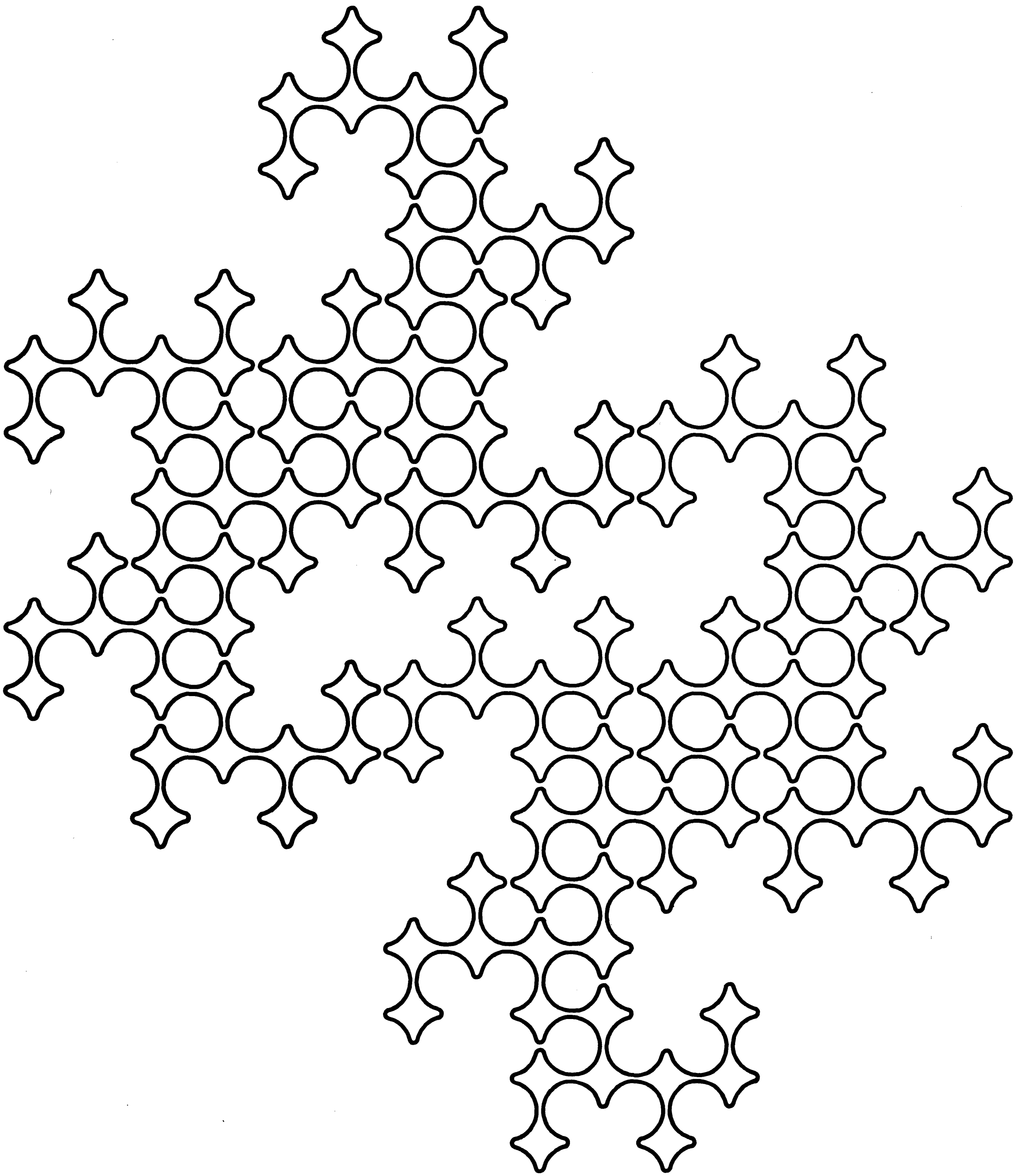

Herbert W. Franke

# Computer Graphics – Computer Art

Second, Revised and Enlarged Edition

With 133 Figures, Some in Color

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Cover graphic:

Mathematical Landscape, *perspective presentation of a mathematical function of two variables; system DIBIAS, DFVLR, Oberpfaffenhofen, Herbert W. Franke and Horst Helbig*

Frontispiece:

*1 Digital graphic from the series DRAKULA* (DRAchenKUrven überLAgert), *1971, by Herbert W. Franke, programmed by Josef Vordermaier, executed with the Siemens System 4004 and a CalComp drum plotter. This drawing is based on a seventh order dragon curve built up from 127 instructions for left and right twists. The elements are taken from a repertoire of curve sections chosen for their superpositioning and connection characteristics. By the choice of different elements, curve sections, and the manner of combination and superimposition, a multiplicity of figuration is achieved*

# Preface to the Second Edition

Ten years have passed since the first edition of this book, a time span during which all activities connected with computers have experienced an enormous upswing, due in particular to the advances in the field of semiconductor electronics which facilitated microminiaturization. With the circuit elements becoming smaller and smaller, i.e. the transition to integrated circuits, the price of hardware was reduced to an amazingly low level: this has definitely been an impulse of great importance to the expansion of computer technology, as well as to areas far removed from technology.

The increased execution times and storage capacities achieved by semiconductors were necessary conditions for the breakthrough of computer graphics which has occurred in the meantime. While a decade ago it was still considered to be a special application for computers, today computer graphics can be regarded as being completely integrated into computer science. The output of computational results in graphical form occurs just as often as the numeric representation, but in addition a multitude of further, partly surprising applications has developed. Picture processing has become a widely used method for evaluating the results of scientific photography, in close collaboration with pattern recognition, a structural analysis effected with the aid of numerical methods. CAD (computer-aided design)/CAM (computer-aided manufacturing) are important areas of current research.

Computer-aided process control has surfaced as a new area, the central supervision of technical systems with the aid of screens. Furthermore, various text processing systems are worth mentioning, the characters of which are generated with computer graphical methods, but which also permit supplementation by simple graphic representations.

The transition from mechanical plotters to graphics terminals is a development characteristic of the last few years. They open the way to regional representation, to the unlimited use of color, to dynamic display, and to interactive use. While in former times the use of color was attributed more to a playful need for ornamentation, it is generally accepted today that much better overviews can be achieved by representing particularly complex configurations in color. In some cases, as for instance in process control, one could hardly do without colors. It is scarcely necessary to stress that the availability of colors further assists artistic ambitions.

The dynamics of display which can be achieved on the screen is also of significance for the visual arts. It is a necessary condition for some technical applications, for example when simulating dynamic processes. Although the graphics systems operating in real time were not designed for artistic purposes, they nonetheless open the most exciting aspects to the visual arts. While the static computer picture was still a realization in line with the usual form of representation in the fine arts, computer graphics now becomes the instrument for a form of artistically created graphical sequences, precursors of which, however imperfect, were the kaleidoscope, water fountains illuminated by color, and, subsequently, animated pictures. Just as it is possible to produce sound elements with a musical instrument in any combination and sequence, computer graphics systems allow free graphical play with colors and shapes. In contrast to animated pictures, production in real time is possible, and thus even free improvisation – surely the most stimulating form of artistic activity.

The free and flexible way to use a computer differs widely from its operation in former years – the off-line mode using punched cards and resulting in long waiting periods for the mechanically produced graphics.

Other developments point in the same direction: excellent adaptation of the machine to man, and not vice versa, leads to an increasing use of interactive systems. The classical computer languages then serve, for the most part, only the purpose of preparing for a user-oriented mode of operation, particularly for users without any knowledge of computer science. The program logic is oriented towards a question-answer-dialogue, menus and decisions which lead to further questions and answers until the desired result is obtained.

The method thus applied is that of trial and error, a mode of operation well adjusted to the processes of human thinking and acting. Routine questions are solved internally, without the user noticing it, and omissions or mistakes are indicated on the printer or graphics terminal. In this way – supplemented by suitable hardware – one comes very close to customary artistic activity, for instance painting and drawing, so that the artist can work in a fashion appropriate for enjoying, in addition, considerable advantages, for instance the possibility to change colors, to enlarge segments of pictures, to move elements across the display surface, etc.

It must be stated, however, that the interest of professional artists in the new tools is relatively low; visual art is heading into other directions and, similar to photography in the past, the new medium will probably not be integrated into the conventional art scene, but might serve as a challenge for the creation of a new profession. This trend was aided by the development of some new applications of computer graphics during the last few years which were commercially oriented and were therefore able to attract the interests of computer scientists more than the free artistic activities, but which, on the other hand, are closely connected with the latter and which can profit from its experiences. Four areas are to be distinguished:

1. *Design* - from architecture to patterns for textiles.
2. *Animation* - from movies and advertising to computer games.
3. *Visualization* for instructional purposes.
4. *Experimental aesthetics.*

The work procedures of designers of industrial products - car bodies are a well-known example - as well as those of architects and of civil engineers resemble the technical processes of CAD and CAM with the aesthetic aspect being added as an additional factor. Basically, the same technically proven methods are being used by the designers. The situation looks a little different in the area of textile design. Technical constraints - as, for example, that of repeat and duplicate - play merely a subordinate role, aesthetical criteria demand to be considered first and foremost. Special systems which are also compatible with the automated production in weaving and knitting mills are offered by some companies for these purposes. Besides, textile design is a task which can also be solved with conventional systems, based on software which is not too complicated.

The area of animation has become known particularly because of new methods in producing animated pictures; its use spans the whole range from generating phase pictures to simulated technical objects and landscapes. But one can also consider the area of computer games under the aspect of animation which, in this case, is still achieved by rather simple means, but which, eventually, will most certainly use more sophisticated simulation techniques - another area of application which will be of commercial interest and which holds great promise for the future.

Besides its use in the movie industry, the advertising industry and the area of computer games, a further interesting possibility for using these techniques has developed, and that is simulation for educational purposes, for example for the training of pilots and railway engineers.

The special task of computer graphics in the field of instruction is the visualization of instructional material, as is possible particularly in mathematics, physics, and chemistry, but which will gradually extend to other subject areas. The new method permits the use of pictures as an alternative to formulas - thus making many relationships visually conceivable, with all the advantages of providing a better overview and of making the material easier to retain. In contrast to the usual illustrations, dynamic processes can also be demonstrated by computer graphics methods, not only in a linear sequence, but also with varying parameters which offer the student the possibility of experimenting. Another consequence of these possibilities is the "electronic museum" in which all kinds of processes can be demonstrated by computer simulation.

The fourth kind of application, experimental aesthetics, is related to computer art in two ways. On the one hand, computer graphics has proven to be the medium which provides the science of the fine arts, aesthetics, with the vehicle for experimenting - by making it possible to construct and vary pictures according to certain aesthetic laws and by succeeding in simulating stylistic peculiarities of certain epochs and artists. On the other hand, it becomes more and more apparent that the aesthetically oriented modes of expression, as they are used in conventional textbooks and academies, are of little avail to the artist who works with technical systems, particularly with computers. He needs a rational theory as theoretical basis which uses principles that can be formulated mathematically and which provides a link to science and technology by referring to the reality of the human processes of perception. Thus, computer graphics proves to be the instrument which, at the same time, contributes to its own theoretical underpinning.

It becomes evident from the situation briefly outlined above that the number of those interested in the possibilities of computer graphics has increased considerably over the last few years. Besides computer scientists themselves, who suddenly find themselves confronted with tasks which are at least partially aesthetically oriented, there are the members of other professions - artists, designers, educators, etc. - who want to inform themselves of the subject matter. Since this book is not only meant for computer scientists, the outline of the new edition will remain unchanged: After a simple description of the means and methods, a historical summary and a discussion of the artistic possibilities facilitated by the computer will follow. These chapters of the book have been thoroughly revised and updated. A section which deals with the above-mentioned new applications of computer graphics means and experiences in the commercial field has been added.

In spite of the considerable progress which computer graphics has experienced within the last ten years, it should not by any means be considered as having reached the stage of full maturity - thus, the last part which is devoted to future prospects remains indispensable. The short time span during which computer graphics has been researched and applied has certainly not been sufficient to let it mature into a great, well-recognized art form. But undoubtedly we are dealing with a part of that "gentle" technology demanded by so many which enriches man's life on a cognitive and creative level without causing any harm.

I would like to thank Dr. Imai-A. Roehreke and *Digital Equipment,* Munich, for assisting me in the design of computer graphics and for providing the possibility of using a *Professional 350.* I would further like to thank Mr. Horst Helbig, DFVLR, Oberpfaffenhofen, Prof. Dr. Georg Nees, Siemens, Erlangen, and Johann Weiss, Technical University, Vienna, for revising the manuscript, and also Prof. Dr. Otto E. Laske, Newcombe, Needham (Massachusetts), for his support in compiling the section on computer music. Further more I am indebted to Prof. Dr. Günther F. Schrack, Vancouver, for his valuable advice, and in particular to his wife Antje, for translating the new parts of this book into English. The first edition was translated by Gustav Metzger. Last but not less heartily I would like to thank Dr. Friedbert Stohner for his careful work on the German and English editions and for his pleasent co-operation during the preparation of this book.

I am also obliged to all friends, colleagues and companies who made their graphics available for illustrating this book.

HWF

# Preface to the First Edition

The works from computers nowadays covered by the term computer art are in my opinion among the most remarkable products of our time:

- not because they surpass, or even approach, the beauty of traditional forms of art, but because they place established ideas of beauty and art in question;
- not because they are intrinsically satisfactory or even finished, but because their very unfinished form indicates the great potential for future development;
- not because they resolve problems, but because they raise and expose them.

Mass-produced electronic digital computers have existed for around twenty years, and the term computer art has been in current use for about five years. Compared with the latest stylish movements - such as Op and Pop - that is a long time, but in relation to technical developments it is a very short one. Computer art, however, is dependent on the computers - it cannot achieve more than these will permit: it expresses the progress taking place in computer science. If one accepts the predictions of the experts, then the most interesting developments are yet to come, especially in the field of programming, i.e. software. As long as this growth continues computer art too has the potential to perfect its methods and thrust toward new domains. The goals toward which it is advancing are still obscure, yet the almost palpable indications of that future appear fantastic. Computer art can place the whole field of aesthetics as well as artistic practice onto new foundations - an idea that will be substantiated later in this book.

Ever since the emergence of computer art, all kinds of arguments have been used to deny a connection between computer and art; this too will be discussed. In this book the terms computer art and computer artist will be used in a descriptive sense; recognition as an art form remains a matter for individual judgment. When I first decided to present a comprehensive survey of the new phenomenon of computer art, I felt that, for once, it would be possible to trace the development of an art form from its earliest beginnings, and that it would be easy to incorporate a complete documentation of its classical phase, in its historical context. This advantage has now disappeared, not only because of the phenomenal increase in activities, but also because it is only now being realized that computer art was practiced in many places well before it attracted international attention. Nonetheless, an attempt will be made to present a survey of initiatives and methods - but on no account can this be complete.

The demarcations of the subject present yet a further difficulty. Many of the works to be discussed have their origin in scientific and technical tasks; in the USA any kind of pictorial output of computer results is designated as computer graphics. Some of these results have a considerable aesthetic interest, and others require only a slight modification to remove them from the realm of science and technology and place them for consideration in the sphere of art. Works by W.A. Fetter, which are among the first computer drawings and which emerged from a strictly technical problem - the most efficient design of an aeroplane cockpit - have received art awards; computer graphics made for scientific and technical purposes cannot therefore be entirely excluded from the field of computer art.

A further question relates to the instruments. Although the first aesthetic graphics produced with the aid of large data processing installations came as a surprise to many, they did in fact have precursors. In particular, the analogue computer had already been employed for free artistic expression. And even before this, attempts had been made to create graphic images by means of optical and mechanical implements; these images too could be seen as aspects of analogue calculation. In accordance with the usage of the first large computer art exhibition - *Cybernetic Serendipity,* London 1968, organized by Jasia Reichardt on a suggestion by Max Bense - a work of computer art will be understood here as being any aesthetic formation which has arisen on the basis of the logical or numerical transposition of given data with the aid of electronic mechanisms.

Computer art already embraces many forms of traditional art - there are computer-generated graphics, sculptures, films, choreography, poems, music. All these developments stand in close relationship; only music has followed its own development, based on the intentions of electronic music. Since a bulky literature is already in existence, computer music will be considered in this book only in so far as it is related to other activities in computer art.

Access to computer art is hindered by a difficulty unknown in other art forms: its practice requires a certain elementary mathematical and technical knowledge. A similar difficulty arises for a comprehensive presentation such as is attempted here: in order to acquire a true understanding, a brief consideration of the functions and working methods of computer installations is unavoidable. Since this leads to a deeper insight into the historical development of computer art as well as its underlying theory, this preparatory section takes up the first part of the book. It also appeared desirable to demonstrate certain methods by examples, which also had to be referred to in the historical part. The result is a certain overlapping, but this does have the advantage of further clarifying the interconnections between the technical and the creative aspects.

As the most convincing evidence for the state of computer graphics is the exemplary image, an effort was made to present an illustrated survey of the manifold possibilities of computer-generated pictorial imagery. Following the addition of many new works, the pictorial part of the book became far larger than had been originally planned; thanks are due to the publishers for the wide scope of the illustrations. I am especially indebted to Dr. Frieder Nake, presently in Vancouver[1], and to Mr. Peter Henne, Bad Godesberg[2], who have taken the trouble to read the manuscript, and who have made valuable suggestions regarding corrections and supplementation of the text. I am also obliged to the firm of Siemens AG, Munich, for enabling me to carry out computer graphic experiments with their data processing installation, the Siemens System 4004: I thank all collaborators from their Bereich Datenverarbeitung for their friendly support of my work. Finally, I am grateful to all those who have supplied pictures, and who have helped with information - especially the members of the Computer Arts Society, London.

HWF

[1] Now (1984) Professor at the University of Bremen
[2] Now (1984) GMD, Birlinghoven

# Contents

# Installations and Methods

## 1 The Computer and Aesthetic Processes

In creating a work of art it is vital to design an arrangement from elements, such as forms, words, and sounds. And these elements have above all to conform to one condition: they must be perceivable. The elements are the smallest perceivable units - *Apperzepteme,* in the terminology of Max Bense. Since only vision and hearing have the capacity of taking in such complex structures as aesthetic objects, our concern is with visually or aurally perceivable units.

Two phases are to be distinguished in the production of a work of art:
1. The preparation of elements *(Apperzepteme).*
2. The conception of the arrangement.

These two phases are different in principle. The making of the sign carriers is a physical procedure. In order to mechanize it, physical machines are needed; examples are drawing machines, typewriters or musical instruments. In contrast, the conception of an arrangement is not a physical but an informational process; and it is only through cybernetics, and particularly through information theory, that this can be clearly elucidated. It follows then that the second, essential phase of the artistic process cannot be accomplished with energetic, physical-technical machines; it has become amenable to mechanization only since effective information-processing machines have appeared - the computers. That is the fundamental novelty of the situation produced by the irruption of the computer into the sphere of the arts; for the first time it has become possible to insert a mechanical aid into the creative phase of artistic production.

## 2 The Analogue Computer

The analogue computer does not have the widespread uses of the more recent digital computer, but it is actually better suited for a variety of functions, and it is likely to remain what it has always been in the past - a major instrument of computing. So-called hybrid computers - combined systems of analogue and digital computers are available for special purposes.

The orders which are grasped by the analogue computer are relations that can be represented with the aid of parallel (synchronously) working calculating registers, namely by electrical quantities, like voltages, which vary with respect to time. Special wiring permits, for example, the addition and subtraction of voltages and their multiplication by constant factors. In technical applications one seeks to imitate, by means of these voltages, the quantities which are to be computed. They function as models of the computing values, they are analogous to them - hence the term analogue computer. In computer technology one tries, through the use of voltages, to produce organizations that are of aesthetic interest. The advantage of analogue computing is that functions can be represented as a whole, and do not have to be dissected into number and dot sequences as with the digital computer.

## 3 The Digital Computer

The digital computer, too, encodes the quantities with which it calculates by means of electric currents and voltages, not, however, as functions of time, but as single impulses. There are only two signs:

- *no impulse* means 0;
- *impulse* means 1.

Any desired number can be expressed using this numerical system, the binary system. The table below shows the binary coding (second column) of the ten decimal numbers (first column). The interpretation of the binary numbers is indicated following the equality sign.

$$
\begin{array}{lrr}
0\ldots & 0 = & 0.2^0 \\
1\ldots & 1 = & 1.2^0 \\
2\ldots & 10 = & 1.2^1+0.2^0 \\
3\ldots & 11 = & 1.2^1+1.2^0 \\
4\ldots & 100 = & 1.2^2+0.2^1+0.2^0 \\
5\ldots & 101 = & 1.2^2+0.2^1+1.2^0 \\
6\ldots & 110 = & 1.2^2+1.2^1+0.2^0 \\
7\ldots & 111 = & 1.2^2+1.2^1+1.2^0 \\
8\ldots & 1000 = & 1.2^3+0.2^2+0.2^1+0.2^0 \\
9\ldots & 1001 = & 1.2^3+0.2^2+0.2^1+1.2^0
\end{array}
$$

Computing involves control elements constructed in such a manner that they can carry out addition, subtraction, multiplication and division in the binary system. The following rules apply:

$$
\begin{aligned}
0+0&=\ \ 0\\
0+1&=\ \ 1\\
1+0&=\ \ 1\\
1+1&=10
\end{aligned}
$$

In this way one can add digit to digit, as in the addition of decimal places:

$$
\begin{array}{r}
101101\\
\underline{110111}\\
1100100
\end{array}
$$

In order to multiply, one has only to remember:

$$
\begin{aligned}
0\times 0&=0\\
0\times 1&=0\\
1\times 0&=0\\
1\times 1&=1
\end{aligned}
$$

Here one can again apply the well-known calculation scheme of the multiplication of decimal numbers:

$$
\begin{array}{l}
\underline{101001\times 11100}\\
101001\\
\ \ 101001\\
\ \ \ \ 101001\\
\ \ \ \ \ \ 000000\\
\underline{\ \ \ \ \ \ \ \ 000000}\\
10001111100
\end{array}
$$

According to the theory, not merely arithmetical but also logical relationships can be represented by the 0, 1 code. Similarly, addition and multiplication, the logical relationships *and* as well as *or* can be achieved with wiring. A simple change from 0 to 1, such as can be produced via a change-over switch, corresponds in formal logic to the *not*-relation. Since according to this science, each logical relation can be broken down into these three elementary relationships, it follows that the most complex logical dependence is open to imitation by means of switching elements. The rendering of the desired aesthetic order in the form of logical relations is therefore an important task of the artist practicing computer graphics. Mathematical relations are treated as special cases of logical relations.

In principle, work with the digital computer is carried out along these lines:

1. *Programming,* production of an interconnected scheme which corresponds to the desired calculation.
2. *Input,* feeding in those values that are to be manipulated.
3. *Data Processing,* performing the logical-mathematical operations.
4. *Output,* directing the results into a converter device, which sets them out in a form comprehensible to human beings.

It is one of the principal advantages of the large digital computer that the production of the necessary connections, as instructed by the program, does not involve a permanent change of the switch network, but a kind of temporary reorganization. In practice, this is achieved by the opening and closing via current impulses of specific switches, and thereby also certain circuits. Thus, nothing is changed in the disposition of the machinery (hardware, as opposed to software - data, programs, etc.). Again, the instructions for the opening and closing of the circuits can be given with a binary code, like this:

0 . . . close the switch.
1 . . . open the switch.

This enables the same data carriers, the memory - a pile of punched cards or magnetic tape for instance - to be used for programs and for calculating data.

## 4 Structure of the Computer

A digital computer is made up of certain building elements, of which the most important are the control unit, the register, and the working store or memory. Attached to these are the external devices: input and output units, various external stores, and in certain circumstances even mini- or satellite computers.

- The control unit brings about the running of the program.
- The calculating register carries out the operation.
- The working store holds the working data and the programs.
- The input unit deals with the acceptance of the programs and the calculating data.
- The output unit delivers the results.
- The external stores hold data for eventual use.
- The satellite computers execute calculations which should not be loaded onto the central processor.

### Microcomputers

Microcomputers, composed of a few small modules, are gradually assuming more and more tasks which just a few years ago were reserved for computers of the classical type, which were much more expensive and required a lot of space. It is an essential characteristic of microcomputers that the arithmetic logic unit and the central processing unit are located on a single chip as a single integrated circuit. Typical for its organization is the so-called bus, a set of parallel wires with the aid of which the information - data and instructions - is exchanged between the connected modules. The programs are stored in ROMs (read only memory) which have a storing capacity of several thousand bits. The freely addressable RAMs (random access memory) serve the purpose of general data storage. It is to be noted that the latter, as opposed to the read only memories, lose the information once the device is turned off.
In a microprocessor data are processed word by word, i.e. in groups of bits; most frequently the words are 8 or 16 bits long, but 2, 4, and 12 bit words are also used. They are transferred in the bus, word by word, in parallel, i.e. simultaneously.
All the usual devices attached to a mainframe computer can be connected to the microcomputer; the result of connecting several microprocessors is inexpensive systems of remarkable effectiveness. The microcomputer is the basis of the home computer or personal computer which permits data processing to permeate all spheres of life. It will result in strong impulses for graphical systems to be used widely.

## 5 Hardware

To be able to use a computer for a specific purpose, it is sufficient to have a rough idea about the way it works, about its structure. This material aspect of computer technology, the hardware, will be the subject of this chapter.

### Memory

What takes place inside a computer is not really of concern for the user. There is no need to have a detailed knowledge of the computing processes, their organization or their temporal flow, etc.; indeed, with large digital computers this would hardly be possible. The computer is a "black box" in terms of cybernetics, that is to say, one is interested only in the incoming and outgoing data - known in professional language as input and output. The computer graphic artist, too, requires only a slight knowledge of the construction of the machine - there is certainly no need for him to be either a technician or a mathematician. What concern him are the previously discussed programs, which relate to the incoming data, as well as the circumstances and possibilities of the output that are to be discussed later on.
The results of the numerical and logical operations of a computer appear at first in the form of binary characters, coded as current impulses. Where outputs are to be reintroduced into the computer, it pays not to translate them immediately into a form understandable to humans, but to hold them as 0, 1 impulses, which can be reintroduced into the machine in that form. This is the purpose of the various kinds of external memories that are also available for computer graphic applications. Among the most frequently used external memories are:

*Punched Cards.* Cards of thin cardboard, 8.2 cm wide and 18.7 cm long, having twelve lines and eighty columns. Punched tape and punched cards are used equally as means of input of data to the computer.

*Punched Tape.* Punched tape is used containing five to eight tracks.

Punched cards and punched tape are mechanical stores. The storing is effected by the punching of holes. The absence of a hole on the prepared store places signifies 0, a hole signifies 1. Reading is carried out by running the cards or tapes beneath metal brushes, electrical contact being produced through the holes. At each hole, i.e. at each contact, there occurs a current impulse that indicates a 1. Mechanical, photoelectrical or dielectrical scanning is also possible.
The use of mechanical means of storage has decreased considerably in the last few years. Compared to storage media using magnetic means, they are awkward to handle, and they do not allow interactive operation.

*Magnetic Tape.* A plastic tape with a layer of iron or chrome oxide on one side, having four, six or eight information tracks plus an additional track for control purposes. The coding of the binary numbers results from the magnetizing direction. Magnetic drums, magnetic plates and magnetic cards work in essentially the same way.

*Disk Drives.* Disk drives also operate on the principle of recording on a magnetic medium. They consist of stacks of up to 12 metal disks with 2000 tracks each and are coated by ferric oxide. They have the advantage, as compared to magnetic tapes, that any disk location can be accessed much more quickly, since the read/write head can be positioned over any selected spot of the disk surface and does not have to follow the tracks. The Winchester drive, a compact version of the hard disk drive in a completely closed housing, is becoming more and more popular.

*Floppy Disks.* Handy floppy disks which also operate on a magnetic basis have become customary particularly for storage purposes in microcomputers. They correspond in shape and size to 45 rpm records.

*Holographic Memories.* Because of its physical qualities, light would be extremely suitable for storage of data - a storage density of approximately one million bits per square millimeter could be achieved on a flat medium, as for instance on a photographic plate, thus surpassing the density of magnetic surfaces by two orders of magnitude. This would allow the information to be recorded digitally in a raster, the presence of a mark representing the binary number 1 and its absence the binary number 0. In order to avoid errors caused by dust particles, scratches, etc., such a picture, correspondingly reduced in size, would have to be recorded as a hologram. This can be retransformed by means of the usual holographic procedures into the original picture which is then read by a photocell to reconstruct the information. So far, this procedure has not been implemented for widespread use, since it has not met the expectations of its designers.

*Bubble Memories.* The storage medium for a bubble memory is a magnetic single crystal layer which, e.g. consists of ytterbium-iron-garnet. The direction of magnetization is aligned vertically to the layer. Regions of some thousandths of a millimeter in diameter serve as storage cells. They are stable, repulse each other, and can be shifted like bubbles floating on a layer of liquid. This facilitates the organization of storage space. The storage density is approximately 3000 bits per square millimeter, the access time about 100 microseconds. Some experts envision the robust and comparatively cheap bubble memory to be the random access memory of the future.

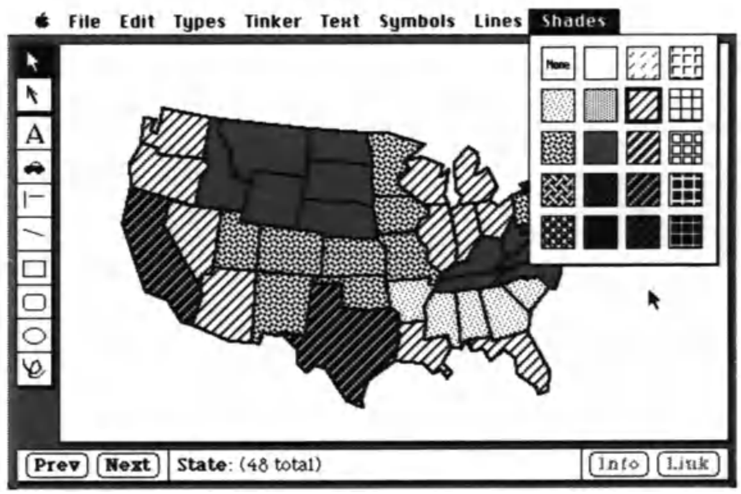
## Input Devices

*Keyboard.* The keyboard, a device similar to the typewriter or teletype, usually supplemented by a set of auxiliary keys, is the most widely used means of input. The input device codes the characters selected by the keys into binary numbers. The off-line operation used exclusively in the past effected the transfer to a recording medium - such as punched cards, paper tape, or magnetic tape - within the same device; in on-line operation which is the usual mode of operation nowadays, the characters are transmitted directly to the computer as electronic binary signals.
The alphanumeric and special characters which are represented by the keys can be used in their primarily assigned value, but their function can be reassigned to other purposes by auxiliary keys, such as SHIFT or ESCAPE, for example to move a cursor

in different directions on the screen or to erase parts of a current text line.
In addition to the different types of alphanumeric keys described above, function keys are available which can be assigned any input functions, for example the choice of colors.

*Digitizing Table.* The digitizing table or tablet is a very versatile input device well adapted to human actions. It is used as a writing or drawing board; styli or cross hairs which are moved across the drawing surface are employed for the input action. Most devices allow point-by-point input as well as the input of line segment sequences.
A matrix of fine wires arranged crosswise is located below the input surface of the tablet. Impulses are transferred according to the same principle used in transformers. The detector loop located in the stylus or in the cross-hair device generates an electromagnetic field which is coupled into the wires. Other models operate according to a different physical principle, but the recording of the grid points basically remains the same. The resolution is usually in the range of a tenth of a millimeter, but can be increased up to 0.02 millimeters for high precision devices.
Digitizing tables can be used for the direct transfer of drawings into the computer memory, for instance by following the contours of a drawing. For artistic purposes, even freehand drawings can be input; depending on the available software, the stored graphical data can be processed further. The point-by-point input offers a mode of operation which is also of interest for artistic use, for instance by indicating merely the vertices of a polygon or of a more complex graphical object which the program then joins by line segments. The digitizing tablet can also be used for coloring or erasing, for example by identifying a given polygon by means of the stylus or the cursor and by initiating the intended operation by depressing a function key. Input procedures of this kind can be simplified if necessary; for instance, the program can include a procedure which renders the exact localization of the points, a tedious task, superfluous – it is sufficient to indicate any point in the vicinity, the program will then automatically substitute the closest point or the closest line segment for the input location.
Another possibility is the use of digitizing tablets in conjunction with menus. These are added to drawings or used as overlay templates; to make his decisions, the user merely needs to place his stylus on a specific area near the graphical representation.

*Light Pen.* The light pen which is employed just as frequently as input device is used in a similar fashion as the digitizing tablet. Basically it is a photocell with an optical aperture of almost pointlike size. If it is placed on the screen of a vector-refresh or raster terminal (cf. paragraphs on output devices), the optical sensor absorbs the light signal generated by the electron beam which causes it to interrupt the computer. This allows a specific circuit to determine which point was indicated by the light pen, and it is thus possible, similar to the use of the stylus or the cursor of the digitizing tablet, to mark points on the screen or to generate line segments. This permits the direct input of drawings, but the input can also occur by means of menus which are output on the screen for this purpose. If they are used for the representation of graphical data in interactive operation, it is of advantage to work with two output terminals, or else part of the screen can be reserved for the menu and the other part for a working surface. Sometimes the drawing on the screen is overlaid by the menu.




2 *Shades menu;* Filevision, *Telos Software, USA*

*Joystick.* The joystick is well known as an input device for computer games, but it can also be used for various other purposes, not the least of which is freeform artistic graphics. It is usually installed in a small box from which a lever protrudes, movable in all directions. Attached are two potentiometers which deliver two voltage values representing coordinate values. The voltages are converted into digital numbers which are stored. In principle, it is possible to refer the numbers to any two given variables, for example direction and speed of a simulated projectile. Usually, however, they are interpreted as point coordinates on the screen. With the aid of this device, it is again possible to mark points or to input sequences of line segments.

*Tracking Ball.* The tracking ball basically works according to the same principle. As implied by the term, it is a sphere which has been installed in a table such that only a small portion protrudes. It can be turned freely by hand. As with the joystick, it is a device which allows the simultaneous determination of two values. Due to the freedom of movement of the ball - rotation around any axis - it is employed in 3D-graphics, especially when tumbling perspective representations of three-dimensional objects on the screen; the movement on the screen is synchronized with that of the ball. But again, it is possible to coordinate the range of other, not necessarily geometric values with the two values of the tracking ball, for example the brightness and saturation of a color table.

*Mouse.* The mouse is a special version of the tracking ball with the ball located at the bottom of a freely movable housing. When guiding the mouse over the table top, the ball rotates and registers the coordinates of the positions and tracks.

*Thumb Wheels.* The setting of coordinates, the guidance of a cursor etc. can also be achieved in a simpler fashion, with the aid of a pair of thumb wheels. They are attached to potentiometers, each one of them controlling the movement of one of the directions parallel to the coordinate axes. As with the tracking ball and the joystick, the voltage range covered is converted into an interval of digital numbers, for instance from 0 to 127. The correspondence is arbitrary - each thumb wheel can be used individually to control any variable.

*Optical Scanners.* A series of devices allows the automatic transfer and digitization of pictures. The best-known example for such devices operating as scanners is the television camera. But there are also special devices in which a photocell moves line by line across a projected picture, across a flat picture, or a picture mounted on a cylinder. With the aid of filters with which the three primary colours are scanned separately, it is possible to input colors. The optically sensed information is transformed into digital data and stored for subsequent processing. Scanners are employed in particular for picture processing and pattern recognition which will be dealt with later, but they also, for artistic purposes, supply the artist with the means for graphical abstraction.

*Sensors.* In addition to the usual means of computer input devices described above, further devices can be employed depending on special requirements - basically all devices which allow any physical quantities to be transformed into electrical impulses. These instruments are called sensors, and among others, are used as aids in controlling systems such as production lines. Under special circumstances, they can become important instruments for the artist, for instance when coordinating the composition of animated pictures with music. It is possible with the aid of volume and frequency filters to select certain signals from the sounds, which eventually control the picture-generating processes. Although techniques of this kind can be implemented by relatively simple means, they have rarely been applied.

## Output Devices

Intermediate results occurring with more complicated calculations do not have to be translated into human language. The computer frequently uses an external store for dumping without the user being aware of the fact; nor is this information required. Generally the installation handles such organizational tasks in an automatic manner.
The final results, however, must be submitted to a translation

process, which to some extent takes place within the output devices. These incorporate decoding devices which transform the 0, 1 sequences into numbers, letters and punctuation signs. An instance of such a device would be an interrogating typewriter, which is comparable to the automatic typewriter of a teletype. These do not merely give out data, but offer the opportunity to intervene in the calculating process, for instance through the input of new data, the demanding of intermediate results, signals for the start, pause or conclusion of a computing process. A kind of dialogue with the machine becomes possible through their use.

Fast printers also give out data in the form of characters on paper, but without offering the possibility of requestioning. Visual display units are picture screen devices, where the writing appears on the screen as on a television set. They operate without output delay and are therefore particularly suited for conversational operation. Due to this feature, they are gradually taking the place of interrogating typewriters.

*Graphic Output*

The issuing of calculation results in the form of numbers corresponds to our conventional methods of calculating with pencil and paper. But frequently it is also possible to represent mathematical relations in other ways, using graphic means and diagrams. For instance, a table can be rendered by entering a point in a coordinate grid; if the points are brought close together, the representation becomes a curve. For many purposes the usual numerical representation is the most convenient form, but for other tasks a better grasp is obtained through curves. One has, of course, to learn to interpret or assess the significance of such curves, in the same way as an understanding of number tables demands a certain practice.

There are various reasons for the current trend toward an increasing use of visual representation:

- Man's visual faculty surpasses all other senses in its capacity to discover complex relationships.
- In the representation of many complex relationships graphic presentation has the advantage over numerical. This applies especially to relations which are not amenable to linear representation – i.e. consequences of a causal or chronological kind.
- The technical methods and means of graphic presentation – photography, film, printing, television, drawing machines, etc. – have been perfected and reduced in price to such an extent in recent years that they can compete with techniques using conventional reproduction, i.e. text printing, typewriters, etc.

The growing preference for visual means of expression manifests itself in many aspects of our life-science, education and entertainment – and has become so widespread that we tend to speak of a *visual age.*

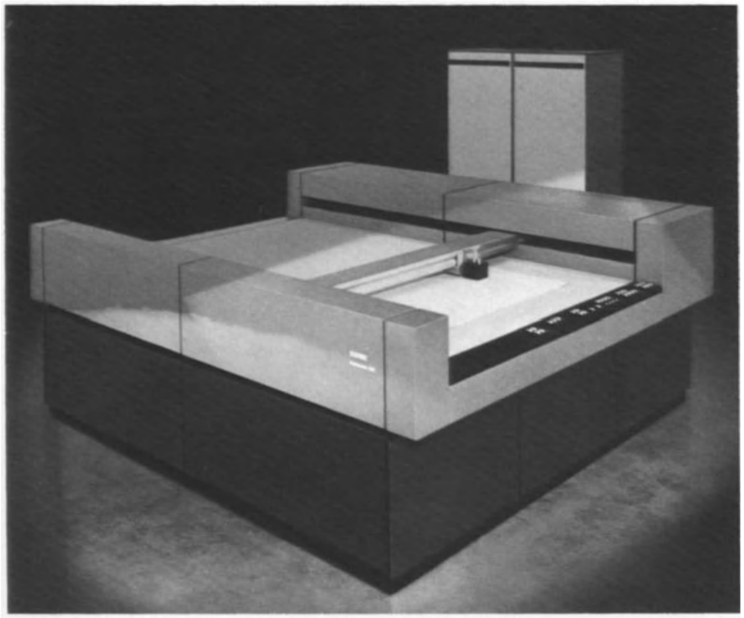
But above all, many of the tasks that science and technology have handed to the computers require a graphic output of the results. The various typewriters and printing machines are not really adequate. That is why machines capable of the graphic representation of calculation results came to be developed, and it was these instruments which finally provided the impetus for the development of aesthetic computer graphics. A device that uses technical programs to produce technical drawings is equally capable of producing aesthetic patterns on the basis of aesthetic programs.

*Mechanical Output Devices*

The first program driven drawing machines – for instance the ZUSE-Graphomat – operated mechanically and were therefore relatively slow. Neither was the problem of coloration solved in a satisfactory manner at that time – differences in line widths, blotches of color, etc. occurred again and again. In the meantime, improved systems are available: Quality models achieve a speed of operation of one meter per second and a resolution of 0.05 millimeters.

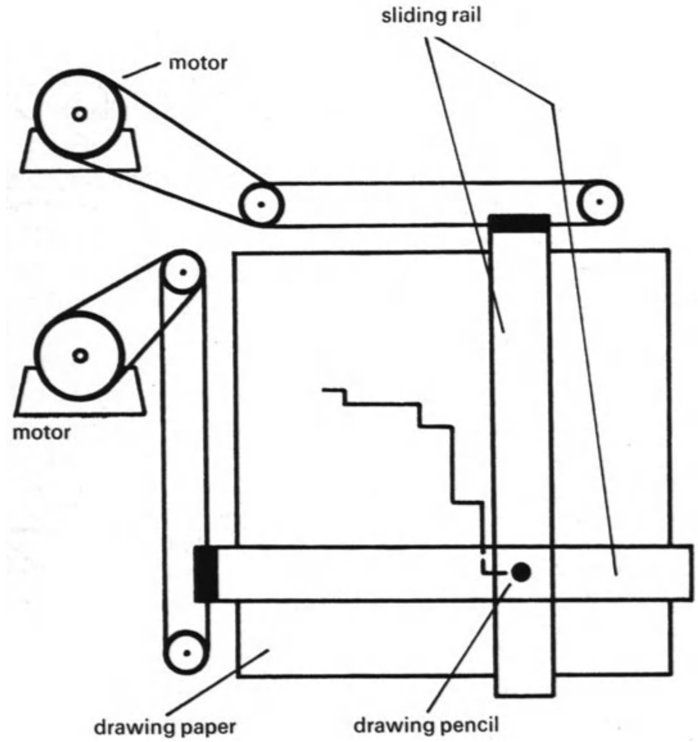
The results are output as line drawings, as for instance in flow charts, circuit diagrams, and construction plans. Since this type of representation is still required at present for these and similar purposes, mechanical drawing machines have not yet been entirely replaced by electronic devices.

The limitation to line output as graphical element renders the



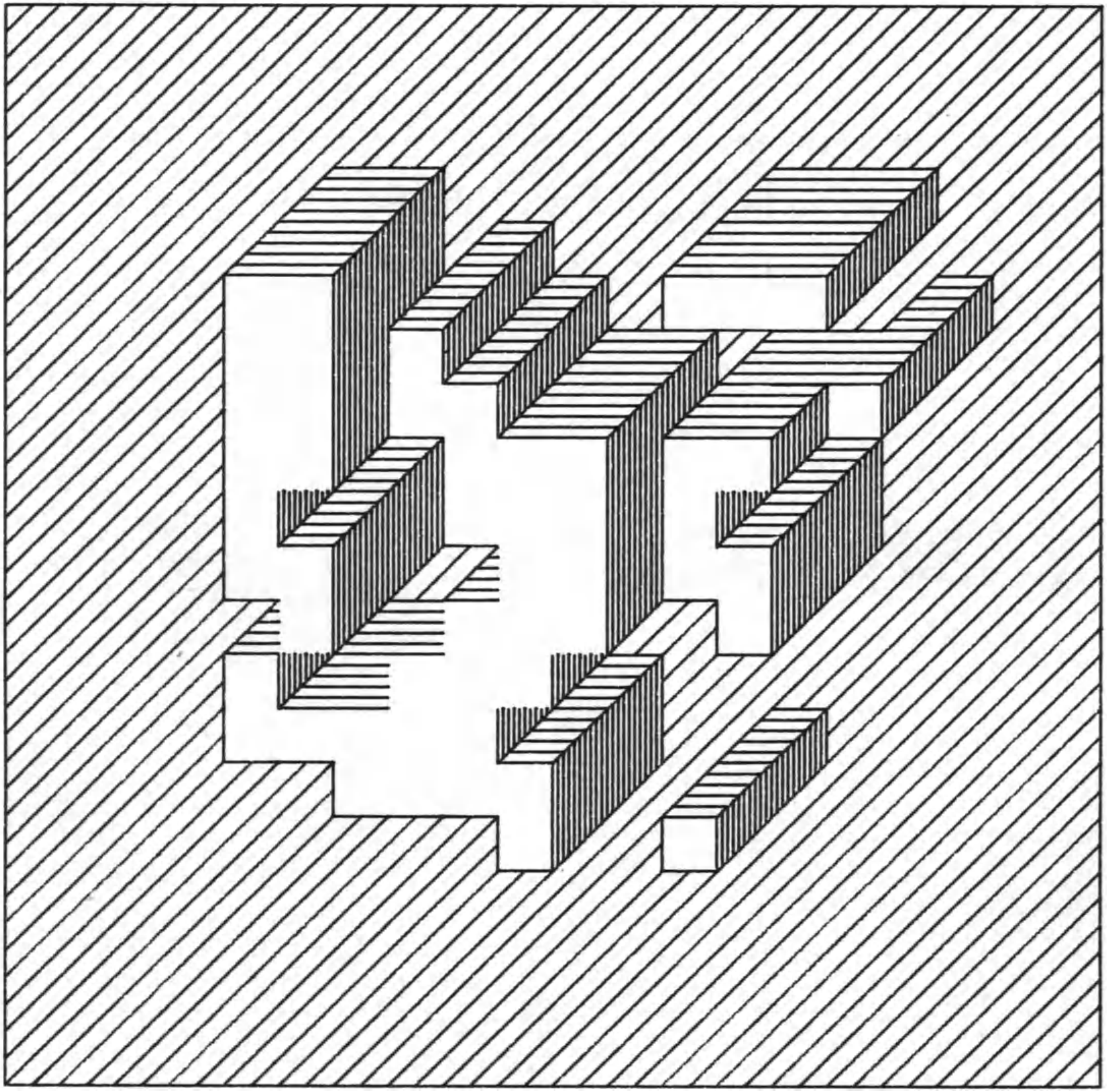
*3* ZUSE-Graphomat, *a mechanical flatbed plotter from the early days of computer technology*

representation of areas more difficult; where these are required, one can resort to dashed lines - not an ideal solution, in particular for artistic purposes. Therefore some devices, the so-called printer-plotters and the ink jet plotters, were developed which allow coloration of regions. The coloration is performed by ink drawing pens, felt-tip drawing pencils, ink ball-point pens, etc. The styluses are fixed to inserts designed for lifting and lowering the instruments and guiding them over the drawing paper by servomotors. There are devices where the stylus moves over the flat surface as on a drawing board.
This method has the advantage of not being restricted to the standardized kinds of paper and shapes, and ordinary drawing paper in any size and shape can equally well be used.
With other types of mechanical plotters, the stylus moves along a straight line in the direction of the axis of a cylinder, over which standardized, edge-perforated paper is rolled. The movement of

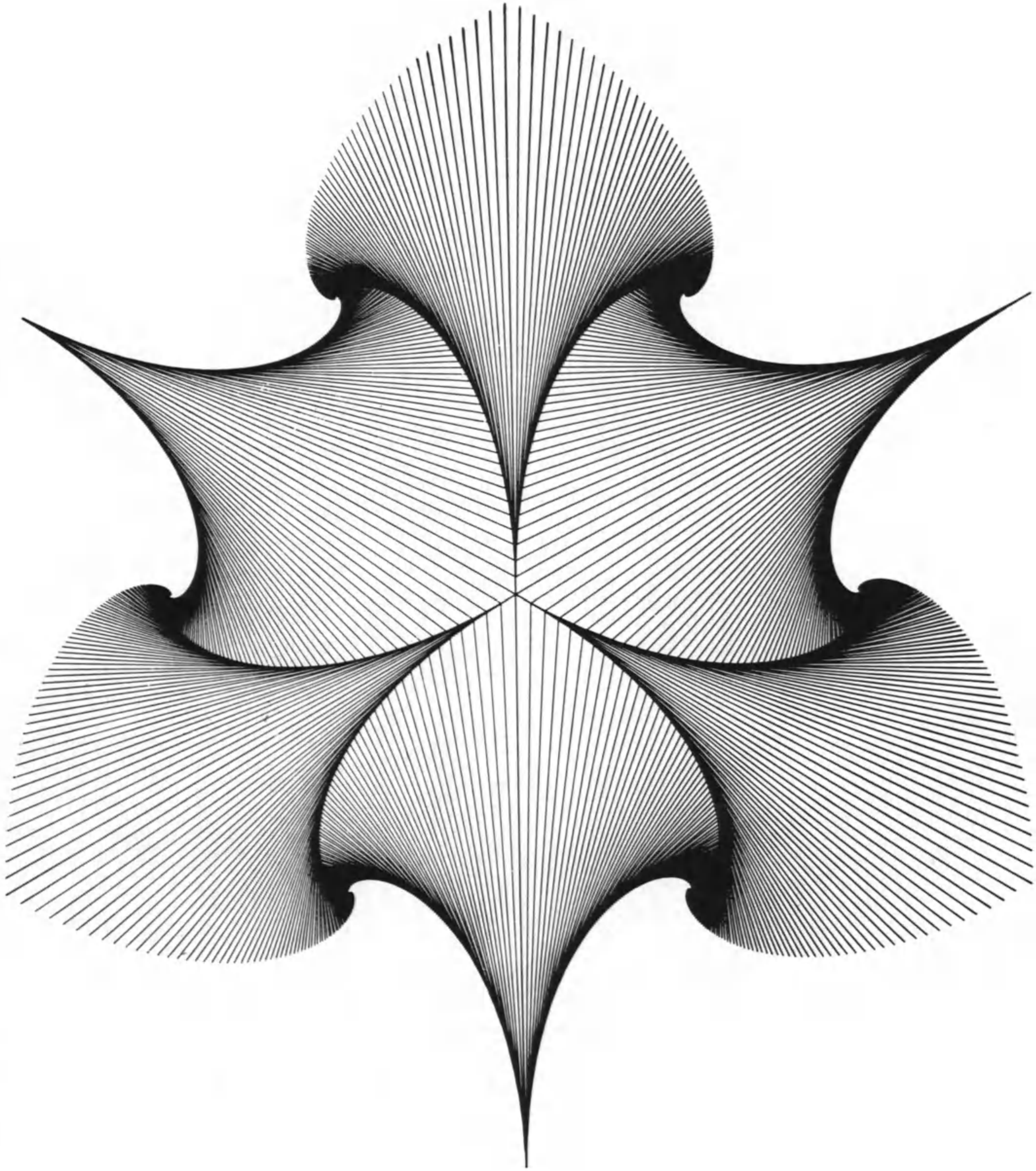



*4 Diagram showing the organization of a mechanical plotter. Two servomotors guide the pencil in the direction of the X- and Y-axis across the drawing plate. Any desired configuration can be obtained through the superimposition of the motion components. A mechanism (not shown here) raises the pencil so that single, interrupted lines can also be drawn*

the pencil in a direction vertical to the axis, and thus a two-dimensional drawing, comes about through the turning of the cylinder. Devices of this kind work faster and take up less space, but can only use edge-perforated paper rolls adapted to the cylinder, in particular to its length and tooth distances.
Originally, these plotters were controlled by magnetic tape, which provided the guiding impulses for the work's execution (off-line activity). But with more modern machines a direct con-



*5* Composition Mode S3, *drawn on a plotter; the shading was achieved by hatching. Edvard Zajec, Syracuse University*



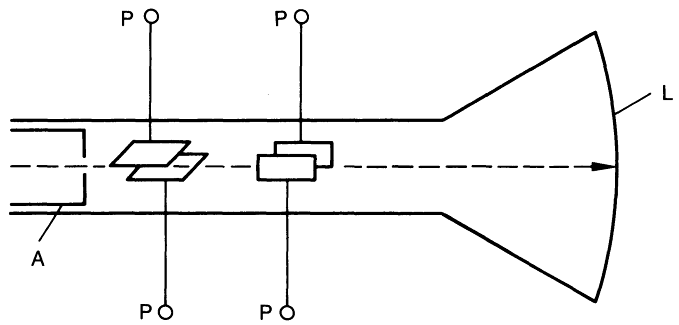
◁ 6 Crest *by Kerry Strand, generated with the CalComp-770 System, and drawn on a drum plotter type 763*

nection to the computer is also possible (on-line activity). In this way one obviates the storing of the intermediate results in special data carriers, but instead burdens the computer with the comparatively slow mechanical drawing procedure.
Industry already offers the most varied sizes and makes of plotters for off-line and on-line work. Many of these include the optional insertion of incising and cutting tools, apart from the usual pencils. With these techniques masks are produced that can serve as negatives for photographic and other procedures; they also open the way for tonal planes. More recently facilities for photographic procedures on light-sensitive material have come into use. These incorporate lens and aperture systems which permit a multitude of variations in the reproduction of densities and line thickness.
Since the graphic possibilities, the precision of the execution, and so on are dependent to quite an extent on these devices, they are often indicated, together with the computers, in the pictorial specifications.

### *Electronic Output Devices*

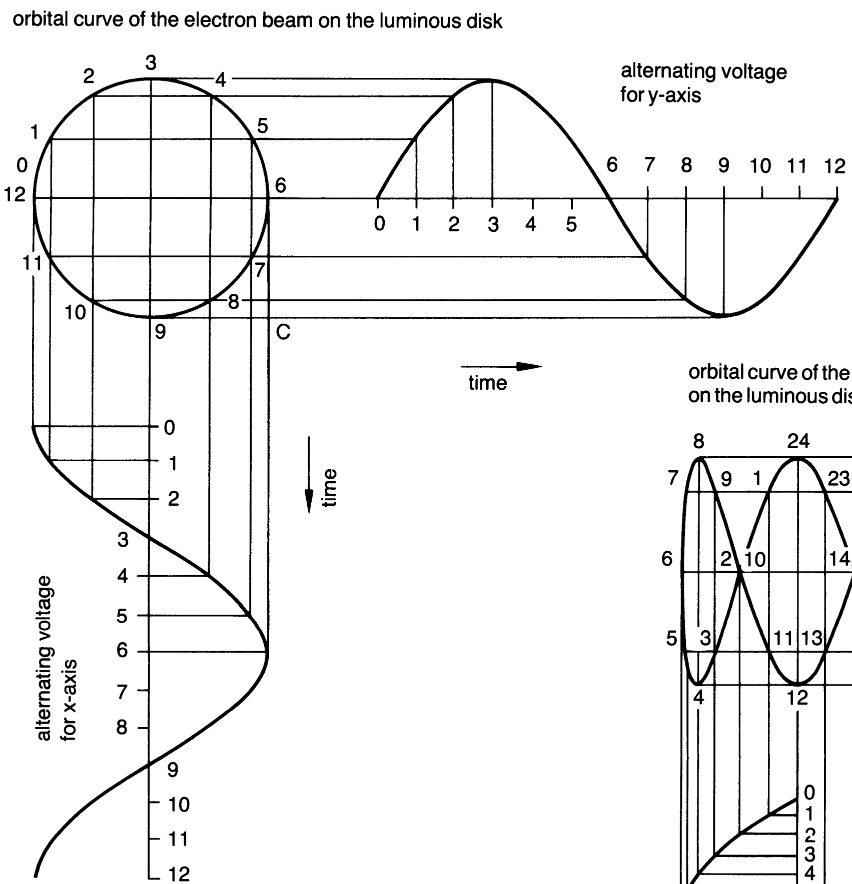
#### Cathode Ray Oscilloscopes

The second route to visual output from computer data is by way of electronics. All visual display units go back to a basic type - the long-established cathode ray oscilloscope. Its primary constituent is the picture tube, as known from television receivers. From the rear, a finely attuned electron beam - the drawing medium - is projected toward the luminous scope. A substance has been applied to this scope which is stimulated by electrons to emit light. The electron beam runs between two pairs of deflector plates, positioned vertically one on top of another, to which electrical voltages are led. These deflect the electron beam - the one pair in the vertical, the other in the horizontal direction.
The usual cathode ray oscilloscopes serve mainly as control devices. They are generally switched in such a way that the cathode ray moves from left to right, jumps back to the left, and then begins a fresh left-right motion. The voltage which one seeks to control is led onto the other pair of deflector plates. Where a

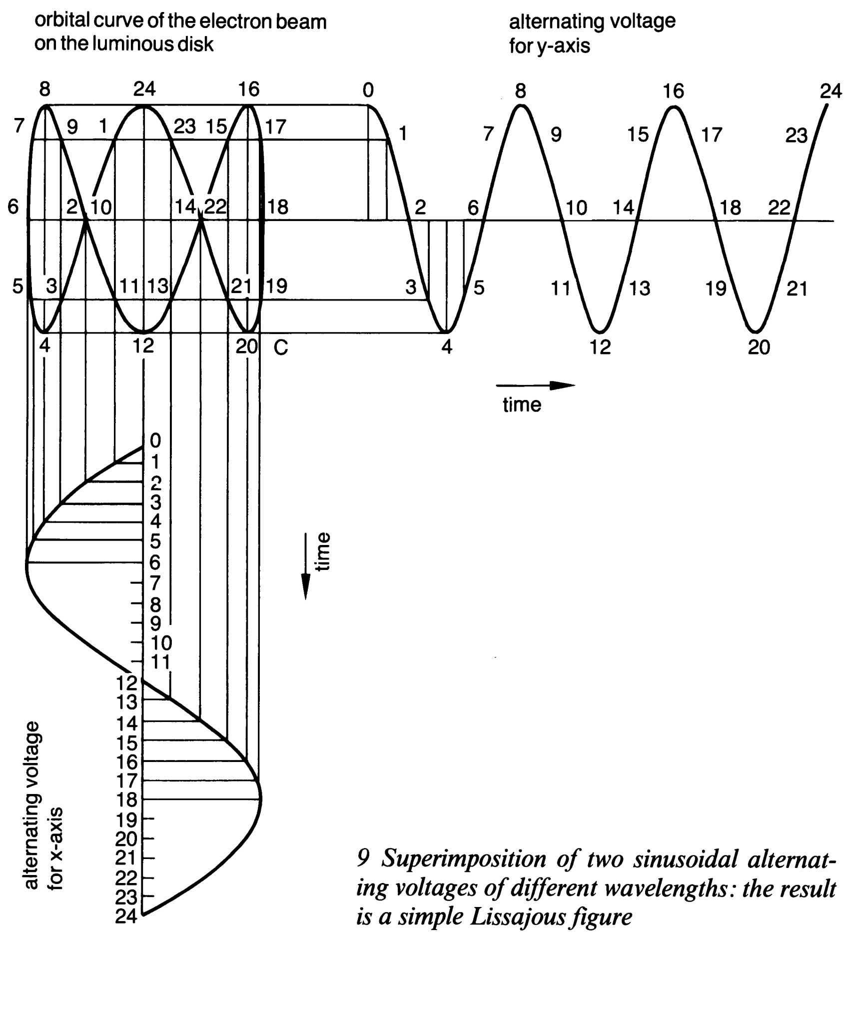



*7 Schematic view of a cathode ray tube; from the positive voltage electron-releasing system - the anode A - the electron beam moves through the two pairs of deflector plates P to hit the luminous screen L*

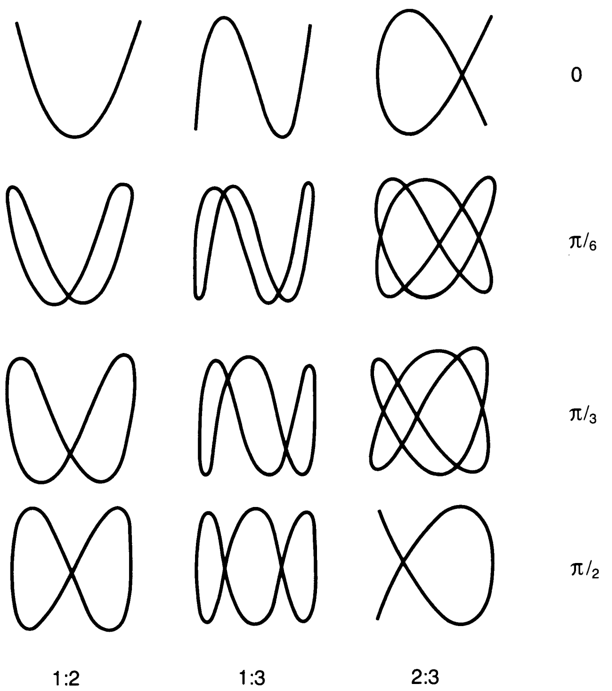
beatlike, repeated phenomenon is involved - for instance, the wave pattern of alternating voltage - one can adapt the beat time to the frequency of the alternating current, with the result that the same progression, the form of the alternating voltage, is repeatedly drawn on the same spot. The eye, unable to follow the rapid motion of the electron beam, receives an impression of an interconnected, still curve line.
For aesthetic purposes another kind of switching can be employed: the second pair of deflector plates is not used as a line writer, but is charged in the same way as the first pair with any chosen alternating voltage. By means of the superimposed diversion through both plate pairs, the cathode ray oscilloscope draws interconnected curving figures that unceasingly return into themselves. If one guides synchronously in the x- and y-direction with a sinusoidal alternating voltage, a circle or an ellipse results through superimposition. If the frequencies of the two alternating currents differ from each other, then the so-called Lissajous figures arise; these were already known from mechanical oscillations, and their aesthetic appeal had long been noted. One can produce and superimpose a great variety of voltage forms with the help of analogue computing systems. Gray tones without gradation are formed by the superimposition of lines, as well as by varying the speed of the beam coursing across the screen.




*8 Formation of a luminous screen picture through the cooperation of the x- and y-steering. Numbers are to be taken as arbitrary time measures. Superimposition of two sinusoidal alternating voltages of equal wavelength: the result is a circle*




*9 Superimposition of two sinusoidal alternating voltages of different wavelengths: the result is a simple Lissajous figure*




*10 The formation of Lissajous figures through superimposition of two sinusoidal motion components in the x- and y-directions. The phase shift measured in parts of a complete oscillation ($=360° = 2\pi^c$) is indicated on the right; below, the ratios of frequencies (oscillations related to time units)*

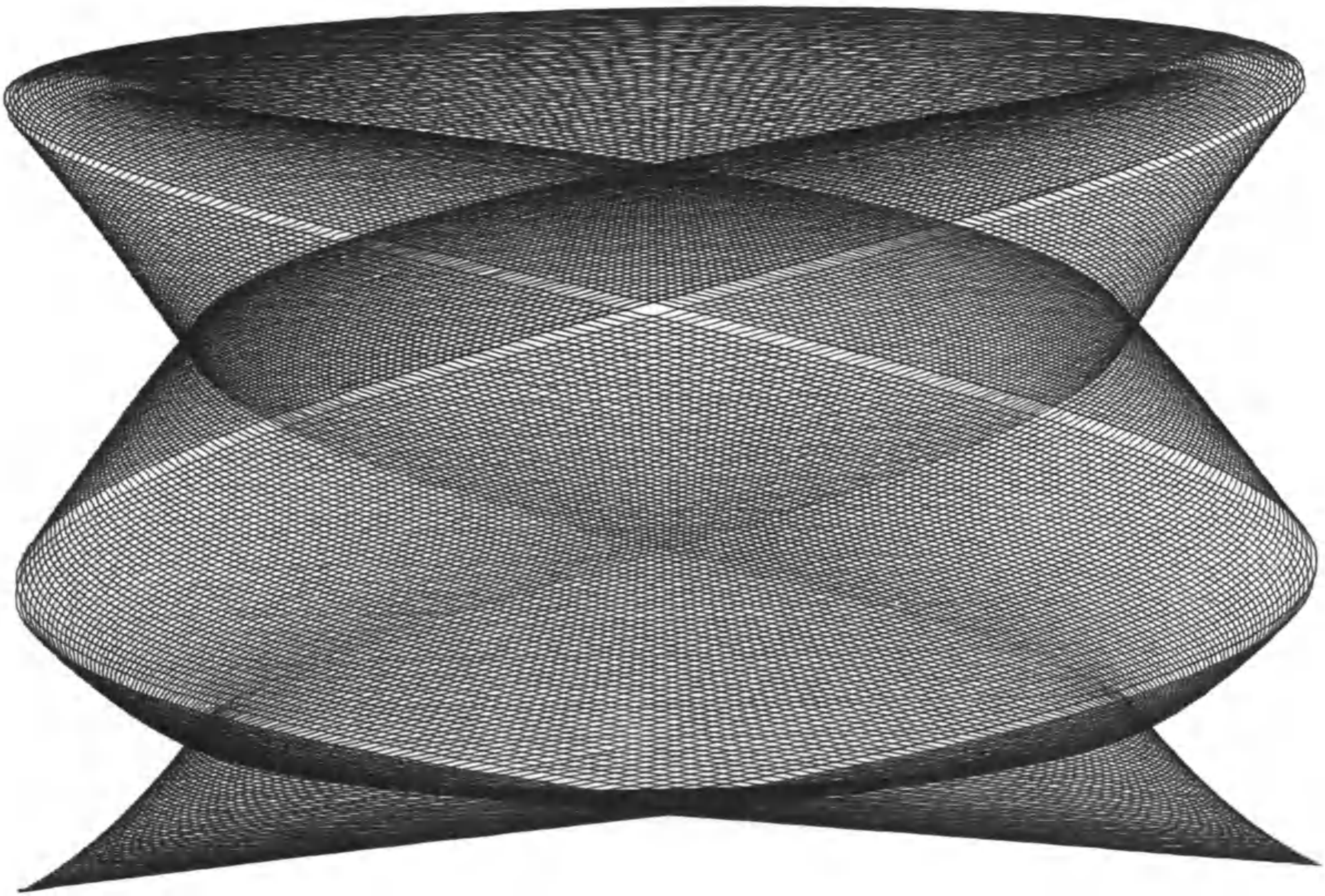
## Digital Output Terminals

The idea of using cathode ray tubes (CRT) patterned after the cathode ray oscilloscope as output terminals first occurred in the late fifties to the scientists at the Massachusetts Institute of Technology where subsequently the first configuration was developed. While it is possible to represent curves by means of analogue systems, when using digitally controlled data terminals, each line sequence must be composed of small linear segments – corresponding to the digital commands. But it is possible to choose picture elements so small that the impression of one continuous curve is created. Compared to mechanical methods, the instantaneous electronic image output without any delay proves to be the major advantage; it allows interactive operation which greatly enhances the possibilities for aesthetic composition.

*Visual display units* are essentially cathode ray oscilloscopes that have been fitted out with precision picture tubes. They can function as output devices for analogue as well as for digital computers. In the latter case, a transposition is called for – the values of x- and y-coordinates that the computer supplies are transformed into voltages. To realize degrees of light gradations, the electron beam is alternately switched on and off. The duration of a beam's application onto a point determines the point's brightness. In current use are grid displays and calligraphic displays – a differentiation of terms that is based on adaptive electronics.

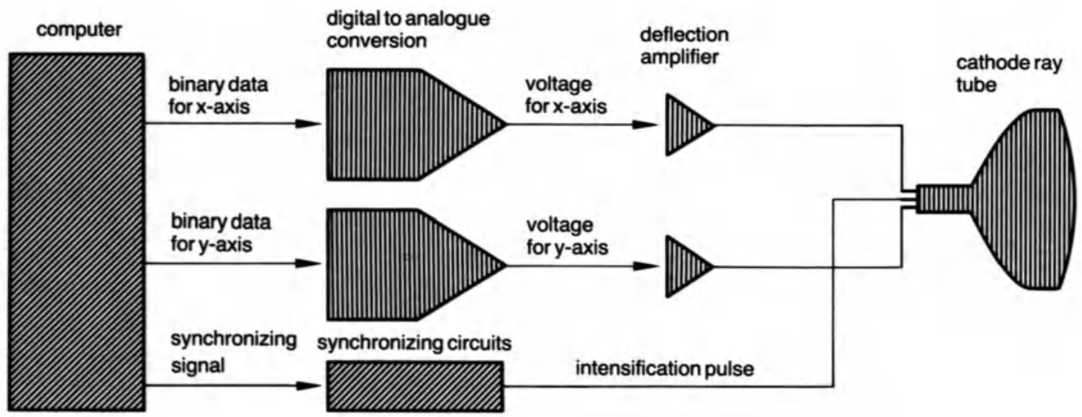
*Grid displays* work on the principle of the television receiver, that is to say, the electronic beam is led in lines from top to bottom, and from left to right across the CRT. They were originally used for the presentation of numbers and characters, but are also suited to the production of halftone images, and are being increasingly used for this purpose. Colored representations can accordingly be achieved.
The definition of a picture is obtained by the resolution of the image, through the number of columns and lines of which it is composed. A typical resolution is 512 ($=2^9$) $\times$ 512 points; some devices also offer 1024 ($=2^{10}$) $\times$ 1024 points and more.

*Vector* or *calligraphic displays* draw pictures as sequences of dots in any desired order. They give an opportunity for adapting the drawing procedure to the linearity of a line drawing. The line-by-line dissection of the picture is thereby avoided.
The original types of calligraphic displays worked on the basis of dot grids, that is, on a digital principle; the electron beam is directed for about a microsecond onto a particular dot; lines and tonal planes are composed from dots. For the faster presentation of lines and characters, analogue switches were developed, which draw particular figure elements, for instance, numbers, in a conjoined manner.
As with any electronic output on the screen, pictures are produced as short-lived patterns; in order to make them visible for the human eye, they must be made stationary in some fashion.



*11/12 Lissajous figures.* Left: *from an analogue system by Wayne B. Hales;* right: *from a digital computer by Ivan L. Finkle. There is a clear distinction between the construction of the digital graphic from linear elements and the process-generated structure of the analogue presentation. In a letter published in 1965 in the periodical* Science, ▷ *Finkle compared his digital figures with Hales's analogue figures of 1945, and so drew the attention of a wider public to the problems of computer-generated aesthetic representation*

14 Rotations/Projections, *a phase picture from a film, vector graphic ▷ drawn on an electronic plotter. Herbert W. Franke, program by G. Geitz, M. Gonauser, E. Hoerbst and P. Schinner, Siemens Research Laboratory, Munich*




*13 Diagram of the arrangement of a visual display unit: the digital impulses coming from the computer are transformed into the analogue physical quantities which are necessary to build up the image in the cathode ray tube*

Two methods are used which are suitable for vector as well as raster displays:

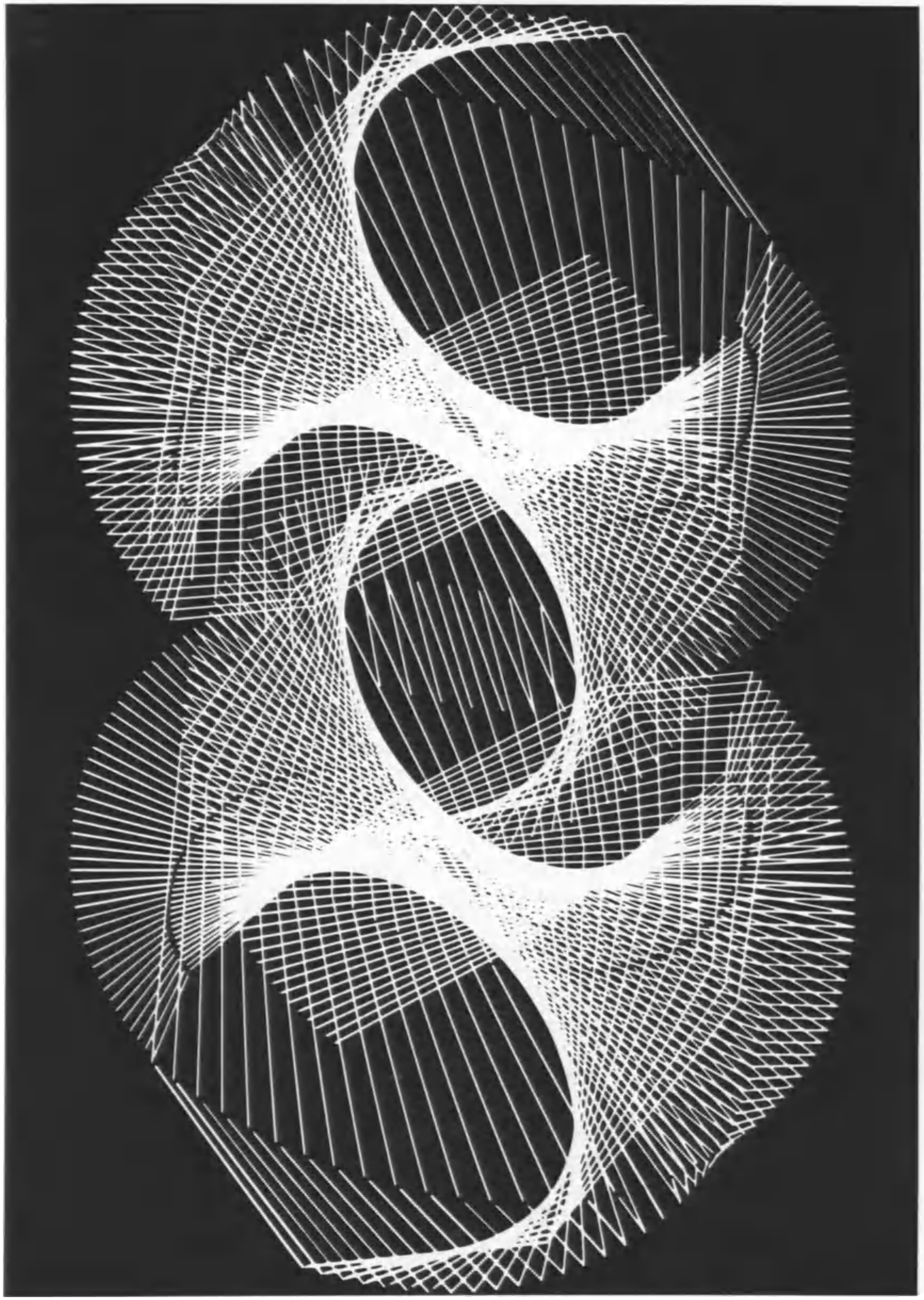
*Storage Tube Display.* The screen is coated with a combination of a phosphorescent substance and a dielectric material which phosphoresces after being excited once by the electron beam. The picture thus stored can be erased again by an electric impulse. Cathode ray tubes of this kind, because of their very nature, are not suitable for the representation of animated actions; even if only a small change in the picture is intended, it must be erased and output anew.

*Refresh Display Terminals.* Today, in the age of interactive operation and computer animation, the old kind of storage tube display is increasingly replaced by refresh systems. Refresh memories are employed which can repeat the image output 30 to 60 times within one second. Since access to this memory is possible at any time, representations which have been output by means of refresh tubes can quickly be changed.

## Color Graphics

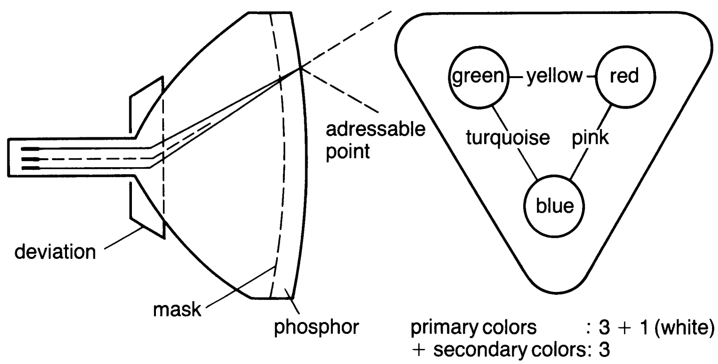
In the beginning stages of computer graphics, when most of the attention was focussed on scientific and technological applications, there seemed to be no need for multicolored computer graphics. At that time there existed only a few users of artistic orientation who would have liked to have the medium of color at their disposal and who devised several technical tricks to achieve the transition. For instance, they photographed pictures on the screen through colored filters, or they subsequently colored black and white pictures of computer graphic art photochemically.

Some of the processes employed at that time still seem useful today, for instance as a means of producing color prints less expensively. The process of separating the colors is rendered unnecessary by producing a black and white computer graphic original for each of the intended colors, usually the primary colors blue, yellow and red, supplemented by black. In order to facilitate handling, these representations should be prepared with registration marks. For screen printing, a template is produced of each original over which the color is applied onto the paper. Other printing processes proceed in a corresponding manner.



