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COMPUTERS AND VISUAL ART*

H. W. Franke**

Abstract—*Computer graphic art is a logical outcome of graphic art produced by simpler machines and by calculation. Up to now digital and analog computers have been used that were originally designed for scientific and technical purposes, and they are adequate for the artistic task but their output still proves to be a bottleneck. A further difficulty arises from the fact that aesthetic theories suitable as a base for computer art are still in their infancy. The use of computers means breaking with some art traditions but, on the other hand, it may well lead to a breakthrough in art and a better, rational understanding of artistic phenomena.*

I. ART AS AN INFORMAL PHENOMENON

One way of regarding the application of the computer in the realm of art is to see it as part of the technological revolution that is transforming all departments of modern life, including those least concerned with technical production processes.

There is no doubt that some phases of art-creating processes can be mechanized and automated. If we set aside the mystic aura, the essential task in producing a work of art consists in designing a composition from basic elements—shapes, sounds or words. The sole condition that these elements must satisfy is that they have to be visually or aurally perceptible.

The production of a work of art consists of two phases:

1. Generation of signals.
2. Arrangement of constituent elements.

The first phase is a physical process that can be 'instrumentalized' quite easily. In music, for instance, the use of sound-producing instruments and machines is accepted as perfectly normal. The generation of visual symbols is likewise a physical process but an understanding of it did not become available until much later than acoustic techniques employed in music. Consequently, the view still widely held in academic circles is that the use of machines disqualifies computer graphics as an art form.

The second phase—the aggregation of the symbols according to certain rules of order—is an informational process that can now be handled by the data processing systems of the computer and, for the first time, one can come to grips with the real problems of visual design through 'instrumentalization' [1–3].

II. THE THEORETICAL BASIS OF COMPUTER ART

A. Statistical analysis of works of art

The belief that the computer can be used to good effect in art rests on the assumption that works of art can be expressed in mathematical and, particularly, in statistical terms. This assumption receives support from the fact that the human brain with the organs of perception constitutes a data processing system that relies on much the same analytical processes as the computer in performing one of its most vital tasks, the recognition of patterns. Since works of art are perceived only by way of the sense organs and the brain—and not by any extrasensory means—there is no apparent reason why aesthetic arrangements cannot be expressed in rational terms. Accordingly, if we take a random selection of patterns and examine them with the aid of statistics for features of regularity, it follows that aesthetic arrangements will be reflected in the results.

Although the method of *statistical aesthetics*, of which the foremost exponent today is Wilhelm Fucks of Aachen [4], cannot be looked upon as a theory, it does provide a quantitative basis for computer art. Once laws of aesthetics have been ascertained statistically, they can be embodied in programs. The resulting compositions will show whether relevant aesthetic principles have been preserved. If, for instance, we use Markoff chains of a certain order for the analysis and construction of aesthetic compositions, it will be apparent whether the information resulting from that order exhibits the effective principles. Examples of this have been given by H. Kupper [5]. Similar procedures can be adopted in computer graphics. A. Michael Noll has

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attempted to capture the characteristics of Piet Mondrian's style and apply them in programs for computer graphics [6]. F. Nake has worked with paintings by Hans Hartung and by Paul Klee [7].

B. Information aesthetics

The disadvantage of the statistical method is that it can draw upon only the rules of style of existing works of art and, consequently, it is not directly useful as a means of achieving artistic progress. To pioneer in the production of art by formulating hitherto untried design principles with the aid of the computer, we need quantitative guidelines for its production. The school of *information aesthetics*, represented by Max Bense and his students, derives these guidelines from philosophical reflection. Using Shannon's statistical information [8], the procedure can specify dimensional values for works of art. In the programs for computer graphics, these values can be assigned to produce compositions. This approach forms the basis of the work of the German computer graphic artists, Frieder Nake and Georg Nees.

C. Cybernetic theory of art

Bense's information aesthetics suffers from the drawback that the correlation between its dimensional values and the subjective qualities of pleasure, beauty etc. is hard to establish. It is clear, however, that his method makes it possible to take human factors into account and to define in quantitative terms when a pattern may stimulate aesthetic interest and when it may not. This school of thought is based on the processes of perception; it regards an artistic composition as having aesthetic value if it satisfies the following conditions:

1. A picture must be designed in a way that stimulates its perception [9]. To ascertain configurations that satisfy these requirements, the method employs the techniques of information psychology.
2. A picture must incorporate certain 'strategic' design features that keep the perception processes active for as long as possible and stimulate them to new activity again and again [9].

