimension of time also falls well within the province of numerical analysis. Even a simple hand calculator is a tool of enormous utility in film and video editing. The strict formalisms of tempo in music may have evolved from an aesthetic necessity, and tempi deserve serious consideration in temporal visual art. Empirical data derived from recording video synthesis performances are one source of timing. These data can be characterized by analysis and can engender formalisms. Complex rhythmic structures that scarcely can be performed by a human [15] suggest that computed time relationships will open subtleties of expression.

Just as the economics of cinema are much more burdensome than those of still photography, Dataists must deal with the cost multiplier of making moving pictures. It can be argued that Dataist engines of calculation are an expense far greater than the price of paint. Just as artistic integrity is compromised by the huge budgets of the film studio, are not Dataists constrained by equipment costs? Again, I turn to an archaeological example. In some primeval societies, red ocher was a decorative pigment available only to the privileged [16]. The silicon in a computer is smart sand, not a commodity destined to be forever dear.

When financial support is required, modest means can produce a telling sketch or sample of the funded work, inviting further investment. This is already the practice when a script, story board or pilot production is submitted to producers, but how can visual artists participate?

Consider that one expense in computer art is the measured resolution of the image. A motion image idea can be developed in low-resolution at low cost before a commitment is made to produce the final product [17]. Indeed, one low-resolution technology, the stroke display, presents a close analogy to the way in which a pencil sketch serves the painter.

Although large and expensive computers may be called upon in industrial production, a curious facet of the so-called Turing Machine is that any digital computer can achieve equivalent results. The tradeoff is solely in time of execution [18]. Although there is a thousand-to-one difference between a million versus a billion calculations a second, the humblest micro can take on the mightiest supercomputer when a timeless inspiration is at stake.

When the Dataist uses a computer, regardless of its size, some of the labor in production has been automated. In contrast to the practices of filmmaking, where large groups of collaborators must be organized, the Dataist calls upon programs and digital images from prior endeavors. With the development of their programming skills, Dataists can maintain the kind of creative integrity enjoyed by painters, composers and writers in their solitary pursuits.

The capacity to begin building where predecessors have stopped distinguishes Dataists from the devolving world of modern art. An impetus to refine and perfect prior art is a reversal of the iconoclasm found in Dada and similar anti-art movements. When practices of the past become resources of the present, practice makes perfect.

VENUES

Artists who use computers face a dilemma if they are lumped together by curators and critics solely on the basis of their medium. If computer art shows such as SIGGRAPH are primary venues, eclecticism blurs the distinction between styles of expression. The grouping of artists by their medium is a curator's convenience, but categorization of artworks by their style, content or historical cultural period is the preferred distinction for art historians and critics. The traditional media of drawing, painting and sculpture have been practiced throughout all history. They are generally grouped and exhibited according to their epoch.

On the other hand, the new media of photography, motion pictures, video and computers have burst on the scene within a single century. Moreover, their appearance has been sequential over time. In this unprecedented circumstance, it is not surprising to encounter the categorization of artists by their medium rather than by their style of expression. Different styles may be lost on those curators who cannot see beyond the medium each artist uses.

If computer art were routinely included in collections defined by style, the dilemma would be resolved; however, rarely is this the case. The new media are excluded from collections, in part because they are not collectible in a traditional sense. There is no singular *objet d'art* but rather a master template for striking endless copies. Collectors have small economic incentive to deal in cheap copies.

Ironically, the very media that are excluded from collections are routinely used as a service to document and study singular *objets d'art*. Computer image acquisition and analysis can produce objective data for archival documentation [19]. Lithographic reproduction of photographs can publicize specific pieces, augmenting market value of each object. Interactive video can tour through collections [20]; films can introduce practicing artists; computers can inventory collections.

The use of new media to document old media can be reversed. Works in old media—that is, drawings, paintings or sculptures—can be based on data generated by computers. The finished *objets d'art* then fit into conventional art collections. Ronald Resch's *Vegreville Pysanka* [21] and Jean-Paul Agosti's *Les Soixante-Treize Jardins* [22] are examples of this antithesis. Although ingenious, it is disingenuous to insinuate Dataism into the collectors' marketplace through a Trojan horse strategy.

A more enduring penetration of the fine art marketplace would call on the strength of Dataist art rather than mask it. For example, there is scarcely a museum that does not have an associated book store. These outlets provide some cash income for the museum, but the shops also bestow credibility on the works of art celebrated in the purveyed literature. Normally, one does not buy the curated artworks themselves in the museum book store, but Dataist art could prove the exception. Be it quality reproductions, videotapes or computer disks, the museum goer could return home with an equivalent to the art on display within the museum.

The museum book store venue presumes museum exhibition, not a likely scenario if collectors have a vested interest in non-duplicable art works. Yet risk-taking investors need not be deprived of their rightful earnings. Art patrons simply need to accept that one measure of worth will include the copyrighted works of music and literature. Ubiquitous distribution of perfect copies in these arts has not diminished the role of primary venues such as concert halls or libraries.

Exclusive social circles may consecrate artists from the avant-garde for exhibition in name galleries and prestigious museums [23], but Dataists can make a direct appeal to the public. The ubiquitous media of print and video can easily assimilate Dataist work. Color separations and video recordings are a windfall by product of computer graphics. Desktop publishing, electronic mail networks and computer bulletin boards give the Dataist communications routes to replace or bypass the cliques from which they are excluded [24].

A broadened marketplace for fine art does pose the question of univer sality, and this test of aesthetic merit presents a meaningful challenge. What makes a work of art attractive? Why do certain works endure? It takes far more than novelty to meet these criteria. The test is not how Dataism would fare as a yet another ephemeral 'Post Modern' fad laden with aesthetic non sequiturs. It is not sufficient to say, 'made with a computer'. The question is, How would a broad audience respond to ownership of these art works?

I believe that the qualities that will characterize successful Dataist art might be summarized in the word 'beauty'. This art will provide both immediate appeal and inexhaustible pleasure upon repeated viewings. Such criteria are not reserved for any one aesthetic. Dataism will encompass the work of many artists and many visions, but they will share an aspiration toward perfection.

SUMMARY

Conventions of the art marketplace, where objects are measured in worth by their singularity, are now challenged by Dataists, whose works are perfectly duplicable. Dataism posits that aesthetic merit determines worth. Dataists are developing a formalism by using computer programs to promulgate their artworks but, unlike sculpture, the works may have no physical mass. The time dimension can be invoked to produce visualizations that dynamically change. Limits in expression imposed by earlier forms of technological art such as photography, motion pictures and video are now being rolled back, because Dataist art is not camera-dependent. Dataism will supplant the moribund epoch of Modernism, its Establishment venues notwithstanding. In the arts, the power of beauty is greater than the beauty of power.

References and Notes

1. A section of the 1918 Berlin Dada Manifesto appears in Robert Hughes, *The Shock of the New* (New York: Knopf, 1981) pp. 68–71.

2. Gerald Marzorati, "Julian Schnabel: Plate It As It Lays", *Art News* (April 1985) p. 63ff. I cannot resist the temptation of labeling Schnabel a crack pot. He describes his method of assembling ceramic shards as "a prosthesis for painting". There is also a double meaning to the word 'prosthesis'. An argument could be made that Schnabel's work fits both.

3. Hughes [1].

4. Suzi Gablik, *Has Modernism Failed?* (London: Thames and Hudson, 1984) p. 63: "Increasing reliance is now placed upon a managerial elite of dealers and curators . . . ". Gablik's essay implies that the dematerialization of art, exemplified by conceptual and performance genres, is a way out of the economics of the art object marketplace. Unfortunately, she fails to address the dematerialization inherent in computer art, where the 'work' is an abstract algorithm or data base.

5. Hughes [1] pp. 324–325.

6. It is not surprising that Fischinger made hundreds of paintings after he stopped making films. He was one of the most prolific artists of this century, as his hand-animated films testify. Lye's kinetic sculptures demonstrate both the aesthetic of motion and the extraordinary technical finesse that appear in his films.

7. This story has been recounted to me by Elfriede, Fischinger's widow. The Disney animators insisted on including their anthropomorphic charicatures in what was supposed to be a work of pure abstraction. Oskar's uncompromising integrity caused him to quit the project, leaving him with a life-long sense of frustration and dooming his family to further poverty.

8. Alexander Marshack, "Exploring the Mind of Ice Age Man", *National Geographic* (January 1975) pp. 74–75.

9. John Whitney, *Digital Harmony* (New York: Byte Books, 1980); Tom DeWitt, "Visual Music: Searching for an Aesthetic", *Leonardo* **20**, No. 2, 115 (1985).

10. Fred Dubery and John Willats, *Perspective and Other Drawing Systems* (New York: Van Nostrand, 1983) p. 55ff; James Burke, "Point of View", in *The Day the Universe Changed* (Little, 1985) p. 72ff Renaissance artists used optics to paint images of startling realism, but it took Alberti, an architect and geometrist, to formalize what they were doing. One of Dürer's woodcuts shows artists experimenting with string to study perspective (cf. Burke, p. 76), but, of course, the process can be formalized mathematically.

11. Tom DeWitt and Phil Edelstein, "Pantomation   A System of Position Tracking", *Proceedings of the Second Symposium on Small Computers in the Arts* (IEEE Computer Society, No. 455, 1982) p. 25.

12. L. Lipton, "Field Sequential Electronic Stereoscopic Projector", *Projection Display Technology, Systems, and Applications*, SPIE Proceedings, **1081**, Section 11 (January 1989).

13. D. J. Sandin, E. Sandor, M. Resch, B. Cunally, T. A. DeFanti and M. D. Brown, "Computer Generated Barrier Strip Auto Stereography", *Non-Holographic True Three-Dimensional Display Technologies*, SPIE Proceedings **1083**, Section 9 (January 1989).

14. There are museums of holography as art in New York, Chicago and Paris.

15. In my visual music videotape, *Philharmonia* (1974), time was divided into increments of 1/60th of a second over a total period of 25 minutes. A complex rhythm was developed which does not follow conventional tempo demarcation.

16. Some pre-Colombian societies used red ocher in their burial rituals. With no iron technology, they placed great value on this substance made from naturally occurring ferrous oxides.

17. Doug Lyon, "Mosaic" (RPI Image Processing Lab, 1984). Lyon's program produces 64 × 64 resolution test images to preview raytraced images that are then calculated to a resolution of 512 × 512.

18. Computers may vary vastly in their hardware, but they all share the same set of Boolean algebraic operators and generally can be programmed to perform the same algorithms. This similarity is sometimes referred to as Turing equivalence.

19. For example, Asmus and Berstein, "Computer Enhancement of the Mona Lisa" *Perspectives in Computing* **7**, No. 1, 11ff (1987).

20. William H. Honan, "The Museum of the Future: It's All in the Chips" *New York Times*, Section 2, p. 1ff (27 November 1988).

21. Melvin L. Prueitt, *Art and the Computer* (New York: McGraw Hill, 1984) p. 16.

22. Cynthia Goodman, *Digital Visions* (New York: Harry N. Abrams, 1987) p. 107.

23. Tom Wolfe, *The Painted Word* (New York: Farrar, Straus & Giroux, 1976).

24. For example, *F.A.S.T., The Fine Art, Science, and Technology Bulletin Board*, Raymond Lauzzana, ed. (International Society for the Arts, Sciences and Technology, Berkeley, CA, U.S.A.).

Art and the Information Revolution

Paul Brown

ABSTRACT

The author expresses his opinion that new imagemaking technology is providing an interdisciplinary language and creating a requirement for generalists rather than specialists. This new technology is also initiating a paradigm shift in those disciplines that make use of it. Lack of acknowledgment of such effects, particularly in the area of higher education, could lead to significant problems that, in the longer term, could affect manufacturing industry and national economic performance. One solution is to involve practitioners of non-applied disciplines (such as fine arts and pure science and mathematics) that have already adapted to a similar paradigm change and whose perception of the new tools and techniques is likely to be less parochial and more flexible.

Computer Graphics—A Common Language

The 1980s have been the decade of the personal computer. The decade began with the IBM PC and it is likely to end with the introduction of affordable personal supercomputers. The more widespread use of supercomputers is likely to exacerbate significant problems concerned with human data overload and data pollution.

As has already been suggested by many commentators, this problem can be ameliorated by the use of computer graphics. The visual cortex operates at speeds that would tax even the most powerful modern supercomputers; thus graphics communication is powerful and effective. Computer graphics can optimise the human-computer interface and maximise the communication potential of the relatively limited input/output channel bandwidths (relative to central processing bandwidth) of all computing machines. It is only recently that the computing community has recognised the value of involving professional imagemakers in the development of computer graphics. With few exceptions artists and designers have also been slow to realise the power and potential of the computer.

Scientists and technologists often underestimate the contribution of creative imagemakers to business, communication and the environment and consider their work to be 'mere' play. Many are unable to distinguish between the work of children and amateurs and that of professionals who may have spent upwards of 7 years in higher education learning their craft. Conversely, many artists perceive scientists as short-sighted and unethical dabblers who are responsible for a variety of 'undesirable' discoveries that now threaten the stability of the earth's ecosystem. Computers are their tools, and they are cold and intimidating.

Despite these differences, a small international community of interdisciplinary workers has developed. Its origins lie in systems art and the art and technology experiments of the fifties and sixties. In many cases these workers have discovered each other and a common language as a consequence of sharing the same tools—the multi-user central computing facilities of education and research institutes.

At the junior end of the spectrum, low-cost microcomputers have been introduced into primary and secondary education and are producing a new generation of individuals who combine art and scientific skills with no pretention of title. That many amateurs are now active in the development of the medium has prompted Patric Prince to coin the label 'Volksart' to distinguish high-tech primitivism from its low-tech counterpart [1].

Paul Brown (researcher, teacher), Computer Image Program, P.O. Box 218, John Street, Hawthorn, VIC 3122, Australia.

Reaction in Higher Education

The higher education sector, however—steeped in tradition, tenure and tightening budgets—is responding slowly. Far too often, and in a wide variety of subjects, it is failing to recognise the fundamental importance and consequence of the new interdisciplinary tools and media.

Typical symptoms are the belief that studies in the area have limited application and should be at the postgraduate level (i.e. introduced after the student has achieved the mind-set associated with undergraduate specialism) or that new methods are merely simple extensions of existing technology (for example, computer drafting or paint systems) and can be dealt with in the same way that the old technology was. The basic assumption is that the discipline is secure and that it will not be changed by new technology. As a consequence, higher education continues to promote specialism at a time when industry is gearing to a requirement for generalism.

This sector is not helped by its paymasters—local and national government. Both higher education and government are failing to learn from those successful and long-lived multi-national corporations that have succeeded by the acuity of their long-term vision and planning. IBM's support of the research of Benoit Mandelbrot is one example. Seemingly 'philanthropic' support has produced some very lucrative ideas. Thus it is particularly important that the current higher education model, which produces tightly focused specialists, be modified to encourage greater breadth of learning in graduates who will need to communicate as a matter of course with colleagues from diverse fields.

Paradigm Shift in the Imagemaking Disciplines

A key aspect in this evolution from specialist to generalist will be the increased use of visual communication methods. It is likely that the common interdisciplinary language of the future will be graphical and, as often as not, the product of computer graphics. This will be accelerated by the increased

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use of high-band graphics networks. As a consequence, the role of visual imagemakers will change dramatically. Currently often a part of service industries, they are responsive rather than initiative, being concerned for example with styling, packaging, advertising, entertainment, etc. However, in a few innovative centres they have become full-fledged collaborators [2]. Since they exercise a great deal of control over the media and channels of communication, it is conceivable that these artists will evolve into leaders in the entire process that leads from pure research and development via manufacturing to marketing and promotion [3].

This has been the experience of graphic designers in current affairs television. In 1979 the British Broadcasting Corp. (BBC) employed five designers in this area. They worked a 40-hour week, produced about 150 diagrams using traditional media and had very little responsibility. Five years later, after the introduction of two electronic studios based on Quantel Paintboxes, effects devices, character generators etc., the same department employed 50 designers and the studios worked 24 hours per day to produce over 2000 images per week [4]. The designers' responsibilities had also increased significantly. Since they now produced the skeletons for live on-air shows, they were amongst the first to be consulted when producers were planning new programmes. This improvement, which was echoed in salaries and further job opportunities, was a direct consequence of the adoption of computer graphics technology.

All this happened in just 5 years. If we accept that the introduction of new technology in other design disciplines will lead to a similar paradigm change, it is particularly important that art and design education urgently respond. Currently enrolling undergraduates need to be prepared for a workplace that will, by the time they graduate, offer opportunities that are considerably different from current practice.

Models in Fine Art and Pure Science

International experience demonstrates that it is practitioners of the fine arts who have most successfully managed this change in fundamental paradigm and who may therefore also provide a model for colleagues in areas of applied design. Here perhaps there are similarities with pure mathematicians and scientists who have also adapted quickly to fundamental change. An example is the development of the science of chaos [5], which has overthrown many of the 'self-evident' truths of determinism. This new science is based on a relatively trivial, though previously impossible, development—the rapid and repetitive iteration of simple functions made possible by computing machines.

Engineers have proved more reactionary than their scientist colleagues; they have been criticised by Mike McGrath [6] for perceiving new technology as a tool to expand their current discipline, whereas experience elsewhere suggests that it is a process that will, perhaps subtly though fairly rapidly, undermine and change that discipline. McGrath has also suggested that the fine artists' use of computers showed a much better grasp of its unique potential.

There are similarities here between engineering and the applied arts. Graphic designers happily use electronic page-make-up and typographers use tools like Fontographer whilst totally rejecting any concepts of paradigm shift.

Truth to the Medium

The major problem associated with this misapprehension of a new medium was highlighted some years ago by the cybernetician Stafford Beer [7]. Systems developers tend to produce computer-based productivity tools that amplify traditional patterns of work instead of optimising new and unique methods. This amplification can cause major problems and have catastrophic results for the application area and end-user. The packaging and promotion of most computer-aided design/computer-aided manufacturing (CADCAM) and graphic arts systems and software packages encourage these misleading beliefs and practices. A typical example is the sales pitch based on the verisimilitude of a computer simulation: . . . our airbrush looks and handles just like the real thing." The implication is that no change in perception or method (or special training) is necessary to use the system. Nevertheless a computer simulation of an airbrush is quite clearly not an airbrush and this falsehood contrasts with the claims of the design disciplines to retain 'truth to the medium'.

This single aspect of the problem would seem to me to be self evident, of extreme importance and amongst the more interesting enigmas facing art and design theory at the current time [8,9]. However, it seems that little is being done to address these problems. As I have mentioned here and elsewhere [10], the education system, particularly in art and design, is finding it difficult even to recognise the potential of such problems, let alone address them.

One aspect of this problem can be expressed concisely: practitioners who work in a manufacturing discipline must, of necessity, be conservative; the more closely practitioners are allied with manufacturing, the more reactionary they are likely to become, and the more remote they are from manufacturing, the more freedom they will have to experiment.

This suggests that, when a major change causes a fundamental paradigm shift in an applied discipline, the wrong people will be at the helm. They, understandably, will try to maintain 'traditional' values. Unfortunately this approach is only likely to increase the magnitude of the problem. The inadequate integration of new technology has already been claimed as the cause of several major bankruptcies and, with the acceleration in price-performance of systems and their growing applicability, it is likely that 'we ain't seen nuthin' yet'.

A Return to the Classical Vision

Leaders of industry, government and academia should be encouraged to give way to less conservative opinion; in particular they should be encouraged to look to the practitioners of the pure sciences and fine arts, who are likely to be formulating better strategies. Unfortunately, during our current recession, governments worldwide perceive such non-applied activities as easy game for budget cuts. This is a short-sighted and extremely dangerous attitude.

Many believe that the 1987 stock market 'crash' was caused by ill-considered and unmonitored high-bandwidth data exchange: that it was caused by data pollution. To suggest that the solution to this kind of disaster lies with eccentrics like artists and pure scientists will not please those who are shoring up the already weakened defences of order and common sense. Nevertheless it is likely that the artists and pure scientists are closer to an understanding of the problems if not yet capable of proposing solutions.

To threaten these areas with cuts in expenditure at this time is ill considered. Governments and industry should instead be encouraged to work with artists and pure scientists. The days of the artist as a romantic outsider have outlived their usefulness. Now we should return to the classical vision of the artist as participant and polymath, perhaps even as catalyst, as the new age of information evolves.

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Computer Art in the Context of the Journal *Leonardo*

Roger F. Malina

ABSTRACT

Since 1968, the journal *Leonardo* has published over 150 articles dealing with the uses of computers in the fine arts. Discussing the work of artists published in *Leonardo*, the author responds to a recent assertion by art theorist David Carrier that ". . . it is genuinely unclear to me whether any art using computers is truly significant". It is argued that the significance of computer art must be viewed in a number of contexts. Within the context of the development of the computer itself, advances in computer graphics and animation have provided the artist with a powerful plastic medium under the artist's control. Most artworks produced, except in animation, either realise artistic ideas developed before the advent of the computer or are artistically equivalent to work produced in other media. The impact is significant in the context of the commercial and applied arts. Contemporary artists, as the colonisers of technology, are producing significant artworks as collaborators in Renaissance teams of artists, scientists and technologists. In the larger context of the history of art, however, the significance of contemporary computer art work is not yet clear. It is argued that artistic significance should be sought in works that could not have been made *without* the use of a computer. Such works must involve the particular attributes of computers, such as their application in interactive situations, their capability for artificial intelligence, their function in networks with telecommunications media, and their ability to allow the synthesis of sound and vision in time-based art forms. The lack of adequate theoretical, historical and critical frameworks is currently the largest impediment in assessing the significance of computer art.

In a recent editorial, *Leonardo* Co-Editor David Carrier made the bold statement ". . . it is genuinely unclear to me whether any art using computers is truly significant" [1]. This statement made by a sympathetic art theorist, almost 25 years after the first computer art exhibitions, could be construed as discouraging. The response to this provocation, I believe, is in part context-dependent. It is still early in the development of computer art, and still earlier in the development of a theoretical and critical understanding of the revolutionary role of computers, electronics and telecommunications in the arts of the future. I will discuss these contexts by citing pertinent articles published in *Leonardo* over the past 22 years.

COMPUTER ART WITHIN THE CONTEXT OF THE DEVELOPMENT OF THE COMPUTER

A review of the evolution of computer art [2,3] reveals that many of the key artistic ideas were understood very rapidly by pioneers such as Herbert Franke [4], although primitive computer systems were difficult to control for specific artisticpurposes. Computer artists were heirs to theoretical ideas developed in algorithmic and generative aesthetics, constructivism and the longstanding connections between art and mathematics. In 1979 Frank J. Malina published the book *Visual Art, Mathematics and Computers*, a collection of 54 articles originally published in *Leonardo* from 1968 to 1979 [5]. The initial section of this book, "Art, Science, Mathematics General", included articles dealing with entropy and art, formal generators of structure, aesthetic tree patterns in graph theory, chirality and symmetry, a scientific theory for aesthetics, and topics connecting mathematics and science to art. The computer was a labor saving device that allowed these ideas to be explored exhaustively and rapidly.