These methods are of limited value today when all picture-oriented media have adopted the use of color.
As far as the program is concerned, the use of color is nothing more than the introduction of an additional parameter. It is the designers of output terminals who are faced with yet another technical problem. For mechanical plotters, the change to multicolored drawings is relatively simple; the simplest method is to stop the plotter before changing to another color and to exchange the color pen. The most widely used models exchange the color pen automatically, controlled by program commands.
In the meantime, commercial problems in various areas of application have arisen which call for the use of color in computer graphics, for instance in the areas of design, simulation, and computer games. Finally, some other well-justified applications have emerged, for instance the use of computer graphics and computer animation for instructional purposes or in business graphics - those diagrams and schematics which are used in business to visualize various data and processes (management information systems). Generating these surveys by computer has proved to be very advantageous, since it allows the business man to monitor the current events immediately. But even in the field of technology situations have arisen which require the use of color, for instance when supervising processes which are increasingly controlled centrally by means of screens, or in computer-aided design which often necessitates the highlighting of certain line segments in complicated line patterns by coloration. Further applications of color graphics in picture processing, picture analysis - in science and medicine -, and cartography should be mentioned. But again, the color output terminals were not developed for artistic purposes, but because of actual commercial demand.
The most convenient and most frequently used kind of color representation is display on electronic screen terminals - an approach which seems particularly sensible, since it permits the connection with other image oriented media, for instance with television and video technology. The producers of personal computers already offer systems which make use of household television sets as output terminals.
The advantages of graphical output on screens are: real-time generation of pictures, the possibility of color output of regions as well as lines, the unhampered transition to motion; it is also of importance that screen terminals are founded on mature technology which enables them to operate error-free, dependably, and relatively inexpensively.
In commercially available screen terminals which have a resolution of 512 × 512 picture elements (pixels), the raster has proved to be too coarse for some applications. Therefore, screens with 750 × 750 picture elements (medium performance) or 1024 × 1024 picture elements (high performance) are offered as well. Experts expect another increase in resolution.
Another difference between plotter graphics and representations on screens needs to be noted, the fact that for the former a hard copy is already available, while for the latter it needs to be output by additional output request.

*Color tubes.* Electronic screen terminals for color output correspond in design and operation to black and white monitors. In order to be able to generate colors, the screen is covered with picture elements which at the same time are the smallest addressable units. They consist of a thin application of substances, which, excited by the electron beam, phosphoresce in red, green, or blue. In raster color tubes, the electron beam is deflected in a raster pattern on the screen at a rate of 30 to 60 times per second. For vector-refresh systems, which are used more rarely, the cycle can




*15 Grid color tube, and the formation of secondary colors by the addition of primary colors*

- particularly in dynamic graphics - depend on the computation time for the individual picture frames and therefore can possibly change during output; but the picture repetition rate can also be fixed.

To produce the primary colors, the electron beam is modulated in such a manner that it strikes only the corresponding picture elements while the beam intensity decreases to zero when passing over the other elements. The generation of blended colors or white requires the excitation of at least three picture elements of different primary colors. If the electron beam operates with full intensity, the blended color white is generated; with lesser intensities grey values down to black are created. If the individual picture elements of a group of three pixels are excited by various degrees of intensity, all the other blended colors result.

Color tubes contain three cathodes, each of them generates an electron beam for red, green, or blue. Each one of them is controlled separately so that in the final picture three color components consisting of the three primary colors are overlaid.

Since it is technically difficult to output the phosphorescing substances in precisely the correct shapes and sizes, shadow masks are used as diaphragms. Normally, the picture elements of a set of three are positioned at the endpoints of an equilateral triangle (delta gun tube), or else they are positioned linearly side by side (in-line tube), but there are also kinds which contain color bands instead of color dots and correspondingly a multiply slotted metal mask instead of the shadow mask.

Misalignment of the electro-optic system results in a mutual shifting of the pictures consisting of the primary colors; the well-known convergence errors in the shape of colored rims are the result. This effect can possibly be utilized artistically, for instance for the abstraction of representational art or to generate pseudo-reliefs.

The software which is offered particularly for microcomputers distinguishes between low-resolution graphics and high-resolution graphics. Low-resolution graphics limits itself to picture elements which combine square or rectangular regions of the picture consisting of, for instance $4 \times 4$ or $8 \times 8$ pixels. In high-resolution graphics, on the other hand, every picture element is addressable individually. If straight lines or curves are drawn in this mode, another undesired color effect results caused by the fact that, in order to generate line segments of a desired position and direction, picture elements of one or the other color are used in preference to the other colors. If the pictures consist of narrowly spaced curves, this effect results in colored interference patterns which lead to an overlay with unexpected colored patterns. But this phenomenon can also be utilized in a positive manner - a number of graphical experiments which can be performed with personal computers are based on it. Not the least reason why working with Moiré interference patterns, etc. is so attractive is the fact that they result in structures of a complexity which can not be achieved as quickly and easily with the logic inherent in the program.

## Graphic Documentation

The most obvious method of documenting the monitor display is *to photograph the picture*. One of the peculiarities which needs to be taken into consideration is the banding effect, the fact that, by repeating the image output several times per second, band like picture segments of the developed photograph appear to be cut off or underexposed. This is caused by the line-by-line scanning of the electron beam; if the exposure times are too short, only part of the scanned picture is exposed. Therefore it is advisable to expose the screen for not less than one second.

The required long exposure times prevent the free-held taking of a picture; use of a tripod is indispensable. Another difficulty is presented by the distortion of the picture caused by the optical system of the camera and further increased by the rounded surface of the screen. Minor misalignment of the centre of the screen will cause asymmetrical distortions of the geometry; exact positioning of the optical axis will reduce the "pin cushion effect" to a bearable level only if long focal distances, more than two meters if possible, are used. Reflections on the screen should also be prevented, and it has proven to be quite difficult to produce color-true pictures.

Of course, all these sources of error also occur in direct viewing, but are largely corrected by compensatory data processing in the brain and therefore are not noticeable. For all these reasons, simply taking snapshots of the screen displays is at best of temporary usefulness as a memory aid or for picture archivation. If more satisfactory results are desired, a camera stand especially adapted to the display terminal and, for best results, a lightproof bellows should be used.

*Color Hardcopy.* Special apparatuses are employed to achieve true-to-scale reproductions of screen images in the form of color copies, called color hardcopies. The devices offered for this purpose contain a black and white cathode ray tube with a flat screen and a camera with special optics directed at the screen. Taking a picture requires three steps: components of the primary colors are extracted and transposed into black and white by photographing them through filters. For this, it is possible to use negative as well as reversal stock which will then be developed in the photo laboratory in the usual manner and which allows the production of paper prints and slides. If immediate output is desired, an instant camera, for example of the Polaroid type, is employed. By using color hardcopy devices, one avoids all of the above-described deficiencies: distortions in particular are avoided because of the flat screen, and the color extraction process guarantees perfect quality of color.

*Computer Output on Microfilm.* Microfilm plotters can either operate in a vector-oriented or in a raster-oriented mode. They can be controlled by magnetic tape or on line. Slides in 35-millimeter format which are intended for microfilm projection have a resolution of more than 350 lines and have 16000 × 16000 addressable picture elements. This ensures a sharpness which is unusual for large scale projections and which offers a good potential for artistic purposes. However, so far it has remained unused.

Depending on the combination of devices chosen, all other output terminals which produce colored pictures on paper or similar materials can also be used for the final documentation of screen pictures. Representations displayed on vector terminals can be reproduced by means of line-generating plotters, representations displayed on raster terminals by means of the various printer plotters and ink jet plotters. For some time, color Xerox machines have been offered as a universally usable method for obtaining color copies.

*Printing Devices*

Where devices for the graphic output of computer data, like mechanical and electronic plotters, are not available, some programmers occasionally improvise by doing a kind of drawing with the usual printing machines, especially the fast printer. These instruments enable the user to mark points at desired places within the grid provided by the lines, for instance, by the placing of an *X* or an *O*. Such points can also be joined as a rough curve if necessary. In many cases, especially where the results will inevitably be subject to a certain margin of error, such a presentation will undoubtedly serve its purpose. But above all, this method gives one a provisional grasp of the results, which can later be presented in a final form with a visual display unit if necessary. In special cases this procedure is also very suitable for aesthetic computer graphics. It can be particularly helpful during the preparatory work, as a means of assistance in the conceptual phase.
Using a printing process it is possible to print out on a roll of paper, in continuous form, the most varied combinations of pictorial elements, and one can then select the most attractive combinations from an abundance of examples. These can then be executed in a definitive form with another device, or realized manually. The speed of the printer - up to 2000 lines per minute - favors such a use. The type patterns of the fast printers are occasionally put forward as the final form of presentation, but they tend to look provisional. It is most likely that the fast printer will no longer be used as soon as modern devices for visual output become generally available.

*Printer-Plotters.* The so-called printer-plotters are designed in such a way that the paper is passed over a nib bar; the pictures are output point by point and line by line - with writing speeds of approximately 40 millimeters per second and approximately 700 lines per minute. Some physical principles are applied in this process: The electrostatic printer-plotter charges the almost point-shaped regions on dielectrically prepared paper, a process corresponding to photographic exposure. The paper is then passed through a developer in which finely dispersed color particles are blown onto the surface of the paper to form a color coat-

*16* The Head of a Tiger, *drawn on a pinhead printer, Ziegler Instruments* ing corresponding to the latent electrical charge pattern and are finally fused by heat onto the paper. The copies can be removed immediately; they are color-fast. The resolutions achieved by printer-plotters, defined by the distance between points, are close to one tenth of a millimeter. Another type of printer-plotter operates with specially prepared paper which discolors when heated; thus, the point-shaped picture elements are permanently "burned in". Besides the above-described models, others are in use which rely on traditional techniques, for instance some which operate with color ribbons. Depending on the construction, the daisy wheel printer, the ballhead printer, and the pinhead printer are to be distinguished. Basically, they reintroduce some construction principles of typewriters while abandoning the line-by-line output and making it possible to advance the writing head incrementally in any of the coordinate directions including diagonally.

*Ink Jet Plotters.* Gradually, the ink jet plotter is being accepted as an alternative color output device. Originally, they were designed for special purposes, one of the first ones - system SICOGRAPH - for permanent documentation in the medical field of scintigraphy. Spray jets are used as a means to deposit color; the three primary colors, occasionally supplemented by black, have proven to be sufficient; as with color terminals, a much wider gamut of colors can be achieved by superposition. The writing head moves across the paper point by point and line by line, accompanied by an even output of color; the density of the color deposit is modulated by changing voltages, the excess of color deflected and collected in filters. Contrary to printer-plotters, ink jet plotters achieve an even color deposit in subtle shades. Therefore, prints generated in this manner are well suited for the output of artistic graphics; the composing itself can be done with the help of an interactive graphics system; the satisfactory final result is produced on a special absorbent paper. The time required to generate a picture is one to two minutes.

*Laser Printer.* The laser printer is very convenient for graphic applications. The fine, highly directional beam, which serves as a drawing instrument, permits high resolutions of as much as 100 lines per centimeter.

## 6 Software

The material equipment of a computer, the hardware, has to be differentiated from the knowledge of data and programs, i. e. the software, which will be dealt with in this chapter.

### Organization of Digital Computer Processes

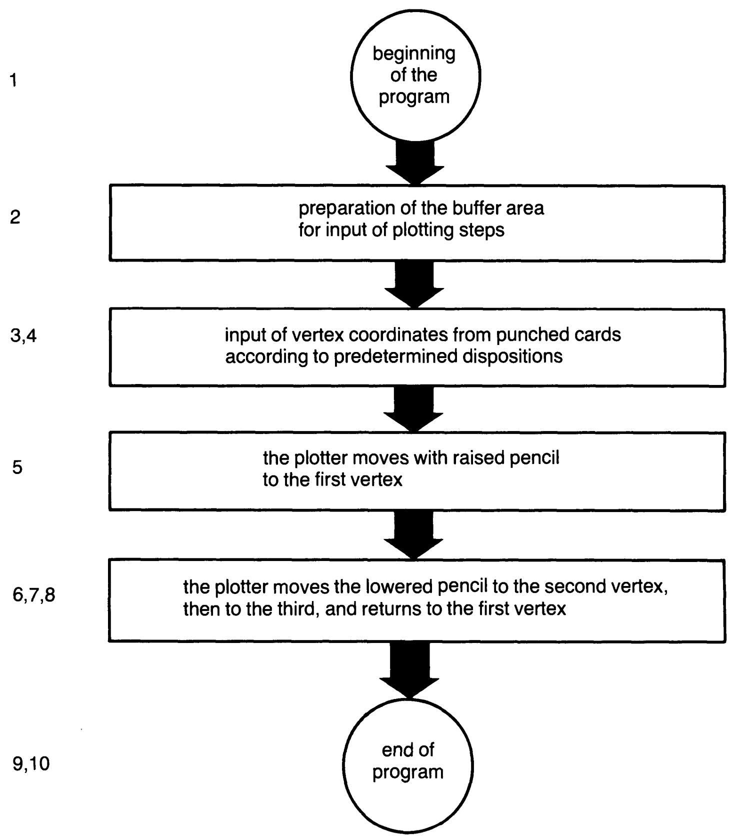
The majority of digital computers operate synchronously. That is to say, the elementary computing processes, which are necessary for the execution of the orders, follow one another at very short intervals, being synchronized by a master clock. Modern large computers function at a rate of up to one thousand million steps a second, of which only a few dozen may be required for an elementary computing instruction. This speedy way of working leads to a situation where the actual calculation takes up less time than the preparation, for example, the designing of the program. The user has no means of intervening in the detailed running of the computational process. Sometimes the machine begins to work at the moment when the last item of data has been entered, and continues its activity until it disburses the results. But in the main these computer systems are so heavily used that waiting periods are inevitable.
In many cases it may be desirable occasionally to interrupt the computation in order to obtain some intermediate results, and perhaps introduce some new data dependent on these. Where a computer is built and programmed to have the capability of following an external process in its time scale, then we talk of real-time activity; the direct cooperation of man and computer, a dialogue activity, is a special instance of this.
In this working method, man's reflection periods are usually much longer than the computing time of the machine. In principle, it would be possible to utilize these breaks for other calculations.
Organization programs are now available, known as supervisors, which divide the computing periods among different users in such a way that no one is hindered by anyone else (time sharing). Depending on time, it is possible to introduce further computing processes of other current programs. In practice, each user operates through a tele-system from the desk in his room.

## Programming Languages

Computing is preceded by a preparatory phase, where the current problem is analyzed and a way to its resolution is sought. Then follows the division into the single logical or computational steps that are to be executed. At this point it is best to draw a flowchart, with the individual phases contained in boxes, which are connected by arrows showing the sequence to be adopted. From this stage of the preparation, the transition to the program, to the standardized instruction sequence, is very easy.
Since it is exceedingly laborious to convey orders to the computer in an 0, 1 code, programming languages have been designed. These consist of systems of symbols that are transformed by the computer into the corresponding 0, 1 sequences by special translation programs known as compilers.
The most useful languages are problem-orientated; this means that they are not adapted to individual machine types, but are designed to cope with specific problems, for instance, the execution of drawings. Several computer artists have developed their own purpose-built computer languages. Here are some of the first examples:

- BEFLIX: originally for music compositions, and later extended for film sequences (Kenneth C. Knowlton).
- SPARTA: a program for any desired line drawings (Leslie Mezei).
- COMP ART ER 56: a program package for the production of many categories of computer graphics (Frieder Nake).
- G1, G2, G3: a sequence of program languages for the generation of computer graphics of increasing complexity (Georg Nees).

```
1          PROGRAM TRIAN1
2          CALL PLOTS(BUF(1),8000,11)
3          READ(97,10)X1,Y1,X2,Y2,X3,Y3
4       10 FORMAT(6F6.3)
5          CALL PLOT(X1,Y1,3)
6          CALL PLOT(X2,Y2,2)
7          CALL PLOT(X3,Y3,2)
8          CALL PLOT(X1,Y1,2)
9          STOP
10         END
```




*17/18 Printer record of a program TRIAN 1 for drawing a triangle ▷ whose vertices are given by the coordinates X1, Y1, X2, Y2 and X3, Y3. The events corresponding to the entries in each line are illustrated in a flowchart. Such a flowchart, giving an overall view of a succession of events in time, is a vital aid in the preparation of a program*

These examples refer in the main to generally used problem-orientated languages, e.g.:

- ALGOL (*Algo*rithmic *L*anguage): a language for mathematical-technical problems
- FORTRAN (*For*mula *Tran*slation): used for similar purposes.
- COBOL (*Co*mmon *B*usiness *O*riented *L*anguage): for the carrying out of commercial tasks.

Further languages have been added recently, such as BASIC, PASCAL, ADA, and LISP. The symbols of such languages are usually constructed mnemonically and often come from colloquial English, such as (in FORTRAN):

- READ for input,
- WRITE for output,
- GO TO for an order to move,
- IF for a conditional order.

These languages have a particular advantage in that they are valid for all machines for which a suitable compiler is available. The programs are made up of linear sequences of such symbols. The fact that these linear sequences do not have to be run in one go from beginning to end enormously extends the computing capacity of the computer, for example:

- GO TO 42 means: move to instruction 42,

or (aligned to a condition)

- IF (A-B) 3, 6, 12 means:
  if A-B is negative: move to instruction 3,
  if A-B = 0: move to instruction 6,
  if A-B is positive: move to instruction 12.

This makes it possible to repeat computing procedures as often as one likes, the sequence being dependent on given conditions. And since calculations are made with fluctuating quantities to which various values are consigned in the course of the running of the program, we are presented with a multiplicity of realizable processes that can hardly be grasped; and all this with relatively simple programs. Naturally, computer art makes use of these possibilities.

## Graphical Programming

Since it is usually desirable to execute calculations and to generate pictures in one session, the logical and numerical constructs of some programming languages were extended by graphical components. In principle, since graphical programming only requires a few commands, it is sufficient to define points on the basis of coordinate values and to assign a color. The coordinates are determined by the user or result from calculations by the program. Depending on the purpose, further commands are usually available which increase the versatility of the programming language. Generally, these are commands for the generation of lines, arcs, and other output primitives which are defined by starting coordinates and end coordinates and other parameters. But the procedures contained in the programs can be arbitrarily complex, for example procedures for interpolations or special kinds of movements like translation and rotation. Finally, the set of commands is supplemented by commands for erasing, storing, and other actions.

Programming systems of the kind described into which mathematical and logical subprograms can be incorporated are particularly well suited for scientific and technical purposes on which, at the beginning of computer graphics, interest was focussed. The subsequent development is characterized by an increasing adaptation to a freer work style of the kind which is customary for design projects. Finally, software systems which hardly require any numerical data were developed for artistic use as well as for games; in these cases, the incorporation of mathematical operations could possibly cause difficulties.

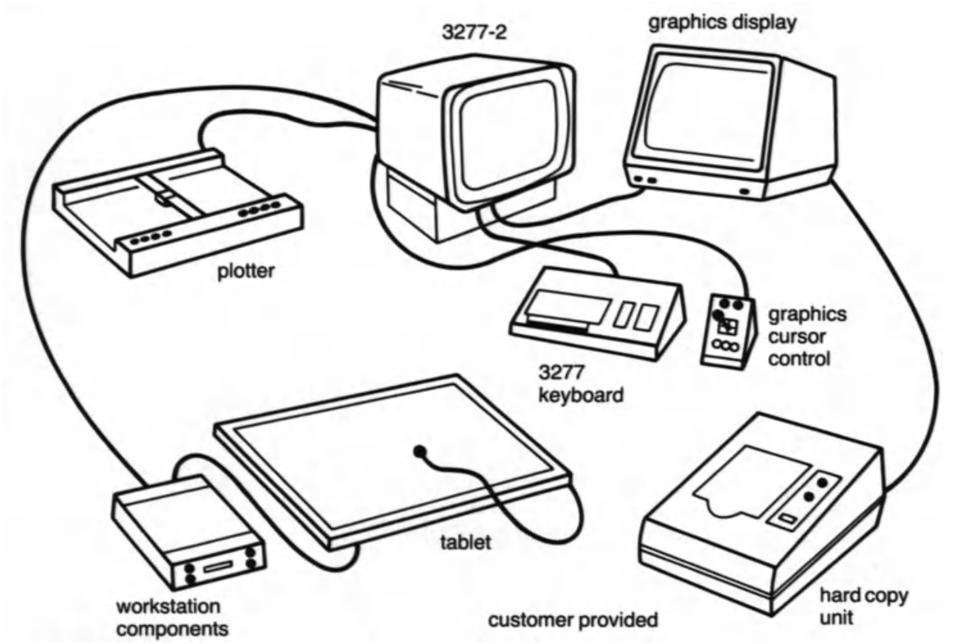
The first step towards free graphical programming is the introduction of the so-called cursor, a light signal on the screen which fixes the chosen location. The signal can be a blinking marker or else a colored marker. The cursor can be moved by various means, most easily by means of the keyboard, assigning certain keys as commands for the control of motion in the direction of the coordinates and also of diagonal motion. By depressing a key one can cause a step-by-step movement, or one can make it continuous by keeping the key depressed. In addition, there is usually another possibility: the cursor which is moved across the screen leaves a trace on the screen – this allows the user, by

*19 Graphics Workstation 9731, Siemens*

means of keyboard control, to produce a drawing on the screen. With this kind of operation, various routine actions can be implemented: for instance there are commands for the coloration of certain regions which are defined by closed polygons.
Operations of this kind can be implemented in an even easier way by means of various peripheral devices, for instance with the aid of joysticks and tracking balls.
During the last years, rather complex hardware/software systems for special purposes were developed by the computer industry as well as by scientific-technological research groups. Usually, the aim is to design them to be independent of any particular terminals which, however, is possible only up to a certain degree, since the potential capabilities of these configurations are naturally dependent on the equipment.

## Computer Graphics in Interactive Operation

Contrary to the first applications of computer graphics which merely involved the production of a drawing, computer graphical operations are nowadays included in many more applications. This often involves the joining of graphics to scientific, technical, and mathematical processes, but often also the processing of information of the most diverse character into a totality of picture, text, and symbols. The procedure required to achieve this is interactive operation, and this, in turn, is dependent on the provision of workstations with adequate input and output devices. They are grouped around two screen terminals, the data terminal providing the means for the dialogue, the graphics terminal serving as a work surface.




*20 Graphic representation of a workstation (IBM 3277)*

*21 Representation of bridge construction on the electronic visual display unit IBM 2250*

In the course of the development, certain routine tasks have crystallized which surface again and again, quite independent of the special application. It would not be sensible to redesign them for each special program. Rather, the trend has developed to provide the graphics terminal with "local intelligence". The circuits required control the dialogue between the terminal and the user; they also execute certain graphic procedures of which the most important ones are enumerated in the following collection of terms:

- *Translation* and *rotation* of pictures and subpictures.
- *Windowing:* singling out a window-like area which can then be treated separately, for instance by coloring it or by zooming it.
- *Zooming:* the enlargement of subpictures or windowed structures;
- *Clipping:* the clipping of line segments which extend beyond the window border.
- *Locator Operation* for locating a point or a line.
- *Pick Operation:* the identification of a graphical element on the basis of spatial coincidence. The so-called choice simulation applies procedures of this kind, for instance when a digitizing table is being overlaid by a menu of light buttons. Since the computer using the pick operation is capable of recognizing the light button picked, it can also understand the associated choice.
- *Temporary Storage:* the stored pictures can be retrieved at any time during a design session.
- *Overlay Technique:* the overlay of storage levels.
- *Filling of Closed Polygons:* for instance by coloring, textures, etc.
- *Support of Modelling of Graphical Objects:* for instance by supplying elements, inter- and extrapolation procedures, etc.
- *Support of Attributes:* among others change of colors, transition to an inverse picture, erasure of segments and structures, etc.

Desirable subprograms can be added to the programming system. Decision aids on the basis of menus (see Fig. 2, p. 5) are particularly suited for graphical systems which offer complex capabilities, so that the choice must not be made by means of abbreviations and symbols, but by means of "reference", for instance by touching a light button. Thus, it proves quite difficult to make the correct selection from a matrix of numbers, whereas one encounters no difficulty doing this from a colored pattern on the screen. The assistance thus offered by the graphical system is part of its "intelligence" - it is immaterial to the user whether it is provided by the hardware or by the software.

In some research laboratories, but also in consulting firms for computer graphics and animation which have sprung up in an increasing number, graphical systems (painting systems) are being used which are adapted to free-form designs. Members of professions of artistic orientation in particular value the freedom of operation which is being offered by selection menus for colors, textures, structures, etc.

Ivan E. Sutherland could be considered the pioneer of interactive systems. At the MIT in 1963 he developed *Scatchpad,* a graphics oriented system which permitted inputs directly on the screen by means of a light pen.

## Graphics Systems

The desirable compatibility of hardware and software of different origin has been the subject of several conferences and standardization attempts. The so-called interfaces, the connection between the various subsystems, have proven to cause problems. It is the familiar problem of the mismatched plug-to-plug connection which reemerges at a higher level, with greater difficulties. Adaptors would not be sufficient; rather, a complicated adaptation interface is needed, systems which permit the transition from one norm to another. Besides the usual tasks of physical-technical adaptation, they have to solve in particular the problem of noncompatible software; this requires complicated switching systems, even specialized computers. Companies may see a temporary advantage in limiting their own production to systems which are only compatible among themselves, but not with the products of others, but this erects barriers which prevent the broad application of their technology significantly - the present video systems are a case in point. Two such machine-dependent systems which are used throughout the whole world are the *Cal-*

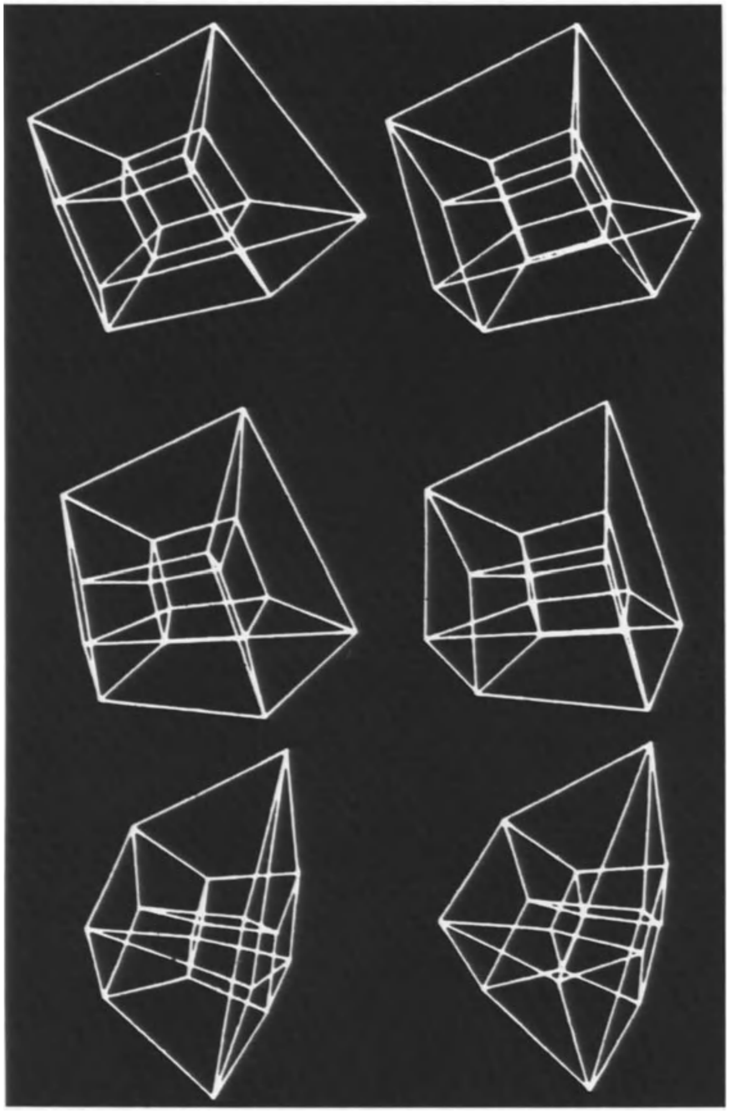
*Comp Plotter Software* and the Tektronix *Terminal Control System* (TCS). In the long run, it should prove to be more advantageous even from the viewpoint of commercial interests to offer systems which can be employed in as varied a manner as possible, independently of specific norms of the producer. The foundations for a generally usable normed graphics system were laid at a workshop of the International Federation of International Processing Societies (IFIP). The system based on norms agreed upon is called *Graphic Kernel System* (GKS), following a German proposal.

## Mathematical Operations / Random Processes

In the early stages of graphical computer art, primarily programmers and mathematicians got involved in aesthetic experiments. One of the reasons was the fact that members of other professions had hardly any access to computer graphics systems. But there was another hurdle to be surmounted. They did not know how to program and were lacking the mathematical fundamentals which the first computer graphics scientists used as a base.
Meanwhile, the situation has changed fundamentally: A person who is seriously interested will find opportunities to work with a computer with graphical output. Besides, hardware as well as software systems have been adapted to such an extent to users who are not adequately trained that special training is hardly required any longer. In many cases, it is possible to get acquainted with a particular method within a few hours, and the user becomes perfectly familiar with the system after a few days of practice. The same holds true for users in business and commerce, and particularly for artists. Painting systems were developed for their use where the user merely has to make selection decisions on the basis of a menu. After selecting the desired kind of command, color, etc., he can draw directly on the screen with the lightpen or on the digitizing table with a cursor. Systems designed for great versatility provide a variety of transformations, for example scaling and translation of windows, which make the handling of the system much more flexible than was possible with the classical means of painting and of graphic art. It should not be overlooked, however, that, compared to the formal mathematically oriented beginnings, an important element of artistic computer graphics is lost, the fact that a wealth of pictures is produced with the aid of mathematical and logical relationships which have not yet been seen by anybody and which increase our knowledge of forms and shapes considerably.
It is impossible to give a complete overview of all the mathematical relationships which are suitable as a basis for computer graphics experiments. Part of the reason for this is that, so far, only a fraction of them has been examined under aesthetic aspects, but partly also because the results attained so far can rarely ever be categorized as definitively belonging to certain subject areas of mathematics and logic; more often, several principles are applied simultaneously. In general, far more mathematical and logical relationships can be visualized than was assumed so far. For artistic purposes, relationships may become valuable which are of no scientific value, for example combinations of algebraic and logic formulas.
On the following pages, some of those principles are summarized which have proven to be productive and useful for mathematically oriented computer graphic art. An essential differentiation which becomes quite visible in the resulting pictures can be made depending on whether stochastic laws are incorporated into the basic relationship or not. They can also be combined, however, with other principles which are not based on statistics.

*Symmetrization.* As the example of the kaleidoscope shows, it is possible to make any configuration, though graphically without appeal, aesthetically pleasing by symmetric overlay. Single and repeated reflections and multiple rotational symmetry are often used. Many mathematical laws, as for instance the laws of algebra and of field theory, are symmetrical by nature. In fact, the principle of the kaleidoscope, which can be simulated by computer graphics, is an example of the use of a combination of stochastic and deterministic laws.

*Transformations.* Reflection and rotation, as shown by the example of symmetry, are examples of simple transformations. Mathematics offers a multitude of further, far more complicated transformations, for instance nonlinear reflections on a circle, distortions by means of dilation, Fourier transformations, etc.



*22 Three-dimensional projection of a four-dimensional cube, represented through pairs of pictures for stereo observation in movement, by A. Michael Noll*

*Mathematical Functions.* Formulas in which the y-coordinate is a function of the x-coordinate can generally be represented by a curve. Experiments with unusual functions often result in rather strange objects which sometimes are acceptable as results as such, or at least they can provide the raw material for further graphical processing. By changing parameters, for example, sequences of slightly varying representations are obtained which, when superimposed or alternatively represented as a sequence, provide many a satisfactory result.

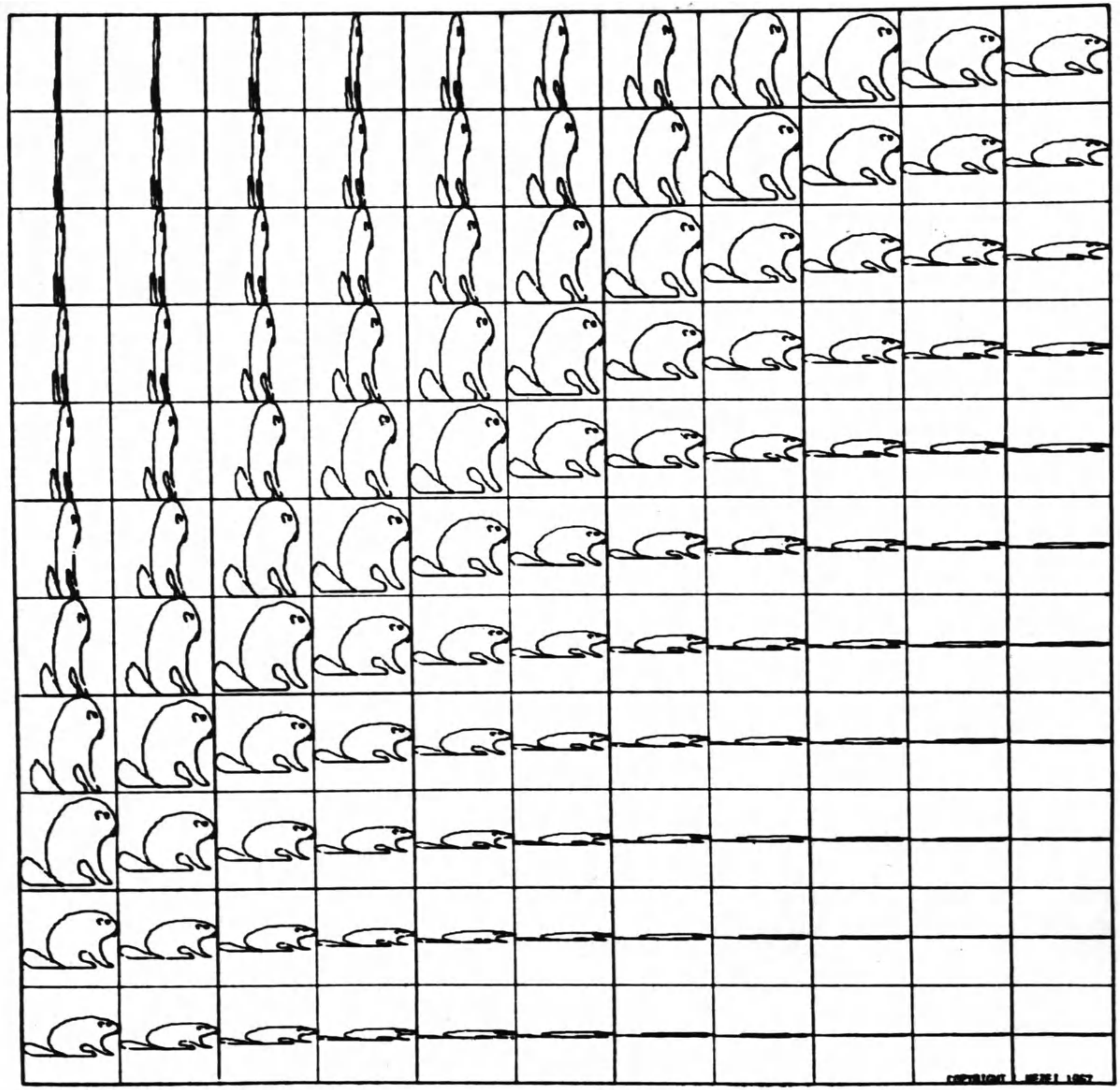
The visual transposition of formulas in which a coordinate z is represented as a function of the coordinates x and y is simpler yet. If a grey value or a color table is associated with the z-value, the formula becomes a direct expression of a two-dimensional graphical representation. Depending on the resolution of the available systems, such pictures are produced as more or less fine mosaics, which need not necessarily be a disadvantage. Occasionally, the increased coarseness can even be used as an additional graphical effect. The possibilities of expression are further extended by replacing the natural color spectrum by an artificial one, a sequence of arbitrarily chosen colored segments and lines. Access to this type of graphic is gained most easily by the algebraic function which describes a spatial surface, for instance

$$z = f(x, y).$$

Other readily usable mathematical bases may be drawn from the field theory of fluid mechanics.

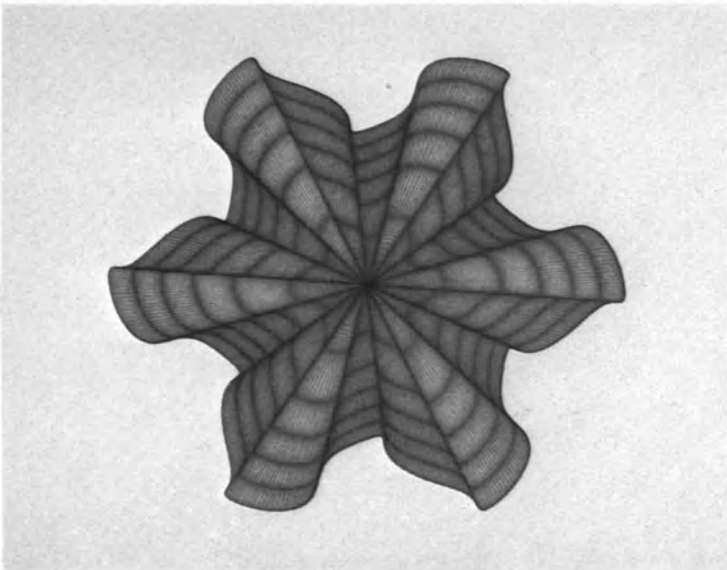
*Moiré Pattern.* The superimposition of curves, particularly when they are located closely to each other, results in a physiological effect which is known as the Moiré pattern. Mathematically and physically, Moiré patterns are closely related to the phenomenon of interference. They become visible when the overlay creates the impression of a coarser, superimposed line pattern. Since the Moiré pattern is graphically interesting, it was applied quite often in artistic computer graphics - as well as in the so-called op-art.

A Moiré pattern can also appear as interference between the picture elements of the picture itself and those of the screen and are normally perceived as visual noise. In certain cases, however, this phenomenon can be utilized for artistic purposes.

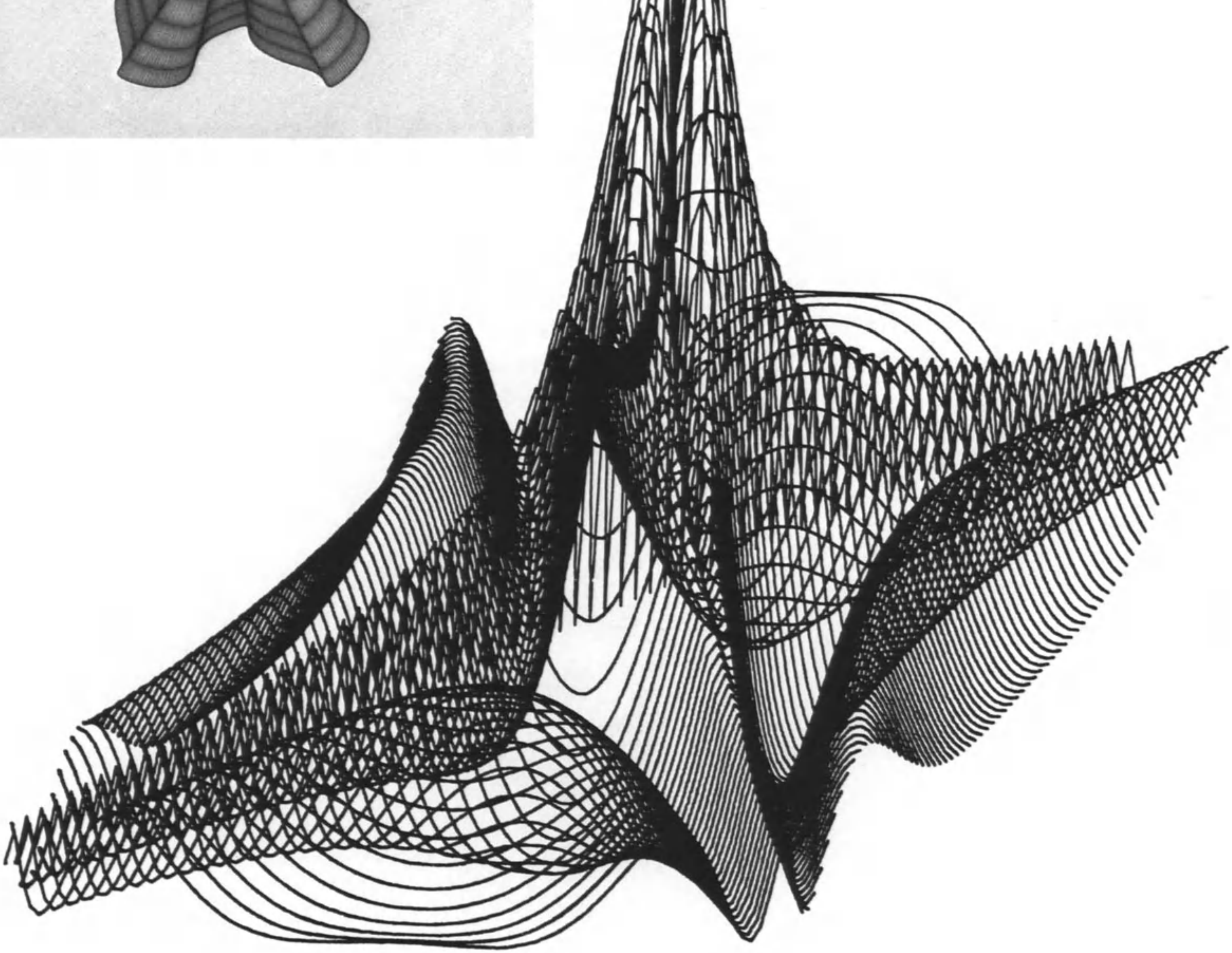


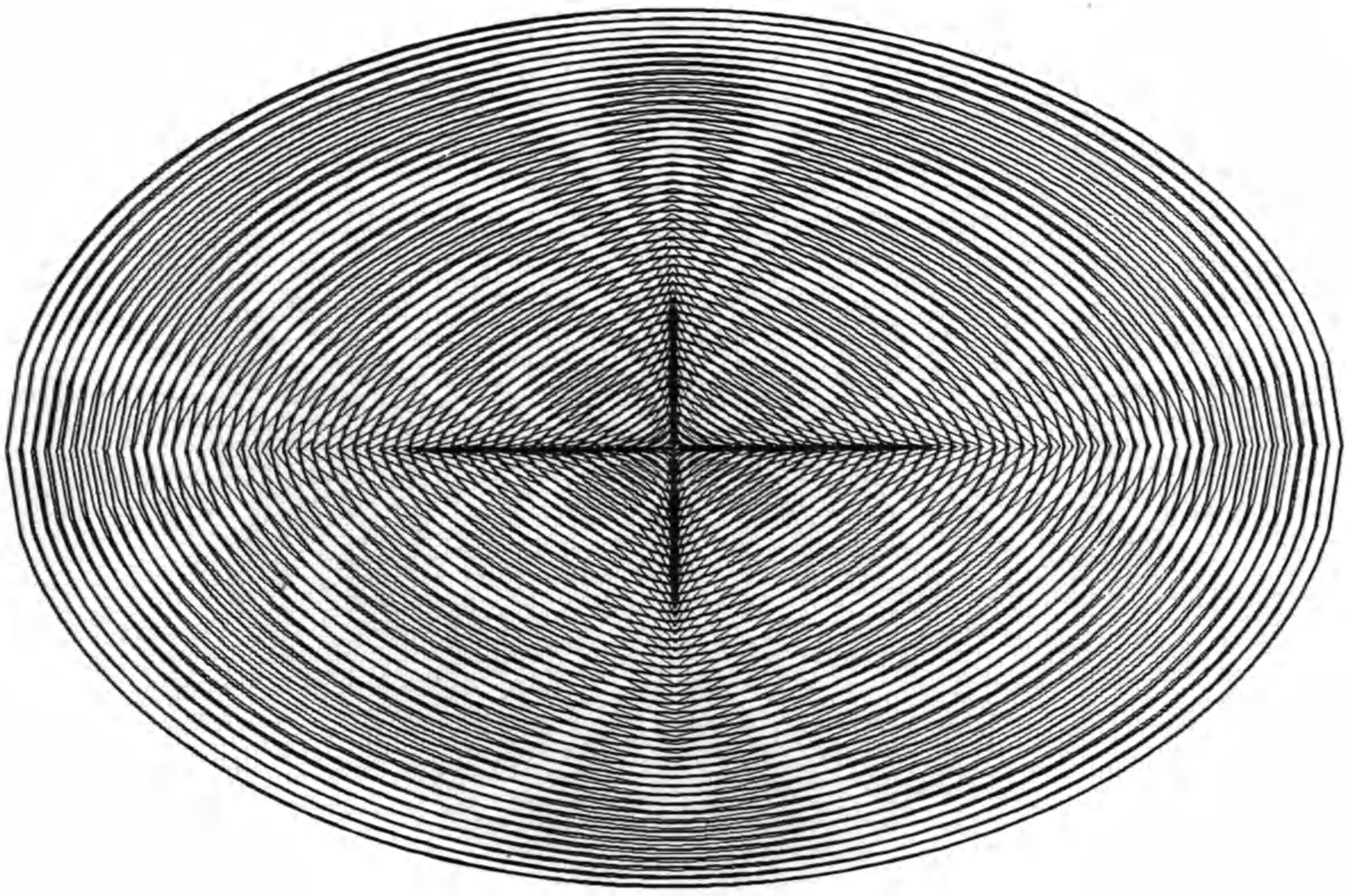
*23* Beavers *by Leslie Mezei. Successive transformations of the drawing of a beaver*

*24* Ornamental Form, *Fourier transformation of a letter; system DIBIAS, DFVLR, Oberpfaffenhofen, Herbert W. Franke and Horst Helbig*



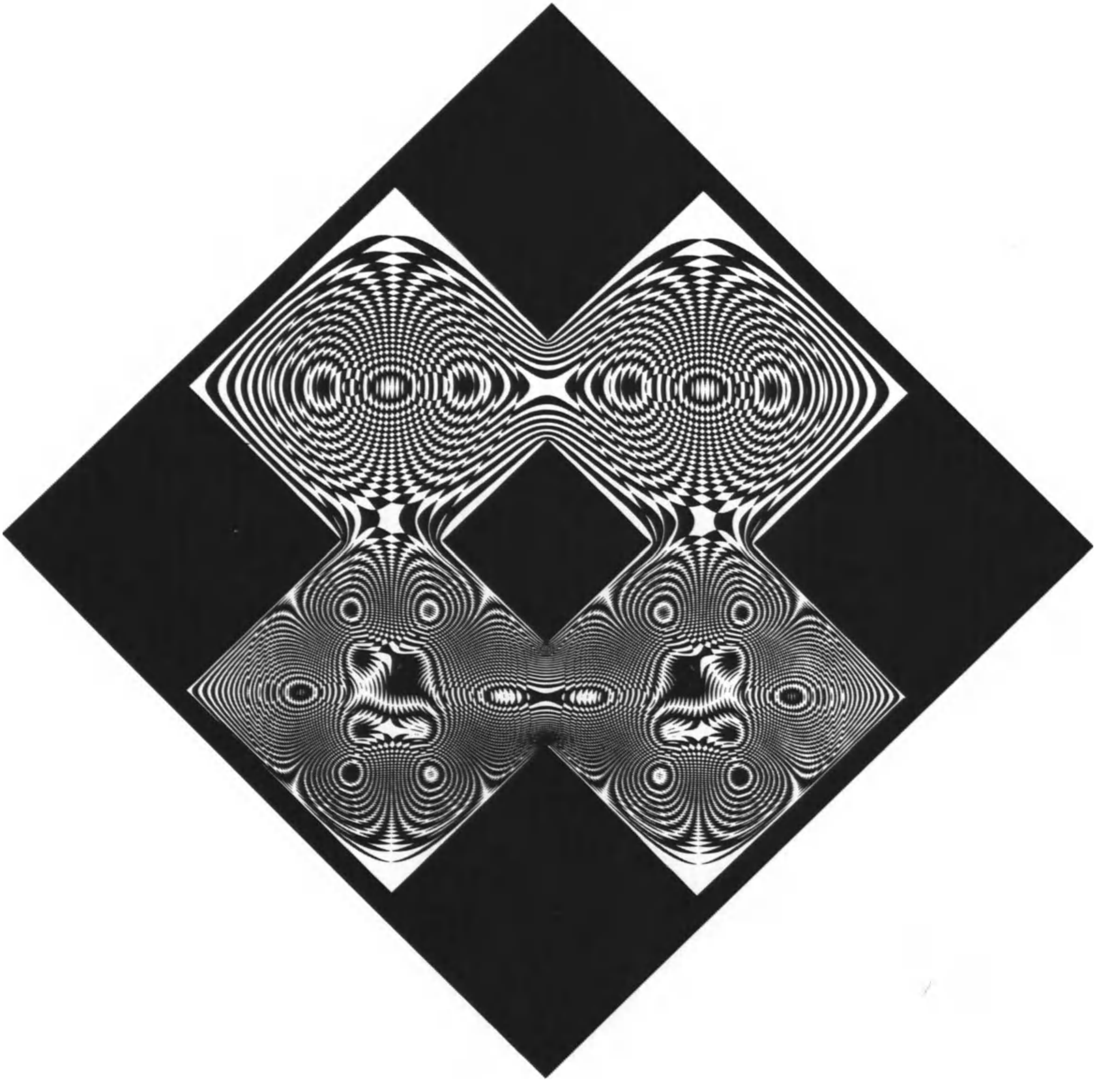
*25* Harmonic Variation, *a graphic representation of a mathematical function, by Norton Starr, Amherst College*
◁



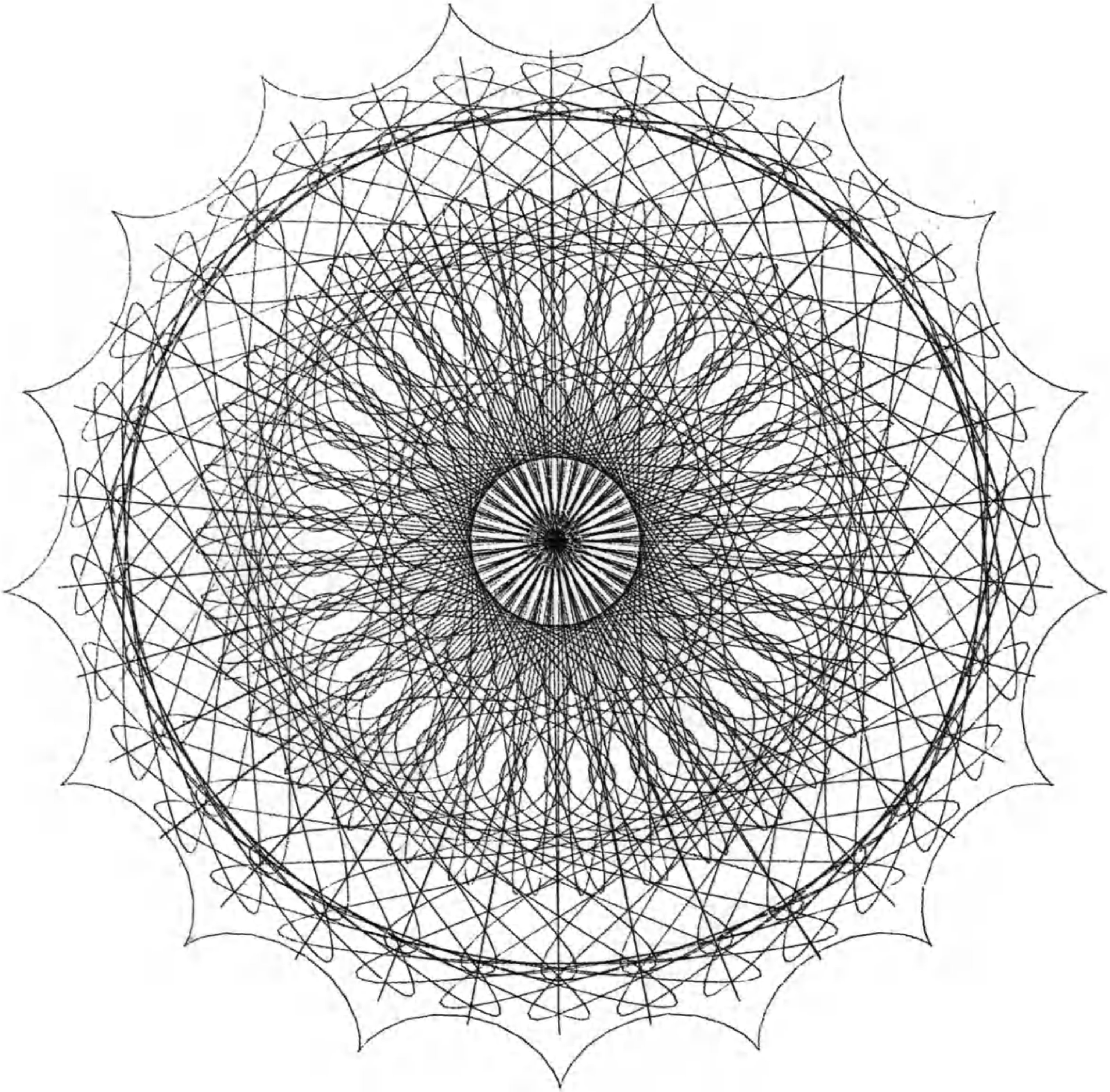


◁ 26 *Spatial surface of the formula* $\frac{\sin\sqrt{|x^2-y^2|+K}}{\sqrt{|x^2-y^2|+K}}$ *programmed by Bernhard Limbeck, represented by the perspective drawing of its lines of intersection with a coordinate grid, executed with the computer plotter of Hewlett-Packard*

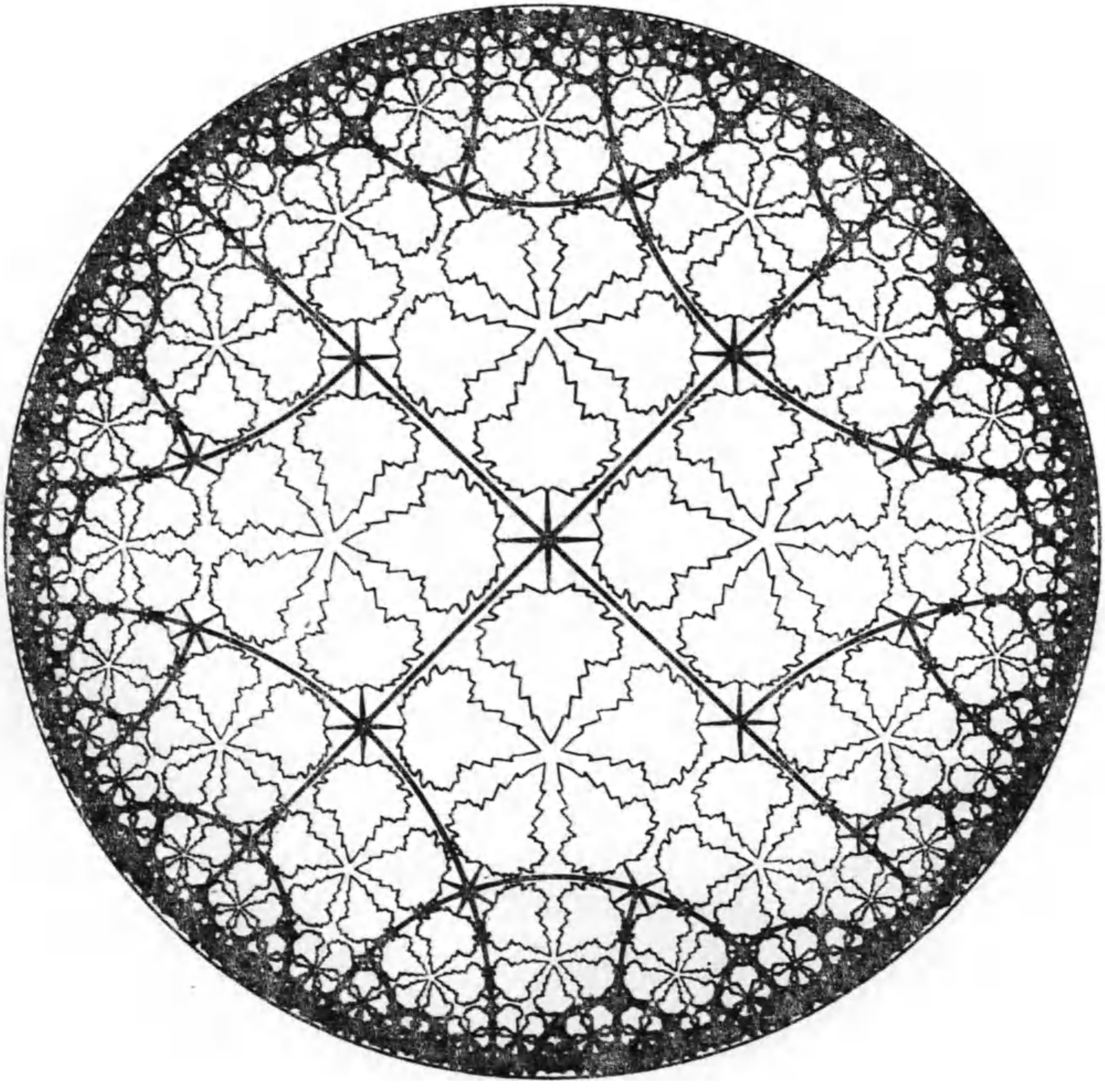
*27* Eye's Delight *by Lloyd Sumner. The original is in two colors, blue and red. An early example of the Moiré effect, which is emphasized by color*



*28* Turbulent Communication *by Aldo Giorgini, computer-aided drawing, drawn with the program FIELDS by Aldo Giorgini and Wei-Chung Chen*



*29 A circle ornament in seventeen parts based on mathematical curves, by Julius Guest, Royal Melbourne Institute of Technology*



*30 Ornament in the hyperbolic geometry by Christoph Pöppe, University of Heidelberg*

Various kinds of home computer pictures provide good examples. It is interesting to note that by means of the Moiré effect a fineness of the pattern is achieved which in its complexity far surpasses the effects generated by the program. The use of color screens also results in colored interference patterns which sometimes enrich a limited palette considerably.

*Permutation.* Constructivist painters discovered the principle of permutation for the arts. Usually this involves a few related, yet varying structural elements, the combination and distribution possibilities of which are examined systematically. The effort which this necessitates quickly becomes so enormous that it cannot be done manually. The computer carries out this work without any effort. To gain preliminary information about the variety of variants developed, the output of schematic configurations with a fast-printer is sometimes sufficient. If stepwise variations of the given elements are included into this method of systematic modification, the room for permutations is extended tremendously – a route taken by several computer graphic artists.

*Interpolation and Extrapolation.* Interpolation and extrapolation are tasks which often occur in scientific problems. Interpolation is concerned with connecting a series of given points by a continuously varying curve. Extrapolation is different from this task only in as far as it extends the curve beyond the given endpoints. Rather unusual lines suitable for aesthetic purposes are achieved if the arbitrarily given points are connected by interpolation, in particular if this is limited to only a few nodes and if perhaps a few discontinuities, as for instance kinks, gaps, etc. are introduced.

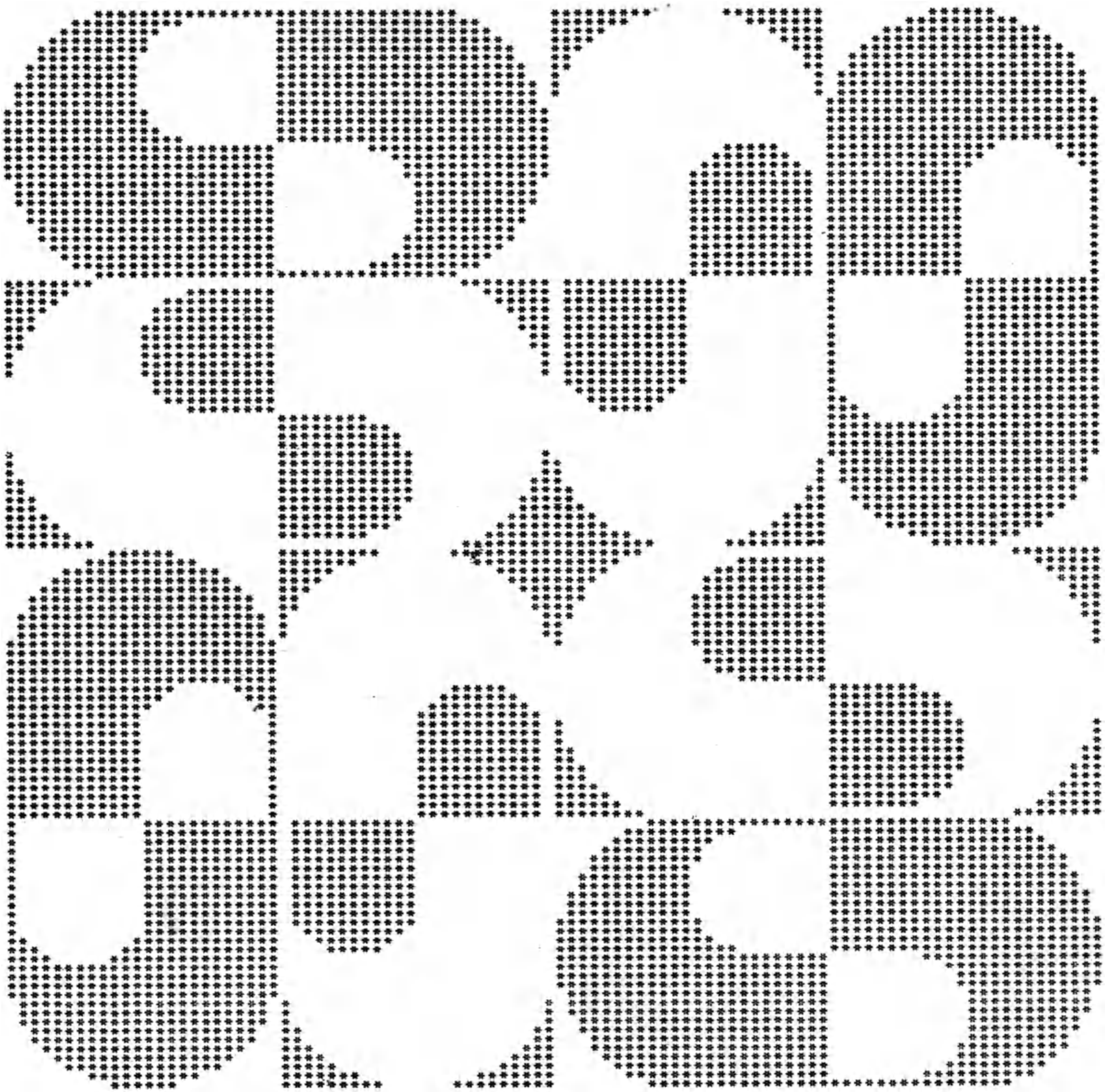
Interpolation has proven to be the essential prerequisite for producing animated pictures. Applied in the same way, it can also lead to rather interesting graphical results, particularly when the interpolation is carried out not between two similar phase pictures, but between two initial basically different graphic configurations.

*Matrix Calculus.* Arrays of numbers with which calculations can be carried out similarly to numbers are called matrices. The correlation of every number of a square or rectangular matrix with a grey scale value or color results in picture representations; conversely, it is possible to perceive every picture as a matrix. This opens the possibility of carrying out calculations with pictures – adding them (which amounts to a simple overlay), multiplying them, raising them to a higher power, etc. Quite often, unexpected results arise, among others abstractions which leave the original motifs recognizable; frequently the results are purely abstract, but visually pleasing.

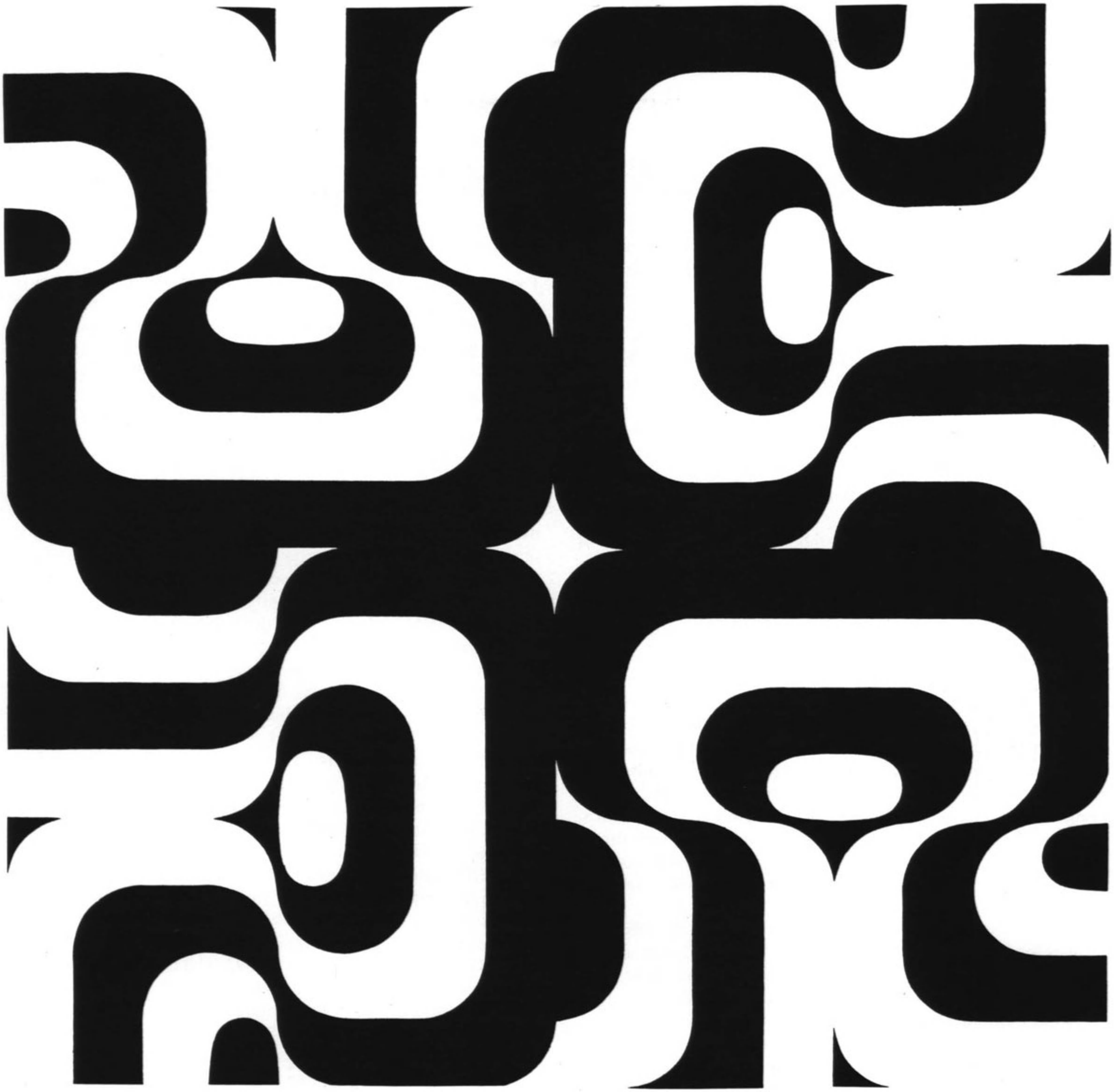
*Random*

The program which the computer normally receives clearly determines the sequence of computation steps. Barring defects in the machine, deviations from the previously established sequence are impossible. In principle, the result is already determined by the programming and the input of calculation values. There are certain processes in science and technology where so-called random numbers play a role – numbers which appear in an unpredictable sequence. In order to bring these into computer calculations, random numbers must somehow be incorporated in programs. Simulations of biological or sociological phenomena, where unpredictable reactions have to be taken into account, are examples of such problems. It is significant that computer graphic practitioners also utilize random numbers; this method was used by all three mathematicians who were the first to emerge with computer graphics: Frieder Nake, Georg Nees and A. Michael Noll. In music, this procedure had been employed already – it was known to Mozart, who gave instructions for the composition of waltzes based on 'diced' notes. The basis for the incorporation of chance may reside in this: stylistic regularities, as captured in programs, are not sufficient for the clear-cut description of a work of art, and in consequence offer certain degrees of freedom, each style permitting a multitude of realizations. In conventional artistic production, these empty places are filled intuitively. The making of computer art, which can be conceived as the simulation of an artistic process, must therefore capture intuition in the form of a model. This is done by means of the so-called random number generators.

Computers are determined systems, and are therefore unsuited to bringing about the unforeseen chance.



*31 Computer original for the making of a graphic by Manuel Barbadillo. The computer works through all possible combinations of elements and outputs them via a fast printer; the selection is made from subjective viewpoints*

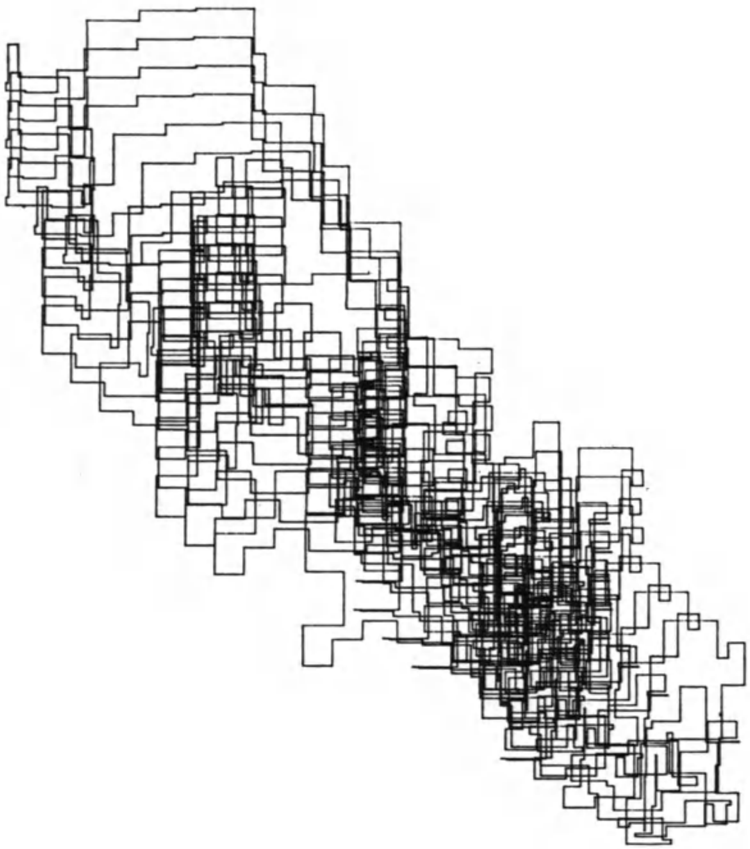


*32 Computer-aided graphic by Manuel Barbadillo. By means of a fast printer, the computer indicates all combinations. The realization is manual, e.g. by coating a base with a layer of plastic*

If genuine chance is to be introduced, then other means must be found. For such purposes, nature offers microprocesses; those of radioactivity for instance. From physics we know that it cannot be predicted in principle when a specific atomic nucleus of a radioactive element will decay. The moments and intervals of the individual decay processes yield a pure chance pattern. This can be applied to the introduction of chance in computing processes. If a Geiger counter is brought into the vicinity of a radioactive preparation, then the penetrating particles provide a random pattern of current impulses. When these are measured with a clock, and the measurement results are stored on magnetic tape, then the phenomenon has become available in the form of a number sequence.
The direct insertion of random numbers, i. e. the introduction of a random number generator in on-line working, is also possible. One of the lesser known precursors of computer art, Peter Scheffler, formerly lecturer at the Psychological Institute of Innsbruck University, fed radioactive impulses directly into an analogue system, which then transposed them into sound frequencies.
Other kinds of random generators come to mind - the simplest and best known are dice and the roulette wheel. But the use of these necessitates tedious manual evaluation; values have to be noted and fed into the computer memory. Wilhelm Fucks, who has occupied himself with statistical art theory, takes his random numbers from the lists of roulette number tables kept by gambling casinos. Noise - the interference present in every electrical conduction and also in the atmosphere - can form a basis for visual exploitation. If a television receiver is turned on during a pause in transmission, we are instantly presented with a random picture of the stochastic process.
From the technical point of view, the introduction of peripheral devices for the generation of the random is certainly not an elegant solution. It would be desirable to generate it somehow within the computer. A procedure is available to do this which does not supply genuine random numbers, but does give values that can be used as such. They do not evince any clearly recognizable regularity, and appear to the observer to have been chosen haphazardly: the term pseudo-random is applied here.

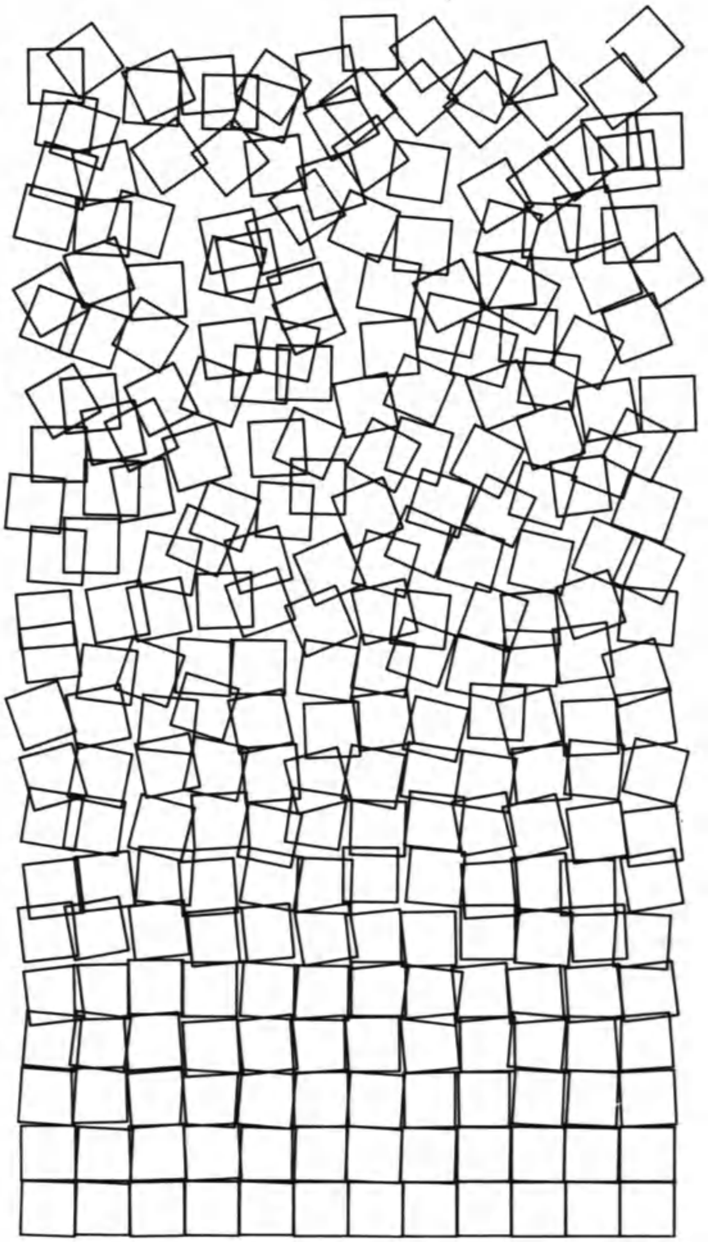
*Pseudo-Random*

Pseudo-random number generators are simple computing programs. A straightforward example would be the calculation of the number $\pi$ to a large number of decimals. Numbers such as $\pi$ belong to the irrational numbers, i. e. they cannot be represented as true fractions. They have an infinite number of decimal places and these never order themselves into periodic sequences. One might utilize, e. g. the first thirty decimals of $\pi$ as a series of random numbers. In practice one introduces other calculation operations, which permit a greater variability.
In his book *Generative Computergraphik,* Georg Nees describes a useful procedure: one takes three consecutive powers of the number 2, say 128, 256 and 512. Assuming for the moment that one was already in possession of a series of random numbers, and that J was the last in the series, then one obtains a further random number by first multiplying J with 5 and then successively subtracting 512, 256, 128 until the number falls below the limit 128. Assuming that 127 is the first random number in the series, then 5 times 127 minus 512 produces 123, which is already less than 128, and hence can serve as the second random number in the series. Second step: 123 times 5 minus 512 equals 103; third step: 103 times 5 minus 512 equals 3; fourth step: 3 times 5 equals 15, then 15 times 5 equals 75; and so on. The first six random numbers in this series are therefore 127, 123, 103, 3, 15, 75. Should one require random numbers within another interval than between 0 and 128, then one multiplies the originally calculated values with a constant factor. It will be found that the random series soon begins to repeat itself if the exponents of the powers of 2 originally chosen are too small. However, all difficulties disappear and sufficient well-distributed random numbers become available if one uses higher powers of 2, such as 2 147 483 648, 429 467 296, 8 589 934 592. The newer programming languages, as for instance several BASIC dialects, include instructions for entering pseudo-random sequences. Thus feature is mainly used for programmable computer games, but also for producing dynamic sequences. Chance is introduced into the computing program by its own symbol, perhaps the instruction RANDOM. On receipt of the command, the computer assigns the random numbers to certain general operands.



