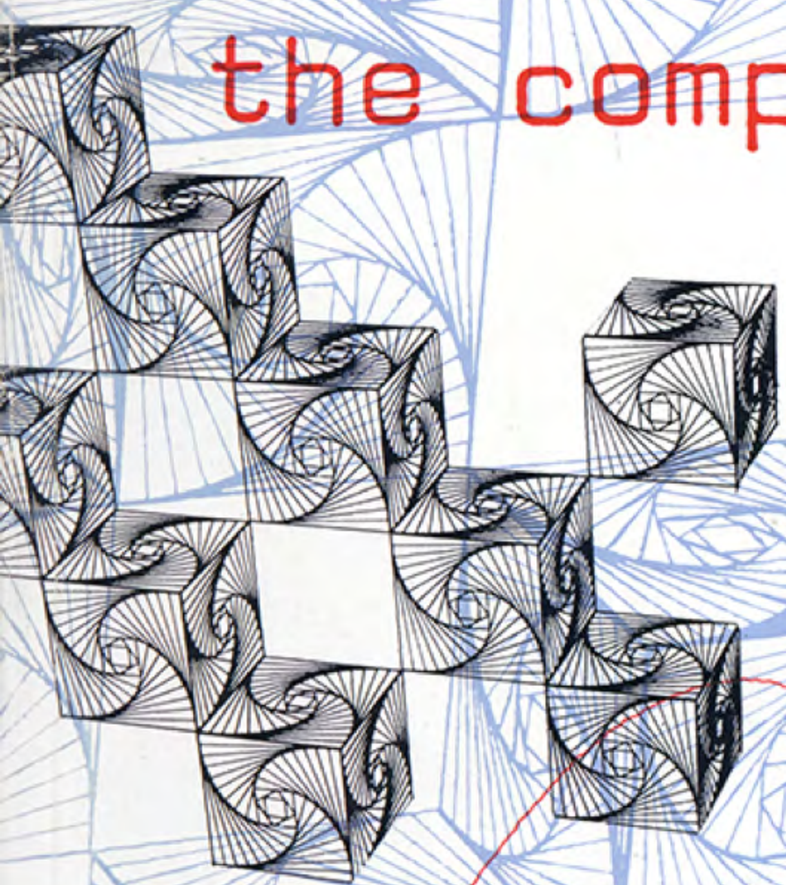