Major achievements in computer graphics and animation have occurred in the past 30 years, as demonstrated by the SIGGRAPH '89 Art Show works illustrated in this issue of *Leonardo*. These developments will continue, and the capabilities of special-purpose graphics workstations will gradually become more accessible to artists through general-purpose systems. However, these developments, at least in static media, are unlikely to be relevant in answering David Carrier's challenge. High resolution, rendering, color range, 3-D perspective systems, ray-tracing and paint 'programs' were developed to the satisfaction of the artist long before the advent of the computer. Few of the current developments in computer graphics have been initiated in response to contemporary artistic goals. Trying out old ideas more quickly, more realistically, on a larger scale—these are not issues that will determine tomorrow's significant art. The fantastic landscapes produced using the most advanced computer graphics systems reveal the use of no new tools by the artist and no visual languages that were not already available to the surrealists over half a century ago. Ironically, just when computers are finally able to reproduce artworks of the nineteenth century, computer graphics courses are being introduced rapidly into art schools to train the artists of the twenty-first century. These observations do not aim to minimise the huge advances in computer graphics and animation or to discourage the use of these systems by artists and art schools. However, computer graphics systems are having a significant impact, primarily on applied and commercial art.

COMPUTER ART WITHIN THE CONTEXT OF ARTISTS COLONISING TECHNOLOGY

Marshall McLuhan once said that "the conscious role of the artist is to explore and create awareness of the new environment created by new technology" [6]. A similar thought was expressed by Frank J. Malina in the introduction of *Visual Art, Mathematics and Computers*, when he argued that the contents of this book had "to be taken into account by those who dream of a world in which the arts will help more effectively to mellow the applications of science and mathematics" [7]. Seen in this context there is already a great amount of significant computer art being generated. One need look no further than the current excitement about

Roger F. Malina (astronomer editor), *Leonardo*, Box 75, 1442A Walnut Street, Berkeley, CA 94709, U.S.A.

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fractals and chaos mathematics to see a whole new generation of artists for whom there is no 'two-cultures' division and for whom the computer has become the tool of choice for new explorations of visual material.

The main issue here is not an aesthetic one, but one that involves the artists' ability to control the most advanced technological tools and involves as well the interest of scientists and technologists in understanding that visualisation is an important facet of communication. In the field of scientific visualisation, as championed by artist Donna Cox [8], not only have artists successfully colonised the technology, but scientists are now realising that they need to colonise some of the traditional domains of the artist [9]. When Experiments in Art and Technology was founded 20 years ago by Billy Kluver and Robert Rauschenberg, the issue of artists' access to high technology was a key issue. At that time, an artist could rarely be an equal creative participant, as pointed out by A. Michael Noll:

> The fallacy of collaborations is clearly evident when the computer is involved as a third party. Here the artist must communicate his ideas to a computer scientist or programmer who must then communicate his interpretations of the artist's ideas to a computer. This is most certainly a noisy process [10].

Since the advent of the home computer and a generation of artists who are sufficiently computer literate to do their own programming, access to technology is no longer the obstacle in the creation of significant computer art. One answer to David Carrier is that significant art is now being made within the context of the artist's social role as humaniser, commentator and coloniser of technology.

COMPUTER ART WITHIN THE CONTEXT OF THE HISTORY OF ART

Science writer and mathematician François le Lionnais defined the plastic fine arts as "a group of activities that aim at producing—through the use of appropriate techniques and procedures—emotions of an aesthetic character (that is, emotions independent of the quest for truth, of the search for utility and of obtaining sentimental satisfaction) by means of visual stimulation" [11]. Within the context of the corresponding definition of computer art, the question must then be whether significant art has been made that could not have been created *without* the use of computers. It is highly unlikely, in this context, that significant computer art will be displayed as static images on the walls of galleries within the confines of a picture frame. If computer art is just another medium like watercolor, oils or acrylics, then it will be only as significant as all other post-modernist attempts to create significant art within the limitations of the static canvas.

In searching for significant computer art I would ask whether the artwork could have been made without the use of a computer and whether it takes advantage of unique new capabilities made possible by the computer. This argues that the computer is not just another tool, but a 'meta-tool' that can lead to new modes of artistic activity [12]. The computer's key attributes include the ability to have an in-built learning capability (artificial intelligence); the ability to be connected to other computers over short or global distances; the ability to collect information from the environment and issue information through a large number of sensory modes, many of them not available directly to human sense organs; the ability to be used in a real-time interactive interplay with humans or other input devices. Finally, in time-based arts, including computer animation, the computer makes possible work that would be practically impossible to realise by other methods, particularly in exploiting connections between sound and vision. The computer has the potential to extend aesthetic issues into a number of totally new domains and eventually to connect directly with the human brain [13]. At some point the computer will allow one to bypass, or supplement, the existing human senses that have formed the bases of all the arts.

ARTIFICIAL INTELLIGENCE

Have significant artworks of this kind been created? I believe that the answer is a tentative 'yes', but without a historical tradition or a critical context it is very difficult to assess current work. One important line of artistic research is being carried out by artists such as Harold Cohen [14] and Roman Verostko [15]. These artists are developing new software containing artistic rules concerning form and structure, coloring and other ideas that the artist embeds in the program. Under the tutelage of the artists, the programs have become more and more sophisticated, to such an extent that Cohen's program AARON is able to generate endless variations on a theme and produce colored drawings that are as interesting as most prints sold in art galleries. Verostko's system now paints with a paint brush and is able to paint in a large number of styles. What is exciting about this work is that the software will continue to evolve with the artist as a member of a creative team. The artist is forced to make explicit the creative process in order to instruct the computer, and this may lead the artist in totally new directions [16].

The kinds of sophistication that these programs (which use techniques of artificial intelligence) may acquire can be seen in the theoretical work by researchers such as Joan and Russell Kirsch [17] and Raymond Lauzzana and Lynn Pocock-Williams [18]. These researchers have been able to codify the stylistic grammars of works by such artists as Diebenkorn, Kandinsky and Klee. These 'rule systems' and 'shape grammars' provide new tools that artists can incorporate into programs like AARON. The works by Cohen and Verostko are recognisably characteristic of the artist who has been making the choices in concert with the computer. This is in contradistinction to most computer art, where the particular computer hardware and commercial software provide the recognisable 'signature' on the work produced.

MULTI-MEDIA AND TIME-BASED ARTS

A natural extension of these systems will include sound and evolution-in-time. Within the field of computer music there are already sophisticated programs that can be used to generate music within rule systems [19]. John Whitney Sr. [20] and Edward Zajec [21] are recent examples of artists who attempt to synthesise sound and visual art forms [22,23]. Computer animation techniques now make it possible to realise artistic ideas, many established by artists in early abstract film, that would be practically impossible to realise using traditional film animation methods. The increased realism of computer animation, including the creation of synthetic human-like actors [24], is perhaps less significant from an artistic viewpoint than from a commercial viewpoint. However, it illustrates the degree of control that computer animation artists are now exerting over desired visual scenes. The computer, with its ability to control visual or aural output devices with equal flexibility and using similar coding strategies, breaks down many of the existing theoretical divisions between time-based visual and sound arts. The computer, as a processing system that can generate outputs in any number of sensory modes, may provide the first practical way to develop significant synaesthetic art forms.

Networks and Telecommunications

Networks of individual computers and people add interesting complexity to the situation. The artistic team 'bcd' has created a number of works based on networks of computers carrying out independent parallel processing [25]. The complex and rich visual displays that result lead the artists to use words such as 'transcendence' to explain the visual experience. The viewer's ability to find pattern and structure in the rich vocabulary of visual data is perhaps closest to the experience of listening to music.

On a larger scale, artists are becoming involved in computer networks connected by various types of telecommunications links. A pioneer in such artforms, *Leonardo* Honorary Editor Roy Ascott, describes the new composite role of the artist as "participant in a system creating meaning seen as art. This contrasts forcibly with the Renaissance paradigm of the artist standing apart from the world and depicting it and the observer standing outside of the artwork and receiving this depiction" [26]. In the work *La Plissure du Texte*, organised by Ascott for the Electra exhibition in Paris in 1983, the work was created in 'dispersed authorship' by groups of artists located in 11 cities around the world. Artworks of this type are so new that there is little vocabulary or theoretical structure—indeed hardly a body of work—to assess their significance. Few institutions are even capable of displaying the works. A determination of significance will have to take into account the role of the artist as the designer of a *system* created for aesthetic reasons, rather than as the creator of a *product* for contemplation. We are on the threshold of a whole range of new artistic questions, as artists take advantage of the combination of computers and telecommunications, or 'telematics', to use Simon Nora's term. *Leonardo* Guest Editors Carl Loeffler, founder of the ArtCom Electronic Network, and Roy Ascott are currently engaged in a project to produce a Special Issue of *Leonardo* on Art and Telecommunications. Many of the works described would not even be recognised as artworks according to most art historians. For example, some software art is made manifest only by the behavior of the computer network and not as specific sensory outputs.

Interactivity

Interactive art has a fairly long history and is connected to parallel work in 'artificial life'. Nicolas Schöffer's early robotic sculptural pieces in his *Cysp* series, for example, were created in 1954 [27]. The behavior of the works was dependent upon a complex interaction of visual and aural stimulae. *Leonardo* Co-Editor Stephen Wilson has described a number of such ideas and has realised artworks that interact both with their environment and with the viewer [28]. Myron Krueger, in his 'Artificial Reality Laboratory' has created humorous pieces that introduce a real element of play into the viewer's interaction with the computer [29]. Artist Joel Slayton has been involved with a team of NASA engineers and scientists developing an artificial environment viewed through goggles worn by the viewer. The viewer's hands and body are connected through the computer to this virtual space. As the viewer walks around and handles objects, the view in the goggles is adjusted correspondingly [30]. New interactive optical disk technology is introducing further artworks of this type. If we look forward to the combination of computer-generated holographic cinema, interactive branching associated with hypertext and hypermedia software structures [31] and advanced computer animation techniques, these interactive media will surely lead to significant new art. Yet, at this point, to be honest, these speculations are based on my belief that these media offer such radically new artistic possibilities that eventually artists will produce significant works. Current work does not yet fulfill the promise of the new media.

Conclusion

Over the past 22 years *Leonardo* published over 150 articles dealing with computer art [32]. Within the context of the development of the computer itself, current work depends upon realising the dreams of the pioneer computer artists and creating visual displays of significant aesthetic interest. Artists can now use computer graphics as a plastic art medium to create realistic and imaginary landscapes and to reproduce various visual art styles. As graphic tools continue to evolve, these media will continue to fall under the control of the artist. Ironically, the majority of this work is ahistorical in the sense that it allows the artist to address issues that are no longer central to the development of the art of the future. The primary arbiter of significance in this context will be the art marketplace, which today functions primarily as a commodity market [33]. As computer art competitions, such as SIGGRAPH or Ars Electronica, develop a history and a critical context, we can expect computer art to be collected by museums and galleries. The ideas of algorithmic and generative aesthetics, of mathematical art and constructivist programs, can now be realised. Recent works using fractals and chaos theory are likely to become part of a rapidly expanding vocabulary of generative art.

In the larger context of the history of art, computer art of significance is imminent. A key issue to be considered is that the context for assessing significance for the new kinds of art forms has not been developed. It is not yet clear what kind of exhibiting context is necessary. A few forward-looking museums, such as the Museum of the Bronx, have provided regular venues for display and assessment of computer art. There have been a few recent major museum shows such as Electra, Les Immateriaux and Digital Visions. It may be that the truly significant computer art of the future is incompatible with the exhibiting context designed for static painting and sculpture, or even for film and video. An institutional context very different from the contemporary museum, such as the new media parks in Karlsruhe, Cologne and Frankfurt in Germany, will be needed; often science museums have provided more suitable contexts for displaying new forms of computer art—even public spaces such as airports have been used to good effect. There is also a need for a new generation of art theorists and art historians to develop the critical and historical context within which the significance of individual computer artworks can be assessed. These theorists and historians should pay particular attention to art that could not have been made *without* the use of a computer and that exploits the unique capabilities of computers, electronics and telecommunications systems [34].

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7. Malina [5] p. ix.

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10. A. Michael Noll, "Arts ex Machine", *IEEE Student Journal*, (1970) p. 134, quoted in Goodman [3] p. 46.

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14. Jasia Reichardt, "Machines As Art", *Leonardo* **20** (1987) p. 371.

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16. Verostko [15].

17. Joan L. Kirsch and Russell A. Kirsch, "The Anatomy of Painting Style: Description with Computer Rules", *Leonardo* **21** (1988) p. 437.

18. Raymond G. Lauzzana and Lynn Pocock-Williams, "A Rule System for Analysis in the Arts", *Leonardo* **21** (1988) p. 445.

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23. Kenneth Peacock, "Instruments to Perform Color Music: Two Centuries of Technological Experimentation" *Leonardo* **21** (1988) p. 397.

24. M. Magnenat-Thalmann, "The Making of a Film with Synthetic Actors", *Leonardo* Supplemental Issue "Electronic Art" (1988) p. 55.

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26. Ascott, [12] p. 8.

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31. Edward Barrett, ed., *The Society of Text: Hypertext, Hypermedia and the Social Construction of Information* (Cambridge, MA: MIT Press, 1989).

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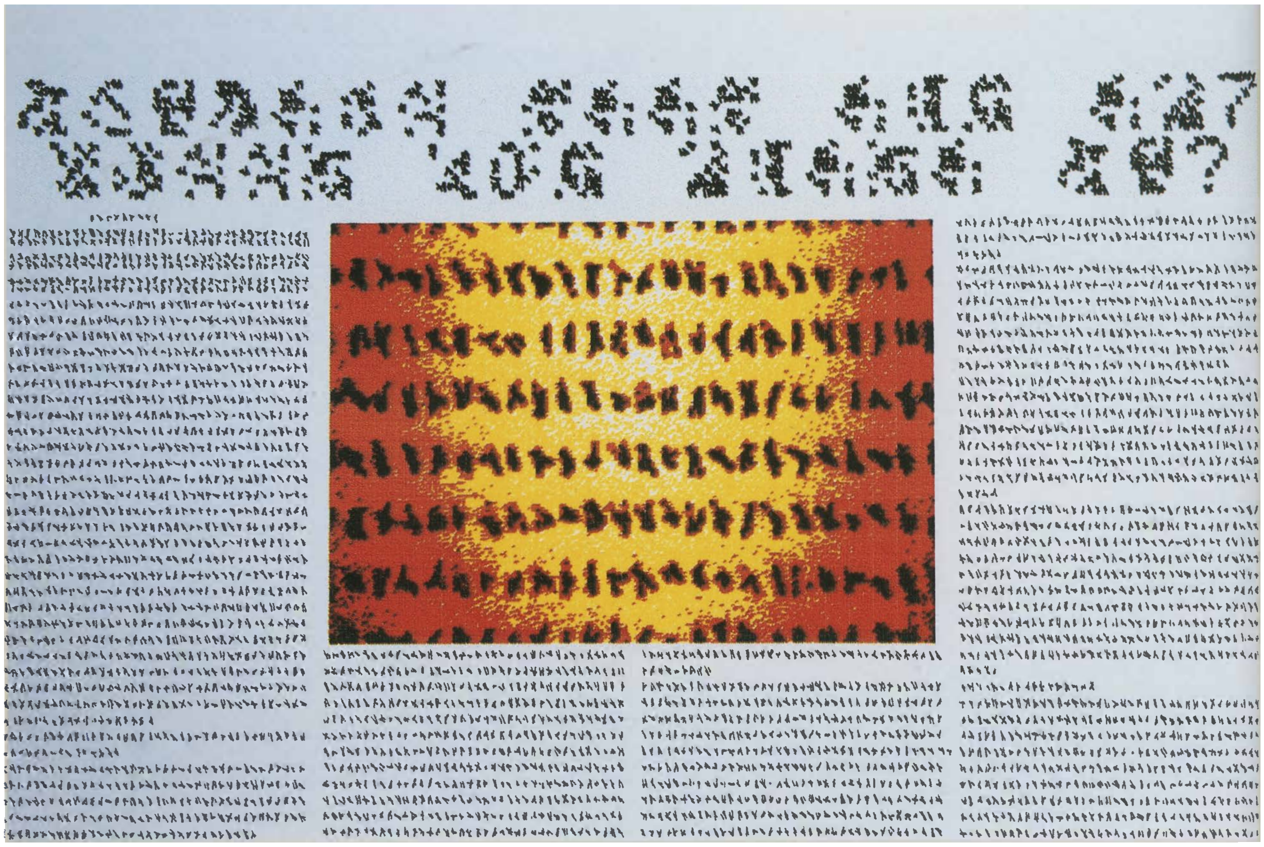
34. I believe that establishing 'significance', in David Carrier's terms, involves assessing at least three aspects of the artwork. First, the work should produce strong emotions of an aesthetic character in the viewer or participant, as characterized by François le Lionnais (see Ref. [11]. Art produced in previous epochs can maintain significance, although such works may produce different aesthetic emotions in later epochs. Second, an artwork must be truly contemporary, in the sense that it could not have been, or was not, produced in a previous epoch. Art in the Impressionist style painted today is not significant in this aspect. Third, in a purely art-historical sense, 'significant' artworks must be identified where an artist has produced an innovative or original masterpiece not produced by previous artists. Artworks that achieve significance in all three aspects, I believe, deserve the attention of aestheticians, art theorists and art historians.

Color Plates



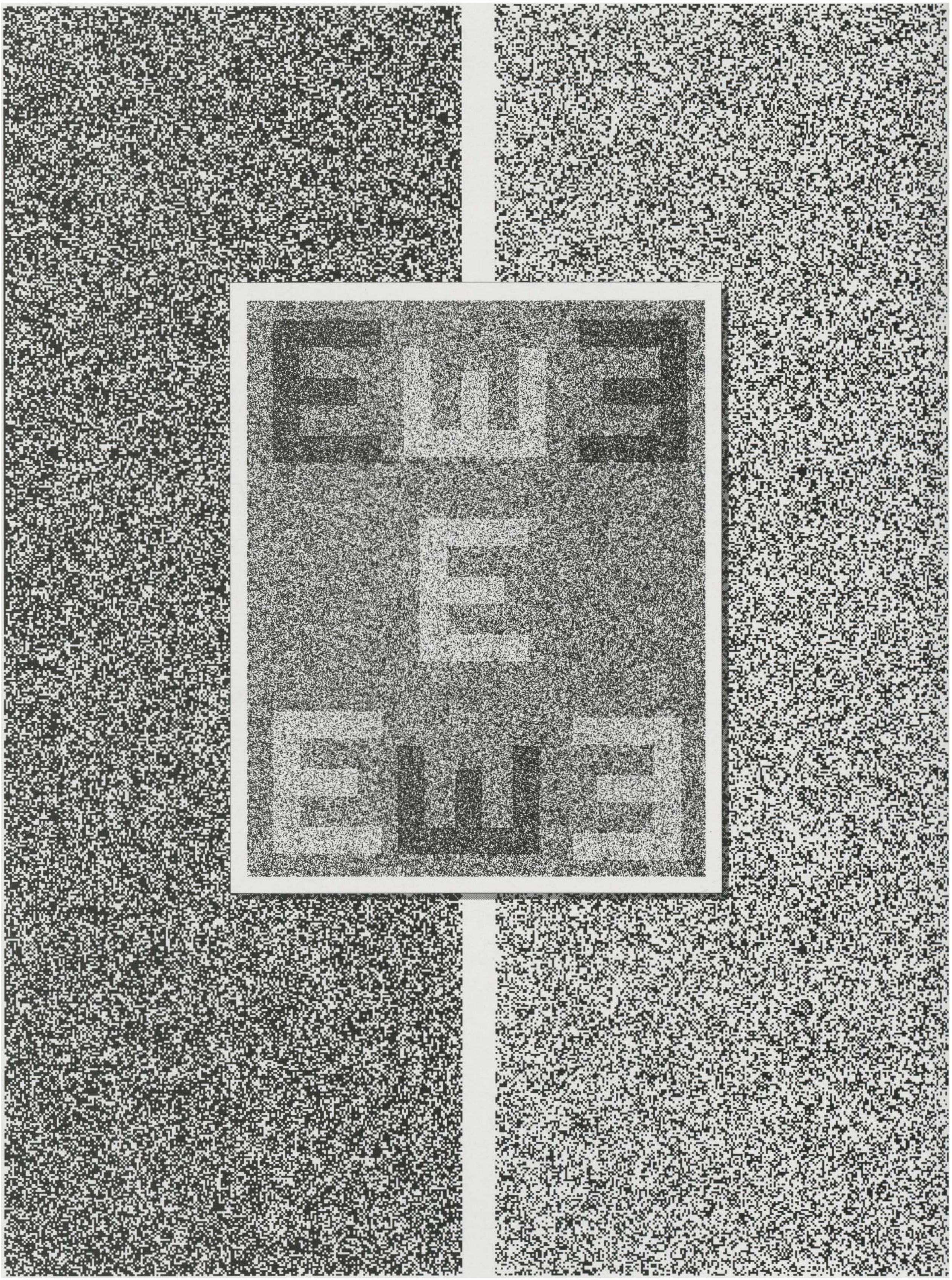
No. 1. (top left) Brian Reffin Smith, *Horse Text Piece*, ink on paper, 8.25 × 11.75 in, 1988.

No. 2. (bottom left) Brian Reffin Smith, *Text Text Piece*, ink on paper, 8.25 × 11.75 in, 1988.

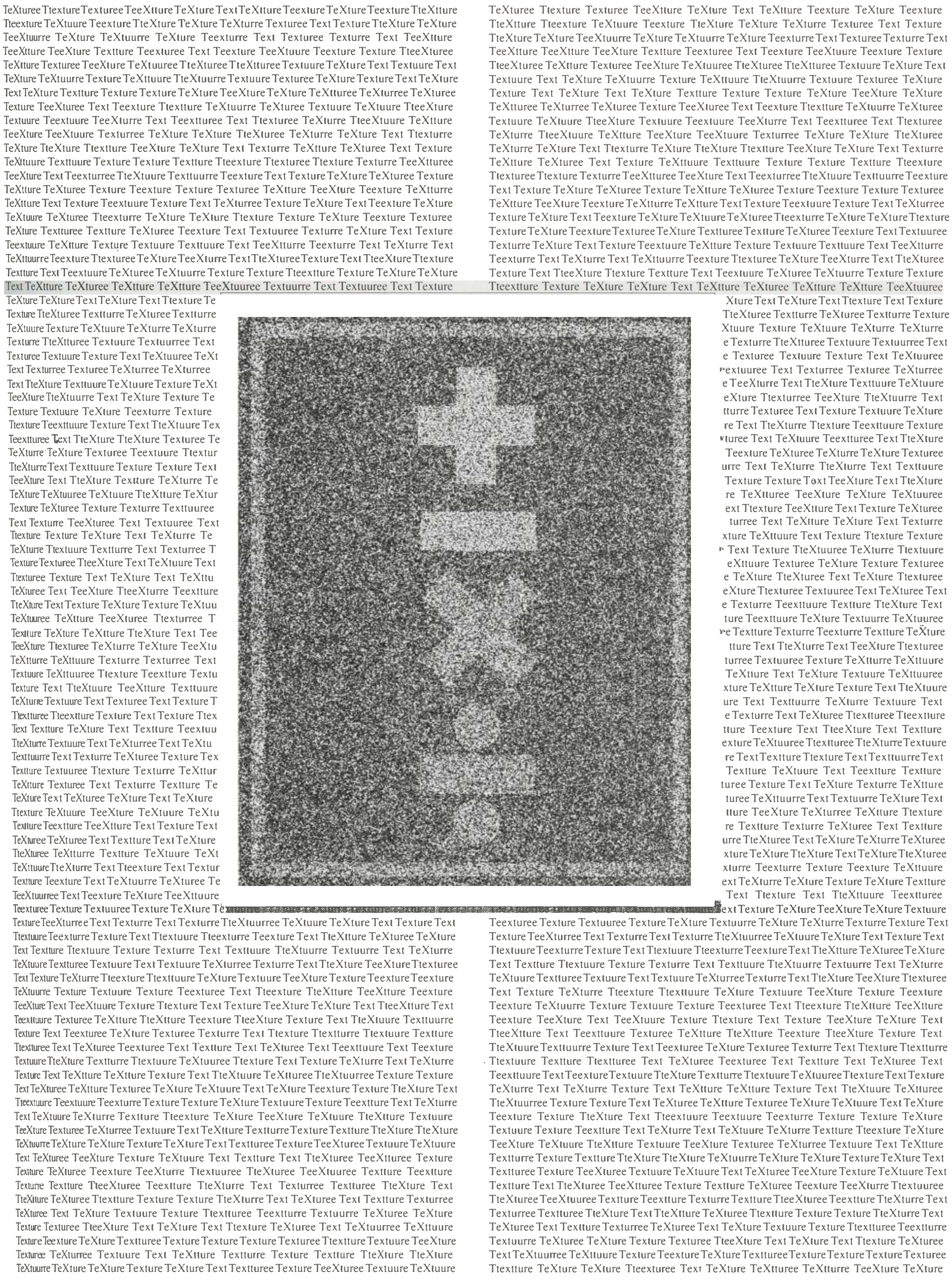
No. 3. (above) Brian Reffin Smith, *Crossing Sign Text Piece*, ink on paper, 8.25 × 11.75 in, 1988.