The science that concerns itself with the study of these processes is called *information psychology*, a branch of cybernetics. *Cybernetic aesthetics* can provide the first leads for systematic production. For the pioneer work in this field, we are indebted to Abraham Moles [10] and Helmar Frank [11].

The essential difference between Bense's information aesthetics and cybernetic aesthetics is that the former requires a high aesthetic content, given by:

$$M_A = f\left(\frac{O}{C}\right),$$

where O is the degree of order and C the complexity; there are specified rules of measurement for these terms [12, 13]. Cybernetic aesthetics, on the other hand, specifies certain optimum ratios of information and redundancy, suited to the receptive capacity of consciousness. If, for instance, a picture element is to stand out with maximum clarity against a background, the ratio of this element to other elements as regards dominance, according to H. Frank, would have the value:

$$p = \frac{1}{e} = 37\%$$

Needless to say, it is also possible to produce computer art, lyrics and music by the method of trial and error, that is, without any theory at all. This playful use of the computer may, of course, lead to pleasing results and, as the available theories are still very rudimentary, it is often the only course open to us.

III. CREATIVE POSSIBILITIES OF COMPUTER ART

The mere fact that it is possible to use a machine is not in itself a justification for using it [14]. In computer art or in any other machine application, there are two criteria by which this issue should be decided:

1. Is it possible, by using a machine, to achieve something that would not be feasible without it?
2. Is it possible, by using a machine, to do something better or faster than before?

It is obvious that not all areas of visual art lend themselves equally well to instrumentalization but there are some for which the answer to these questions is definitely affirmative. Two examples will illustrate the point:

A. Non-figurative or abstract graphics

The fact that many works of computer graphics are of geometrical design—that is, akin to constructivism and Op art—might lead one to suppose that these are the only styles the computer can handle. This is not the case. Since any distribution of form and color elements theoretically can be incorporated in programs, there is no style that must elude the computer. There are, of course, certain simpler aesthetic guidelines that it is particularly well equipped to follow and, undoubtedly, this is the case for geometrical art.

If we disregard the conflicting views of artists regarding their constructivist works, it will be seen that for these kinds of pictures mathematical precision has been discovered to be of aesthetic value. Mathematical precision, however, is one of those qualities that can be attained by mechanical aids far beyond the degree attainable by hand. The ruler and compass used by the classical constructivists obviously limit the range of lines that can be drawn. Curves of higher order, easily made by the computer, afford a much wider range of graphic possibilities to the artist. The fine construction of a set of curves to produce a translucent texture akin to the chords of a musical composition calls for high precision. In design based on constructivist principles, at least, the computer enables us to go far beyond what was possible by conventional means.

B. Figurative graphics

Figurative art is another field where the computer can explore uncharted territory. Just like any artist engaged in representational figurative work, the computer must begin by using its 'eyes' to see objects in the environment that it wishes to use in a picture. An ordinary camera or a television camera will serve for this purpose. The special feature of representational computer graphics is that the visual information received can be altered in a great variety of ways. It is possible, for instance, to disintegrate human figures successively, or—more interesting still—process a number of pictures to achieve a blend. Examples of computer-controlled picture transformation are available in the work of Charles Csuri and the Japanese Computer Technique Group (CTG).

IV. IMPLICATIONS OF COMPUTER SPEED OF PRODUCTION

Even where the computer has nothing fundamentally new to offer but is merely a faster method of working, it can represent an important advance. Here again I will take two examples:

A. Calculated graphics

There are works of constructive art that, although not produced with the aid of a computer, are nevertheless calculated. The works of Klaus Basset and Hermann Stiegler, for example, were first computed and then executed by hand. The use of the computer equipped with a plotter system would make it possible to produce, within a matter of days, series on which the painters and graphic artists spent years of work. The time required for execution, which hitherto has accounted for the greater part of the total working time, would then be inconsiderable and the artist could devote himself to his proper task, the formation of ideas. Many of the works of Frieder Nake, for example, those based on matrix multiplications, belong to this class of calculated graphics.