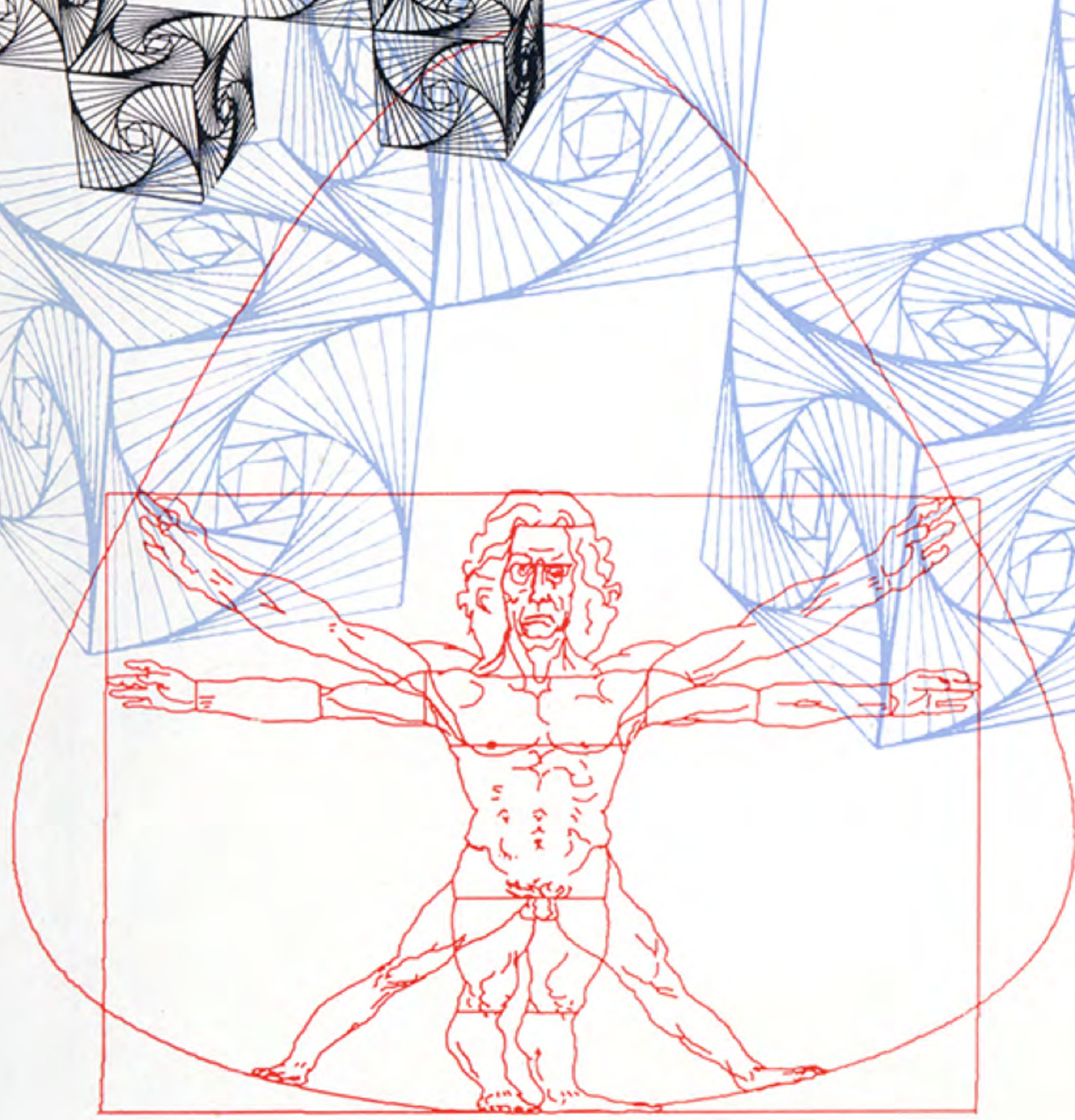
Cybernetic Serendipity