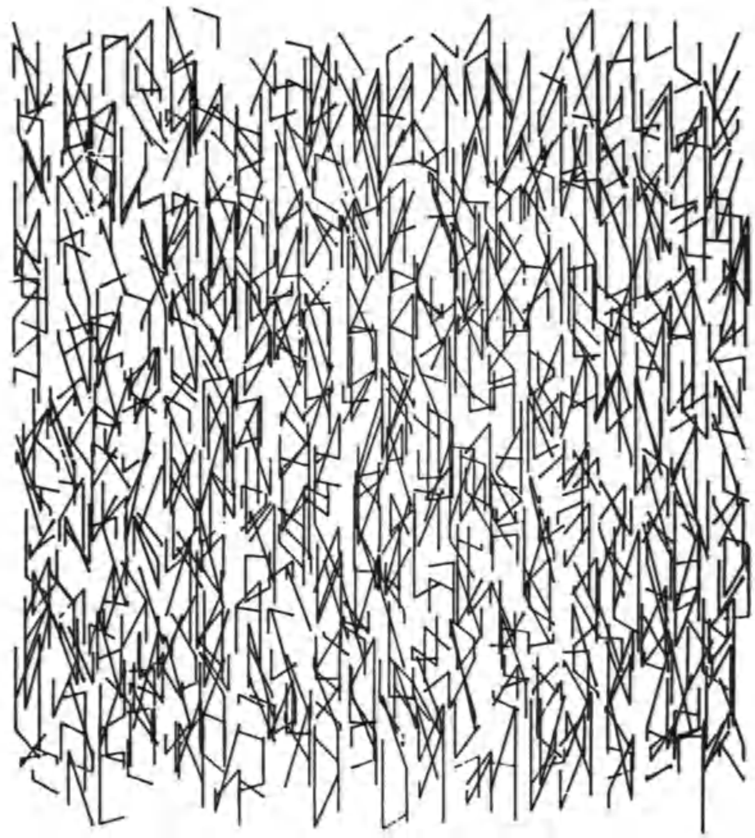
*33* Maze *by Georg Nees, generated from 2000 vertical and horizontal elements using a "degraded" random number generator (on the basis of an insufficient calculation instruction for the pseudo-random which reveals periodicities)*

*34* Gravel Stones *by Georg Nees. A random number generator causes* ▷ *the increasing swaying of the squares*



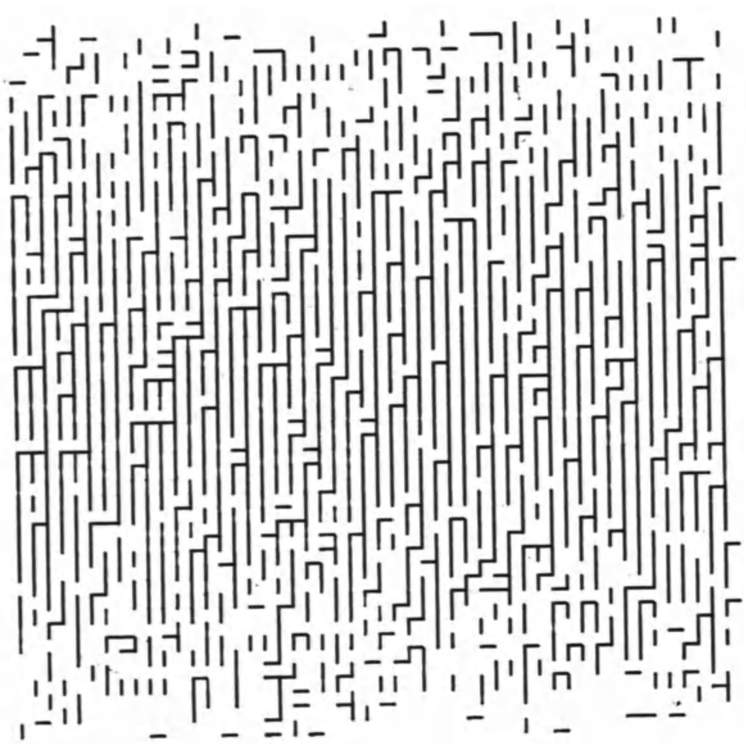
Many drawings, especially from the early days of computer graphics, are based on simple random assignments. Here, as in many other areas of computer art, we can recognize a reciprocity of purpose: chance helps to bring about an aesthetic arrangement,

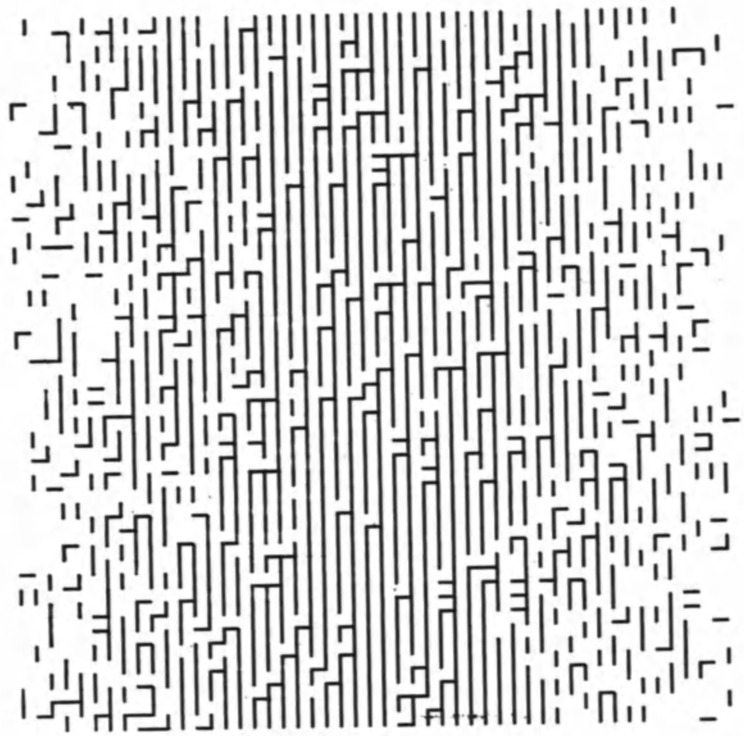
and this in turn can serve as a demonstration of aleatory processes.
A good example of this is the *Maze* series by Georg Nees. In his program 2000 vertical and horizontal straight lines were placed together in a step formation. When the staircase curve approached the picture edge, the program prescribed a reflection. The individual line lengths as well as the 90° turns to the left or right were then left to a random number generator. In addition, Nees introduced various random number generators including some that do not really justify the name since the number sequences which they yield are soon recognized as periodicities. The completely arbitrary distribution arising from a genuine random number generator can be clearly distinguished from structures where the random programming was insufficient. Their regularity, as shown by symmetrical superimposition effects, the appearance of repetitions, etc., does not escape notice.
It is possible to extend this method and operate with "controlled" chance. In this approach there is no need to work with an entirely free random distribution where the appearance of all numbers is equally probable, since randomness can, as it were, be distributed.
An example is the well-known Gaussian distribution, where the chance values tend to aggregate around a mean value. But in computer art such a distribution can come about quite arbitrarily - for instance, the packing density of picture elements can be planned for distribution over certain areas, but their local position left to chance.
Random influences can be introduced into programs in yet another way. Since the procedure about to be considered is mainly applied in music, it will be demonstrated with an example of tone composition. The first tasks is to establish stylistic laws by means of a program. These might take the form of fixed instructions, perhaps a veto on the succession of certain harmonies, or else of probabilistic laws such as might indicate the frequency of the appearance of sound sequences. During the actual production phase, the random number generator offers one number after another, and the program tests these for conformity to the stylistic rules. In the positive case the note encoded with the random number concerned is taken into the composition, otherwise it will be eliminated and the next number will be called up - whereupon the procedure begins anew. Along these lines a composition finally results which, although produced with the aid of a random program, yet fulfills all the prescribed stylistic laws.
Chance can also be introduced in figurative computer graphics, for example as interference which breaks up given orders or figures - an approach that can lead to fascinating graphic effects.

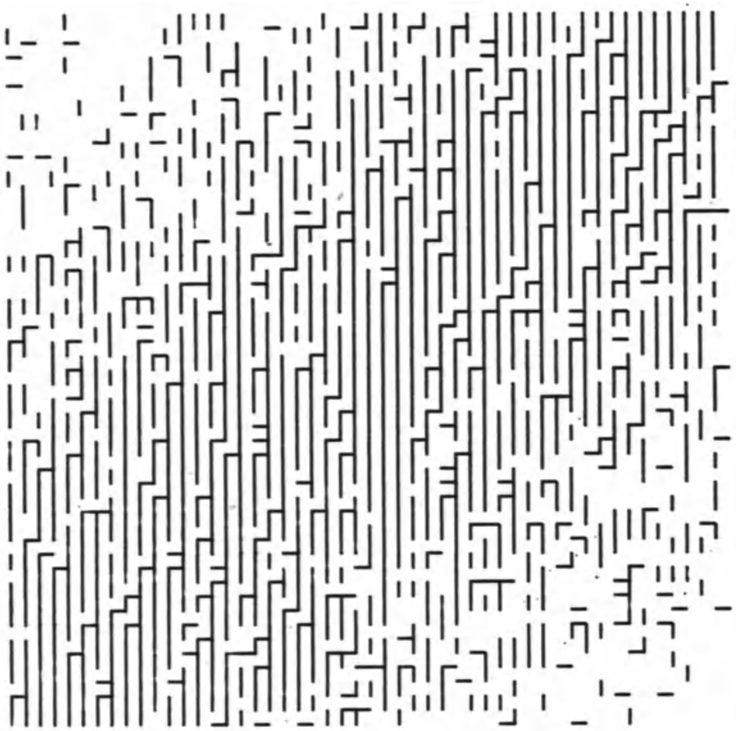


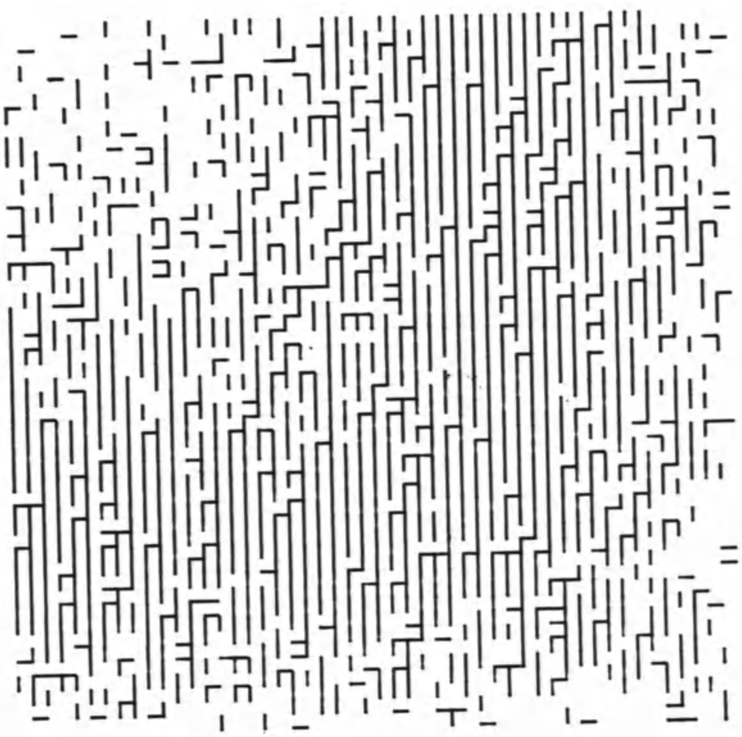
*35 Computer graphic by Vera Molnar, Paris, produced by using random number generators*

*36 Digital graphic by Frieder Nake. Four realizations of a very versatile program, in which the sign repertoire can be freely selected. Here it consists of three signs distributed over a base grid: "horizontal line element", "vertical line element" and "empty sign". The production procedure occurs in one movement which embraces the entire grid area. From one occupation spot to another it is decided which signs are to be used, based on a probability function dependent on the signs already placed. The result is a distribution with "weighted" chance; the individual signs are packed in different densities in the various areas of the field* ▷









## 7 Computer Graphics in Practice

While computer graphics initially focussed on program-controlled generation of pictures, various other, far more demanding areas of application have developed. The tasks with which computer graphics is concerned can be categorized roughly according to the type of data which are input and output:

| Input | Output | |
|---|---|---|
| Data | Picture | Computer Graphics |
| Picture | Picture | Picture Processing |
| Picture | Data | Pattern Recognition |

The first case describes computer graphics in the strict sense of the word, the generation of pictures effected by commands via programs or via the keyboard. In the second case, pictures or picture elements are input which are then transformed in some manner, so that as a result a changed picture, possibly a picture of completely different appearance is output. The typical task of pattern recognition is the analysis or interpretation of pictures: The picture is input into the computer which subjects it to mathematical or logical analyses in order to determine certain characteristics; these are subsequently output as alphanumeric descriptions.

Again, it should be noted that all the hardware and software arising from these methods was developed for technical and commercial reasons without regard to artistic interests, but that, nonetheless, systems emerged which are surprisingly useful for artistic applications. For instance, while in the past critics repeatedly pointed out that artistic activities using computer graphics would necessarily have to be limited to geometrically oriented representations, which means basically to the styles of constructivism and op art, picture processing opens the possibility of artistic capture of the representational picture by means of computer systems. And the problems which are dealt with by pattern recognition and which seem to be far removed from artistic goals have proven to be of aesthetic interest as well; on the one hand, it demonstrates different possibilities of unconventional picture processing, for instance by means of transformations and abstractions. On the other hand, it also leads to insights into optical and visual data processing which are illuminating the processes of perception in general, but particularly the processes of aesthetic reception. Thus, the limitation lamented by so many artists that the computer graphic set of devices is insufficiently adapted to artistic goals is turned into a considerable advantage: aesthetically highly effective operations, unused so far, have emerged. As desirable as is the recent development of new systems which are adapted to the needs of painters and graphic artists, this also results in negative trends - they tend to simulate the traditional artistic tools without utilizing the widely usable mathematical and logical capacities of computer systems. Certainly, instruments have emerged which, because of the manifold possibilities of interactive operation, greatly surpass all traditional artistic tools. The range of problems thus created, however, shows that the significance of computer graphics is not restricted to providing an optimal set of instruments, but is also directed at widening the knowledge and insight of scientists as well as technologists. Since the procedures which are created for technical and commercial reasons can also stimulate artistic activities to develop into new directions, the following summary will briefly discuss them.

### Graphic Data Processing

The trend to graphically representing verbal or alphanumeric data has probably existed since early ages, as demonstrated by the examples of cave art which are ten to fifteen thousand years old. Since the emergence of picture-oriented mass media, the picture as a medium for objective information transfer, for instance by means of diagrams and graphs in newspapers, has more and more come to the foreground. Certainly, the computer enhances the possibilities provided by printing technology considerably, not least by also capturing motion. Furthermore, the personal computer enables small firms and private users to express themselves by means of pictures and to generate them within a short period of time; this represents a novum in the history of the "visual age".

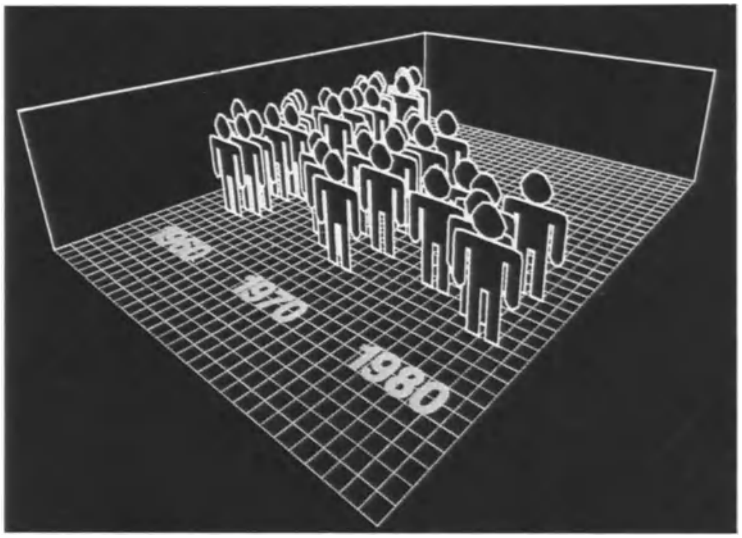
Magazines and television should be mentioned as areas of application of graphically processed data; present interest in research and development is directed at those systems which combine picture and text processing. Layout problems in printed products are increasingly resolved by computer-aided systems into which graphical data can be integrated without difficulty. For instance, an optimum distribution of text, graphics, and pictures can be achieved interactively on the screen.

## Word Processing Systems

Even if computer-aided text processing is usually not considered to be part of computer graphics, it basically uses the same methods. Designers of video text systems do not limit themselves to making different fonts and characters available, but they immediately attempt to integrate pictures into the text. The fact that graphics used in text systems are quite primitive and therefore can be said to assume the function of symbols or pictograms is due to the rather low resolutions used so far; the improvement of the systems - commercial television will sooner or later also convert to high-resolution screens - will entail an improvement of the possibilities on picture generation.

## Business Graphics

Management of large and small businesses is increasingly confronted with complex situations necessitating decisions which require a grasp of large amounts of data. To provide this, graphical representations are more and more frequently used; for their computer-aided generation, management information systems were developed which allow the fast output of curves, histograms, pie charts, etc. Graphical support for project planning, for instance for critical pass methods, is also available. There are further possibilities for applying these methods in employee training, in meetings of employees and workers, in public relations, etc.



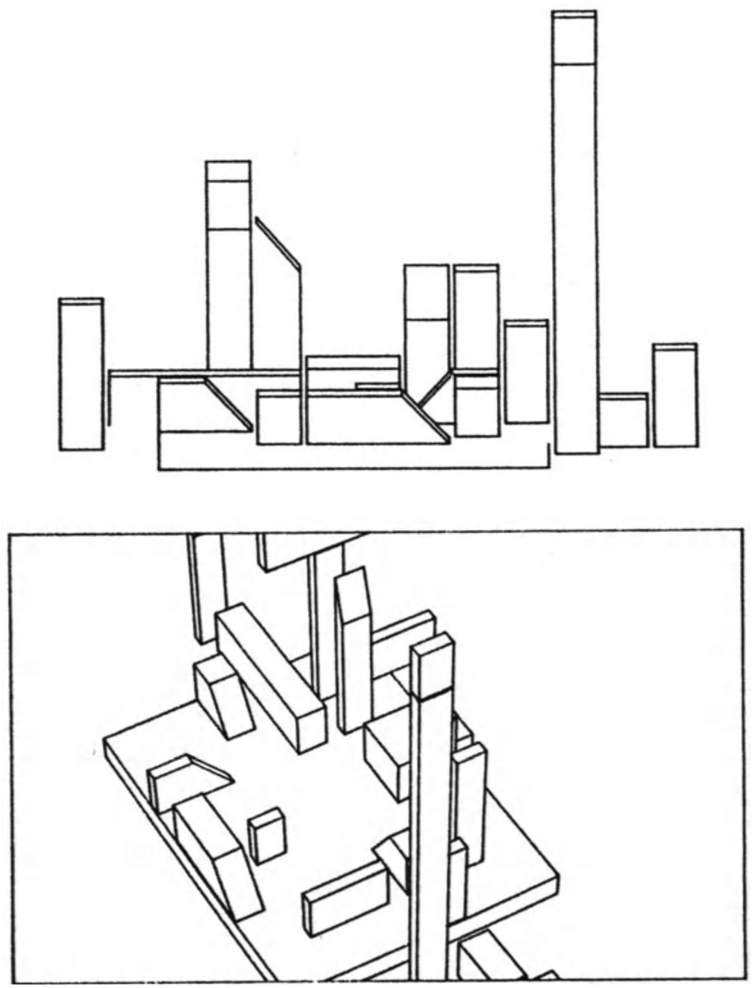

*37 Business graphic, ISSCO Graphics Software*

## CAD/CAM

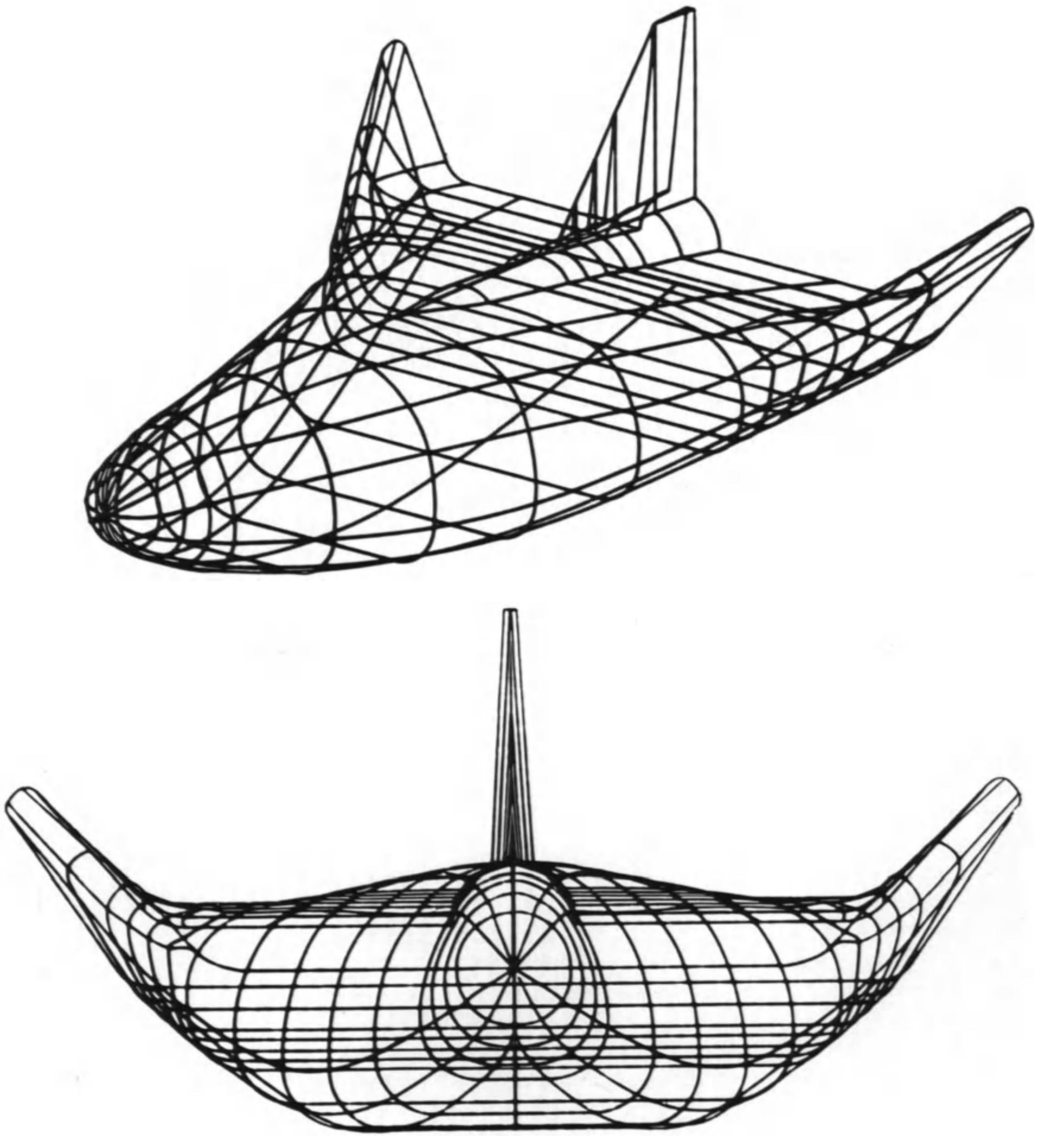
The most recent and most promising development of computer graphics is concealed behind the acronyms CAD (computer-aided design) and CAM (computer-aided manufacturing). CAD encompasses the interactive processing of graphical data for design and construction purposes. The screen of the graphics terminal is used as a kind of electronic drafting board. The computer provides in particular the advantage of being able to make all sorts of changes in the drawing which, carried out by traditional mechanical means, would be highly time consuming and which can now be done practically without delay: transformations to other scales, translation and rotation of picture segments, duplication, and erasure of parts of the picture, etc. The possibility of modification without delay not only results in savings of time and cost, but facilitates a much freer work style which includes phases of experimenting to a much larger extent than before. This benefits in particular one of the most frequently occurring tasks of designers, the *adaptable design,* which involves the change of the finished design in such a way that it can be adjusted to varying demands. It should be mentioned that the possibility of fast output on paper, transparencies, or film is one of the most useful possibilities offered by this mode of operation. One of the most important tasks of CAD is the design of mechanical parts of machines for which two-dimensional plans - plan view and side view - are usually required. Some of the modern CAD-systems also offer the possibility of three-dimensional, perspective representations from arbitrarily chosen viewpoints. These also permit the generation of projections or sections. But more and more frequently, the perspective representations themselves are used to replace mechanical models.

Three-dimensional representations were first produced as so-called wire frame models - to represent a spatial object, only its edges without the elimination of hidden lines are output. By now, several subroutine systems are available which solve the problem of hidden-surface removal. The resulting representation is different from the wire frame model in that the edges are clipped where they are hidden by other parts. Further developments of the 3 D-programs finally led to the output of regions; the brightness of each region is calculated according to the assumed position of light sources. Shadows can also be calculated and included in the picture. The most sophisticated programs of this kind allow the output of pictures of perceived objects which are indistinguishable from real photographs. It is furthermore possible to depict transparent objects with physically correct reflections or surface textures - for instance dull or finely carved - with correctly rendered effects of refraction and highlighting. If these objects are depicted in motion, it is called real-time animation.

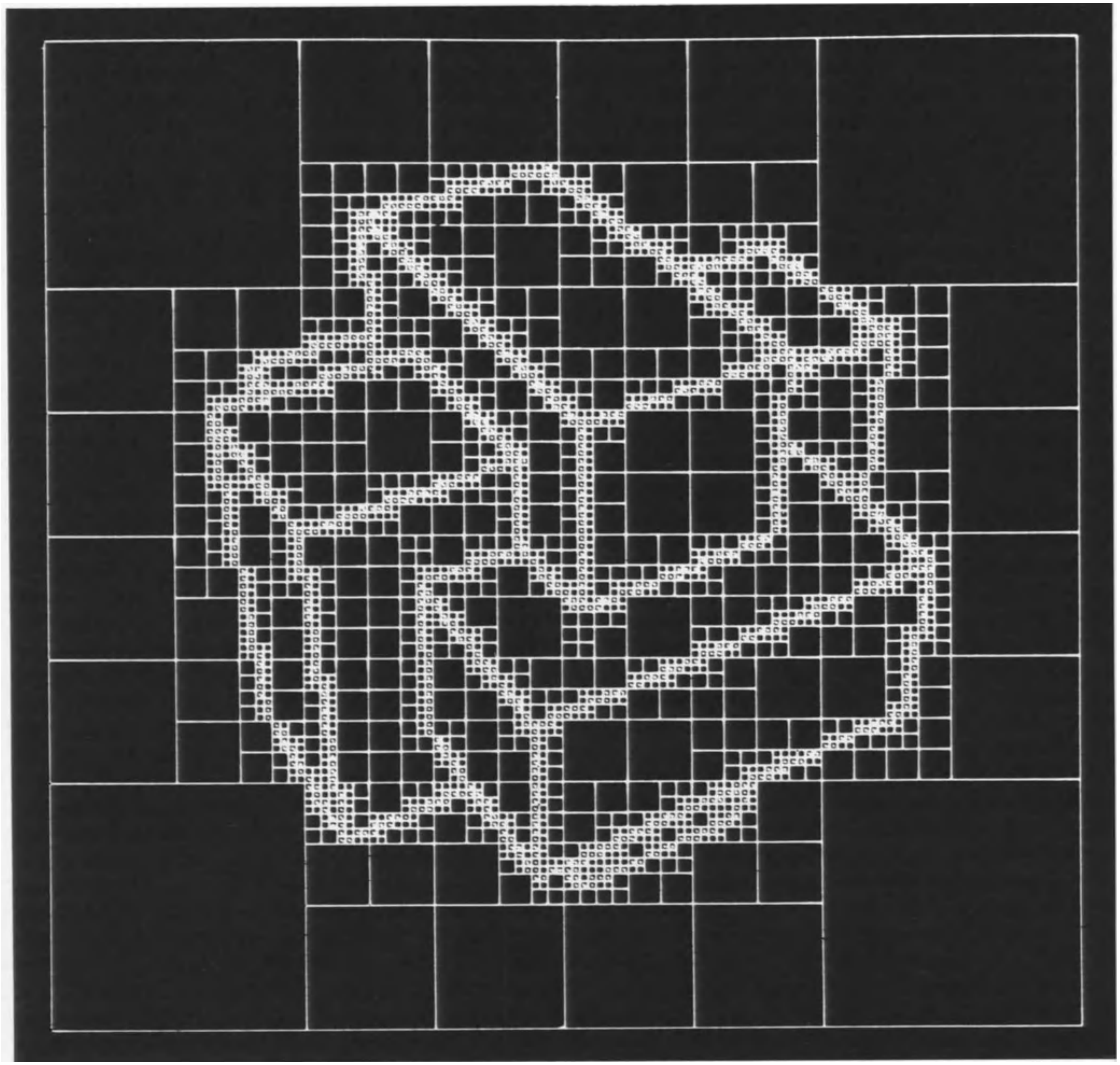
The methods of CAD are often coordinated with those of CAM; some phases of process control can be obtained from the results of CAD. For instance, a device which will produce a machine part by a pressing or casting process contains a mould of that part, the geometry of which can be obtained from the computer-aided design. Those programs, which control numerically controlled machine tools, can be traced in their relevant parts to the pioneering work of CAD. As far as computer art is concerned, these developments open the possibility for computer-aided sculpture, although this has so far been utilized only in exceptional cases.

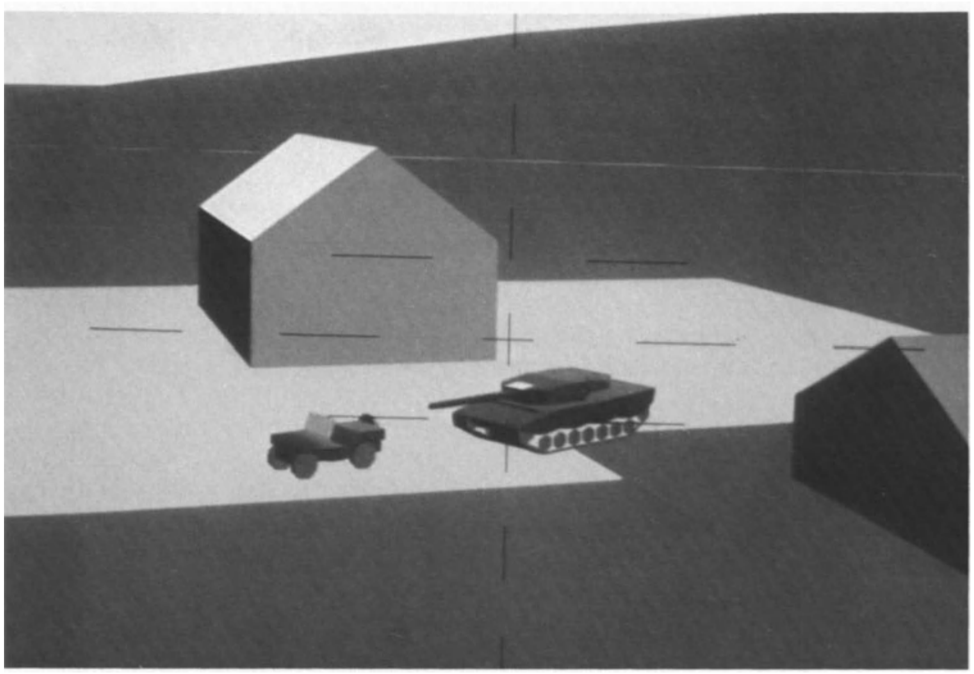


*38* SHAPE, *perspective representations of three-dimensional forms, by Robert Mallary, University of Massachusetts, Amherst*



*39* HL-10, *an early Space Shuttle model, Boeing; wire frame model by Univac*





*41 Real-time simulation of a landscape for teaching purposes, Link-Division, Singer* *(see also Fig. 80, p. 92)*

## Process Supervision

The tasks of process supervision are similar to those of project planning, however, real-time output is a necessary condition: The graphics terminals must indicate the state of the supervised system without delay. Moreover, it has to provide a complete presentation, so that deviations from the normal operation are recognized immediately. Not only are controlling units with their sensors and transformers integrated into the graphical output of the supervisory system, but also the microprocessors which supervise the current process variables. Every situation which necessitates human intervention must be characterized by signals which also indicate the source. For all these reasons, color graphics terminals are required.
All centrally controlled plants, particularly those with automated production, are suitable for the application of graphic process control systems. Other areas of application, although rarely mentioned, are the military and the police.

◁ *40 A solution of the "hidden-line" problem by John Warnock, University of Utah. The picture is dissected into part-areas, and a comparison procedure determines which lines are in front and which are hidden*

## Simulation

Simulation is sometimes defined as the numeric representation of processes. However, here we shall limit ourselves to visual representations. This may encompass the symbolic depiction of actions as well as realistic animated representations.
Science in particular is an area of application for simulation; it allows, for instance, the representation of the most varied physical processes in simplified pictures - well-known examples are the penetration by an electron of a potential barrier in the vicinity of a nucleus, or the explosion of a supernova. The most spectacular results of simulation are achieved with those systems which are employed for the training of locomotive engineers, of pilots, and of astronauts. In all these areas, it is imperative that the situation is presented as realistically as possible, so that the learning situation approximates reality as closely as possible. For this reason, some of the high-performance computer systems are specifically applied in simulations; the software contains all the procedures which handle the changing situations, as they occur when flying over landscapes, in poor weather conditions during a train ride, or in complicated maneuvres of space vehicles. Although the tasks are of a purely scientific/commercial nature, they led to results which are noteworthy from an artistic viewpoint as well.

## Animation

The term animation includes all procedures which are required in the generation of animated picture sequences, particularly in the production of cartoons. Since this involves a predominantly artistically oriented problem set, computer animation will be dealt with in another chapter, but it should be stressed at this point that the particular problems have stimulated software development which, in turn, can be applied in other related areas, for instance in CAD and in simulation.

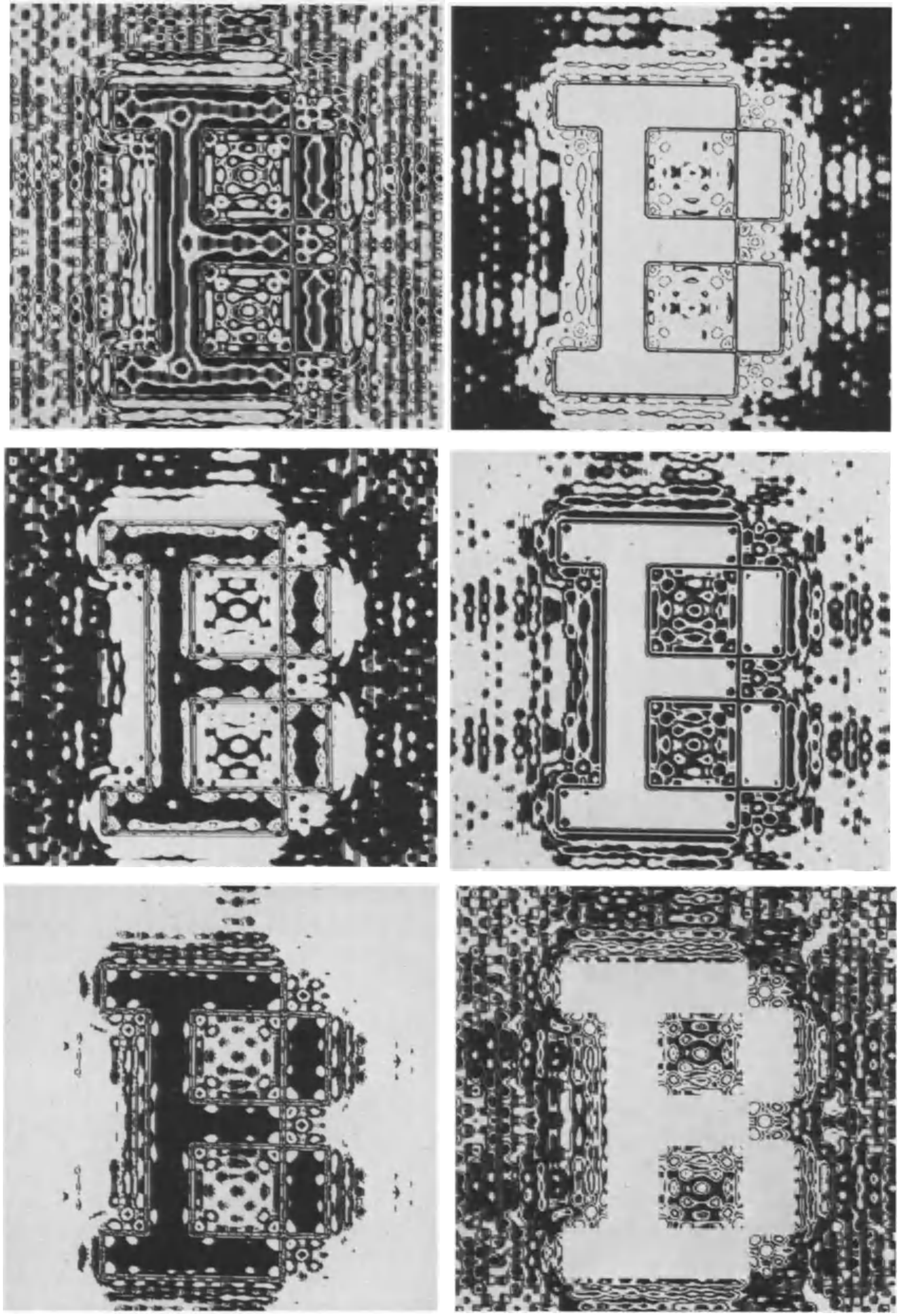
## Picture Processing

Photographic processes which were originally aimed at improving pictures or at an improved picture analysis can be considered to be the forerunners of computer-controlled picture processing. The equidensity film material which allows the changing of grey values into colors is an example in case.
The first attempts to improve pictures by electronic means became known when scientists post-processed qualitatively rather poor satellite pictures of the far side of the moon which had been transmitted to the earth, and succeeded in improving them to such an extent that the surface of the moon structured by craters was relatively well recognizable. In the meantime, these procedures have been developed to perfection. James Blinn, a computer scientist working for NASA, has achieved results with the aid of picture processing and using the pictures transmitted to earth from Jupiter and Saturn, which can be ranked as some of the most impressive photo documentations anywhere. Since they far exceed technical requirements in their coloring, they more closely resemble artistic productions than material for scientific documentation. Not surprisingly, they are used less in scientific evaluations than in popular books and television shows, for instance in Carl Sagan's series *Cosmos.*
One of the earliest applications of picture processing were those in medical diagnostics. For example, its methods are used to improve pictures obtained by the scintigraphy of ingested radioactive tracer substances. The scintiscope scans the diseased parts of the body point by point and line by line and measures the intensity of the radioactive processes. The recorded values are then composed into a picture. Since it is desired to keep the radioactive doses as low as possible, the results usually represent no more than intensity values at random points; they are transformed into an equidensity image by computation. The resulting color pictures serve as a good basis for the localization of pathological areas as well as for the visual evaluation by the physician.
Some of the simplest picture processing methods are the intensification of contrasts, highlighting of contours, false color mapping, etc. - transformations which were also possible by using photographic methods in the laboratory. Integration by area which results in an areal representation on the basis of some nodes belongs to the category of more sophisticated methods. Recently, transformation procedures have been applied for the improvement of satellite pictures. They permit modifications of the image structure which so far have been believed to be hardly possible, for instance the suppression of textures of a certain degree of coarseness or of a certain preferred direction. To achieve this, Fourier, cosine, and other transforms are used, a type of picture transformation which generates completely new picture structures without losing relevant information; essentially, all kinds of regularities, repetitions, etc. are thus expressed by means of positions in the transformed representation. If certain parts are deleted from this representation, for example annuli and sectors of circles, the retransformation results in variations of the original picture exhibiting the desired changes, usually in order to achieve an improved evaluation.
This seems to open up an area which allows the fruitful use of the computer for artistic purposes, on the one hand by experimenting with certain kinds of transformations to evaluate their aesthetic effect, and on the other hand by experimentation in the direction of graphically attractive alienations and abstractions of pictures.
The task of computer-aided cartography or mapping is also connected with the interpretation of aerial and satellite pictures. In computer-aided cartography, further problems need to be solved besides those of image improvement, for instance removal of distortions inherent in the process of image recording or correctly scaled matching of contiguous images.

*42* Circles Around Eye *by Manfred R. Schroeder. The brightness was transposed into the line thickness of the concentric circles*

*43* Leprosy *by Manfred R. Schroeder. Contours are given through the points of equal brightness in the original photo; the brightness is expressed in line thickness*

Computer graphics, being concerned with the input, generation, and output of pictures without considering these operations to be typical picture processing methods, encompasses some other tasks which are concerned with the placement of graphical objects on a surface, for example layout optimization. This involves the cutting of certain parts out of sheet metal in such a manner that as little waste as possible is produced. Similar problems arise during the design of the placement of electronic components on printed circuit boards. The computation of the optimal layout, constrained by the required electrical connections, is one of the tasks in which the methods of computer-aided design and of picture processing overlap. Presently, such overlaps are rather exceptional, but it is to be expected that the three important areas – computer graphics, picture processing, and pattern recognition – will supplement each other more and more. The generation of pictures and their subsequent processing carried out by automatic analysis may well prove to be desirable for a variety of tasks where artistic-creative components are included, for example for layout problems in the printing industry and in the film and video industries. Similar problems arise in the advertisement and textile industries – from computer-aided pattern design to the cutting of material where a computer-aided mode of operation



◁ 44 Serie B, *Fourier transformations of the letter* B *and retransformations of the slightly modified result; system DIBIAS, DFVLR, Oberpfaffenhofen, Herbert W. Franke and Horst Helbig*

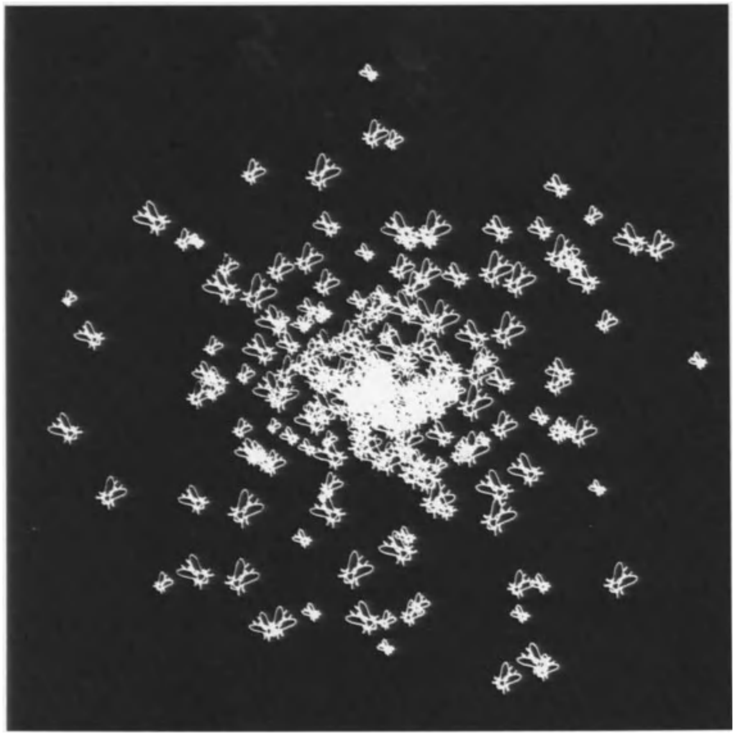
allows a better adaptation to the individual body measurements of the wearer, in addition to integrating the task of minimization of waste in the cutting process.
The field of architecture poses special problems combining artistic intentions with those of a technical nature. Apart from the design, this involves the placement of structural components in a given area as well as the intermediate control of technical data, for instance the loadability of scaffoldings. While these methods are only gradually accepted by academically trained architects, they have long been firmly established in civil engineering.

### Pattern Recognition

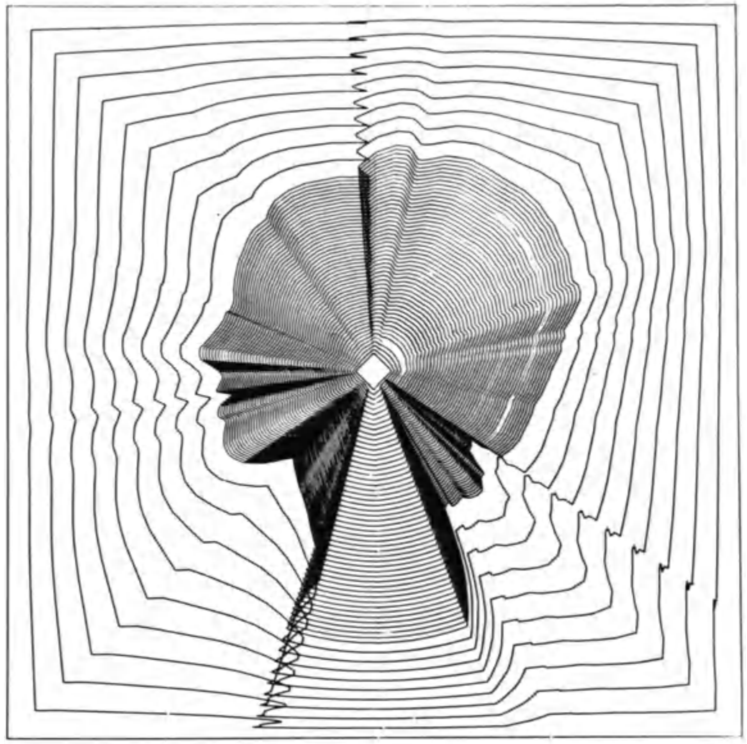
The latest offspring of computer graphics is pattern recognition – probably because it attempts to imitate certain highly complex tasks of the human visual data processing system. As in the human brain, a series of transformation processes precedes the analysis, expressed by such technical terms as contrast enhancement, color table assignment, filtering, noise suppression, geometrical correction, removal of distortion, reduction of redundancy (abstraction), etc. It is for this reason that pattern recognition can hardly be imagined without the methods of picture processing.
While the extraction of simple physical quantities of pictures – values of lightness, contrast range, color spectrum, etc. – poses few problems, the problem becomes considerably more difficult when tasks of perception of structural features or even of semantic classification are required. In simple cases, this involves the recognition of given structures and shapes, a requirement which is much more difficult to meet if the process of identification is to succeed under more difficult conditions, for instance in the case of partial occlusion, of distortion, etc. Examples of such evaluations are known in meteorology, geology, forestry, limnology, but also in the military field. Similar problems arise when interpreting microscope images, for instance when bacteria or genes are to be identified in the examination of cell contents. Many of these tasks can be expressed by numerical data only with difficulty. More often logical relationships need to be considered when comparing given prototype shapes; frequently, similarity relationships have to be taken into consideration. The more complex the requirements are, the more the mode of operation of human perception, interpretation, and thought process is approximated – capabilities which today constitute an important subject of research under the general heading of "artificial intelligence". Thus pattern recognition also proves to be an experimental contribution to the theory of perception.

## 8 Representational Pictures in Computer Graphics

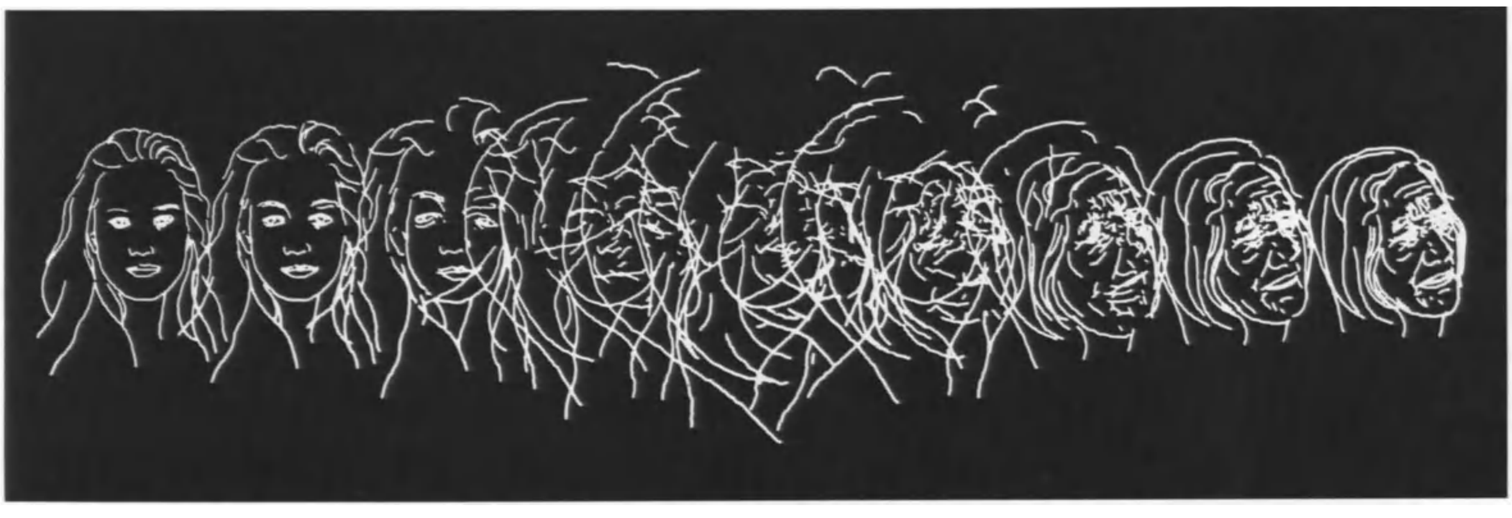
A large proportion of computer graphics still belongs to the constructivist tendency, although the equipment available is capable of assisting in the creation of representational pictures. In earlier stages of development this procedure was rather complicated: a figure that could not be described by mathematical or logical formulae had to be indicated point by point or composed of small line elements. None the less, the pioneers of artistic computer graphics went through the effect of creating representative pictures, in particular because data processing offers attractive possibilities for this artistic application, e.g. where the objects depicted are based on relatively simple forms, and where the diversity of the picture is due to modification of repetition, and possibly variations, of the basic shape. One of many examples of this is the picture *Flies in a Circle* by Charles Csuri and James Shaffer, where the element – the fly – recurs repeatedly in different orientations and sizes. Leslie Mezei's *Beavers* (see Fig. 23, p. 30), where the basic figure is made to grow or shrink to curious monsters by simply reducing and enlarging it in both coordinate directions, is a further instance of successive transformations of an outline drawing.
But this account by no means exhausts the computer's capacities for the transformation of pictures. The CTG (Computer Technique Group) give some further indication of the possibilities with their picture *Return to Square,* where a square contour by progressive reduction and distortion is gradually changed into a human profile, which after further modification again ends up as a square. Another impressive example is Csuri's and Shaffer's *Transformation,* where the face of a young girl is turned into that of an old woman. We have here intimations of entirely novel



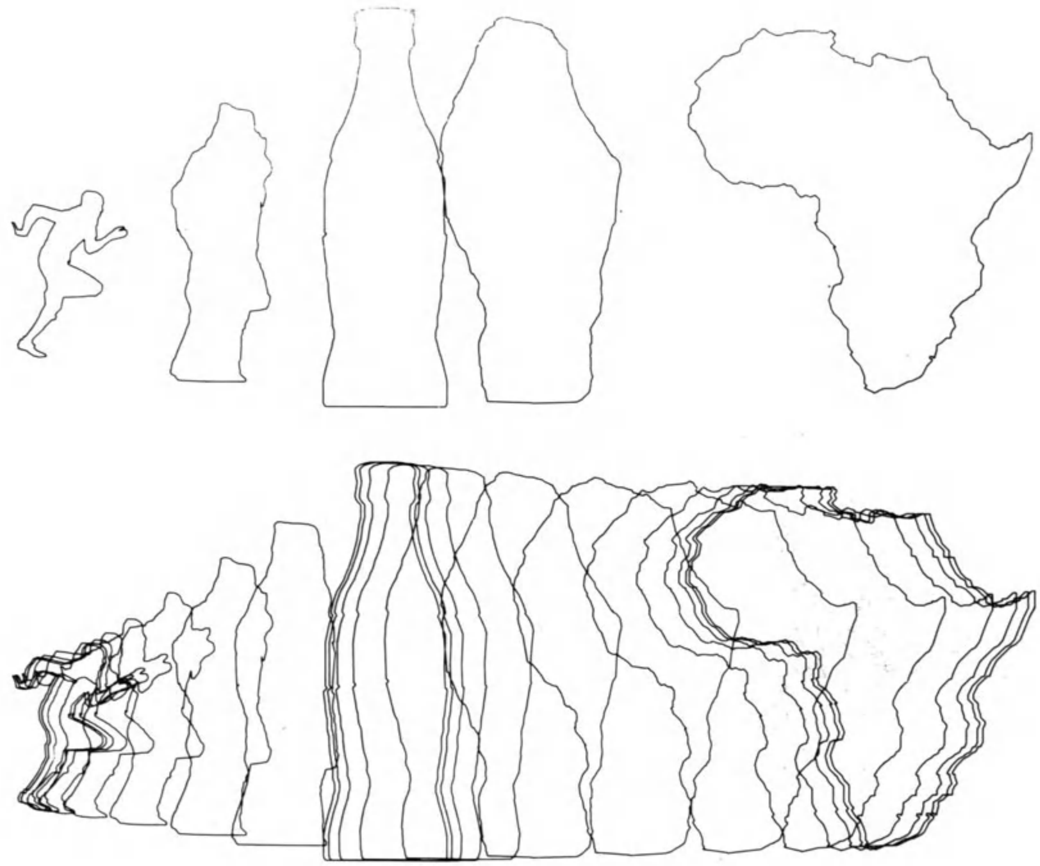
*45* Flies in a Circle, *1966, by Charles Csuri and James Shaffer. The line drawing of a fly serves as the picture element – a random number generator distributes it across concentric ring areas, and size and orientation are also determined by a random principle. This drawing forms part of a series where the transition from one representation to another follows rules that are employed in the making of maps*



*46* Return to Square, *CTG, Japan. Stepwise transformation of a square into the profile of a woman's head*



*47* Transformation *by Charles Csuri and James Shaffer. The face of a girl turns gradually into that of an old woman*



*48* Running Cola is Africa, *CTG, Japan. An instance of the graphic transformation of objects*

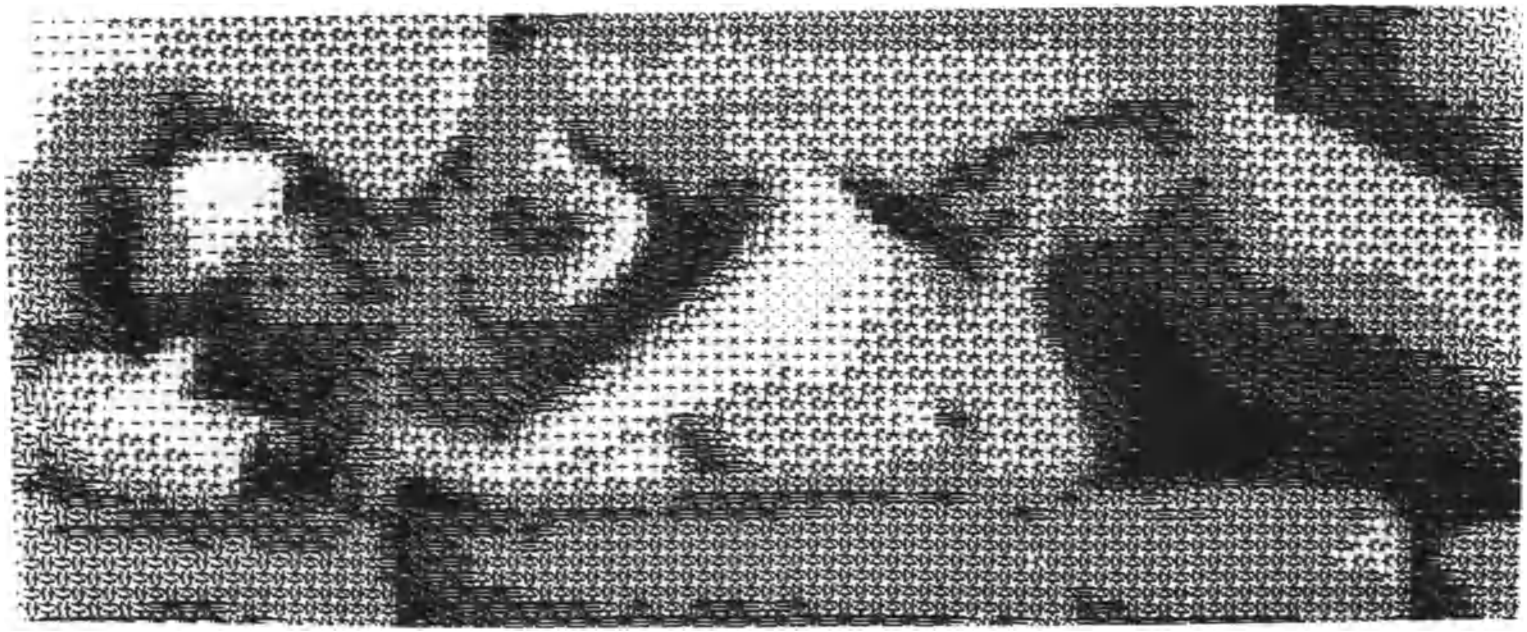
methods of abstract painting, and it is worth noting that the abstractions follow far stricter rules than could ever be applied by the manual artist. The random element utilized in the destruction of the picture can be distributed as desired.

But there are even more complicated methods of picture transformation which might be defined as picture reckoning. Frieder Nake has shown in his *Matrix Multiplications* (see Fig. 58, p. 70) how this can be done. In principle, what he did with square grids can be repeated with any picture: one can add or subtract pictures, which would correspond to a simple or a positive-negative superimposition, as is common in photography, but one can also multiply pictures or raise them to a power. Thus hybrid formations are obtained from two different pictures. A simple example is the computer graphic *Running Cola is Africa* by the Computer Technique Group, Japan - a running figure transformed into a Coca-Cola bottle and into a contour of Africa via several intermediate phases.

These picture reckoning processes require highly complex and expensive technical facilities, and this is probably why there are only a few examples as yet, and those relatively simple; but there can be no doubt that this is a practically untouched, exciting field for graphic experimentation.

## Picture Processing in Computer Art

As we have seen, works from the sphere of picture processing lie on the frontier between science and art. Kenneth C. Knowlton of the Bell Telephone Laboratories, who can be regarded as one of the pioneers of this method, has used it, in collaboration with B. Julesz and C. Bosche, for making test pictures used in the investigation of human perceptive faculties. The results were interesting not only in scientific but also in aesthetic terms. Jointly with Leon D. Harmon, Knowlton has also used the scanning method for purely artistic graphics. A series that became widely known consisted of photographic slides overlaid with a grid and



*49* Mural, *a computer graphic by Kenneth C. Knowlton and Leon D. Harmon, 1966. A typical example of picture processing. The picture was produced through the scanning of a photograph and the transposition according to a gray scale, with the tone values represented by micropatterns*

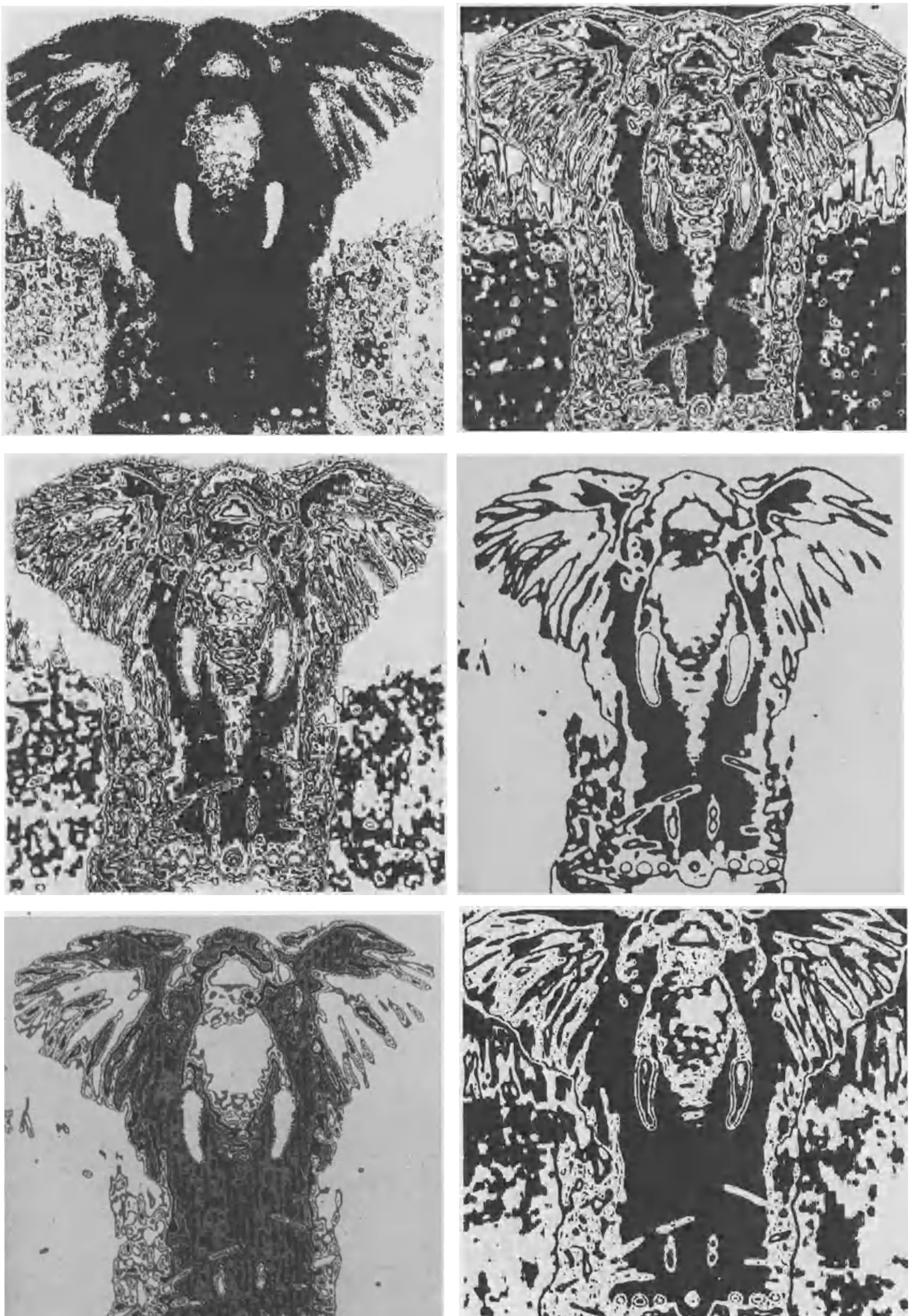
transposed into a series of tone value indications. The tone values were then assigned micropatterns, where the proportion of black to white corresponded exactly to the tonal value concerned. These micropatterns were eventually used for reconstructing the picture. In this way pictures were realized where on the one hand an overall figure can be recognized, but which are also interesting at close quarters. H. Philip Peterson, of the Control Data Corporation Digigraphics Laboratories, Burlington, Massachusetts, has produced pictures that used a similar construction principle; his work *Mona by the Numbers* has attracted special attention. Artistic computer graphics made with picture processing methods have also been produced by Manfred R. Schroeder, who, like Knowlton, was able to conduct his experiments in the Bell Telephone Laboratories (see Figs. 42 and 43, p. 51, and 60, p. 72).

Figurative computer graphics, such as the well-known Kennedy series by the CTG, Japan (see Fig. 96, p. 113), also come under the heading of picture processing.

## New Tasks of Picture Processing

The output of scientific and technical data in the form of visual information is gaining in importance, and picture processing is likely to have good prospects and widespread application. Since the human nervous system has been recognized, in cybernetic terms, as a data processing system, the technology of picture processing has become useful also in the investigation of visual perception, as well as a departure point for bionics research. (Bionics is a hybrid science which seeks to use biological examples for

*50* Mona by the Numbers
*by H. Philip Peterson*



◁*51* Elephant, *picture processing transformations, system DIBIAS, DFVLR, Oberpfaffenhofen, Herbert W. Franke and Horst Helbig*

the solution of technical problems.) Technical as well as aesthetic experiences made in picture processing will eventually find an application in the preparation of pedagogical information for audio-visual instruction.

## 9 Further Artistic Applications

As far as the conception - as opposed to the execution - of works of art is concerned, there is a remarkable affinity in the methods that are used - whether it be in graphics, music or poetry. Computer art gives us the chance to see all generative processes in art from common viewpoints. Differences are enforced merely through variations in human perceptual abilities. We must always be aware that the orders perceived by the individual sense channels differ not merely in terms of physical quality, but also in terms of informational capacity, for example, dimension and complexity. Thus hearing is essentially confined to linear sequences, whereas vision embraces surface as well as spatial dimensions. When dealing with computer texts, grammatical and other rules of language have to be taken into account. It is grounds such as these which prevent the direct transfer of stylistic rules from one medium to another: a program for computer graphics is not suitable for musical notation. It has, however, become easier to conceive multi-media works in a unified manner. Working with the computer simplifies the matching of one art form with another, particularly in the visual sphere, and also eases the change from one medium to another - many computer artists have worked with graphics as well as music.

### Dynamic Pictures

One of the obvious extensions of computer graphics is the transition to dynamic pictures. This was facilitated by programming methods which provide the possibility of modification. In practice, hardly a program is written for the production of one single picture - each program contains variables and parameters the change of which supply any number of variations of the picture. If the step size is kept sufficiently small, a procedure produces the raw material for cinematography. In the age of the mechanical plotter, it was necessary to compose a film by taking a picture sequence in single shots, a procedure which is quite time consuming, yet far simpler than producing each drawing manually. The production procedure is accelerated considerably by filming the screen of a graphics terminal directly or by recording on videotape with the aid of an adaptor. If a high performance system is available or if the user is satisfied with relatively simple configurations, this can even be achieved in real-time. On the other hand, there is no real disadvantage in synchronizing the camera with the graphics terminal and in taking the pictures individually - picture by picture.

### Cinematography

The possibility of generating variations of pictures automatically existed at an early stage for commercial use, namely for the production of cartoons. Graphic designers no longer have to hand draw each phase, it is sufficient to design a series of individual pictures which characterizes the movement in general outline. These are entered into the computer and additional data are input indicating which points of the previous representation are to be transposed into which points of the following picture. Then the computer applies certain formulas for interpolation: the computation of in-between pictures with arbitrarily selectable intervals. Further subroutines allow the coloration of areas. Corresponding interpolation algorithms were later also applied for the transition between pictures with sound.

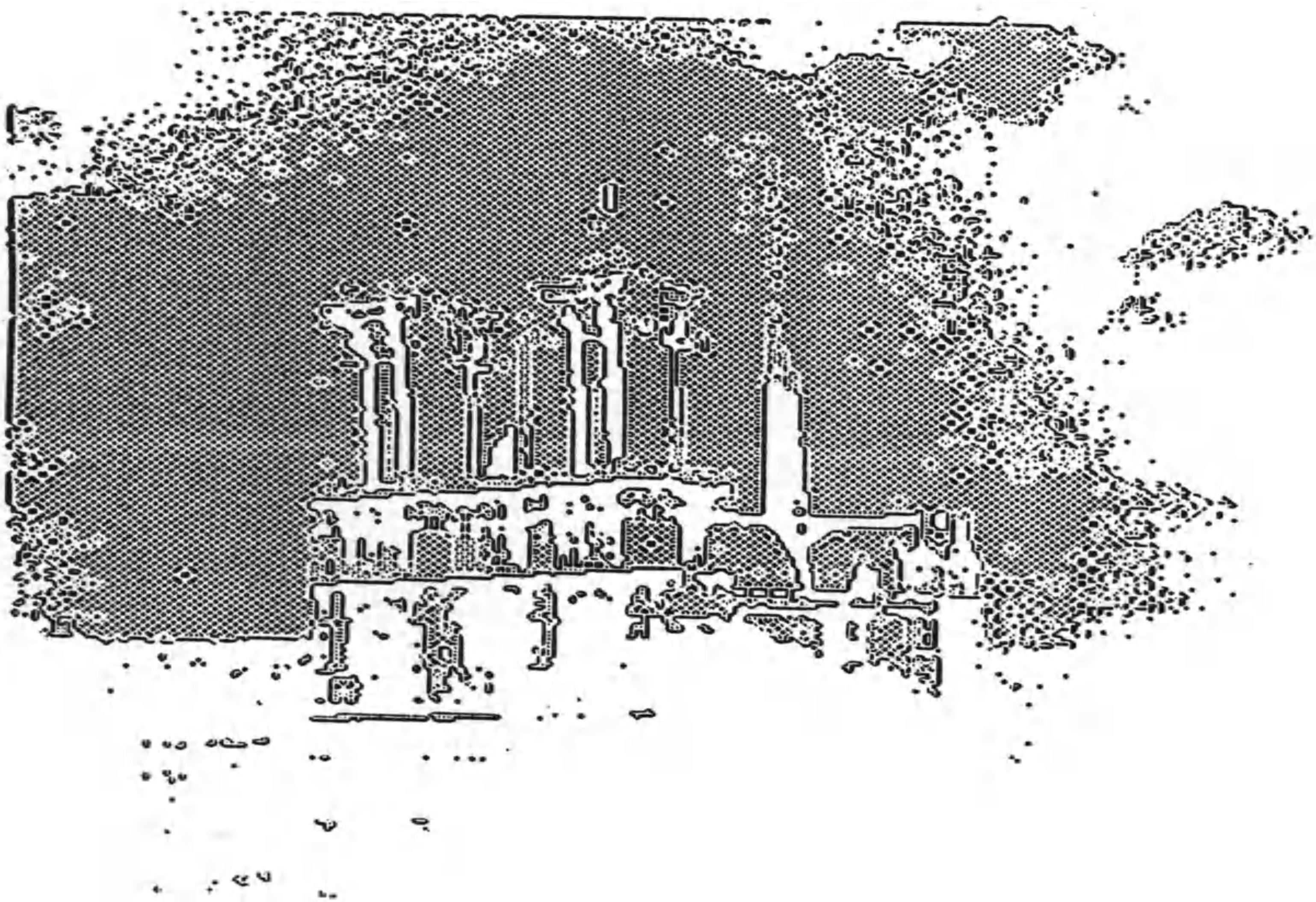
### Animation

The procedure described above was the beginning of a technique which today is called animation and which meanwhile has progressed at an almost sensational pace. Such improvements were made possible in particular by modern computer systems with high storage capacity and fast processing units. A necessary condition was the transition from vector displays to raster displays which led to the generation of computer graphic pictures with

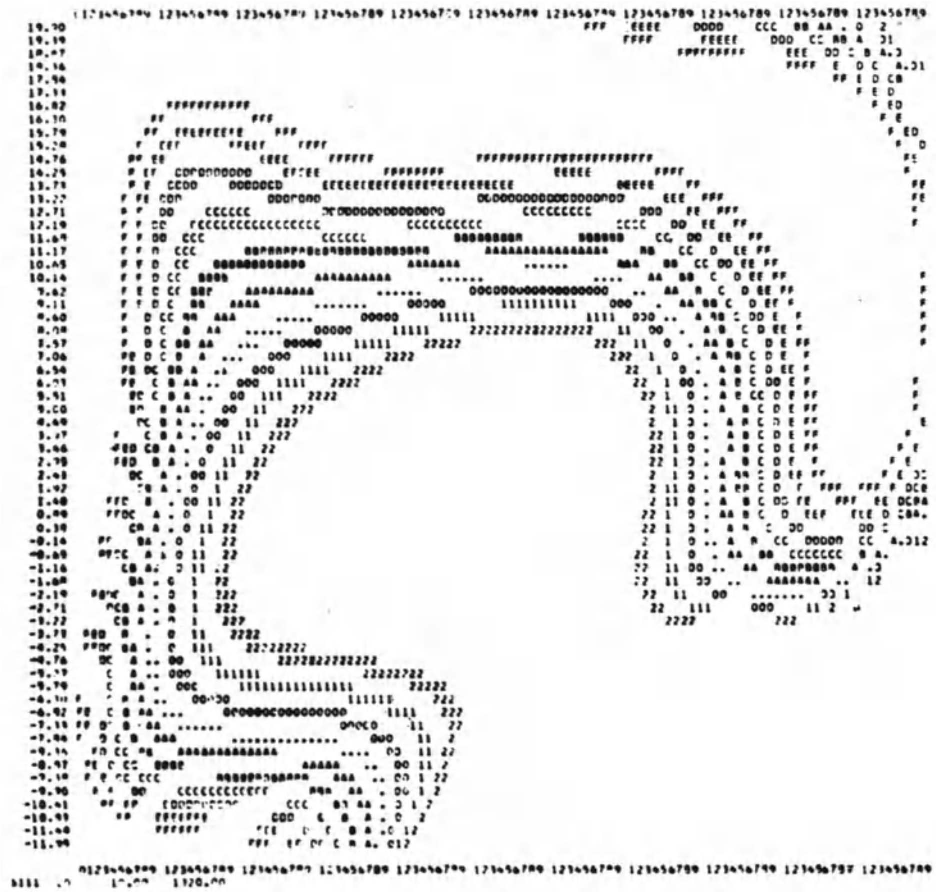
sound. One of the consequences is the transition from 2 D to 3 D, i. e. from flat representations to perspective spatial representations. Such programming systems have access to procedures which permit the perspective projection of moving objects, for example tumbling objects, onto the output surface. They solve the problem of hidden-surface removal - the objects in the background are covered topologically correctly by the ones in the foreground. Furthermore, light intensities are calculated with the assumption of arbitrarily distributed light sources, thus assigning the surfaces with the correct light factor. Shadows are calculated in a similar fashion. Some sophisticated programs even permit the realistic representation of surfaces, however structured, with corresponding reflection effects, as well as the rendering of transparency with an optically correct angle of refraction.
The results of real-time simulations are indistinguishable from photographic or cinematographic pictures. It requires so much computing effort, however, that it cannot be attempted in real time at the present time; the computation of individual pictures takes several minutes, so that days or months would be necessary for the production of longer sequences of scenes. The costs for producing pictures in this fashion are too high to be borne by artists. Therefore it is used mainly by industry with sufficient financial resources, especially by the advertising and entertainment industry. Real-time simulation has yielded amazing results, particularly in science fiction productions, for example in representations of spaceships and planetary scenarios. As already mentioned, the training of pilots, astronauts, and railway engineers, who must learn to master proper vehicle operation by instruments in routine and emergency situations which are simulated as realistically as possible, provides another form of application for these methods. Since in this case the pictures must be output in real time, one tries to overcome the hurdle of insufficient speed of the central processing unit for image generation by limiting the images to slightly simplified, schematic representations.