B. Computer cinema production

The computer's speed of operation makes it an ideal instrument for the production of animated films. Since the movements a human body is able to make can be programmed, all that is required to produce a film with moving figures is a set of positioning instructions. An example of a computer film is 'Hummingbird' by Charles Csuri.

V. SHORT HISTORY OF COMPUTER GRAPHICS

Viewed historically, computer graphics are the result of two distinct lines of development. The first began with ornaments and led in a direct line, via constructivism and calculated graphics, to the computer. The second began with virtually unrecognized machine-based art that led by way of mechanical, optical and electrical systems to its culmination in electronically automated objects.

Fig. 1. Electronic graphic design, made with the aid of an analog computer and a cathode ray oscilloscope. The elements used were various voltage waveforms, sine curves, saw-tooth curves, rectangular curves etc., generated by a Siemens demonstration unit. The basic elements were manipulated in a switching unit by addition, subtraction, integration, differentiation etc. via a mixer console. The composition was produced by H. W. Franke in 1961/62.

In 1952, computer graphics were generated with analog systems by Ben F. Laposky (U.S.A.) [15] and by myself, in 1956, (cf. Fig. 1) and by Kurd Alsleben and by Cord Passow in 1960 in the Federal Republic of Germany. Digital graphics were published in 1963, simultaneously but independently, by Frieder Nake (F.R.G.) (cf. Fig. 2) and by Georg Nees (F.R.G.) (cf. Fig. 3) and by A. Michael Noll (U.S.A.). The first examples of figurative art were made in 1967 by Charles Csuri (U.S.A.).

Large exhibitions of computer graphics have been the following:

Cybernetic Serendipity, London, 1968
Tendencija 4, Zagreb, 1969
Computerkünst, Hannover, 1969; Munich, 1970; Hamburg, 1970.

Since 1963 the periodical, *Computer and Automation*, published at Newtonville, Mass., has held an annual computer graphics competition.

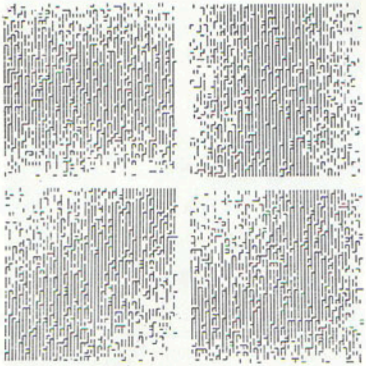


Fig. 2. F. Nake: Distribution with a weighted randomness, Series 2.1—1/2/3/5. The area of greatest density at the top left is a horizontal strip in the center of the picture; at the top right a vertical strip; and at both bottom left and right the most densely packed area runs diagonally across the square surface.

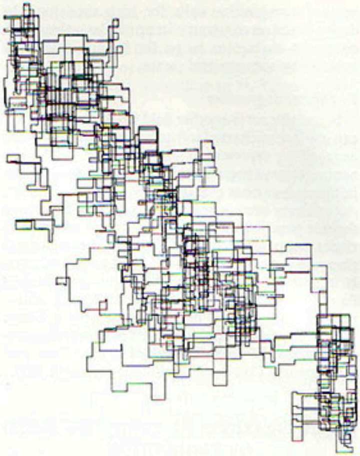


Fig. 3. G. Nees: 'Irrweg' (Maze). Generated from 2000 vertical and horizontal elements with a 'degenerate random generator' (based on an inadequate calculating statement for pseudo-randomness, which shows periodicity).

Up to now, chiefly mathematicians and engineers have achieved practical results with computer graphics. Few of them deliberately explore new artistic ideas. For them it is more a question of experimenting light-heartedly without any definite aim in view. Usually the starting-point has been some attractive design of scientific or technical origin, although occasionally the incentive has come from companies seeking demonstration material for their computers and plotters.

Otto Beckmann (Austria), a painter and sculptor, uses the computer for designing sculptures and choreographies (cf. Fig. 4). Lloyd Sumner (U.S.A.), an engineer and artist, designs computer graphics for sale, for example, in the form of Christmas cards. Little by little, computer graphic art is being given recognition by aestheticians and art experts. The latest evidence of this was the attention drawn by a special exhibition of some of these works by Franke, Lecci, Nake, Nees, Peterson and others at the Venice Biennale in 1970.