the computer and the arts





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Cybernetic Serendipity

the computer and the arts

edited by Jasia Reichardt

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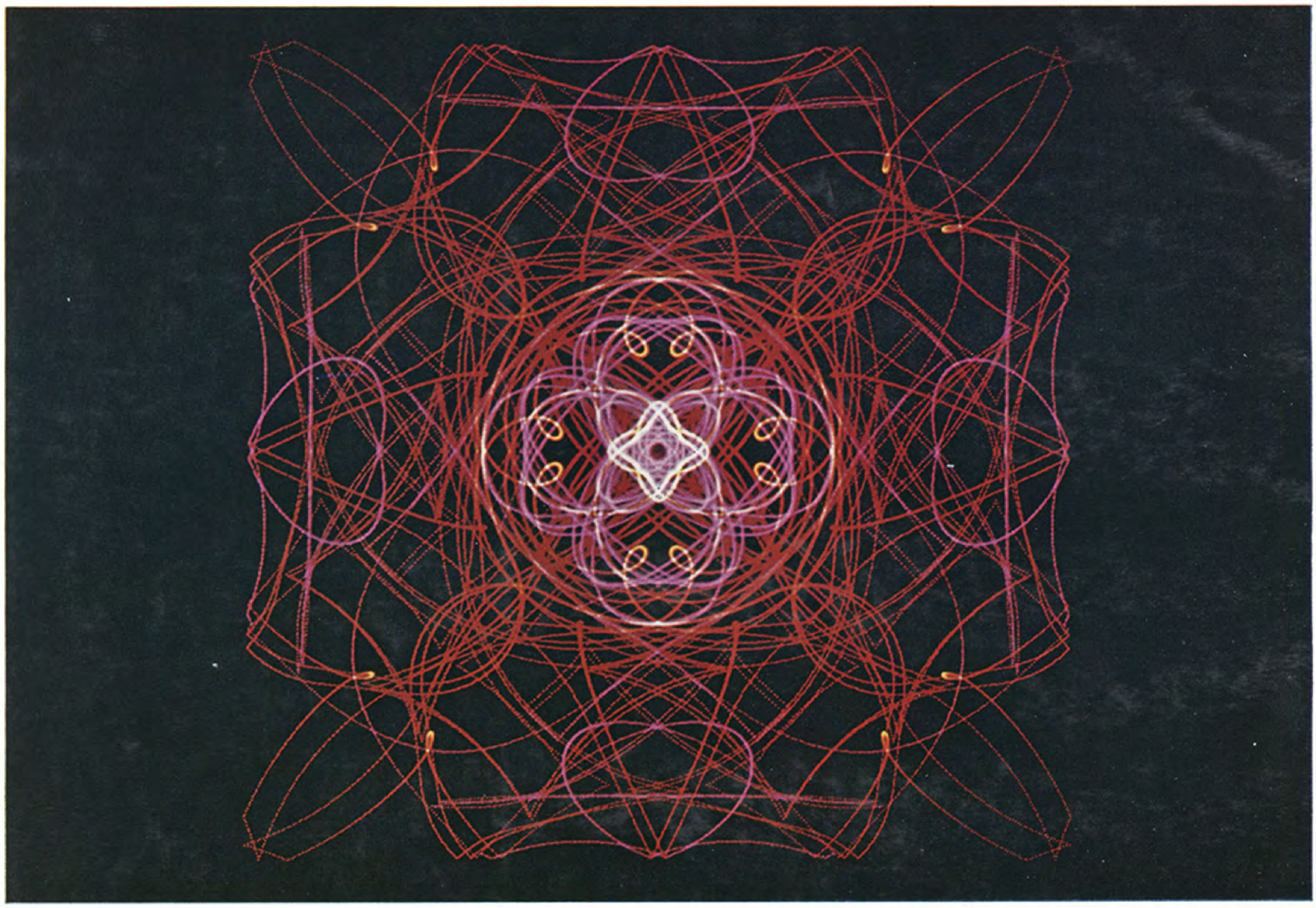

Colour computer graphic by John C. Mott-Smith

Of his colour computer graphics John C. Mott-Smith, Chief of the Image Processing Branch of the Data Sciences Laboratory at the Air Force Cambridge Research Laboratories, Bedford, Massachusetts, says, 'On the technical side, the pictures were made by time-lapse photography successively exposed through coloured filters, of an oscilloscope connected to a computer. The original programme on which much of my work is based is called the Minskytron after Marvin Minsky of the Massachusetts Institute of Technology. It was apparently written by an anonymous student as a demonstration that a computer can be used to demonstrate the motion of particles in a complicated force field, a fact of particular interest in cases where the mathematics is intractable. After seeing the Minskytron display I tried to develop a set of programmes specifically to generate interesting patterns. These pictures are a sample of the result, each representing a lengthy period of exploration and experimentation to achieve a desired effect.'

adj. of cybernetics–
a science of control and communication
in complex electronic machines like computers
and the human nervous system

the faculty of making happy chance discoveries

Cybernetic Serendipity

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This Studio International special issue was first published to coincide with an exhibition entitled 'Cybernetic Serendipity', dealing broadly with the demonstration of how man can use the computer and new technology to extend his creativity and inventiveness, held at the Institute of Contemporary Arts, Nash House, The Mall, London, S.W.1, August 2–October 20, 1968. The exhibition was organized by Jasia Reichardt in collaboration with Mark Dowson (technological adviser) and Peter Schmidt (musical adviser). The exhibition was designed by Franciszka Themerson.