## Video

While video technology in the framework of commercial television has matured up to a certain degree, a breakthrough for amateurs did not occur until relatively recently. This also opened a new, promising medium for artistic representation.
Although digital switching modules have been integrated into video technology from the beginning, they are deemed to belong to the analog side. It was only recently that video and computer technology have been linked. The first impulse for this development arose from the use of graphics terminals, in particular by the transition to raster graphics - in principle the same output method as that of television. Since graphics systems employed for the professional tasks of computer technology are not compatible with those of television, the use of conversion units which synchronize timing and the scan line sequence of one system with that of the other are required. Recently some simple computer systems, particularly personal computers, have been introduced to the market which use commercial television receivers as output terminals. The images and sequences which they generate can be recorded directly, without additional electronic circuits, on video recorders.
The adaptation of video to computer technology is desirable for several reasons. On the one hand, there are a number of visual effects which can be realized more easily by employing analogue rather than digital circuits, and on the other hand, progress in digital animation is utilized for video. Some of the servicing companies which produce electronically generated image sequences for film, television, and advertising use hybrid systems, i. e. combinations of digital and analogue circuits.
Cartoon production studios which make use of computer animation also work with analogue and digital methods. Usually, scenes with actors are recorded with a television camera and blended with the help of a blue screen with various backgrounds which are generated entirely artificially. Digital methods also offer two basically different possibilities: Paint systems are used more and more often; they imitate the work habits of the traditional painter, who now, however, works at a screen by manually recording partial pictures, nodes, etc., either with a light pen directly on the screen or with a cursor or electronic stylus on a tablet. The same possibilities of coloration as in ordinary painting are available, but there are additional possibilities, such as simulation of an air brush, random distribution of strokes across a given line, any desired coloration of regions, etc. Picture segments



*52* A View of a Village, *picture transformation with the SMC-system (Système Multimedia Conversational), LACTAMME, Paris; Jean-François Colonna*



*53 Preliminary study for the production of a sculpture made up of disks by J. L. Alexanco. Representation of contour lines with a fast printer*

generated in this fashion can then be combined with computer generated subpictures, for intance 3 D-representations of buildings, vehicles, places, and landscapes.

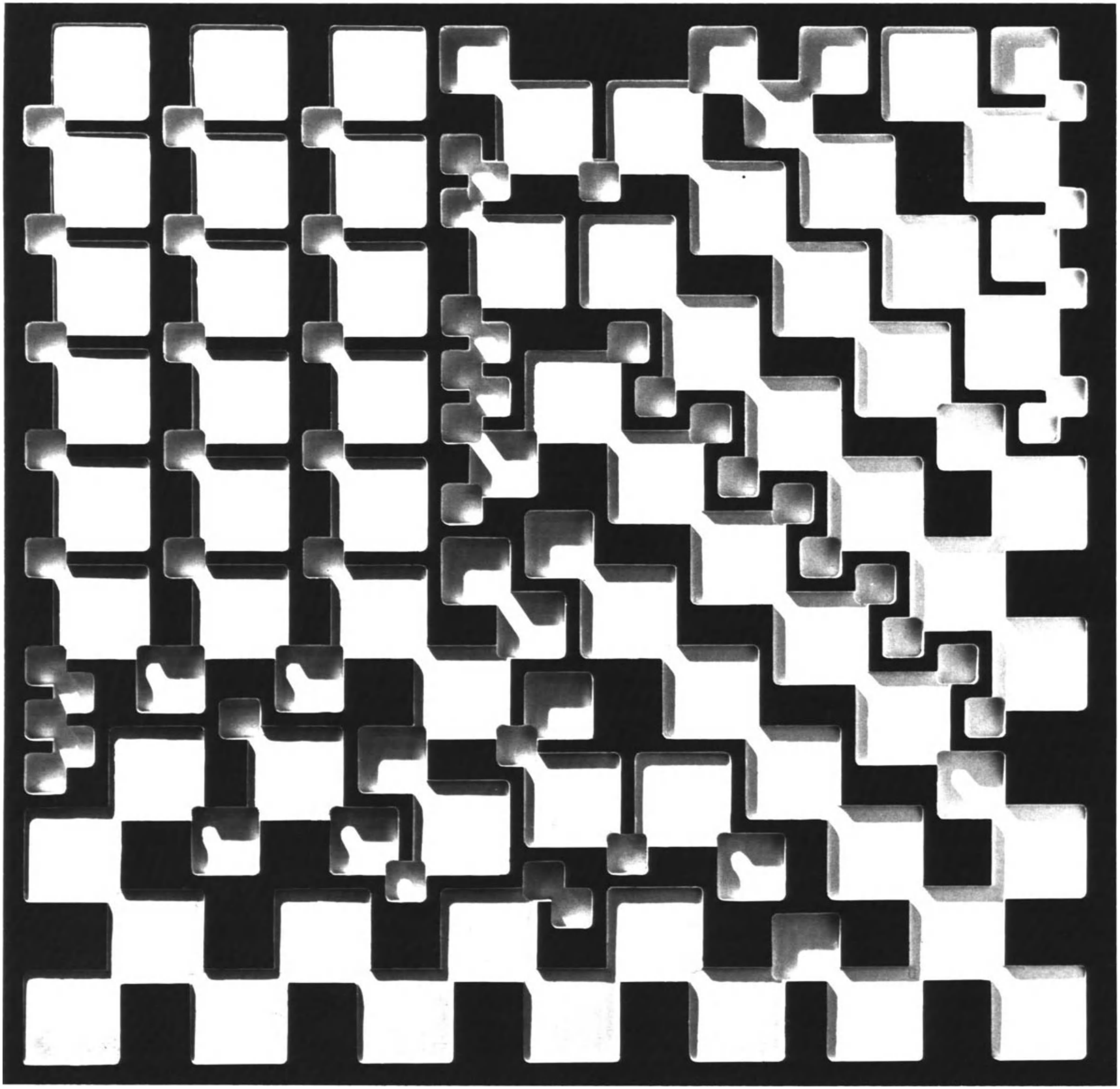
## Sculpture

Computer systems available at the present time are not entirely suitable for the generation of three-dimensional representations such as sculptures. At most, numerically controlled tooling machines could be employed to produce small objects, or else larger three-dimensional objects could be composed from smaller separate parts.

The first attempts at computer-aided production of sculptures made use of the computer merely as an aid for design, for the production of construction plans and perspective drawings. Remarkable results can be achieved if the computer is used merely to produce designs without actually realizing them as in conceptual art. In this case, the qualities of materials and natural laws need not be taken into consideration, but it is possible, for instance, to combine free-floating parts at random or to place fantastic buildings into utopian landscapes. Pictures which are based on a pseudo-perspective view are an attractive variation; the Dutch painter Maurits C. Escher who created topologically impossible constructions has become a model for several computer graphics artists.

Stereography is one method which is of interest also for artistic purposes and which can easily be implemented by means of computer graphics, provided 3 D-programs are available.

*54 Computer sculpture by Georg Nees. A distribution of squares across a square field, according to a program in which several determining steps are left to chance, serves as the basic pattern. The digital computer, a data processing installation of Siemens System 4004, issues a punched tape; this guides an automatic machine tool (operating according to the SINUMERIK system) which cuts the relief pattern from wood or aluminium* ▷



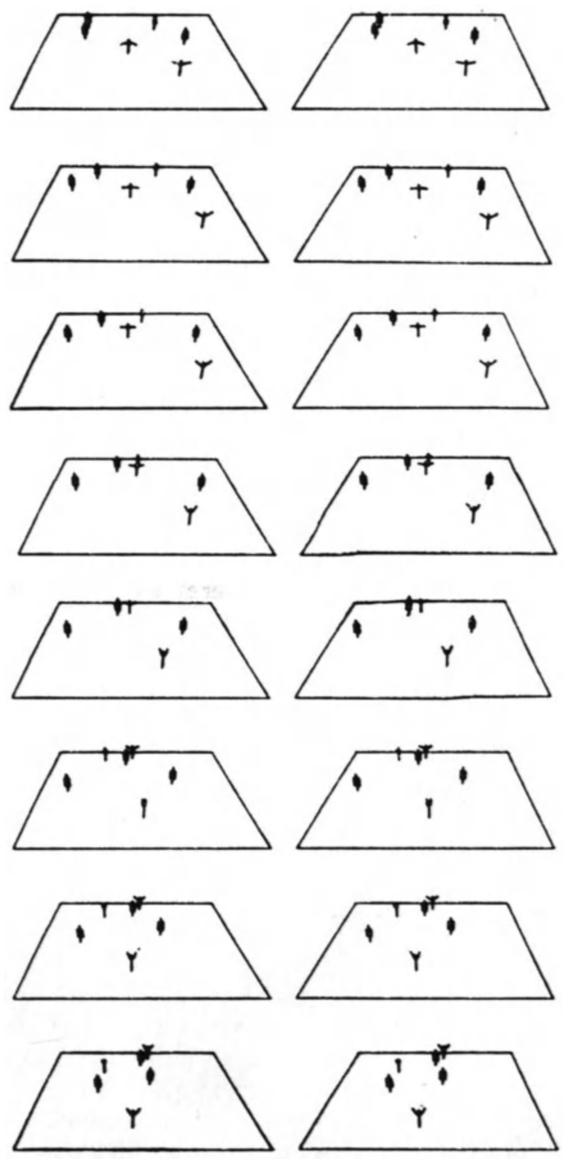
For its implementation, either red-green viewers or polarizing filters can be employed. It is necessary to produce two representations which differ slightly in their perspectives, corresponding to the distance between the eyes.
While discussing sculptures, relief representations also should be mentioned. Numerically controlled milling machines are suitable for their realization. Compared to conventional computer graphics systems, a direct analogy can be drawn: the plotter is replaced by the milling head and the paper by a metal block.
In the future, holography, a three-dimensional representation with the aid of laser beams, should gain in importance in computer art. A holographic picture would be calculated and output by computer graphics which could then be transformed into a three-dimensional representation with the usual means of holographic reproduction.

## Dance

Occasionally, attempts have been made to utilize computers for the design of choreographies. Initially, users were satisfied with stick figures for the characterization of dance patterns, but recently such sequences are illustrated by three-dimensional schematic figures of dancers.

## Music

While artistic computer graphics is still developing, computer music has already reached a certain stage of maturity. On the one hand, it has been included in the curriculum of music academies at least in the United States; on the other hand it has experienced widespread acceptance in the popular music scene. Obviously, the resistance of conservative circles to computer-generated music is far less pronounced than that against computer-generated graphics. The reasons for this are easy to discover. Physical tools and later very complicated physical machines - which is what musical instruments are - have been employed to realize musical ideas since prehistoric times. Thus, the transition to electronic tools was merely the latest step in a long course of development.



*55 Example of "computer choreography" by A. Michael Noll. The positions and movements of dancers on a stage are manifested spatially by means of a stereo film*

Besides, music, with its strict, formal structure and its abstract rules of harmony and counterpoint, has a natural tendency to quantification and programming.
The spectrum of applications of electronic effects in music today extends so far that its description alone would fill a book – and there are already several publications on this recently developed field (cf. the bibliography in the references section). Nonetheless, at least a short mention should be made of the methods and means applied in computer generated music, particularly since computer art diminishes some of the barriers between the classical arts, especially the ones between visual and auditive works of art. In particular, there is the challenge of combining dynamic graphics with music. In the simplest case, this can be achieved by adapting a graphical procedure to a certain piece of music, or vice versa. The most progressive method, however, uses the same program to direct the output of optical as well as acoustical effects.
However, when comparing graphics and music, a significant difference is to be noted which presents some difficulties for a reciprocal correlation: Music is a typically analogue process. The ear, which receives acoustical phenomena, functions according to the analogue principle as well; accordingly, all classical music instruments belong to the analogue category. Neglecting the level of light quanta, pictures also present themselves as analogue phenomena. The eye, however, with its resolution by means of rods and cones, is a typical digital instrument, and most methods of picture reproduction and picture documentation – from the raster print to the screen – operate on a digital basis. If an attempt is made, continuing the present trend, to employ digital operations which are more suitable to acoustical phenomena for various reasons, additional devices for the analogue to digital transformation are required. Accordingly, the first electronic instruments for the production of music were analogue computers for which the problem of digitization does not exist. In principle, all electronic music instruments designed to resemble classical prototypes were systems of electronic oscillating circuits the oscillations of which are made audible by loudspeakers. The basic materials are sine waves in a frequency range of several hertz up to 20 kilohertz. According to a mathematical law, it is possible to synthesize all other wave forms by combining sine waves. The early work of technologically inclined musicians made the construction of synthesizers possible which allow the production and combination of sounds in various frequencies, volumes, and timbres. In addition, electronic circuits are available which permit the production of noise effects, for instance the so-called white noise.
The simplest form of this digital approach is the use of a keyboard which permits the switching on and off of individual elements, oscillating circuits, noise generators, etc. Thus it becomes possible to produce music in one single process starting with the input of a program and arbitrarily selected parameters and ending with a musical performance and its taping. The use of computers for writing scores is also worth mentioning. This method is in line with European musical tradition and has been applied by, among others, Jannis Xenakis and Gottfried Michael Koenig. IRCAM, Paris, for example, use the method of computer compositions including magnetic tape, instruments and vocals.
The desire to use tones, sounds, and other acoustic sequences produced in the traditional manner as input for digital processing is derived from the usual practice in music. This requires analogue-to-digital converters which digitalize (quantify, transpose into quanta) natural sounds at a certain sampling rate. To avoid distortions, sounds must be sampled at a rate of two and a half times the highest frequency. For computer music, sampling rates of 5000 to 50 000 samples per second are used. Devices which operate according to the sampling principle provide musicians with a kind of picture processing method for sounds – they do not need to structure their sequences digitally from scratch, but can input them with a traditional instrument or even with their own voice in order to abstract, alienate, or combine them in any fashion (digital *musique concrète*). The first devices which allowed transformations of this kind, the so-called vocoders, were not produced, as is generally believed, for the purposes of sound research, but for digital language coding in cryptography. While the first vocoders were extremely expensive, the wave of microminiaturization resulted in a significant decrease in price, so that they are now generally found amoung the equipment of medium-sized studios for electronic music.
In computer music, especially where it serves music-theoretical purposes, a procedure is frequently adopted in which the stylistic

characteristics do not have to be explicitly given. The first step is the analytical phase. The computer is offered several musical pieces which are in the style desired for the finished composition. These might be works of a specific period or of a particular composer. The computer now compiles the significant data of this music, relating in particular to the probability of the succession and consonance of sounds. Extensive use is made of the Markoff chain procedure, where the probability of the occurrence of a sound is determined by its dependence on several previous sounds. In the second phase of the production process, the computer uses the established laws to select from a choice of random numbers those that are suitable. The result is a composition which corresponds to the style of the original example. In this way one saves the effort of encoding musical styles in a program – the computer creates its own program on the basis of the stylistic analysis.

The drawback of the method is that it permits only the generation of examples in known styles. But there is nothing to prevent a deviation from the stylistic analysis on certain specific points, and in this way arriving at new results. The control possibilities inherent in this approach give science the chance to determine how specific stylistic means influence the auditive effect. This is experimental aesthetics in the best sense of the term, with results that are in no way inferior to those of classical art, and with insights that are valuable not only for musicology but also for the psychology of perception.

During the last few years, a remarkable advance in programmable electronic music instruments on a digital basis occurred. A number of music computers, for instance the Fairlight CMI, the Synklavier, and the McLevyier Klavier are available for purely professional use. Besides various possibilities of synthesis and transformation, such systems permit any wave form to be drawn on a screen by means of a light pen and the corresponding waves to be transcribed into sounds. Another professional device is the Crumar/MTI which contains 32 oscillators for the generation of sounds. Since personal computers offer the possibility of generating freely designed graphical sequences in real time, compatible music computers, along with generally available microcomputers, have caught the attention of producers of electronic devices. While the first products of this kind, dating back more than ten years, were still quite limited in their capabilities, much more flexible devices entered the market in 1980, for instance a wave generator produced by the ALF company to be used in connection with the Apple computer, or – with much greater capacity – the Casheab which generates 32 voices from 16 different wave forms and exhibits some of the other capabilities of commercial synthesizers.

Computer generated music, in combination with computer graphics and video, particularly that produced by amateurs, is the favourite subject of the *Personal Computer Arts Festivals* of the Computer Arts Forum in Philadelphia, which are held annually. Worth mentioning here is the *Große Preis* of ARS ELECTRONICA, a festival in Linz, Austria, which awards prizes for the most original recent developments in electronic instruments to professionals as well as amateurs.

## Literature

However tempting it may be to employ the computer for the generation of texts, computer poetry is undoubtedly the most difficult task of the computer in art. This is due to the fact that human language is the most complicated communication system that we know, just as the human brain, which creates and receives language, is the most complex system with which science has concerned itself until now. We are still far from understanding its function, and the exploration of language is also still in its embryonic stage.

The attempt to produce linguistic manifestations with the aid of computers is also connected with practical purposes, namely the problems of mechanical translation. We now have programs that produce a fairly comprehensible translation, say from Russian into English. They prove useful in the translation of news items, e.g. from newspapers, as well as in the translation of scientific publications where linguistic elegance is not important. A serviceable translation of literary texts is not yet possible, and so it hardly makes sense to see this kind of computer utilization from artistic viewpoints. But if one is aiming to use the computer for artistic production then one needs that very knowledge that is still lacking in language translation, i.e. knowledge about the rules which determine linguistic expression. These rules do not merely relate to grammar or phonetics but primarily to semantics - to meaning-relations. This may be the key to the phenomenon of language - it has evolved as a tool for the encoding and transmission of meaning-relations.

But despite these difficulties computer lyrics do exist. Although, in the main, they are based on relatively simple programs, they are important as indications of possible future developments. First, it is necessary to capture the syntax of language in a program; up to the present this has been restricted to simplified models. Next, the computer is provided with a 'dictionary', that is to say, a list of the available words, in all possible variations; characteristic data indicate the circumstances under which this or that form is to be employed. It now becomes possible to generate a limited number of sentence types in grammatically correct forms. Again use is made of methods that have proved their worth in music. A random number generator offers a sequence of words and the program tests these for admissibility. If this proves to be positive, then the word concerned is used for the construction of the text. The random number generator also determines the length of the texts as well as the sequences of the sentence types utilized. The program does not concern itself with meaning-relations, but it is possible to compose the dictionary from ideas that share certain associations.

This was the origin of the well-known poem *Weihnacht* by Rul Gunzenhäuser. And so the probability of related ideas appearing together is increased, but in fact we are merely faced with random effects. It is of course conceivable that the system of rules

> Der Schnee ist kalt
> und jeder Friede ist tief
> und kein Christbaum ist leise
> oder jede Kerze ist weiß
> oder ein Friede ist kalt
> oder nicht jede Kerze ist rein
> und ein Engel ist rein
> und jeder Friede ist still
> oder jeder Friede ist weiß
> oder das Kind ist still
> ein Engel ist überall

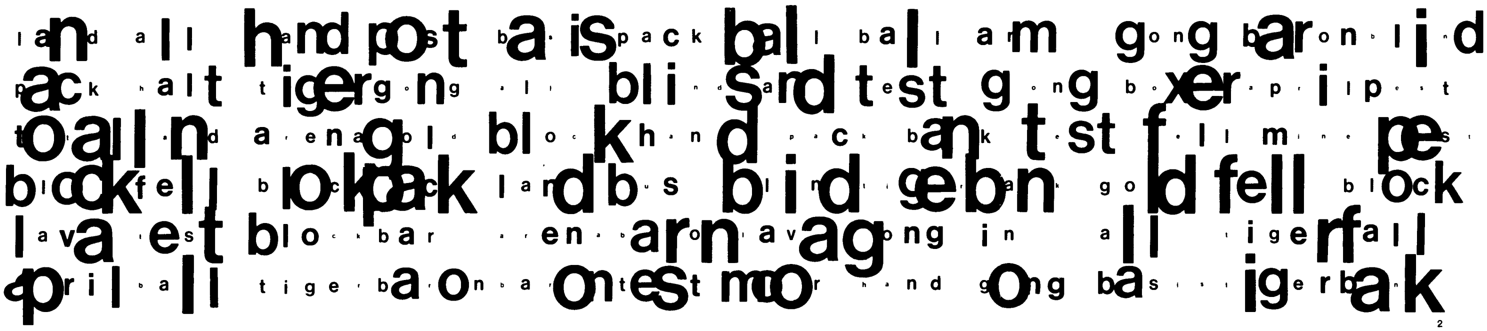
can be developed to such an extent that we can achieve texts which gradually approximate to normal language. But this is only a different approach toward the complete linguistic rules to which computer translation aspires.

The relatively simple language patterns accessible to contemporary computer poetry are reminiscent of the stylistic means of concrete poetry. This is marked by a restriction to linguistic elements of the utmost simplicity, the breaking up of relations, the juxtaposition of fragments and so on. If computers are introduced for such experiments, satisfactory results may well follow. Alan Sutcliffe's works are an example of this. The kind of concrete poetry where the surface distribution of linguistic elements becomes a formative component - in a sense already a transition to graphics - is also open to the application of the computer. Works of this kind come from Marc Adrian.

There is a vast range of experimental possibilities incorporating the computer that has not as yet been taken up. Texts, like images, could be successively destructured, changed according to specific principles, or even reckoned with each other. The superimposition of interferences; the exchange of words for those of another semantic field; the mixing of two entirely different texts in accordance with strictly prescribed, or even statistical, rules could surely lead to fascinating new territory. In the meantime, linguistics has worked out new grammatical theories that are available as program systems, and which could be used for the generation of texts. With these, far more complex sentences having greater meaning-relations could be achieved, and thus we could obtain poetic texts with a wider scope for variation.

Occasionally, another possibility of using the computer for literary purposes is discussed, and that is for the conception of literary plots. Some programs for adventure scenarios which are not necessarily meant for actual use are already available.

Such procedures could have some rather interesting applications in those fields which are not concerned with fixed sequences of events, but rather with flexible ones, for instance those which are dependent on decisions of the user. The design of computer games contains elements of this, but one can also imagine future forms of some kind of "experience theater": the users are located within a similator; on screens, by holographic representation, they are subjected to events in which they are involved them-



*56 Semantic infra- und metastructure, computer-generated "concrete" text by Marc Adrian*

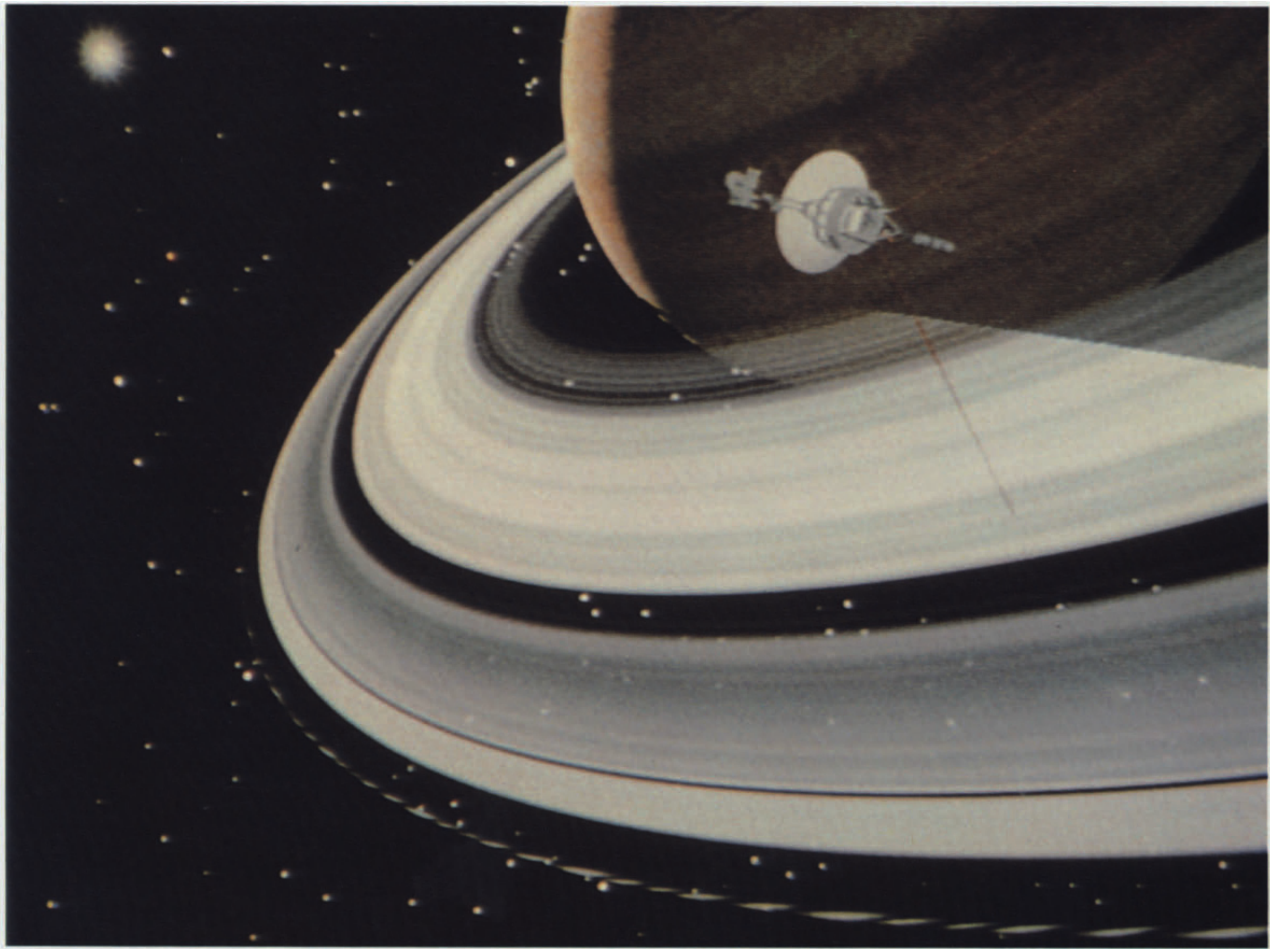
selves; depending on their decisions, different variations of the program are executed. The basic difference of this new form of entertainment, compared to the ones offered traditionally, is the interaction between the user and a program.
It can be assumed that these possibilities will initially be realized for general purposes, but there is nothing to prevent artistic applications as well.
Thus, the computer open up new avenues in the area of art and entertainment which are not imaginable without the interactive operation of electronic technology.

## Multi-Media

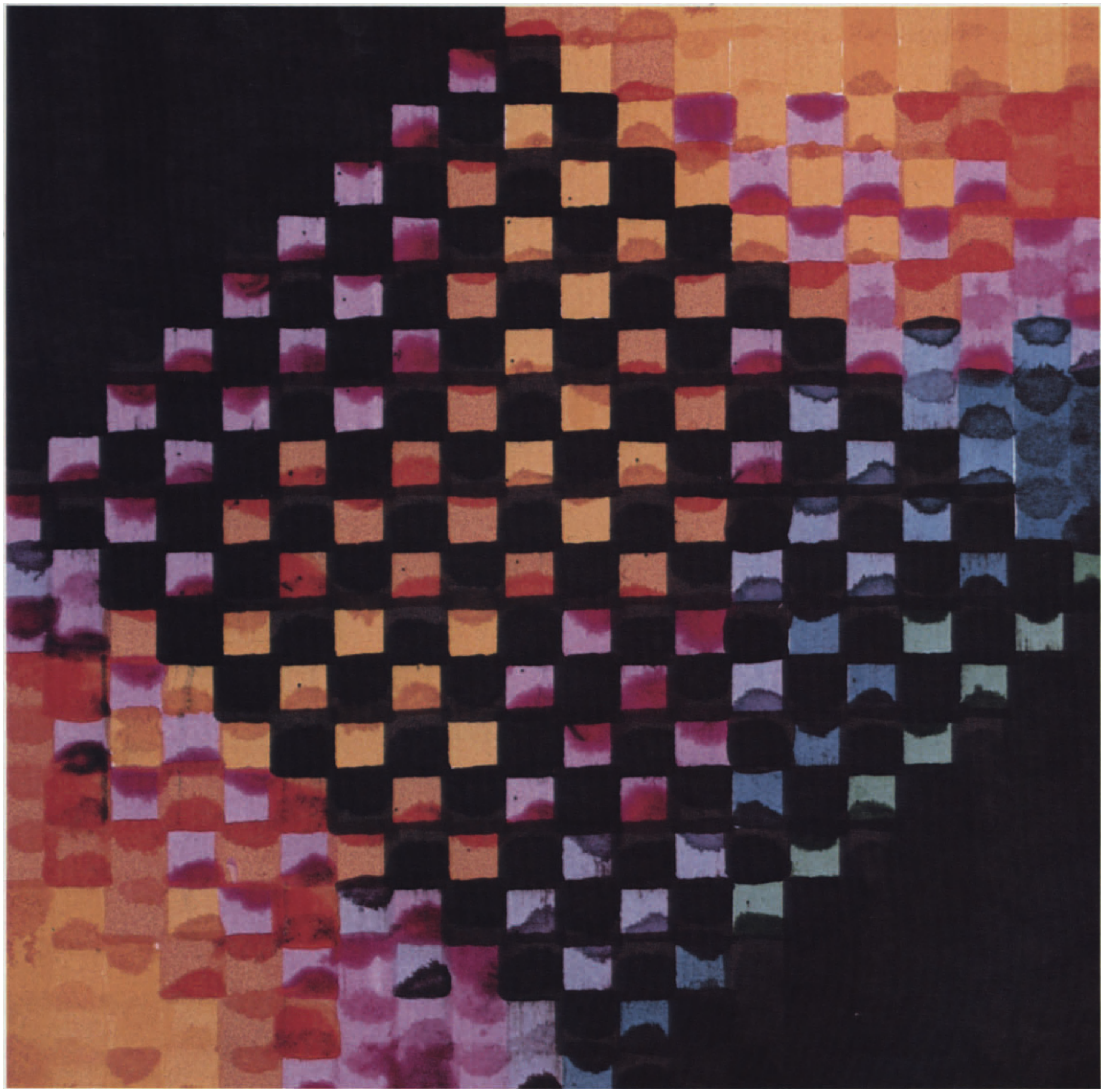
As far as work with the computer is concerned, the advance into the multi-media dimension means only the combination of individual methods with a certain harmonizing of the various sequences. An example might be film accompanied by music, or a ballet. The computer offers excellent scope for such experiments since it can handle the control and thus the synchronization of the developments, either directly or through punched or magnetic tape. It is precisely at the point where a team of executive artists is not equal to the complexity of a task that the introduction of the computer becomes particularly valid.

## The Computer and the Environment

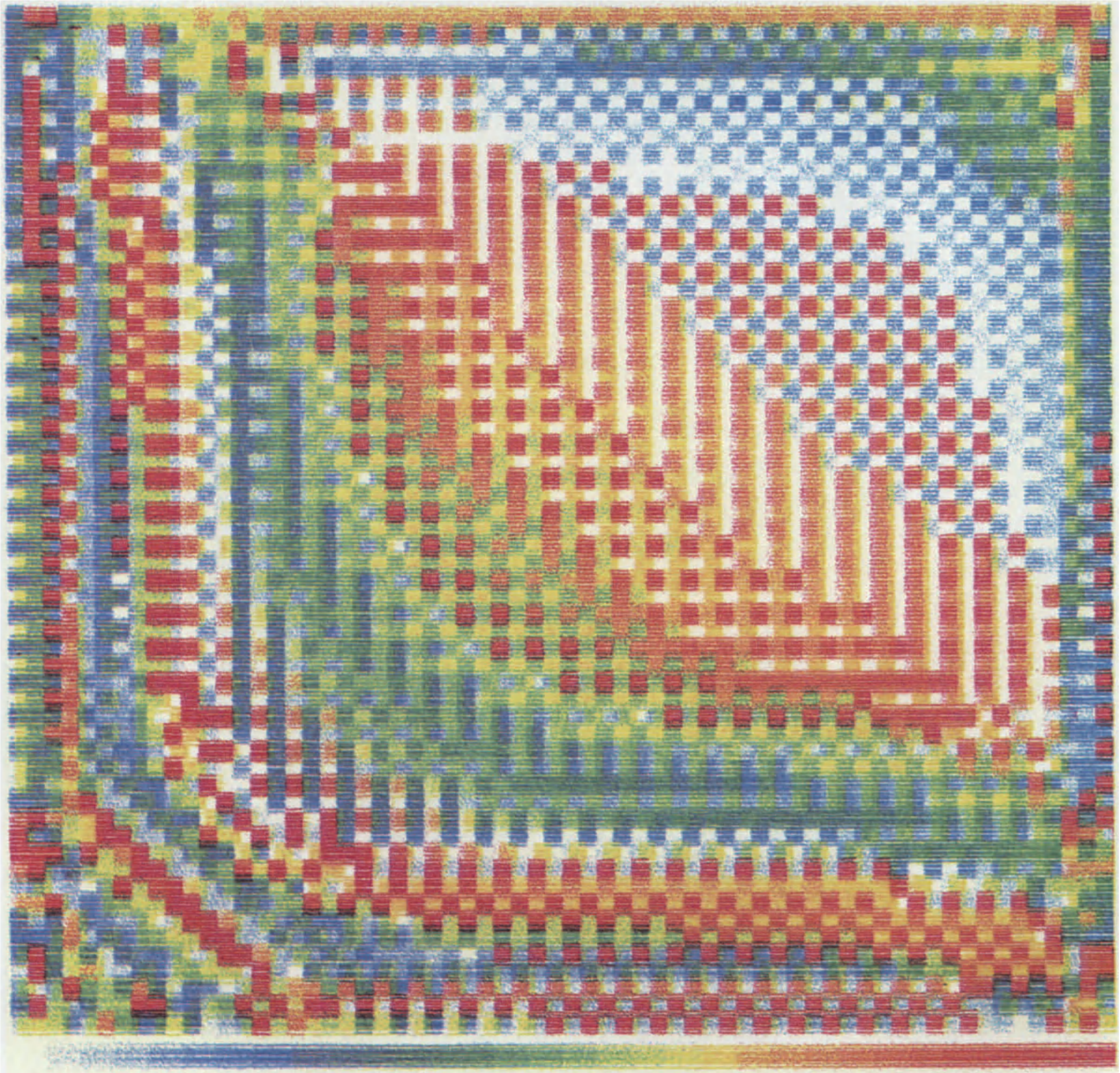
Environmental change, town planning and architecture pose problems for the solution of which the computer is being increasingly called on. But since this area is hardly concerned with free aesthetic creation, it is mentioned here only in passing.



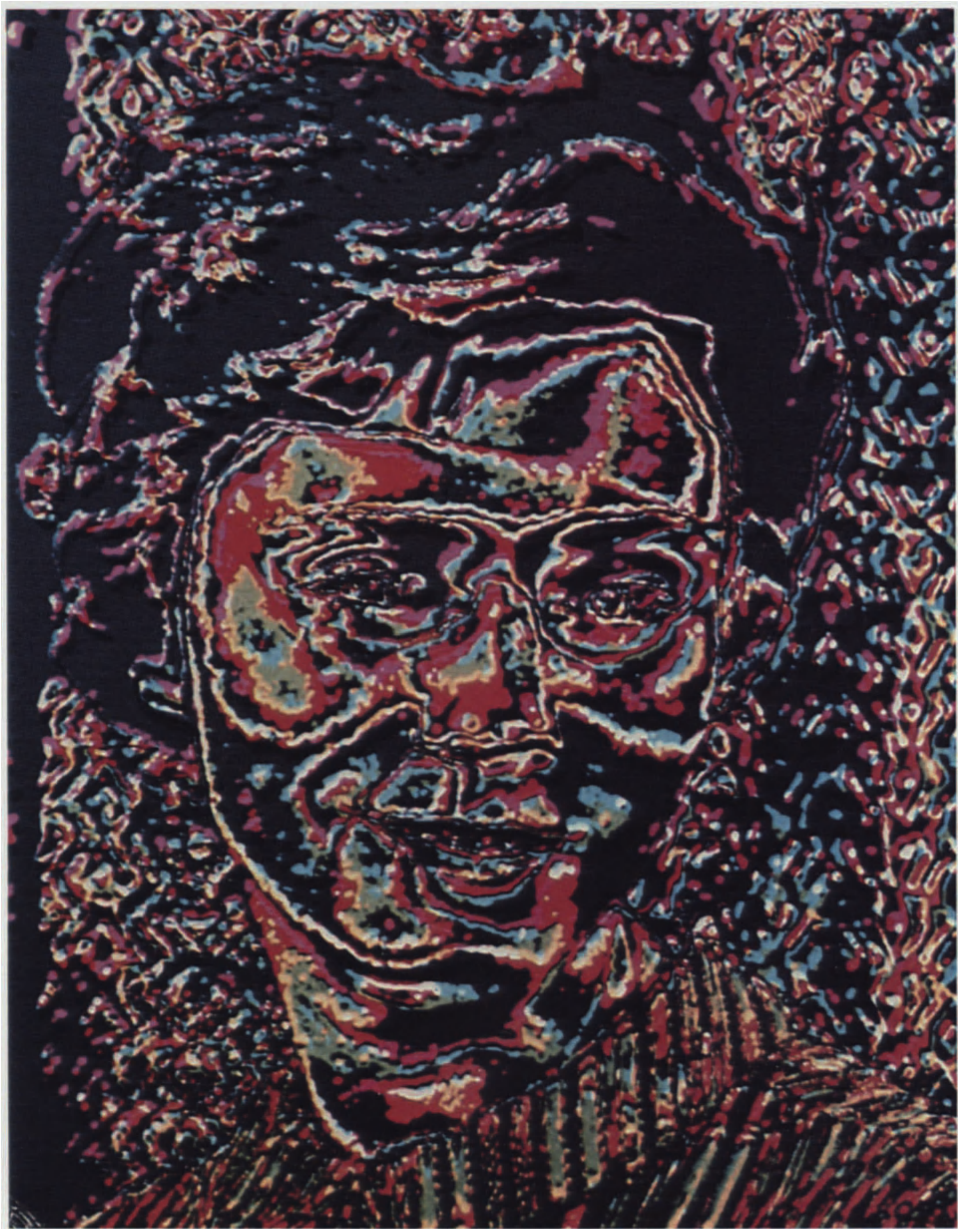
*57* Rings of Saturn, *picture processing by James Blinn, JPL, NASA*



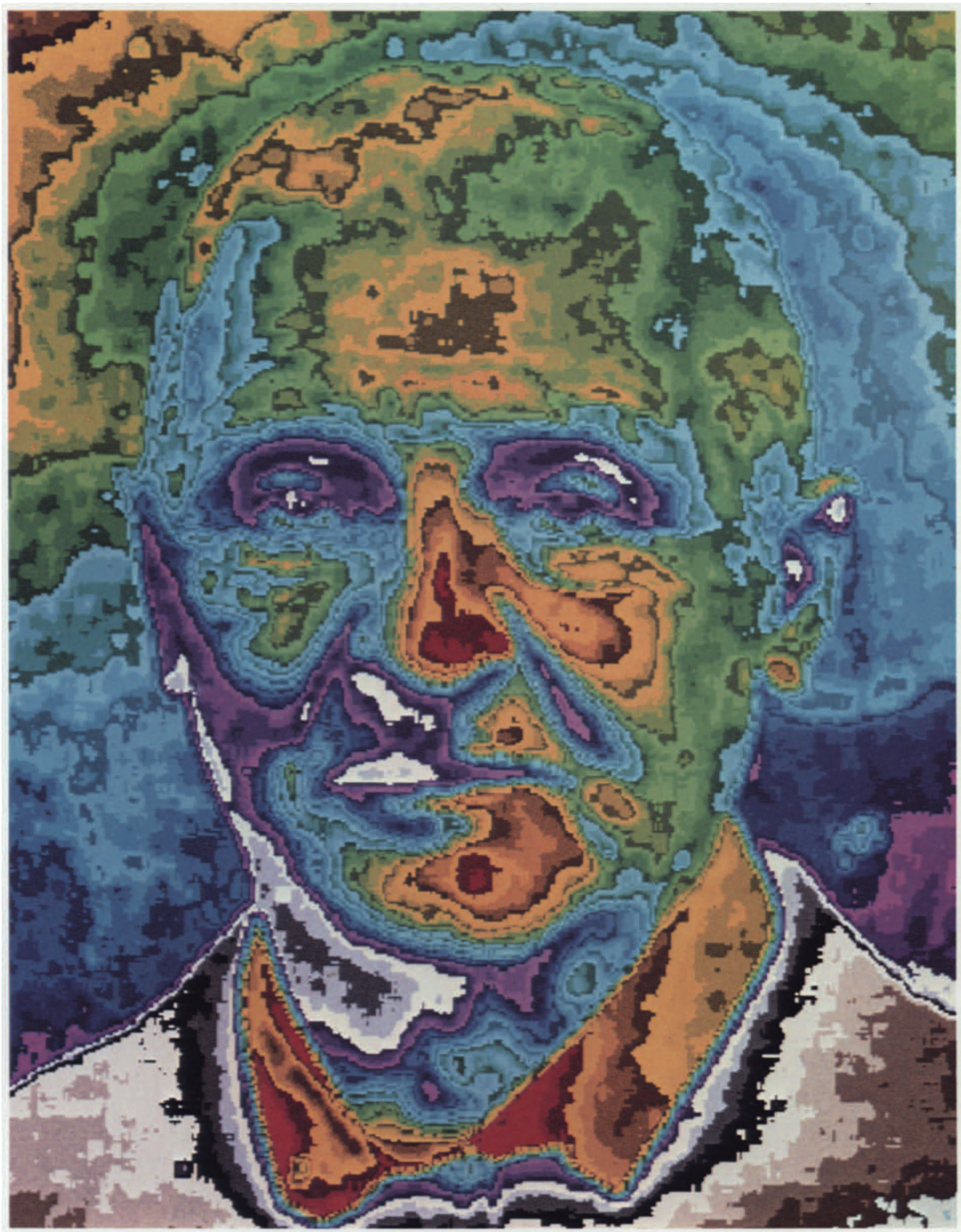
*58* Matrix Multiplication, *1967, by Frieder Nake, an example of the visualization of the mathematical processes. Following elementary operations of matrix multiplication, numbers were arranged on the field. A color was assigned to each number and applied with maximum line thickness to the basic square of the grid by the mechanical drawing machine GRAPHOMAT*



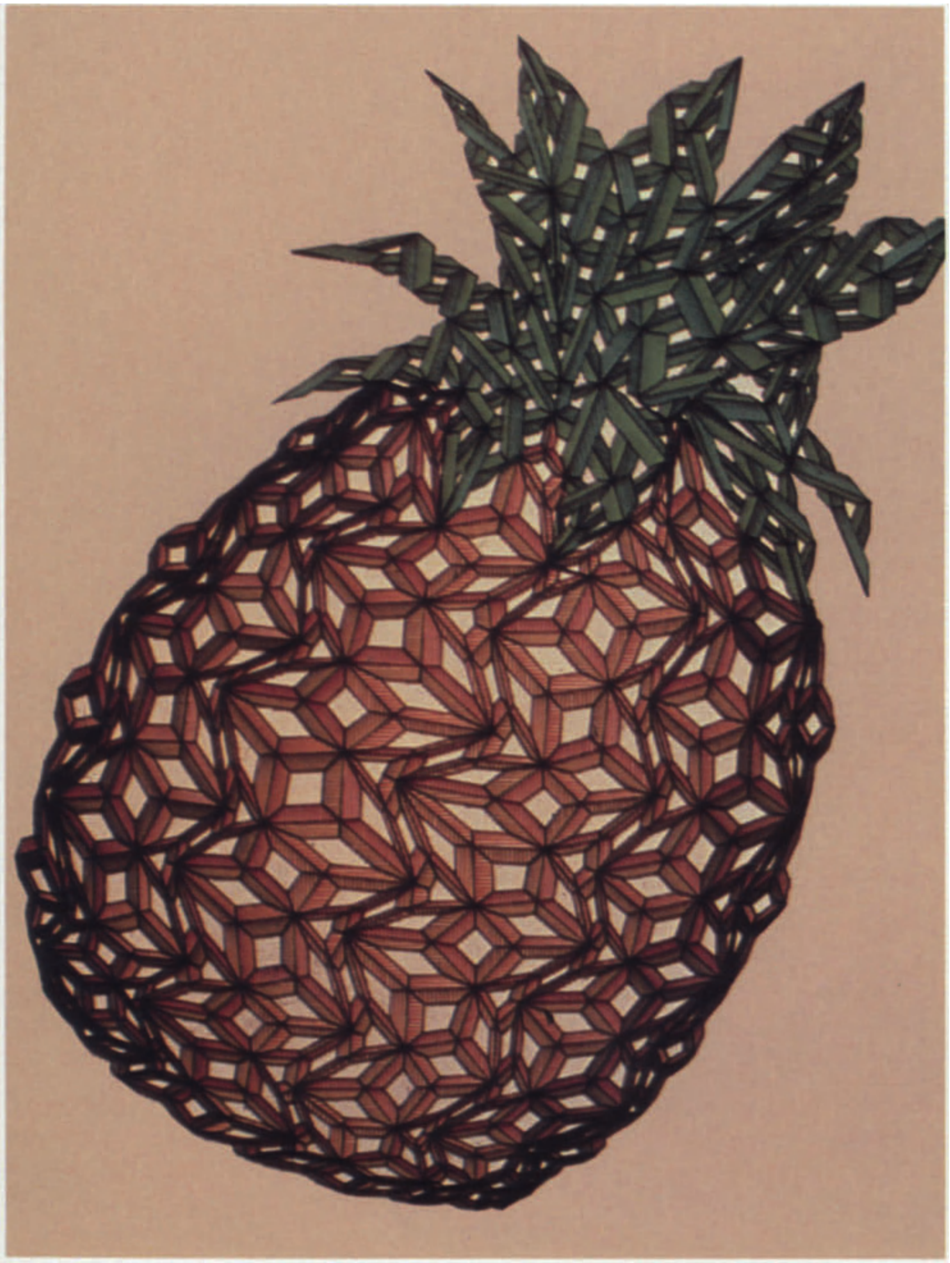
*59* Farbraster 75, *computer graphic, composed on the monitor, printed on an ink jet plotter; system SICOGRAPH, Herbert W. Franke*



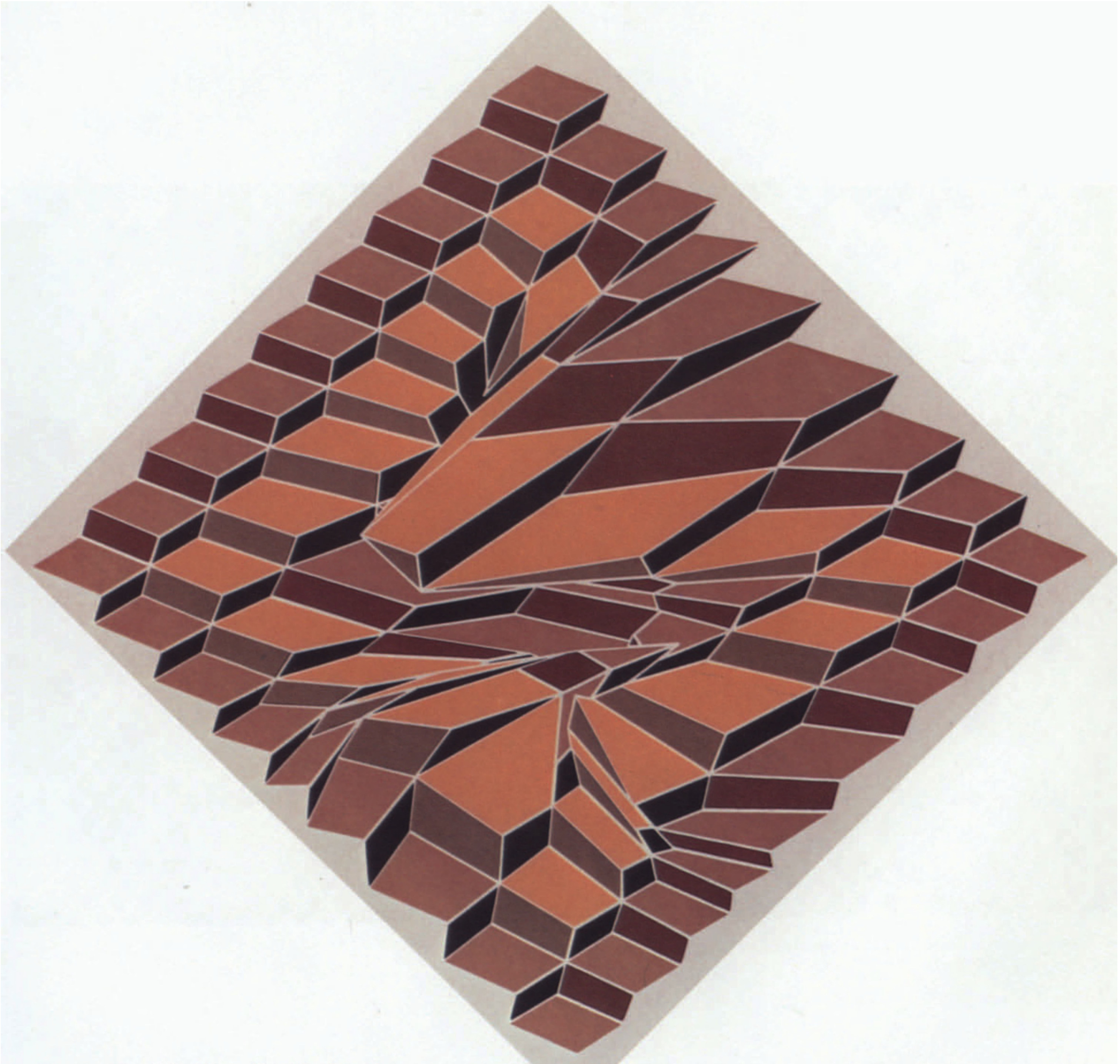
*60 An example of the picture processing series by Manfred R. Schroeder, one of the first color designs; Bell Telephone Laboratories*



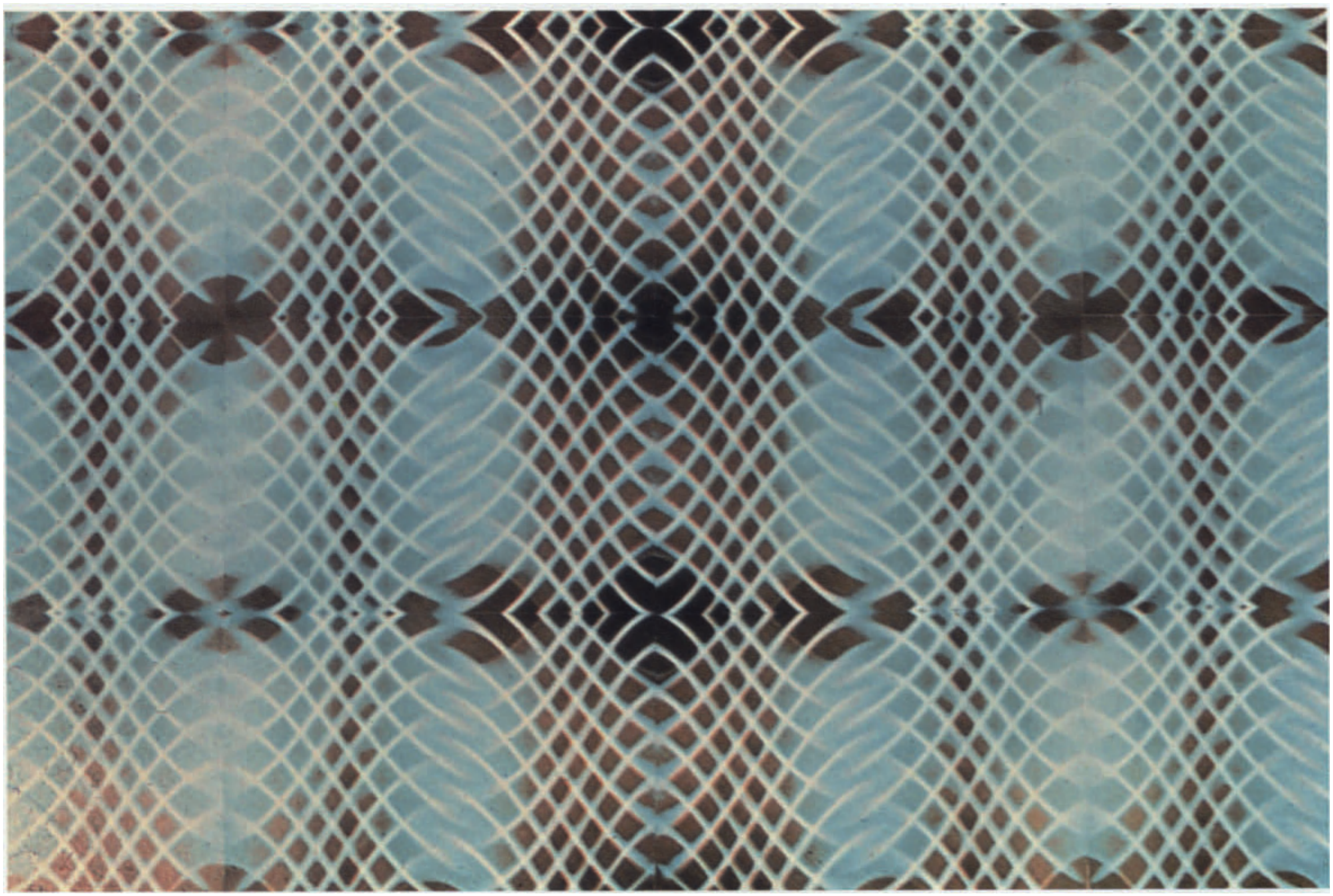
*61* Anton Bruckner,
*picture processing after an old black-and-white print; system DIBIAS, DFVLR, Herbert W. Franke*



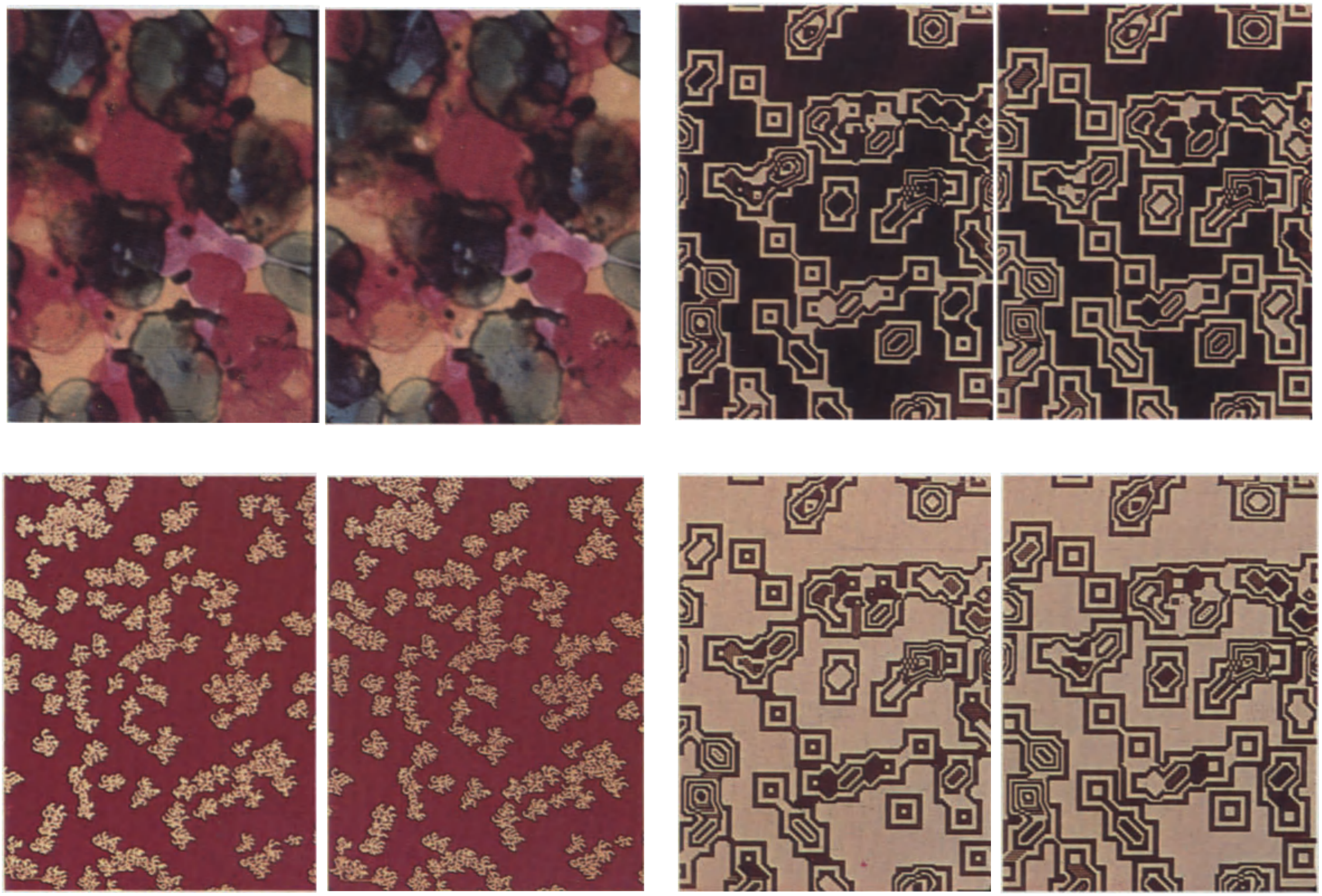
*62* Pineapple, *computer graphic, A. R. T. A. (Atelier de Recherches Techniques Avancées), Centre Georges Pompidou, Christian Cavadia*



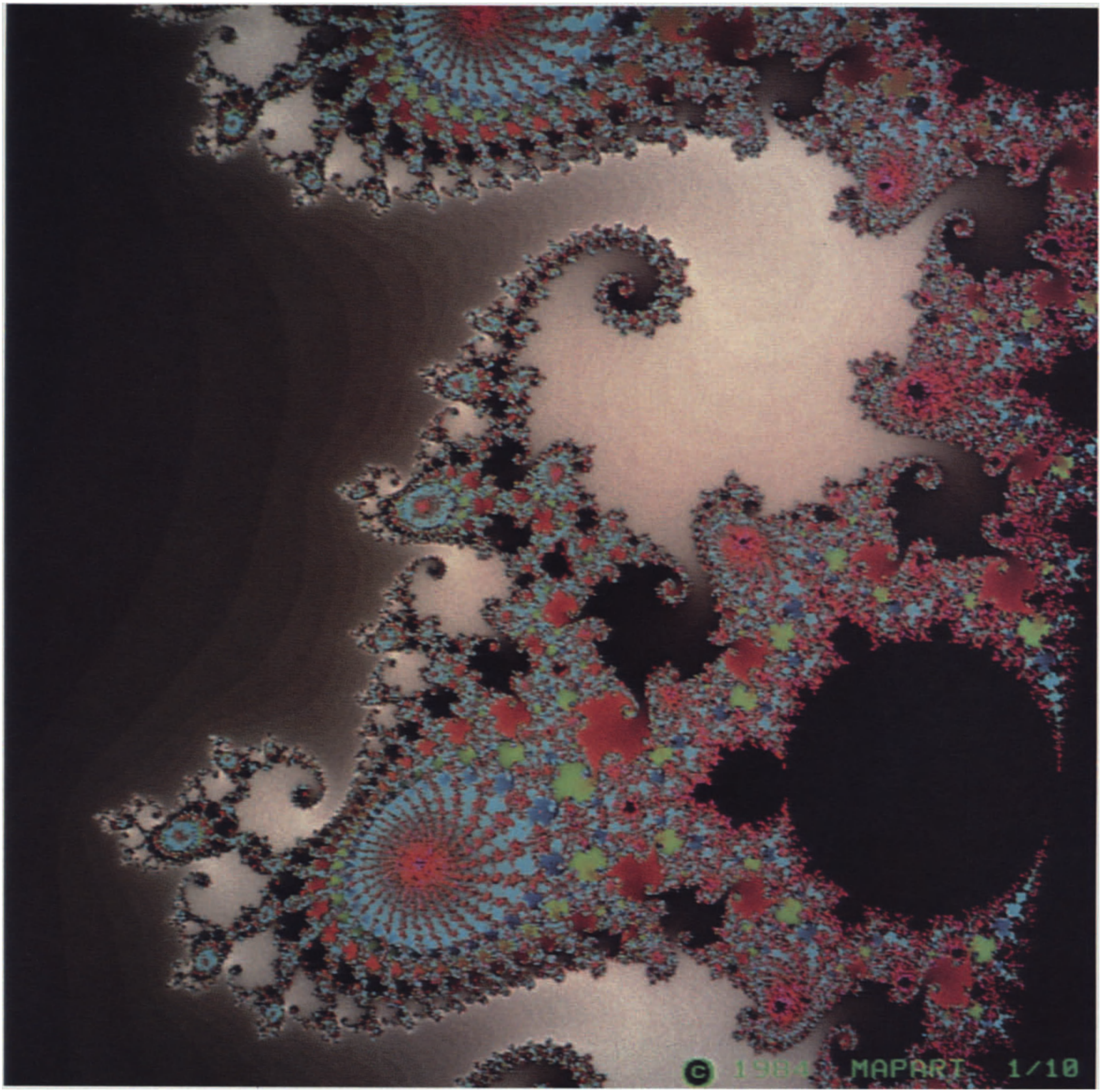
*63* Diamond-Variation II, *produced by distortion of a regular pattern, Ruth Leavitt*



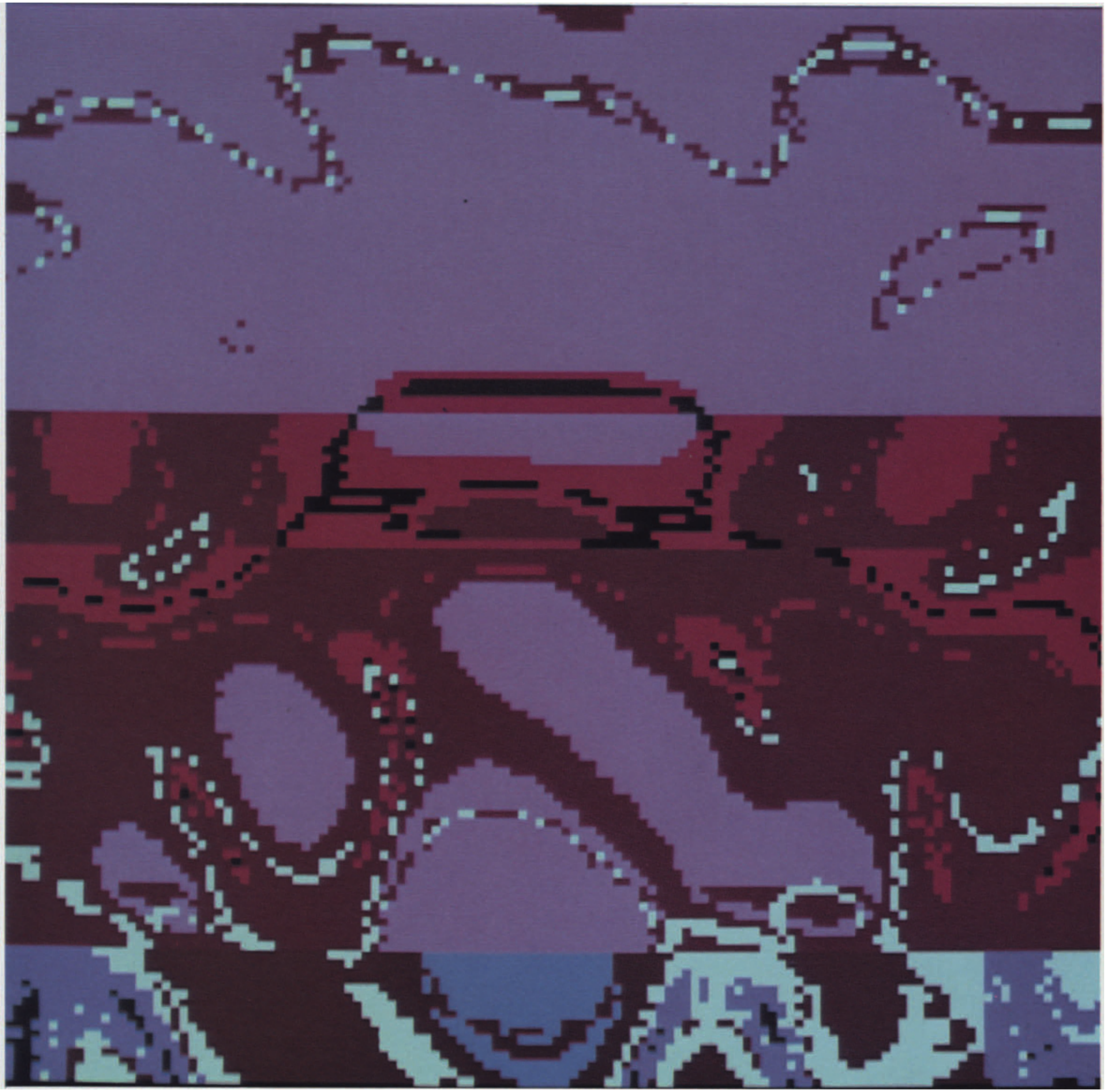
*64 Textile design, generated with the graphics data processing system, Dolphin Productions, New York, Susan Casey*



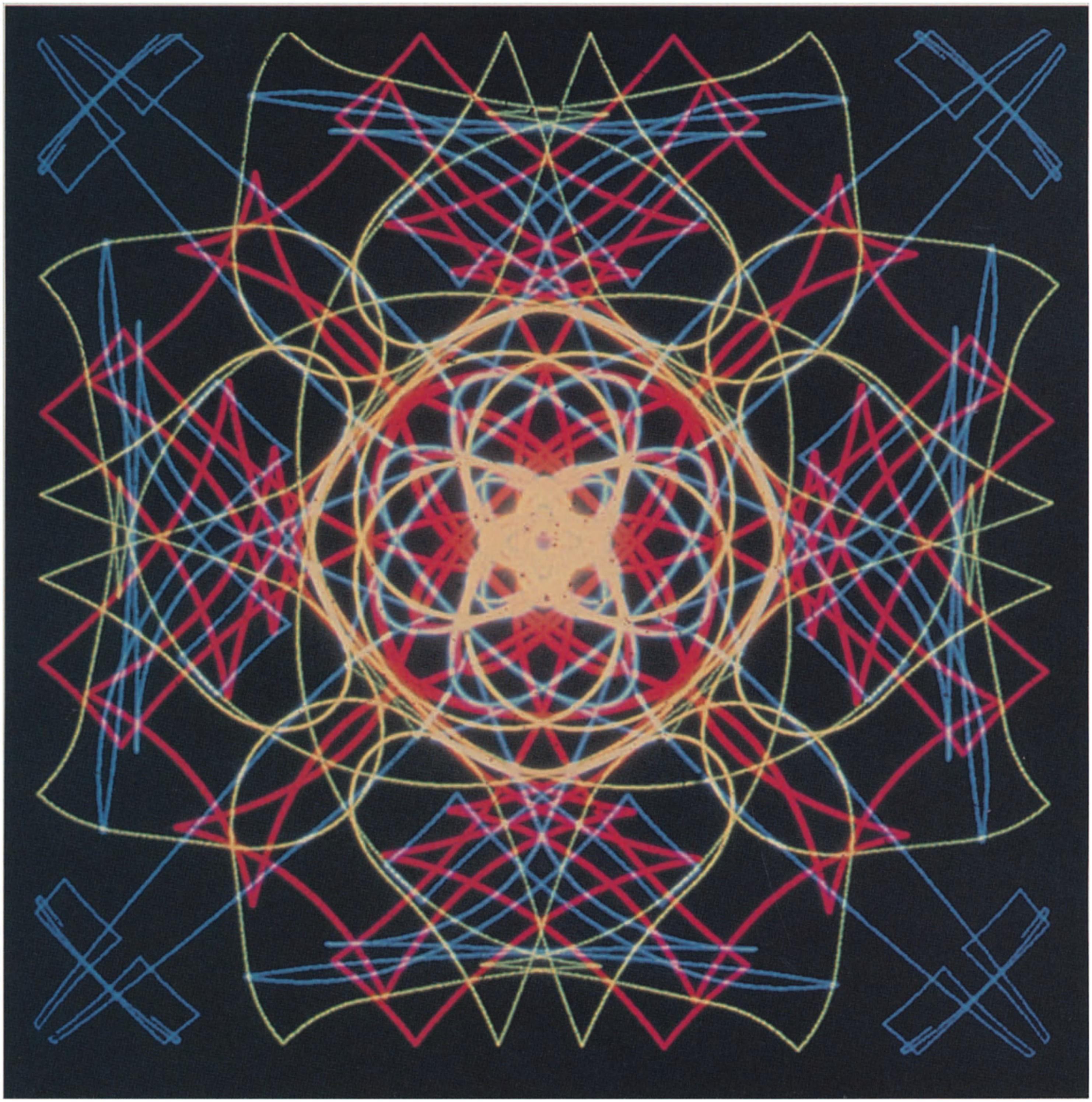
*65 Computer-generated phase pictures from the film* Pixillation *by Lillian F. Schwartz, in which color sequences made in a conventional manner alternate with computer-generated sequences. These were made with the BEFLIX system of Kenneth C. Knowlton; the music was composed after the GROOVE system of Max V. Mathews*



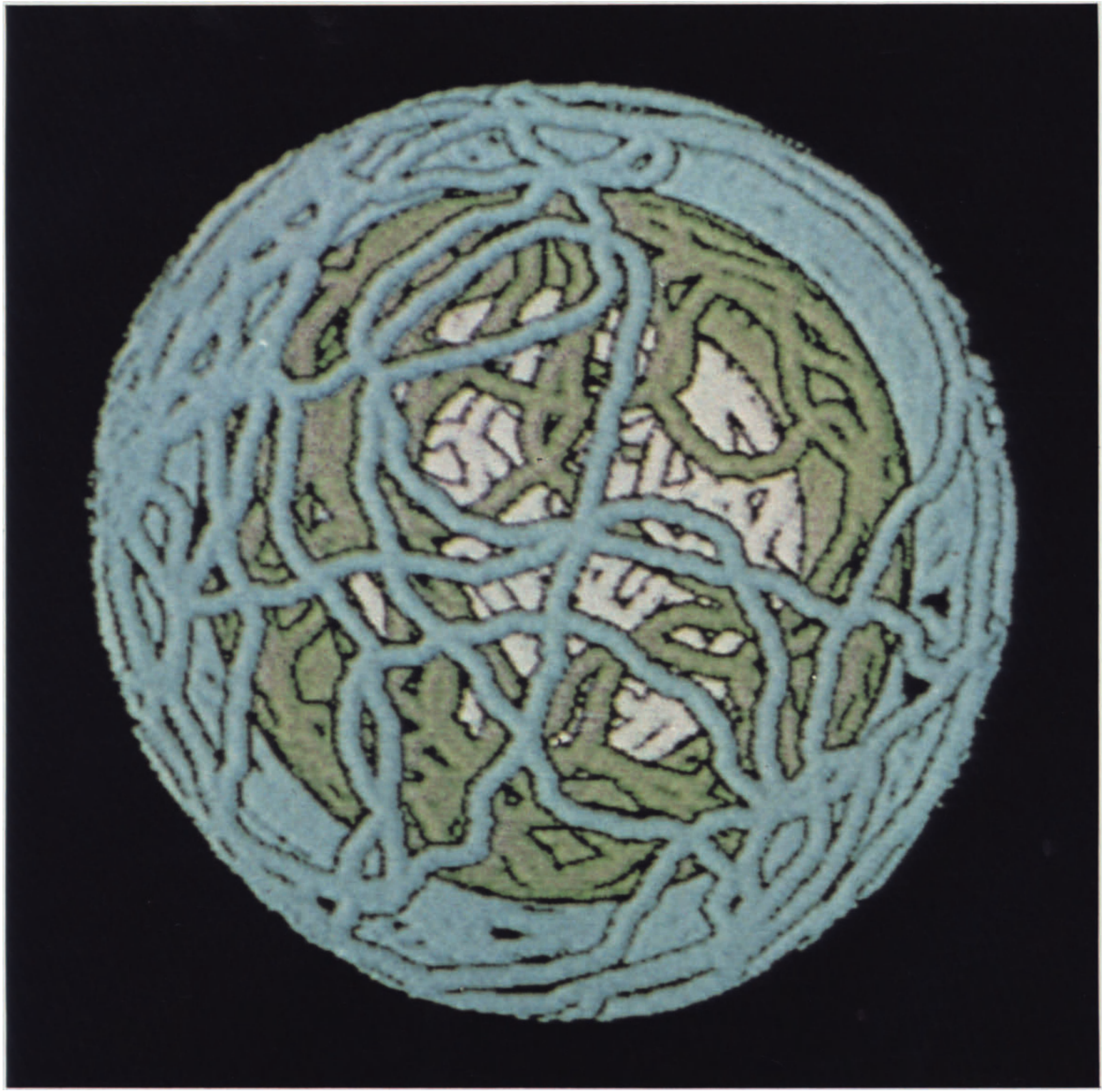

*66* Apfelmännchen, *a form discovered by Benoit B. Mandelbrot which illustrates a mathematical connection in the field of Julia sets; Heinz-Otto Peitgen and Peter H. Richter, University of Bremen*



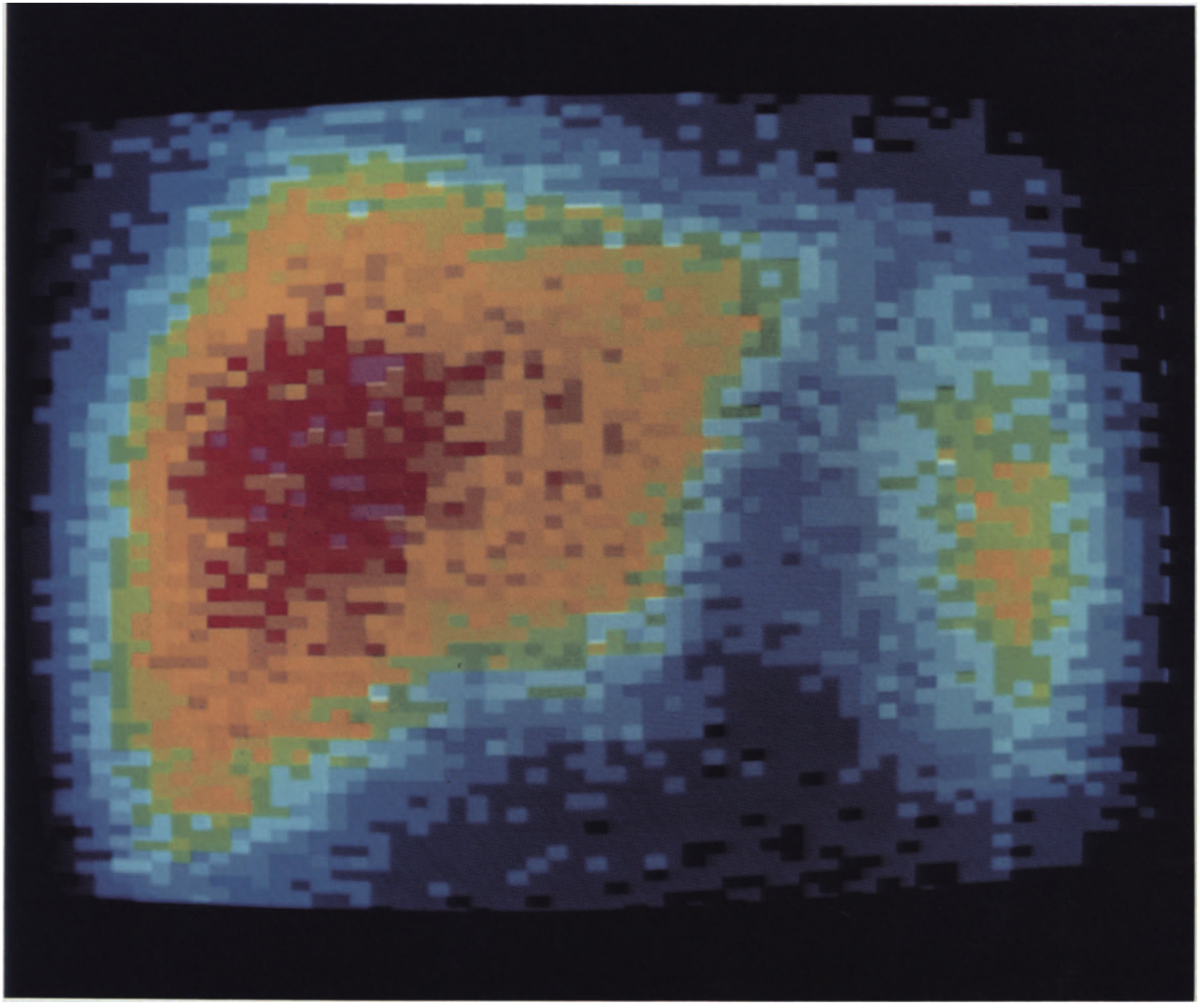
*67* Free Form, *a combination of mathematical and logical transformations; system DIBIAS, DFVLR, Herbert W. Franke and Horst Helbig*