VI. RECENT ACTIVITIES IN COMPUTER GRAPHICS

During the last two years there has been evidence of mounting interest in computer art, not only on the part of the public but among mathematicians and artists as well. Without attempting to give a complete list, a few of the activities will be mentioned below.

Systematic cooperation between artists and mathematicians has been arranged at the computer center of the University of Madrid. The results have been exhibited three times there. The most recent exhibition 'Generacion Automatica de Formas Plasticas', organized by E. Garcia Camarero, drew international attention. The foremost Spanish representatives of computer art are J. L. Alexanco, M. Barbadillo, M. Quejido and S. Sevilla. Of special note are some graphic and sculptural works that were executed in plastic material by hand after the computer had produced a large number of combinations of simple elements (cf. Fig. 5).

Several Dutch artists, A. Eikelenboom, H. Koetsier, R. D. E. Oxenaar and P. Struycken (cf. Fig. 6) have been in the news, in particular, Oxenaar for his design that has been used on a postage stamp. Manfred Mohr (France) (cf. Fig. 7) has produced over 100 computer drawings, which he exhibited in May 1971 at the Musée d'Art Moderne de la Ville de Paris. In Austria, at Vienna and Wiener Neustadt, the group, *Ars Intermedia*, has been busy under the leadership of Otto Beckmann. Their aim is the application of the computer for the production of graphics, sculpture, poetry and music. Special mention should be made of their latest development, a hybrid system for the simultaneous production of computer films with sound. In Switzerland, G. Honnegger-Lavater has been occupied with the computer-aided generation of reliefs. Pictures are being made with the aid of the computer by Auro Lecci (Italy) (cf. Fig. 8), by Zdeněk Sýkora in Czechoslovakia [2] and graphics by Waldemar Cordeiro and Giorgio Moscati in Brazil (cf. Fig. 9).

Fig. 4. O. Beckmann and A. Grassl of the Ars Intermedia *group: Electronic computer graphics for the design of a sculpture. The output device was a cathode ray oscilloscope.*

Stimulated by the work on computer graphics of the CTG (*Computer Technique Group*) in Japan, the CEAC (*Centro de estudios de arte y comunicacion*) of Buenos Aires, Argentina, brought computer technicians and artists together and the resulting works by Luis Benedit, Antonio Berni, Ernesto Deira, Eduardo Mac Entyre, Osvaldo Romberg and Miguel Angel Vidal were shown in October, 1969, in an exhibition entitled 'Arte y cibernetica en Olavarria'. Works by the CTG and by artists from other countries were included.

Since examples of computer graphics from Great Britain and the U.S.A. are rather widely known, the illustrations for this article have been drawn chiefly from the less familiar material of the younger generation of computer artists mentioned above.

VII. THE TOOLS OF COMPUTER GRAPHICS

Nearly all computer equipment used for producing an art output has been developed for scientific and technical applications.

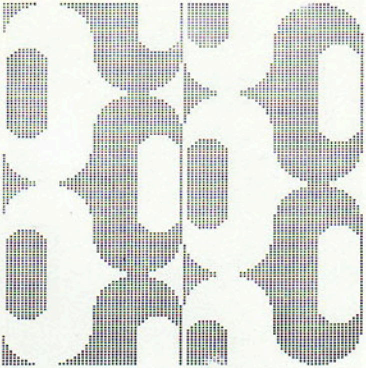


Fig. 5. Computer copy for the production of a drawing. The computer runs through many possible combinations of elements; the selection is determined by subjective criteria. Project carried out by M. Barbadillo, University of Madrid.