No. 4. (following pages) Craig Hickman, *Signal to Noise, pages 20, 21*, linotronic print, 20 × 24 in, 1989.

20

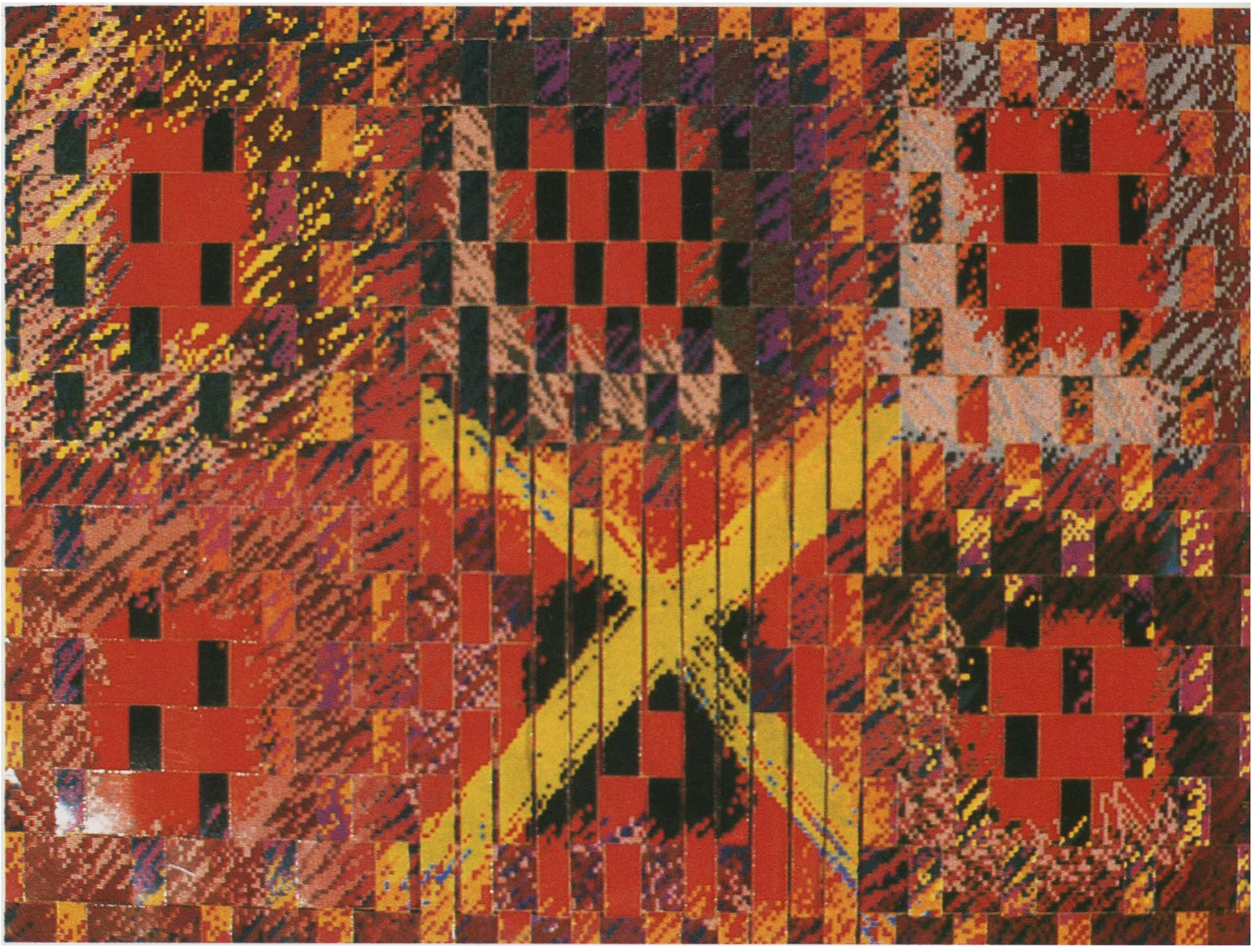


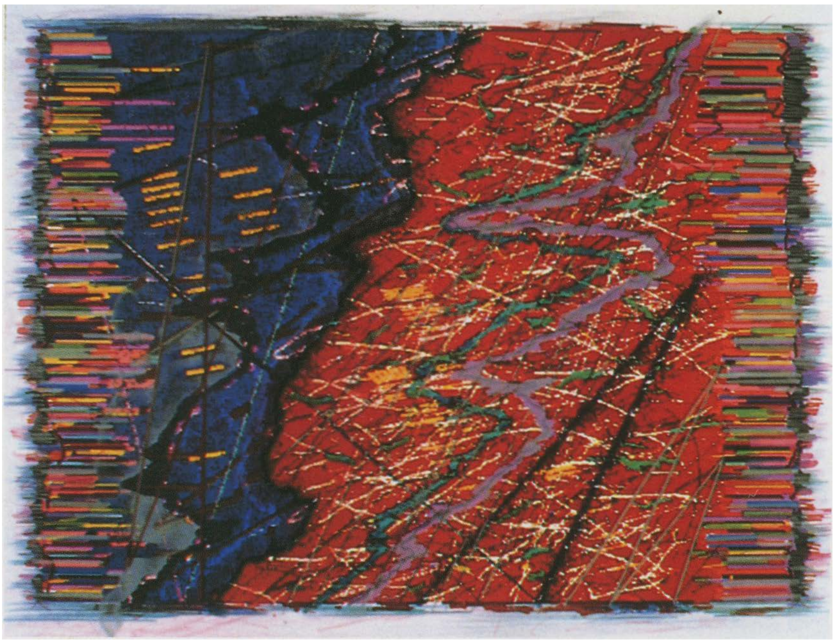
seeing seek seem seen seep seepage seersucker seethe seventeen seventeenth Shawnee Sheehan sheen sheep sheepskin sheer sheet shopkeep sightsee sightseeing sightseer sixteen sixteenth skeet sleek sleep sleepwalk sleepy sleet sleety sleeve sloganeer smithereens smokescreen sneer sneeze soignee soiree speech speed speedboat speedometer speedup speedwell speedy spleen spleenwort spree squeegee squeeze steed steel Steele steelmake steely Steen steep steepen steeple steeplebush steer steeve storekeep street streetcar succeed Sweeney sweep sweepstake sweet sweetheart sweetish Tallahassee tee



21

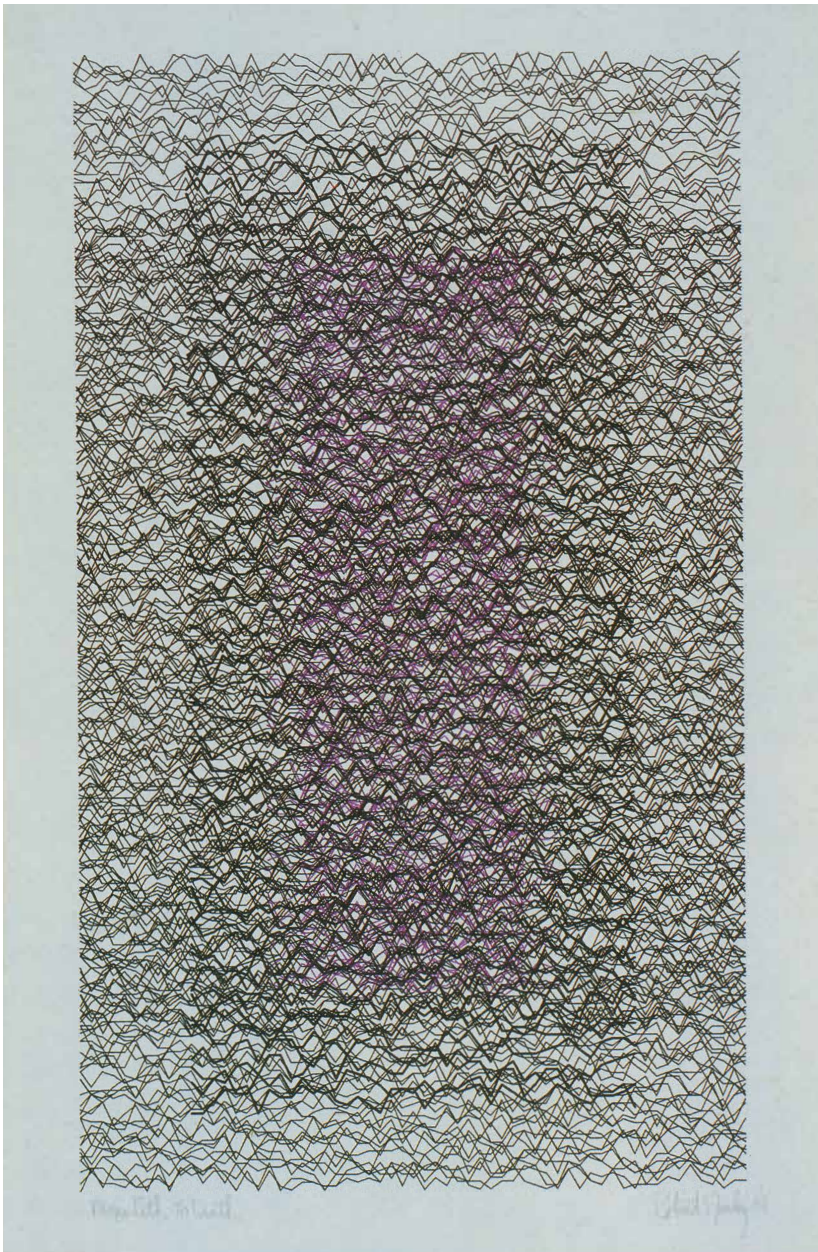
Key Words: aRITHMETIc, tEXt, tEXTURe.

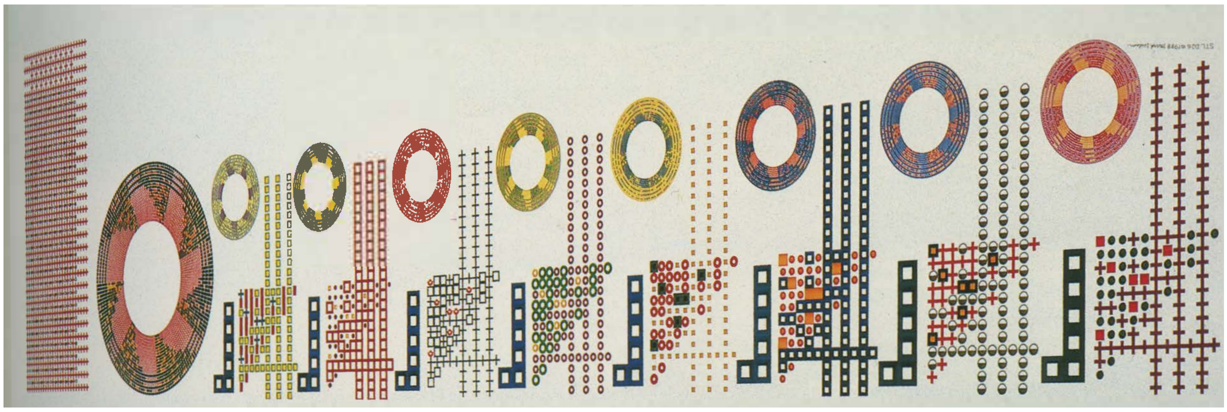




No. 5. (above) Tracy Colby, *Six Holes, Five Read*, color thermal print collage, 12.75 × 13.75 in, 1989.

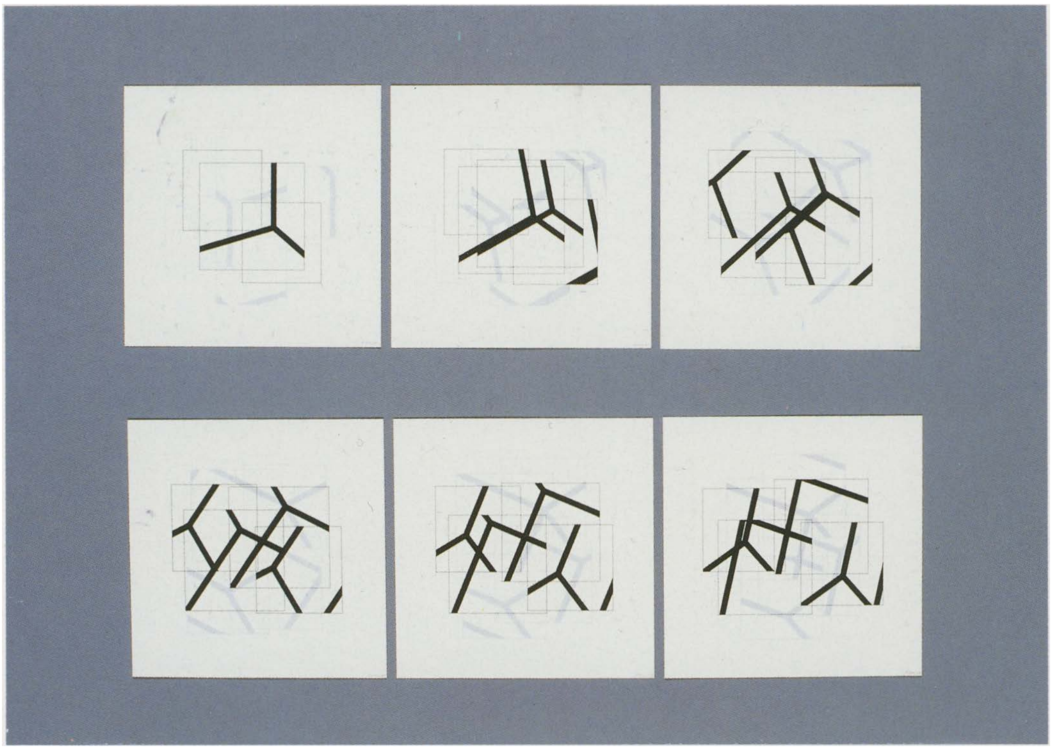
No. 6. (left) Karen Guzak, *Red Ridge*, lithograph, 22 × 29 in, 1987. Collaborators: Chuck Matson and Sheila Coppola, printers.

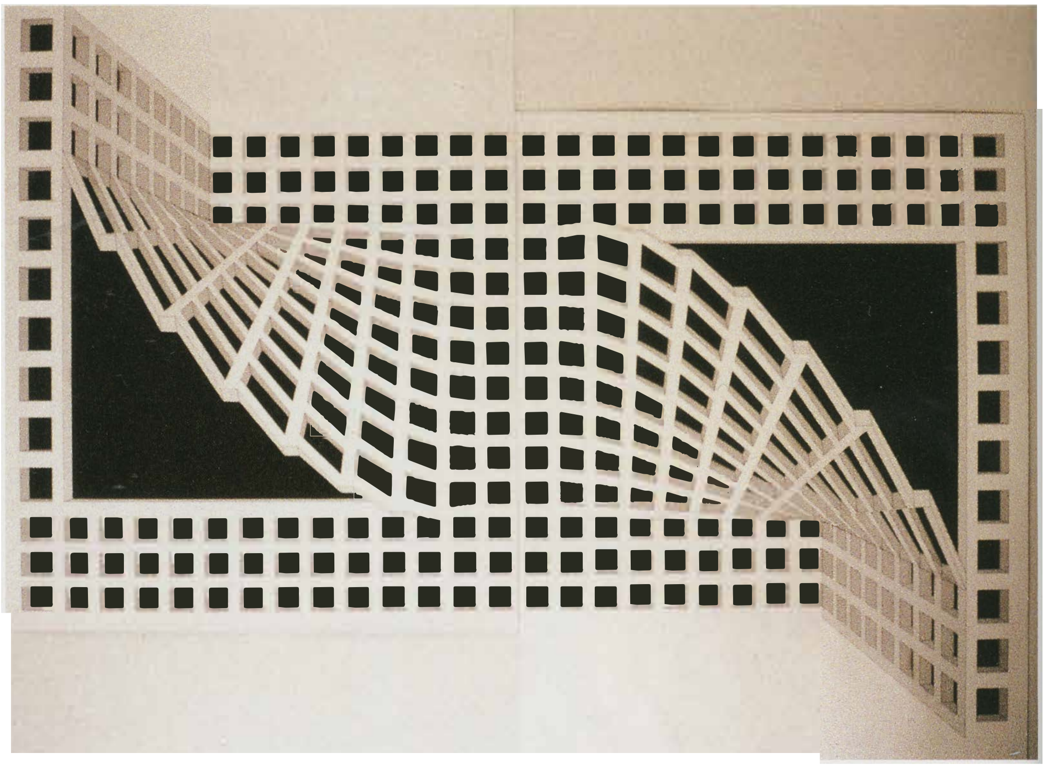




No. 7. (right) Robert (Steve) Finley, *Biblio.Face*, ink on paper (plotter drawing), 18 × 12 in, 1988.

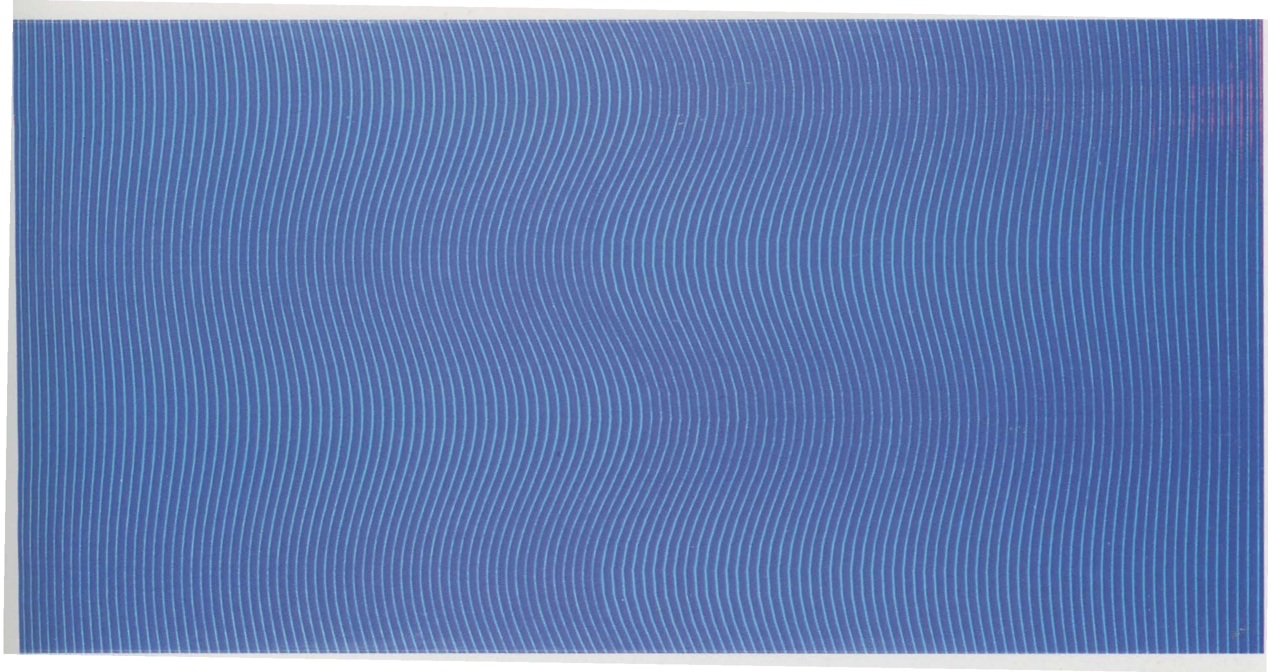
No. 8. (below) Mark Wilson, *STL D26*, acrylic on canvas, 40 × 120 in, 1988.





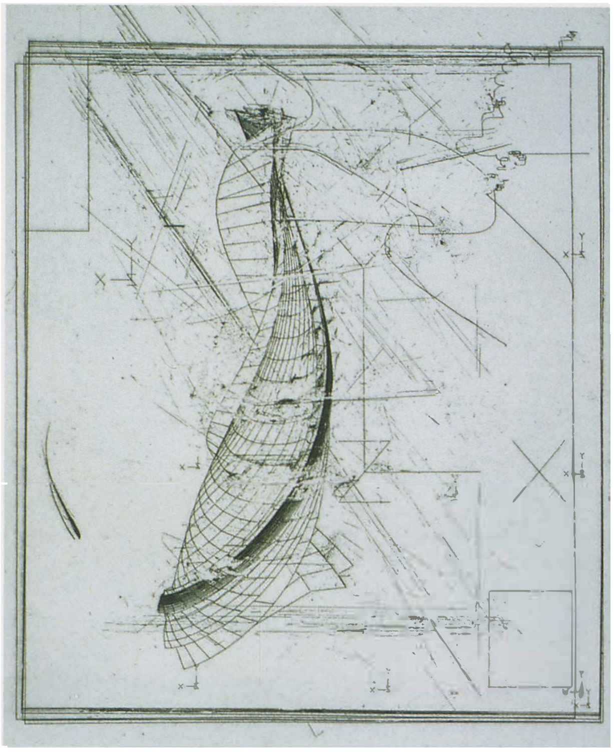
No. 9. (top) Manfred Mohr, *P-417-E*, ink on paper (plotter drawing), series of 6, 8 × 8 in each, 1988.