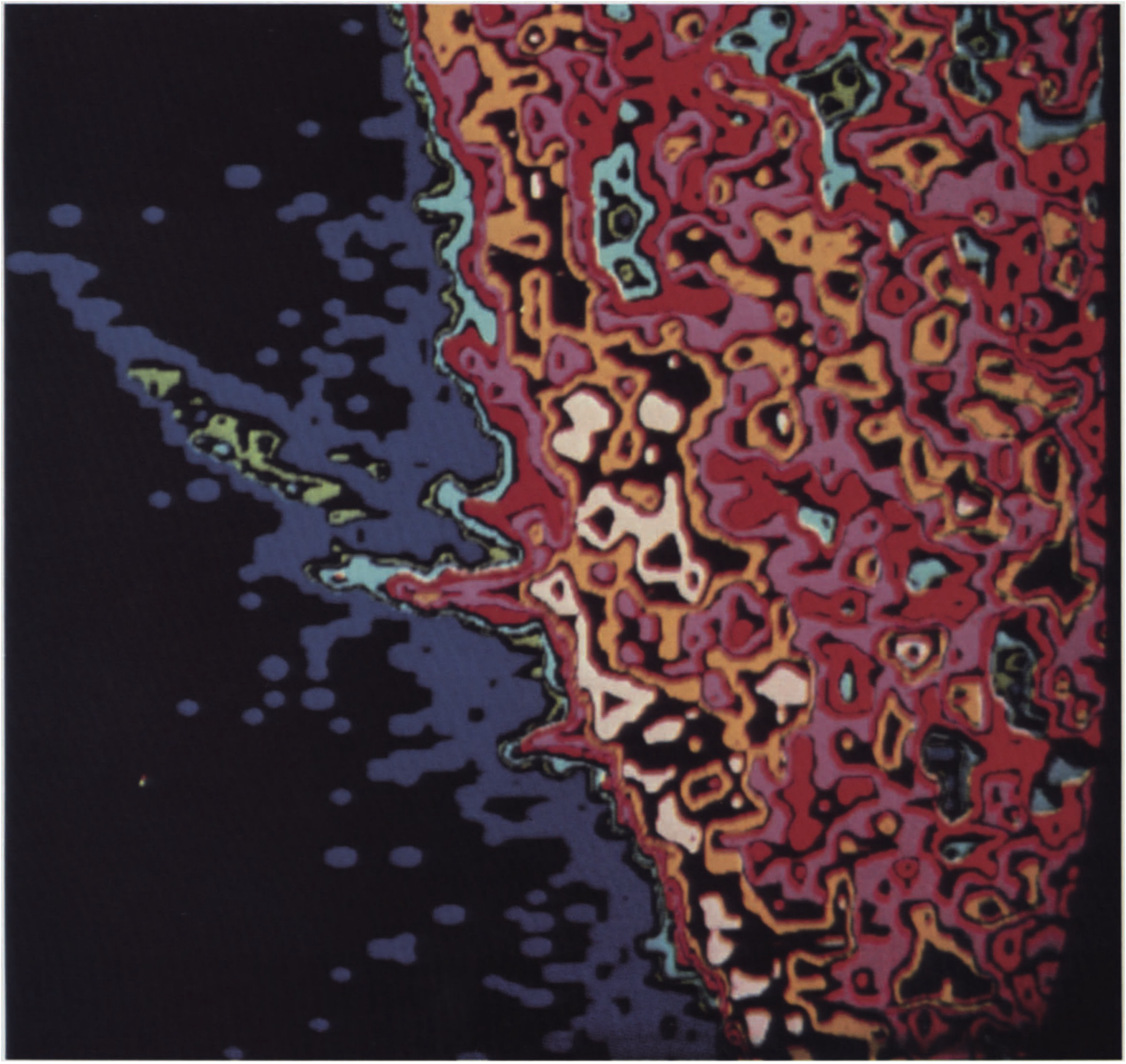


*68 Color computer graphic by John C. Mott-Smith, produced by successive superimposing through color filters of display screen patterns, after a program originally designed for the demonstration of particle motion in force fields*



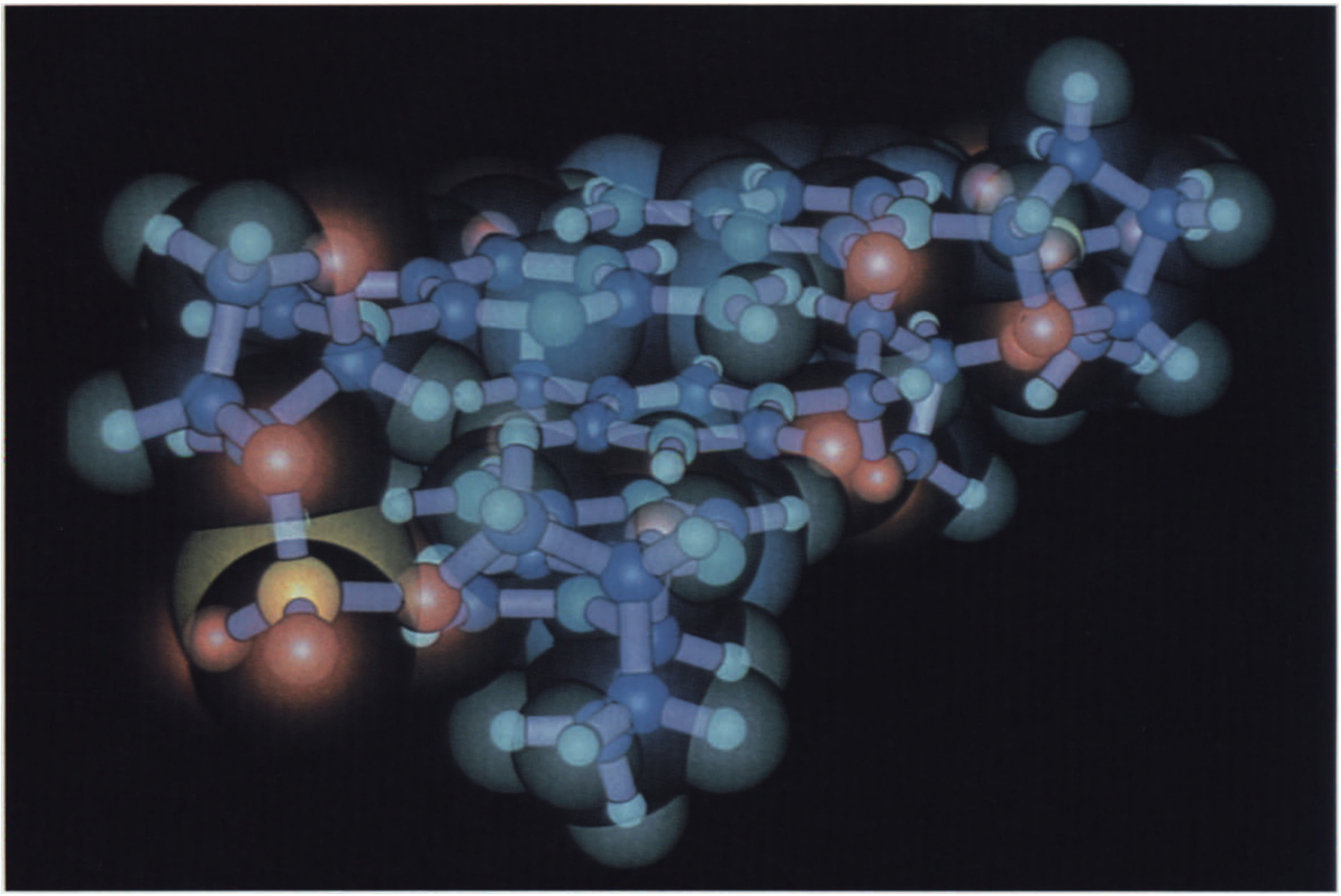
*69* Synthetic Organic Form, *based on a program for visual presentation, Kenneth C. Knowlton*





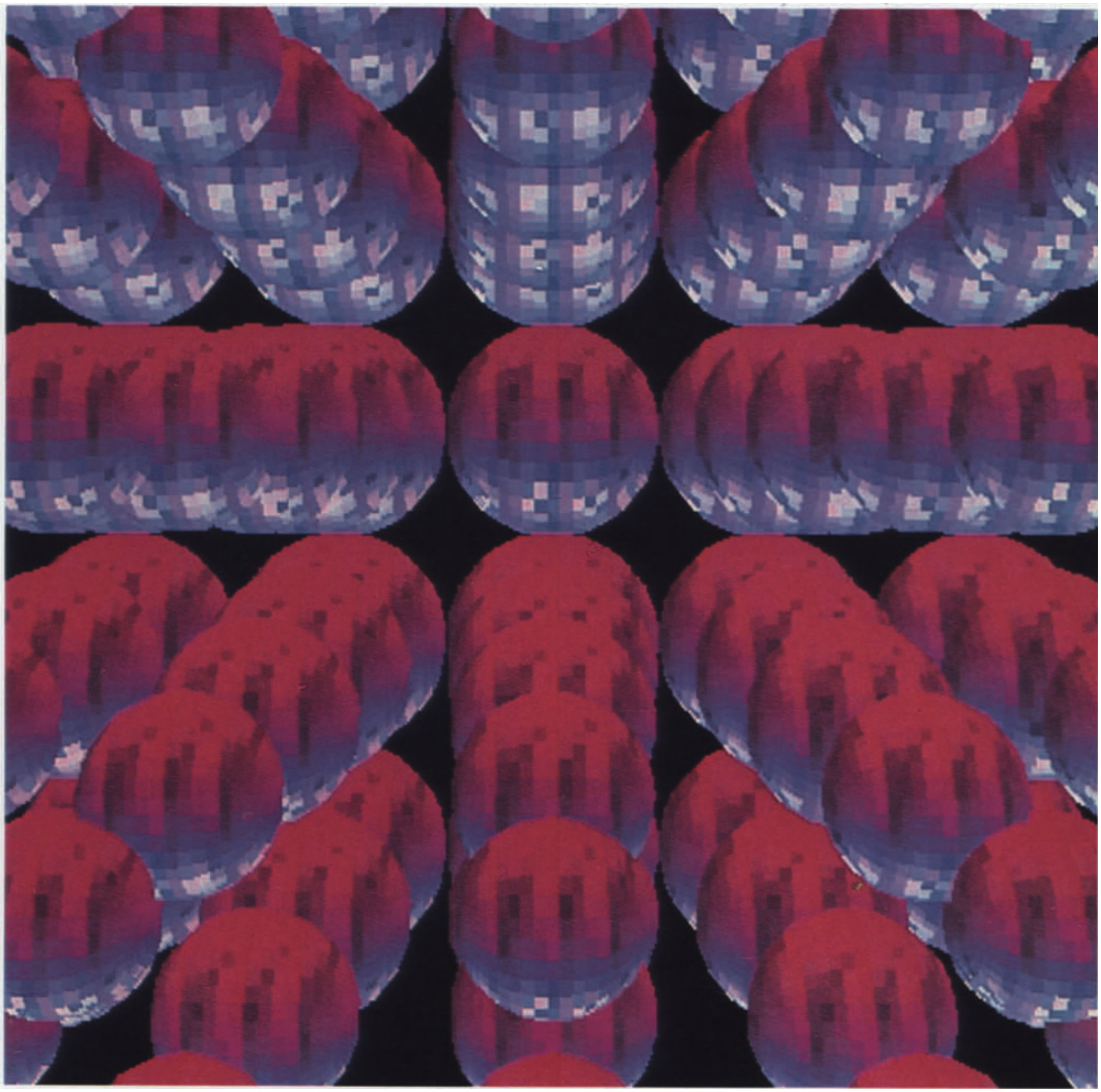
*71 Eruptions on the sun's horizon, recorded on the solar telescope in Skylab, picture processing, USIS*

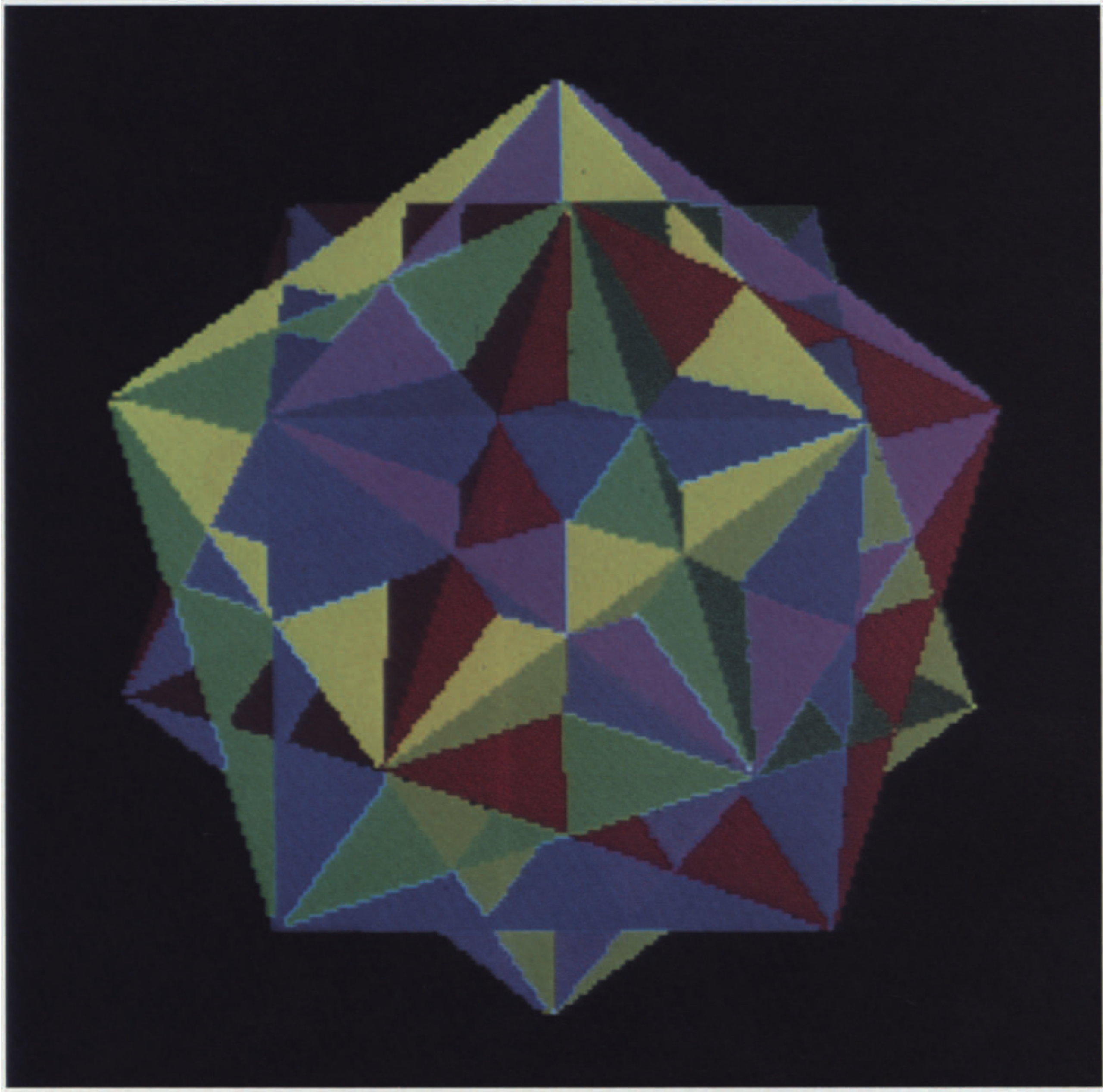
*◁70 Scintigram of liver and spleen, an example of picture processing in medicine, Siemens, SICOGRAPH*

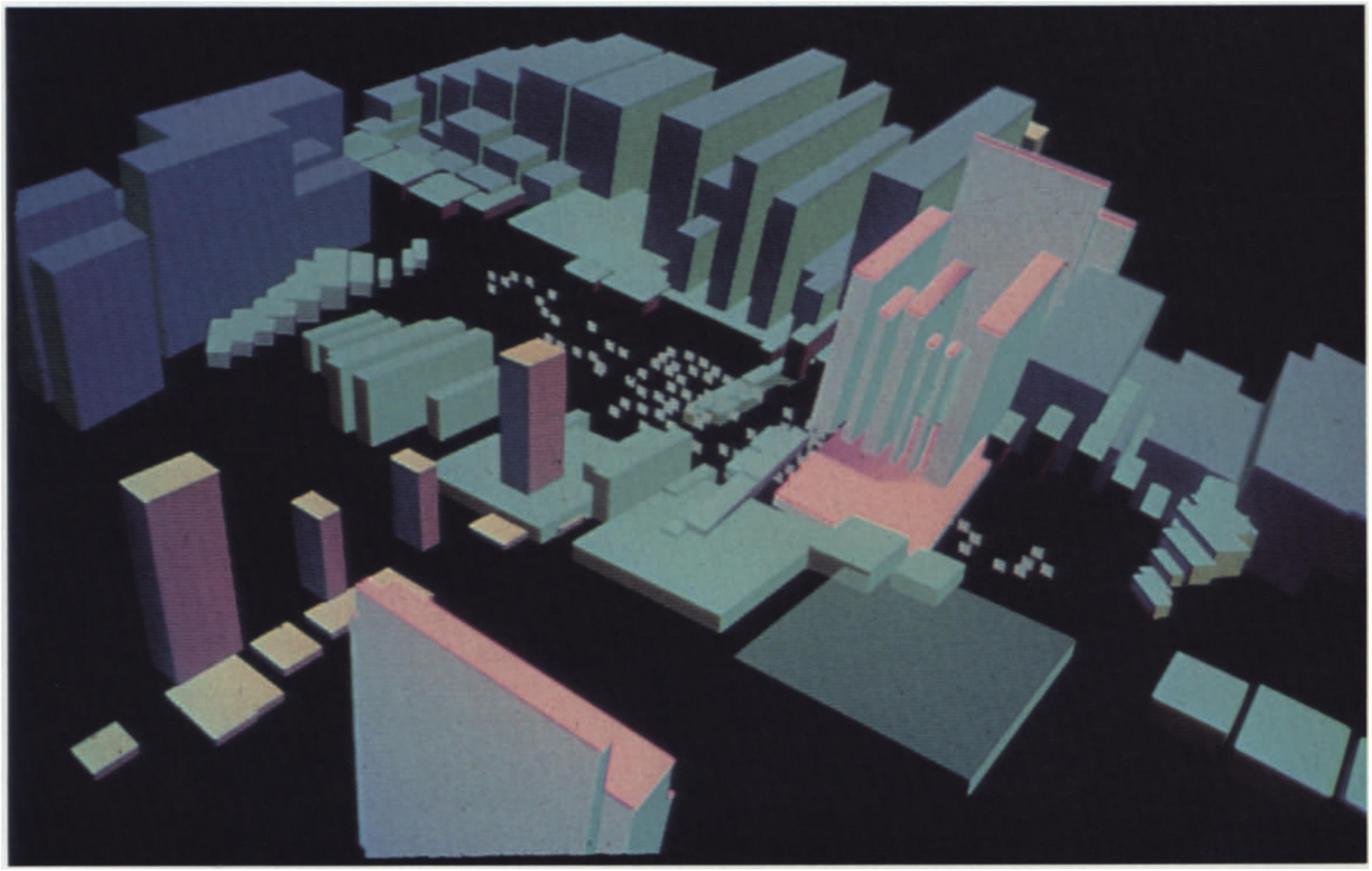


*72 Molecule of an organo-chemical bond, DICOMED D 48, Lawrence Livermore Laboratory*

*73* Sphere Collection, *free composition, Digital Effects Inc., New York* ▷

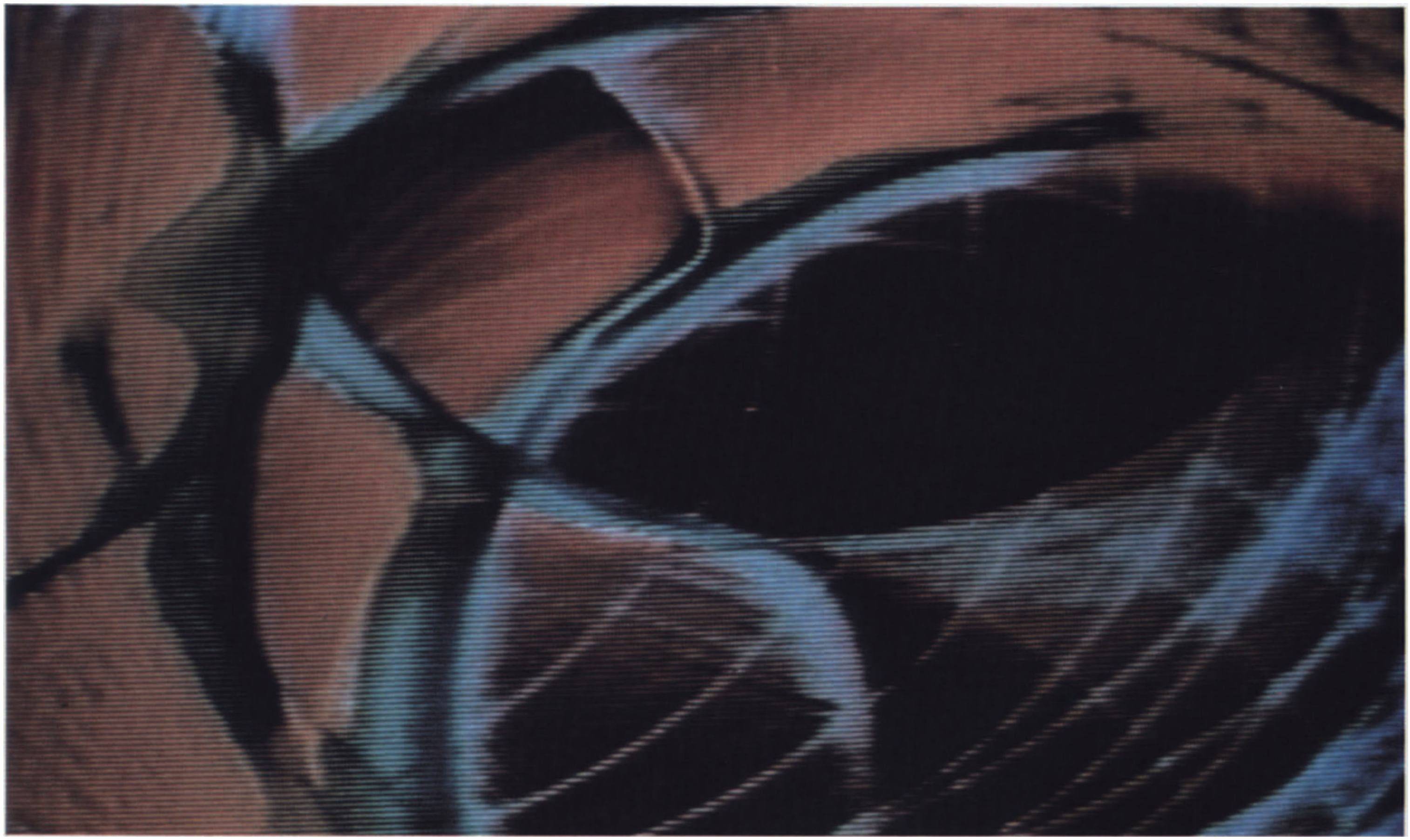




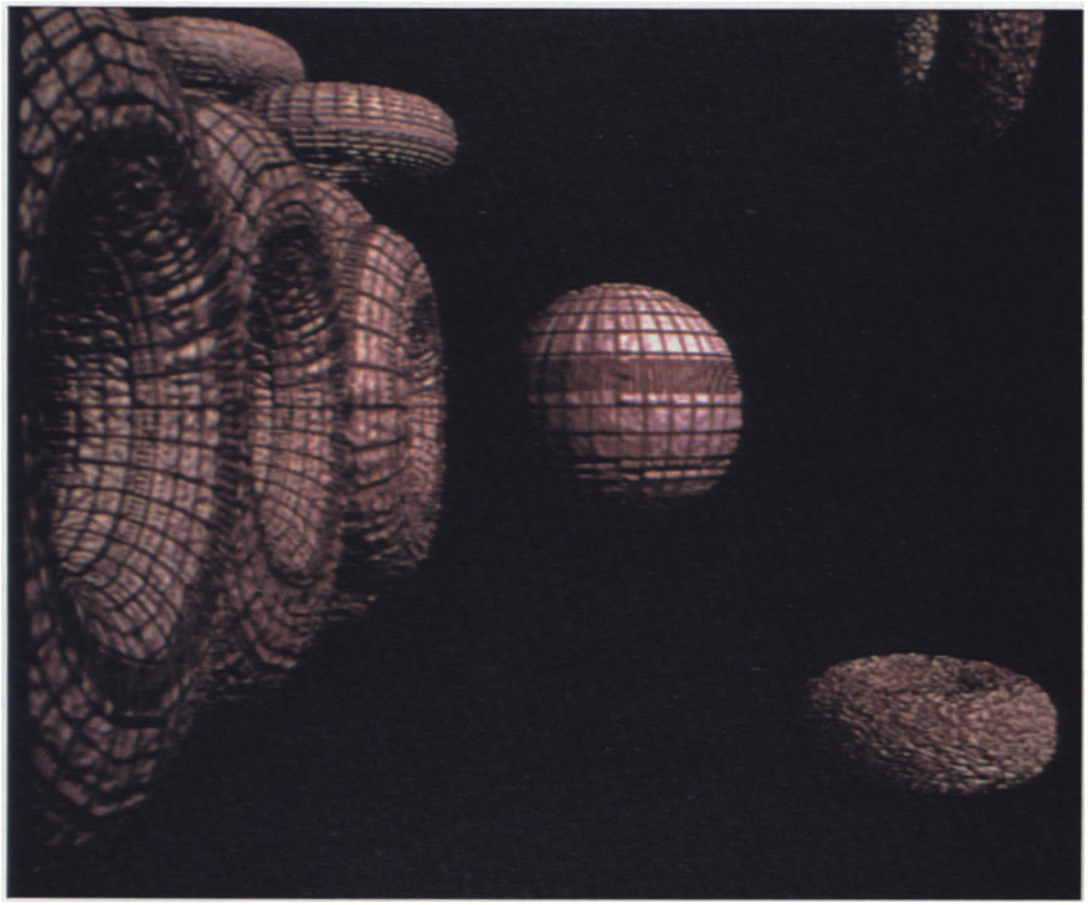


*75* Design for a Fractal Cityscape, *Lee Anderson, School of Architecture, University of Minnesota, and Richard A. Weinberg, Cray Research Inc.*

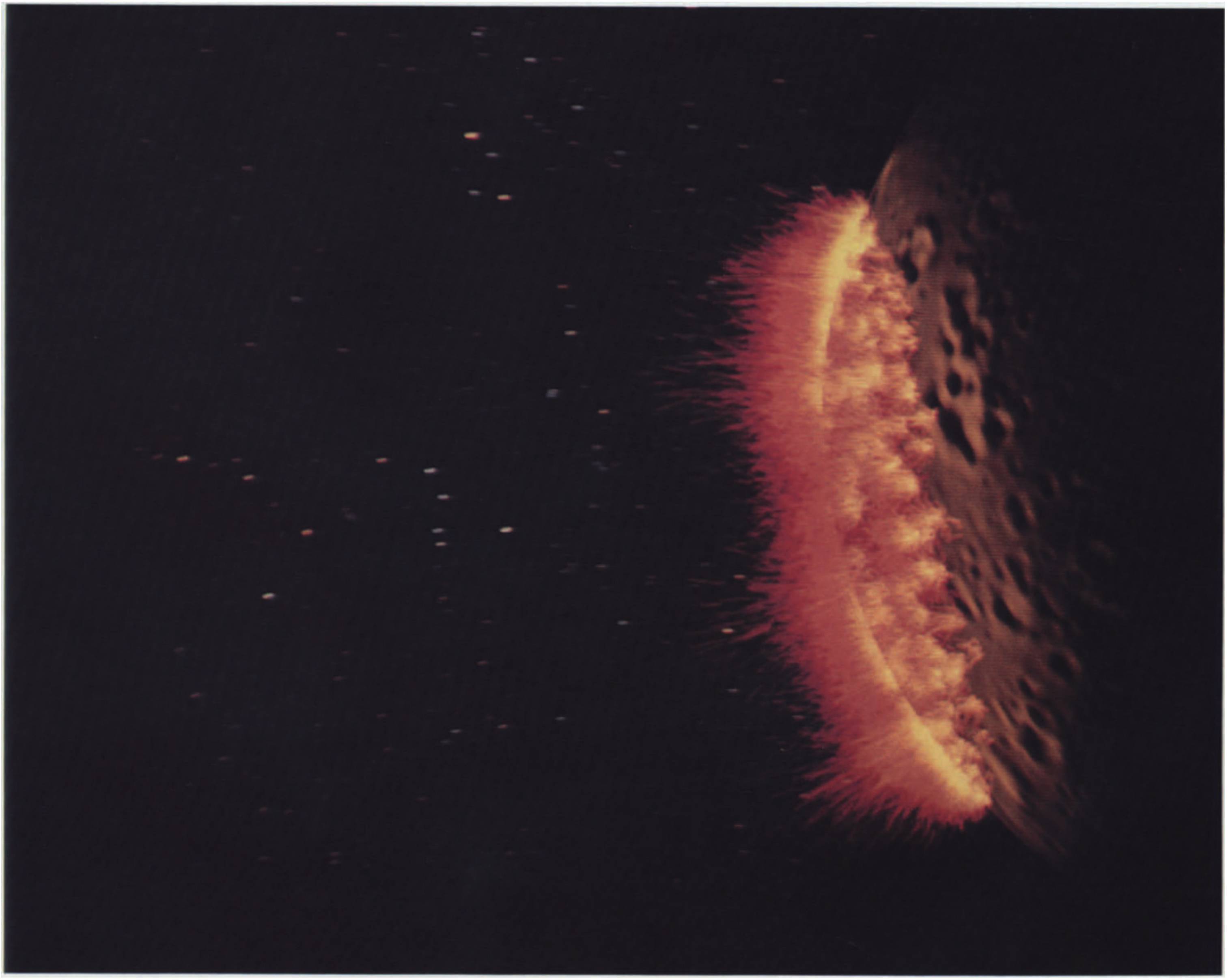
◁ *74* Polyhedral Stellation, *Norman I. Badler, Kathy McKeown and Gary Rathsmill, University of Pennsylvania*



*76 Phase picture of a dynamical sequence, Electronic Visualization Laboratory, University of Illinois at Chicago Circle, Thomas A. DeFanti and B. Sykes*

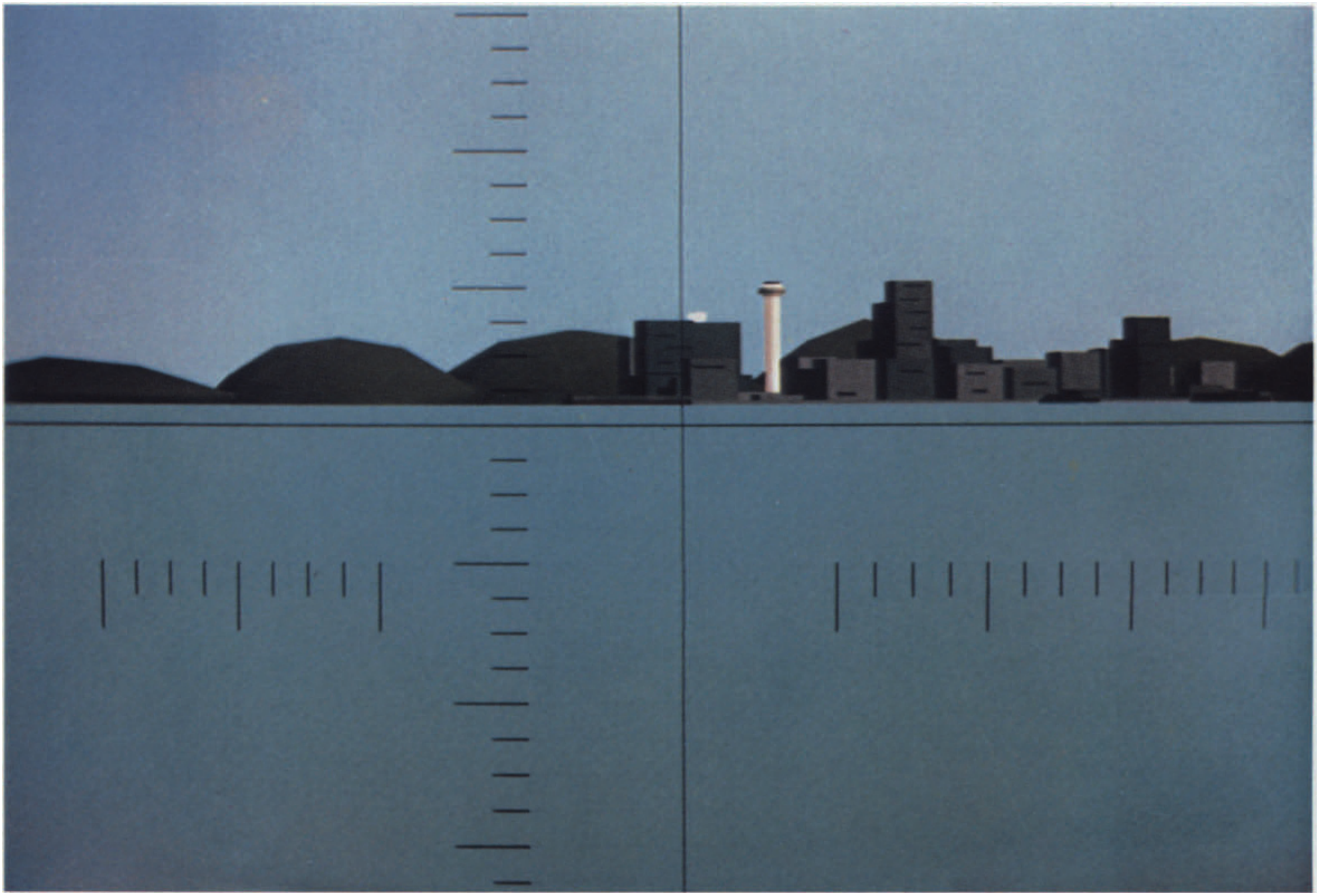


*77* Cosmic Vision *by David Em; software by James Blinn*



*78 Phase picture from* Star Trek II: The Wrath of Khan, *Lucasfilm Ltd.*

*79 Phase picture from* Star Trek II: The Wrath of Khan, *Lucasfilm Ltd.*



*80 Real-time simulation of a landscape for teaching purposes, Link-Division, Singer (see also Fig. 41, p. 49)*

# History of Computer Art

## 1 The Move to Computer Graphics

The general public reacted with surprise to the artistic products of the computer, but in fact these are merely the logical result of a development that is hundreds, indeed thousands of years old.

### Technological Progress

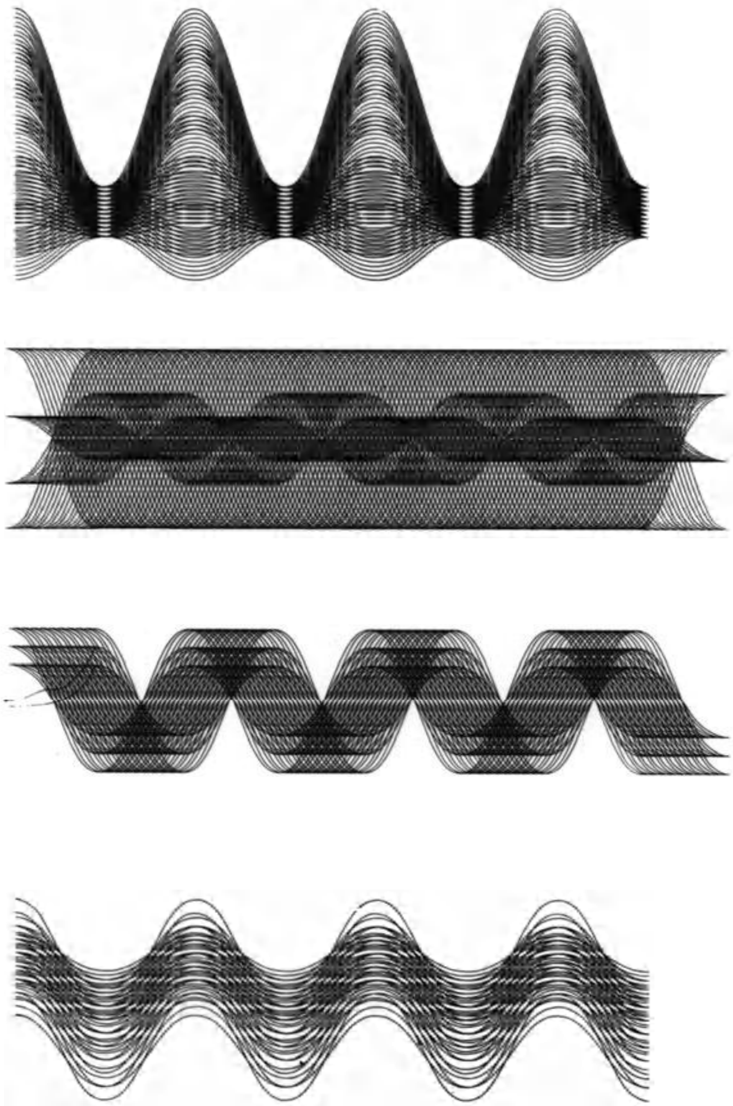
Human evolution is closely bound up with technological change, with the introduction of ever more efficient machines and machine-like systems. An increase in leisure time, which does not have to be used for the immediate needs of life, and the consequent growth of pure science and the arts are among the benefits of this development. These activities, in turn, have often produced impulses that were vital for the further development of mankind. Technical progress proceeds through various steps, and in general goes through these phases:

- handicrafts,
- mechanical mechanization,
- classical physical technology,
- electro-technology,
- electronic automation.

In the course of this development man has succeeded in transferring an increasing share of work to machines: there undoubtedly exists a trend toward the fullest possible mechanization of all activities that can be taken over by machines.
Analogous tendencies have also shown themselves in the arts. Music was the first art accessible to technical progress because sounds can be produced with fairly simple mechanical means - drums and string and wind instruments are known from prehistoric times. It is perhaps this early start which accounts for the absence of taboos on the use of machines in music. Mechanization proceeded via more complicated musical instruments - some of which are highly advanced physical machines - right up to the phase of automation.
Visual, and particularly language patterns, are far less accessible to mechanization. Visualization requires machines of an optical and electronic nature that are far beyond the level of mechanization, and the automation of language requires high-capacity computers of a kind that has not as yet been developed.
The most significant stage on the path to the mechanization of the fine arts has been photography. There have been numerous other experiments in this direction but they failed to achieve popularity. One might refer to the guilloche machine, where a mechanical gear governs the complex motions of a steel stylus; this engraves calligraphic patterns in metal for the production of bank notes, cheques, etc. Particularly in the final years before computer art became known, numerous attempts were made at mechanical pictorial composition; these were largely based on photography in conjunction with mechanical aids. We should mention the "photomechanical transformations" by Hein Gravenhorst, for instance, and the *Lochblendenstrukturen* (shutter structures) by Gottfried Jäger, which are results of a generative photography created in programmed working stages. From here it is but a step to electronic automation and so to the computer.

| | Information-psychological conditions | | Physio-physical conditions |
|---|---|---|---|
| | Information-condition | Redun-dance-condition | |
| Manual art | Man | Man | Man |
| Instrumental art | Man | Man | Physical machine |
| Deterministic computer art | Man | Classical automata | Physical machine |
| Stochastic computer art | Random number generator | Classical automata | Physical machine |

*81 Delegation of aesthetic-creative processes to machines. First of all the physical execution is delegated to machines (for example in musical instruments or guilloche machines), then also the conception of aesthetic orders (classical automata). With probabilistic automata, the random number generators, it finally becomes possible to leave the really creative phase - the generation of information - to the machine*



*82 Oscillating figure by Bruno Sonderegger, built up from sinusoidal curves. They were produced with the CORAGRAPH of the firm of Contraves AG, Zürich, and served as preliminary studies for the design of bank paper for the firm of Joh. Enschede en Zonen, Grafische Inrichtingen, N. V., Haarlem, Holland*

## Calculation Graphics

Mathematically conceived figuration is relatively accessible to mechanized production. Such forms are exceedingly ancient; among them are the ornaments whose geometric shapes, repetitions and symmetry follow rules that can be mathematically formulated. Other milestones in the evolution toward the mathematization of art are all the attempts to express aesthetic structures in mathematical form. Considerations of this kind led the Greeks to found a theory of harmony; in the plastic arts Leonardo da Vinci and Albrecht Dürer were pioneers of similar efforts, and the line leads through Piet Mondrian, Le Corbusier, Victor Vasarely to the adherents of exact aesthetics. The Constructivists and the members of the *Stijl* movement used still relatively simple mathematical relations, such as proportions. Gradually other mathematical rules were introduced like those of permutation; there are well-known works of this kind by Alvir Mavignier and Klaus Basset. Finally there are the manually produced works which are based on programs that could easily be realized through the computer, e.g. the butterfly forms by Hermann Stiegler.

The aim of many supporters of constructivist tendencies - a rejection of the personal element; a crystal-clear, objective presentation; the maximum precision - can be realized by the computer in a hitherto unparalleled degree. A further essential advantage is of course the considerable saving in time afforded by the machine. But the computer does not merely lead to a reduction of labor - it also opens up entirely new prospects. Mathematical curves of a higher order are for many reasons aesthetically more appealing than straight lines and circles, which the Constructivists realized with rulers and compasses - i.e. with the aid of tools - and which they frequently used in their work as pictorial elements. Such curves need not be cut off arbitrarily at the edge of the drawing surface, but can be led to closed figurations. And besides, the variety which they offer is far greater than that of straight lines and circles.

Single curves of a higher order can be drawn by hand with a certain effort. But it is practically impossible to combine many different, perhaps successively modified curves to complex formations. But it is only through this kind of coordination, superimposition or symmetrical relation that we obtain that wealth of coordinated relations which are the starting points of the perceptual processes. As will be established later, one of the fundamental effects of art is based on this. The precision reached through the computer brings graphics close to classical music, which is also based on highly complex order-structures.

## Alienated Science

There is yet a third development which leads logically to computer graphics. Its distinguishing characteristic is that one begins to see everyday objects, which bear no apparent relation to art, as aesthetic forms. A pioneer of this approach is Ernst Haeckel, who coined the term *art forms of nature*. The discovery of the beauty of scientific structures is a corresponding activity; Wilhelm Ostwald and Ferdinand Runge have initiated this direction. Among contemporary scientists who emphasize the aesthetic aspects of their research objects are Adolf Portmann and Horst Reumuth.

The discovery of beauty in fields outside art implies an active engagement with aesthetic concepts and values, but falls short of the creative act - the overriding aim in the production of scientific pictures being to obtain information in a particular field.

The boundaries only begin to be blurred when investigators approach a scientific medium with sheer pleasure in graphic experimentation and when, discarding professional ends, they begin to manipulate structures in conformity with aesthetic notions. Wilhelm Stürmer and Manfred Kage have given examples: crystal graphics, products of directed crystal growth, whose multifarious colors are revealed through the polarization microscope. Hans Jenny developed *Cymatics* - a play of forms with vibrating substances.

A milestone in this development was the book *foto-auge* by Franz Roh, published around 1930. He was the first to see photographs of medical diagnostics, astronomy, aerial photography etc. as aesthetic objects; his book includes examples of scientific photographs regarded as purely aesthetic images. This shift of attitudes has also taken place in computer graphics, which was after all originally a result of scientific and technical aims.

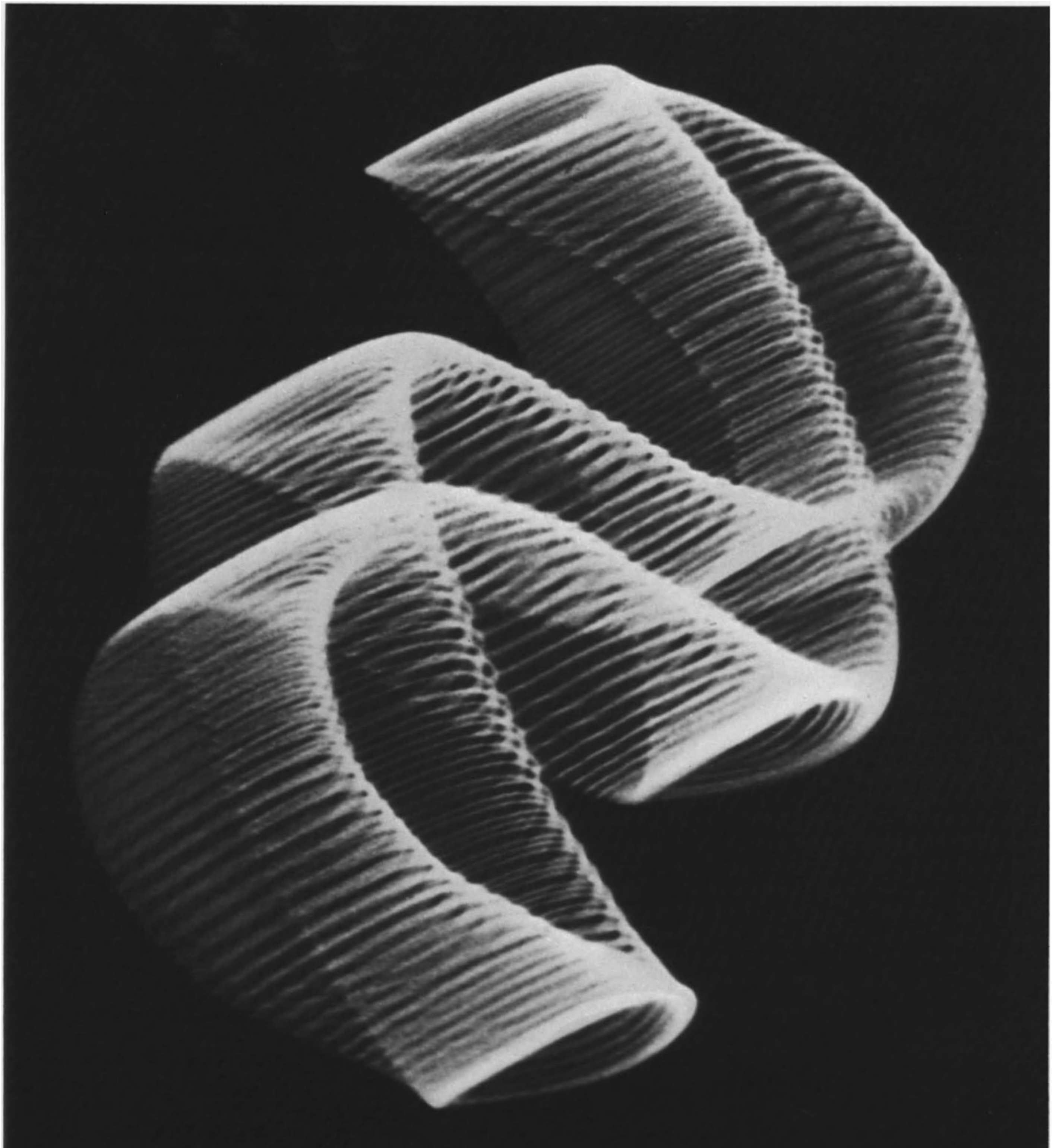
Among the first drawings entered for exhibitions or competitions there were some that were made without any aesthetic intentions. Representations of geometric spatial surfaces or of electrical fields are typical cases. Probably the best known are the human figures which William A. Fetter made the computer draw as studies of ergonomic problems (see Figs. 88 and 89, pp. 102, 103).

Computer graphics originating in alienated scientific or technical programs are encountered even more frequently. Quite often it only requires a minor intervention - the establishing of symmetry or of a superimposition effect - to turn a scientific structure into an aesthetic form. An example can be found in the work by John C. Mott-Smith, who designed his computer graphics with the aid of a program for the simulation of particle motions (see Fig. 68, p. 80).

A complete dissolution of the boundaries between science and art takes place where computer graphics are made for the purposes of experimental aesthetics, that is, as aids in the theory of art. Here it is particularly difficult to define any limits: any computer graphic can be classed as a contribution to the investigation of aesthetic perception processes. Even if this was not the present author's original intention, by giving a logical explanation of the formation scheme he is in fact preparing the ground for scientific investigation.

## 2 The Beginning of Computer Graphics

Mathematicians and scientists were aware of the graphic fascination of Lissajous figures (see, for example Figs. 11/12, pp. 14, 15) even before cathode ray oscilloscopes existed, and these instruments were used for aesthetic experiments well before the concept of computer art emerged. Maughan S. Mason, one of the earliest computer artists, found inspiration for his graphic experiments in pendulum motions. Lissajous figures from digital computers were made by R. K. Mitchell of the Batelle Memorial Institute, Columbus, Ohio, as well as by Ivan L. Finkle of the Rand Corporation, Santa Monica, California. The idea of using such effects for design purposes - wallpaper for instance - goes back some way. According to information from Ben F. Laposky, C. Burnett was the first to propose this kind of application for



◁ *83* Oscillon 7 *by Ben F. Laposky, generated with an analogue system, made visible on a CRT; one of the first analogue graphics*

Lissajous figures as early as 1937. A patent for similar purposes was granted to G. H. Hille in Germany at a later date. Some further information from Leslie Mezei is worth mentioning in this context: in 1958 A. P. Rich of the Applied Physics Laboratory, Johns Hopkins University, wrote a program for the design of wave patterns for textiles. And in 1963, system for designs were developed at the Massachusetts Institute of Technology.

Ben F. Laposky provided the first major initiative, and thus the origin of graphics generated by means of electronic machines and computer installations. His work, which commenced in 1950, is based on the superimposition of electrical oscillations of varying time functions, for instance sine waves, sawtooth curves, or square waves, which were led to the deflector plates of a cathode ray oscilloscope. In this way the figurative variation width of the oscillating figures is enormously increased. Even today, the images generated by Laposky, which he termed *oscillons* or *electronic abstractions,* remain consummate achievements, and even with contemporary instruments, a substantial improvement is hardly conceivable. Laposky exhibited his works for the first time in the Sanford Museum in Cherokee, Iowa, and subsequently in more than one hundred other cities in the USA. Since 1956 Laposky has turned to what would now be termed colored analogue graphics. He adds rotating color filters before the display screen. Laposky has also done pioneering work with film.

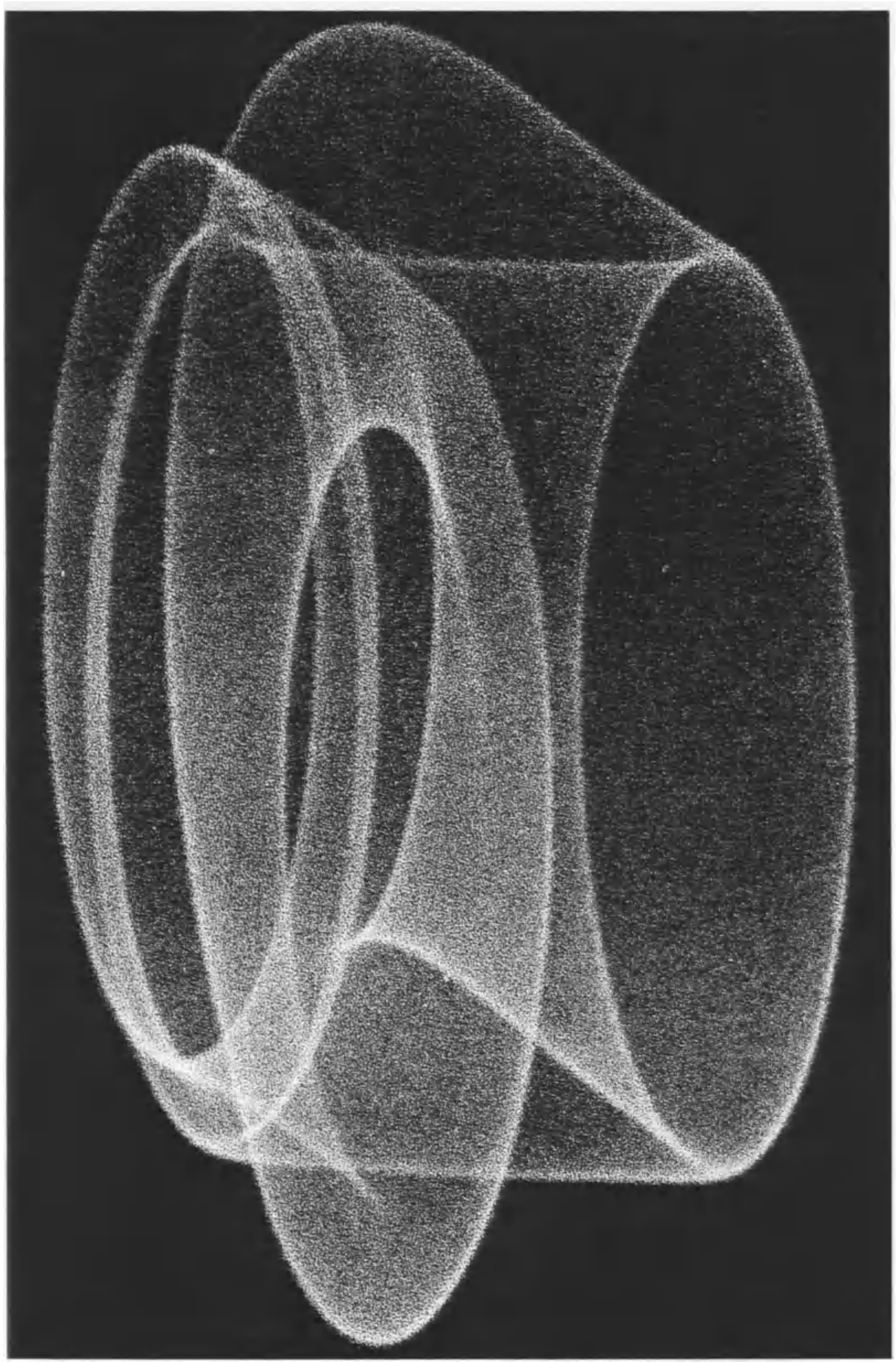
In Europe, analogue graphics from cathode ray oscilloscopes became known mainly through the exhibition *Elektronische Graphik,* which was shown partly on its own, and partly in the framework of the *Experimentelle Ästhetik* exhibition in Germany, Austria, Britain and Switzerland; the exhibition opened in January 1959 in the Museum für Angewandte Kunst, Vienna. These works, known as *oscillograms* or *electronic graphics,* were developed by the author from 1956 and originated in a similar way to the works by Laposky. The superimposition of the voltage forms occurs through a master control, and the voltages can be put through calculation switches which permit operations such as multiplication or integration. The master control was constructed by the Viennese physicist Franz Raimann.

In 1960 Kurd Alsleben, in collaboration with Cord Passow, started to make drawings by means of an analogue system and a mechanical drawing installation. The results are the graphic expression of a differential equation which has been changed through variations of the parameters or through the lock-on of statistical disturbance. The first aesthetic computer graphics to be made with the help of large digital computers became known in 1963. They were pioneered by the periodical *Computers and Automation,* which announced in 1963 the first competition for computer graphic works, where the selection was based on aesthetic considerations. There was little response at first, but nonetheless the editors in their August number awarded prizes to two works submitted by the Ballistic Research Laboratories, Aberdeen, Maryland; these works can still be regarded as outstandingly successful examples of digital graphics. Ever since, the competition has been repeated each year and the best works are published in the August number. From 1963 to 1966 the first prize winners were:

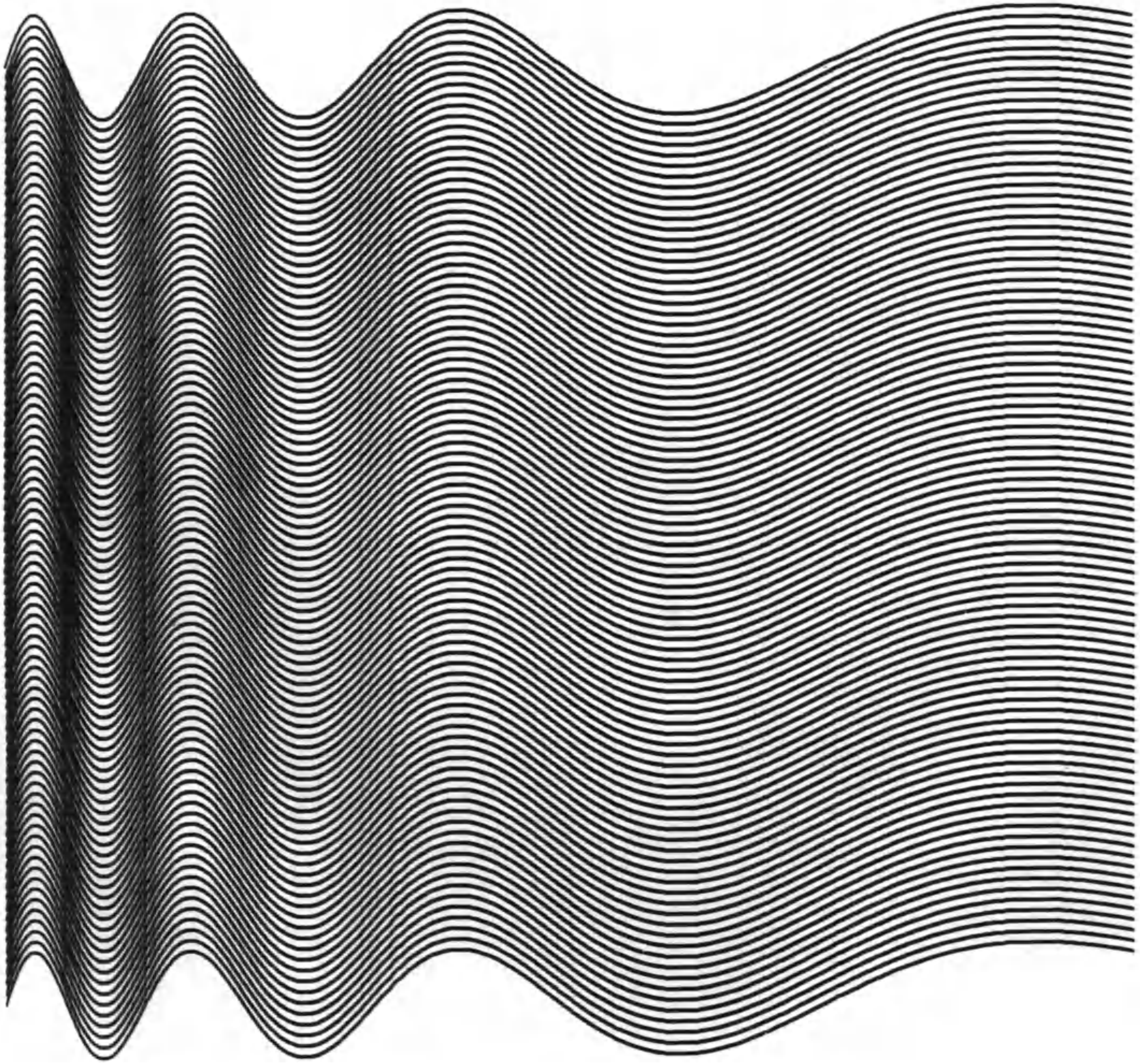
1963: US Army Ballistic Missile Research Laboratories, Aberdeen, Maryland, with *Splatter Pattern.*
1964: US Army Ballistic Missile Research Laboratories, with *Trajectories of a Ricocheting Projectile.*
1965: A. Michael Noll, with *Computer Composition with Lines.*
1966: Frieder Nake, with *Composition with Squares.*

Computer graphics became more generally known in 1965. Three mathematicians had started at the same time to work systematically on the development of aesthetic computer graphics using digital computers: two Germans, Frieder Nake (see Fig. 58, p. 70) and Georg Nees, and the American A. Michael Noll. Nees arranged the first exhibition in January 1965 in the Studio Gallery of the Technische Hochschule (now University) in Stuttgart, in Max Bense's institute. In the same year Nees had a joint exhibition with Frieder Nake in the Niedlichs Galerie, Stuttgart. In 1966 P. Hartwig showed his digital graphics for the first time; in November of that year he exhibited with Kurd Alsleben, Frieder Nake and Georg Nees in the *Galerie d,* Frankfurt am Main.

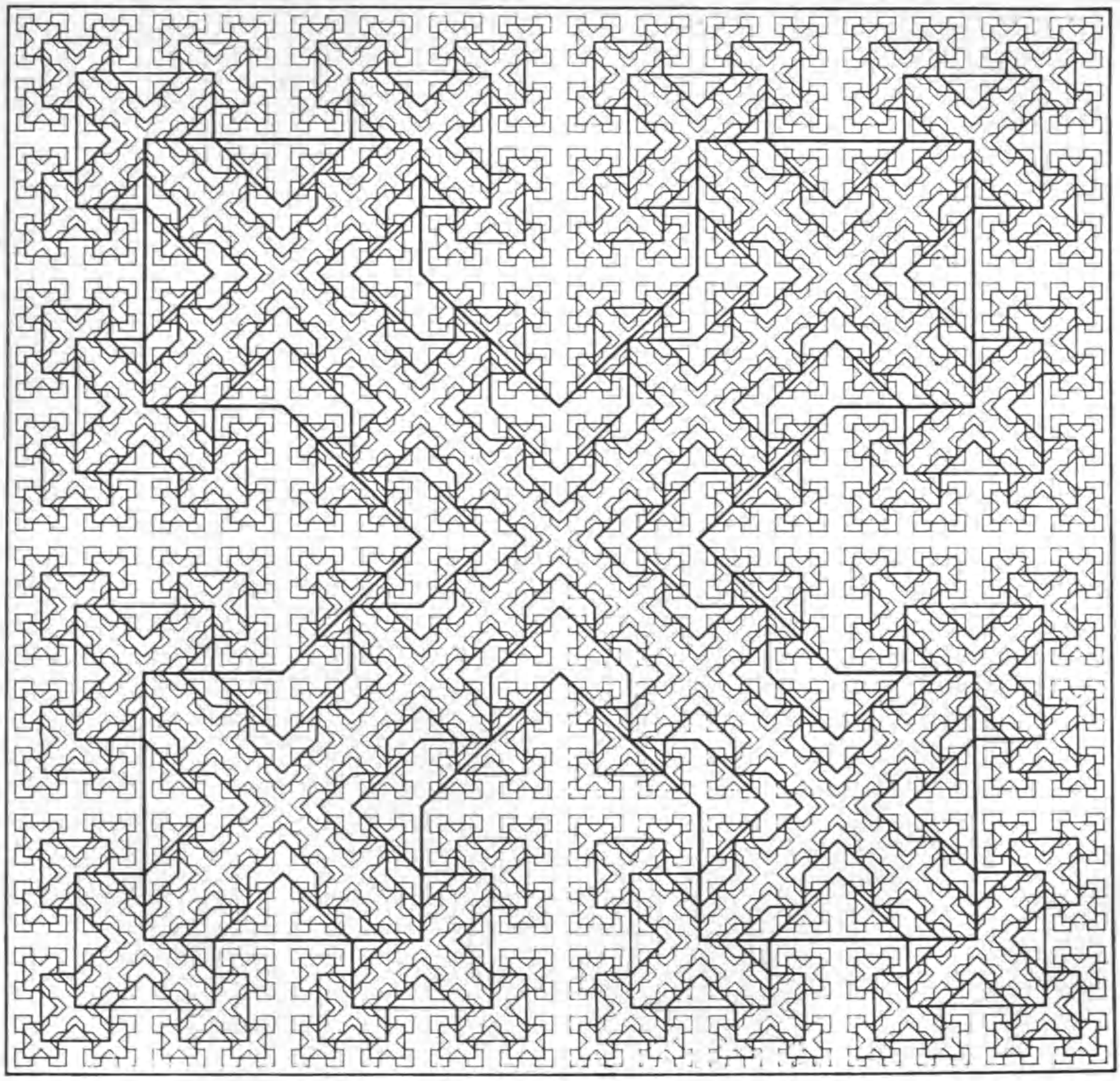
The year 1965 also witnessed the first exhibition of digital graphics in the USA; this took place at the Howard Wise Gallery, New York, in April – only a few weeks after the first show by Georg Nees. The title was *World Exhibition of Computer Graphics* and it consisted of works by A. Michael Noll and Bela Julesz.



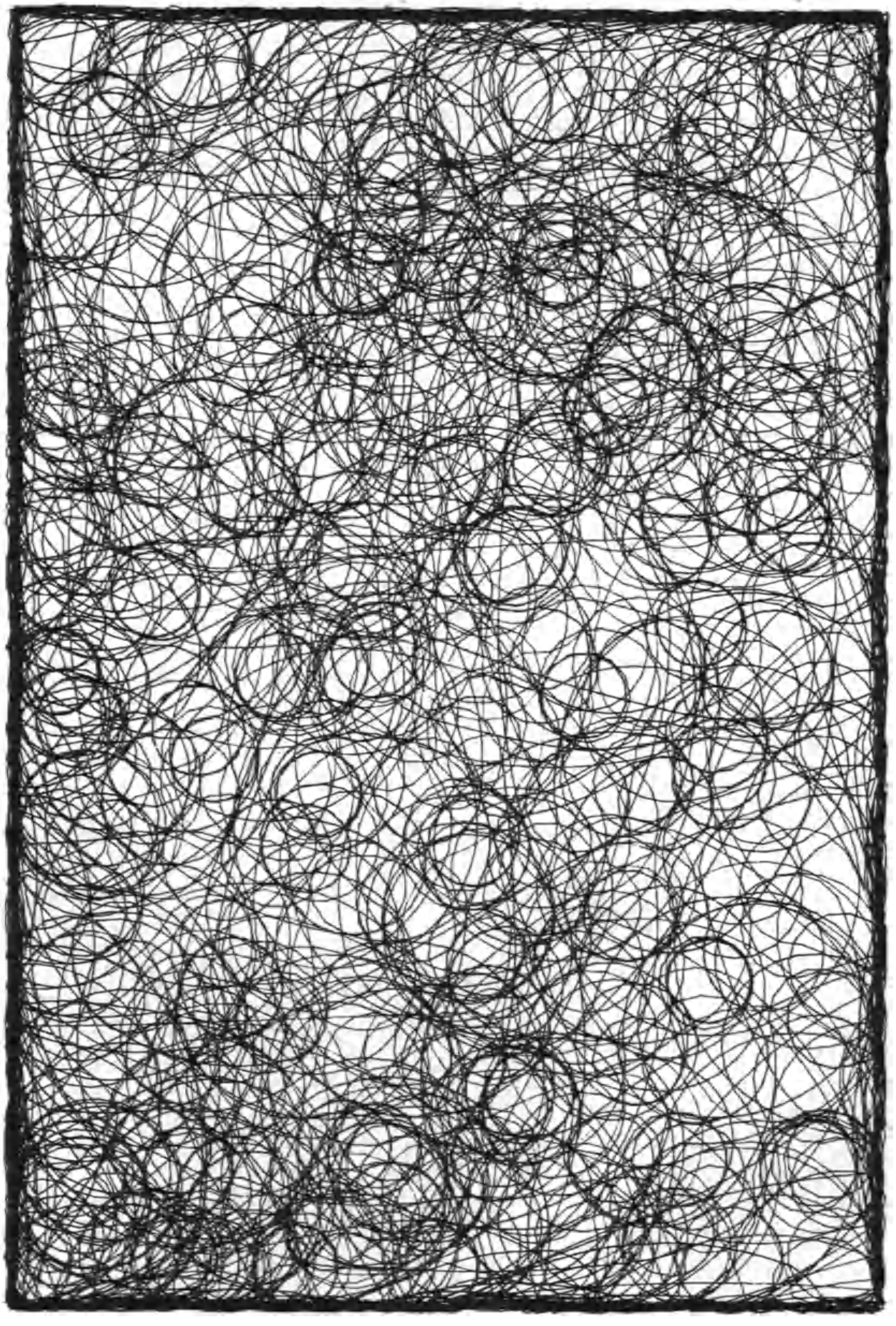
◁ *84 Electronic graphic by Herbert W. Franke, created with the aid of an analogue computer system and a cathode ray oscilloscope. Various voltage forms as found in voltage generators - sine curves, sawtooth curves and so on - served as elements. The voltage forms were produced with a Siemens demonstration model. The individual voltage forms were used in two channels, corresponding to the ordinate and abscissa of the flat representation. The elementary forms were computed in an electrical aggregate in various ways: by addition, subtraction, integration, differentiation, etc. The manipulation took place in a master control. The designer of this system is the Viennese physicist Franz Raimann. These configurations are not usually produced as still pictures but as events; the graphic is a phase picture of such an event*



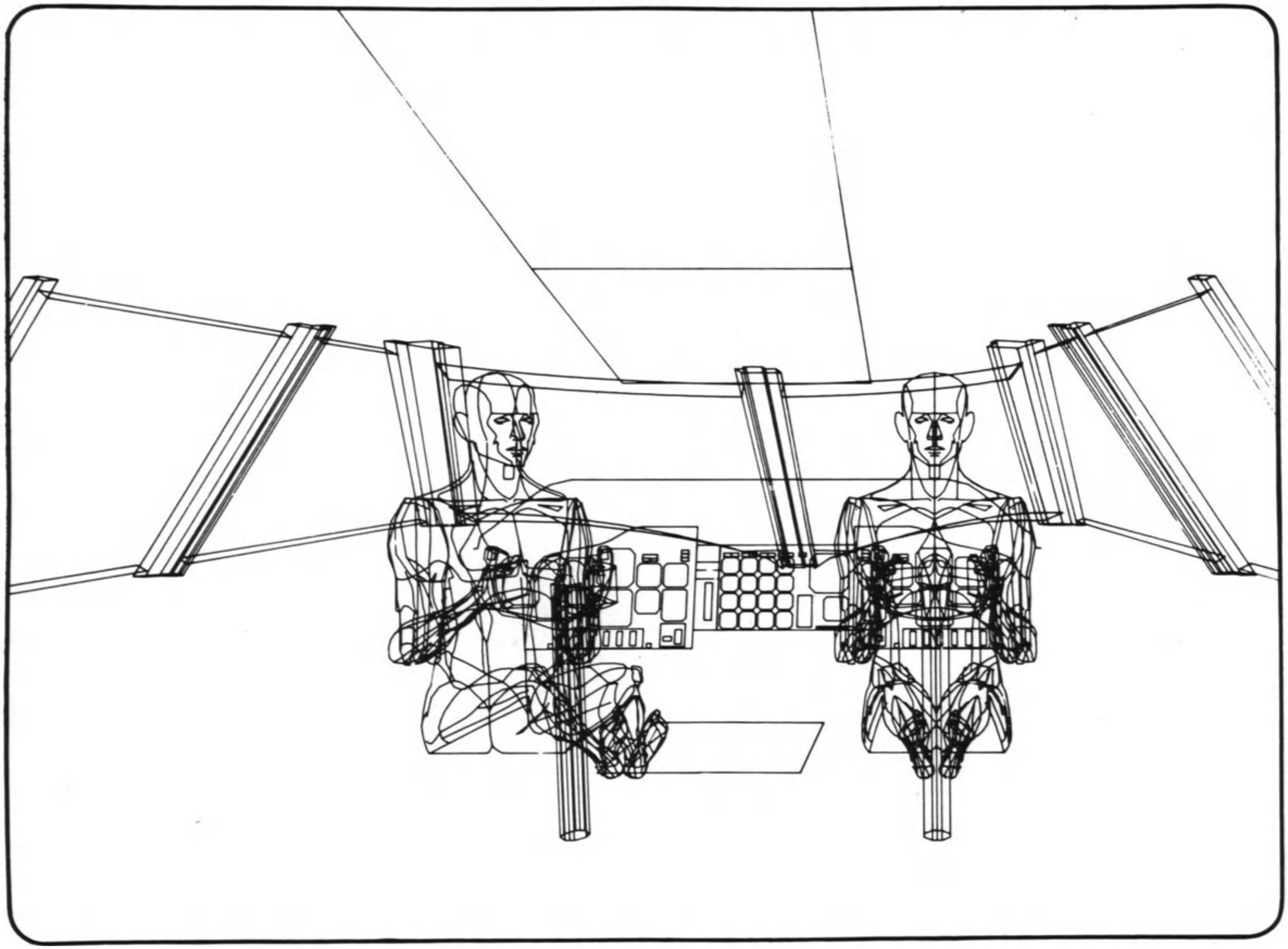
*85* Waveform *by A. Michael Noll. A representation which utilizes the irritation effect of repeated line patterns in the manner of op art (© A. Michael Noll 1965)*



*86* Stained Glass Window, *author not named. One of the first digital computer graphics made as an exercise in aesthetics. Generated on the principle of the "snow-flake curve" with a data plotter. This work was submitted by the US Army Ballistic Research Laboratory in the first computer art contest of the magazine* Computers and Automation *in 1963, and was awarded the second prize*



*87* Locks *by Georg Nees. Superimposed circular arcs*

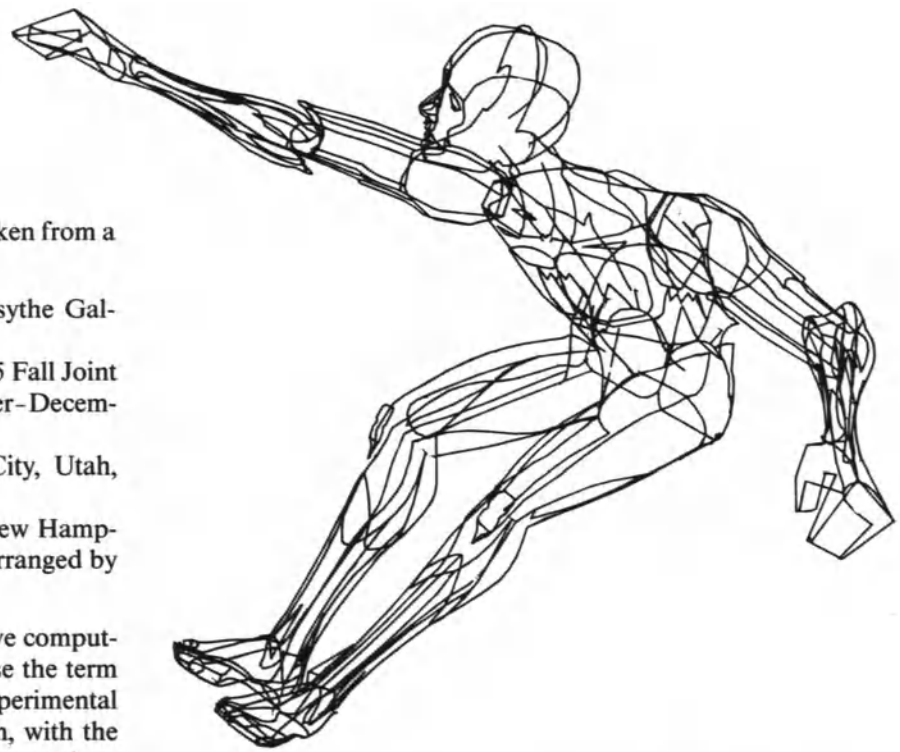


*88 Computer drawing by William A. Fetter. The task was to design an aeroplane cockpit so as to give the pilot the maximum freedom of movement*

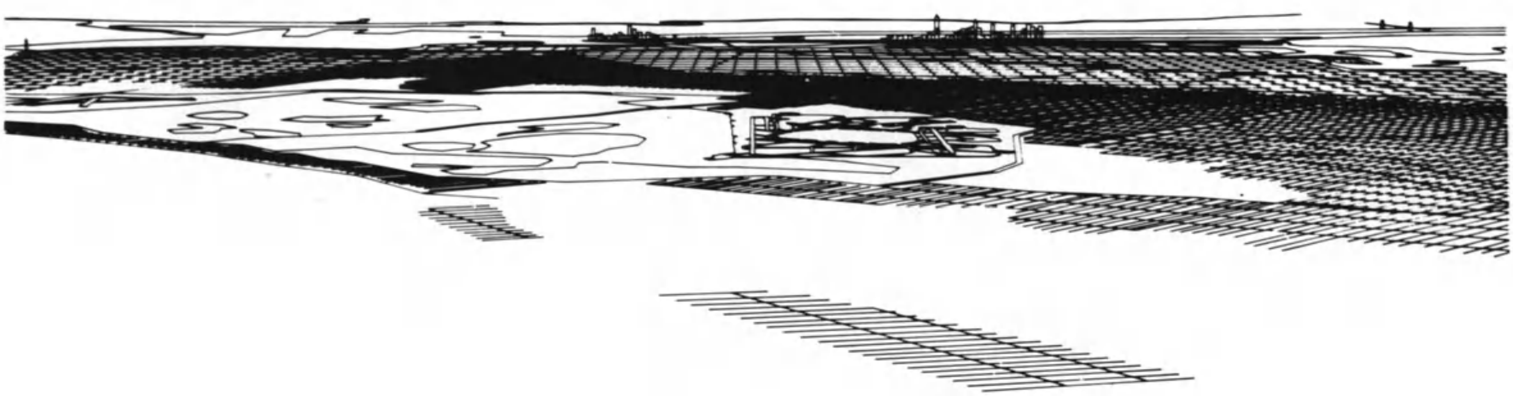
The following important exhibitions in the USA are taken from a list compiled by Leslie Mezei:

W. Gale Biggs, Fred V. Brock, Paul R. Harrison: Forsythe Gallery, Ann Arbor, Michigan, April-May 1965;
Maughan S. Mason, Bela Julesz, A. Michael Noll: 1965 Fall Joint Computer Conference, Las Vegas, Nevada, November-December 1965;
Maughan S. Mason: Salt Lake Center, Salt Lake City, Utah, April-May 1966;
Maughan S. Mason: Dartmouth College, Hanover, New Hampshire, November-December 1966; a traveling show arranged by the Western Association of Art Museums.