Jasia Reichardt

Peter Schmidt

Mark Dowson

Franciszka Themerson

Introduction

Jasia Reichardt

Cybernetic Serendipity is an international exhibition exploring and demonstrating some of the relationships between technology and creativity.

The idea behind this venture, for which I am grateful to Professor Max Bense of Stuttgart, is to show some of the creative forms engendered by technology The aim is to present an area of activity which manifests artists' involvement with science, and the scientists' involvement with the arts; also, to show the links between the random systems employed by artists, composers and poets, and those involved with the making and the use of cybernetic devices.

The exhibition is divided into three sections, and these sections are represented in the catalogue in a different order:

1. Computer-generated graphics, computer-animated films, computer-composed and -played music, and computer poems and texts
2. Cybernetic devices as works of art, cybernetic environments, remote-control robots and painting machines
3. Machines demonstrating the uses of computers and an environment dealing with the history of cybernetics.

Cybernetic Serendipity deals with possibilities rather than achievements, and in this sense it is prematurely optimistic. There are no heroic claims to be made because computers have so far neither revolutionized music, nor art, nor poetry, in the same way that they have revolutionized science.

There are two main points which make this exhibition and this catalogue unusual in the contexts in which art exhibitions and catalogues are normally seen. The first is that no visitor to the exhibition, unless he reads all the notes relating to all the works, will know whether he is looking at something made by an artist, engineer, mathematician, or architect. Nor is it particularly important to know the background of the makers of the various robots, machines and graphics—it will not alter their impact, although it might make us see them differently.

The other point is more significant.

New media, such as plastics, or new systems such as visual music notation and the parameters of concrete poetry, inevitably alter the shape of art, the characteristics of music, and the content of poetry. New possibilities extend the range of expression of those creative people whom we identify as painters, film makers, composers, and poets. It is very rare, however, that new media and new systems should bring in their wake new people to become involved in creative activity, be it composing music, drawing, constructing or writing.

This has happened with the advent of computers. The engineers for whom the graphic plotter driven by a computer represented nothing more than a means of solving certain problems visually, have occasionally become so interested in the possibilities of this visual output, that they have started to make drawings which bear no practical application, and for which the only real motives are the desire to explore, and the sheer pleasure of seeing a drawing materialize. Thus people who would never have put pencil to paper, or brush to canvas, have started making images, both still and animated, which approximate and often look identical to what we call 'art' and put in public galleries.

This is the most important single revelation of this exhibition.

Work on this project started in the autumn of 1965. Only by 1968, however, was there enough financial support for it to go ahead. Since the project involves computers, cybernetics, electronics, music, art, poetry, machines, as well as the problem of how to present this hybrid mixture, I could not have done it on my own. I was very lucky to have had the help and advice of:

technological adviser—Mark Dowson, freelance electronics and system design consultant, associated with Dr Gordon Pask and System Research Ltd.
music adviser—Peter Schmidt, painter, who has a particular interest in electronic and computer music and who has composed music himself.
exhibition designer—Franciszka Themerson, FSIA, OGG Collège de Pataphysique (Paris), painter and theatrical designer.

I would also like to acknowledge the kind help, valuable advice, and very real encouragement I have received from the following:

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Cartoon by Norman Toynton

Norbert Wiener on cybernetics

The best-known definition of cybernetics is Norbert Wiener's sub-title for his book *Cybernetics:* 'Or control and communication in the animal and the machine'.

He described it further in 1950 as the study of messages as a means of controlling machinery and society.