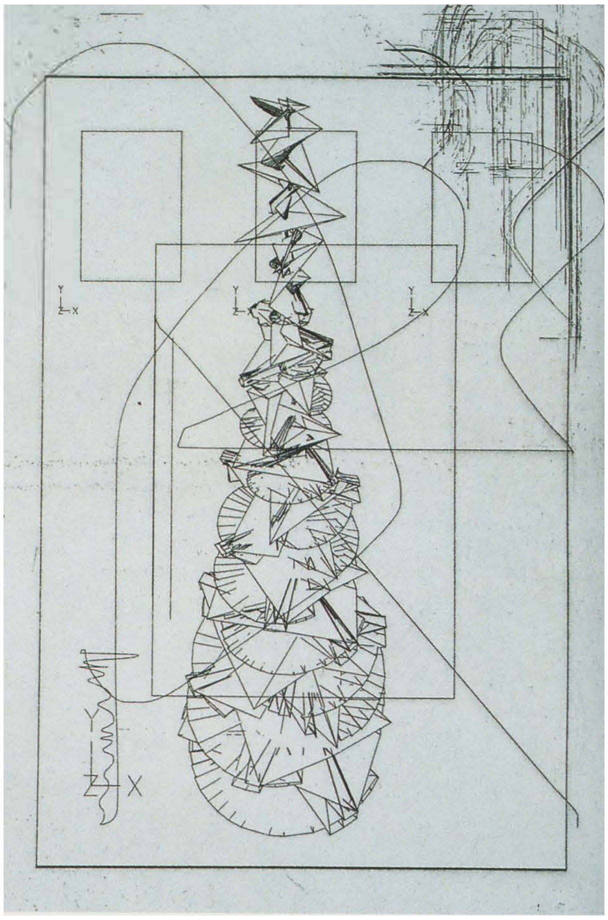
No. 10. (bottom) Daniela Bertol, *Bending and Twisting : Hypothesis #3*, collage, 40 × 60 in, 1988.



No. 11. (above) Jürgen Lit Fischer, *Vibrant*, serigraph, 39.33 × 70.75 in, 1987.

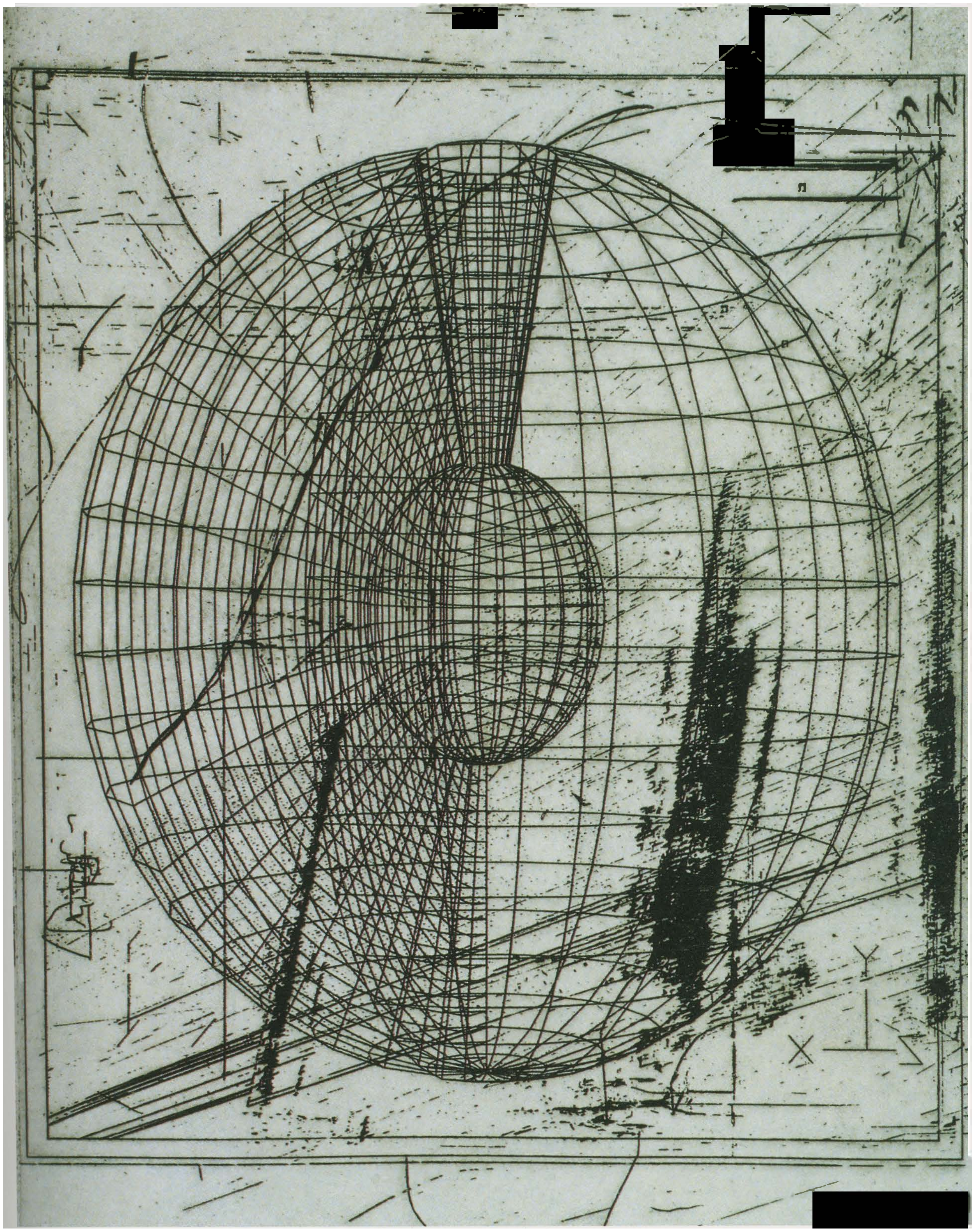
No. 12. (right) Robert (Steve) Finley, *Redtower.S*, ink on mylar (plotter drawing), 54 × 36 in, 1988.





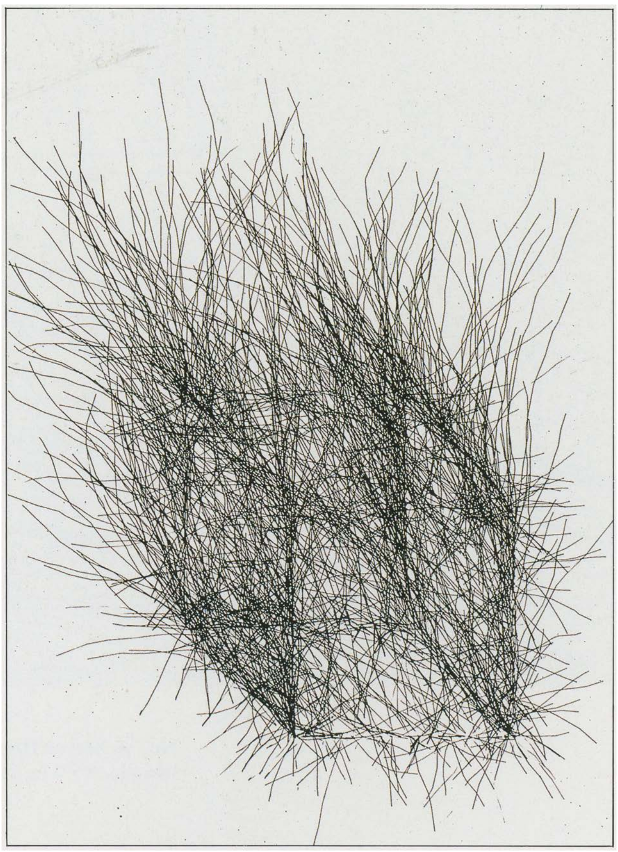
No. 13. (above) Steven Herrnstadt, *Phoenix Nov 03*, intaglio, 9 × 7 in, 1988.

No. 14. (right) Steven Herrnstadt, *Phoenix Nov 06*, intaglio, 9 × 7 in, 1988.

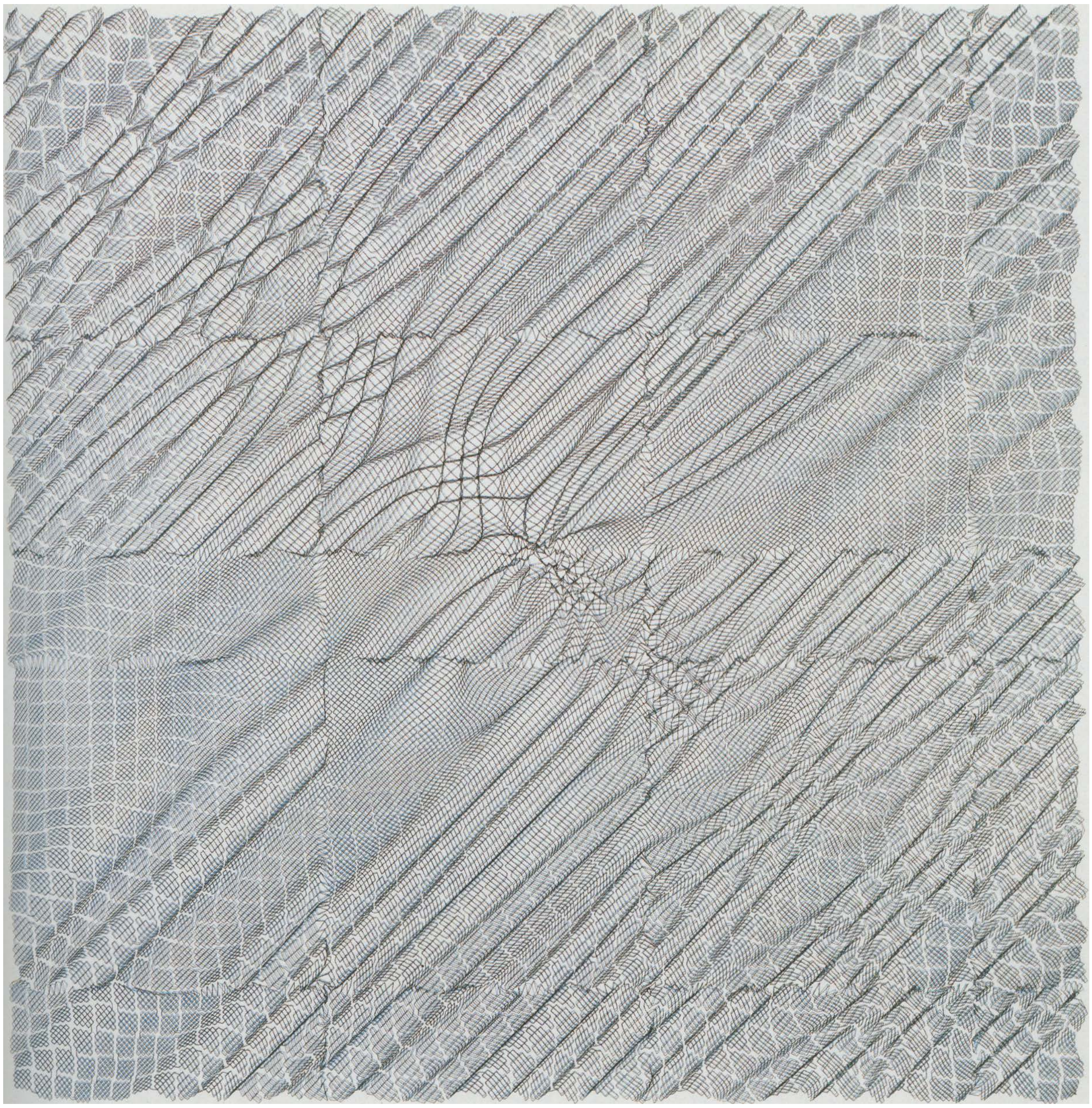


No. 15. Steven Herrnstadt, *Global Pillage*, intaglio, 9 × 7 in, 1989.

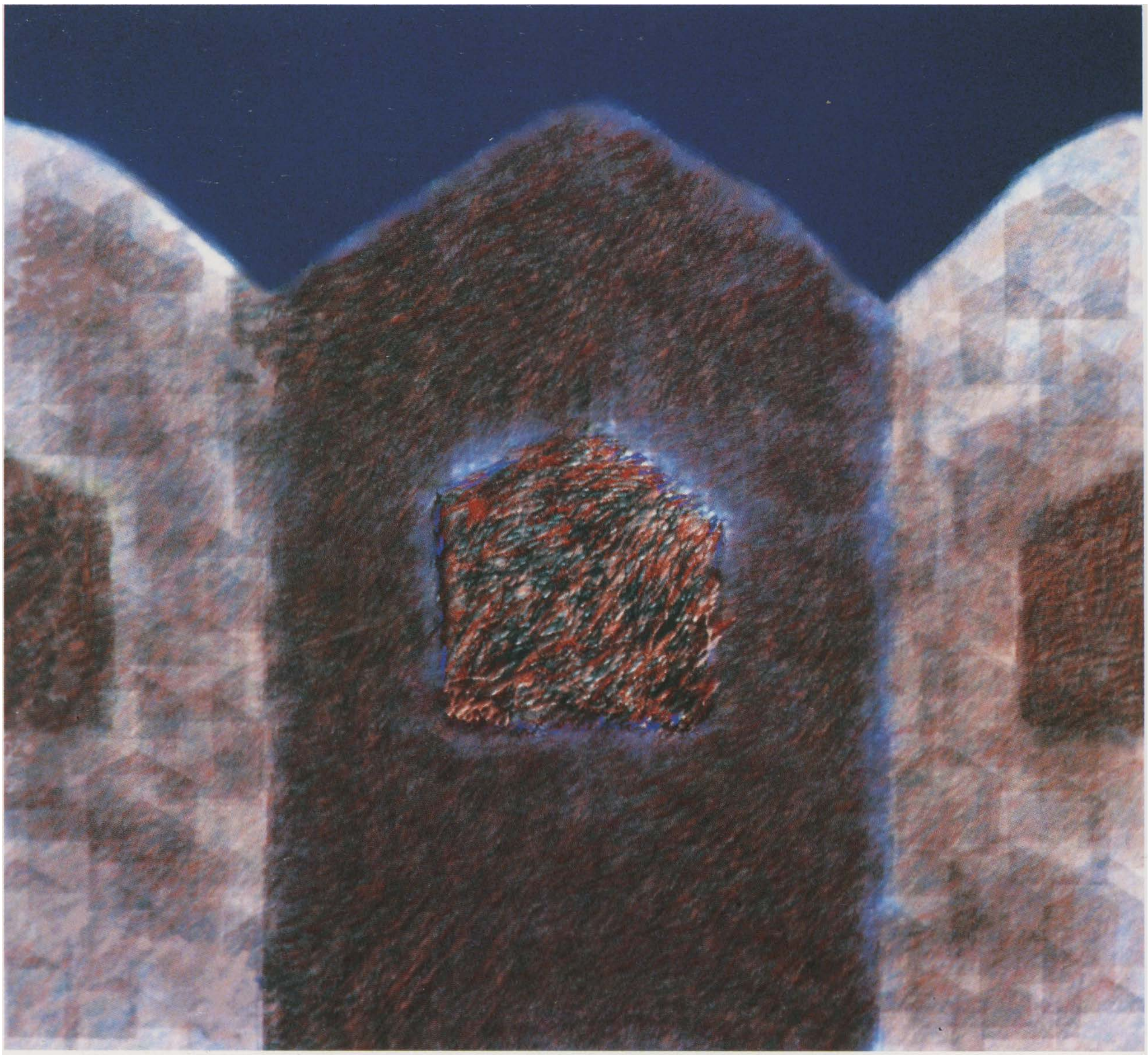
No. 16. Susan Migliore, *Two Triangles*, fabric construction, 24 × 24 × 36 in and 18 × 18 × 24 in (two pieces), 1988.



No. 17. Hans Dehlinger, *Cube 4*, ink on paper (plotter drawing), 45.25 × 31.5 in, 1987.



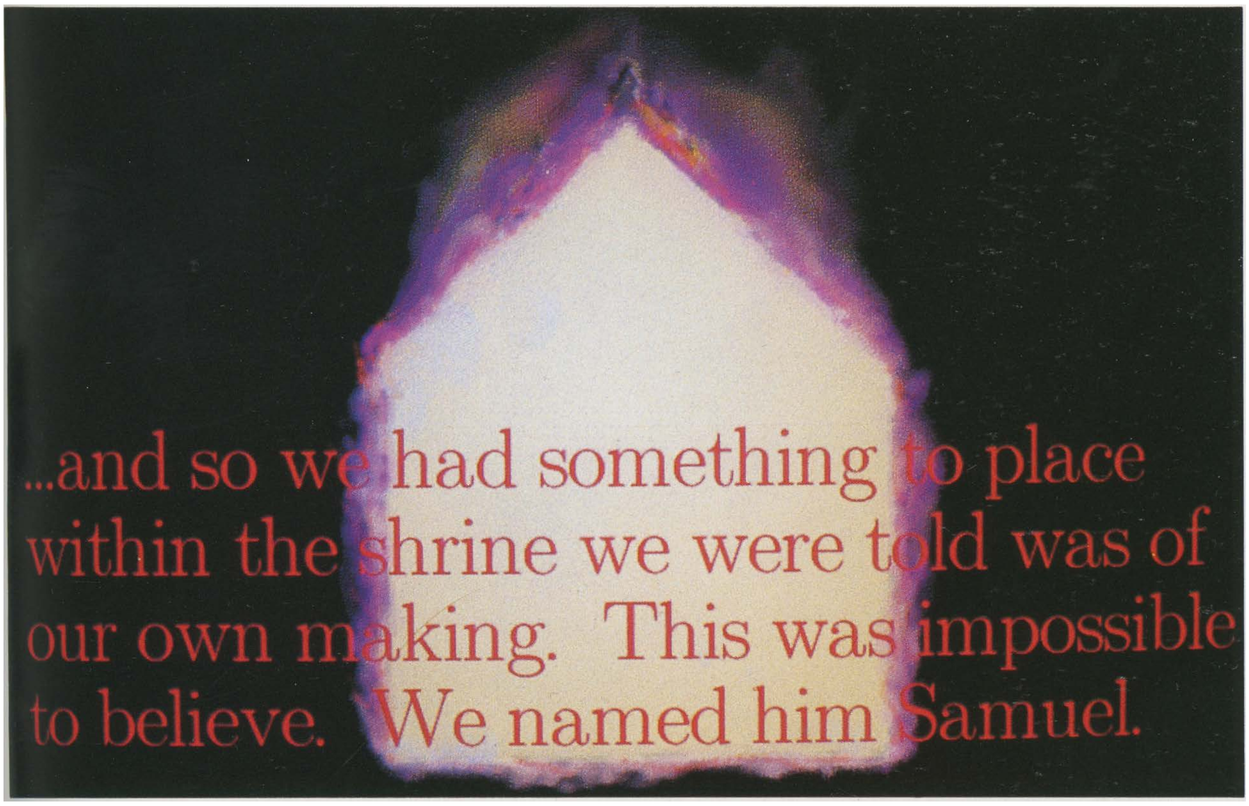
No. 18. Jean-Pierre Hebert, *Untitled (reference #87)*, ink on paper (plotter drawing), 26 × 26 in, 1989.

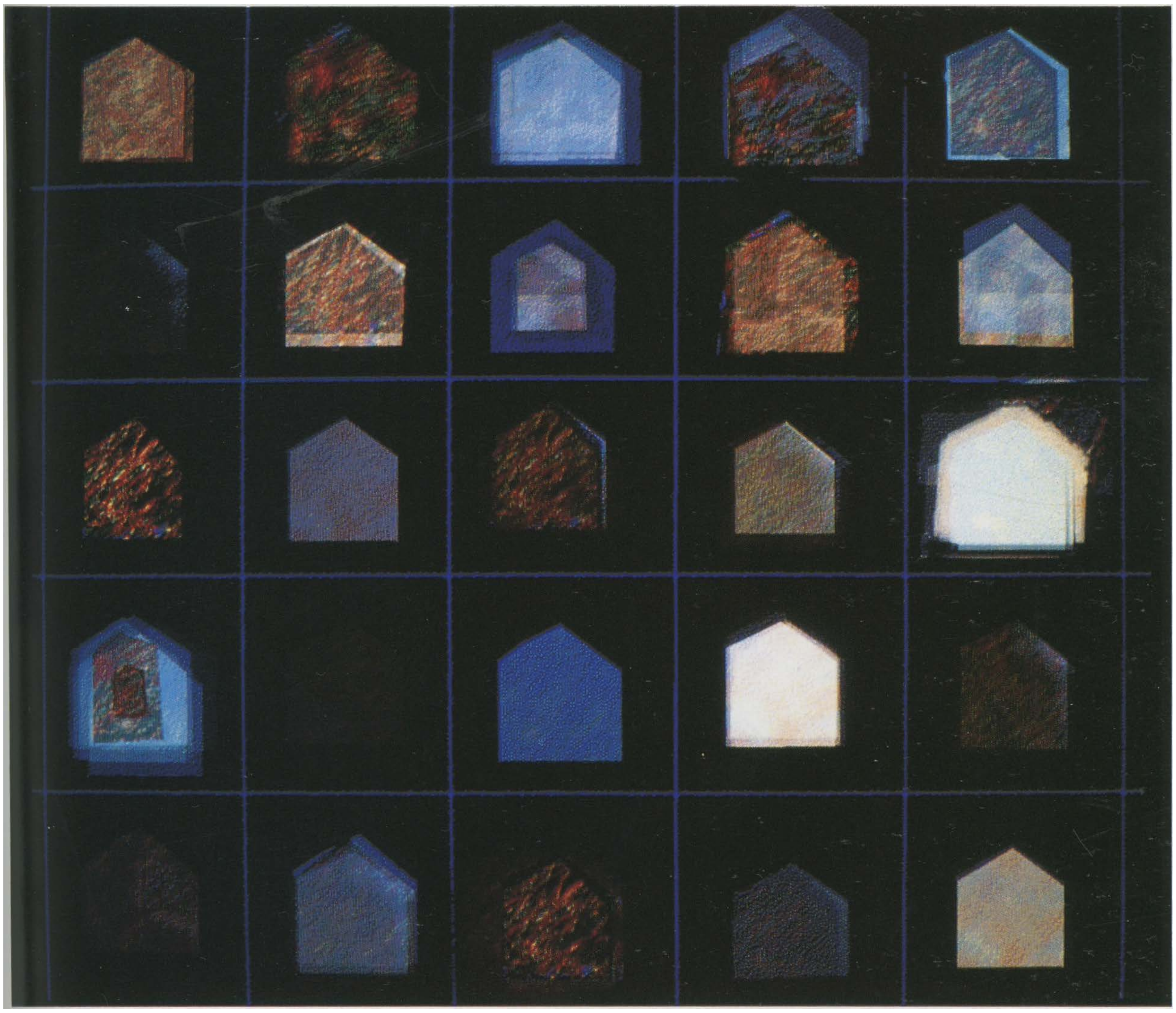


No. 19. Karen Hillier, *Mud Shrine*, photograph, 10 × 9 in, 1988.

No. 20. (top right) Karen Hillier, *Bringing Samuel Home*, photograph, 7.75 × 9.25 in, 1988.