The USA also produced the first examples of figurative computer graphics. William A. Fetter, who was the first to use the term *computer graphics,* created an extensive series of experimental works for the Boeing Company, Renton, Washington, with the aim of determining the most efficient layout of an aeroplane cockpit. He designed a program with the aid of which plotter drawings of people in various positions and perspectives were generated, and he also produced drawings to represent different views of an airport as seen by a pilot about to land.



*89 Another example from the series of drawings by William A. Fetter for the most efficient design of a cockpit. The figure of the pilot was programmed in such a way that all possible positions which accord with his bodily proportions could be represented (see Fig. 88)*



*90 Computer drawing of the landing apron of an airport by William A. Fetter, for the study of approach conditions that can be represented in various perspective views*

◁ *91* Sine Curve Man *by Charles Csuri and James Shaffer. Representation of a human face through the combination of sine curves. This picture was awarded the first prize in the 1967 computer art contest of the magazine* Computers and Automation

Although these works had strictly scientific purposes in the first place, their aesthetic aspects were so striking that they have always been seen in the context of computer art.

Figurative computer graphics having purely artistic purposes resulted from the collaboration of Charles Csuri, Professor of Art, Ohio State University, and James Shaffer, a programmer at the same institution. Their departure point was figuration - faces, for instance - submitted to complex mathematical procedures. Through this work they succeeded in focussing attention on the abundant possibilities inherent in the computer to aid pictorial modifications - abstractions, successive destructuring, etc. The *Computers and Automation* computer art contest for 1967 was won by Csuri and Shaffer with their picture *Sine Curve Man* (see also Figs. 45 and 47, p. 54).

Their methods brought them close to picture processing, the goal of which is slanted toward real forms. Here we must mention above all the pioneering work of Kenneth C. Knowlton, Manfred R. Schroeder and others at the Bell Telephone Laboratories (see, for example Figs. 60, p. 72, and 69, p. 81). Their experimental series established guidelines for representative computer graphics.

### 3 International Exhibitions

*Cybernetic Serendipity,* an exhibition suggested by Max Bense and organized by Jasia Reichardt, took place in London in 1968 and aroused world-wide interest for computer art and especially for computer graphics. Here was brought together for the first time everything which had till then appeared in the field of computer-aesthetic efforts. All the pioneers of computer graphics were represented, and in addition there was an extensive lecture program, as well as performances of music and films.

In the same year the Museum of Modern Art in Zagreb arranged a smaller exhibition of computer graphics. Up to that time, the interest of the organizing committee under the direction of Boris Kelemen was focussed on op art; the gravitation toward computer art was a natural consequence of this interest. The conference associated with this small show in the autumn of 1968 served for the preparation of the international symposium *Computers and Visual Research* and a large exhibition, entitled *Tendencija 4,* of op art and computer graphics in the spring of 1969.

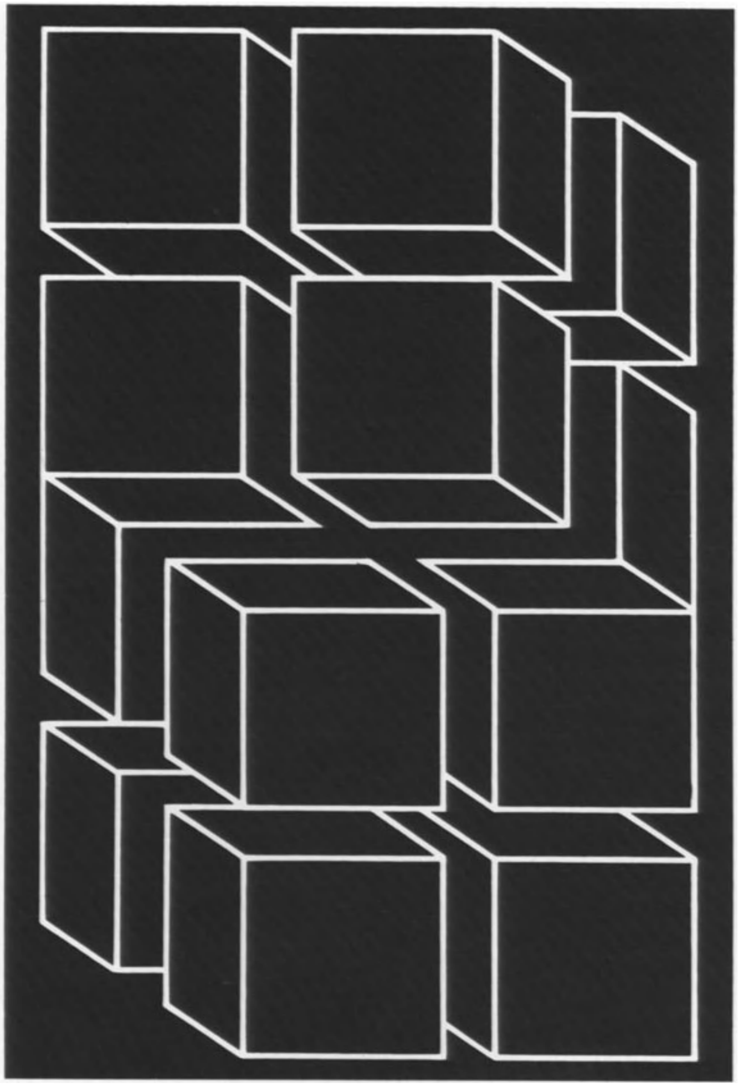
A significant contribution toward the popularization of computer art in central Europe, and particularly in Germany, was made by the exhibition *Computerkunst - On the Eve of Tomorrow,* arranged by Käthe Schröder in Hanover in 1969, and subsequently transferred to Munich and Hamburg. In the following years it was shown in various places including Oslo, Brussels, Rome and Tokyo, under the aegis of the Goethe-Institut.

From the outset, exhibitions of computer art have been associated with lectures and discussions to a greater extent than art events of a traditional nature. Many were linked with conferences, for example the exhibition *On the Path to Computer Art* by the *parallel* group, which took place in Berlin in the summer of 1968 at the same time as the joint summer conference of the Massachusetts Institute of Technology and the Technical University, Berlin. This show contained computer-generated works of art as well as examples of their forerunners: mathematically and mechanically produced graphics. It was later shown in more than 150 towns and cities all over the world, also under the aegis of the Goethe-Institut.

The conferences largely devoted to computer graphics and also covering aesthetic aspects include the symposium of the Dutch *Werkgroep voor Computers en Woord, Beeld en Geluid,* which took place in Delft and Amsterdam in March 1970; the international symposium *Computer Graphics 70* at Brunel University, Uxbridge, England, in April 1970; and the *International Conference on Systems, Networks and Computers* arranged by IEEE in Oaxtepec, Mexico, in January 1971.

In 1970, the Mathematical Institute of the University of Madrid arranged an exhibition in conjunction with a seminar called *Generación automática de formas plásticas.* Spanish constructivists in particular, among others Manuel Barbadillo, José Luis Gómez Perales, Eusebio Sempere, Gerardo Delgado, José M. Yturralde, and Soledad Seville had been invited to participate. The cooperation of the artists with the computer scientists of the institute, initiated by its director E. García Camarero, was continued for some time. In 1970, a similar event - exhibition and seminar - took place with international participation.

Similar efforts to bring artists and mathematicians together were



*92 An example from a series of computer-generated "impossible perspective" figures by José María Yturralde*

also made in South America. The first impulse came from Waldemar Cordeiro, who unfortunately died at an early age, who organized the exhibition *Arteónica* in São Paulo in 1971. During the following years, art and technology initiatives were taken, in particular by the Centro de Estudios de Arte y Comunicación (CAYC) in Buenos Aires and its director Jorge Glusberg. In 1971, the exhibition *Arte y Cibernética* was held in that city. In 1973, a similar presentation of computer generated pictures - *Arte y Computadoras* - was arranged in cooperation with the University of Minnesota, Minneapolis as part of the first ICCH (International Conference on Computing in the Humanities). The following conferences of the ICCH were also held in connection with important computer graphics art exhibitions, first in Los Angeles in 1975, organized by Grace C. Hertlein, then in 1977 at the University of Waterloo in Canada.

A significant contribution to computer art was also made in France where several international events took place. The first one of this kind, *Art et Ordinateur,* seminar and exhibition, took place in Bordeaux; in the same year SESA (Software et Engineering des Systèmes d' Informatique et d' Automatique) arranged a computer graphics art show *Ordinateur et Création Artistique,* and in the following year, in 1974, the *Art et Informatique* exhibition and presentation of computer generated films was organized in Angers. Exhibitions were also part of some seminars in Paris in 1977: *L'ordinateur et les arts visuels,* in 1978 *Arts et Informatique,* and in 1979 *Artiste et Ordinateur,* organized by the Swedish Cultural Centre - notable also for the participation of some Swedish computer graphic scientists and artists, among others Holger Bäckström and Bo Jungberg (who cooperate under the pseudonym of Beck and Jung), Sven Höglund, Bror Wikström, and Torsten Riddell. In 1982, CISI (Compagnie Internationale de Service en Informatique) organized a seminar and an exhibition *L'art et l'ordinateur,* again in Paris.

As previously, the best opportunities for presenting computer graphics art were found at scientific conferences, particularly computer science conferences, while only a few events of purely artistically oriented institutions are devoted to computer art. In 1972, an exhibition called *Grenzgebiete der bildenden Kunst* (Frontiers of Fine Arts) took place in the Staatsgalerie Stuttgart and also included computer graphics. In 1973, the Computer Art

Society, in cooperation with artistic committees, organized the exhibition *Interaction, Machine: Man: Society* in Edinburgh in connection with a conference and various live events. Belgium was also the scene of some important presentations of computer graphics. In 1974, the exhibition *Art et Ordinateur* took place in Brussels, organized by the Institut Supérieur pour l'Étude du Langage Plastique, initiated by Mme. G. Brys-Schatan. In 1981, Peter Beyls arranged the *Internationaal Festival voor Elektronische Muziek, Video en Computer Art* in Brussels; for 14 days, partly in four concurrent series of events, a broadly conceived outline of today's state of computer-aided art was presented.

A remarkable event took place in 1974 in Jerusalem: the *Bat-Sheva-Seminar on the Interaction of Art and Science;* the initiator, Vladimir Bonačić, had invited an international body of participants. It was the aim of the lectures and presentations which lasted fourteen days to achieve a lasting international cooperation within the framework of computer art, with the Bezalel Institute in Jerusalem which is devoted in particular to artistic design as the centre. Because of political events this initial effort was not pursued any further, however.

A series of annually repeated exhibitions in Tokyo called *International Computer Art Exhibition* provided an incentive to artistic activity with the aid of the computer - a continuation of those ideas which had already been advocated by the CTG group (cf. p. 115).

In 1979 the first ARS ELECTRONICA festival took place in Linz, Austria with the participation of numerous graphic artists and musicians who were using the computer as a tool. This event, which is part of the International Bruckner Festival, is being repeated at two-year intervals. It should be mentioned that ARS ELECTRONICA is partly based on the concepts which had been designed for an exhibition *ars ex machina* planned to be held at the Künstlerhaus Wien; unfortunately, the plans were not executed because of financial difficulties.

In spite of many events in Europe devoted to computer art, the centre of development is, and always has been, the United States. The following are some of the most important computer graphics exhibitions of the last years:

- 1978: *Art of the Space Era.* Museum of Art, Huntsville, Alabama
- 1978: *Arts and the Computer.* Worcester Art Museum, Worcester, Massachusetts
- 1978: *Computer Generated Art Exhibit.* Old Dominion University, Norfolk, Virginia
- 1979: *Cybernetic Symbiosis.* Lawrence Hall of Science, Berkeley, California
- 1980: *Art In/Art Out.* Ukrainian Institute of Modern Art, Chicago, Illinois

Several exhibitions shown during the ICCH (International Conference on Computing in the Humanities) in Minneapolis, Minnesota; Los Angeles, California, and Waterloo, Ontario (Canada) should also be mentioned.

## 4 Publications on Computer Art

Whereas nowadays it is almost impossible to keep track of the literature on computer art, there are only a handful of examples from the early days. The theoretical writings of Max Bense of Stuttgart University can be regarded as pioneering works - particularly the four volumes of his *Aesthetica,* which appeared between 1954 and 1960. One volume had the significant title *The Programming of the Beautiful.* In these works Bense anticipated a great deal of what is now accepted as the theoretical foundation of computer art.

Leslie Mezei of Toronto University, whose writings have appeared in many journals, was one of the first propagandists for computer art. He has distinguished himself as a promoter of all initiatives in this area; he gave Frieder Nake the opportunity of working in Toronto, and so helped to improve the contacts between American and European computer artists.

The *Programm-Information PI-21* of the Deutsche Rechenzentrum, Darmstadt, published in April 1966, was one of the first publications devoted to computer art. It included an essay by Frieder Nake on computer graphics, a short text on computer music taken from the sleeve of the record *Music from Mathematics,* and a contribution by G. Stickel, *Monte-Carlo-Texte,* with examples of computer-generated poems (see p. 134). An exhibition

of computer graphics by Frieder Nake in the Darmstadt Rechenzentrum provided the occasion for this publication.
The Zagreb group, which initiated the computer art exhibition *Tendencija 4,* issued the periodical *bit international* since 1969. The first three numbers, devoted to computer art, provided a great range of material, including articles by Max Bense, Abraham A. Moles and Leslie Mezei.
An issue of the periodical *Exakte Ästhetik* – No. 5, 1967, under the heading *Art from the Computer* – was concerned with computer graphics, poetry, and music as well as design. This series was devoted to theoretical aspects of art and published by the Gesellschaft für Exakte Ästhetik, founded by the psychologist William E. Simmat, Frankfurt am Main.
The article *Art and Computer* by Günther Pfeiffer, published in *magazin KUNST,* No. 39, 1970, contained the most complete survey of computer art, especially its history and theory, that had appeared up to then.
Two important publications grew out of exhibitions: *Event One,* organized by the Computer Arts Society, London, 1969, and *Cybernetic Serendipity,* a catalogue of more than a hundred pages.
Among the books on the subject, Lloyd Sumner's *Computer Art and Human Response* is to be mentioned, a highly personal view of computer art. *Generative Computergraphik* by Georg Nees is a major contribution; it is a reprint of a thesis written under the supervision of Max Bense, and deals with programming methods used by Nees and to a large extent developed by him.
In 1966 the organization Experiments in Art and Technology (EAT) was founded in America with the objective of encouraging collaboration between science, technology and art. A newsletter with short articles, *EAT News,* was published. EAT now produces another publication called *TECHNE,* which appears from time to time. Although computer art is only of peripheral concern to the organization, computer graphics were included in their exhibitions and attracted considerable attention.
The most important alliance of computer artists came about with the foundation of the Computer Arts Society by Alan Sutcliffe as a specialist group of the British Computer Society. Its public communication medium *PAGE* is edited by Dominic Boreham (formerly by Gustav Metzger) and concentrates on current news items from all areas of computer art. The relations between art and technology, including computer art, are the special concern of the periodical *Leonardo,* which was founded by Frank J. Malina and is now edited by his son, Roger F. Malina, Art Department of San Francisco State University.
With computer graphics developing and expanding, the number of publications grew. This applies in particular to those of scientific-technical orientation of which many are undoubtedly of interest for artistic applications as well. In this connection, the latest and most detailed bibliography for this area should be mentioned, published by Günther F. Schrack in 1980–1982 in three parts in the journal *Computer Graphics and Image Processing: Computer Graphics: A Keyword-Indexed Bibliography for the Years 1976 . . . 1980.* The bibliography for the year 1981 appeared in *Computer Graphics, A Quarterly Report of SIGGRAPH (ACM)* in 1983. It is almost impossible to keep informed of all articles devoted specifically to artistic problems. Therefore a reference to probably the most complete survey: *Computer-Generated Visual Arts Bibliography,* collected by Roger Coqart and published by himself in mimeographed form, is justified.
Compared to the flood of relevant articles, publications in book form are still extremely rare. Textbooks especially, of which Georg Nees' *Generative Computergraphik* was the first one, can be counted on the fingers of one hand. Probably the most important book is Frieder Nake's *Aesthetik als Informationsverarbeitung* (Aesthetics as Information Processing), 1974, which considers practical aspects of aesthetic programming as well as its theoretical basis. In 1977, the Master's degree thesis *Computergraphik* by Lothar Limbeck was published; it provides a good survey of the entire subject area. An expanded version of this publication appeared in 1979 under the same title with Reiner Schneeberger as co-author; the supplemented sections are concerned in particular with a practicable approach towards programming for non-professionals, the direction of which has been shown by Schneeberger's graphics system SNE COMP ART.
Several publications appeared in connection with arts events, among others detailed catalogues, for instance for a series of exhibitions arranged by the Goethe-Institut called *Computerkunst* (Computer Art), or the catalogue *Grenzgebiete der bildenden Kunst* (Frontiers of Fine Arts) of the Staatsgalerie Stuttgart, 1972.
In a few cases, these publications extend far beyond the limits of

exhibition catalogues containing detailed theoretical sections as well. In this connection, some pamphlets should be mentioned which were issued at the University of Madrid, occasioned by their computer graphics activities. Extensive material was presented as a series of loose leaves in 1971 in São Paulo as part of the event *Arteónica*. A good survey of the work of the most diverse artists - including those from the area of music - is provided in the catalogue for the *Internationaal Festival voor Elektronische Muziek, Video en Computer Art,* 1981 in Brussels.

Some aspects of computer applications in the field of design were discussed at a symposium of the confederation Gesamttextil in 1971 in Mainz which was followed by a publication *Computer-Design in der Textilindustrie* (Computer Design in the Textile Industry) which includes a large number of good pictures. It also introduces a programming language suitable for textile design, a further development of a combined effort of Stephan Eusemann and Georg Nees.

In 1972, Ugo Volli published the book *La scienza e l'arte* which, among others, contains a contribution *Computer Art* by Ernesto García Camarero; he discusses in particular the mathematical foundations for the generation of aesthetically interesting shapes.

Ruth Leavitt's book *Artist and Computer,* 1976, is an informative publication featuring short articles and examples of pictures by the most important representatives of artistic computer graphics.

An extensively illustrated publication examining visual computer graphics from various viewpoints was published by IBM France in a special edition *IBM-Informatique* which subsequently also appeared in an Italian and German version. It presents the viewpoints of American as well as European and in particular French artists.

In two surveys of computer graphic activities of Japanese origin, the activities of Japanese artists seem to be particularly interesting; in 1973 *Cybernetic Artrip* appeared, and in 1981 *Digital Image.*

We owe Frank J. Malina, patron of art-technology combinations, who died in 1980, the publication of a book in large format, *Visual Art, Mathematics, and Computers,* published in 1979, which contains the papers devoted to this subject first published in the journal *Leonardo.*

A number of other books deals with the activities of artists and groups of artists. The book *Open Research,* published in 1972, is very well designed graphically and describes the activities of Dutch artists working with technical tools; Peter Struycken stands out as a computer user. A magnificent book with title *Computer Graphics* was published in 1972 by Johann Willsberger. It provides a survey of the results of a research team which had joined their efforts at MBB (Messerschmidt-Bölkow-Blohm), a German company. Originally it was planned to invite artists to cooperate with computer scientists and mathematicians, but for most of them it proved to be impossible to adopt the mode of thinking of computer logics - only one artist, Sylvia Roubaud, was assimilated into the team. Members of the team were Frank Böttger, Aron Warszawski, Gerold Weiss, and Rolf Wölk. The graphics which have been presented are of a mathematical-geometrical character and undoubtedly represent some of the most impressive results of scientifically oriented thinking. Unfortunately, after presenting the graphics at some exhibitions and after publishing a book, the research team dissolved.

Another illustrated book with the same title *Computer Graphics,* arranged and edited by Melvin L. Prueitt and published in 1975 in the United States, is worth mentioning. Its orientation towards mathematical tasks, particularly in the representation of space surfaces, is even more pronounced than in the MBB publication.

The book *Informatrix* by Edvard Zajec is devoted to a series of computer graphics, a portfolio of single prints published in 1979. Finally, a volume called *Graphic Design Education* by Igildo G. Biesele, published in 1981 in Switzerland, is quite remarkable, presenting technically oriented methods of design - first and foremost computer graphics, discussed by Reiner Schneeberger.

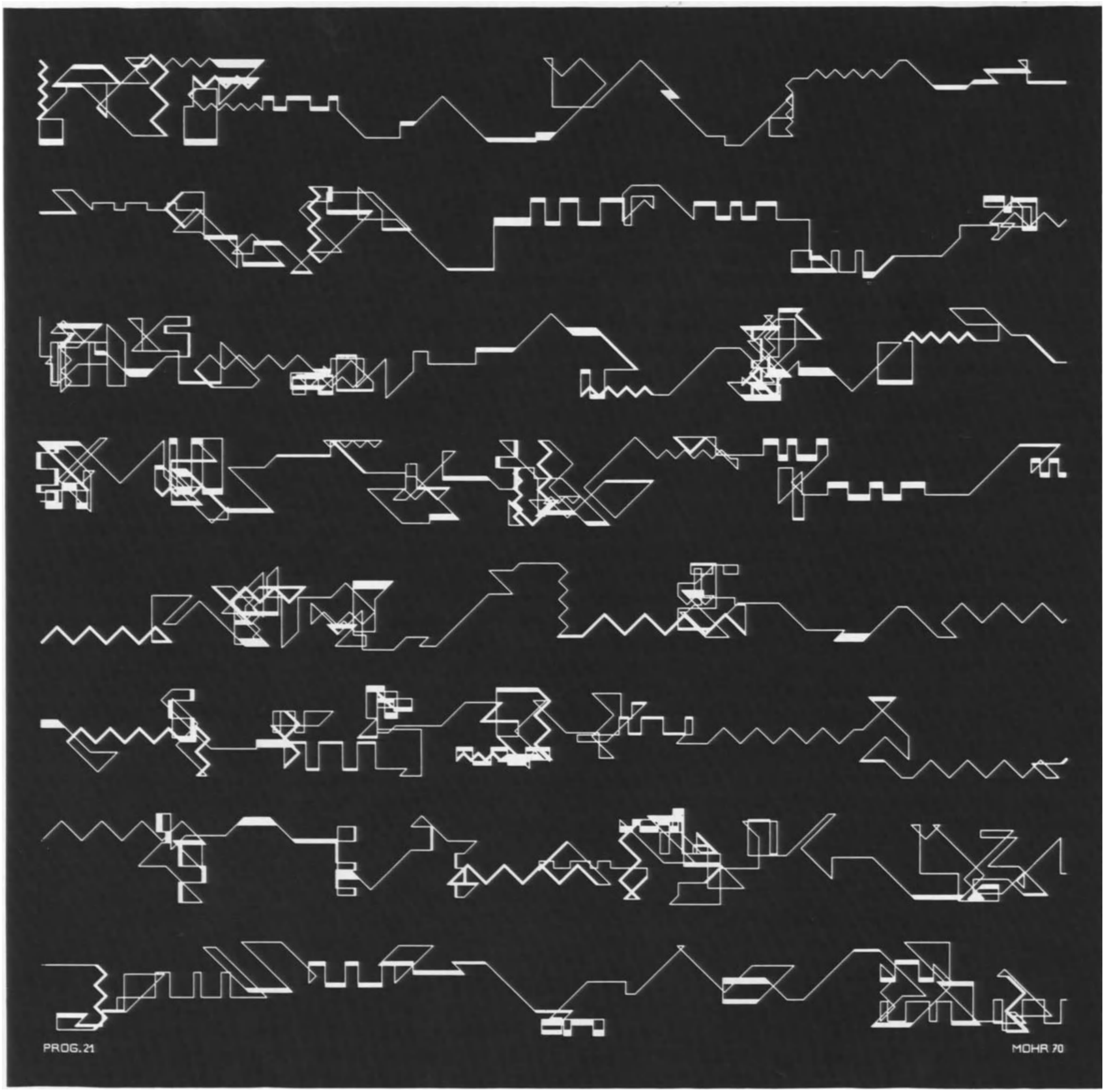
This summary does not exhaust the series of well-designed and informative publications on the subject, many of which have been published as catalogues for various exhibitions. Some of the outstanding ones are those by Roger Coqart, Manfred Mohr, and Vera Molnar, who can each be credited with several publications. Two publications describing Swedish activities deserve special attention: technical reports by Torsten Riddell, *Linjepermutationer,* and by the team Beck and Jung, *Chromo Cube,* published in 1982. Perhaps the artists' catalogues can be consid-

*93 Computer graphic by Otto Beckmann and Alfred Grassl as study ▷ for a sculpture. Made with a hybrid system, output on a storage oscilloscope*

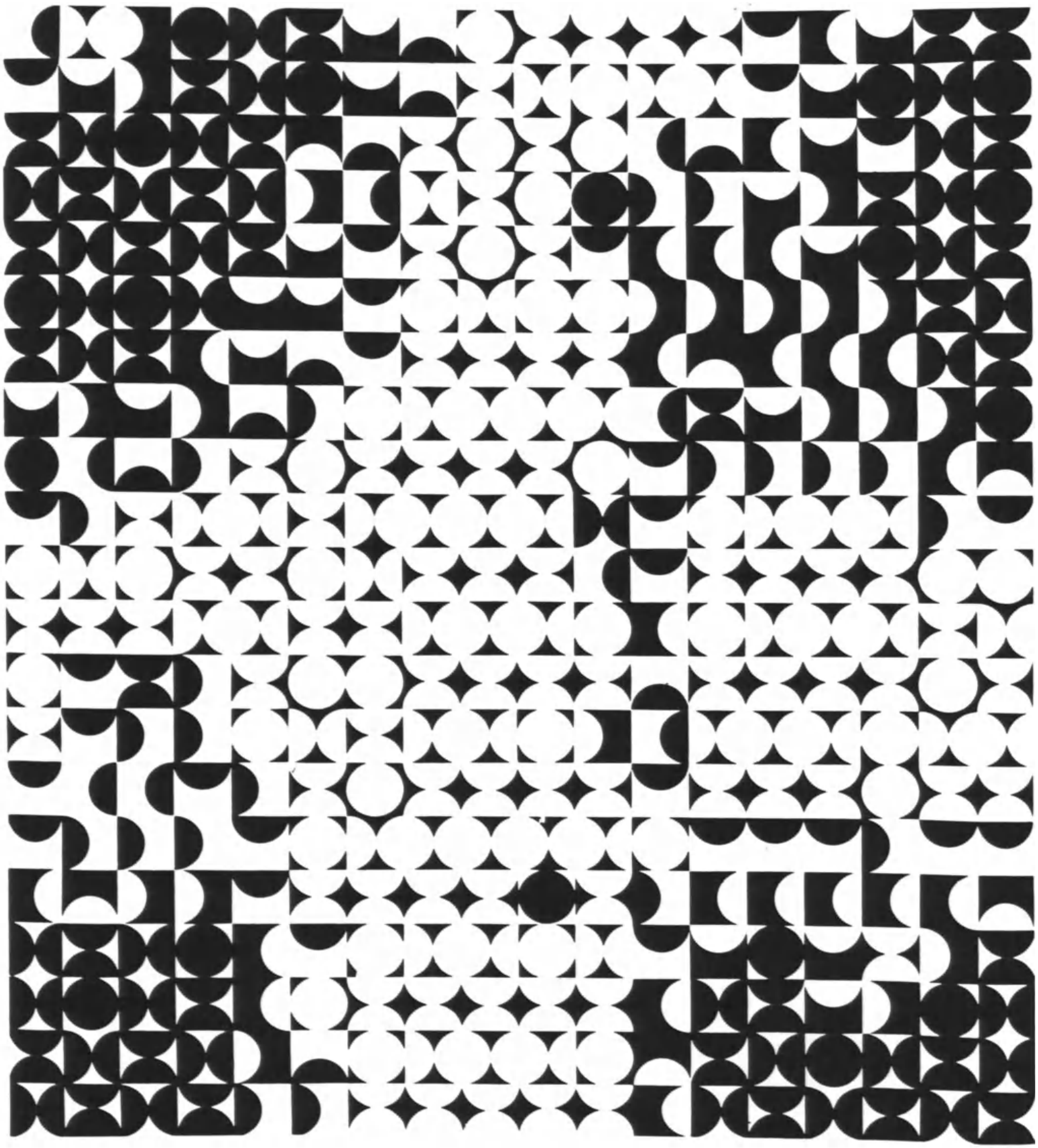
ered the most important documents of progress in artistic computer graphics; it is unfortunate that there is no central agency which collects and archives them.

### 5 The Expansive Period

The earliest initiatives in computer art came from scientists and mathematicians. They alone had sufficient knowledge to generate programs, and access to the necessary equipment. The first exhibitions of computer art were held in rather modest settings, and computer art was always exhibited in isolation; nonetheless there was a considerable response.
We have now passed well beyond this stage. The public takes a lively interest in computer art. Computer graphics and computer music are presented side by side with works produced by traditional methods, for instance in the exhibitions arranged by EAT in New York in 1967; the exhibition *Auf dem Weg zur Computerkunst* in Berlin in 1968, as well as exhibitions by the *parallel* group in Ludwigshafen, Stuttgart and Bonn. In 1969 Wilhelm Bleicher founded the Galerie Franzius in Munich specializing in computer graphics. In connection with this gallery, Werkstatt-Edition Kroll published the first German series of screen printings of computer-generated motifs. But the collapse of the barriers was conclusively demonstrated by a special show of the 1970 Venice Biennale, where computer graphics by A. Lecci, F. Nake, G. Nees, H. Ph. Peterson, the Computer Technique Group, Japan, and by the author, were exhibited next to works by Constructivists such as Josef Albers and Max Bill.
In the meantime several artists had acquired the necessary knowledge to do their own programming. In the United States the painter Lloyd Sumner had been engaged on computer graphics since 1964, and founded a firm, *Computer Creations,* which marketed his works (see Fig. 27, p. 33). John Whitney, who has become widely known through his computer films (see Fig. 116, p. 132), was originally a painter and maker of abstract films. The artist Charles Csuri teamed up with the programmer James Shaffer as early as 1967 in order to produce aesthetic graphics (see Figs. 45 and 47, p. 54, and Fig. 91, p. 104).

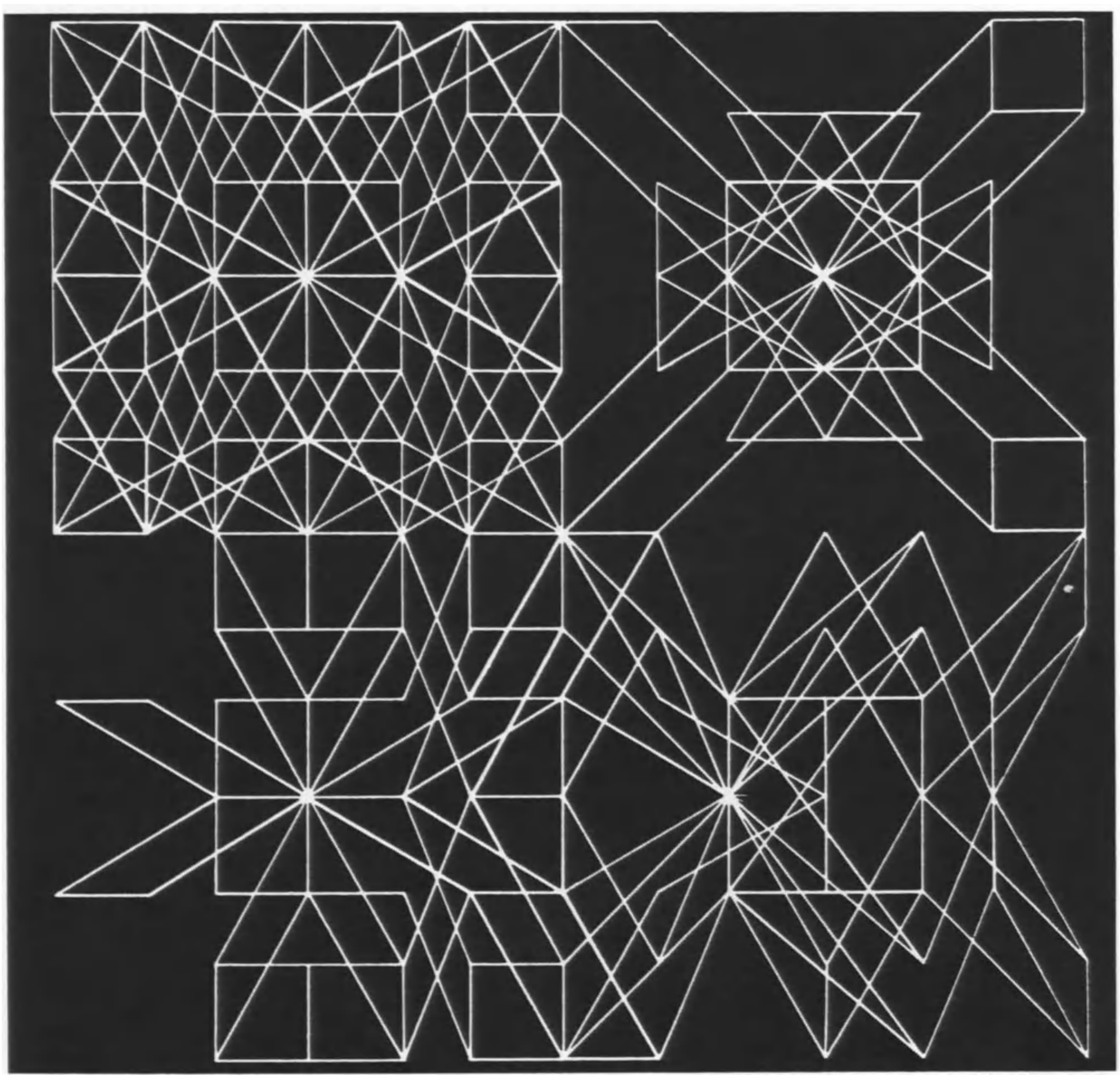



*94* Pseudo-writing, *digital graphic by Manfred Mohr. A random humber generator determines length, direction (0°, 45°, 90°), line thickness, etc. of a calligraphic line sequence. The calculation was performed on a BENSON-1284 drawing machine*

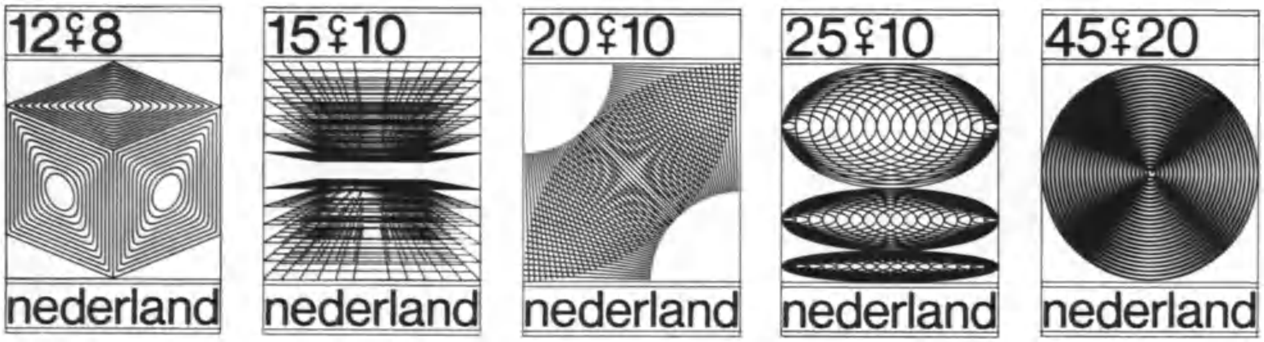


*95 Computer-aided graphic* (part) *by Zdeněk Sýkora. The basic structure was designed with the help of a computer program which distributes the picture elements over a grid and expresses the pictorial conception in a kind of notation. The final graphic is made in a second manual working stage based on this pattern*

*96* Cubic Kennedy, *CTG, Japan. From a series based on a photo portrait of John F. Kennedy*



◁ *97 Digital graphic by Miguel Angel Vidal. Result of the cooperation of scientists and artists on the initiative of CAYC (Centro de Estudios de Arte y Comunicación), Buenos Aires*




*98 A series of Dutch special stamps after computer drawings by R. D. E. Oxenaar*

The artist Manfred Mohr turned to computer graphics in France in 1969. The Czech artist Zdeněk Sýkora turned to computer graphics from a fine art background.

In the following years several groups of technicians and artists formed themselves into more or less loose groups to exchange ideas and collaborate in making computer art. One of the best known is the CTG (Computer Technique Group), Japan, consisting of Haruki Tsuchiya, systems engineer; Masao Komura, product designer; Kunio Yamanaka, aeronautical engineer; Junichiro Kakizaki, electronic engineer; Makoto Ohtake, architectural designer; Koji Fujino, systems engineer; and Fujio Niwa, systems engineer. The scope of their work ranges from the geometric to figurative work. Their variations on a portrait of John F. Kennedy, produced by the superimposition of the simplest components such as strokes and rectangles, have received considerable acclaim (see also Figs. 46, p. 54, and 48, p. 55).

The initiatives for computer-aesthetic creations in Vienna came largely from Otto Beckmann, a professional painter and sculptor. In 1966 he founded the *ars intermedia* group, of which two members, Alfred Grassl and Oskar Beckmann, are engineers. As its name suggests, the group specializes in presentations in which several arts, like dance or film, are brought together. The group has produced various graphic works; some of these stand on their own, while others are preparatory works for sculptures or films. These were made with a hybrid computer and are reminiscent of stylized human groups.

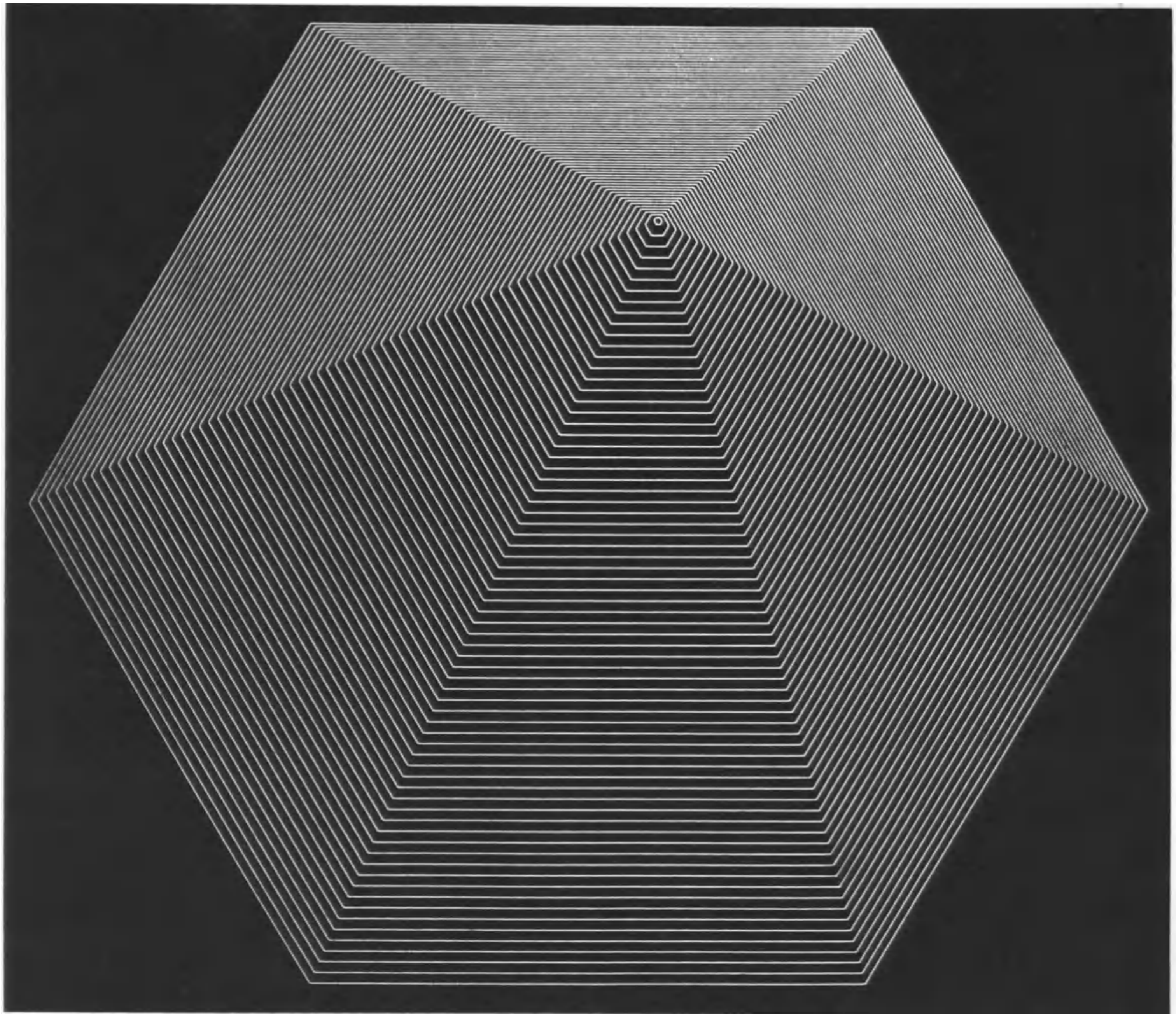
One of the few places where systematic, large-scale collaboration between artists and mathematicians has occurred is the University of Madrid. Already three exhibitions have been held at the Mathematical Center. The latest, *Generación automática de formas plásticas,* arranged by E. García Camarero, was on an international level.

The most important Spanish representatives of computer art are J. L. Alexanco, M. Barbadillo, S. Seville, M. Quejido, and J. M. Yturralde (see Fig. 92, p. 106).

Certain graphic and sculptural works where the computer issues a multitude of combinations of simple elements are particularly remarkable. The final execution follows manually in plastic on the basis of the computer pattern.

Inspired by the CTG, Japan, the Centro de Estudios de Arte y Comunicación (CAYC), Buenos Aires, launched a collaboration between computer experts and artists. The results were shown in October 1969 in Buenos Aires in the exhibition *Arte y Cibernética,* in which, apart from the CTG and other well-known representatives of computer graphics, the following Argentine artists took part: Luis Benedit, Antonio Berni, Ernesto Deira, Eduardo MacEntyre, Osvaldo Romberg and Miguel Angel Vidal.

A number of Dutch practitioners of computer graphics and computer art have aroused interest: A. Eikelenboom, H. Koetsier, R. D. E. Oxenaar and in particular Peter Struycken one of the pioneers of computer art. Some designs for postage stamps by R. D. E. Oxenaar have become widely known.



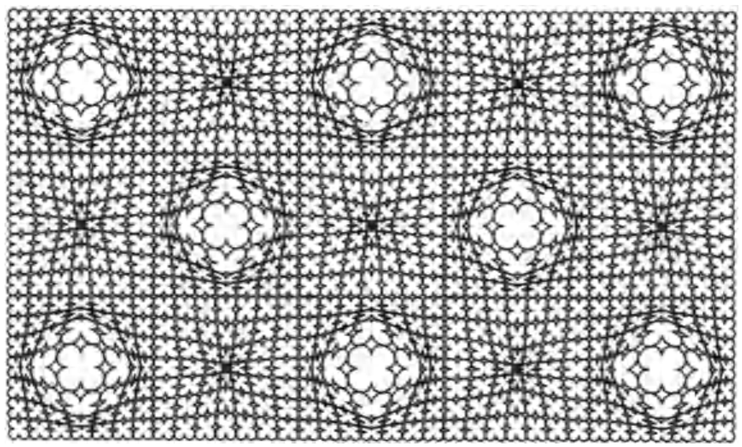
*99* Shift 2, *1969, by Auro Lecci, after a program which permits the drawing of a two-dimensional stripe pattern related to a central point. The varying distance between stripes creates a spatial effect*

*100* Derivative of an Image, *1970, by Waldemar Cordeiro and Giorgio Moscati developed on an IBM 360/44* ▷ *at the University of São Paulo, and reproduced on a fast printer; four transformations of the basic structure of a photographic original*

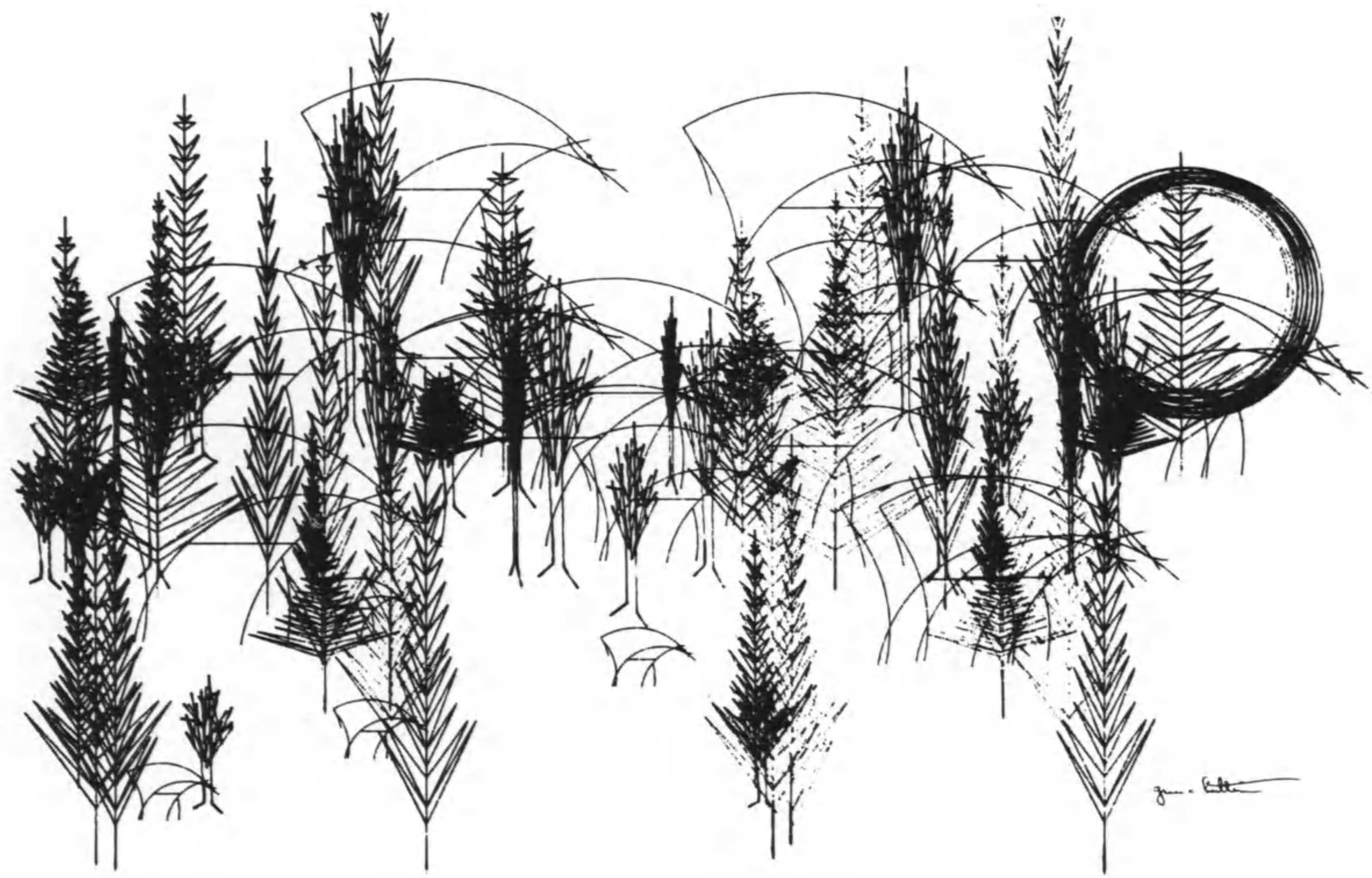
Further initiatives have been developed in Italy by A. Lecci, who later started to work in the United States, Manfred Mohr in Paris, Zdeněk Sýkora in Prague, and the late Waldemar Cordeiro in São Paulo.
In Germany, too, there has been an increase in the number of people concerned with computer graphics; Roland Fuchshuber, Peter Henne and Peter Kreis are among them.

### 6 Recent Activities

In spite of all the arbitrariness which is inherent in dividing historical developments into sections, it is with some justification that the expansive period of computer art is considered to have been finished by 1970 - the year of the first presentation of computer-generated graphics at the Biennale in Venice. The subsequent years were characterized among others by a different attitude towards the computer - its use for artistic purposes was no longer regarded as a provocation. This resulted in computer art losing its spectacular character; the discussion was primarily concentrated on aesthetic questions. But the past decade also witnessed a progressive development of semiconductor electronics and computer technology; the invention of integrated circuits in particular expanded the breadth of application of computer technology to include private use. The progress thus achieved also benefitted computer graphics which moved more and more to the foreground and is today of equal importance as alphanumerical data processing. All this also led to increased acitivities in the field of computer art, particularly in the area of visual design. Today it is hardly possible to keep informed of all the relevant publications, symposia, exhibitions, etc. If the following chapter nonetheless attempts to describe the most important efforts of the last few years, this can only be done in broad outlines - an attempt to grasp the development at least in its characteristic features.
Some courses and seminars at universities greatly assisted in establishing graphical computer art. Grace C. Hertlein, State University in Chico, California, made an essential contribution. An artist by training, she directed all her efforts at promoting computer graphics. Among her own works are particularly remarkable those which reproduce elements of landscapes in a schematic fashion. She trained promising students in extensive courses and seminars which were based on art history as well as practical aspects. Meanwhile, many of her students presented their own artistic work to the public, for instance Michael L. Graves with impressions from the pop scene and of space utopia. Grace C. Hertlein also founded the journal *Computer Graphics and Art* which, in 1979, was changed into a year book.
More recent initiatives for the training of computer graphic artists are due to William J. Kolomyjec, University of Columbus, Ohio. He also presented a voluminous computer-generated oeuvre with attempts, among others, to follow in the direction pointed to by the master of optical illusions, the Dutch painter Maurits C. Escher.
The University of Illinois at Chicago Circle also trains users of computer graphics for artistic tasks, in particular with regard to dynamic sequences for output on video. Some outstanding scientists working at the UICC Electronic Visualization Laboratory are Daniel Sandin and Thomas A. DeFanti (see Fig. 76, p. 88). The latter developed the System ZGRASS designed particularly for artists; it allows the interactive production of complicated



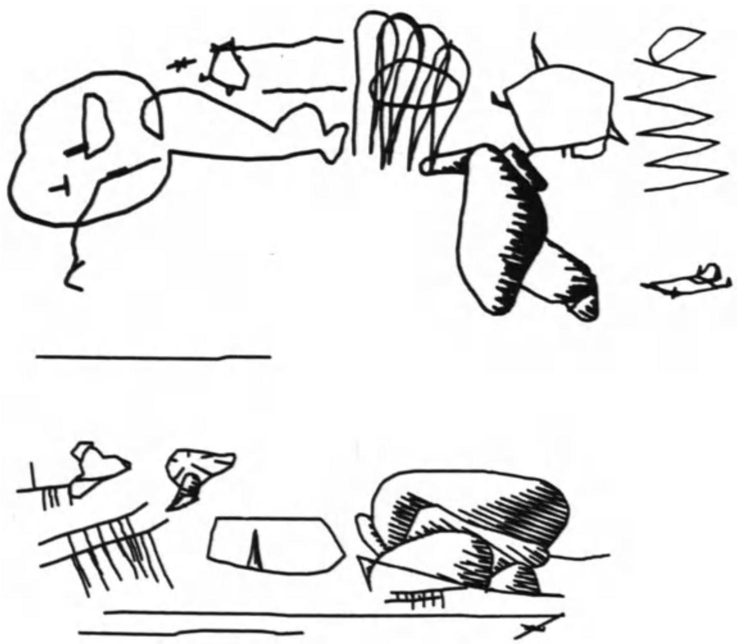
*101 Net structure with distortions which imitate enlargements and reductions, by William J. Kolomyjec, University of Columbia, Ohio*



*102* Beasts in the Forest *by Grace C. Hertlein, California State University, Ohio. Original in green, blue and black*

raster pictures and sequences. Younger members of the institute, among others Frank Dietrich and Zsuzsa Molnar, have also become prominent with remarkable computer graphic productions.

The courses and seminars of Robert Mallary at the University of Massachusetts in Amherst are also, quite unexpectedly, immensely popular. He himself wrote several versatile computer programs which he uses, partly in cooperation with his students, for the generation of graphics, but in addition for optimal landscaping (see Fig. 38, p. 46). Robert Mallary is also intensively engaged in theoretical work; he hopes to find the solution to some questions of art aesthetics with the help of the computer.



*103 Computer-generated drawing by Harold Cohen, University of California, San Diego*

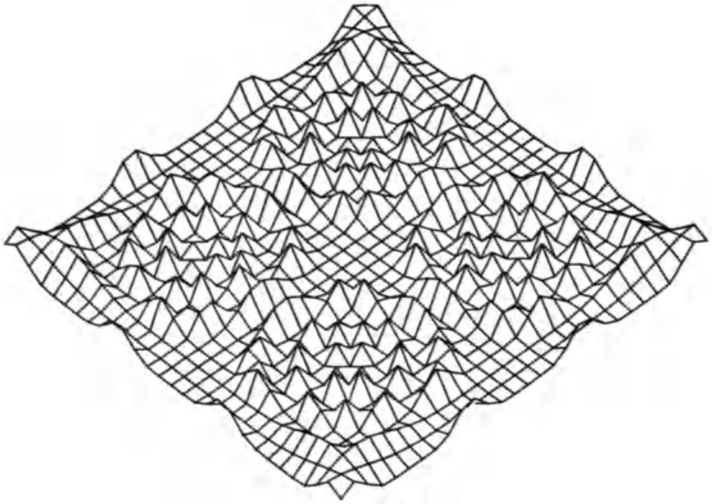
Harold Cohen, an Englishman by birth, is also a university professor and teaches at the University of California in San Diego. In his computer graphics, he traces the generative origins of drawing and painting. Therefore it is not coincidental that his computer graphics resemble the engraved drawings on rock and cave walls. He created quite a sensation with his remote control drawing machine which he calls turtle because of its looks. It is a kind of cart with a pen attached to it which can be lifted and lowered and which is connected to the computer by cable. Harold Cohen was invited by the Tate Gallery in London as well as by Documenta 3 and 6 in Kassel to demonstrate his machine.

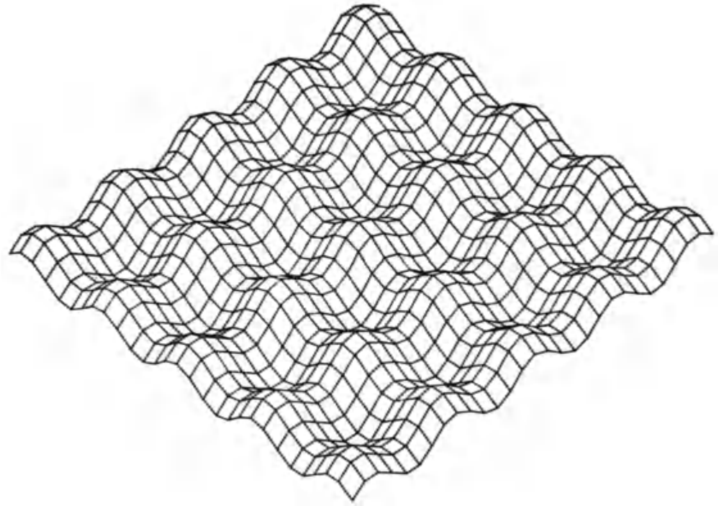
Edvard Zajec (see Fig. 5, p. 9) also works as a teacher for computer graphics, at the University of Syracuse, New York. He became well known for his computer graphic series produced in his native Trieste where he worked for a long time as a teacher of drawing and art history. His last extensive project, the theoretical basis of which he summarized in *Informatrix,* a book combined with many examples, is a programming system for plotter graphics, in particular for the generation and distribution of graphical elements.

There exist no comparable initiatives in Germany either at universities or at academies, possibly because a wave of hostility towards technology is spreading in this country which is particularly strongly noticeable in artistic circles. Some courses initiated by the efforts of several individuals who are themselves working in this field are that much more noteworthy. Reiner Schneeberger, still a college student at the time, succeeded in being invited to teach a course at the Faculty of Education of the University of Munich. In cooperation with his students, he created a series of graphics which is based on a programming system SNE COMP ART for plotter graphics designed by himself. Reiner Schneeberger is also the founder of the Deutsche Gesellschaft für Computergraphik und -kunst (German Society for Computer Graphics and Computer Art).

Artistically oriented computer graphics is also a field of study at the University of Bielefeld. Here, a photographer using experimental approaches, Gottfried Jäger, enticed a mathematician of the University of Bielefeld, Christoph Nahrgang, to become a lecturer in computer graphics. The latter used the tools of computer graphics for interesting aesthetic experiments on the basis of mathematical relationships.

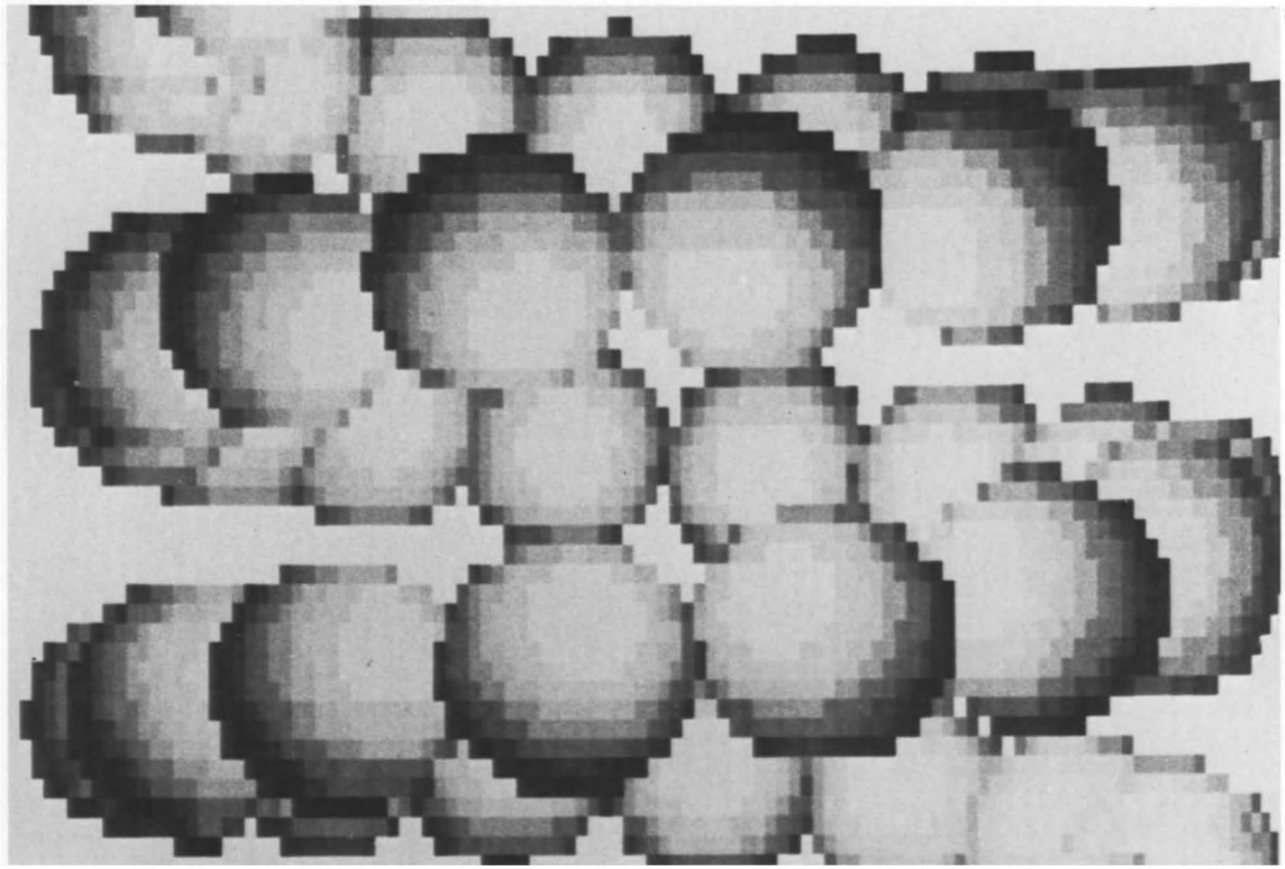
Christian Cavadia, Roumanian born but now a French national, also made a remarkable contribution to the popularization of computer art. Originally entrusted with programming projects which were required when the Centre Pompidou was founded (among others the organization of the library), he succeeded in having a small computer graphics institute established which operates within the cultural centre and of which he is now the director. It arranges demonstrations for the visitor and offers them the opportunity to produce simple graphics. In addition, the institute with its resources is open to professional artists who can use these for their own work. In the meantime, Christian Cavadia and several guests working at the institute were able to present an extensive portfolio of graphics of individualistic character (see, for example Fig. 62, p. 74).





*104* Series L3DL/W *by Reiner Schneeberger, Munich*

Although computer art is presently taught in only relatively few institutions, this is not due to basic reservations, but more to a lack of understanding of the importance which this mode of production will soon gain in art and design. Until now, the majority of computer graphic art is still created by people who became active out of their own motivation. Among them are individuals working in the sciences who came into contact with computer-controlled drawing systems and were thereby challenged to engage in their own aesthetic activities. Psychology of perception provides an incentive for this. As demonstrated by Bela Julesz in the early stages of computer art, the computer can be used to design various visual structures for experimental purposes. Dominic Boreham, at the present time editor of the journal *PAGE*, the news magazine of the Computer Arts Society in England, drew texture patterns for testing spatial impressions which indicate a transition to op art. Chris French, an Englishman like Boreham, worked at this problem and drew pairs of stereo pictures for this purpose which can be regarded as imaginary sculptures.
The strongest impulses for computer-aided visualization undoubtedly are to be found amoung mathematicians who discovered it as a didactically very effective tool for presenting course materials. For example, worth mentioning are the plotter graphics by Norton Starr at Amherst College in Amherst, Massachusetts, with which various mathematical relationships are illustrated (see Fig. 25, p. 32), or the computer graphics which Benoit B. Mandelbrot had generated as illustrations for his book *Fractals – Form, Chance, and Dimension* (see also Fig. 66, p. 78). Other mathematicians as well learned in how to produce graphical forms unknown so far in their subject area; Christoph Nahrgang, who studies mathematical approximation procedures, has already been mentioned. There is also Christoph Pöppe who turned his interest to relationships in hyperbolic geometry (see Fig. 30, p. 36) and Julius Guest, a Vienna-born mathematician now living in Australia, who – following Gauss – studies modulo seventeen rotation symmetry (see Fig. 29, p. 35). Also a member of this circle of scientists is Aldo Giorgini who at the present time teaches civil engineering courses as well as a course on "Aesthetics in Civil Engineering" at the Department of Civil Engineering at Purdue University in West Lafayette, Indiana. His computer graphics projects are devoted in particular to graphically attrac-



*105* Spheres in Helix Form *by Chris French, University of Manchester*

tive illustrations of mathematical fields (see Fig. 28, p. 34). Remarkable computer graphics were also created by the German mathematician and computer scientist Ernst Schott who collaborates with his wife Milada Schott, a graphic designer by training. Besides mathematically abstract drawings, he also generated configurations patterned after organic structures.

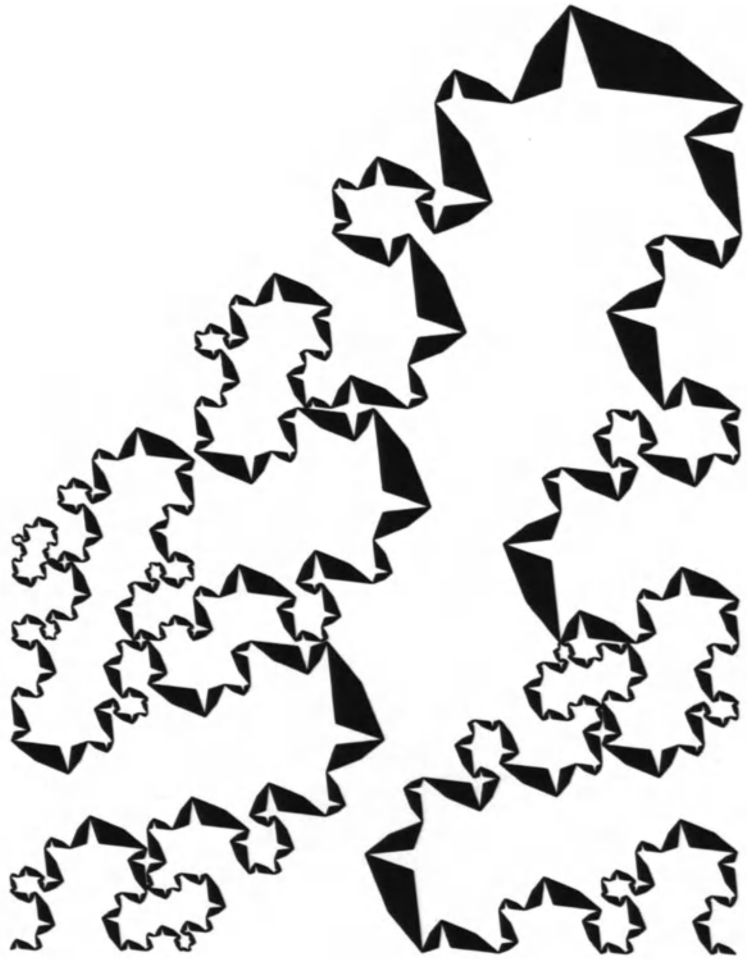
The American Kerry Jones also became involved with computers in his first job and discovered their usefulness as an artistic tool very early. Among the numerous picture series presented by him, various complicated ornamental forms are particularly striking. Some members of the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (German Research and Experimental Institute for Aviation and Spaceflight) in Oberpfaffenhofen, West Germany, who from time to time participate in aesthetic experiments (see, for example Figs. 44, p. 52, 51, p. 58, and 121, p. 146), also have a mathematical background. They have at their disposal a mainframe computer which is meant for the evaluation of aerial and satellite pictures, as well as the coordinated system DIBIAS (Digitales Bildauswertesystem, Digital Picture Evaluation System). It was designed by Ernst E. Triendl and the members of his team for the purposes of picture analysis during many years of research, but it is also well suited for the visualization of mathematical relationships and artistic experimental series based on these (see, for example Fig. 67, p. 79). E. E. Triendl devoted his efforts in particular to the representation of spatial areas in a kind of colored representation of contour lines; Manfred Lehner designed one part of the program suitable for aesthetically pleasing areal Fourier transformations, and Horst Helbig was the principal participant in artistic evaluations of connections between mathematical and logical relationships.

Teams comprised of artists as well as scientists represent a transition to professional artistic projects. Highly regarded results were created by, among others, Charles J. and Colette S. Bangert, a husband-wife team at the University of Kansas. Colette, a drawer and painter, and Charles, a mathematician, found their own artistic style which is reminiscent of organic structures and landscapes.

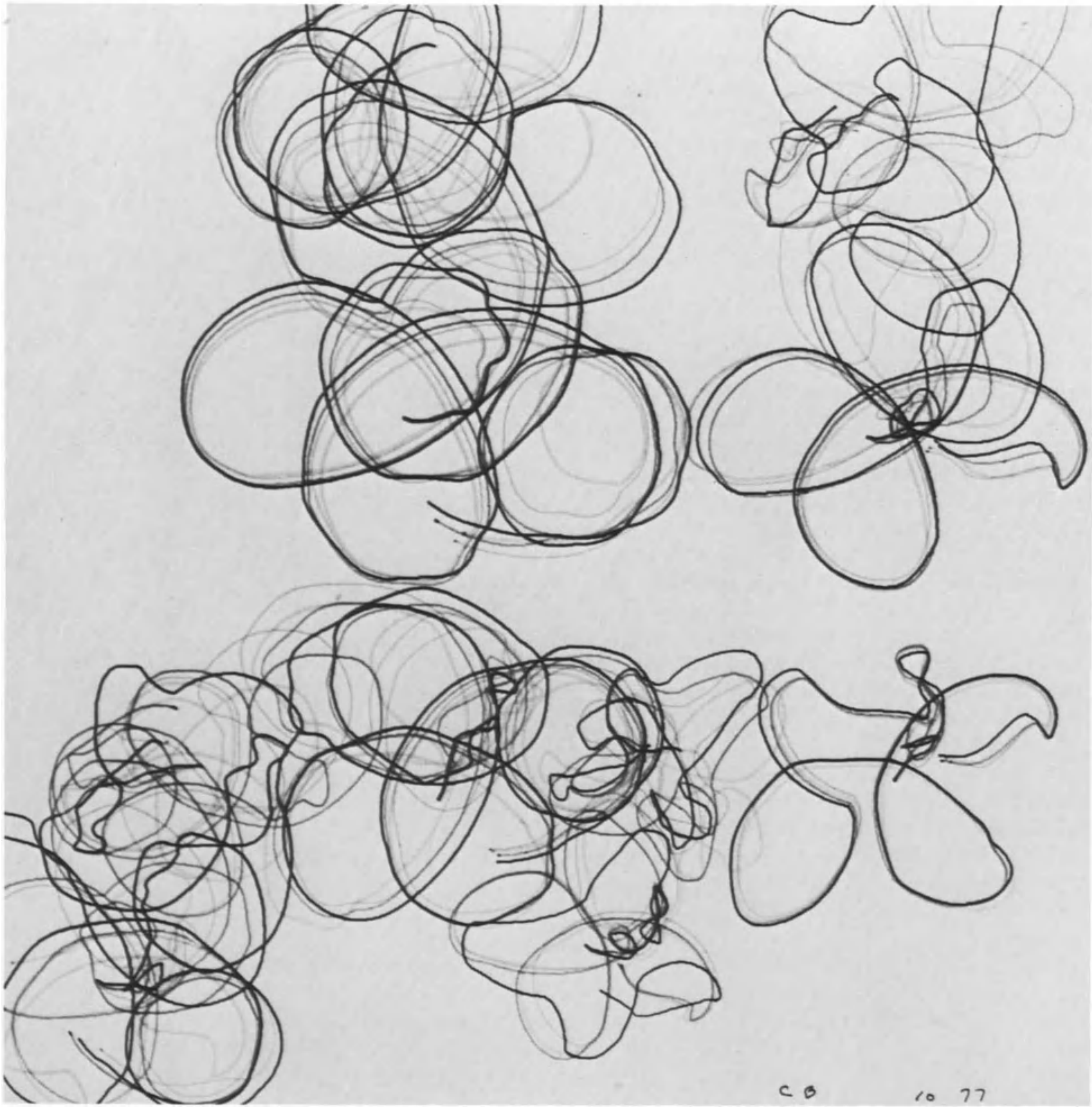
Two members of quite different professions, the artist Paul Shao and the architect and engineer Kenneth F. Dunker, both teaching at universities in Iowa, have worked as a team since 1970 and have excelled in producing finely structured regular and randomly distorted patterns.

It was the festival ARS ELECTRONICA in Linz, Austria which resulted in the teamwork of an artist and a technician. Klaus Basset, a painter and graphic artist using the constructivist style had initially studied regular areal arrangements of basic signs with the aid of a typewriter; the cooperation with his friend Willi Plöchl enabled him to use the line printer for corresponding tasks.

While initially there were only a few professional artists who turned to the computer as a tool for artistic experiments, it is almost impossible to estimate their number today. Some of the pioneers, as for instance Ruth Leavitt (see Fig. 63, p. 75) and Manfred Mohr (see Fig. 94, p. 111), have continued to work in this field and have produced new remarkable results. In attempting to list the most important newcomers, one is struck by the internationality of computer art. Besides the Americans, whose predominance cannot be denied, English artists have attracted attention; besides Harold Cohen and Chris French, there is for example Tony Longson, whose particular interest is the representation of three-dimensional objects.