His first book on this subject was a technical one, and Wiener in order to make his ideas acceptable to the lay public wrote another volume *The human use of human beings*, subtitled *Cybernetics and society*. In the second edition of this book, in 1954, Wiener elaborated further the new context in which cybernetics had become relevant:

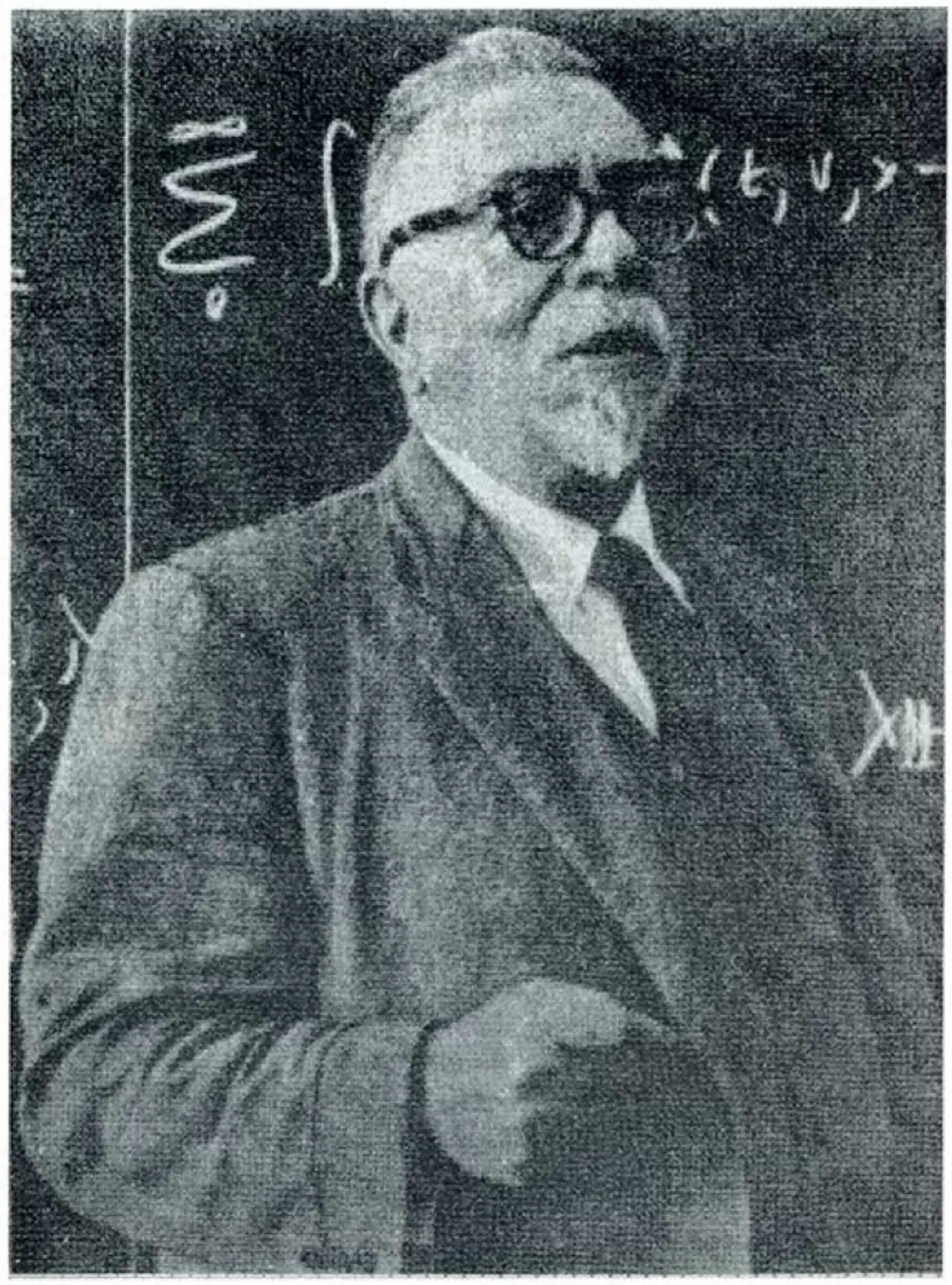
'In giving the definition of Cybernetics in the original book, I classed communication and control together. Why did I do this? When I communicate with another person, I impart a message to him, and when he communicates back with me he returns a related message which contains information primarily accessible to him and not to me. When I control the actions of another person, I communicate a message to him, and although this message is in the imperative mood, the technique of communication does not differ from that of a message of fact. Furthermore, if my control is to be effective I must take cognizance of any messages from him which may indicate that the order is understood and has been obeyed.