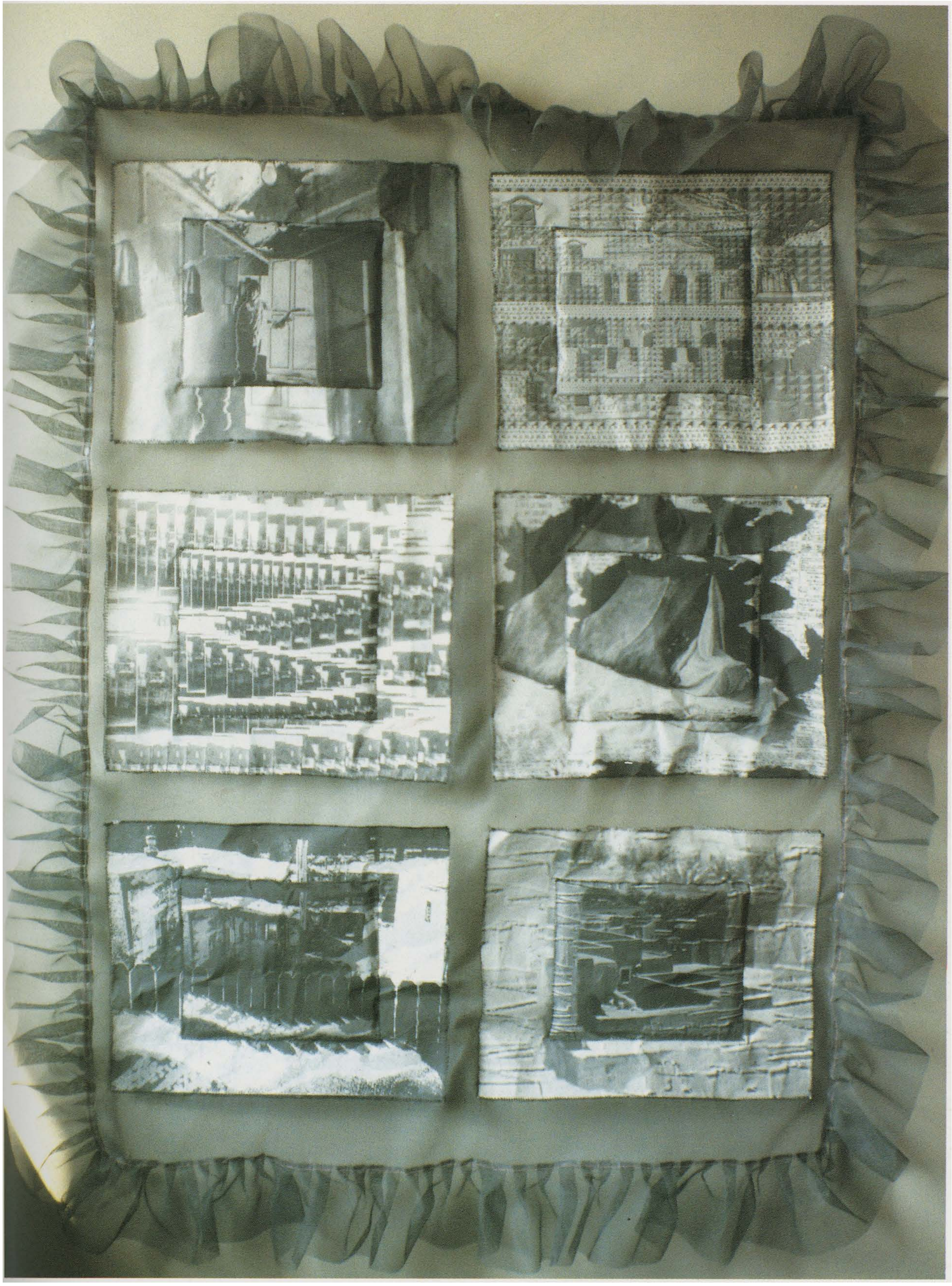
No. 21. (bottom right) Karen Hillier, *Shrine Quilt*, photograph, 10 × 14 in, 1988.


...and so we had something to place within the shrine we were told was of our own making. This was impossible to believe. We named him Samuel.



No. 22. (above) Az Ursyn, *Two Skies*, mixed media, 40 × 50 in, 1988.

No. 23. (left) Robert Martin, *Back to the Future*, construction with photographic transparency, 25 × 26 × 7 in, 1988.



No. 24. Patricia Hoffman, *Home Sweet Home Quilt*, photo on linen, mixed media, 60 × 46 in, 1989.

No. 25. Micha Riss, *Leo Castelli*, photograph, 60 × 84 in, 1988.

No. 26. (right) Bob Sabiston, *Chaos*,
photograph, 19 × 19 in, 1988.

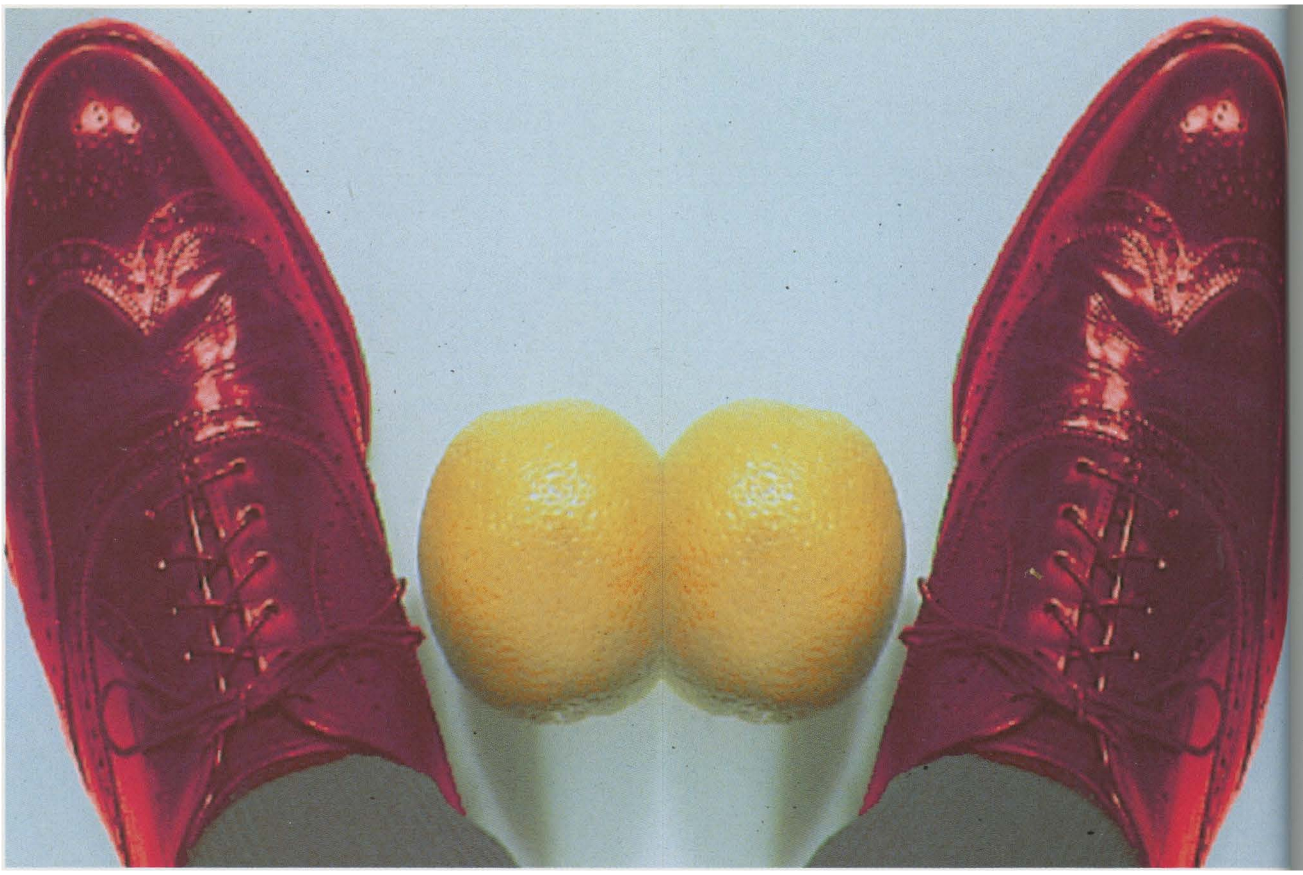
No. 27. (below) John Stamos, *Smokers #4*,
photograph, 20 × 24 in, 1988.

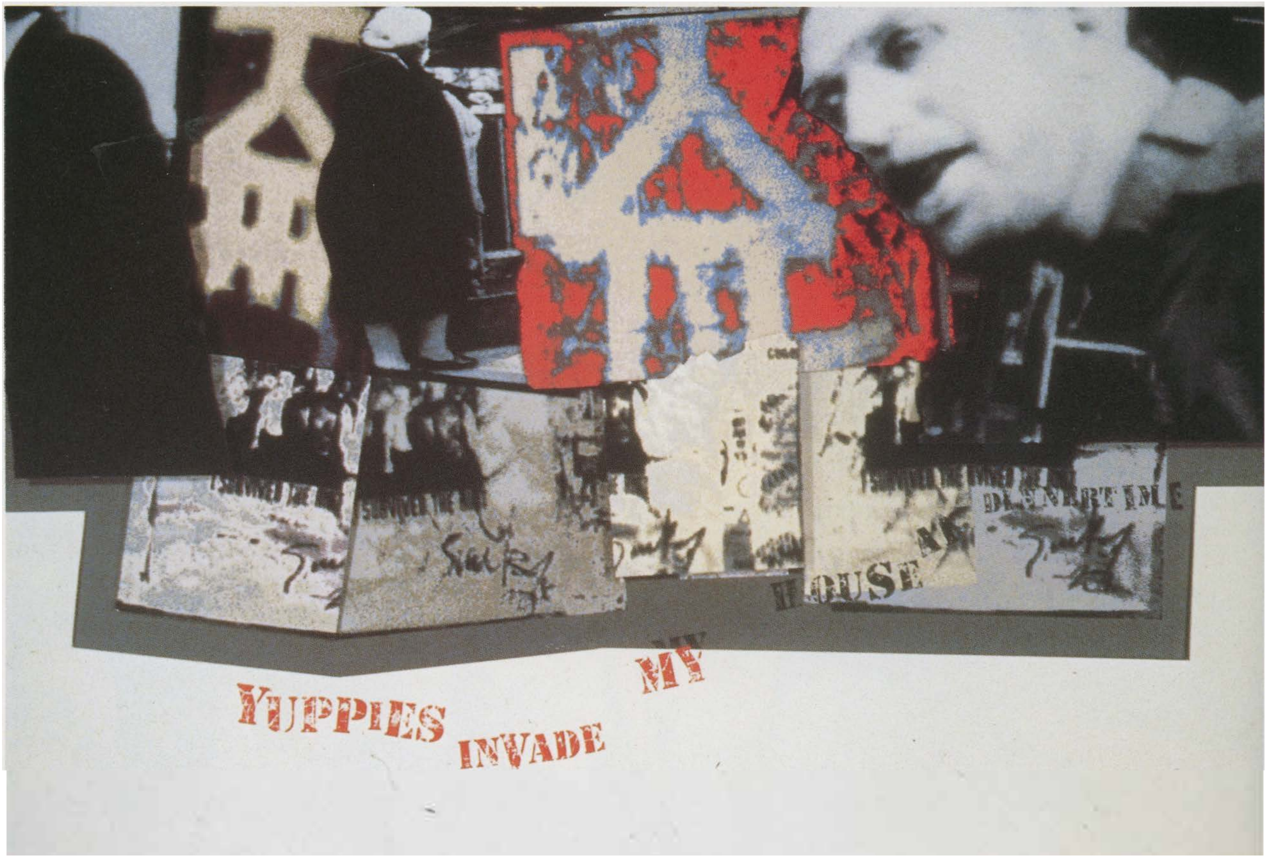
No. 28. Marsha McDevitt, *Mornings*, photograph, 16 × 20 in, 1989.

No. 29. (top right) Sharon Calahan, *Night Cafe—Wurlitzer*, photograph, 14 × 20 in, 1989. Collaborators: Cubicomp's Vertigo Hardware and Software Teams.

No. 30. (bottom right) Michael S. Simmons, *Essence of Form*, photograph, 20 × 26 in, 1988.


Menu
Coffee 5¢ Tea 5¢
Donuts 5¢ Milk 10¢
Sodas 5¢ Soup 15¢
Ham & Cheese 25¢
Grilled Cheese 20¢
Stew 20¢ Hash 30¢
WURLITZER
Calahan





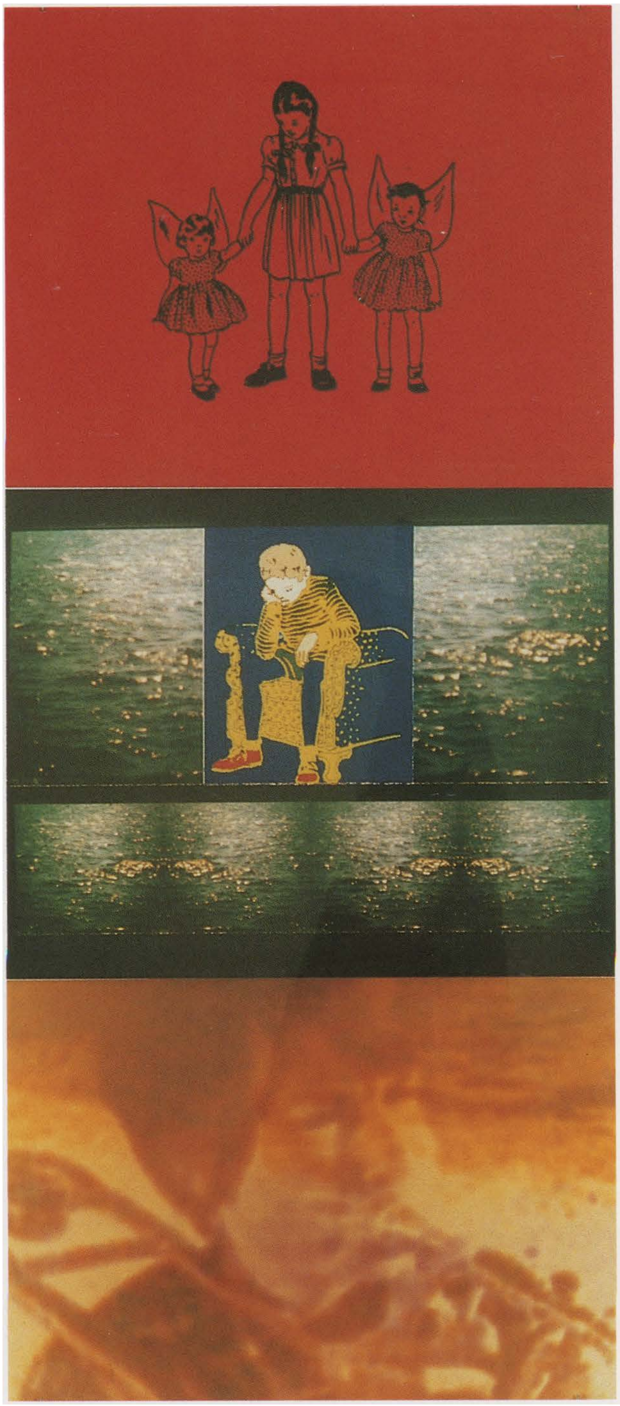
No. 31. (above) Terry Rosen, *The Ruby Slippers*, photograph, 16 × 20 in, 1987.

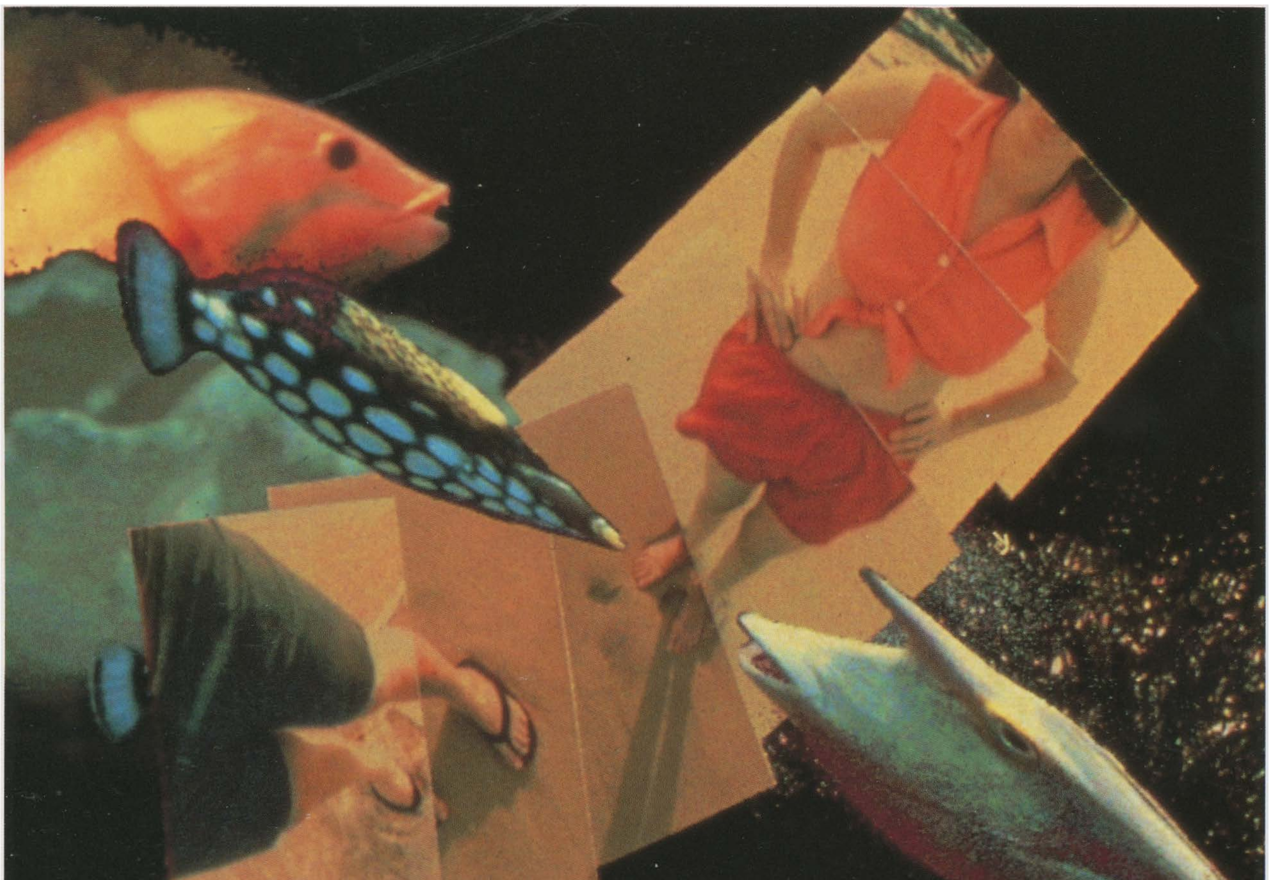
No. 32. (below) Dennis H. Rexroad, *Missing Foundation 3*, collage, 24 × 36 in, 1989.

No. 33. Jacquelyn Ford Morie, *The Powers That Be*, color thermal print, 13.37 × 6 in, 1989.

No. 34. Robert Flanagan, *Five Volts*, color photocopy, 7 × 10.75 in, 1989.

No. 35. James Lenavitt, *Syntagram #1*, color print, 48 × 20 in, 1987.

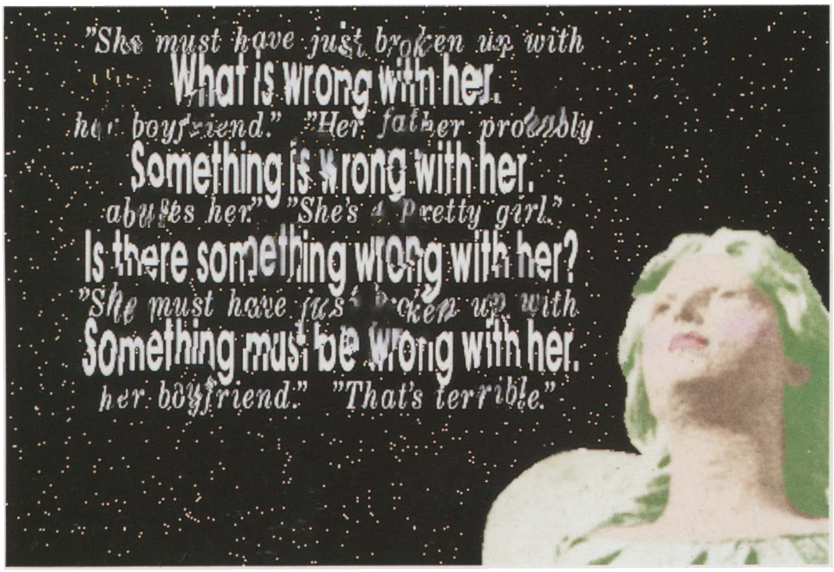




No. 38. Hiroshi Kamoi, *Flower Power*, digital color print, 7.7 × 12.8 in, 1988.

No. 36. (top left) Luz Bueno, *Medieval Figures*, photograph, 30 × 40 in, 1988.

No. 37. (bottom left) Ron MacNeil, *Ronfish*, photograph, 16 × 20 in, 1988.



Nos. 39, 40, 41. Kathleen Kirka, *Student 14*, color thermal print (triptych), each 8 × 10 in, 1989.

No. 42. (top) John Sturgeon, *Curtain*, photograph, 16 × 20 in, 1988.

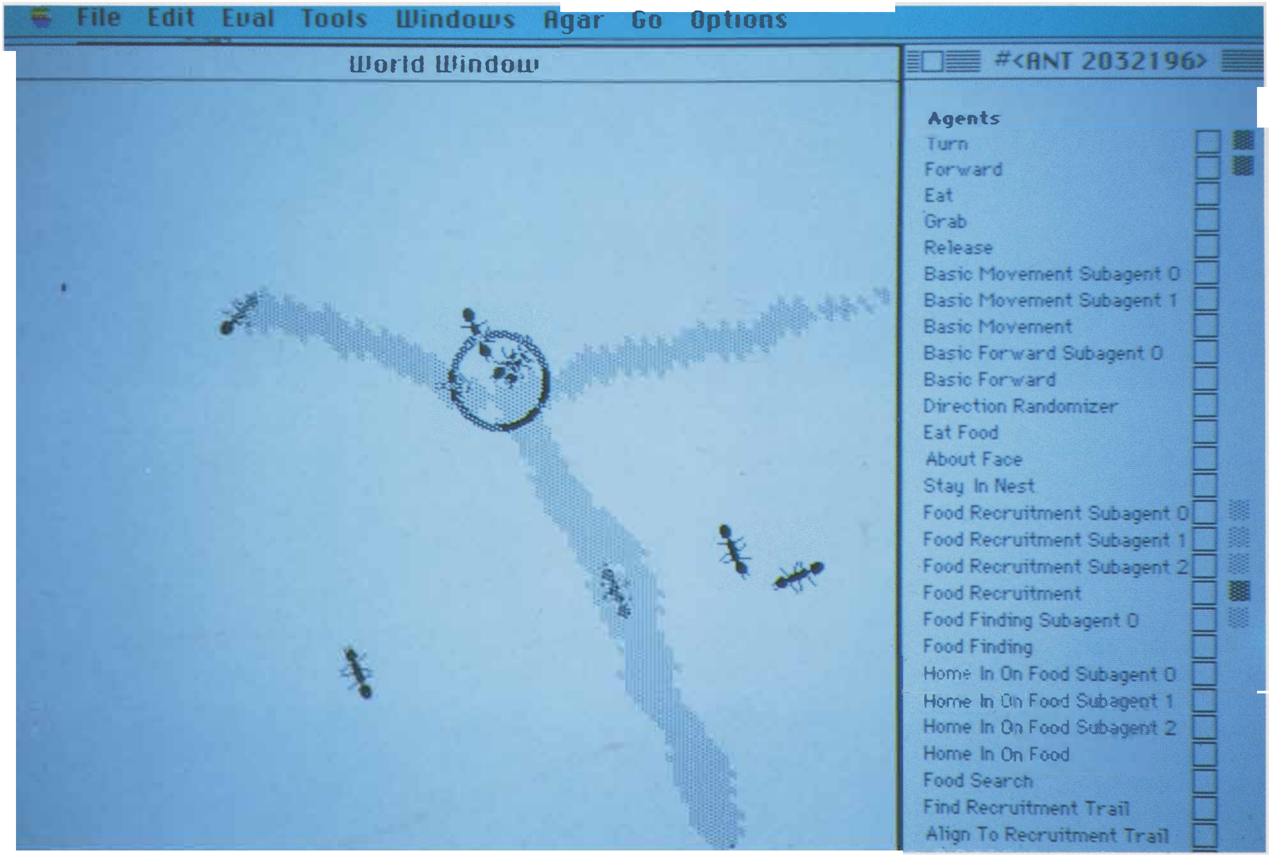
No. 43. (center) John Sturgeon, *Face Mask*, photograph, 16 × 20 in, 1988.