*106* Peano-Collier, *fractal curve by Benoit B. Mandelbrot, computer-aided drawing*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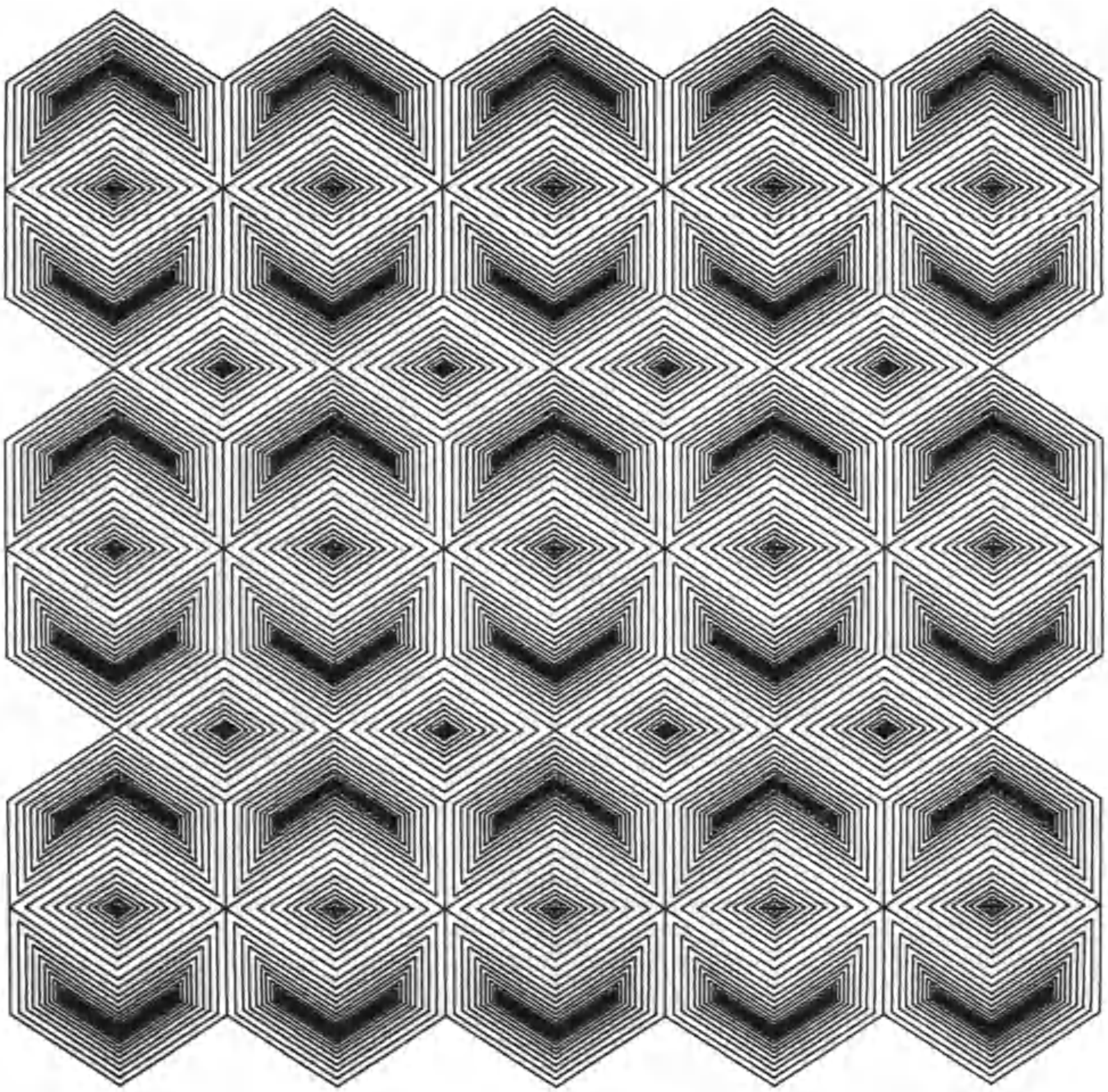
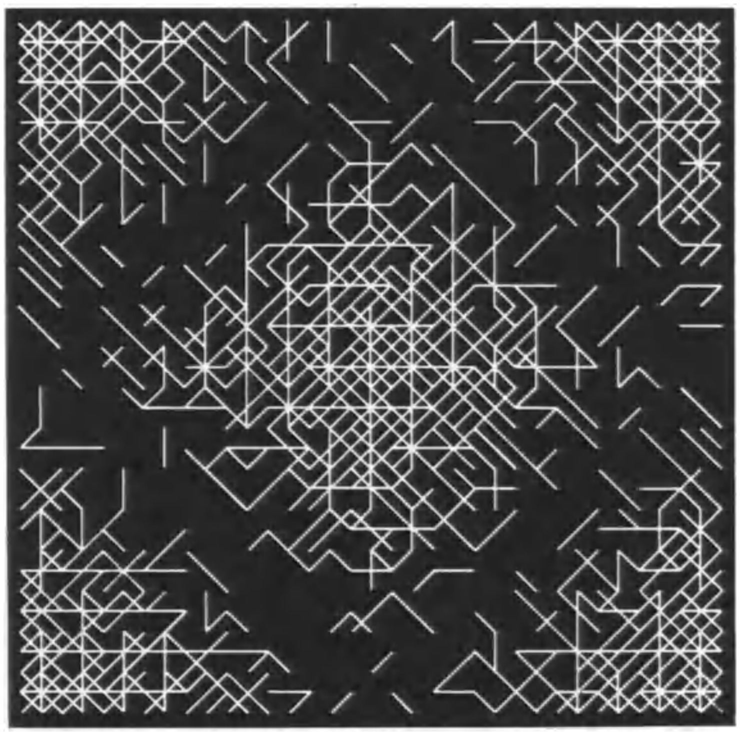
◁ *107* Structure Study, *computer graphic by Colette and Charles Bangert. Original in red, yellow and black*

*108* Optic Study 101, *computer graphic by Paul Shao, Iowa State University, and Kenneth F. Dunker, University of Oklahoma*

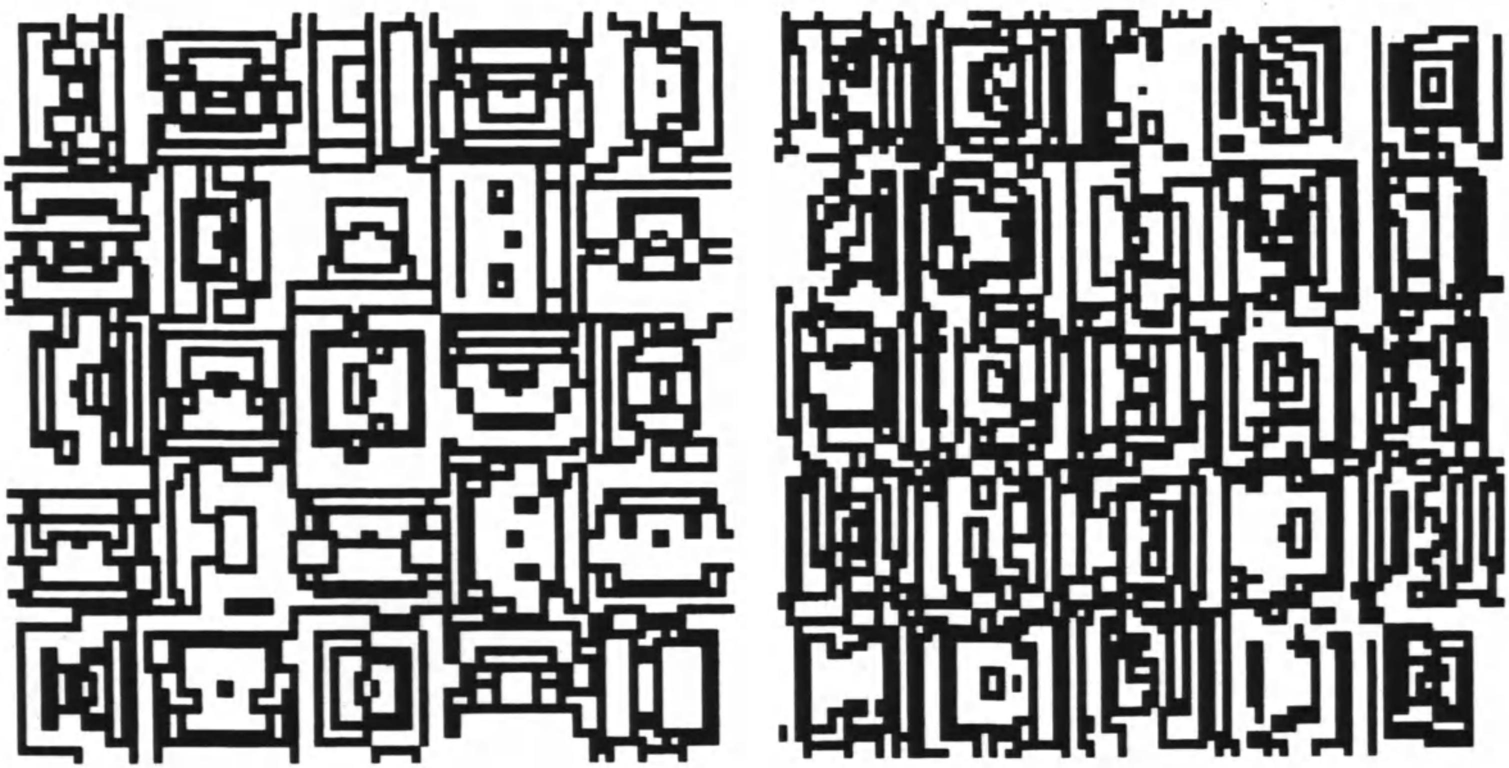


*109* Simulacija prijelaza *by Vilko Žiljak, Zagreb, a study for a screen printing*



*110* Negative Grid Structure, *Roger Coqart, Brussels*

The Yugoslavian Vilko Žiljak should also be mentioned. The work of two artists who now live in Canada, Roger Vilder and Jacques Palumbo, gets its orientation from constructivism. The two Belgians Roger Coqart and Peter Beyls have presented graphics in the same style, although their work extends far beyond purely geometrical structures. Coqart made use of interesting combinations of computer-generated and photographic methods. Beyls, a musician by training and profession, is, among others, involved in various experiments with picture processing.
In 1969, the *Groupe Art et Informatique de Vincennes* was formed in France which is attached to the Department of Computer Science at that university and cooperates closely with the Departments of Music and Fine Arts. Its members, who see themselves neither as artists nor as computer scientists, but as members of a new profession combining both fields, have gained recognition at many exhibitions in Paris.
Ernst Havlik, an Austrian by nationality, has become prominent in recent years with many charactistic results. He uses a multiple-crystal scintillation camera and subsequent computer processing to generate his pictures.
Several talents have re-emerged in Japan after the dissolution of the CTG group, especially Hiroshi Kawano who has also excelled in theoretical work, Shihaya Shimomura who has achieved new aspects of the vertical-horizontal principle with a



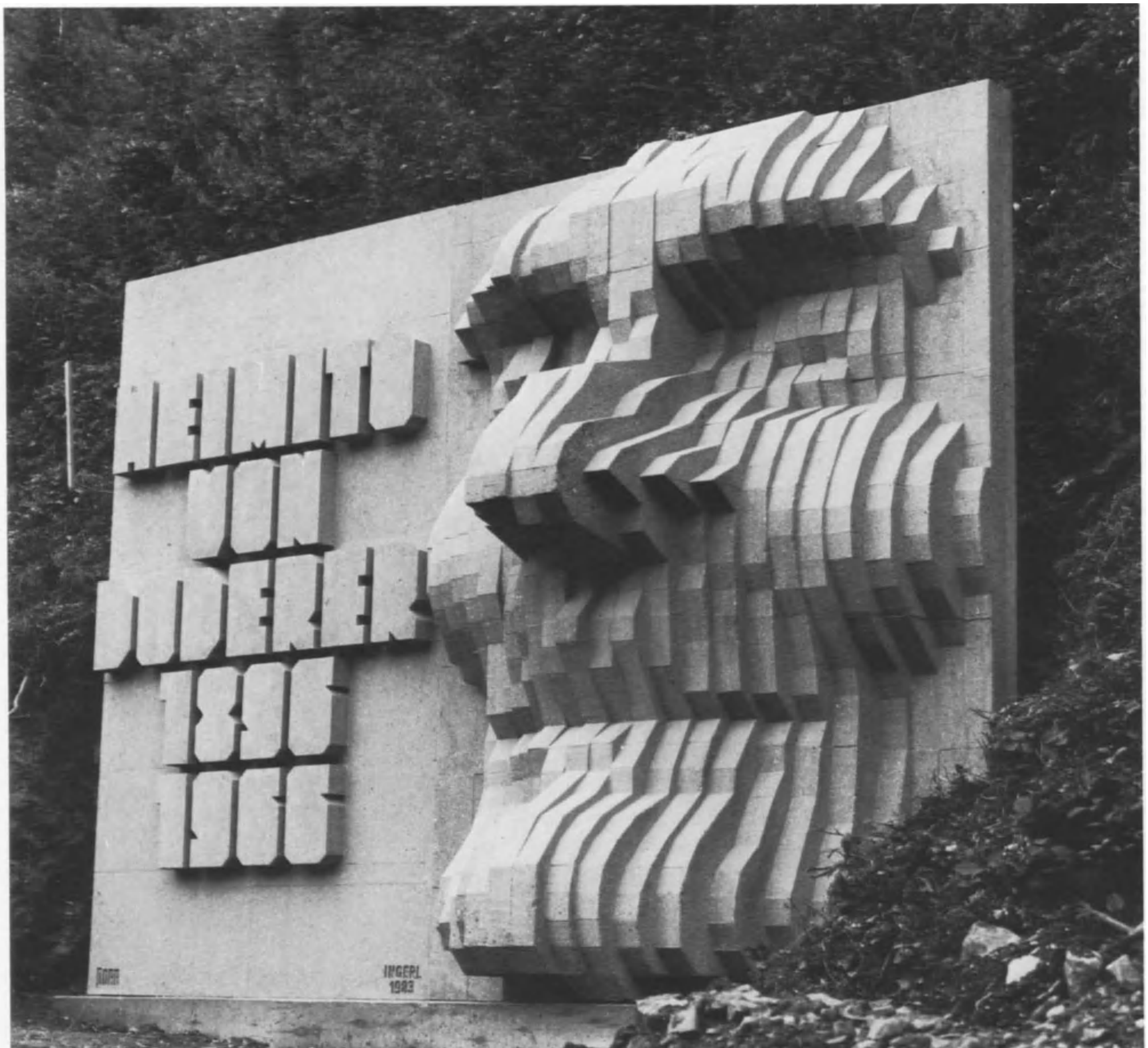
*111 Graphic from the PTS (Picture Transformation System) by Shihaya Shimomura, Tokyo*

"Picture Transformation System" designed by him, and Sozo Hashimoto who has incorporated the formal qualities of the mandala into his computer program thus outputting new mandala configurations.

### 7 Computer Sculpture

The production of sculptures by computer is still beset by technical difficulties; so far no method has been developed for fully automating the steps from program to finished execution. Where computers have been used for experiments in this field, they have been confined in the main to the design stage. According to Otto Beckmann, computer-produced sculpture is the goal of some of the *ars intermedia* group's endeavors. Alfred M. Duca has made computer sculptures composed of disks.

The Spanish painter and sculptor J. L Alexanco's point of departure was a realistic model, a human figure, and by using a computer, he changed the spatial disposition - but he had to use the expedient of contour lines (see Fig. 53, p. 62). The sculpture was sectioned into horizontal disks, and the resulting plane-like elements were successively transformed. The computer provided contour lines for the individual horizontal sections via a fast printer; the execution of the sculpture followed by hand.



◁ *112* Heimito von Doderer, *computer-aided sculpture by Kurt Ingerl. The shape of the concrete slabs was calculated by the computer on the basis of the measures of the death-mask*

This kind of production process has been defined as *computer-assisted art.* The term has been used by, among others, the physicist and painter Richard C. Raymond, at present working with General Electric Motors, New York, for his mobiles - structures consisting of moving colored surfaces set in periodic motion through thin levers. Here too the computer can calculate the grouping and the sequences, but the construction is still by hand. The introduction of computer-guided milling machines for the production of three-dimensional aesthetic objects is due to Charles Csuri. Georg Nees, too, later used this method to make computer reliefs. One of these, or rather a series, based on one program, is milled from wood or plastic and is to be reproduced by molding (see Fig. 54, p. 63). Another computer sculpture by Georg Nees suggests a transition from relief to sculpture in the round: it is composed of individual square blocks, which are aligned on a plane but are of different heights and thus convey a three-dimensional extension. The Swiss Gottfried Honegger-Lavater has also produced reliefs based on computer designs: they are in the form of arched indentations in smooth surfaces.

A sculpture which is still based on a spatial distribution of elements, but which is basically different from classical sculptures was created by the German painter and sculptor K.-L. Schmaltz, His cellular plastic sculpture *Galax K 324* has the shape of a polyhedron which is composed of 324 octahedral modules. Computer-drawn representations of the lattice planes served as construction plans.

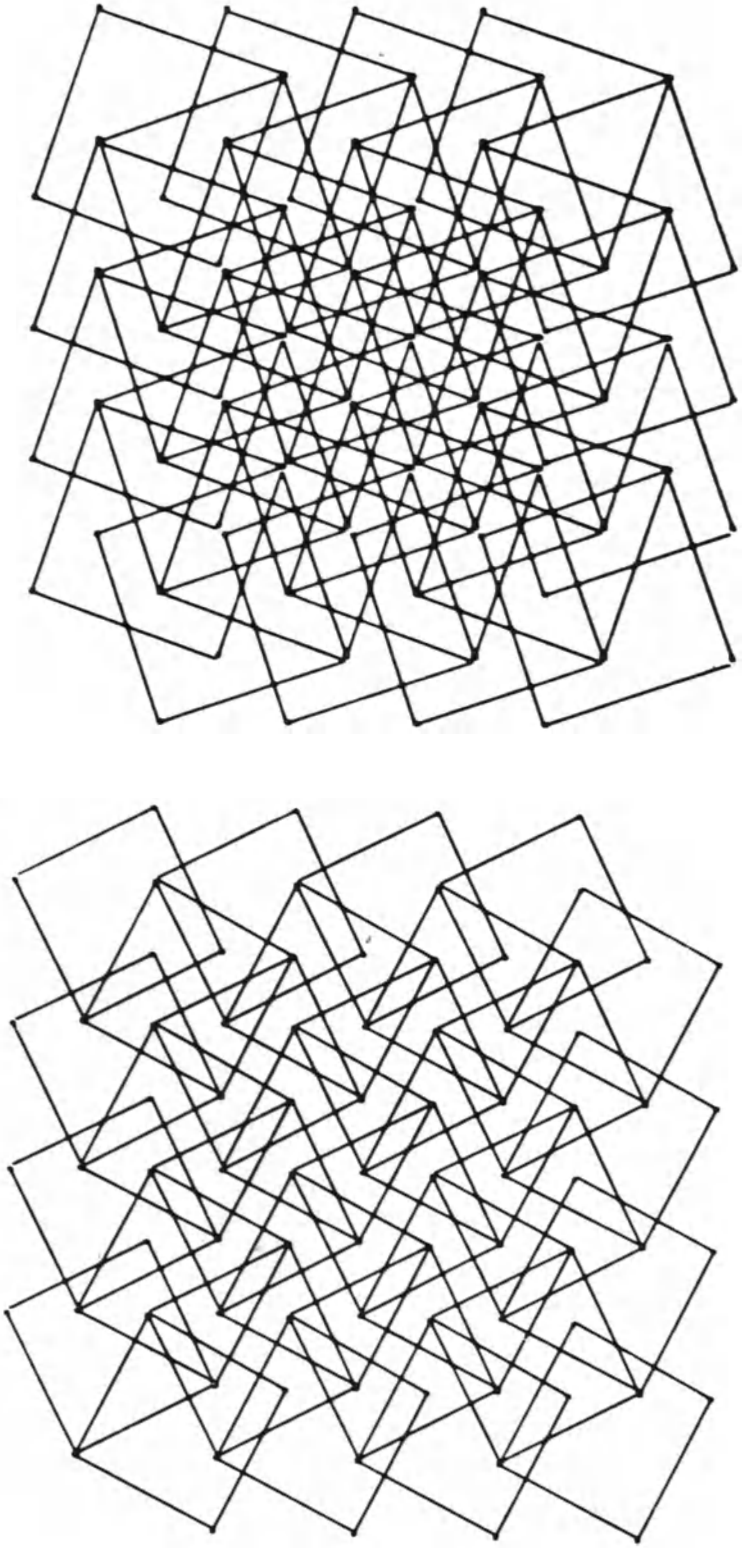
Kinetic objects and light objects can be regarded as an expansion of sculptures. Microprocessors are especially suitable for their control. Probably the first one to incorporate a computer system into a spatial work of art was Vladimir Bonačić. His constructions could be called light rasters, lamps arranged in rows and columns which are activated in groups in continually changing intervals with the distribution being patterned after the mathematical laws of Galois fields. Such a system can operate for years without ever repeating itself. This marks a transition to the so-called cybernetic objects, openly displayed electronic circuits which control lamps or produce a sequence of sounds and noises - partly as a reaction to the utterances of the audience. In Germany, artists like Hans Martin Ihme, Walter Giers, and Peter Vogel have become prominent with creations like this.

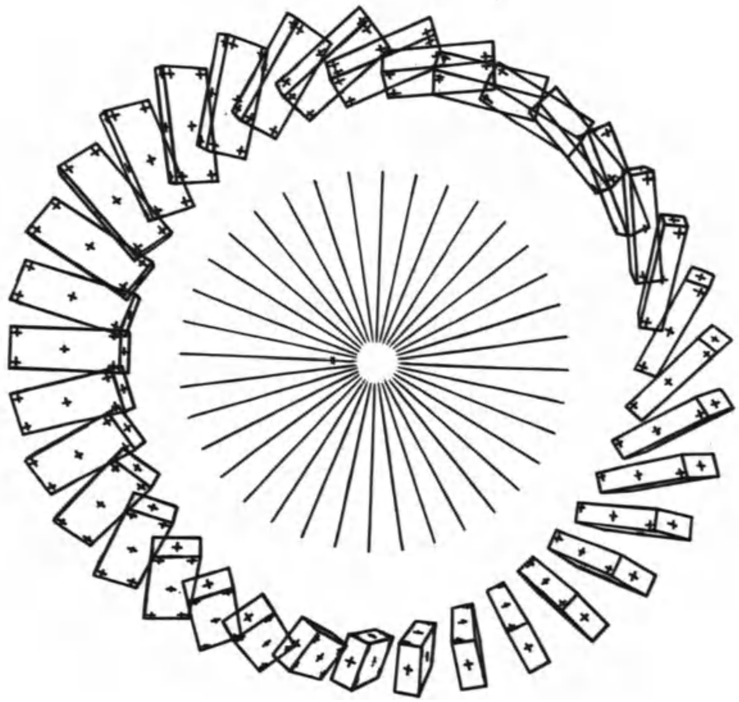
One of the most ambitious examples of mobile, cybernetic sculpture is *Senster,* designed in about 1970 by Edvard Ihnatovicz, London. Among others, it provides for microphones and a radar transmitter/receiver system in order to record movements and noises from the audience. The data are processed by a computer system which also controls the hydraulically operated movements of the sculpture. Recently, Nigel Johnson, another artist living in London, has been working on the problem of computer-controlled reactive sculptures and presented several examples of his realizations.

## 8 Computer Film

Computer film is closely related to computer graphics; it can be regarded as a run of successively modified computer graphics. Equally, phase images from computer films have frequently been exhibited as computer graphics. The first computer film was made in the Bell Telephone Laboratories in 1963. E. E. Zajac simulated the motion and autorotation of a communication satellite as a succession of single phases. Experimental work relating to aesthetic aspects was begun soon afterward; Kenneth C. Knowlton made a substantial contribution to this work. With his own mosaic-picture system BEFLIX Knowlton, in collaboration with Stan Vanderbeek, produced the film *Man and His World* - an abstract play on the letters of the title. *Contour Charts* is another film by Knowlton, where the three-dimensional projection of a four-dimensional cube, which can only be conceived theoretically, is rendered in perspective (see also Fig. 22, p. 29). A more recent film produced with the help of Knowlton's method is *Pixillation* by Lillian F. Schwartz, where computer-generated plane patterns are intermingled with flowing color effects (see Fig. 65, p. 77). The music was composed by Dick Moore after the GROOVE system by Max V. Mathews. Also from Bell Telephone Laboratories came a film by A. Michael Noll showing a kind of spatial play on his initials, and the film *A Pair of Paradoxes* by E. E. Zajac, founded on optical and acoustic illusionistic effects.

In 1967 Charles Csuri, Professor at the School of Art, and James Shaffer, programmer, both working at Ohio State University,





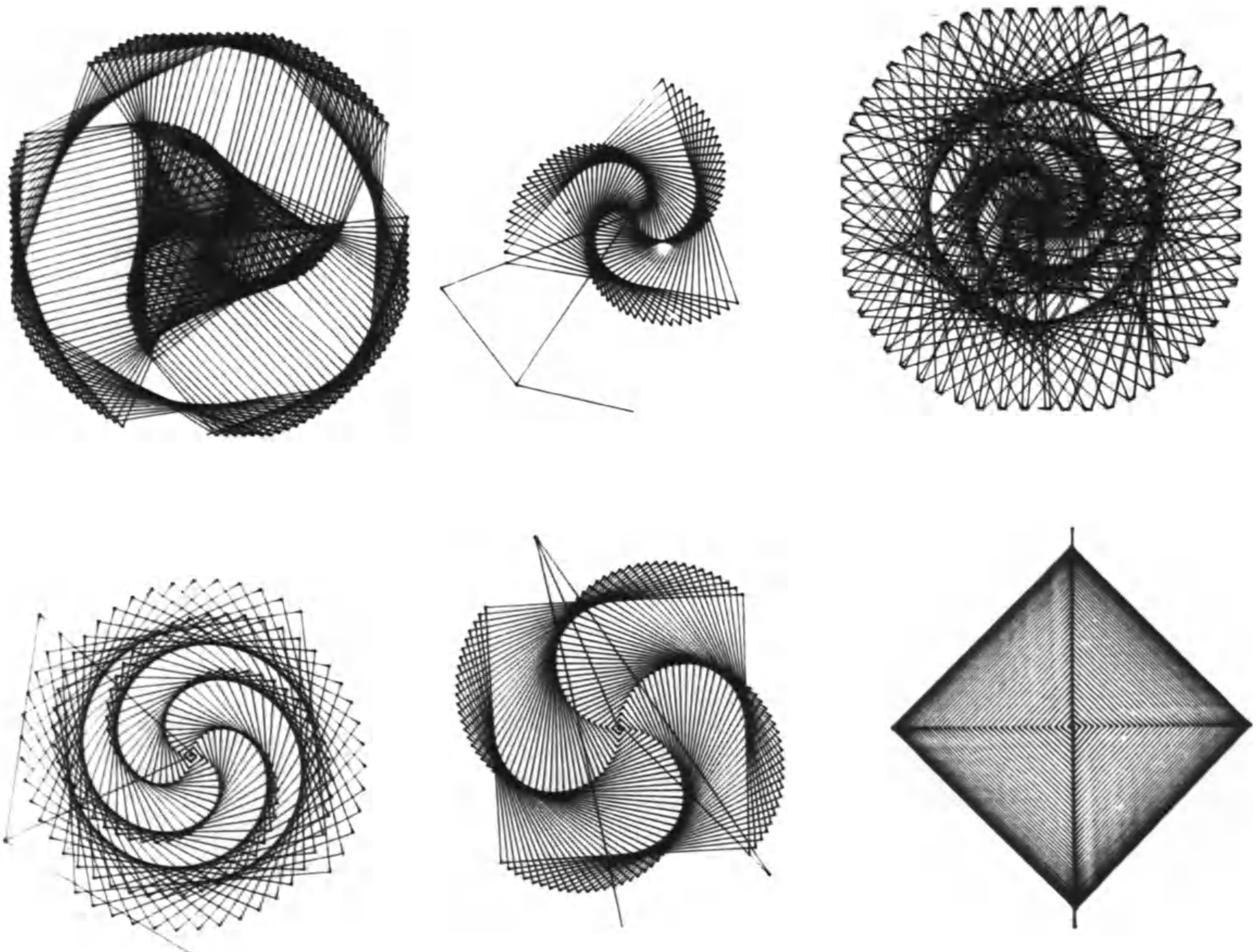
*113 Phase image from the first computer-generated film, produced in 1963 by E. E. Zajac. The orbital path of a satellite is symbolized by a box shown in perspective, whose changing positions indicate the course of its autorotation. The program, transposed by the data processing system IBM 7090, produces between two and five frames per second, which are filmed in single frames from the screen of a picture tube, and are shown at 16 frames per second*

*◁ 114 Two phases of a film by Ronald Resch where a net structure is transformed into a single square and then returns to the net structure*

*115 Four phases from the film* Hummingbird *by Charles Csuri and James Shaffer, which has received several prizes. A bird dissolves into a chaos of singly circling parts, which eventually reunite into the basic figure*

started their collaboration on computer graphics and computer films. Their ten-minute film *Hummingbird,* which performs the most varied graphic manipulations with the image of a hummingbird, has become famous; at the fourth International Experimental Film Competition in Brussels it was one of ten films which received prizes out of a total entry of 335.
Ronald Resch of the Coordinated Science Laboratory, University of Illinois, has programmed computer films for architectural purposes. The illustrative methods used in these films - lattice structures - were also used by Resch in a freely designed film in which a checkerboard pattern is transformed into a single square before eventually resuming its original form.
The best-known creator of computer films is John Whitney, who had previously made abstract films and had also practiced music and photography. In 1966, IBM gave him the opportunity of a thorough training in the use of data processing systems, and since that time he has worked closely with Jack P. Citron of the IBM Scientific Center, Los Angeles. Citron, whose main interest was computer-generated music, adapted a program for sound generation to the production of electronic music for films.

*Binary Bit Pattern* by Michael Whitney, son of John Whitney, with music by Charles Villiers, is an enchanting example of a computer film. It is anchored on a single basic figure - a small star, and the program is exceptionally simple and transparent. But the principle used has such a capacity for extension that an incredible multiplicity of attractive ornaments results from a continuation of the composition process. If one may speak of elegance of method in computer art then here is an outstanding instance. Among the more recent computer films from the USA are the three minute reel *Linesthetic* by Lloyd Sumner, and a seven-minute film *Event I* by John C. Mott-Smith, which is composed of the same primary pattern, based on physics, as his static color graphics (see Fig. 68, p. 80).
England, too, has produced computer films, among them *The Flexipede* by Tony Pritchett, which succeeded in introducing a humorous note into computer film for the first time. Georg Nees has also produced a short computer film. It shows among other things the build-up of the graphic structure which forms the basis of his computer-generated relief (see Fig. 54, p. 63), and the perspective transformation of a grid detail.



*116 Sequences from the film* per-mu-ta-tions *by John Whitney, with program language by Jack P. Citron, formulated on an IBM 360, and issued on the optical output IBM 2250. The program is founded on a trigonometric function written as a polar coordinate equation, which is determined by sixty parameters; the rosettes illustrated merely indicate the multiplicity of the variations captured in the program. The film is in color; the original black and white patterns were colored, faded and edited on an optical printer. Photo: IBM*

*Ars intermedia,* the experimental group from Vienna and Wiener Neustadt, has made searching studies of computer-generated sound and film sequences. It is worth noting that these computer sound films arise through a program whereby image and sound are directly related and jointly emitted. Otto Beckmann calls it image-sound-related film.

It was Peter Foldes, a native of Hungary who unfortunately died at an early age, who used the new possibilities provided by computers in the most consistent manner for artistic purposes in the production of several animated cartoons produced in Canada. In producing his film *Faim,* he had not only the intermediate frames generated by computer, but he also used interpolation for transitions between mutually independent pictures which resulted in graphically interesting abstract intermediate frames. He employed the same stylistic medium in his film *Metadate* where, among others, he has a flower change into a landscape.

The transition to commercial films took place with the aid of computer graphics systems which were adapted especially for animation, for example the system ANTICS by Alan Kitching, England. Initially, abstract sequences were used for TV commercials and for the representation of unusual phenomena in science fiction films; the final sequence of Stanley Kubrick's film *2001 - A Space Odyssey* is an early example, it was coproduced by John Whitney. Larry Cuba, who also made himself a name with his own computer films of artistic value, collaborated with him.

The transition from two-dimensional to three-dimensional representation made possible by advanced techniques of computer graphics also represents an important step forward in the history of film technology. This development is closely intertwined with computer-aided design. While, initially, static pictures were deemed satisfactory, soon the desire arose to include dynamic sequences as well - for example for the purpose of making visible the effects of loading a tool or a beam.

While it is not necessarily important for applications in the scientific and technical field to achieve representations which are visually realistic, this appeared to be more desirable for producing movie and TV animation sequences: for the first time computer-generated sequences can be used for the production of full length feature films. A mixing technique is used which electronically blends that part of the picture showing the actors in action in front of a computer-generated background. Producers of science fiction movies especially employ this method because they are faced with the task of showing technical objects which do not yet exist and landscapes of unknown planets which are not yet within reach.

At the present time, real simulation is still quite time consuming; however, real-time systems will probably be available within the foreseeable future, as is indicated in another area of application, that of simulators. Finally, the combination of computer animation and computer games could result in a new form of representation not yet realized, a kind of adventure in the area of movies in which users themselves make the decisions which control the sequencing of the action anticipated by programs. Methods of this kind could also be utilized in a meaningful manner in the framework of art; Charles Csuri, for example, has developed a computer-animation configuration which allows the spectator to interfere in and change the sequence of events.

## 9 Computer Texts

Up to the present there have been comparatively few attempts at the generation of computer texts. The earliest computer poems are by Theo Lutz; these were programmed at the Mathematical Center of the Technische Hochschule (now University) of Stuttgart, and published in 1959. Each of eight nouns was linked to one of eight adjectives by one of four given logical junctures. In the following example the vocabulary was taken from Kafka's novel *The Castle:*

Nicht jeder Blick ist nah. Kein Dorf ist spät.
Ein Schloß ist frei und jeder Bauer ist fern.
Jeder Fremde ist fern. Ein Tag ist spät.
Jedes Haus ist dunkel. Ein Auge ist tief.
Nicht jedes Schloß ist alt. Jeder Tag ist alt.

Rul Gunzenhäuser produced some computer-generated poems in 1963; his poem *Weihnacht,* whose vocabulary was made up of words from the semantic area of the concept Christmas, was widely published (see p. 67).

Gerhard Stickel's *Monte-Carlo-Texte* are among the first computer lyrics. They were published in the *Programm-Information PI-21* of the Deutsche Rechenzentrum, Darmstadt. Stickel gives a brief description of his methods and then presents five *Autopoems* two examples are given below:

Autopoem No. 303

Wenn die Dunkelheit spielt, erstarrt ein Abend
Gold und Schönheit strahlen manchmal
Ich tanze und sinne
Oft berührt mich das Gras
Die Glocke wächst rauh und golden
Pfade und Boten sind drunten stürmisch
Wer küßt eine Pflanze? –
Der Poet

Autopoem No. 312

Die fröhlichen Träume regnen
Das Herz küßt den Grashalm
Das Grün verstreut den schlanken Geliebten
Fern ist eine Weite und melancholisch
Die Füchse schlafen ruhig
Der Traum streichelt die Lichter
Traumhaftes Schlafen gewinnt eine Erde
Anmut friert, wo dieses Leuchten tändelt
Magisch tanzt der schwache Hirte

In the Deutsche Rechenzentrum, Darmstadt, in the period between 1966 and 1968, so-called *Verbale Blockmontagen* were produced on the IBM 7090 in collaboration with Otto Beckmann; for example:

blaues zittern sucht die sorge
silbern sind die lüfte
ich tröste die lerchen

*

träume und fische
sind schlank und zärtlich
blau erscheint das traumhafte reh
ein magischer klang spielt
und morgen regnet die stille

*

trauriges erstarren
erlebt die bitteren minuten
wenn der raum weint
entdeck ich die tage

*

das sinnbild lächelt in dem sinnbild
der tropfen jagt das ruhende verlangen
morgen
schließt sich
die Zeit

The program TAPE MARK 1 was developed by Nanni Balestrini in Milan in 1961. It is based on three texts written by human beings and subsequently subdivided and recombined; for example:

CHI MANCAVA DA UNA PARTE ALL ALTRA SI LIBRA AD ALI TESE
ASPETTANDO CHE FINISCA L ARIA DA RESPIRARE FACENDO FINTA
LE PAROLE NON DETTE NELLA BOCCA PIENA DI SANGUE TUTTO TACE
FINO AI CAPELLI APPICCICA ALLA PELLE NON CAPITERA MAI PIU
LO SGOMBERO DELLA NEVE ORA GIALLA ORA VERDE NESSUNO VOLEVA RESTARE

ATTRAVERSANDO BOCCONI LA DISTANZA ESATTA PER FARNE A MENO
LA FOLLA CAMMINAVA AGAGIO NON CAPITERA MAI PIU LE DITA IMMERSE
NELL ISTANTE INATTESO MONTACI SOPRA ORA GIALLA ORA VERDE
L ARIA DA RESPIRARE ASPETTANDO CHE FINISCA I PASSI NECESSARI
FINO AI CAPELLI L ESTATE FU CALDA NELLE NOSTRE TENEBRE

TUTTO TACE NELLA BOCCA PIENA DI SANGUE LO SGOMBERO DELLA NEVE
SU TUTTA LA STRADA I PASSI NECESSARI PERCHE NON ENTRINO I LEONI
SI LIBRA AD ALI TESE SULL ERBA FUORI L ESTATE FU CALDA
NON CAPITERA MAI PIU LA FOLLA CAMMINAVA ADAGIO DA UNA PARTE ALL ALTRA
L ARIA DA RESPIRARE FACENDO FINTA IMMOBILI GIORNI

ORA GIALLA ORA VERDE MONTACI SOPRA FINO AI CAPELLI
NESSUNO VOLEVA RESTARE DA UNA PARTE ALL ALTRA IL TENDINE E SPEZZATO
PER FARNE A MENO SPUTA ANCHE IL MIELE FACENDO FINTA
I PASSI NECESSARI SU TUTTA LA STRADA LA DISTANZA ESATTA
NON CAPITERA MAI PIU LE DITA IMMERSE GUARDANDO BENE

Among computer texts of more recent date mention should be made of the *Haiku Poems* by Margaret Masterman and Robin McKinnon Wood; for example:

eons deep in the ice
I paint all time in a whorl
bang the sludge has cracked

eons deep in the ice
I see gelled time in a whorl
pffftt the sludge has cracked

all green in the leaves
I smell dark pools in the trees
crash the moon has fled

all white in the buds
I flash snow peaks in the spring
bang the sun has fogged

The computer poem *The House,* of which an extract is printed below, is by Alison Knowles and James Tenney.

A HOUSE OF STEEL
IN A COLD WINDY CLIMATE
USING ELECTRICITY
INHABITED BY NEGROS WEARING ALL COLORS

A HOUSE OF SAND
IN SOUTHERN FRANCE
USING ELECTRICITY
INHABITED BY VEGETARIANS

A HOUSE OF PLASTIC
IN A PLACE WITH BOTH HEAVY RAIN AND BRIGHT SUN
USING CANDLES
INHABITED BY COLLECTORS OF ALL TYPES

A HOUSE OF PLASTIC
UNDERWATER
USING NATURAL LIGHT
INHABITED BY FRIENDS

A HOUSE OF BROKEN DISHES
AMONG SMALL HILLS
USING NATURAL LIGHT
INHABITED BY LITTLE BOYS

A HOUSE OF MUD
IN A HOT CLIMATE
USING ALL AVAILABLE LIGHTING
INHABITED BY FRENCH AND GERMAN SPEAKING PEOPLE

A HOUSE OF MUD
IN A HOT CLIMATE
USING NATURAL LIGHT
INHABITED BY COLLECTORS OF ALL TYPES

A HOUSE OF GLASS
IN MICHIGAN
USING NATURAL LIGHT
INHABITED BY FRIENDS

A HOUSE OF SAND
IN A HOT CLIMATE
USING NATURAL LIGHT
INHABITED BY LITTLE BOYS

A HOUSE OF BRICK
IN HEAVY JUNGLE UNDERGROWTH
USING CANDLES
INHABITED BY AMERICAN INDIANS

A HOUSE OF DISCARDED CLOTHING
IN DENSE WOODS
USING NATURAL LIGHT
INHABITED BY LOVERS

A HOUSE OF DUST
ON AN ISLAND
USING CANDLES
INHABITED BY NEGROS WEARING ALL COLORS

Programs for concrete texts by Edwin Morgan and by R. John Lansdown should be mentioned. Jean A. Baudot has been engaged in the automatic generation of sentences, and E. Mendoza,

REJECT JUDGE LOVES ANARCHY

TILES LIKEGRIT
LIKETIME
LIKEZINC

LIKEWOOD LIKEVEINS LIKEMORTAR LIKEFLOWERS LIKECHROMIUM LIKE
LIKETIME LIKEGLASS LIKEPOETRY LIKEPLANETS LIKEMACHINES LIKE
LIKEGRIT LIKECHALK LIKETIMBER LIKECRYSTAL LIKEMINERALS LIKE
LIKESNOW LIKEROCKS LIKEBRECKS LIKECOBBLES LIKEPATTERNS LIKE
LIKESAND LIKETILES LIKESTECKS LIKEGRANITE LIKECONCRETE LIKE
LIKEIRON LIKEGLASS LIKEPOETRY LIKEPLANETS LIKEMACHINES LIKE
LIKETIME LIKECHALK LIKETIMBER LIKECRYSTAL LIKEMINERALS LIKE
LIKEBONE LIKEVEINS LIKEMORTAR LIKEFLOWERS LIKECHROMIUM LIKE
LIKESAND LIKETILES LIKESTECKS LIKEGRANITE LIKECONCRETE LIKE
LIKESAND LIKEEARTH LIKESTONES LIKESCARLET LIKE LIKE
LIKETIME LIKESTEEL LIKELEAVES LIKEPEBBLES LIKESUNLIGHT LIKE
LIKESNOW LIKEVEINS LIKEMORTAR LIKEFLOWERS LIKECHROMIUM LIKE
LIKEBONE LIKETILES LIKESTECKS LIKEGRANITE LIKECONCRETE LIKE
LIKESOIL LIKECHALK LIKETIMBER LIKECRYSTAL LIKEMINERALS LIKE
LIKESOIL LIKEROCKS LIKEBRECKS LIKECOBBLES LIKEPATTERNS LIKE
LIKE STEEL LIKE CEMENT
LIKE GLASS LIKE SILVER
LIKE VEINS LIKE SILVER
LIKE CHALK LIKE LOAVES GRANITE
LIKE TILES LIKE LEAVES CRYSTAL
LIKE ROCKS LIKE POETRY PEBBLES
LIKE EARTH LIKE MORTAR PLANETS
LIKE TREES LIKE TIMBER FLOWERS

WHEN YOU SEE THE ROAD PLEASE SAY THIS POEM BEGINNING QUIETLY

LIKELEAD LIKEPAPER LIKEBRICKS LIKEFLOWERS LIKEPATTERNS LIKE
LIKESOIL LIKETILES LIKEMARBLE LIKEPLANETS LIKE LIKE
GRASS LIKEBRICKS
BONE LIKETIMBER
LIKEMARBLE
LIKEMORTAR
LIKEGRAVEL
LIKECOPPER
LIKECEMENT
LIKESILVER
LIKELEAVES

LIKE EARTH LIKE MARBLE LIGHT
LIKE TILES LIKE MORTAR CHALK
LIKE LIGHT LIKE GRAVEL GRASS
LIKE CHALK LIKE COPPER PAINT
LIKE GRASS LIKE CEMENT BRASS
LIKE PAINT LIKE SILVER STONE
LIKES LIKE PATTERNS
LIKESO LIKECHROMIU
LIKEBON LIKEMINER
LIKEWOOD LIKEPAT
LIKELEAD LIKE

◁ *117* Poems for SPASMO *by Alan Sutcliffe. These works are components of SPASMO, a multi-media composition for magnetic tape and color slide presentation. Each run of the program produces 256 poems. Through the input of a vocabulary and other data, a fresh series of poems can be produced. The program is written in FORTRAN and was run in the ICL office at Reading, Berks., on an ICL 194. The première took place on February 10, 1969, in the Queen Elizabeth Hall, London*

of the Physics Department of the University College of North Wales, has produced computer essays. From Alan Sutcliffe there is the series of poems which arose in the context of the multi-media program *SPASMO*. At the University of Surrey, Guildford, England, the Poetry Group, consisting of Robin Shirley, Graham Wallen, Jeff Harris and Lynette Willoughby, has been occupied with computer-produced poetry. A series of works based on a general program language for the creation of poetry - BARD 1 - is in the planning stage.

In 1967 and in 1969 - in an extended edition -, Manfred Krause and Götz F. Schaudt presented a booklet containing some dozens of poems which were written with the aid of computer programs. The attempt to present computer generated alternative versions of existing poetry written by human authors in combination with the author's original version, challenging the reader to select the original, is indeed remarkable. Two examples are given below.

*Weil späte Tränen*

Und weite Lieder flüchtig gleichen
Doch Gräser warnend Höhen geben
Weil hohe Funken perlend weichen
Da Strahlen murmelnd Klänge weben

Zwar kranke Dunkel zagend enden
Denn Blüten schlafend Kreise schwanken
Weil späte Tränen glimmend blenden
Denn Fluten trauernd Lampen danken

Und rohe Stimmen einsam fliehen
Weil Täler leise Grüße breiten
Doch freie Berge langsam ziehen
Da Küsse dämmernd Zweige gleiten

*Because late tears*

And distant songs resemble fleetingly
But blades of grass heights forewarning
Because high sparks are glittering receding
Since rays murmuring weave sounds

However sick darknesses end faint-heartedly,
For blossoms sleeping move circles to and fro
Because late tears dazzle gleamingly
Because floods mournfully thank lamps

And rough voices lonely flee
Because valleys softly spread out greetings
But free mountains slowly move
Since kisses dawning glide branches.

*Nachdichtung Friedrich von Schiller*

Wie heißt der Hirt, wo wagt sich hier
die falsche Dogge treu herfür?
Spricht Thodus hinter Mutes Flammen?
Es stachelt sich im Bauch zusammen,
und einen Bissen, tief im Hirn,
ergreif ich aus der Heldenstirn,
doch unter ihm, solch Sarazen!
hört es bewegt ein Atemwehen,
ein Knappe zieht es im Geschoß,
auf dünnen Basiliskenblicken,
und gar nichts kämpft errötend bloß
die Weisheit ab und oft die Bitten.

*Imitation in the style of Friedrich von Schiller*

What is the shepherd called? Where does
the deceitful bulldog faithfully dare to come out?
Does Rhodos speak behind Mute's flames?
There is a sting in the stomach,
and I grasp from the forehead of the hero
a bite, seated deeply in the brain,
but underneath him, such Saracen!
it hears, moved, the wave of breath,
a page is drawn in the bullet,
on thin glances of basilisks,
and nothing fights off merely blushing
the wisdom and often the requests.

One of the computer-generated works which is worth attention simply because of its volume is the *Volksbuch* (People's Book) by the Austrian Heidulf Gerngross. The raw material consisted of quotes from daily newspapers, detective stories, folklore novels, science fiction, etc. supplemented by passages from folklore songs and mythology. With the aid of a computer and using strict criteria for selecting and connecting the passages, it was combined into a literary work of 1280 pages. The result, full of original and comical passages, is comparable with many products of absurd literature.

## 10 Computer Music

The first attempts to use the computer for musical purposes were made during the period of electronic music on the one hand, and during the period of composition according to aleatory and serial principles on the other hand. Attention was focussed on new instrumental means and approaches to composition theory. Both of them made the abandonment of traditional stylistic rules possible - or rather enforced it: it became necessary to rethink the rules of composition applied so far; furthermore, it became possible to test completely new tonal structures.

The present characteristic direction of serious music is characterized by the use of computers for the production of scores, for their orchestration, as well as for the control of electronic output terminals. The utilization of computers for the purposes of music theory is, particularly because of research in artificial intelligence, an integral part of these various approaches. These activities are so far-reaching that it is not possible to give more than some general indications of a historical and technical nature in the framework of this book.

Research in computer-aided composition began at the end of the fifties, simultaneously in Europe (Jannis Xenakis, Pierre Barbaud) and in the United States (Lejaren A. Hiller); in addition, first successes were achieved on the American side in the area of programmed generation of sounds (Max V. Mathews and Jean Claude Risset, Bell Laboratories: Music V). Music V became the prototype of a whole generation of systems for the generation of sounds (for instance Music 360, Music 10, Music 11), while programs for composition remained to a large extent idiosyncratic (for instance Xenakis: St 10; Koenig: Project One, Project Two). The University of Illinois, where Lejaren A. Hiller made pioneering contributions, may be regarded as the real place of origin of computer music. It was there that the *ILLIAC-Suite* by Hiller and Leonard Isaacson received its première on 9 August 1956. These two men then founded a studio for experimental music at the University of Illinois in 1958, and a number of computer composers who have in the meantime become well known have worked there, including Robert Baker, Herbert Brün and John Myhill. The compiler program MUSICOMP, designed by Hiller and Baker originally for the IBM 7090 and later for the IBM 7094, signifies a considerable step forward. It incorporates a series of subroutines for solving problems of musical composition. This program came through its first test with the *Computer Cantata,* a sequence in five sections, where a successive approximation to spoken English was reached.

Two subroutines are used for the direct control of musical reproduction through the computer; in addition there is a converter of numbers into sounds as well as an output device for sound effects. This total installation, including the ILLIAC II computer, is regarded as the most comprehensive system for production of computer music. The *ILLIAC-Suite* had still to be played by human performers - a string quartet from the University of Illinois. The next large composition by Lejaren A. Hiller, which he created in collaboration with Robert Baker using the MUSICOMP system, was also presented by the chamber orchestra of the University of Illinois with the soprano Helen Hamm.

Between 1967 and 1969 Lejaren A. Hiller, together with John Cage, produced the tonal structure HPSCHD for harpsichord and magnetic tape. Each realization of HPSCHD combines contributions from both musicians - seven solo compositions for harpsichord and 51 computer-produced sequences registered on tape. A special program called KNOBS permits the listener to intervene in the development.

Max V. Mathews, who occupies a leading position in the Bell Telephone Laboratories, has also been working on computer compositions. His composition *Slider* is produced as follows: the notes are indicated in the form of graphic symbols on the screen of a cathode ray oscilloscope by means of a light pen and are taken up by a mini-computer. The intermediate stored information, which already comprises the entire conception of the work, is now transformed into digital character sequences by a large computer, which also synthesizes the sound and projects it instantly over an amplifier. These sound synthesis programs MUSIC N and MUSIC V were also used for several compositions by Gerald Strang, Professor of Electronic Music at the University of California, and by J. K. Randall, Professor in the Music Department of Princeton University. Computer music became known to a wider audience through the gramophone record *Music from Mathematics* (Brunswick LAT 8523). This includes experiments in computer music by M. V. Mathews, J. R. Pierce, S. D. Speeth, D. Levin, N. Guttman and J. Tenney, using an IBM 7090 computer and played with the help of a digital sound transducer, as well as mathematically based pieces by Orlando Gibbons.

In France, too, there have been early moves toward computer music, with Pierre Barbaud taking a leading role. Barbaud, who had been occupied with the mathematization of music since 1950, turned to computers in 1958, concentrating on the elaboration of programs for music composition termed ALGOM. The 'Festival de la Recherche' in 1960 saw the première of his work *C'est 7!* He has since continued his work with the support of the firm of Bull General Electric. In 1958 he founded the *Groupe Algorithmique* with Roger Blanchard; they were later joined by Janine Charbonnier.

There are now several versions of the ALGOM program (after the program language ALGOL), each of them somewhat extending the preceding version. The large number of subroutines in these programs permits the calculation and production of a great variety of tonal and rhythmic orders.

Jannis Xenakis, the well-known specialist in electronic music, who by introducing chance in his magnetic tape-generated music had already been heading toward computer music, designed in 1962 a program which allowed the production of a series of computer compositions.

The European center for studies in computer music was, until 1975, the Instituut voor Fonologie in Utrecht, Holland where Werner Kaegi, Gottfried Michael Koenig, and Otto E. Laske were working. Other studios developed in Stockholm (EMS), Pisa (Pietro Grossi), Padova (Debiasi), and Naples (di Giugno).

Since the mid-seventies, Paris has increasingly become a center of computer music, owing in particular to the establishment of IRCAM (Institut de Recherches et de Coordination Acoustique Musique) which at the present time is drected by Pierre Boulez. The institute forms part of one of the four departments of the Centre George Pompidou; researchers from Stanford University in California who were the first to work at the institute had a lasting impact on its character. In addition, Xenakis established CEMAMU (Centre d'Études Mathématiques et Automatiques Musicales), an institute which is largely devoted to research on computer-aided music education. Finally, a studio developed in the *Groupe de Recherches Musicales* (GRM) directed by Pierre Schaeffer, the discoverer of *musique concrète*.

The centers of development of computer music in the United States are to be found at the large universities of the country, particularly at Stanford University, Colgate University, Princeton University, and at the Massachusetts Institute of Technology (MIT). In all these places, research as well as teaching and composition is carried on. MIT also publishes the most important professional journal in this field, the *Computer Music Journal,* edited since 1977 by Curtis Roads. The (International) Computer Music Association located in San Francisco organizes annual international conferences which are artistic as well as scientific events.

In some institutions, an attempt is made to establish a correlation between graphics and music. One of the first to become prominent with such efforts was Herbert Brün, who teaches at the School of Music of the University of Illinois. By means of electronic music, he attempts to give some kind of improvised interpretation of computer graphics produced by himself. The composer Theo Goldberg works according to much stricter principles, in cooperation with the computer scientist Günther F. Schrack, both at the University of British Columbia in Vancouver, Canada. A separate program is used to generate color graphics. These can be considered to be a kind of notation which sets the limits for the composition of a correlated music program. Besides its didactic purpose, the aim of this work is to generate visual and musical structures which are isomorphic.

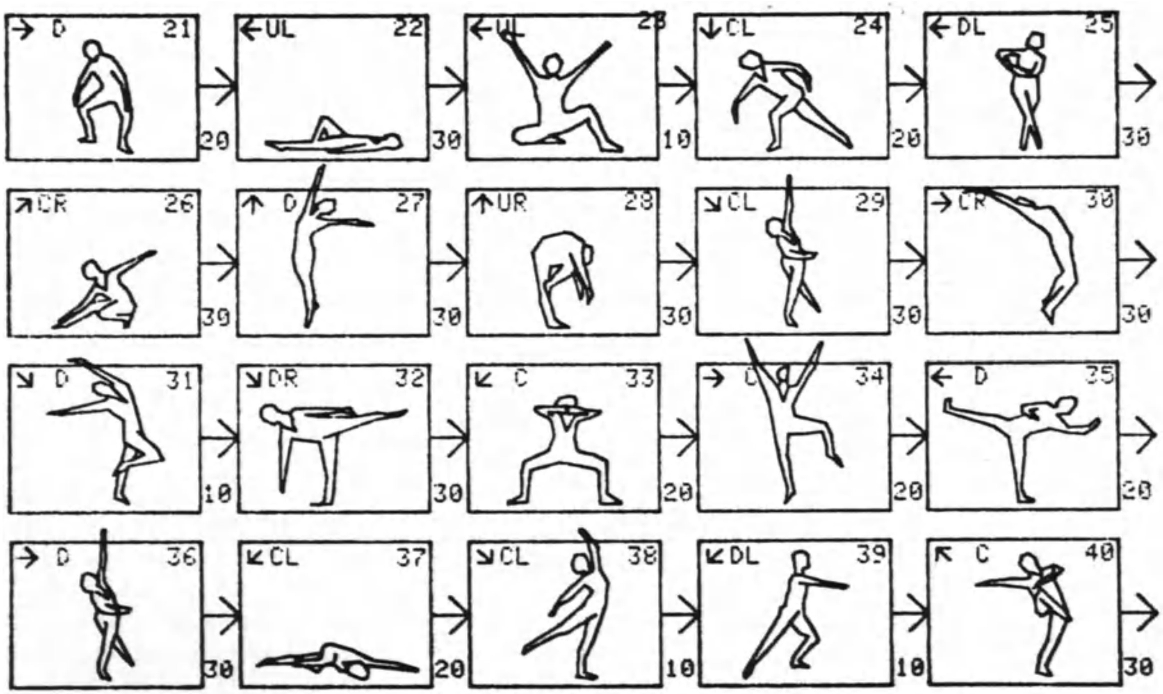
The correlation between computer-generated music and the projection of electronically produced pictures is one of the areas of

study of Guiseppe Englert, Paris. The combination of picture and sound is probably one of the most current subject areas in computer art offering the most diverse range of possibilities: from musical improvisations as a spontaneous reaction to computer-generated sequences to picture/sound compositions based on a common program.
Walter Giers took a completely different route with his *Concert Machine;* it is a kind of "cybernetic sculpture" which is, at the same time, a complex composition system. It produces a concert consisting of the four movements *Nature, Village, City,* and *War.* Infrasound effects which are felt as vibrations are incorporated into the sound effects. The use of random generators result in every performance being an individual composition.

## 11 Theater, Dance, Multi-Media

However attractive the idea of using the computer for multi-media experiments may appear, there are a number of difficulties in the way, mainly relating to the extensive executive support that is required; beginning with a theater and optical and acoustic instruments, they include the problem of finding human or mechanical performers. That is the reason why a number of projects are still in the planning stage.
Marc Adrian, who designed the first concrete texts *Semantische Infra- und Metastrukturen* with the aid of a computer at the Institut für höhere Studien und wissenschaftliche Forschung in Vienna, has also produced, in collaboration with Gottfried Schlemmer and the programmer Horst Wegscheider, a theatrical piece with a digital computer that is ready for performance. The semantic raw material comes from the advertising and editorial sections of three periodicals (*Eltern, Jasmin* and *Spiegel*), and the characterization of the actors from the advertisement section of a newspaper. The computer's function is essentially that of the storing, collecting and mixing of phrases, where this sequence is used as a schema: introductory phrase - catchphrase - end phrase. The program language SNOBOL was used for the generation of this theatrical piece, which is called SYSPOT. There are also programs for experimental theater by John Lifton and George Mallen and by R. John Lansdown.

The dance, too, is within the realm of musically accompanied space-time performances.
Among the first products of computer-programmed choreography were the *Random Dances* developed by Jeanne H. Beaman jointly with Paul Le Vasseur of the Computer and Data Processing Center at the University of Pittsburgh. The computer, on the basis of a randomizing principle, determines the selection and sequence from three lists of instructions.
A. Michael Noll has also worked with computer-generated choreography. In one of his three-minute films (see Fig. 55, p. 64) the motions of dancers on a stage were symbolized by stick men. By such means the choreographer, collaborating with a computer, can develop dances with sight control.
R. John Lansdown has devised a program for the choreography of a short ballet, which was screened on BBC television. Analivia Cordeiro, the daughter of Waldemar Cordeiro, also employed the computer for choreographic purposes. Norman I. Badler together with Stephen Smoliar, Pennsylvania, established a connection with earlier efforts to produce a choreographic notation by attempting to transfer labanotation to the computer. A system generated by Edward Dombrower, a dancer who graduated with a degree in applied mathematics, in collaboration with the engineer Mike Lopez, both living in the United States, points in the same direction. It allows the threedimensional, although simplified representation of dance figures.
Work is also proceeding on guidance systems for sound and light performances which are based on and controlled by computer calculations; in this connection, a large-scale project of the Mimi Garrard Dance Company which is aimed at creating computer-aided composition and at achieving computer-aided performance control, including the control of light effects and other effects, is worth mentioning.
The first publicly performed multi-media show - *SPASMO* - was devised by Alan Sutcliffe, London. This is a program-directed interaction of magnetic tape effects, color slides and solo piano. In addition, the active participation is invited of the audience, who are given the task of reciting computer-written poetry. The program, written in FORTRAN, was realized on an ICL 1904, one run producing 256 poems (see Fig. 117, p. 136). Various series of poems are produced according to the vocabu-




*118* Dance Script, *notation of a sequence of dance movements from a computer program, by John Lansdown*

lary. The performance took place in the Queen Elizabeth Hall, London, in 1969.

The Munich composer Josef Anton Riedl, whose departure point is electronic music, also aims at the multi-media show. In his light-sound presentations, acoustic happenings and "Ars-Nova" recitals, he combines electronic with conventional music and projects slides of computer graphics.

## 12 Computer Architecture

According to the classical division of disciplines, architecture is part of the arts, but the professional reality of modern architecture hardly confirms this division. More and more often, the commissioning party turns to a construction company directly without consulting an architect. A multitude of regulations passed by the municipality limit the freedom of design, but costs especially are a limiting factor.

By now, computer graphics systems are used in the construction industry as a matter of course. This is, however, of little interest to the arts – basically, the methods of computer-aided design (CAD) patterned after the aeronautics and automobile industry are being applied. Architects are reluctant to make the transition to computer graphics due mainly to the fact that the systems which are required for somewhat demanding tasks, for example three-dimensional perspective output, are still relatively expensive. But as more and more powerful small computers become available at increasingly lower costs, the situation will soon change considerably. In a profession like that of the architect, in which more than fifty percent of the work is devoted to producing drawings, the use of a computer-aided mode of operation offers so many advantages that it cannot be ignored in the long run. One of the first architects who made use of computer graphics was Ronald Resch. He used a computer to calculate the frame construction of a *geodesic dome* by Buckminster Fuller, and managed to produce a number of variations with the aid of a computer system. Since 1968 several teams in the Laboratory of Computer Graphics, Harvard University, have been concentrating on problems in this area. John Weeks has applied the computer for design purposes in architecture. He left the arrangement of structural elements in the design of an exterior wall for a hospital to a computer random number generator.

An instance of computer application for bridging the creative and the optimizing phases in architecture is found in the work of the Munich architect Ludwig Rase. The relevant program, worked out by Georg Nees, leads to the graphic representation of the building in various perspectives, and decisions on certain building characteristics are taken on the basis of these drawings. Another example by Rase and Nees concerns an exhibition stand. The commission included several restrictions as regards the division of available space, and furthermore the pallets had to be six-sided. The computer drew the most varied ground plan projections. Finally, the computer drew several perspective views of the selected execution design. The collaboration between man and machine led to the resolution of constructive problems.

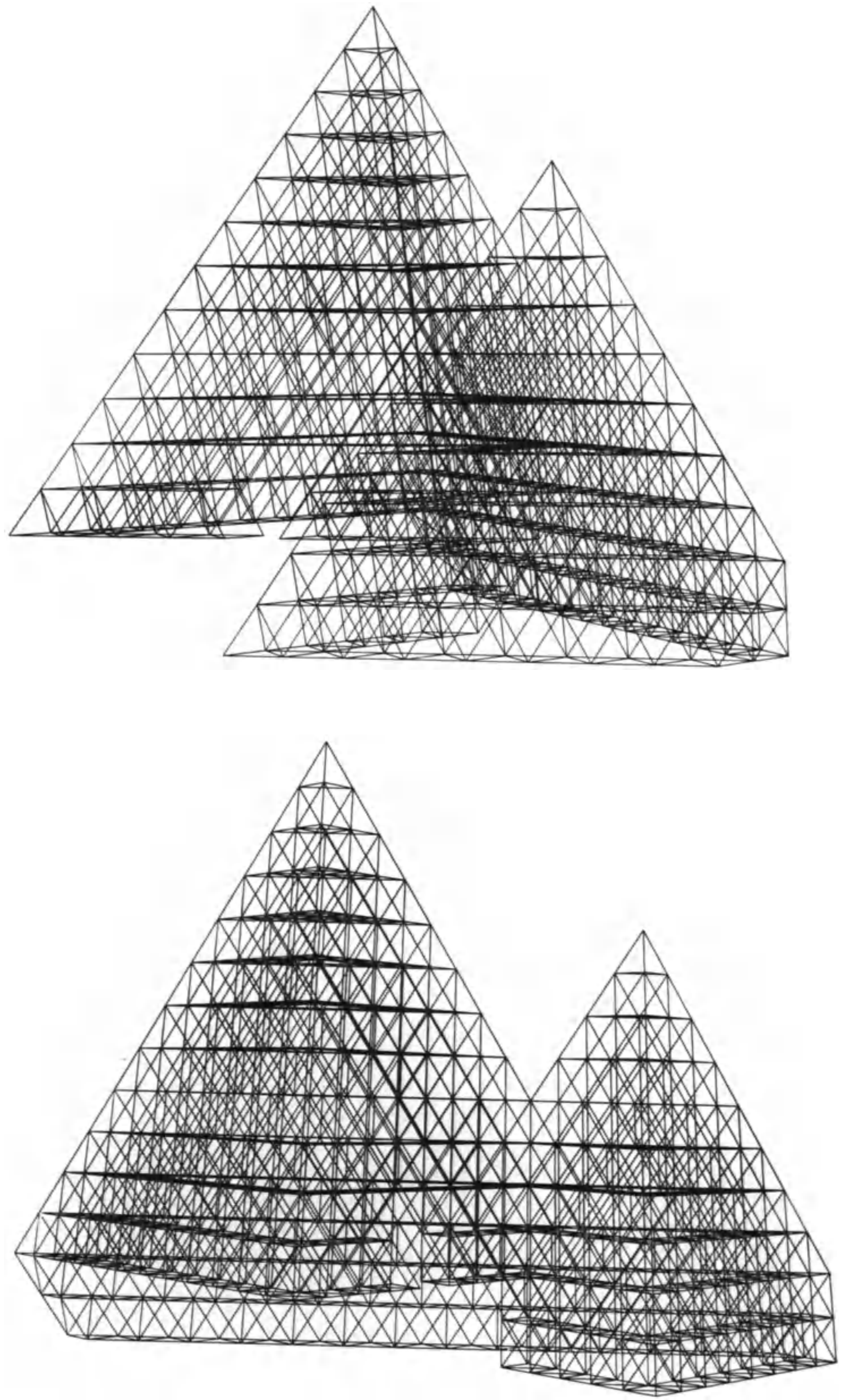
Architecture and town planning clearly provide a wide field for the application of computers. Ludwig Rase underlines this idea in his writing: "This example is perhaps a pointer to the future tasks of the computer, which are not merely confined to the creation of single buildings but can extend to the shaping of integrated systems such as apply in town planning. But in order to coordinate these difficult problems and maximize the inherent creative possibilities, it will be necessary for all professionals such as sociologists, doctors, traffic planners, building constructors, civil engineers and other experts to join in this approach." But such applications of the computer fall within the province of technology rather than art, and will not be pursued here any further.

Similarly, computer graphics has quite often been employed as a tool, especially for the planning of large scale projects. Boyd Auger created the *Basic Architectural Investigation and Design Program One* which was implemented during a workshop on computer-aided design at the Department of Engineering of the University of Leicester. It is intended to be used for the design of developments of medium to high density and is meant especially as an alternative for high-rise developments. Another program called TOPAZ (Technique for the Optimum Placement of Activities into Zones) designed for city planning was developed by Eric Teicholz and Helvio Mation from 1972 to 1974. The program ECOSITE created by Robert Mallary, University of Amherst, is worth mentioning. It is concerned with earth movement calculations in connection with open pit mining, giving special consideration to aesthetic aspects.

Most of these and similar advanced efforts which attempt to solve problems of large scale projects of architecture and environmental control are carried out in cooperation with universities. The *Architectural Machine* of Nicholas Negroponte's team at MIT is one of the most spectacular projects. It is remarkable particularly because of its utopian component: Its fictitious aim is to replace the architect by a robot. The results which are of practical use are side-products of the solution of partial problems; for instance, the team is involved in the design of cardreading automata and of program-controlled distribution of cubic building modules.

## 13 Applied Computer Art

For a long period of time, the activities of free aesthetic computer-aided design were regarded by other computer users with skepticism or with condescension. This may be caused by the different mode of operation of computer artists which is far less deterministic and goal-oriented than that of commercial and technical computer users. Thus, it is quite customary for computer graphic artists to be led by preliminary results when determining their aim; frequently, particularly when using random generators, the result is quite unexpected and surprising for the aesthetic programmer. It even happens that a programming error pro-



*119 Computer drawings of a spatial lattice structure by Ludwig Rase. The program, written by Georg Nees, produces the drawing of any chosen perspective view* vides impulses for a design which is only vaguely defined or that inadequacies of the system, for example interferences as a result of insufficient resolution of the screen, are used and amplified as artistic effects. Computer scientists opposed to computer graphic art overlook, however, the fact that the unconventional manner of programming, as it is used for aesthetic experiments, has a tremendously stimulating effect, that it leads to a better understanding of the systems and of one's own method of working, and that, occasionally, it even yields results which appear usable also from a mathematical or technical viewpoint.

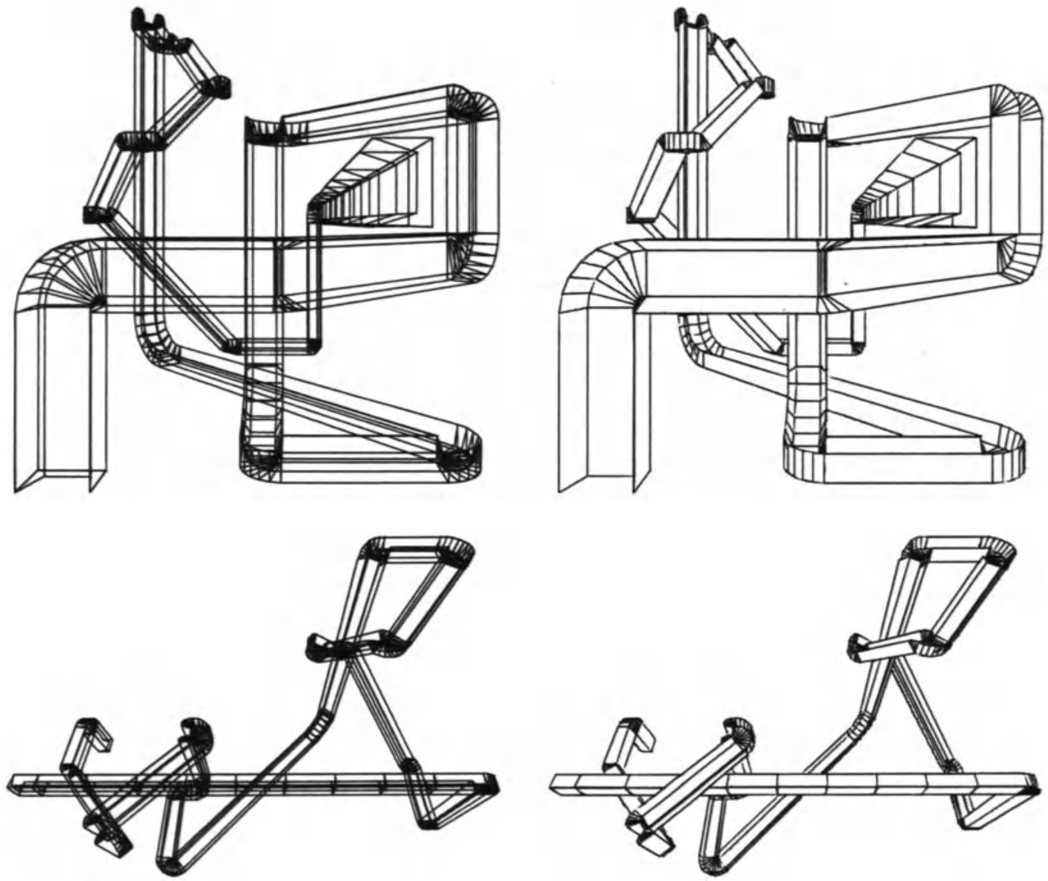
But meanwhile the skeptical attitude of professional computer scientists towards computer art has changed, one reason, and not the least important, being that amazing applications from the wealth of experience in aesthetic programming gathered over the years have emerged in some commercially oriented areas. Some of these areas have for the longest time been part of the list of traditional professions; the computer is merely being added as a new tool offering a diverse range of advantages. All branches of design belong to this type of application, ranging from textile design to industrial design to architecture. In addition, completely new areas of application have developed as a result of the availability of computer graphics; computer games ought to be mentioned in this context, the use of simulation and animation techniques in film and video, computer-aided visualization of instructional material, and the possibility of experimental aesthetics to support a rational art theory. As for some of the new areas of application, it is probably the already existing professional groups which will adapt to the new tools, such as designers and educators. In other cases, new professions seem to emerge, for instance in the area of computer games and animation. The members of traditional professions are the ones who show considerable opposition to the use of the computer in their professional field, often for emotional reasons; the reasons are to be found, to a large extent, in lack of education: Teachers who were trained in previous generations are not familiar with the use of computers and programs and therefore cannot prepare students for the use of the new tools.

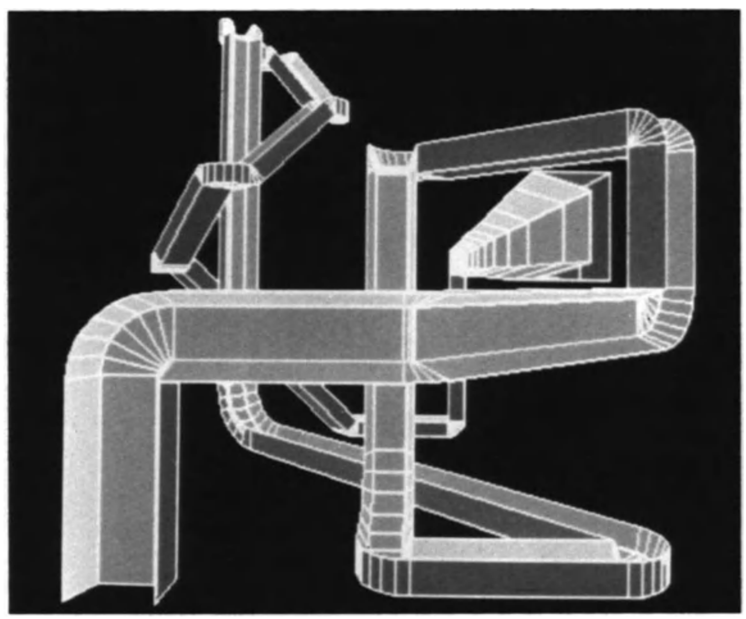
The computer-aided activites discussed in the following summary rarely permit a definite determination of whether initiatives originated more from professional computer scientists or from computer users with a different background. In any case, user-oriented interactive systems greatly facilitate access to members of professions not related to computer science, and, indeed, the increase in painters and designers who have become computer users is noticeable.

## Design

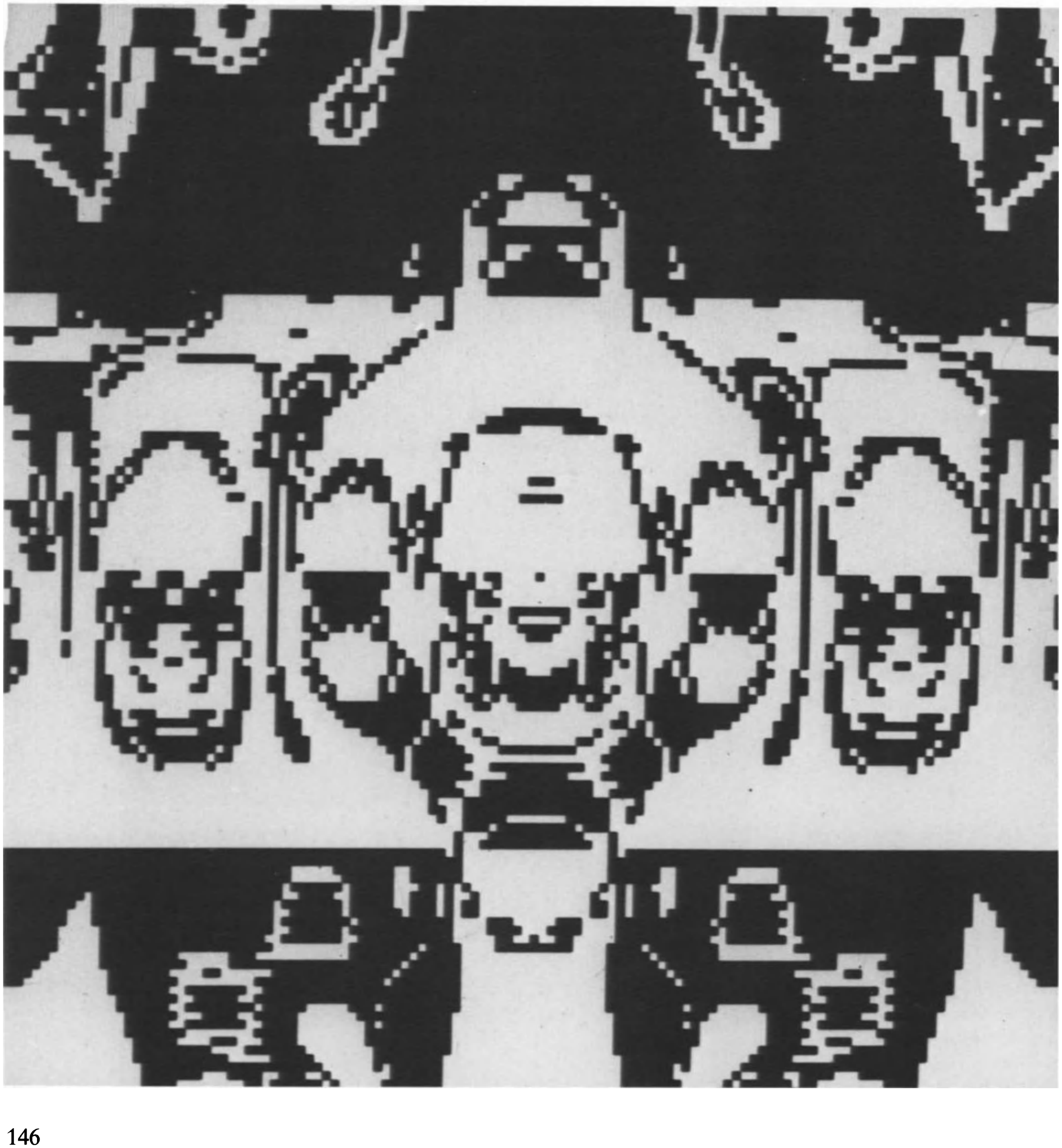
The efforts of computer-aided design (CAD) were initially restricted to technical problems, to designs of machine parts, auto bodies, construction of scaffolds, etc. But the methods which have thereby become available can be applied, at the most slightly modified or supplemented in many areas of design, which stress artistic components or in which these become dominant. Design sessions at the terminal, the possibility of getting realistic pictures from interim results which are then optimized step by step - all this can be applied in product design. The use of computer graphics appears to be particularly advantageous where large and expensive products are involved for which models can be produced only at considerable cost and expense of time. Therefore it seems understandable that aeronautics and automobile engineers were the first ones to make use of computer-aided methods. Of course, it involves a certain amount of reorientation for a designer who was educated at an institute of technology, to have to develop ideas on the basis of a range of modeling techniques such as wire frame and solid models. In practice, however, this change has proved to present no major problems. In cooperation with design engineers, additional tools were developed for such tasks, for instance scanning systems for the determination of spatial coordinates of already existing models for three-dimensional input. Devices of this kind confirm that in present design, objects are rarely ever developed from scratch, but are usually based on existing forms which have to be improved or adapted to new circumstances.