'It is the thesis of this book that society can only be understood through a study of the messages and the communication facilities which belong to it; and that in the future development of these messages and communication facilities, messages between man and machines, between machines and man, and between machine and machine, are destined to play an ever-increasing part.

'When I give an order to a machine, the situation is not essentially different from that which arises when I give an order to a person. In other words, as far as my consciousness goes I am aware of the order that has gone out and of the signal of compliance that has come back. To me, personally, the fact that the signal in its intermediate stages has gone through a machine rather than through a person is irrelevant and does not in any case greatly change my relation to the signal. Thus the theory of control in engineering, whether human or animal or mechanical, is a chapter in the theory of messages.

'Naturally there are detailed differences in messages and in problems of control not only between a living organism and a machine, but within each narrower class of beings. It is the purpose of Cybernetics to develop a language and techniques that will enable us indeed to attack the problem of control and communication in general, but also to find the proper repertory of ideas and techniques to classify their particular manifestations under certain concepts.'

(From *The human use of human beings* by Norbert Wiener, Doubleday, 1964.)



This digital Norbert Wiener is the work of H. Philip Peterson of the Control Data Corporation Digigraphics Laboratories, Burlington, Mass. The picture is composed entirely of numbers. Each two-digit number represents the density of colour in the area it occupies, based on a 'grey scale' of 100 increments. Philip Peterson designed the numerical character font so that the higher the number, the darker it appears to the eye. A Control Data Model 280 Digigraphic Scanner was used with a Model 160 computer to scan a 35 mm. black and white slide of Wiener, averaging the density in each of 100,000 'cells'. A Calcomp Model 564 plotter, driven on-line by a Control Data Model 3200 computer, was then used to plot the digits within the cells, which are ·115 in. squares in the original plot. Scanning and processing time is about 4 minutes on the CDC 160, and plotting time on the Calcomp 564 is about 16 hours.

Notes on cybernetics

Mark Dowson

Robots and computers have been with us for a long time. The first computer was the abacus used thousands of years ago; the first robot (in myth, if not reality) the Golem, a man made of clay by the High Rabbi Lev Ben Bezalel of Prague in the sixteenth century. This is also the first cautionary tale about robots; for the Golem, animated by a slip of paper bearing the name of God, stuck to its forehead, turned on the Rabbi and killed him when he made it work on the Sabbath. The word 'robot' comes to us from the Czech writer Karel Capek and his play, *R.U.R. (Russums Universal Robots)* of 1928. Meanwhile computers had been developing steadily; the first adding machine was Pascal's calculator, 1642, followed closely by Leibniz's calculating machine which could multiply, divide and extract roots. Automation started with Jacquard's punch-card-controlled loom (1801) and, of course, fairground organs controlled on a similar principle.

The first computer in the modern sense of a machine whose *operations* are controlled by its input, would have been Charles Babbage's Analytical Engine (c.1840) had he completed it, but we must wait till this century and Bush's Differential Analyser (1927) for the first working example of this type of machine. The Second World War gave a spur to the development of servomechanisms and electronic computation and saw the creation of the first stored-programme digital electronic computer, ENIAC.

Cybernetics was born officially in 1948 with the publication of Wiener's book—*Cybernetics:* Or *control and communication in the animal and the machine.* A year later, Shannon's paper, *A mathematical theory of communication,* consolidated the foundations of cybernetics as we know it today.