No. 44. (bottom) John Sturgeon, *Head Wand*, photograph, 16 × 20 in, 1988.

No. 45. Robert Hamilton, *Exhibition Experiment #2A*, color dot matrix print, 18.75 × 77 in, 1989.

No. 46. (top) Nancy Freeman, *All Sisters, Small Change*, ink jet print, 40 × 64 in, 1989.

No. 47. (bottom) Peggy Weil, *Scan/Look/Express*, interactive installation, 1981. Collaborator: Howard Eglowstein, Architecture Machine Group.

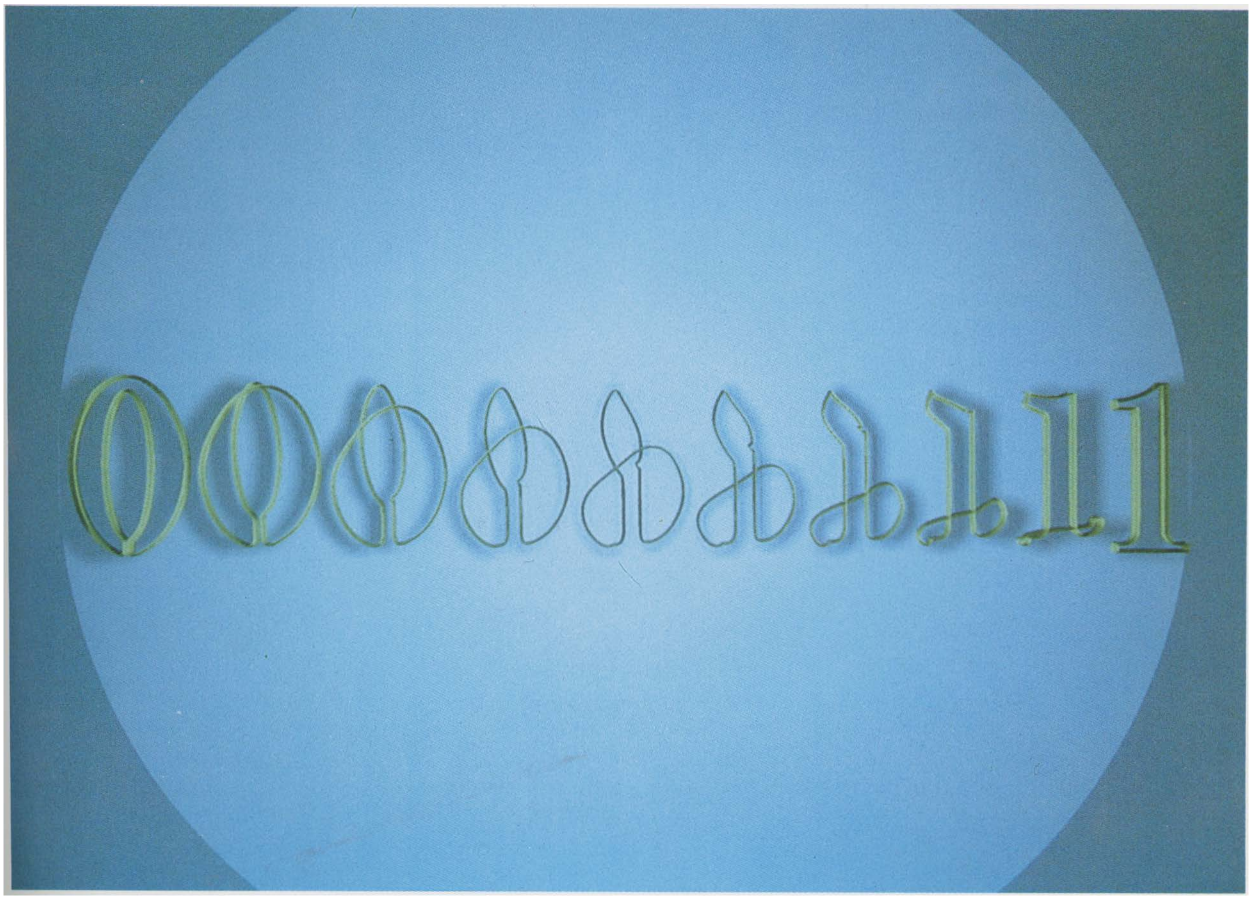


No. 48. Michael Travers, *Electric Anthill*, interactive installation, 1989.

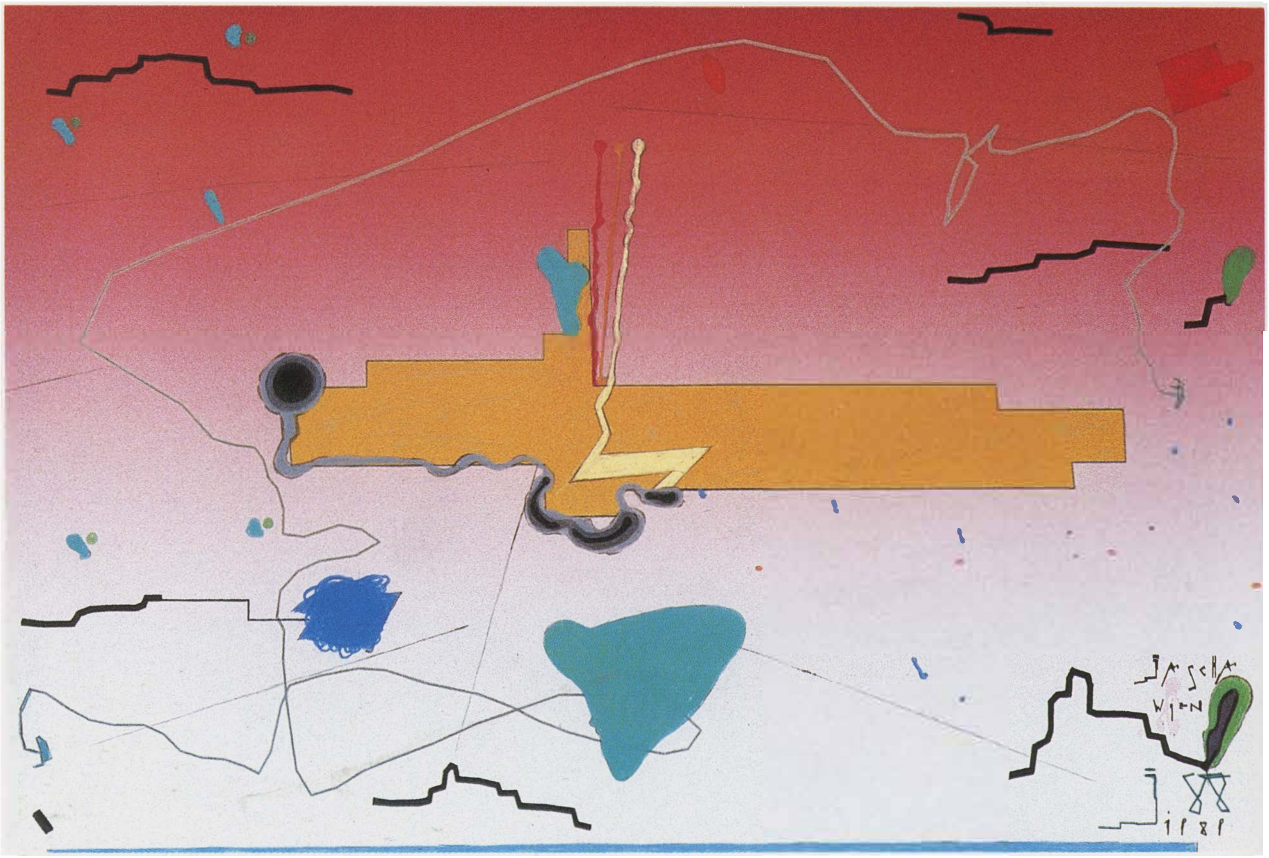
No. 49. Jeffrey Shaw, *The Legible City*, interactive installation, 1989. Collaborators: Dirk Groeneveld—co-author; Gideon May—application software.

No. 50. (left) Barbara Nessim, *Thoughts of the Moon*, pastel, 44 × 33 in, 1988.

No. 51. (below) Rosalyn Muskovitz, *Woman's Work*, ink on paper, photocopy, 28 × 32 in, 1987.



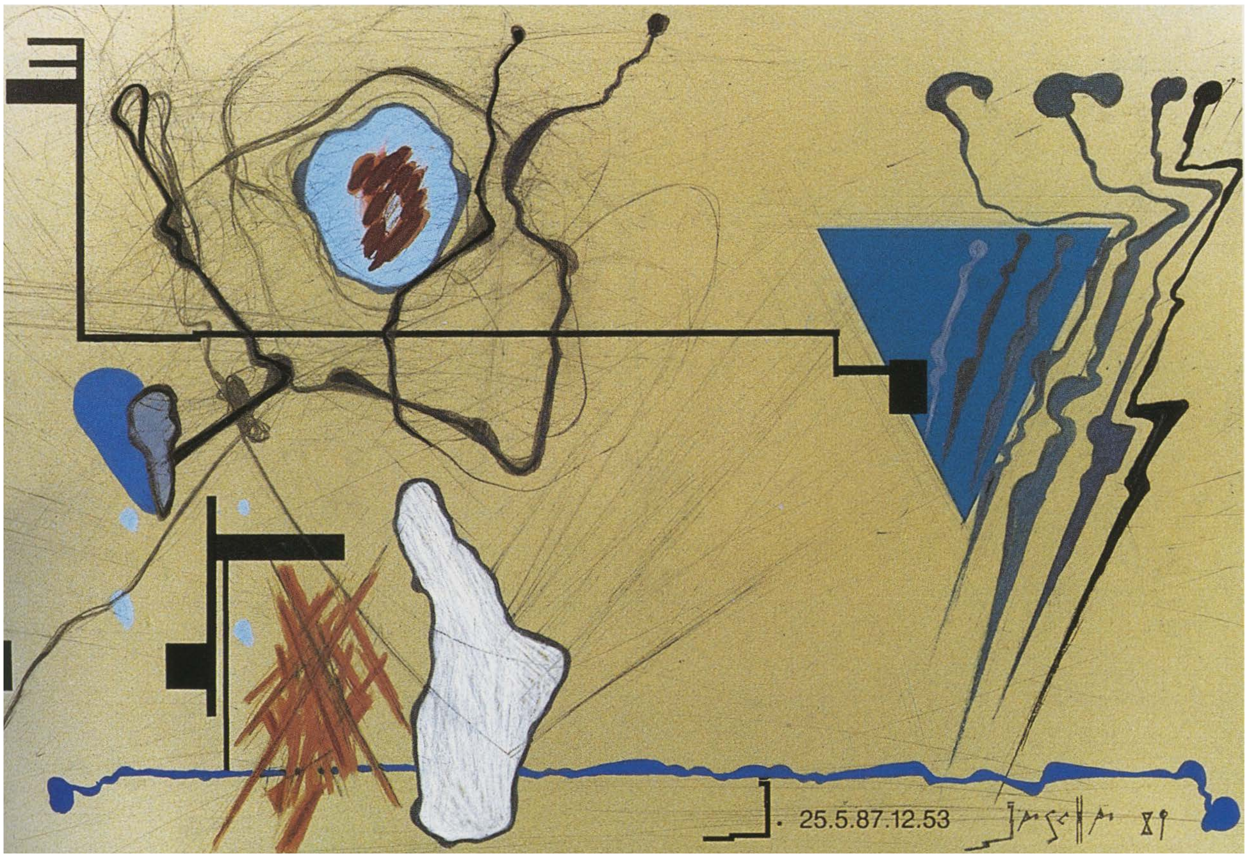
No. 52. Kamran Moojedi, *Number Series*, stereolithograph, 60 × 12 × 1 in, 1989.

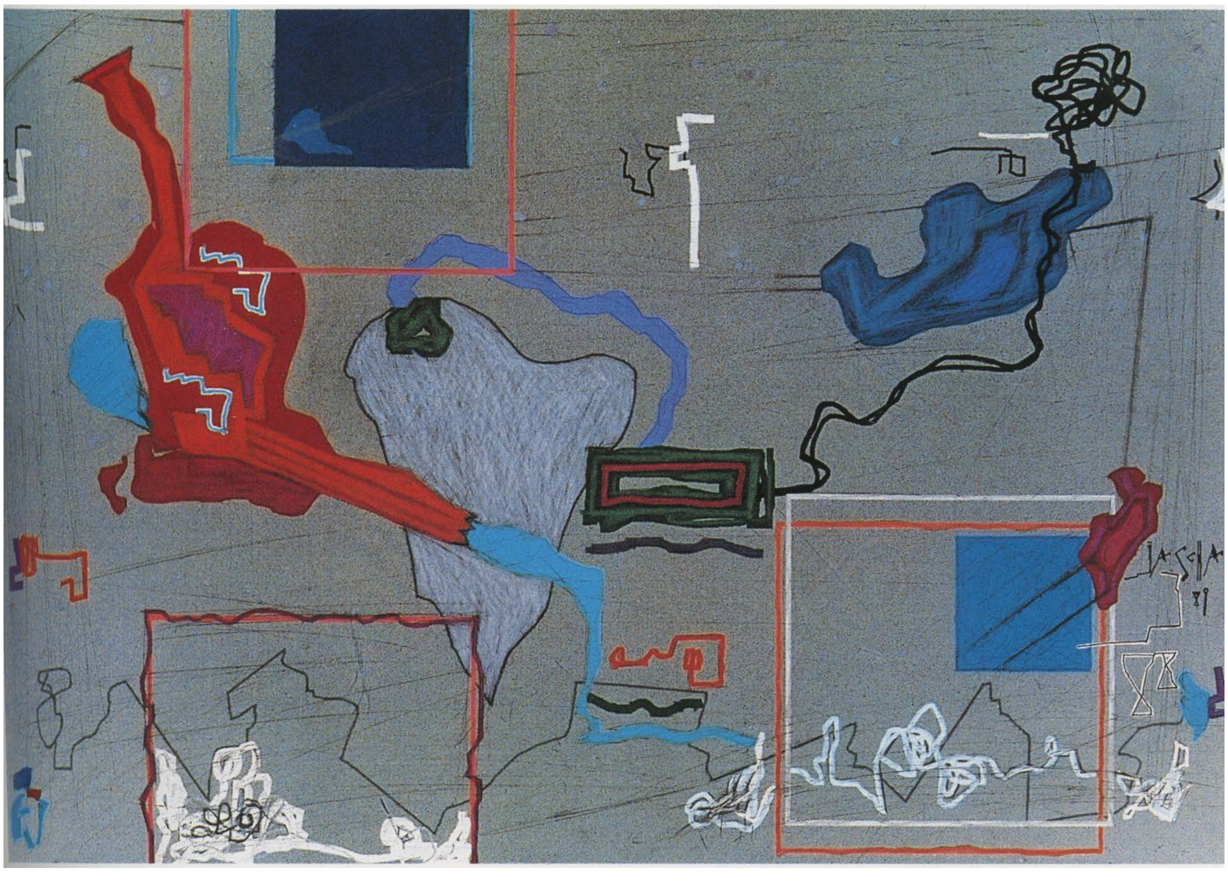


No. 53. Johann Jascha, *Innersoul*, mixed media, 19.67 × 29.5 in, 1989.

No. 54. (top right) Johann Jascha, *Line Brain*, mixed media, 19.67 × 29.5 in, 1989.

No. 55. (bottom right) Johann Jascha, *African Heart*, mixed media, 19.67 × 29.5 in, 1989.

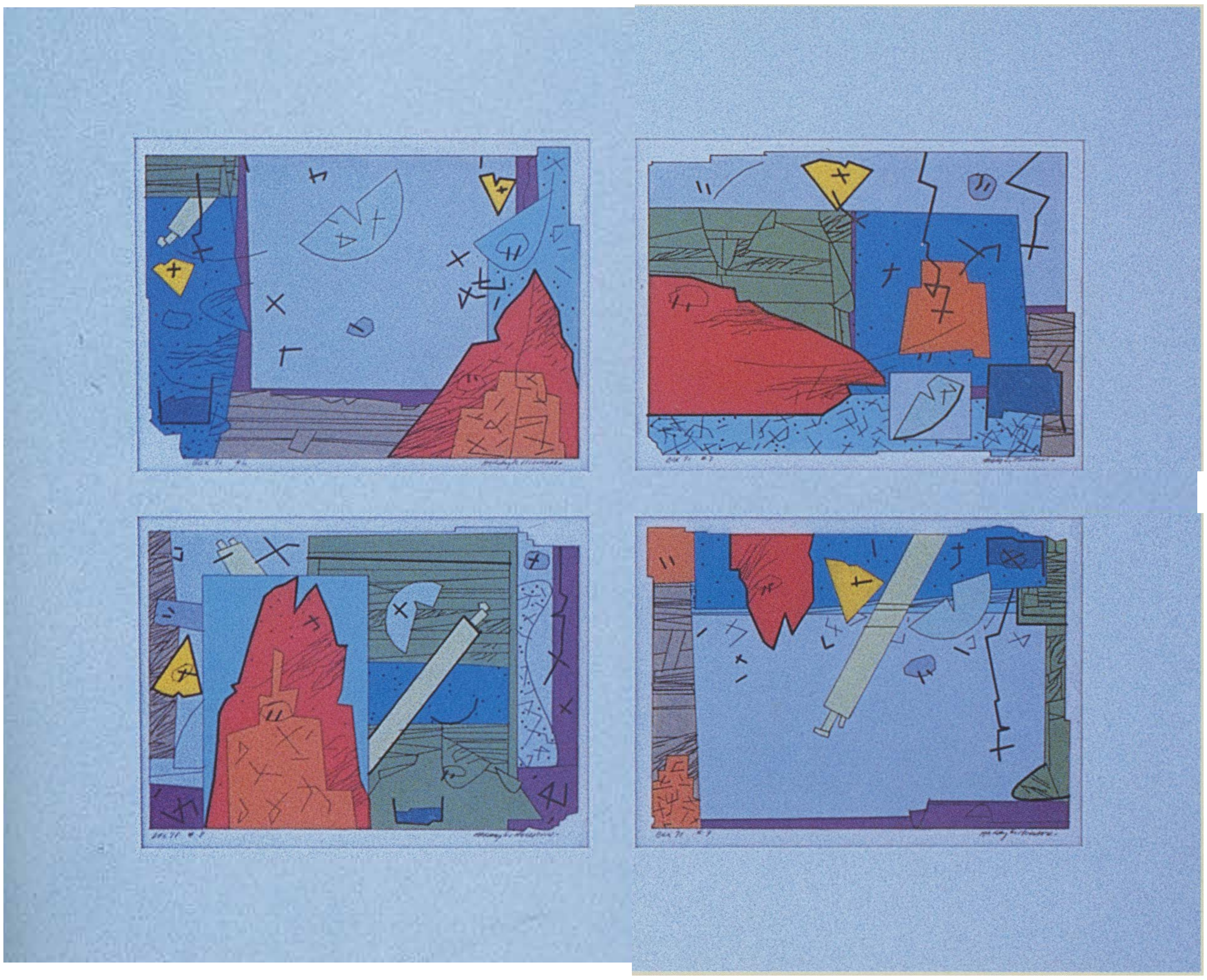

25.5.87.12.53



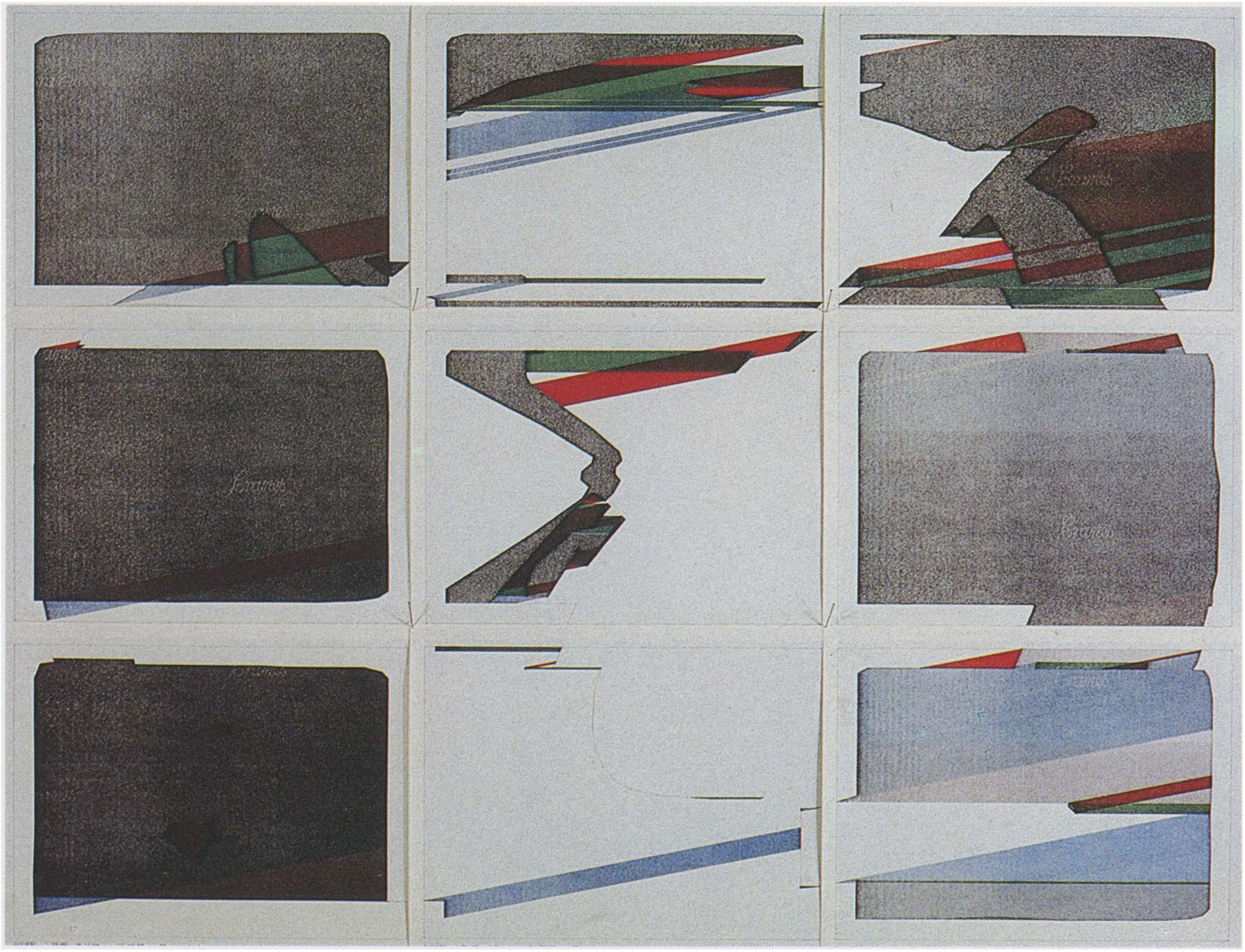
**No. 56. Barbara Joffe, *Tower*,
Cibachrome print, 24 × 30.5 in, 1988.
Collaborator: Lumena 16 to 32
Conversion: Computer Arts Institute.**

No. 57. Barbara Joffe, *Circus*, Cibachrome print, 30 × 27 in, 1989. Collaborator: Computer Arts Institute, Scans.