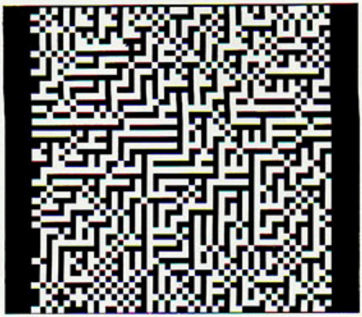


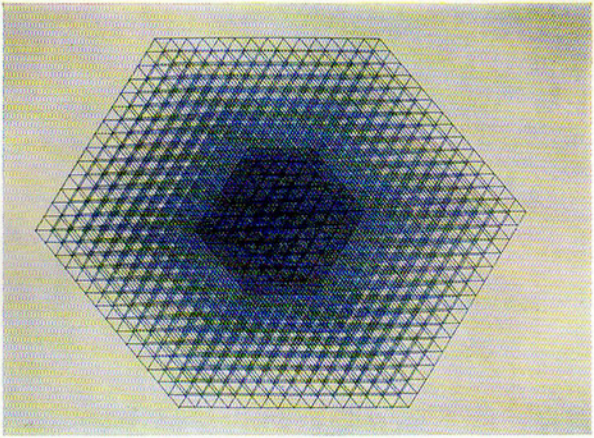
Fig. 6. P. Struycken: 'Computer Structure, 3a', 1969.

A. Analog computers

Analog computers, which were the first to be used, have proved particularly successful for drawing algebraic graphics, that is, the overlaying of curves (cf. Fig. 1). Complicated Lissajous figures, graphic solutions of differential equations, representations of space surface areas in the form of networks and the like have all resulted in patterns of aesthetic quality.

B. Digital computers

The range of possibilities has been greatly extended by the use of the digital computer, which allows the production of discontinuous patterns, for example, faster images. Frieder Nake uses matrix representation to assign colors, etc., to particular



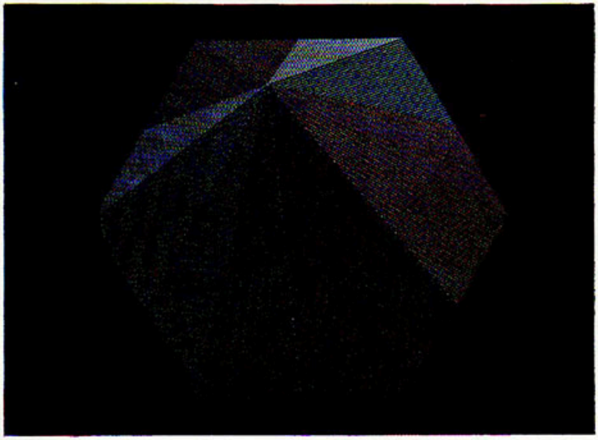


Fig. 8. A. Lecci: 'Lattice', 1969 (at top). Produced by a program of stereometric images of hexahedral lattices that can be rotated in space. Lattice nodes may be connected in different ways and their density inside the framework can also be controlled.

'Shift', 1970, (at bottom). Produced by a program, starting from a static two-dimensional linear pattern, that through the progressive displacement of a focal point in the pattern itself leads to a series of related images, each of which is a mapping of the original displacement. Different linear densities are caused in certain regions of the image with a corresponding simulated effect of three dimensions.

Both pictures made with an IBM 7090 computer and a 29 in. Calcomp 563 plotter at the Centro Nazionale Universitario di Calculo Elettronico, Pisa, Italy. The programming language was Fortran IV.

[facing p. 336]

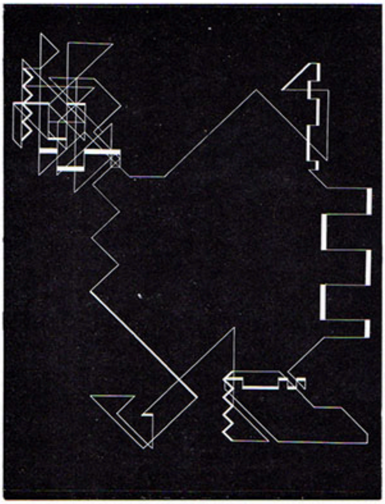


Fig. 7. M. Mohr: 'Polygonal Course', 1969.

points on a basic raster. An example of digital computer graphics is shown in Figure 10. Georg Nees has written programs for hieroglyphic-type characters with which he fills sheets in the same way as with writing. Digital computers are also the means for making figurative representations. A well-known example is a series of human figures by William A. Fetter. The program he used was originally designed to determine the most favorable arrangement of instruments in an aircraft cockpit.