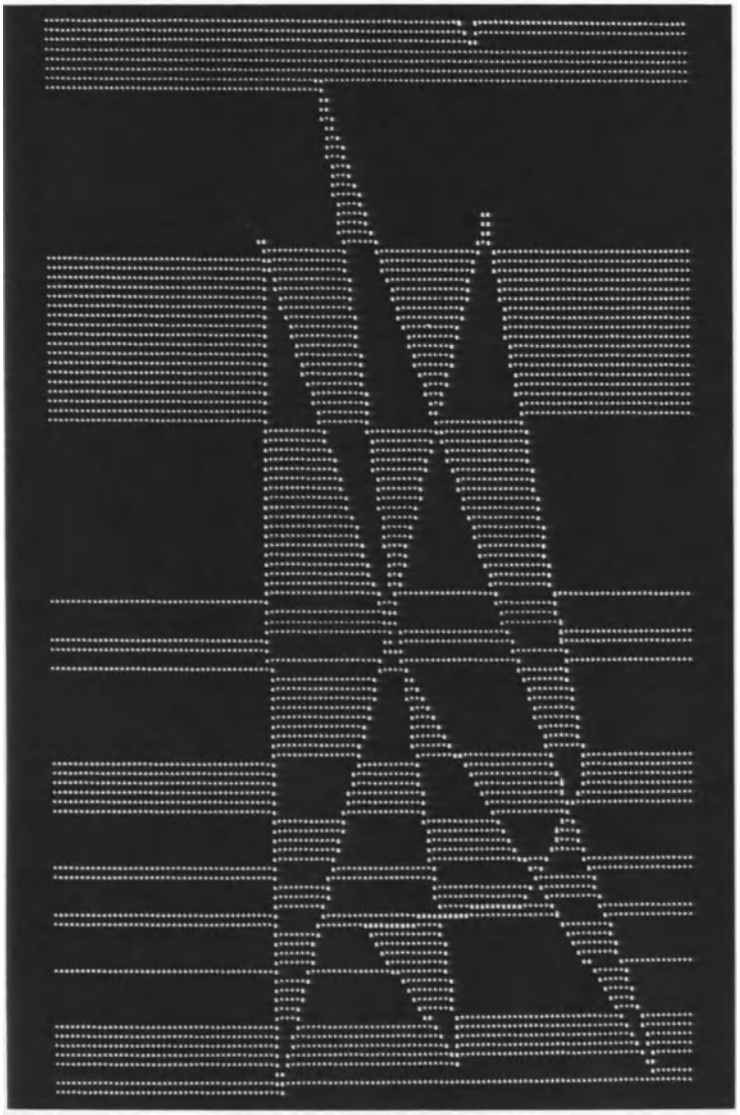
Since architecture is traditionally considered to be an art form, it will be discussed in another context; but it should at least be mentioned that the newly developed CAD techniques offer good possibilities for application by architects. Architecture is closely related to town planning and environmental control, a design problem of the highest order.

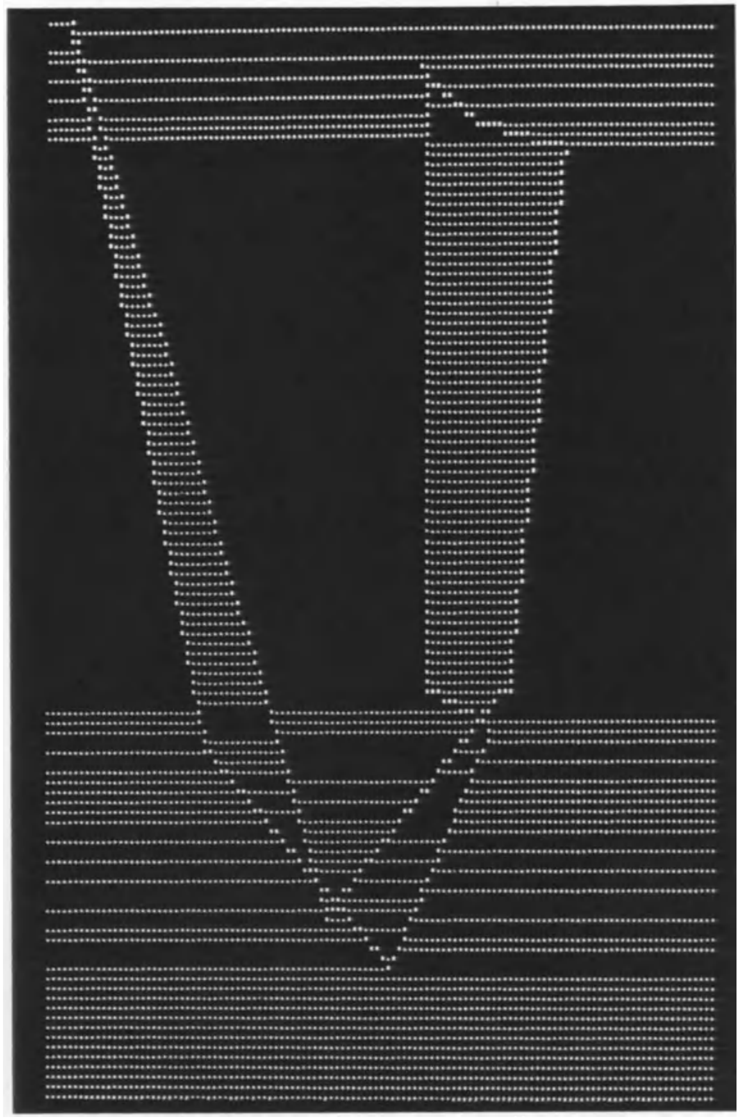




*120 Three-dimensional form (CAD),* left side *as a wire frame model,* right side *with cover,* below *with colored surfaces (denoted here by shading) Robert Ross and Günther F. Schrack, The University of Columbia, Vancouver*







*122 Two examples from the program ICARE, printed on a fast printer; G. F. Kammerer-Luka and J. B. Kempf, Belfort. The subject matter is city planning*

*◁121 Layout for a stage backdrop, by Herbert W. Franke and Horst Helbig; system DIBIAS, DFVLR, Oberpfaffenhofen*

The computer-aided mode of operation also allows the application of the techniques of mapping, for instance as a basis for geographic surveying which is the basis for planning on a large scale. The large scale use of computer graphics systems for such problems as discussed above require extensive preparations and will probably not be ready for use for the next five to ten years. In this context, the initiative of Robert Mallary, computer graphics artist and sculptor at the University of Amherst, to establish an interdisciplinarian team is worth mentioning. The team is studying possibilities of restoring landscapes which have been disturbed by open pit mining.

An important special area of design which differs considerably from the situation discussed above is the design of patterns for textiles, wallpapers, wrapping paper, etc. As mentioned before, special hardware systems were developed for this purpose. Color raster terminals are particularly useful, the resolution of which does not need to be high, since it serves no purpose to increase the closeness of the woven or knitted material which is determined by the size of the stitch or the tightness of the weave. Technical limitations are imposed merely by the problems created by matching the elements of a continuously repeated pattern. Constraints of this kind can easily be dealt with in the program by taking advantage of their symmetry and by visual inspection.

Scanners which allow the scanning of colored patterns of manually produced prototypes and their input into a computer are required as peripherals for this method; in this manner, the gap between traditional manual work and the use of modern technology is bridged.

The latest developments of microprocessors, which led to the routine use of color terminals, in no way renders special textile computers superfluous, because they provide a connection to the control units for the knitting and weaving machines. Thus, the material can be produced on-line from the design to the ready-made product.

The universally usable microcomputer with an attached color screen can indeed compete with work stations for textile design, given the possibilities it offers for the generation of designs. The consequences resulting from this development are rather interesting from a social viewpoint: Every owner of a personal computer is basically in a position to design the patterns for his home environment; basically, it is already possible today to have materials, wallpapers, etc. printed according to one's own designs or wishes, but industry is not yet sufficiently organized or prepared. This example clearly demonstrates that the increased use of computers, in connection with interactive methods which are oriented towards human needs, does not at all lead to the uniformity which many people have been afraid of, but will contribute to the shaping of our environment.

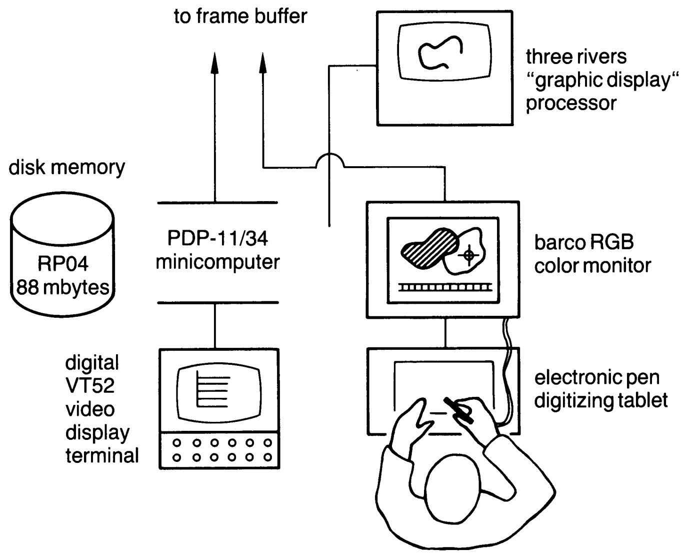
## Games and Entertainment

When computer games became popular, their connection with computer graphics activities was hardly noticeable. The principal task seemed to be the invention of new games utilizing the latest electronic capabilities and the description of their rules in algorithmic form. Graphical programming for the figures on the screen was realized in the most primitive way, primarily to save memory space. As storage modules and other hardware became cheaper, this limiting factor was no longer a decisive factor, and therefore nothing precluded the use of more intricate pictures. This, in turn, awoke the games manufacturers' interest for the methods and experiences of artistically oriented computer graphics, in particular simulation and animation. In fact, the dividing line between simulation work stations and computer game systems cannot be drawn exactly and will probably become more blurred. Some of the games offered in arcades show close resemblance to training sessions which pilots are exposed to in simulators. This type of simulation game also points to a future form of medium which will appear as a successor to television and film. What is meant is an "experience theater" in which the visitor is engulfed by a simulated environment; the sequence of events will then depend on the visitor's own decisions, controlled by a complex master program.

## Animation

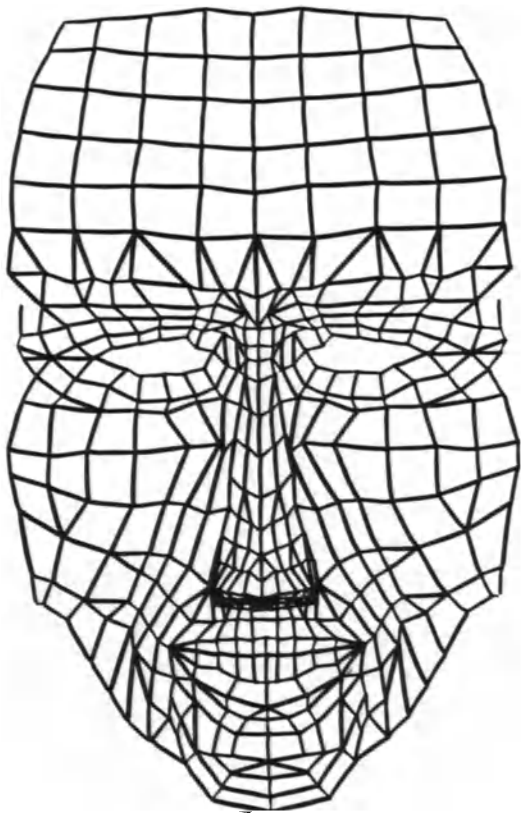
Animation in its strict sense is defined as the generation of animated pictures for cartoons, and, in fact, computer graphics has proven to be an excellent tool in decreasing their cost of production. The simplest kind of use which is, however, quite convinc-

ing in its usefulness is the production of intermediate frames. While ordinarily 24 only slightly varying frames have to be produced manually for every second of film, the preparation of only a few key frames for the required sequences is now sufficient. The method of interpolation is used for this: The computer is capable, by simple calculation, to indicate any number of intermediate points of the process which is predetermined by only a few nodes. If two nodes in two similar drawings are matched, the result of the interpolation is a representation which can be interpreted as a transitional picture from the first to the second drawing. This rather simple use of computer technology already results in considerable savings in time and cost. The same argument holds for the matching of colors which requires little time when done on a terminal screen, whereas the coloring of the transparencies which were necessary so far was one of the most time-consuming activities.
Once computer graphics has started to conquer the animation studio, it will be only a matter of time until other methods are used, for example for designing the layout of a drawing. Depending on the subject matter of the film, certain graphical objects, for example trees, houses, figures, can be prepared independently and subsequently displayed on the screen in any required size, orientation, color, or they can be combined, etc.
Whereas the classical animated film was limited to a two-dimensional, at best pseudo-perspective representation, the methods of computer-aided design allow access to three-dimensional animation. If one is satisfied with simplified representations, for example a kind of computer-generated puppet film, the expenditure of computer time can be kept within limits. Its potential increases enormously, however, if real-time animation is attempted: representations true to reality which are indistinguishable from television or motion pictures. In order to achieve adequate quality, frames of high resolution are necessary, at least with 1024 x 1024 picture elements. But then, each frame requires five minutes of calculation time, even on large computer systems like the Cyber 174. This is an example of a computer application for which a further increase in storage capacity and computing power would be useful. So far, three-dimensional animation with realistic representations has only been used once for a motion picture, a science fiction movie - a meaningful kind of use, since it in-




*123 Schematic view of the animation station of the computer graphic laboratory of the NYIT (New York Institute of Technology), Old Westbury*

cludes landscapes and settings which do not exist in real life. The animation part of this film was produced at the New York Institute of Technology, Long Island. It created work stations especially designed for the use of trained painters and graphic artists which allowed the classical kinds of drawing and painting, but in addition a number of operations which cannot be realized by means of pencil, brush, and paper, for instance the temporary partial enlargement of images or the simultaneous output of stored partial pictures.
The first computer-aided animation system developed especially for producers of animated cartoons was designed by Alan Kitching; it is called *Antics,* operates interactively, provides various methods of interpolation and distortion besides the usual means of modeling a picture, and finally outputs the results to a camera or video monitor.
It was probably George Lucas who first recognized the possibilities offered by computer animation. He established his own insti-



*124 Wire frame model of a face, from a series of studies on human facial expressions; Stephen M. Platt, Department of Engineering, Swarthmore College and Department of Computer Science, University of Pennsylvania*

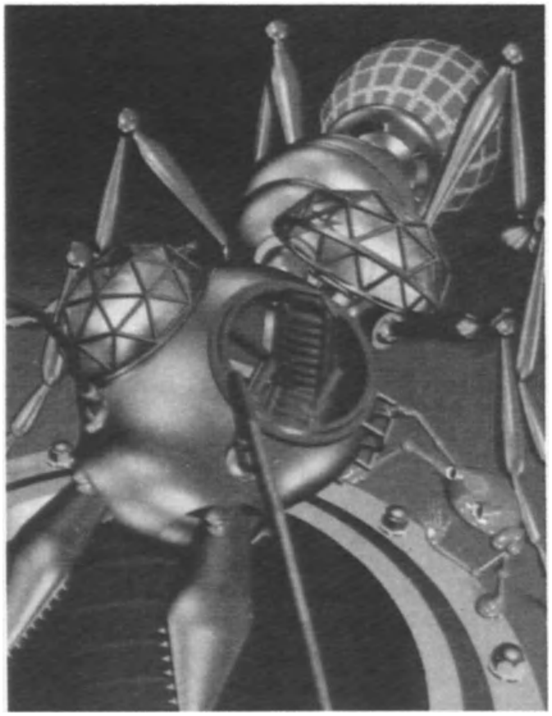
tute as part of his department for animated films for which he engaged the best-known computer graphics artists of the United States: among others Lauren C. Carpenter, Edwin E. Catmull, David DiFrancesco, Alvy Ray Smith, and, at times, James Blinn who had become well known for his computer-enhanced NASA pictures of Saturn (see Fig. 57, p. 69) and Jupiter. Ed Catmull created a picture algorithm which proceeds on the basis of curved patches, a technique which was further developed by James Blinn. The artist David Em, who is supported by NASA, uses this system for the generation of cosmic sceneries which closely resemble reality (see Fig. 77, p. 89).

The Computer Animation Institute of the Lucas Film Society created that scene in *Startrek II: The Wrath of Khan* which shows a landing on a planet with a remarkable arcing swoop over a mountainous landscape dotted with lakes (see Fig. 78, p. 90, and 79, p. 91). It was generated with the help of fractals proposed by Benoit B. Mandelbrot, i.e. mathematical configurations of fractioned dimensions.

The first users of computer animation in film were satisfied with schematic representations, for instance in the first of the *Star Wars* motion pictures to which Larry Cuba contributed long flight sequences over an artificial celestial body. Similar effects were used in *Alien* and *Black Hole*.

A production that adequately reflects the present state of computer animation is the cinema film TRON. Besides one of the most advanced computer graphics institutes in the world, the Lawrence Livermore Laboratory in California, some of the best-known commercial computer graphics studios took part in its production: III (Information International Inc., Culver City, Ca.), also called Triple I, the Robert Abel Studios in Los Angeles, Digital Effects in New York, and MAGI (Mathematical Applications Group Inc., Elmford, NY). They all earn their living by producing commercial advertisements and title sequences. The plot of the movie TRON is trivial, but its artistic computer world is that much more fascinating: A programmer for computer games gets lost in the fictitious world created and experiences those adventures at close range which are usually set in motion from outside, at the video game machines.

The motion picture *The Works,* a science fiction motion picture created entirely by computer is an example for the highest level of real-time simulation. The basic work was done at the New York Institute of Technology; its computer graphics laboratory is one of the world centers for computer animation. Among others, the computer technologist Ephraim Cohen and the painter Paul Xander are presently working here. The latter uses one of the most sophisticated paint systems which are presently available for the modeling of spaceships, landscapes, and human beings.



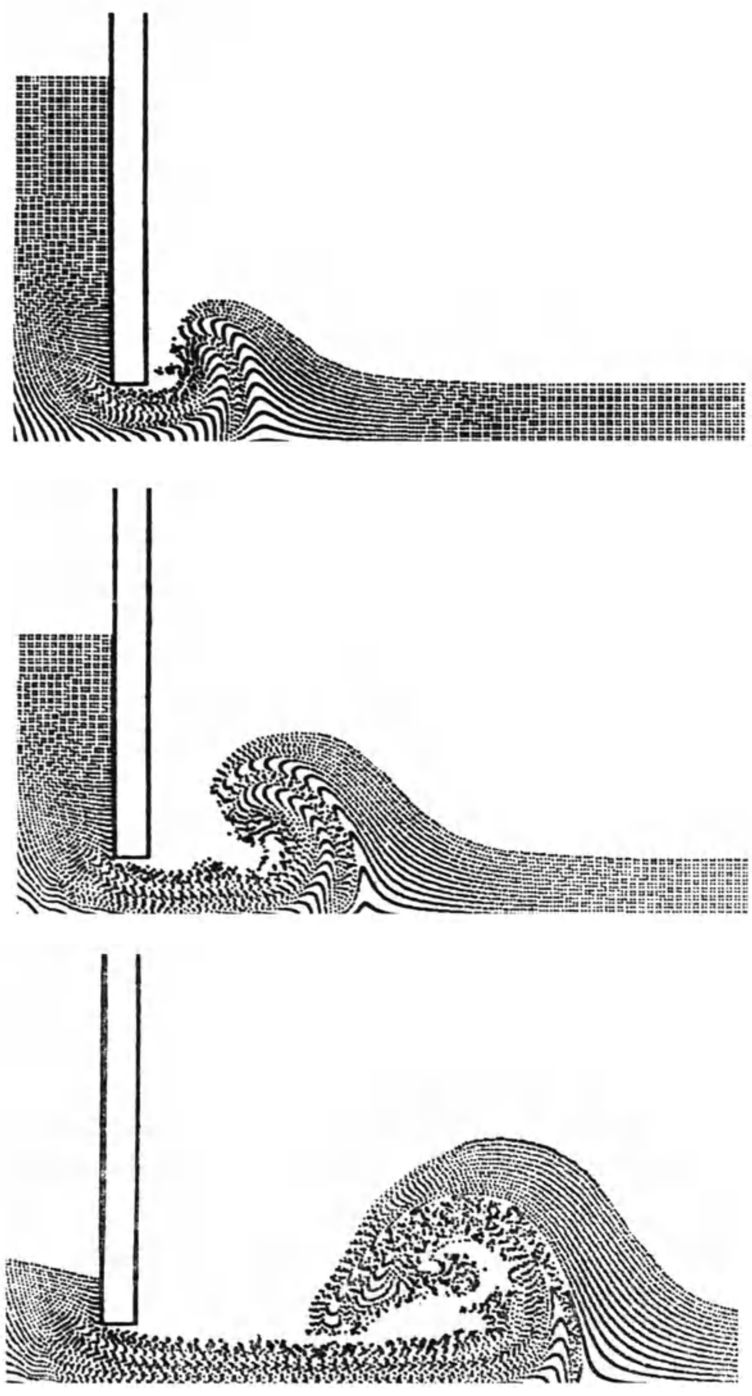
*125* Robot Ant, *real-time simulation from the motion picture* The Works, *NYIT*

## Visualization in the Classroom

The conventional methods of teaching in schools, universities, and institutions for adult education have been based since time immemorial on the spoken word and the formula. The emergence of photography has resulted in a gradual acceptance of visual representations, limited however to the static picture, corresponding to the media most widely used in schools, charts and projections. The tools provided by computer graphics could create an entirely new situation; to a large extent, the instructional material which has been transferred so far by means of word or symbol could be replaced by visual representations. The fact that the use of computer graphics is not limited to the representation of static conditions must be considered a particular advantage. The major portion of those processes which are taught in the classroom are of a dynamic nature; besides the actual experiment, computer graphics provides the only means of representing them in all variations. In this regard, a connection with simulation emerges; it will be made use of especially where a demonstration or an experimental approach are not feasible. The occasions for its use can hardly all be summarized: they include phenomena which, for reasons of cost or because of dangerous circumstances, prohibit any experimenting, as well as processes which occur in the microcosmos of atoms and molecules and in the macrocosmos of space. Dilation and contraction of time are just as accessible as the modification of parameters, which permits the study of the impact of external influences or disturbances. Furthermore, these techniques are amenable to a new form of information center halfway between a museum and a library. Not only the desired educational material, but also any informational programs can be culled from data banks, and they can be utilized for the user's own simulation experiments.

Basically, the same techniques of computer graphics, picture processing, and pattern recognition are being used, accompanied, however, by a certain change of viewpoint. When disseminating information in the classroom, the aim is to achieve clarity and ease of comprehension. As has been proven in perception theories, questions of this kind are closely connected with aesthetic ones; it can safely be maintained that a representation which has achieved an optimum in clarity and ease of comprehension has also gained in aesthetic value. It is obviously desirable that artistically trained professions get involved more closely in the tasks of visualization; for this the tools of computer graphics provide an excellent aid.

The example of mathematics is particularly noteworthy. Because of its high degree of abstraction expressed by the use of formulas, it has a deterring effect on many students. It is not well known that a large portion of mathematical relationships can also be expressed by pictures, especially by animated pictures, which are just as expressive as formulas. This opens a kind of royal road towards mathematics: Comprehension of mathematical relationships results from an analysis of representations in the form of images – a type of approach which appears to be remarkably ap-



*126 Phase pictures from a film for teaching purposes, showing water movements behind an obstacle*

pealing as compared to the conventional form of interpreting formulas. Besides, a formula cannot only be transposed into pictures in one fashion, but always in various ways; this is where artistic expression comes into its own: A representation which is beautiful raises much more positive interest than a graphically unattractive one and is much easer to memorize. And what has been said with regards to mathematics is equally valid for many other scientific and technical disciplines which also make use of mathematical representations.

## Art Theory

If one attempts to make generally valid statements about art and beauty - corresponding to a scientific mode of thinking - it is necessary to carry out experiments as a source of experience and as a means of argumentation. Such a mode of thinking - that of rational aesthetics - is far removed from art theory, which was developed originally in the framework of philosophy, but it has considerably gained in importance since the attempt has been made, above all others with the aid of the computer, to store works of art in programs. As has been demonstrated, there is no a priori cognition in art; rather, all its phenomena are closely connected with human perception and thinking. Works of art have proven to be "offers for perception", its particular aesthetic qualities being its optimal adjustment to the capacity and willingness to perceive. Statements of this kind require proof which can only be given - limiting ourselves to the visual field - by examining series of pictures, modifying certain parameters, and examining them for their aesthetic effect. So far, procedures of this kind were possible to a limited extent, for example using mosaics. Computer graphics, however, is superbly suited for the realization of this idea. It allows the composition of pictures according to defined logic or quantitative rules and the production of any number of variations. Simulation of artistic styles is being added as an additional new method of investigation.
Since the area of experimental aesthetics opens a new field of application for computer graphics which contributes to the composition of its theoretical basis as well, the next chapter shall expand further on this.

# Theoretical Foundations of Computer Art

## 1 Computer Art and Art Criticism

There is no absolute need to have a theory before proceeding to create computer art. One can quite simply take the computer and its auxiliary devices as highly sophisticated mechanisms whose sole function is the easing of the artist's labors. Once he has acquired the necessary skills to service the computer then he proceeds to use it for the realization of his ideas as he might any other instrument. This pragmatic attitude is particularly common in the USA, where writing on the subject of computer graphics is largely taken up with the discussion of programming, the technical possibilities, and so on, while theoretical considerations are underplayed. But there can be no disputing the fact that theory is in fact highly relevant. A professional critic could hardly survive without well-established conceptions, without certain schemas of judgement which he applies to specific situations in forming his point of view. Such criteria usually derive from a background knowledge of art history and comprise insights deriving from the established state of art.
As might be expected, computer art has overtaxed many a critic. It is so difficult to apply the usual historical or psychological yardsticks, and to make matters worse it is obvious that many critics make no effort to look for new standards that would have to cover the formal and configurative aspects, but go on trying to form opinions from generalized viewpoints having but little to do with art. It is patently far too crude a reading of history to assert that, because until now machines have not been used for the creation of plastic art, computer creations cannot qualify as art; yet such a defensive position is still being maintained by a number of critics, and it is only in recent years, especially since the world-wide repercussions of *Cybernetic Serendipity,* that the art world has begun to take some notice, and that computer art has gained entry to museums and art galleries.
The speed of execution is another factor differentiating computer art from conventional forms of art, and manual skills are no longer a precondition for engaging in art. All this encourages the impression that it is easy and cheap, but in fact computer art is no different from any other application of the computer, where only routine activity is relegated to the machine, while the application of intellect and hard work lies in the preliminary creative phase.
Another distinguishing feature is the insistent demand on the part of the spectator for information regarding the productive process of computer art; this accounts for the welcome profusion of performances, lectures and public discussions which have been linked with computer art exhibitions. Here, too, those who have presented themselves as art pundits have had to give way – increasingly it has been scientists, mathematicians and technicians who, becoming involved in the discussions, have injected new energy into the field. This particular situation is to some extent a natural result of the specialized language of the practitioners of computer graphics, music and poetry, but it is also partly caused by a lack of understanding and even a distinct rejection of the technical side of modern life by representatives of the arts. One of the most important effects of computer art is that it actively encourages the bringing together of the two cultures – the technical, and the humanistic and literary.
Although, as we have pointed out, it is possible to produce computer art in terms of classical art production processes, certain tendencies are revealed that introduce a progressive element into the development of art. As long as the programs are restricted to those that merely capture routine processes of artistic creation, then the trend toward theorizing does not yet predominate. But with each move toward generalization the question becomes ever more insistent: how far can we go in programming the beautiful? Are there superior multilevel programs that incorporate general laws of aesthetics? Such questions come within the province of an exact science of art, in which those practicing computer graphics are of course more at home than artists who confine themselves to intuition and spontaneity.
Another question facing computer graphics relates to its future development. Thanks to general purpose programs following the same principles, whether meant for graphics, poetry or music, the practitioner will find it easy to shift from one field to another, or to move into the multi-media sphere. In reflecting on their work, computer graphics practitioners often voice thoughts of an extension of their means of expression.
In the commentary to the first part of his film *per-mu-ta-tions* (see Fig. 116, p. 132), which is largely devoted to demonstrating methods of making films with the aid of computers, John Whitney goes into problems of art. He holds the view that through hun-

dreds of years of practice we have acquired the capacity for a direct understanding of music, but this has not as yet developed for an abstract graphic style. Whitney voices the hope that this might change in the near future: "I would like to witness the time when such graphics make up a regular part of the daily television program" (from a statement at a press conference). There would then be ample opportunity for direct contact with graphic film.
Gerhard Maurer of IBM Germany sees contemporary computer art as a general representative form that will eventually become part of the multi-media sphere. In his *Thesis for Multi-Media Art* he writes: "Generally speaking, the productive capacity of the modern computer is not even remotely exhausted in present-day computer art. This applies to the speed of computers, as well as to their capacity for guiding complex systems. Just as process control computers, rolling mills and conveyor belts operate according to operation data, so they should also have the capacity to analyze harmonies, rhythms, frequencies, volume and graphic figures, and to transform these subjects to programs, depending on sequence data, switching, feedback controls and projections. A computer-guided multi-media program synchronizing the development in time of corresponding elements of graphics, melody, color, rhythm, light intensity, motion and projection strikes the speaker as an art form that might claim to have utilized the potential of modern computer technology almost to the full."
The change in the valuation of computer art that has come about in the past few years is also evident from the way certain works of art are referred to. Sundry works were labeled cybernetic art that really do not qualify for the name, since for the most part these are derived from relatively simple mechanical or optical machines, in which there is barely a hint of the program-control typical for computer programs. There is even an undeniable tendency to pass off as computer compositions, graphics and so on, works that have unmistakably been conceived and fashioned in the ordinary way. This applies particularly to some works of computer-assisted art where quite often the description makes no mention of the manual production phase. Even within computer art itself, we are now witnessing the emergence of a kind of purism, where works produced through computer guidance in all phases are being valued more highly than works where the automatic production process has been halted by intervening production stages of a conventional kind. It really is pathetic that such distinctions should be introduced by a development in art that is committed to the breaking down of barriers.
In many areas, especially those which used to be far removed from the exact sciences - psychology and sociology for instance - the introduction of computers has released tendencies for precise discussion, rational observation, and formularized perception. The necessity for determining artistic ideas in program form also leads to the demystification of computer graphics.
The partisans of a theoretical underpinning of computer art can point to the fact that the application of formalized models has led to a sharp rise in efficiency in all technical areas, and there cannot be the slightest doubt that the same will apply in computer art just as soon as a practical exact aesthetic becomes available. At that stage it should then be possible in principle to frame programs in such a way that they themselves bring about an optimal aesthetic effect.

## 2 Exact Aesthetics

In assuming a particularly active role in the pioneering of exact aesthetics, Germany continued a well-established tradition. Whereas the commitment to computer art is generally only slowly being established on the practical plane, there it was discussed from the outset in terms of theory. It was truly recognized that the interpolation of the machine in the artistic process opens up numerous questions, as regards the essential creative act in the genesis of a work of art, or objective valuation principles, for example.

### Statistical Methods

The establishing of law-like relations that are typical of the phenomena under investigation is already a significant step toward an exact aesthetics. If a sufficient number of research objects is available, then it becomes possible to search out all their inherent regularities by means of statistical evaluation. Provided that there are aesthetic laws, they must come under the fixed catalogue of regulations. It is naturally more difficult to separate aesthetic laws from others - but then this separation is not absolutely demanded in practice. The analysis of musical compositions can be used directly for synthesis, and here it is irrelevant which of the laws that emerge in the synthetic pattern are the cause of the aesthetic effect and which are not.

The statistical analysis of works of art is not itself to be regarded as an aesthetic theory; rather it can count as an aid in theory construction, and is of decisive theoretical as well as practical significance. Information theory, which has a major role in exact aesthetics, can certainly gain from its results. The most well-known representative of the statistical investigation approach is the physicist Wilhelm Fucks of Aachen. He has applied his theory to many areas of art, above all to texts, music and architecture. Among other successes he has managed to isolate certain characteristic dimensions that are typical for the evolution of music. These apply for instance to the increase of the aleatoric (random-conditioned) element. With other dimensions the significance or applicability of his method is less clear, but in practice it offers the opportunity for a comparison of compositions and texts. A new form of historical research has now been opened up along these lines which makes it possible to determine relations of artistic styles, whilst one is engaged in a search for common or at least similar characteristic identification values, or to determine the authors of obscure works by comparing the corresponding identification dimensions of a basic repertoire.

But the statistical method does suffer from a drawback; it can only be applied to existing works of art. Should the analytical procedure be used for the production of new works, then they will only be created in that same style. It is however fairly easy to depart from fixed stylistic rules and so step into new spheres.

But despite this the idea of an objective theory, a theory which draws its viewpoints from general principles - from philosophy and the natural sciences, for instance - continues to exert its attraction. The rules emerging from such a general model are then applicable not only for existing art, but for all works of art, including all future works, and works produced for any and every reason.

## The School of Max Bense

The most influential champion of exact aesthetics is the German philosopher and mathematician Max Bense. In his writings, particularly in his work *The Programming of the Beautiful,* Bense already anticipated the principle that was to be fulfilled at a later date in computer art. Bense's influence is also to be seen in the large number of his pupils who have made valuable contributions toward theory as well as practice. Georg Nees studied with Max Bense; his book *Generative Computergraphik* is in essence a reprint of his thesis. Frieder Nake also attended Bense's lectures and took up some of his ideas. Siegfried Maser, who was a pupil and assistant of Max Bense for a long time, produced an exact mathematical setting of the theory that became known under the name *Informationsästhetik* as his inaugural text. Rul Gunzenhäuser and Felix von Cube should also be mentioned. Helmar Frank is an outstanding pupil of Max Bense who considerably boosted the consolidation of exact aesthetics with his thesis *Basic Problems of Information Aesthetics and First Application to the Mime Pure,* and whose information psychology can be taken as the keystone science of cybernetic aesthetics.

In the framework of this book it is impossible fully to appreciate and acknowledge the various trends in exact aesthetics; all we can do is to give a summary indication of the intellectual methods and appraisals that were used in solving problems - for the rest, the reader must be referred to the literature on the subject.

## Information Aesthetics

In order to arrive at an aesthetic measure, Bense made use of an idea by George D. Birkhoff, who used the expression:

$$\text{Measure} = \frac{\text{Order}}{\text{Complexity}}.$$

Here it depends on the problem under consideration how the values order and complexity are to be obtained. Bense succeeded in generalizing this departure point. He utilizes it on the one hand in Birkhoff's term for the judgement of superior classifications of form, and he also applies it in the context of a "micro-aesthetic" observation, as well as for the description of the smallest perceivable picture elements. In addition he takes up the idea of information theory, particularly Shannon's formula for the value of information, which can also serve as a measure of complexity. In this manner Birkhoff's measure is turned around in terms of micro-aesthetics:

$$\text{Measure} = \frac{\text{Redundancy}}{\text{Information}}.$$

On this basis Siegfried Maser arrives at a quantitative description of micro-aesthetic conditions which is independent of the spectator. Bense justifies the establishment of these historic statements by a comparison with the characteristic state of order in the world. He sees the artistic process as a kind of anti-process of natural phenomena, along the line that nature tends to bring forth chaos, whilst art permits the emergence of unlikely conditions of order.

## Cybernetic Art Theory

The scientist finds unsatisfactory a thought model that is only open to heuristic arguments, and goes on to search for connections between the phenomenon of art and natural phenomena. The departure point and the basis of reference is man - man who both makes and absorbs art. The question can now be posed like this: how is it that man has the capacity to create art, and is ready to occupy himself with art? In terms of cybernetics, no living being has capacities or requirements that are not finally traceable to the need for survival. It is therefore necessary to elucidate the biologically meaningful behavior modes on which art rests.

In a number of illuminating works the psychologist D. E. Berlyne of the University of Toronto has been concerned with so-called explorative behavior, with that program of behavior trends that comes into play when we try to take in the objects that make up our environment through our perceptual system. Berlyne has published some research results which firmly suggest that art follows from this behavior. Man does not only have the capacity to perceive the environment and to comprehend its interrelations, but he also has a need to get to grips with such problems. This is the precondition for a human type that is both open-minded and critical as regards the environment. This approach also seems to resolve the question of a link with the problem of survival. The work of art provides a stimulus for a perceptual confrontation with an object, and it is irrelevant whether the reception of the information takes place through vision, hearing, or any other way, such as braille.

A specific adjustment of the patterns to the data processing capacities of the human perceptual system, i.e. the brain, is a precondition for the satisfactory conclusion of such processes. Here there is a connection between behavioral research on the one hand and information psychology and cybernetics on the other, as it was originally represented by Abraham A. Moles and subsequently by Helmar Frank. It is now possible through information psychology to give a quantitative expression for optimally perceivable information aggregates. We now find that in the case of periodically changing patterns, not more than 16 bits per second of information enter consciousness, and that a maximum of 0.7 bits per second can enter the memory; here one bit stands for the unit of information represented by *1* or *0* in a computer store. In the case of static arrangements, the complexity of the picture must not exceed 160 bits - at least not in one plane of observation. Should this nonetheless occur, then the perceptual process cannot be brought to the desired end - the increase in pleasure that follows success does not arise.

It has been established that an offer of information that is noticeably below these optimal values for the influx capacity leads to the negative emotion of boredom. This fact is particularly important for all forms of instruction. Instruction that is low in information, and which does not reach the achievement capacity of the pupil, fails to achieve a satisfactory conclusion to the transmission of information. From this it follows that those objects which serve explorative behavior, and which should bring the corresponding perceptual processes to a satisfactory conclusion, must have a complexity that is approximately in the region of the maximal value.

Of course the determination of the relevant information values is quite difficult. "Subjective information" is decisive for the effects of the aesthetic patterns on the individual, and naturally this differs from person to person. Furthermore, mathematical or geometrical elements are not used in calculating the information values, but instead the *Apperzepteme* - the smallest perceivable units - and the entities which arise when these are joined - the so-called superpatterns. But these entities are dependent on gestalt formation processes in the brain of which very little is known at present. The fulfilling of the conditions for information capacities is clearly necessary, but is by no means a complete criterion for the realization of works of art. The effects of an object fulfilling the optimal conditions will soon be exhausted - the desired insight having been gained in a single viewing, the object ceases to hold any interest. It is therefore necessary to allow more time for the perceptual processes to run their course, or else see to it that they can always start afresh. If we examine the foundations of traditional art we find that such provisions do indeed exist.

These include:

- The employment of hierarchically dependent sign categories. The reduction of information can take place separately on each plane - for instance, the syntactic and the semantic.
- The reduction of information taking place in several (possibly many) ways.
- A switch to microstructures, where a new reduction of information becomes possible.
- The suggestion of secondary meanings, associations - the activation of emotions.

### Practical Consequences

However simple and incomplete the theoretical model of information psychology and cybernetic art theory may be, it is not difficult to see how it might be usefully applied in the practice of computer art. Firstly, there is no particular difficulty in writing programs for those events in motion generating an information flow of approximately 16 bits per second.
Furthermore, a glance at the possible steps that will prolong the effects makes it clear that they too can be contained in a program - and probably in a far more precise way than was ever possible by the old methods of trial and error; several kinds of computer graphics indicate that such provisions have already been applied intuitively, for instance in the composition by Kenneth C. Knowlton of some computer graphics. With these it is possible to transfer attention from the plane of the superimposed image to the micropatterns. A similar experience is offered by the Kennedy portraits of the Japanese Computer Technique Group (see Fig. 96, p. 113). As far as practice is concerned, there is no reason why the artist should be completely at home with the theory right from the start. Even approximations and partial results can be taken into consideration and will lead to improved results, if only in details.
Of the other rules to be considered, those relating to information flow in the memory are probably among the most important. Should it be necessary in the course of a development, for instance in the running of a computer film, to refer to something that has already been shown, then it must be borne in mind that only 0.7 bits per second remains in the memory, i.e. only a twentieth part of the consciously accepted information. The reception of a work of art functions as a learning process, and the relevant rules are closely linked with those of learning theory. The way in which information is distributed, repeated, connected, and so on, follows a strict schema that can be formulated, as is proved by the formal didactics used in programmed teaching.

## 3 Experimental Aesthetics

A scientific theory aiming at objective results has to adopt the working methods of the natural sciences which are characterized by the interaction of theory and practice. In some cases, for instance astronomy, experimental work proves difficult, if not impossible; therefore it has been tried recently to replace experiment by simulation. The connection with reality, which is characterized by a ceaseless testing of hypotheses, must then be limited to observation. All attempts to formulate a rational, scientific theory of art found themselves in this situation until recently. The spectrum of realizable art was posed as the subject of investigation: intentionally to modify its components; to extrapolate individual aspects; or to achieve an undiluted presentation of phenomena such as the experiment aims at - turned out to be an impossibility. The computer has completely transformed this impasse. Of the advantages it offers, the following deserve emphasis: mathematically based programs are available for works of computer art, which conveniently permit evaluation, for example, a search for regularities; it is simple to transform a computer graphic according to any chosen point of view - this merely calls for a change of parameter; it is quite easy to achieve a greater or lesser degree of complexity in the produced patterns. The speed of execution is a great practical advantage. Only the fast working capacity of the computer permits the production of large series such as modifications of one particular style, through which psychological tests can be conducted, particularly in the area of information psychology.

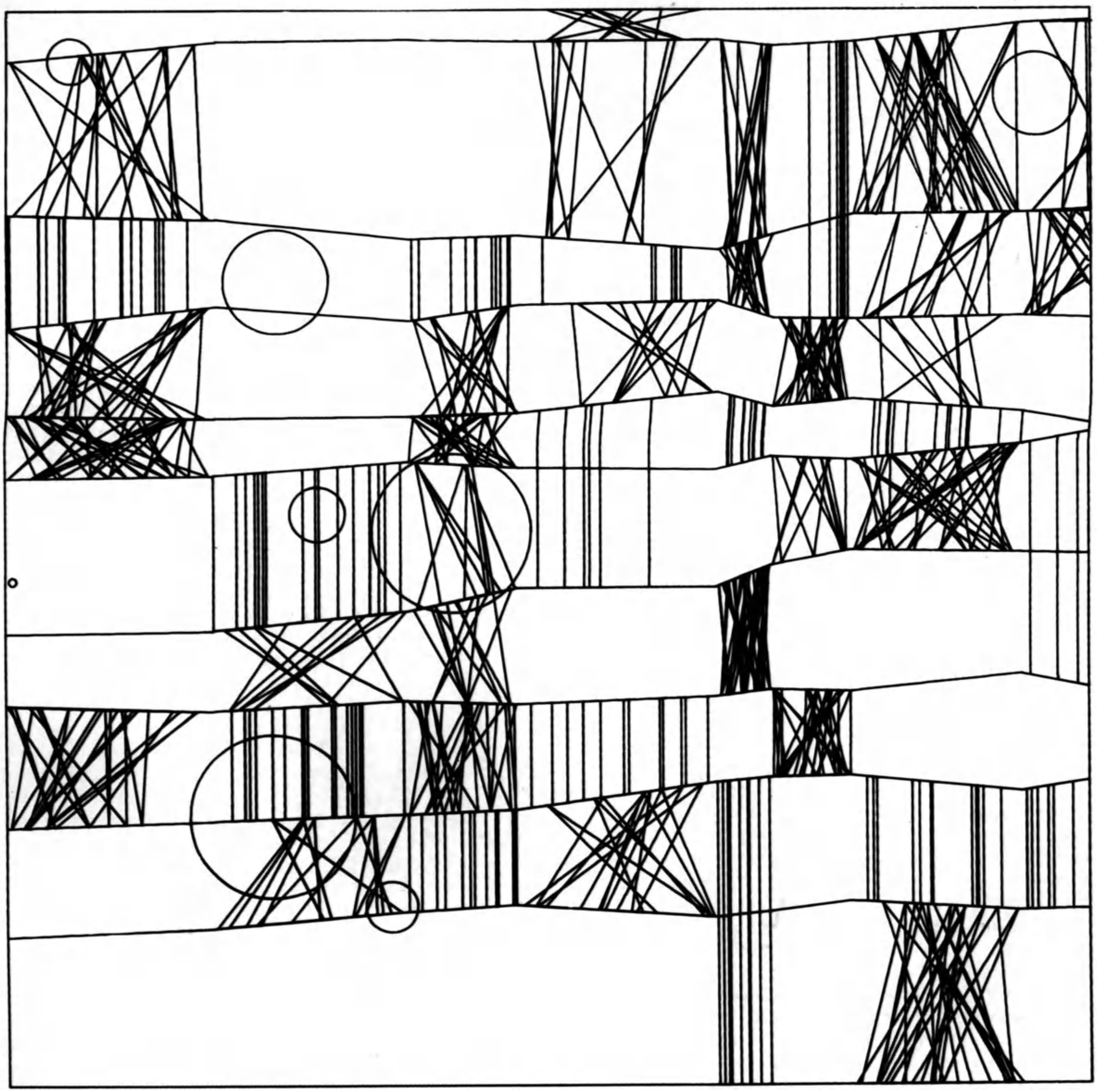
Here it is irrelevant whether the artistic quality of the computer-generated work is recognized or not. In terms of cybernetics it is possible to practice the science of art with a model, and the patterns made with the computer are then taken as simulated art objects. Examples of this approach are known from A. Michael Noll and Frieder Nake. Nake tried to determine in programs the stylistic laws of the painters Paul Klee and Hans Hartung, and created a series of Klee and Hartung simulations. Noll's experiment with a Mondrian painting was even more spectacular. This was constructed of horizontal and vertical line elements, and based on its stylistic laws he produced a series of structures where the division of the line elements was changed step by step; he then presented the entire series to a test audience. Remarkably, it was not the original but the computer picture that was adjudged to be the finest.

Where rational methods are applied to the exploration of the phenomenon of art, there follow all kinds of links with phenomena in general that are subject to scientific investigation, such as perception, behavior, learning, feeling. We now have to consider what are the distinguishing marks of these processes once they rise to aesthetic effects.

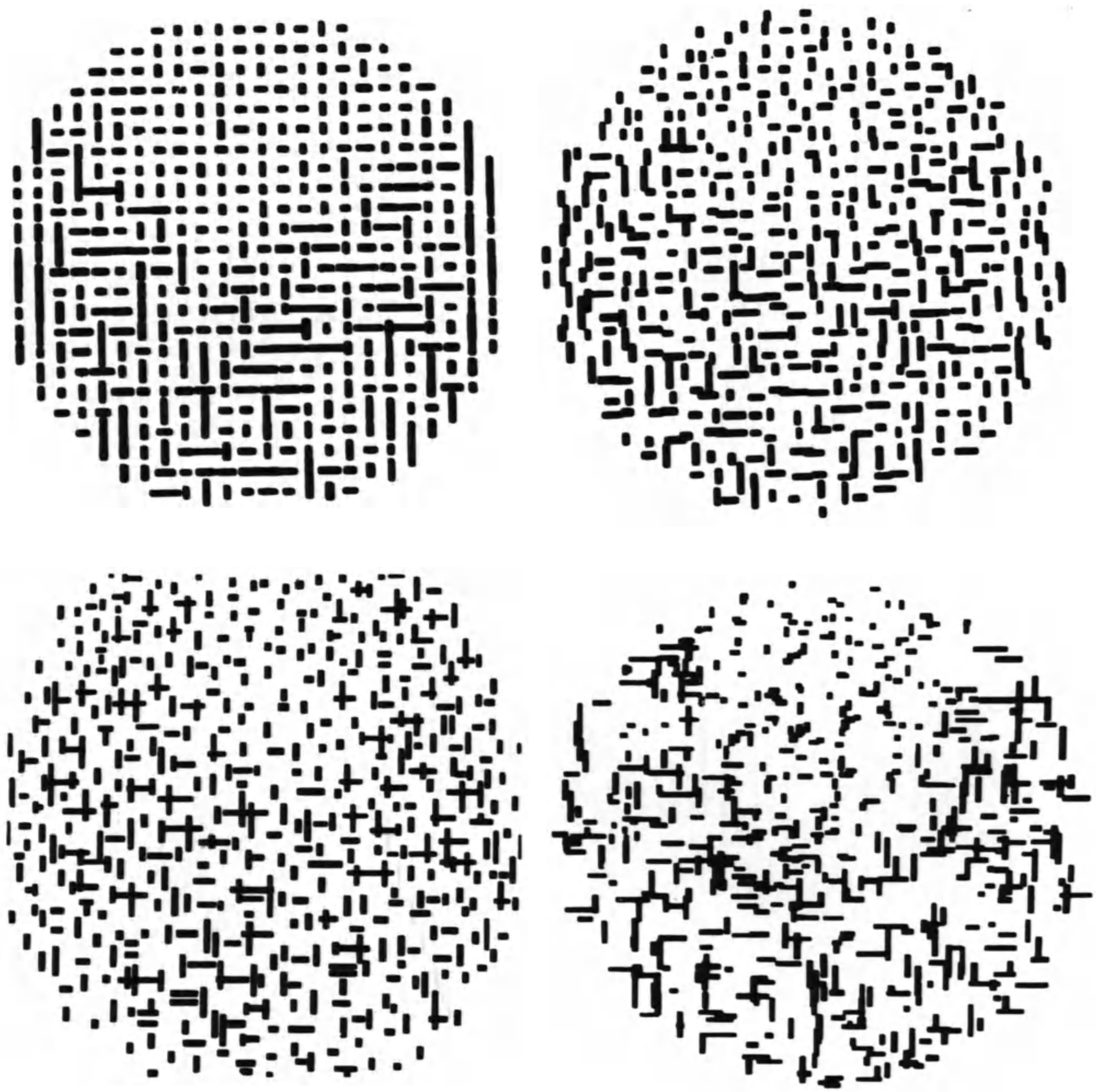
Since the setting of the stylistic laws in an algorithmic form is a precondition for the generation of computer art, each of its products may serve as a preliminary study for investigations in the science of art. Indeed, as we know, several of the scientists, technicians or artists who have produced computer graphics or music are interested in the investigation of perceptual and artistic phenomena. B. Julesz and C. Bosche have produced films that were used for research in gestalt psychology. In their otherwise randomly constructed grid pictures, lateral or repeating symmetries appear; an attempt was made to discover if these regularities were perceived. These patterns do of course have aesthetic qualities - this is probably connected with the interaction of the random and the regular. The same applies to the film *Order in Disorder* by Peter Scheffler produced at the Psychological Institute of Innsbruck University, which is also among the first examples of film made with an analogue system. This shows jumping patterns composed of polygons, and illustrates a fact of great interest to gestalt psychology, that a change subjected to pure chance control is perceived as a motion phenomenon.

Of all directions in psychology, information psychology has made the most progress as far as quantitative modeling is concerned. This makes for a direct link between psychology and art theory. Helmar Frank, the former director of the Institut für Kybernetik attached to the Pädagogische Hochschule in Berlin, has been primarily concerned with learning theories in the framework of programmed instruction. Since in each teaching subject there are elements which contain no factual information, but which do contribute to aesthetic quality, termed by Frank, "aesthetic information" - this shift in the center of gravity does not signal any turning away from aesthetics. A work group has been formed in the Cybernetic Institute consisting of Klaus Dieter Graf, Georg Hansmann and Bärbel Lieske, devoted to the aesthetic qualities of teaching programs. The first experimental results from this group consist of a series of character patterns where the complexity, conspicuousness, and other values relevant for the perception of information-psychological values are established. Frieder Nake has developed a program system through which can be obtained pictures with prescribed values for information, surprise effects, conspicuousness and aesthetic measure (after G. D. Birkhoff). This consists of a statistical selector, *Generative Ästhetik P,* which rejects data deviating from the prescribed values, and a linked program section serving as a topological selector which builds up characters on various planes in hierarchic dependence.

On the other hand, works of computer art, and computer graphics in particular, originating from purely aesthetic intentions are valuable in relation to problems of education. Anyone



*127* Klee, *digital graphic by Frieder Nake. The starting point was a picture by Paul Klee. It was investigated for stylistic regularities, which were then combined into a program*

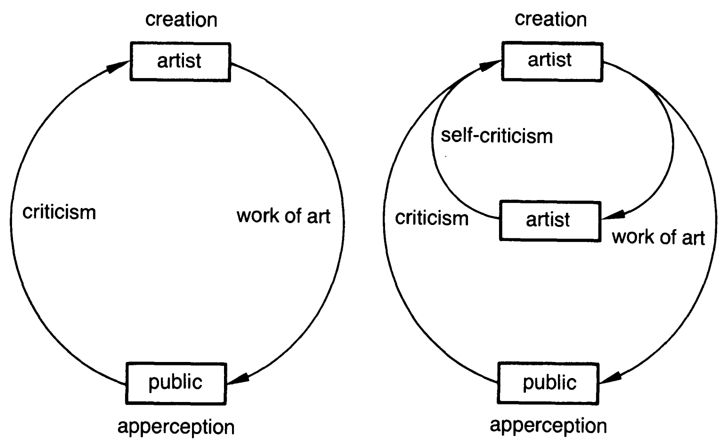


◁ *128/129* Computer Compositions with Lines *by A. Michael Noll and* Composition with Lines *by Piet Mondrian. Noll used random number generators to generate line divisions in accordance with the structure of the Mondrian picture. The subjectively "best" picture was found through tests; it is the one on the top right. The Mondrian picture is the one on the left below*

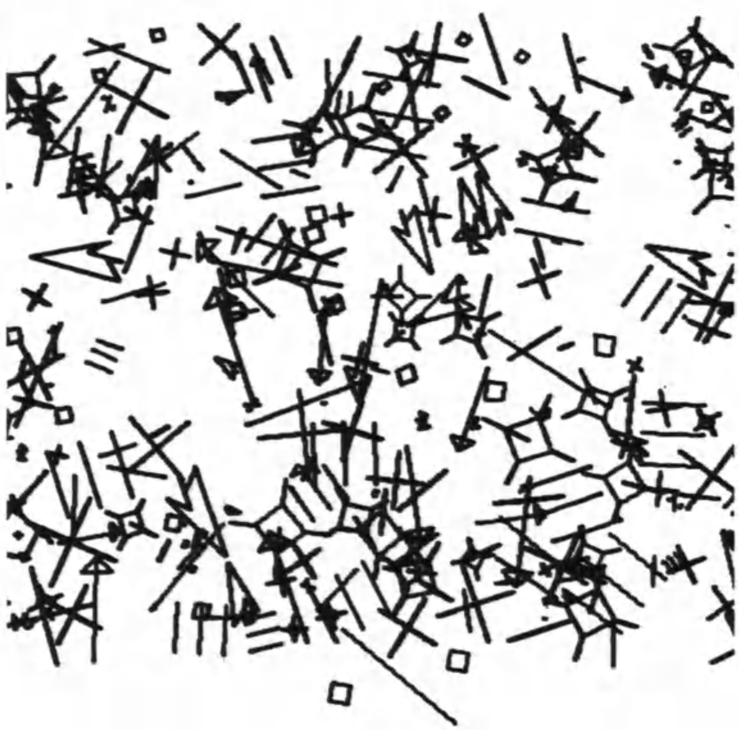
who has managed to produce a large series of computer graphics will be aware that very few points of view exist regarding the satisfactory visual elucidation of the represented material. This applies even to the simplest qualities, for instance the line thickness or the surface density of elements in the drawing plane. But even more intractable questions such as the building up of configurations can be approached in the course of computer aesthetic efforts. Georg Nees, in his book *Generative Computergraphik,* points out that in a pattern consisting of circular elements, the enlargement of the circles does not lead to merely quantitative effects. Rather, the intersections provide starting points for perceptual processes, and so provide the occasion for the formation of interconnected images - the so-called superpatterns. Experiments like these establish the idea that the elements which information aesthetics has to consider in calculating its information dimensions are not abstract mathematical quantities, but those where the perceptual processes actually begin. This exceptionally important idea, related to the problem of perception, understanding and thinking, has hardly been considered by research up to now. That is why Georg Nees makes these proposals: "The computer's capacity for the rapid analysis of complex problems should be harnessed for the simulation of vision devices in connection with problems of information aesthetics. Of the three machines that are to be studied in the context of a complete communication aesthetics, the information analyzer is well on the way to practical realization and experimental usage. The present report points to the practicality of the information generator, whilst as an information channel the outer optical channel might be used (supplemented eventually by a lens system). The light pen could be used as an immediately available device. This consists of a stylus that can be used to write on a CRT attached to a computer. All sign-like information that is written onto the CRT by the light pen appears instantly on its surface and is simultaneously entered into the computer store. The computer is programmed in such a way that it is capable of writing answers on the CRT. With these arrangements it becomes possible to imitate the retina with its nerve centers, if not entirely then at least in relation to certain information processes that are of interest to the aesthetician."
The numerous interrelations of computer art with many other areas of life, from science, research and education to sociology, of which more will be said, is not only to be welcomed, but valued as an integrating component of computer-aesthetic endeavors.

## 4 The Random as Generative Impulse

In the first place, the experiences of information psychology refer to only one aspect of the artistic process, namely that of perceptual reception. But if art is envisaged as a communication process between artist and public then it becomes possible to construct a model of the creative process using apperception as a starting point.
The artist approaches the public with his works in terms of a communication process. The public accepts the offer and reacts in some way - be it through applause, rejection, or indifference. This reaction is a feedback for the artist, providing him with clues for a further phase of the creative process. It can be demonstrated that a disruption of this circular process leads to alien-




*130 The social communication circle in art. The feedback process of art incorporates in the production phase a corresponding circular process where the artist, by letting his work act upon him, successively perfects it, in terms of trial and error*



*131 Patterns made up of splintered glass, distributed according to a random principle, by Petar Milojević*

ation between artist and public, the final consequence of which is art without public. Since the social aspect is lost at that stage, it might be asked if such a situation can still be regarded as an art process - hence we shall let the matter rest.
If we obtain decisive criteria for works of art from the process of apperception in the public, then these generative rules can be utilized for the construction of aesthetic objects. This however does not mean that there is any ultimate determination of aesthetic configurations, since even within the aggregates of *Apperzepteme* optimally orientated toward perceptual processes the number of variations is infinitely large. The given degrees of freedom that result must somehow be taken care of.
The adjustment to the apperception capacity of the public is usually made through the artist, in so far as he is constantly testing his work while it is in progress; in a sense he stands in for the public in the process of creation. In this manner - after trial and error - any desired approximation to ideal conditions can be achieved.
Generally, the artist disposes the remaining determining quantities in an intuitive, spontaneous manner. Where an art creation process is delegated to machines, the style, which is usually adjusted to perceptual capacity, is added in the form of the program. A special disposition has to be made for the choice of open parameters.
The production of the "new" in terms of cybernetics means the creation of information - the heightening of complexity. Now a machine that is working in accordance with logical principles cannot produce genuine chance - and this applies to the computer. It only permits the simulation of the random, and we then talk in terms of pseudo-random number generators. If we search nature for processes that run according to random principles, we find only the quantum processes which occur in microphysics. That is why we can obtain genuine random number generators from radioactive random processes or from electronic noise. It is remarkable that a phenomenon - chance - that usually appears as a disturbance turns out to be a generative principle. And yet its capacity for generating information is understandable; as chance destroys order it creates more complex structures and achieves the unexpected, the unforeseen, to which we react with surprise.
A legal battle in the United States provides an illustration for this. A design office had used pictures that appeared on television through faults in transmission as a basis for designs, and was then taken to court by the television company for infringement of copyright.
Since chance processes are clearly the only information-generating events, the computer linked with a random number generator, and composing music and producing graphics, appears in a fresh perspective - namely as a simulation model for creative processes. It is along these lines that we now approach the fundamental questions: how did organized life first establish itself on earth; does the human brain have the capacity to create the fundamentally new? But even if questions of this order remain beyond the scope of computer graphics it is good to know that the application of chance is clearly more than a somewhat crude trick.

# The Future of Computer Art

The use of the computer for artistic purposes is the last and decisive step towards technologizing the arts. Whereas instruments have been used in the area of music for a long time, their acceptance is much more recent in the visual sector. The printing media and photography are above all directed at reproduction and multiplication, while there existed hardly a technical tool in fine arts allowing freedom of creativity before the advent of the computer. And since computer art also encompasses the possibility of expressing animated processes, computer art opens a new dimension of creativity.

The subject art in the age of media brings various problems to the foreground to which little attention has been paid so far - a situation which has been aggravated by computer art. Merely by making use of machines for the production of artistic pictures, certain changes are taking place in the sale of art, in its popularization, in its forms of expression. Technological and automated processes always go hand in hand with a trend towards mass production, a phenomenon which also becomes noticeable in computer art. This is caused in particular by the fact that its methods were derived from technical developments for which multiplication is a natural requirement. An unusual situation arises from the fact that some of the new techniques no longer produce an original in the usual sense of the word. In photography, the true original is a negative which, as such, is not suitable for immediate viewing; rather it is the prototype for any number of multiplications. The same applies to the matrices of records. The computer advances this phase even further: the essential process of production occurs at the stage of programming. A fully developed computer program includes all possibilities of execution. A completely new element, however, is being added: artistic programs often contain random elements and thus do not give a definite description of the art work which is realized at a later stage: rather, they include a variety of possible realizations which can exhibit any degree of divergence.

This leads to a number of questions which concern legal and commercial problems more than aesthetic ones, but are nonetheless relevant in practice. One of them is the question of adequate remuneration for the artistic achievement. As long as computer graphics are reproduced on paper, for example as serigraphs, and are sold in the usual fashion, the problem is not too difficult - computer artists will get their share as a fee in the usual fashion. More difficult are realizations which are multiplied by means of tape; they can be presented in various manners or used in many other ways; for instance by renting cassettes or by broadcasting on television. In this case, similar measures need to be taken as are customary today in the area of music and literature, namely the administration of the copyrights by copyrights associations.

Fair remuneration is much more difficult if the artistic idea is propagated in the form of programs, particularly if they contain stochastic elements. It should be mentioned in this context that the legal situation which arises through the use of machines in art has already been the subject of an extensive study - Max Kummer: *Das urheberrechtlich schützbare Werk* (Works Protectable by Copyrights), Bern 1968. So far, however, the legal situation is not even close to being settled.

Those effects, however, which are caused by any kind of technical and especially computer-aided aesthetic creativity in the arts weigh much more heavily. Perhaps most striking is the fact that the use of a computer relieves the user of the necessity of acquiring manual skills and techniques. This eliminates that close connection between the creating hand and the material which is considered to be important by some art experts. The reproach that the routine of a machine is now replacing creative activity can hardly be accepted by those who are familiar with programming. It must be recognized as a fact, however - whether this is desirable or not - that the act of artistic creativity shifts from the manual to those areas which have been described as cerebral.

The usual training by academics, which is confined to manual skills, is made superfluous by the facilitation of artistic production brought about by computers. No longer must manual hurdles be overcome on the road from idea to realization - it will be established much sooner whether the computer user can draw on a wealth of creative ideas or not. Thus, the new situation provides the best conditions for activating artistic capabilities, but it also increases the chances of achieving better quality. But for many years only a few people, programmers in technical and economic institutes, had the medium, a computer graphics system, at their disposal. This seemed to renew the danger of being limited to elitist circles which has threatened modern art from another di-

*133 Several results from a program developed by Klaus Thomas for* ▷ *demonstration purposes for IBM Germany. By the input of eight figures, the spectator determines the order in which a number of fixed points are interconnected: a revolution of the entire figure follows each run, inducing "hidden lines"*

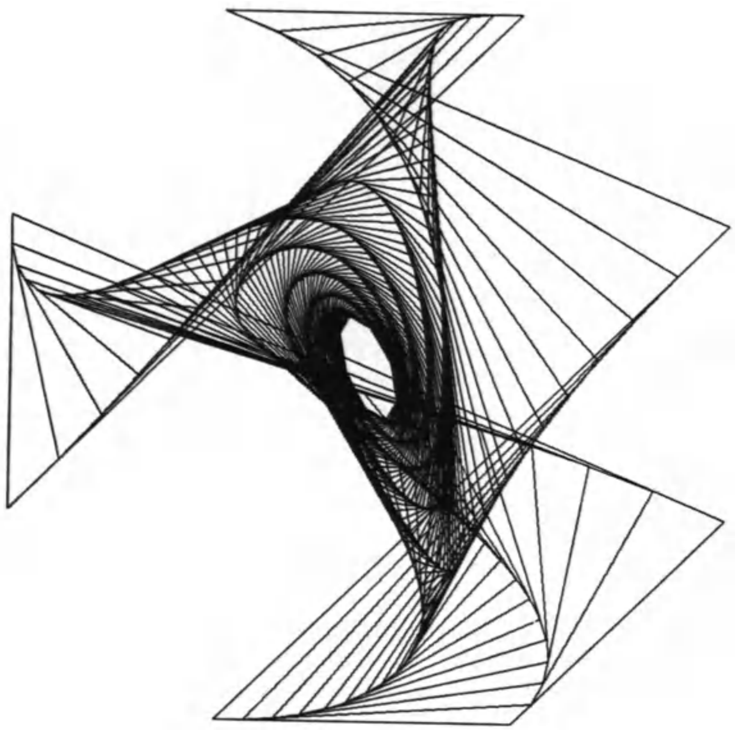
*132* Finsteraarhorn (above) *and* Silberhörner (below), *graphics from a low-resolution microcomputer; Peter Stampfli (Schweiz)*

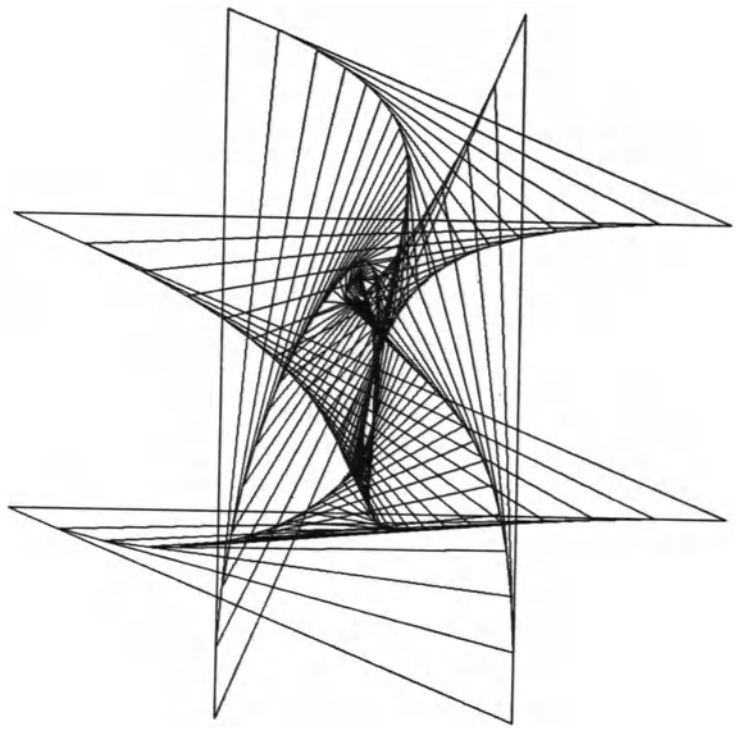
rection. But the emergence of microprocessors and microcomputers, which came as a surprise even to experts, and with it the general availability of "decentralized intelligence" has created an entirely new situation.

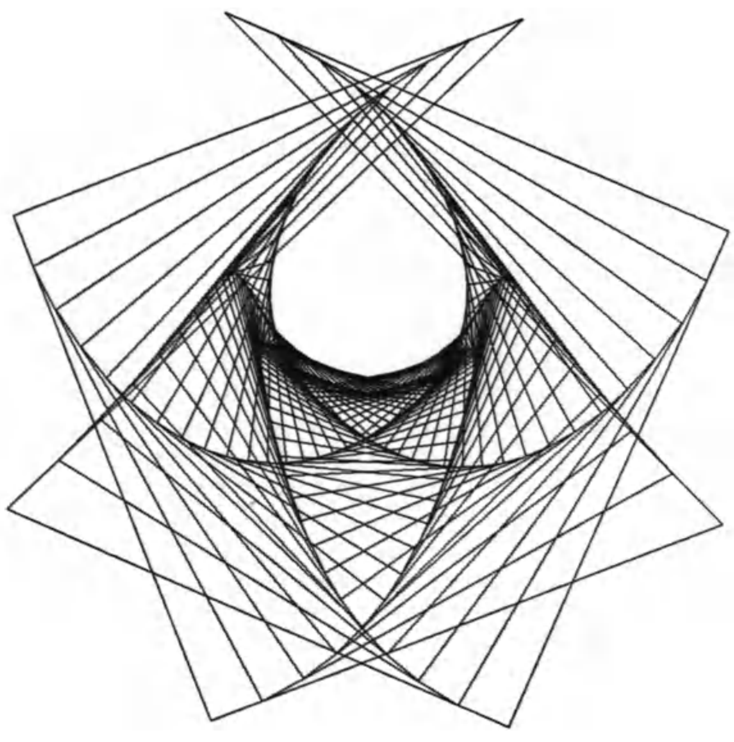
Furthermore, the progress in semiconductor technology, the mass production of highly integrated electronic circuits of which the microprocessor so far represents the most advanced stage, led to an amazing decrease in the cost of all devices designed for data processing, benefitting in particular computer graphics which, owing to the lower cost of the hardware, became an activity which had an effect on many areas.

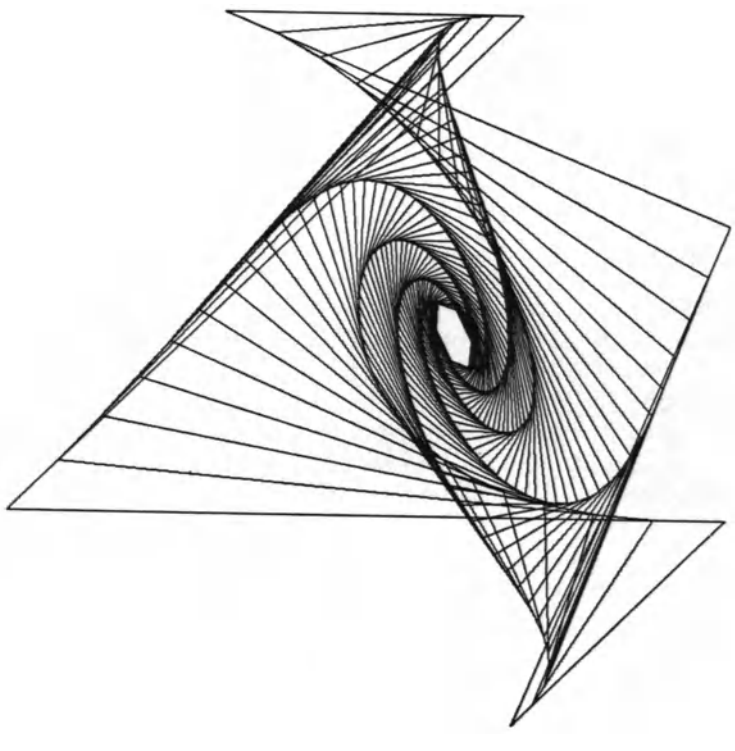
Of course, the new hardware was not developed with the arts in mind; the aim was rather to represent data of the most diverse types as pictures - the various applications were described above. But this easy access to graphical instruments will bring about far-reaching modifications in our behavior patterns - similar to what happened after the introduction of television. The consequences extend from new methods of transmitting information to aspects which are of importance for much of the professional and business world. It is imaginable that in a few years' time one no longer commutes to an office, but works at home where, by means of a screen terminal, one has access to all colleagues and to all implements offered by today's office. But it is also possible with the aid of such implements to transfer products and programs of computer art into the home, for graphical games as well as for artistic purposes.

The newly opened dimension of animated graphics which represents an analogy to music and which could lead to a development just as impressive as that in music will probably have similarly far-reaching effects. From this viewpoint, as well, there are consequences which extend from formal categories to repercussions on the actions and the thinking of human beings. The traditional places of communication for fine arts, museums and galleries, for example, are not suitable in their present form for the presentation of dynamic visual processes. Centers for active and passive artistic activity which are adapted to the new requirements must be equipped with the necessary electronic devices for data processing, optical and acoustical output terminals, memory capacity, etc. Since these are not designed specifically for artistic use, but encompass more general activities as well, for in-









stance those of education, entertainment, games, etc., institutions will emerge which, while being designed for cultural purposes in general, offer the opportunity for a wide range of cognitive, explorative, and creative activity.

But electronic media lead to other forms of communication which counteract the usual trend towards centralization; for instance, data networks, incorporating the existing telephone networks, with terminals including high-resolution screens, could form a kind of imaginary theater which facilitates the undelayed transfer of artistic information, for example of computer graphics programs, as much as it facilitates teamwork carried out by means of a telesystem. Precursors of this can already be found with users of personal computers who exchange programs as well as floppy disks or video tapes.

A very important effect which is caused by commercially available computer graphics systems is the challenge they present to actively participate in artistic activities. Such a development will contribute considerably to questioning the traditional concepts of art. In 1969, Marc Adrian already wrote in the catalogue for the exhibition *Art and Computer* held in the Computing Center of the Central Credit Union in Vienna: "This process will automatically result in a destruction of the prestige, the aura surrounding art, the superb individual achievement of manual perfection which a work of art is still considered to be today, as well as the concept of art as an object of representation and as the status symbol of a privileged class. A work of art will then emerge unconcealed in the only function it can have today: as an object to be consumed in large quantities for intellectual pleasure, comparable to the pocket book or the newspaper which are also passed on or destroyed after consumption". It hardly needs further explanation that the professional image of the artist will change as these changes occur. In future it will be the task of an aesthetic systems analyst to prepare generally usable programs according to selected rules partly contributed by himself, the use of which is then left to the public for the realization of individual works or sequences of works.

It has been mentioned several times that it is the possibility of dynamic graphics, of the animated play of color and form which could result in the emergence of an entirely new form of art. The best object for comparison is music, a form of art which has relied on physical tools and machines for millenia. A timespan of approximately two millenia was required for its development up to polyphonic music of Western society with all its variants which also include the influence of other cultural developments. In comparison, freely created dynamic graphics has existed only for a short timespan, hence the time has not arrived yet for comparisons of quality. But whatever starts to show itself today in various places justifies the expectation that an artistic development is emerging which could gradually mature into a similarly highly developed and widely spread form of art.

The development which was started by the emergence of computer graphics could lead into other, quite different directions, for instance to unconventional, nondeterministic forms of theater. A necessary condition for this is the method of real-time animation as it is used for the purposes of simulation which has already been employed in films and advertisements. Besides technical and economic applications of these techniques, they will also gain in importance in the area of computer games - the user is more and more drawn into a simulated situation in which he has to implement certain decisions predetermined by the rules of the game and take certain actions - with the expectation of winning or losing. Practices of this kind can also be used in a more literary manner by causing the user to participate much more intensively in the action than the audience of epic or dramatic performances ever did. Programs providing different variants of the plot to be chosen by the user's own decision would replace theater or film scripts. If random generators are included in these dramatic simulation games, plots will result which cannot be predicted by anybody, not even by the author/programmer. Georg Nees who got intensively involved in this future vision of an "experience theater" made some general observations on the kind of programming required.

Today's terminals, however, are not entirely suitable for entertainment of this kind; some arrangements in amusement arcades give us some indication in which direction the development might lead. Compared to the special devices in the area of games, more generally usable equipment can be expected in the arts. A first step in that direction would be large scale projection, and later on the use of circular horizons and projection domes. Besides the acoustic addition of polyphonic loudspeaker systems,

other kinds of applications will probably be employed, using the simulation devices for the training of pilots as a model, for instance vibration systems, scent dispensers, etc. Equipment of this sort can, of course, not only be used for physical actions, but also for abstract entertainment; in extension of today's multi-media shows, effects on the audience are imaginable which will completely captivate all its senses.
Description of this kind do not at all exhaust all the possibilities which computer art offers; undoubtedly, there will be unexpected applications, which is, of course, a major reason for its attractiveness. But even today's applications have caused remarkable unrest in the practice and theory of the contemporary art scene. The question of the possibilities of new machine-dependent techniques, of evaluating the creative elements of expression and beauty are being raised anew. Compared to the innovations which this has caused in society, it appears to be of secondary importance whether the results of unfettered creativity with the aid of the computer are recognized as true art or not. It remains a fact that it has made clear the effects and countereffects of art, technology, and science as no other medium did before. This is enough gain for today - and a challenge for tomorrow.

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