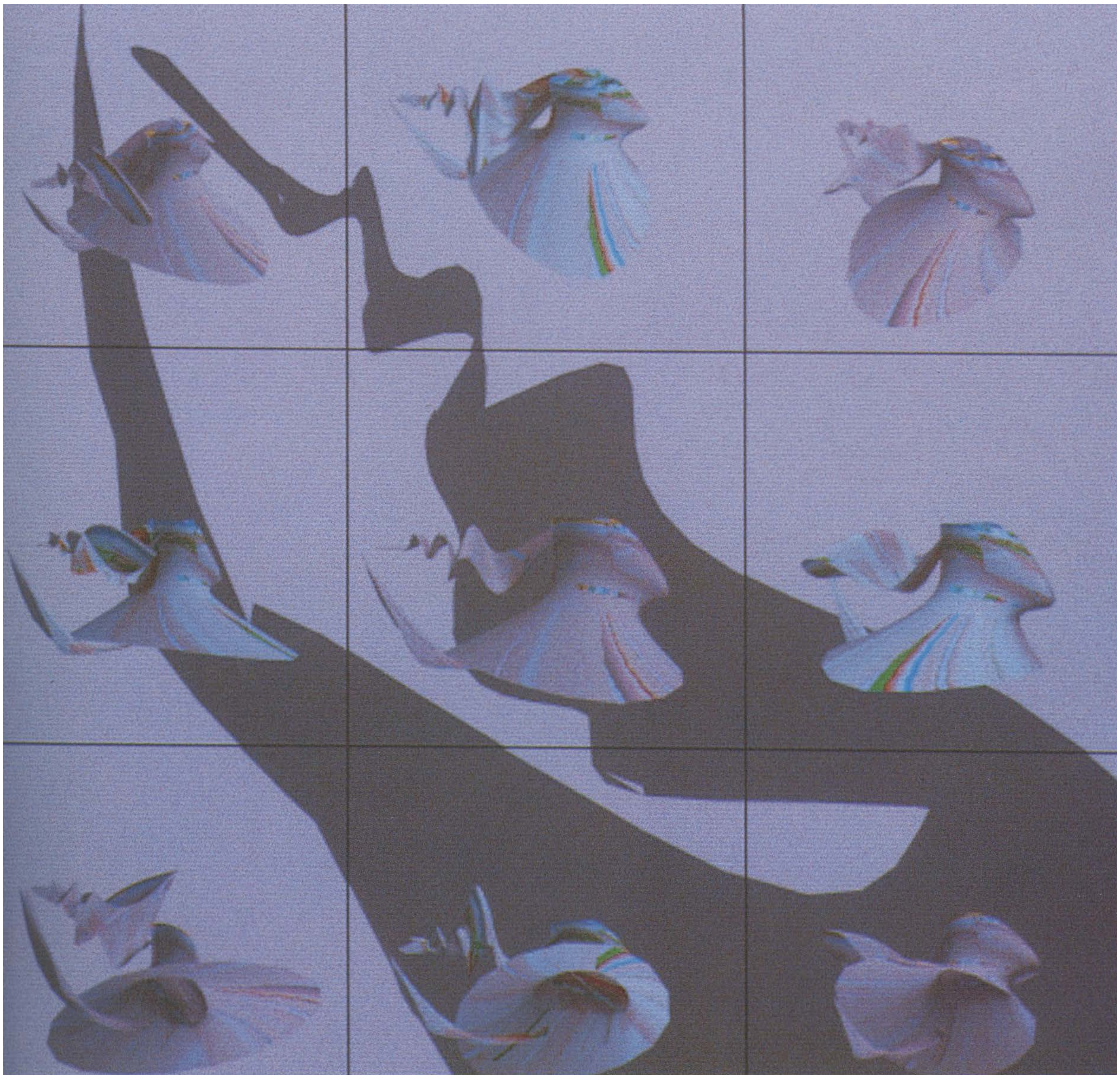
No. 58. Jim McLean, *The Sprite Fantastic #4*, serigraph, 15 × 21 in, 1989.



No. 59. Harry Holland, *Box 71 Series (#6, #7, #8, #9)*, acrylic and ink on acetate, 26 × 30 in, 1988.

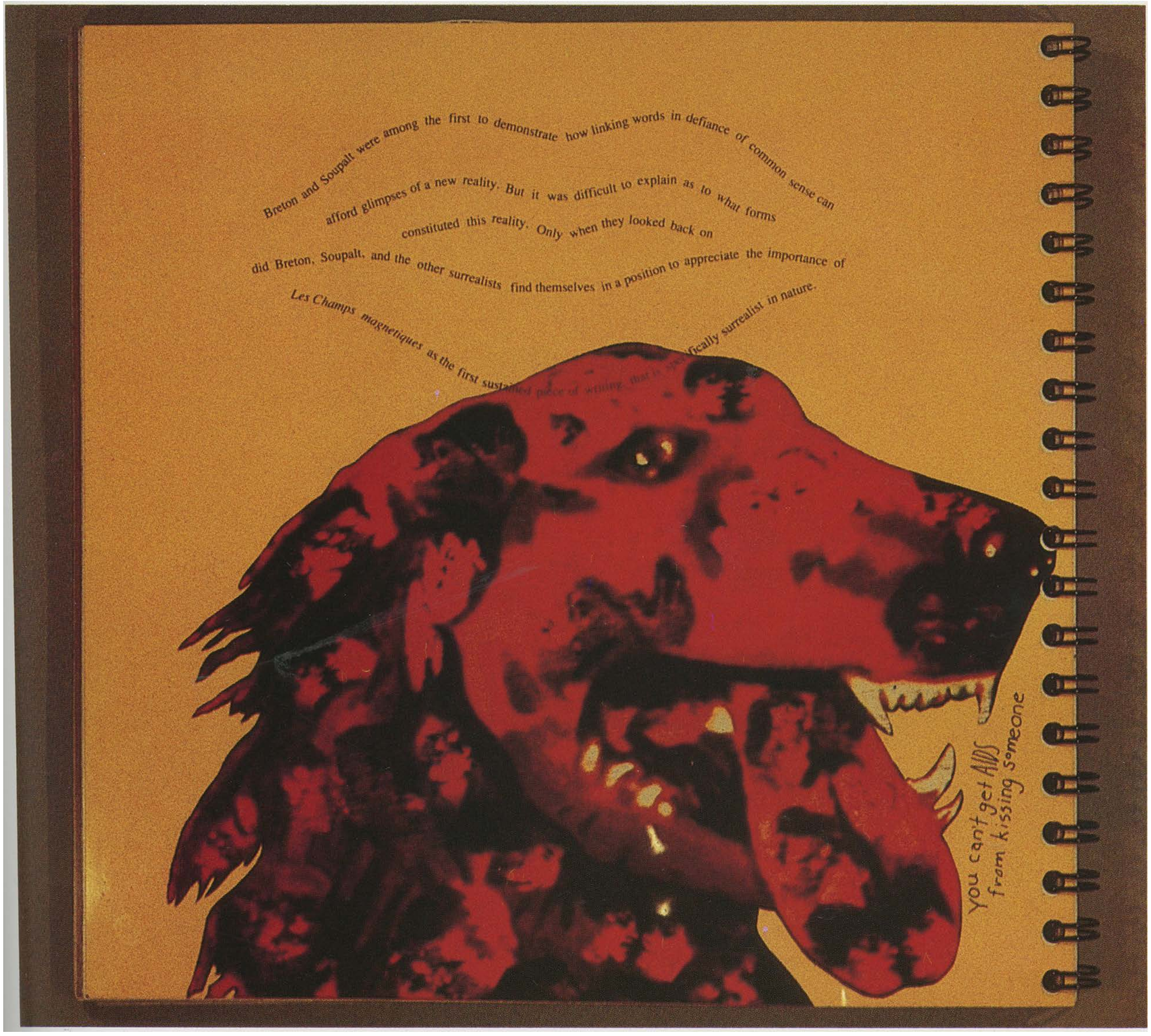


No. 60. Colette and Charles Bangert,
***Dawn's Diagonals*, colored ink on paper,**
25.5 × 33 in, 1989.

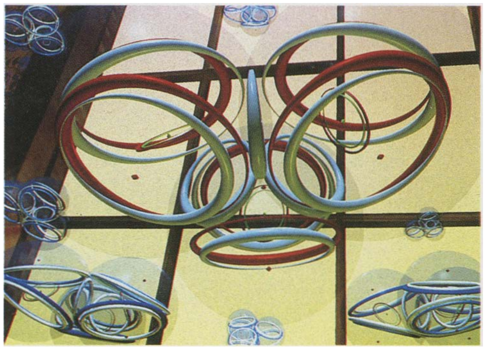
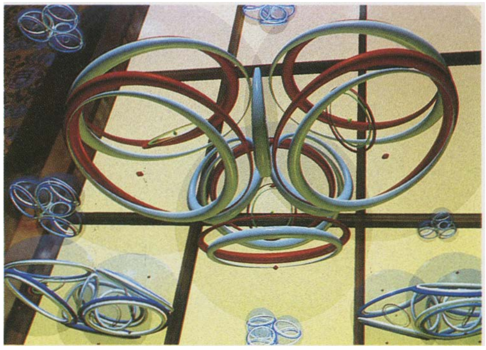


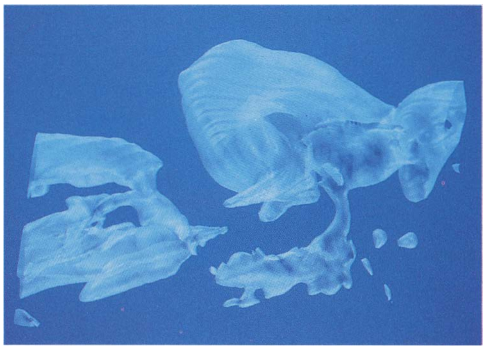
No. 61. Gerald Hushlak and David Jevans, *Spherical Corner*, ink on paper (plotter drawing), 90 × 90 × 90 in (floor and two walls around vertex of a corner), 1989.

Nos. 62, 63. Waltraut Cooper, *Klangmikado*, interactive computer-regulated installation, 31.5 × 73 × 67 in, 1984. Collaborators: Gerhard E. Winkler music; Walter Behr-electronics.



No. 64. Venantius Pinto, David Spicer and Maurice Bastian, *And You Thought the Eighties Were Bad*, (book) prints on paper, acetate, 10 × 10 × 1 in, 1988.

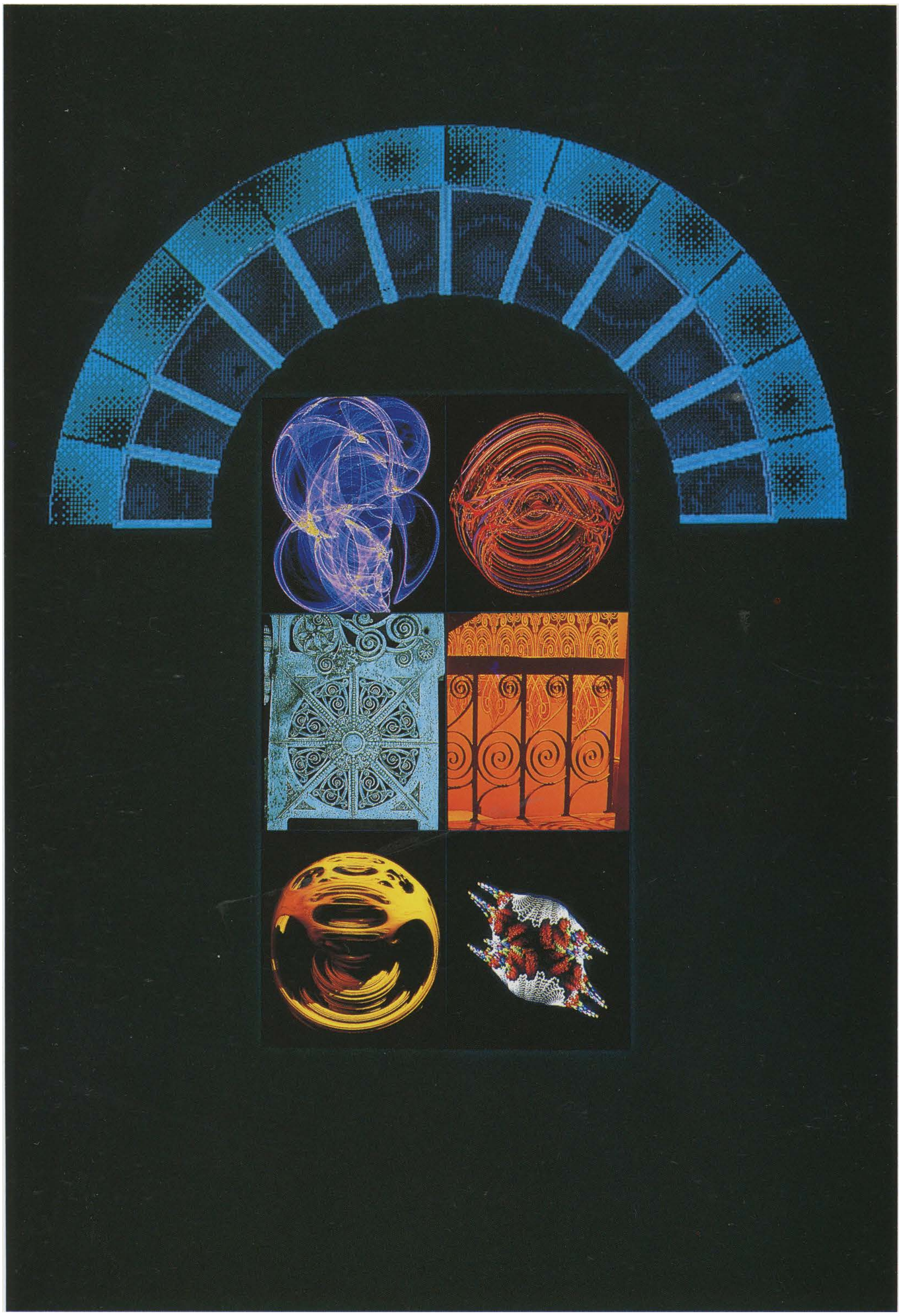





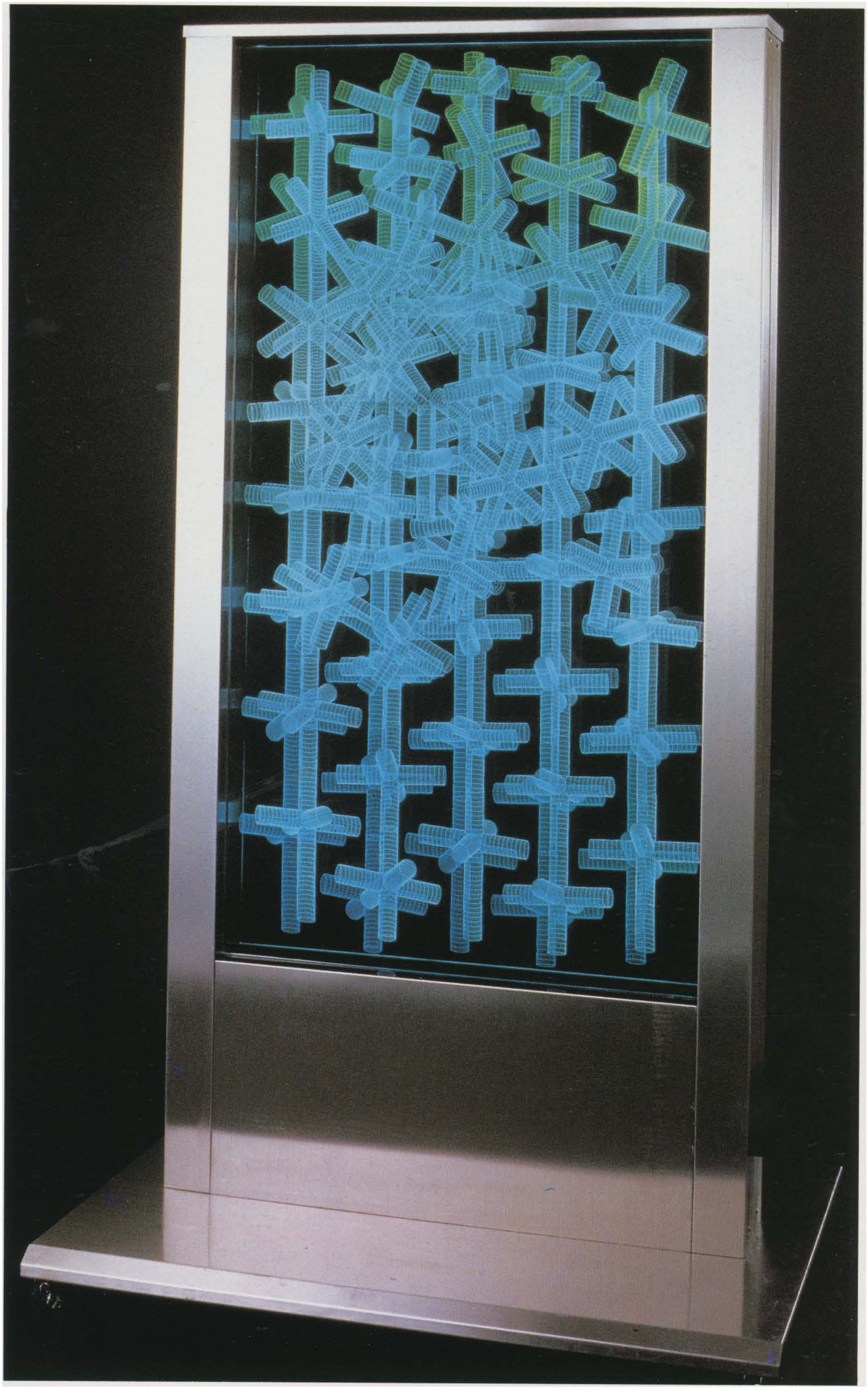
Nos. 65, 66. (top) Kenneth Snelson, *Invasion*, stereo slide pair, 1989.

Nos. 67, 68. (bottom) Michael Johnson, *Views From Below: on the Eye of the Storm*, stereo slide pair, 1989. Collaborators: Stefen Fangmeier—contouring software; David Chen—rendering software; Michael McKenna preview software; Bob Wihelmson, Crystal Shaw and Lou Wicker—simulation data.

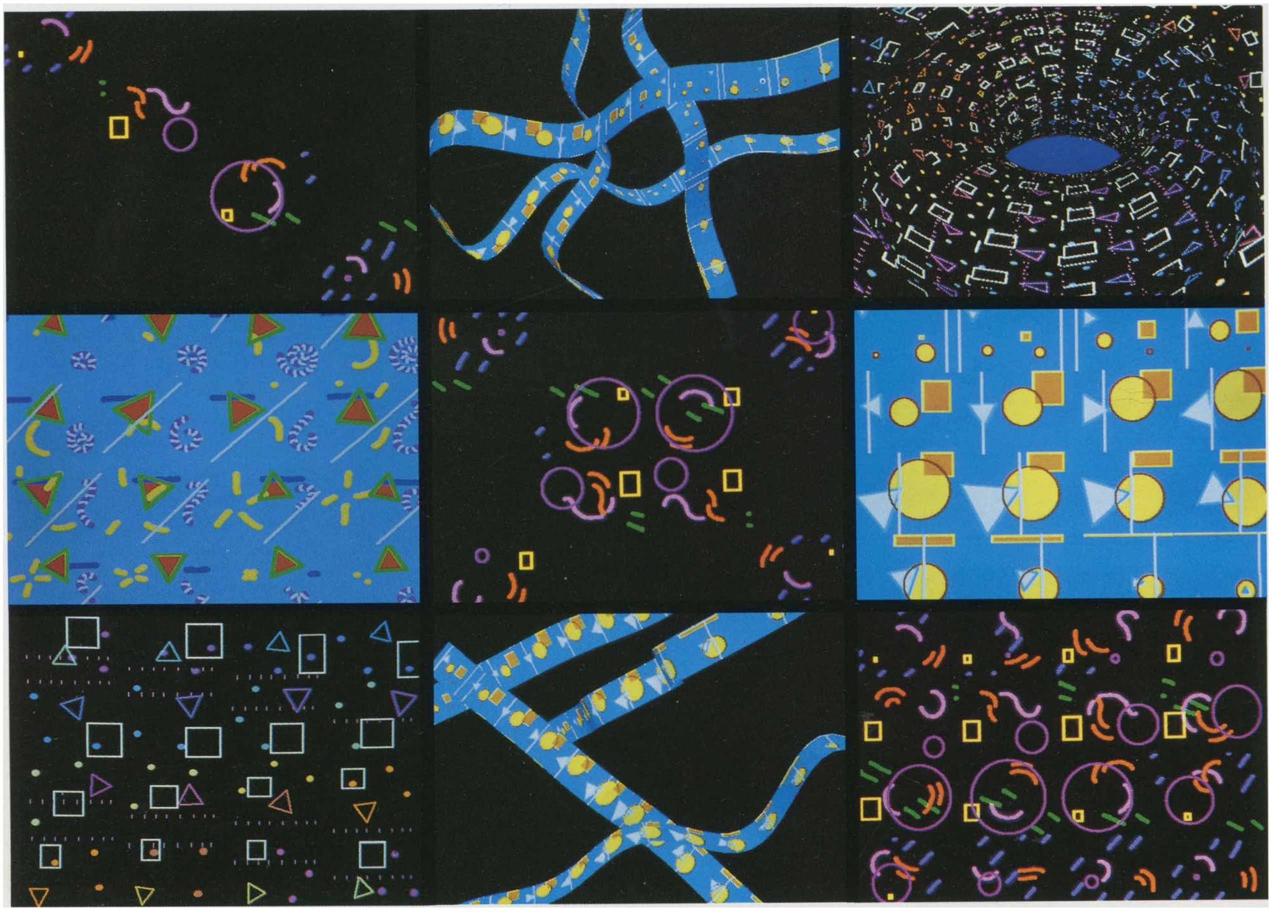
No. 69. Helaman Ferguson, *Umbilic Torus NC*, silicon bronze, 27 × 27 × 9 in, 1988. Collaborators: Paul Oliphant programmer; Kent Kokohnen—manufacturing engineer; Jordan Cox—mechanical engineer; and the Computer Aided Manufacturing Lab., Brigham Young University; casting by Wasatch Bronzeworks, Lehi, Utah.