C. Output devices

The most suitable output devices are electron-optical systems, such as the cathode ray oscilloscope and the television receiver. To obtain a permanent record of the pictures displayed on the screen, however, a reproduction process is required; usually a photographic one is used. This has proved an obstacle to gaining recognition for these compositions as works of plastic art, as it is contrary to the traditional form of such works. Many computer artists, therefore, make use of mechanical plotters, which suffer from the following disadvantages: they are slow in operation (20 minutes or more are required for a drawing) and they cannot produce a continuous transition from white to black or from one color to another, as can be done on a screen. Thus, the fact that the majority of computer graphics are line drawings is due to the output devices and not to the computer.

There are conversion systems which are used in machine tool manufacture for milling computer-calculated workpiece shapes. This type of output device, a sinumeric system, has been used by Georg Nees for the production of computer reliefs.

Fig. 9. Waldemar Cordeiro and Giorgio Moscati: Two transformations of the basic composition "Derivative of an Image". Made with the IBM 360/44 *computer at the University of São Paulo, Brazil.*

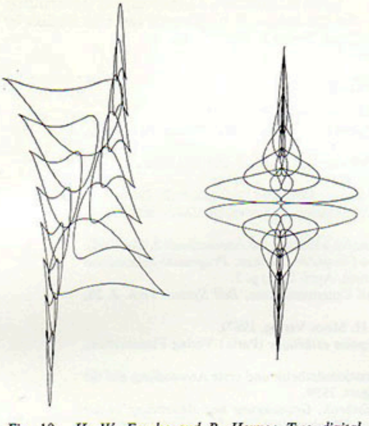


Fig. 10. *H. W. Franke and P. Henne: Two digital computer graphics,* 1970. *Produced with a program for overlaying algebraic and transcendental curves. Executed by Helmut Maier on a Siemens System* 4004 *computer.*

D. Software

To produce programs for aesthetic purposes, a variety of computer languages can be used; two that are frequently employed are ALGOL and FORTRAN. Some authors have worked out special languages for computer graphics based on these two languages [16, 17]. The development of these logical systems that lead to the production of outputs with various artistic styles can be regarded as the actual creative phase of computer art.

E. Random number generators

In some computer art programs, special importance is attached to the use of random numbers. The reason for this seems to be the fact that many works of art are not fully described by artistic style and that, accordingly, provision has to be made for elements of randomness. The artist is able to use intuition, spontaneity etc.; the cybernetic equivalent of these faculties appears to be the random number generator [18].

For this purpose, one can use lists of roulette numbers as well as numbers provided by systems such as noise generators or Geiger counter tubes. More commonly, pseudo-random sequences are used because they are well suited to the computer and sub-routines are obtainable from most computer program libraries. A simple way of generating random numbers would be to calculate an irrational number and use its decimal digits as a random sequence. The result is not, of course, a sequence of pure random numbers but it is free from correlations with any of the rules embodied in the program and therefore fulfils the same purpose.

A simple example of a randomly generated computer drawing is the 'maze' [17]. The program provides for a sequence of horizontal and vertical lines, whose lengths are left to chance (cf. Fig. 3). The only other requirements are a break signal and an instruction to prevent the plotter from running off the drawing surface.

A more interesting type of program is the stochastic program, which uses the method of 'weighted' randomness, that is, predetermined probabilities and mean values for the variables. This is illustrated by the graphics of F. Nake (Fig. 2). In figurative computer graphics, randomness may lead to the deformation of the subject matter, resulting in effects of the kind that are found in the style of cubism.

VIII. FUTURE PROBLEMS IN COMPUTER ART

The recognition of the computer as a means of artistic production may well mean that some of the traditionally held views of the artist's profession will have to be abandoned. It can be foreseen, for example, that:

a. the unique value of the original may be open to dispute;
b. manual fabrication by the artist may no longer be regarded as essential;
c. the artist may lose the mystic veneration that surrounds him;
d. scholars and art critics will be encouraged to use understandable concepts.