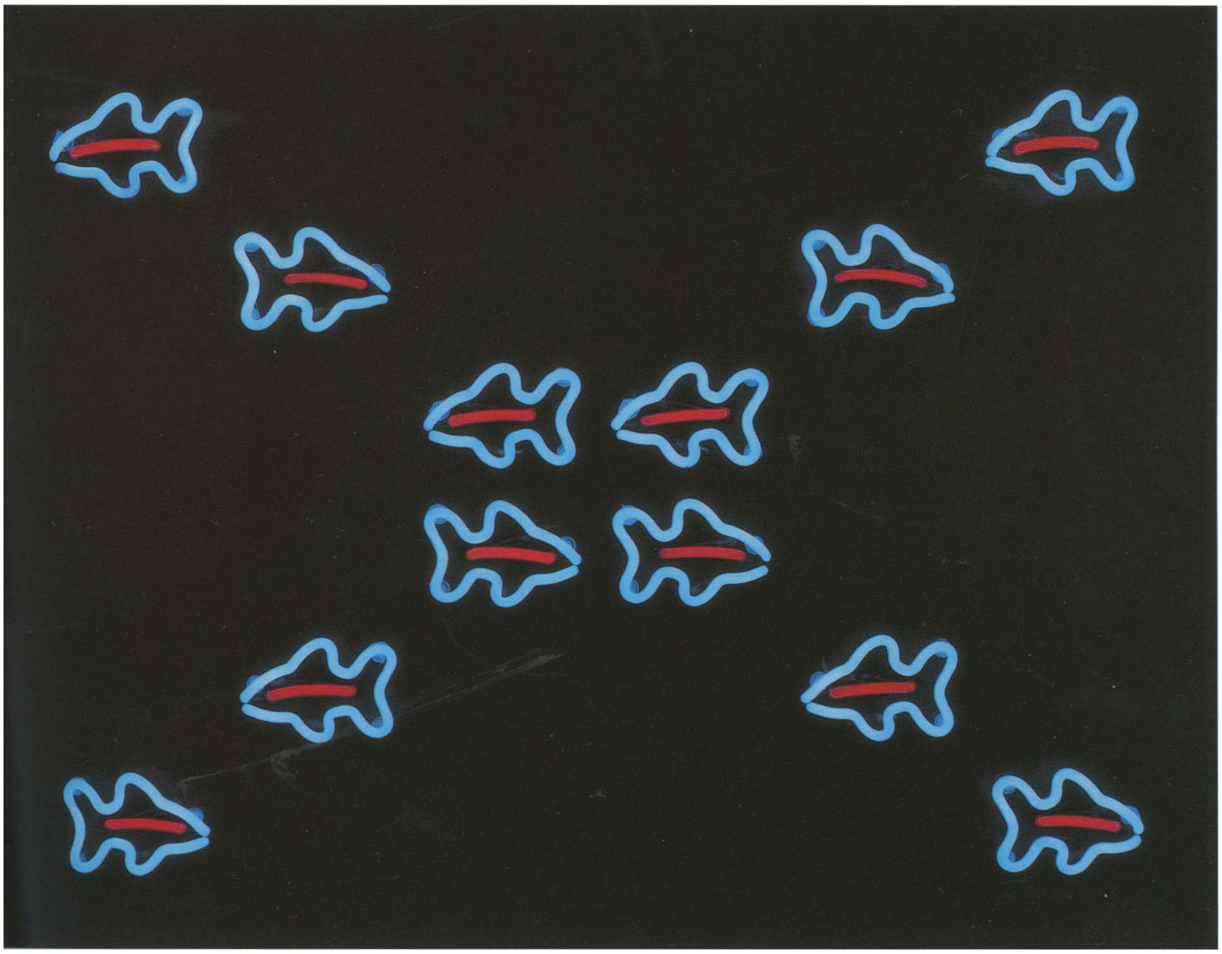
No. 70. Ellen Sandor, *Chaos/Information as Ornament/A Tribute to Louis Sullivan*, aluminum, glass, barrier-strip autostereograms, 18 × 60 × 96 in, 1989. Collaborators: Tom DeFanti, Dan Sandin, Stephan Meyers and John Hart, Electronic Visualization Lab., University of Illinois at Chicago; Randy Johnson, sculptor; Ron Nielsen, Nielsen Studios; Alan Norton, IBM TJ Watson Research Center.



No. 71. Shin Yusa, *Computer Jungle*, sculpture, 78.75 × 46 × 32.25 in, 1988.



No. 72. Vibeke Sorensen, *NLOOPS*, video installation, 1989. Collaborator: Rand Steiger—music.



No. 73. Karl X. Hauser, *wall-o-fish*, computer-animated neon, 60 × 84 in, 1989.

SIGGRAPH '89 ART SHOW ARTISTS LIST

(with plate numbers and artwork names)

Anderson, Steve
Folk Art Fish Tank (not shown), sculpture using broken computer terminal, 24 × 24 × 36 in, 1988. Collaborators: Rich Gould, Joan Stavely.
Ohio Supercomputer Graphics Project
1224 Kinnear Rd.
Colombus, OH 43212
U.S.A.

Bangert, Colette and Charles
Dawn's Diagonals, No. 60
Dawn's Leaf (not shown), colored ink on paper, 17 × 22 in, 1989.
721 Tennessee
Lawrence, KS 66044
U.S.A.

Banks, John
Manuscript 27 (not shown), photograph, 20 × 24 in, 1988.
PO 10369
Chicago, IL 60601
U.S.A.

Bertol, Daniela
Bending and Twisting: Hypothesis #3, No. 10
18 W 70th Street #5C
New York, NY 10023
U.S.A.

Bueno, Luz
Medieval Figures, No. 36
548 Cragmont
Berkeley, CA 94708
U.S.A.

Burnham, Sheriann Ki-Sun
Caprice (not shown), mixed-media construction, 32 × 28 × 3 in, 1989.
227 Ancona Drive
Long Beach, CA 90803
U.S.A.

Calahan, Sharon
Night Cafe Wurlitzer, No. 29
Cubicomp Canada Limited
450-1550 Alberni Street
Vancouver, BC
Canada, V6G 1A5

Colby, Tracy
Six Holes, Five Read, No. 5
5529 SW Patton Rd
Portland, OR 97221
U.S.A.

Cooper, Waltraut
Klangmikado, Nos. 62, 63
Ottensheimerstrasse 41
A4040 Linz
Austria

Cox, Michael
Disk (not shown), enamel and watercolor on paper, wood, 45 × 45 in, 1987.
308 N. Pleasant St, #2
Amherst, MA 01002
U.S.A.

Dehlinger, Hans
Cube 4, No. 17
Stiegelwiesen 3
3500 Kassel
Federal Republic of Germany

Ferguson, Helaman
Umbilic Torus NC, No. 69
10512 Pilla Terra Court
Warfield's Range
Laurel, MD 20707-5728
U.S.A.

Finley, Robert (Steve)
Biblio.Face, No. 7
Redtower.S, No. 12
514 S. Kimbrough
Springfield, MO 65806
U.S.A.

Fischer, Jürgen Lit
Vibrant, No. 11
Geibelstr. 24
4000 Düsseldorf
Federal Republic of Germany

Flanagan, Robert
Five Volts, No. 34
PO Box 14186
Fort Lauderdale, FL 33302
U.S.A.

Freeman, Nancy
All Sisters, Small Change, No. 46
3600 Sprucedale Dr.
Annadale, VA 22003
U.S.A.

Guzak, Karen
Red Ridge, No. 6
1517 12th Avenue
Seattle, WA 98122
U.S.A.

Hamilton, Robert
Exhibition Experiment #2A, No. 45
2120 Enon Road
Atlanta, GA 30331
U.S.A.

Hauser, Karl X.
wall o-fish, No. 73
1093 Dolores #4
San Francisco, CA 94110
U.S.A.

Hebert, Jean-Pierre
Untitled (reference #87), No. 18
801 Via Herba
Santa Barbara, CA 93110
U.S.A.

Herrnstadt, Steven
Phoenix Nov 03, No. 13
Phoenix Nov 06, No. 14
Global Pillage, No. 15
1613 Clark
Ames, IA 50010
U.S.A.

Hickman, Craig
Signal to Noise, pages 20, 21, No. 4
615 E. 39th
Eugene, OR 97405
U.S.A.

Hillier, Karen
Mud Shrine, No. 19
Bringing Samuel Home, No. 20
Shrine Quilt, No. 21
712 Eagle Pass
Bryan, TX 77802
U.S.A.

Hoffman, Patricia
Home Sweet Home Quilt, No. 24
124 West 60th St #14E
New York, NY 10023
U.S.A.

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Holland, Harry
Box 71 Series (#6, #7, #8, #9), No. 59
Art Dept., Carnegie Mellon University
Schenley Park
Pittsburgh, PA 15213
U.S.A

Hushlak, Gerald and Jevans, David
Spherical Corner, No. 61
Art Department, University of Calgary
2500 University Drive, NW
Calgary, Alberta
Canada T2N 1N4

Jascha, Johann
Innersoul, No. 53
Line Brain, No. 54
African Heart, No. 55
Engerthstr. 195
A-1020 Vienna
Austria

Joffe, Barbara
Tower, No. 56
Circus, No. 57
4432 Park Blvd #2
Oakland, CA 94602
U.S.A.

Johnson, Michael
View From Below: on the Eye of the Storm, Nos. 67, 68
MIT Media Lab., E15-318
20 Ames Street
Cambridge, MA 01239
U.S.A.

Johnson, Patricia
Bumper Crop (not shown), serigraph, 16 × 24 in, 1989.
239 Ninth Avenue, Apt. 2B
New York, NY 10001
U.S.A.

Kamoi, Hiroshi
Flower Power, No. 38
NAMCO CG PROJECT
15-1/Shinei-Cho Kouhoku-ku
Yokohama
Japan 223

Kapan, Hillary
Emerging Forms (not shown), interactive installation, 1989.
Cleveland Institute of Art
11141 East Blvd.
Cleveland, OH 44106
U.S.A.

Kirka, Kathleen
Student 14, Nos. 39, 40, 41
2140 W. Webster
Chicago, IL 60647
U.S.A.

Lenavitt, James
Syntagram #1, No. 35
218 Pineland Dr.
Akron, OH 44321
U.S.A.

MacNeil, Ron
Ronfish, No. 37
Visible Language Workshop, MIT Media Lab.
20 Ames Street, RM E15-443
Cambridge, MA 02139
U.S.A.

Mallary, Robert
Untitled (not shown), stereo slide pair, 1989.
Art Department
University of Massachusetts at Amherst
Amherst, MA 01003
U.S.A.

Martin, Robert
Back to the Future, No. 23
8905 E Jefferson, Apt. 905
Detroit, MI 48214
U.S.A.

McDevitt, Marsha
Mornings, No. 28
1224 Kinnear Road, c/o ACCAD The Ohio State University
Columbus, OH 43212
U.S.A.

McLean, Jim
The Sprite Fantastic #4, No. 58
Once Over Sprightly (not shown), serigraph, 10 × 13 in, 1988.
3509 Cold Spring Lane
Chamblee, GA 30341
U.S.A.

Migliore, Susan
Two Triangles, No. 16
1589 Caribbean Way
Laguna Beach, CA 92651
U.S.A.

Mohr, Manfred
P 417-E, No. 9
20 North Moore Street
New York, NY 10013
U.S.A.

Monroe, Kit
Series—Does Appropriation Count? 1 (not shown), ink jet print, 24 × 30 in, 1989.
2148 Sand Hill Road
Menlo Park, CA 94025
U.S.A.

Moojedi, Kamran
Number Series, No. 52
900 Sierra Madre #122
Azusa, CA 91702
U.S.A.

Morie, Jacquelyn Ford
The Powers That Be, No. 33
2425 Riverview Blvd. W.
Bradenton, FL 34205
U.S.A.

Muskovitz, Rosalyn
Woman's Work, No. 51
Betty Furness Metamorphosis (not shown), ink on paper, photocopy, 13 × 33 in, 1987.
3731 Highgate
Muskegon, MI 48441
U.S.A.

Nessim, Barbara
Thoughts of the Moon, No. 50
63 Greene St.
New York, NY 10012
U.S.A.

Oskoui, Saba and Sitton, Rodney
Pixel Frame (not shown), plexiglass, wood, steel, 35 × 11.5 × 4 in, 1988.
4427 Fox Hollow #6
Eugene, OR 97405
U.S.A.

Paston, Herbert
The Magic Revealed (not shown), assemblage, 17 × 12 × 3 in, 1988.
28 S Silver Lane
Sunderland, MA 01375
U.S.A.

Pinto, Venantius; Spicer, David; Bastian, Maurice
And You Thought the Eighties Were Bad, No. 64
215 Willoughby Ave, #1207
Brooklyn, NY 11205-3896
U.S.A.

Reffin Smith, Brian
Horse Text Piece, No. 1
Text Text Piece, No. 2
Crossing Sign Text Piece, No. 3
Stettiner Strasse 59
1000 Berlin 65
Federal Republic of Germany

Rexroad, Dennis H.
Missing Foundation, No. 32
My First Appearance at Rockefeller Center (not shown), collage, 20 × 24 in, 1989.
510 S. Kimbrough
Springfield, MO 65806
U.S.A.

Riss, Micha
Leo Castelli, No. 25
39-51 44th Street, 2nd Floor
Sunnyside Gardens, NY 11104
U.S.A.

Rosen, Terry
The Ruby Slippers, No. 31
101 West 81st St.
New York, NY 10024
U.S.A.

Sabiston, Bob
Chaos, No. 26
Visible Language Workshop, MIT Media Lab.
20 Ames St, RM E15-443
Cambridge, MA 02139
U.S.A.

Sandor, Ellen
Chaos/Information as Ornament/A Tribute to Louis Sullivan, No. 70
$(\text{Art})^n$ Laboratory
Illinois Institute of Technology
319 Wishnick Hall
3255 S. Dearborn Avenue
Chicago, IL 60616
U.S.A.

Schminke, Karin
Triple Cross (not shown), ink jet print on rice paper, 8 × 23 in, 1988.
4226 Esteban Road
Woodland Hills, CA 91364
U.S.A.

Shaw, Jeffrey
The Legible City, No. 49
Javastraat 126
Amsterdam 1094hp
Holland

Simmons, Michael S.
Essence of Form, No. 30
50 4th Avenue North
Minneapolis, MN 55401
U.S.A.

Snelson, Kenneth
Invasion, Nos. 65, 66
140 Sullivan Street
New York, NY 10012
U.S.A.

Sorensen, Vibeke
NLOOPS, No. 72
301 E Claremont Street
Pasadena, CA 91104
U.S.A.

Stamos, John
Smokers #4, No. 27
425 W. Surf St. #615
Chicago, IL 60657
U.S.A.

Sturgeon, John
Curtain, No. 42
Face Mask, No. 43
Head Wand, No. 44
Department of the Arts
Rensselaer Polytechnic Institute
Troy, NY 12180
U.S.A.

Toscano, Antonio
Silences (not shown), dot matrix print, 7 × 7 in, 1987.
Rochester Inst. of Technology
School of Visual Communication
1 Lomb Memorial Drive
Rochester, NY 14623-0887
U.S.A.

Travers, Michael
Electric Anthill, No. 48
MIT Media Lab.
20 Ames Street
Cambridge, MA 02139
U.S.A.

Ursyn, Az
Two Skies, No. 22
2201 Warren
Laramie, WY 82070
U.S.A.

Valesco, Frances
Transition 12 (not shown), serigraph, 20 × 30 in, 1988.
135 Jersey St.
San Francisco, CA 94114
U.S.A.

Weil, Peggy
Scan/Look/Express, No. 47
3448 Mandeville Canyon Road
Los Angeles, CA 90049
U.S.A.

Wilson, Mark
STL D26, No. 8
POB 23
18 River Road
West Cornwall, CT 06796
U.S.A.

Yazzolino, Brad
Voltaic/Transistor/Chip (not shown), glazed ceramic tile, 39 × 39 in, 1988.
1324 SE Harney Street
Portland, OR 97202
U.S.A.

Yusa, Shin
Computer Jungle, No. 71
NEC Corporation
4-28 Mita 1-chome, Minato-ku
Tokyo 108
Japan

SIGGRAPH '89 Art Show Jury

Patric D. Prince is an art historian and theorist specializing in the history of computer art. She has taught at the Pratt Institute in Brooklyn, California State University (Los Angeles) and West Coast University (Los Angeles). Prince has curated a number of computer art exhibitions, including the Second Emerging Expression Biennial at the Bronx Museum of the Arts. She is currently curating a stereo-optic art exhibition for CADRE to be held in June 1989. Prince is the director of the SIGGRAPH educational committee's library project and is the SIGGRAPH '89–90 Traveling Art Show Chair. Prince has written a number of articles on the history of art and technology and has contributed to several previous ACM/SIGGRAPH publications.

Dorothy Spencer has a masters degree in printmaking and design and one in twentieth-century art history, both from Temple University in Philadelphia. She has just finished a book, *Total Design*, to be published by Chronicle Books, San Francisco, in the fall of 1989. Spencer is a contributing editor for several art magazines and a partner in the publishing company Read/Write Press, Princeton, NJ.

Copper Giloth is a computer graphics artist/programmer and an Associate Professor in the Art Department at the University of Massachusetts, Amherst. She teaches computer graphics and video. Giloth's research interests include real-time animation, software tools for artmaking, graphics languages and user interfaces for plotters and interactive installations. She has taught at the School of the Art Institute, Chicago, and the University of Michigan, Ann Arbor, and was with Real Time Design from 1981 to 1984 as a software engineer and vice president in charge of applications software.

Lorne Falk is an independent curator and critic of contemporary art living in Montreal, Quebec. Formerly the curator of the Walter Phillips Gallery in Banff, Alberta, Canada, he established an international program for contemporary art that included exhibitions such as "Chicago: Biographies of an Interactive Lifestyle", and "The Second Link—Viewpoints on Video in the 1980s". Falk has published more than 50 essays. In 1985 he coedited the anthology *The Event Horizon: Essays on Hope, Sexuality, Social Space and Media in Art*. In September 1989 he will be in charge of a studio residency program for artists at the Banff Centre in Alberta.

Christine Schöpf began working at the Upper Austria Regional television and radio studio in Linz, Austria, in 1977 in the area of news and politics. In 1981 Schöpf was made responsible for the art and science program at ORF. In 1979 Schöpf helped to create ARS ELECTRONICA: The Festival of Art, Technology, and Society, held annually at Linz, Austria. She has contributed greatly to the conception and organization of the festival itself as well as many programs sponsored by the festival including the PRIX ARS ELECTRONICA, an international computer art competition. In 1988 she served as the editor of the PRIX catalog *Meisterwerke der Computerkunst*. Schöpf actively promotes and supports the creation of computer art.

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SIGGRAPH '89 Art Show Catalog Article Reviewers

Phil Burk, applications developer, Center for Contemporary Music, Mills College, Oakland, California.

Vladimir Bonacic, corresponding member, European Academy of Arts, Sciences and Humanities.

Jane Veeder, Director, Advanced Computer Imaging Center, School of Creative Arts, San Francisco State University, San Francisco, California.

Rob Fisher, professor and artist-in-residence, College of Engineering, Pennsylvania State University, State College, Pennsylvania.

Joan Shafran, teacher, manager of typographic research, Bitstream, Inc., Cambridge, Massachusetts.

Rob Haimes, design consultant, 14 Lee Street, Cambridge, Massachusetts.

Vibeke Sorensen, Film and Video Faculty at the California Institute of Technology, Pasadena, California.

Copper Giloth, Associate Professor, Art Department, University of Massachusetts, Amherst, Massachusetts.

George Shortess, teacher of art and psychology, Lehigh University, Behtlehem, Pennsylvania.

Frank Dietrich, European Marketing Manager, Animation and Publishing, Silicon Graphics, Mountain View, California.

Joan Truckenbrod, director of Art and Technology program, School of the Art Institute of Chicago.

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Edward Zajec, professor, Department of Art Media Studies at Syracuse University, Syracuse, New York.

Russell A. Kirsch, Director of Research, Sturvil Corporation, Clarksburg, Maryland.

Hank Clauser, research associate in computer graphics and visual arts, SUNY, Purchase, New York.

Robert Mallary, teacher of graphics programming and computer art, University of Massachusetts, Amherst, Massachusetts.

Edward Pope, Associate Professor, University of Wisconsin at Madison.

Ray Lauzzana, professor of art and computer graphics, University of Massachusetts, Amherst, Massachusetts.

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Aaron Marcus, graphics design consultant, Aaron Marcus and Associates, Berkeley, California.

Edward Zajec, professor, Department of Art Media Studies at Syracuse University, Syracuse, New York.

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The International Society for the Arts, Sciences and Technology is a non-profit organization founded in 1981 for professional artists, scientists, engineers and others interested in the contemporary arts. The Society, through its projects and services, seeks to encourage the interaction of art, science and technology.

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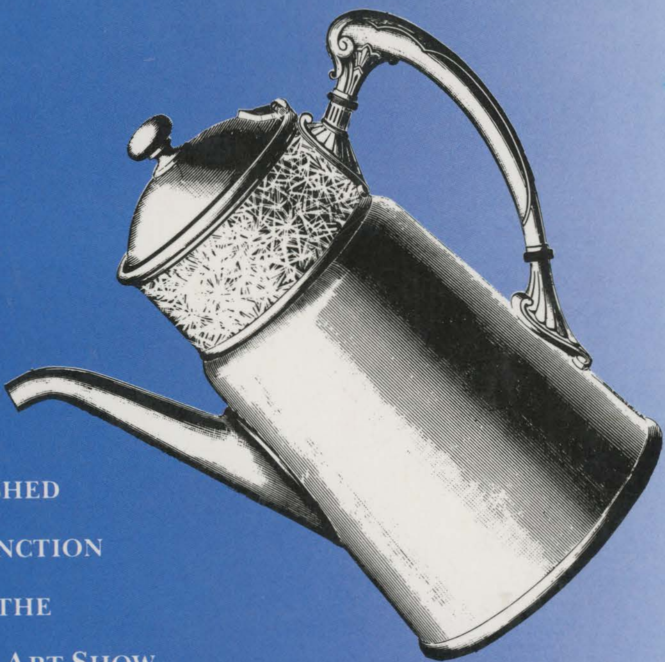
Headquarters
Theodosia H. Ferguson
Executive Director
I.S.A.S.T.
1442A Walnut Street, Box 75
Berkeley, CA 94709
U.S.A.
Phone: 415-845-8306
Electronic Mail:
leonardo@well.UU.NET

Secretariat
Heide Scheiter-Rohland
Membership Manager
I.S.A.S.T.
8000 Westpark Drive, Suite 400
McLean, VA 22102
U.S.A.
Phone: 703-790-1745

European Office
c/o Mrs. Marjorie Malina
Leonardo
8 rue Émile Dunois
92100 Boulogne-sur-Seine
France



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