Even outside the fields of computer art, trends of this kind are increasingly evident, for example, the trend towards art objects in the form of multiples. In part, they also can be attributed to sociological considerations, that is, to the artist's desire to reach a larger number of people than is the case at the present time. Computer art lends itself well to these aspirations. Rapid and inexpensive production and the ability to duplicate are integral to the method. If the day comes, as we are told it will, when every household is connected to a computer network via a display terminal, anyone will be able to tune in on a large variety of aesthetic programs. For this purpose, variable programs that permit intervention by the viewer will be far more suitable than the static programs that are available today [19]. Perhaps in this way the gulf that yawns between the producer and the consumer will be slowly bridged. It will be some time before these possibilities can be realized but they should be borne in mind in any discussion of the practical implications of computer art.

From the technical, artistic and art lover point of view, it has to be admitted that computer art has barely taken off the ground. Although it happens at present to be one of the talking-points of contemporary art, it may well be that it will disappear from public view for a while. Taking the longer view, however, there is little doubt in my mind that it will bring more far-reaching changes than many of the art fashions that today dominate the scene in many countries.

I wish to thank the Siemens company for arranging the translation of my German text into English by Colin Jenkins.

REFERENCES

1. R. I. Land, Computer Art: Color-stereo Displays, *Leonardo* **2**, 335 (1969).
2. Z. Sýkora and J. Blažek, Computer-aided Multi-element Geometrical Abstract Paintings, *Leonardo* **3**, 409 (1970).
3. K. Nash and R. H. Williams, Computer Program for Artists: *ART* 1, *Leonardo* **3**, 439 (1970).
4. W. Fucks, *Nach allen Regeln der Kunst* (Stuttgart: Deutsche Verlagsanstalt, 1968).
5. H. Kupper, Computer und musikalische Komposition, *Elektronische Datenverarbeitung* **11**, 492 (1969).
6. A. M. Noll, The Digital Computer as a Creative Medium, *Bit International* **2**, 51 (1968).
7. F. Nake, *Bemerkung zur Programmierung von Computer-Grafiken. Programm-Information PI-21* (Darmstadt: Deutsches Rechenzentrum, April 1966) p. 3.
8. C. E. Shannon, A Mathematical Theory of Communication, *Bell System Tech. J.* **28**, 379, 623 (1948).
9. H. W. Franke, *Phänomen Kunst* (Munich: H. Moos Verlag, 1967).
10. A. Moles, *Théorie de l'information et perception esthétique* (Paris: Verlag Flammarion, 1958).
11. H. Frank, Grundlagenprobleme der Informationsästhetik und erste Anwendung auf die Mime Pure, *Dissertationsschrift*, TH, Stuttgart, 1959.
12. M. Bense, *Einführung in die Informationsästhetik, Grundlegung und Anwendung in der Text Theorie*. Rowohlt Taschenbuch Verlag, Oktober 1969.
13. S. Maser, Neue mathematische Verfahren zur quantitativen Beschreibung und Bewertung ästhetischer Zustände. *Habilitationsschrift*, TH, Stuttgart, 1969.
14. F. J. Malina, Comments on Visual Fine Art Produced by Digital Computers, *Leonardo* **4**, 263 (1971).
15. B. F. Laposky, Oscillons: Electronic Abstractions, *Leonardo* **2**, 345 (1969).
16. L. Mezei, Sparta, a Procedure Oriented Programming for the Manipulation Language of Arbitrary Line Drawings, *Bit International*, **2**, 81 (1968).
17. G. Nees, *Generative Computergraphik* (Munich: Siemens AG, 1969).
18. H. W. Franke, Ein kybernetisches Modell der Kreativität. *Grundlagenstudien aus Kybernetik und Geisteswissenschaft* **9**, 85 (1968).
19. H. W. Franke, Gesellschaftliche Aspekte der Computerkunst, *Bit International* **6** (1971).

Les calculatrices et l'art graphique

Résumé—L'art graphique par calculatrices est une conséquence logique de l'art graphique obtenu avec des machines plus simples ou par le calcul. On a utilisé des ordinateurs et des calculateurs analogiques initialement destinés à un usage scientifique ou technique; or, s'ils conviennent à cette tâche artistique, leur rendement est encore un blocage. Une autre difficulté se présente du fait que les théories esthétiques qui pourraient servir de base à l'art par calculatrices sont encore balbutiantes. L'usage de calculatrices signifie une rupture par rapport à certaines traditions artistiques mais d'autre part, il se peut que cela amène une percée nouvelle dans le domaine de l'art et une meilleure compréhension rationnelle des phénomènes artistiques.