A list of a few significant events and their dates:

1642 Pascal's calculator was built
1673 Leibniz builds his calculating machine
1801 Jacquard's punch-card-controlled loom
1840 Babbage working on his Analytical Engine
1868 Maxwell publishes his theoretical analysis of Watt's governor
1927 Bush constructs his Differential Analyser
1944 ENIAC constructed
1946 First Josiah Macy Foundation conference on Cybernetics
1948 Norbert Wiener's book *Cybernetics* published
1949 Shannon publishes his paper *The mathematical theory of communication*
1956 First congress of the International Association of Cybernetics at Namur, Belgium.

Since the early 1950's the pace of work on cybernetics has been so intense and the rate of new discoveries so fast that time alone will tell which events will prove to have been crucial in the development of this still relatively young science.

Digital computers

Mark Dowson

A digital computer consists of four main sections: an Arithmetic Unit which performs simple operations on data; a Memory System for storing data; Input-Output equipment; and a Control Unit for controlling the flow of information in the system.

Memory

Information is stored in a computer in the form of binary numbers or a fixed number—from twelve to about forty-eight—of digits; these are known as words. There are two main types of storage. One, high speed storage, which often consists of ferrite cores, holds information which must be instantly available and may have a capacity of from 4,000 to over a million words. The time it takes to get one word of information to or from this type of storage, known as 'memory cycle time', determines the overall speed of operation of the computer. As well as data, the high speed storage holds the programme or set of instructions which determines the sequence of operations. The other type of storage contains data which may be required during the course of a long computation or even programmes which are not currently being used. It consists of either magnetic tape, which will store large quantities of information but has the disadvantage of relatively long access time, or magnetic disc or drum storage—spinning discs or drums of recording-tape-like material—which is intermediate in both capacity and access time between ferrite core storage and magnetic tape.

Input/output devices

Computer input/output devices may handle information in a variety of forms—holes punched in card or paper tape, printed characters, or visual display on a cathode ray tube, amongst others. Line printers will print out information at up to 1,200 lines per minute. Recently, light-pen systems have been developed which allow the user to communicate directly with a computer by drawing on the face of a cathode ray tube.

Arithmetic unit

The function of the arithmetic unit is to perform very simple operations on data very quickly. A programmer's job, therefore, consists in breaking down problems into very small and simple parts which are then done by the machine at great speed. In many cases this has led to the complete revision of conventional methods of solving problems.

Control unit

As digital computers become larger and more elaborate their control units necessarily increase in complexity. The primary function of the control unit is to interpret the instructions in the programme, control the transfer of information within the computer, and control the operations of the arithmetic unit. In larger systems which are 'multi-programmed', i.e. contain and perform several programmes simultaneously, the control unit must select which programme is to be followed at any particular instant taking into

account the most efficient use of computer time and the priorities of the various programmes. In time-sharing, when two operators are able to use the computer simultaneously, the control unit must apportion time between the users so that they may all act as if they have the computer to themselves.

Size of computing systems
The largest modern computing systems, although many times smaller than their counterparts of a few years ago, can still take up thousands of square feet of floor space and their cost may run into millions of pounds. In contrast the smallest (commercially) available computers are no larger than an electric typewriter and cost as little as £4,000. Terminals connected by telephone line to a large central computer can be bought and run for as little cost as that of a small car. Thus the idea of a computer in every home is not as distant as it seemed a few years ago.

Computers and the arts
It is merely an historical accident that computers are largely used for mathematical calculations. Computers manipulate symbols which can represent words, shapes or musical notes as easily as numbers. Soon it will no longer be surprising to see a computer on the stage of the Queen Elizabeth Hall—this actually happened in January 1968—interpreting and performing a piece of music before a fascinated audience.

Ramon Lull's logic machine
This was originally designed by the Spanish theologian and visionary, Ramon Lull in the 1270's. Lull's diagrams dealt with the attributes of God, states of the soul, and the seven virtues and the seven deadly sins.

Warren McCulloch referred to Lull's 'attributes of God' machine, as digital, an either/or machine:

This figure concerns the soul which is designated by the letter S.

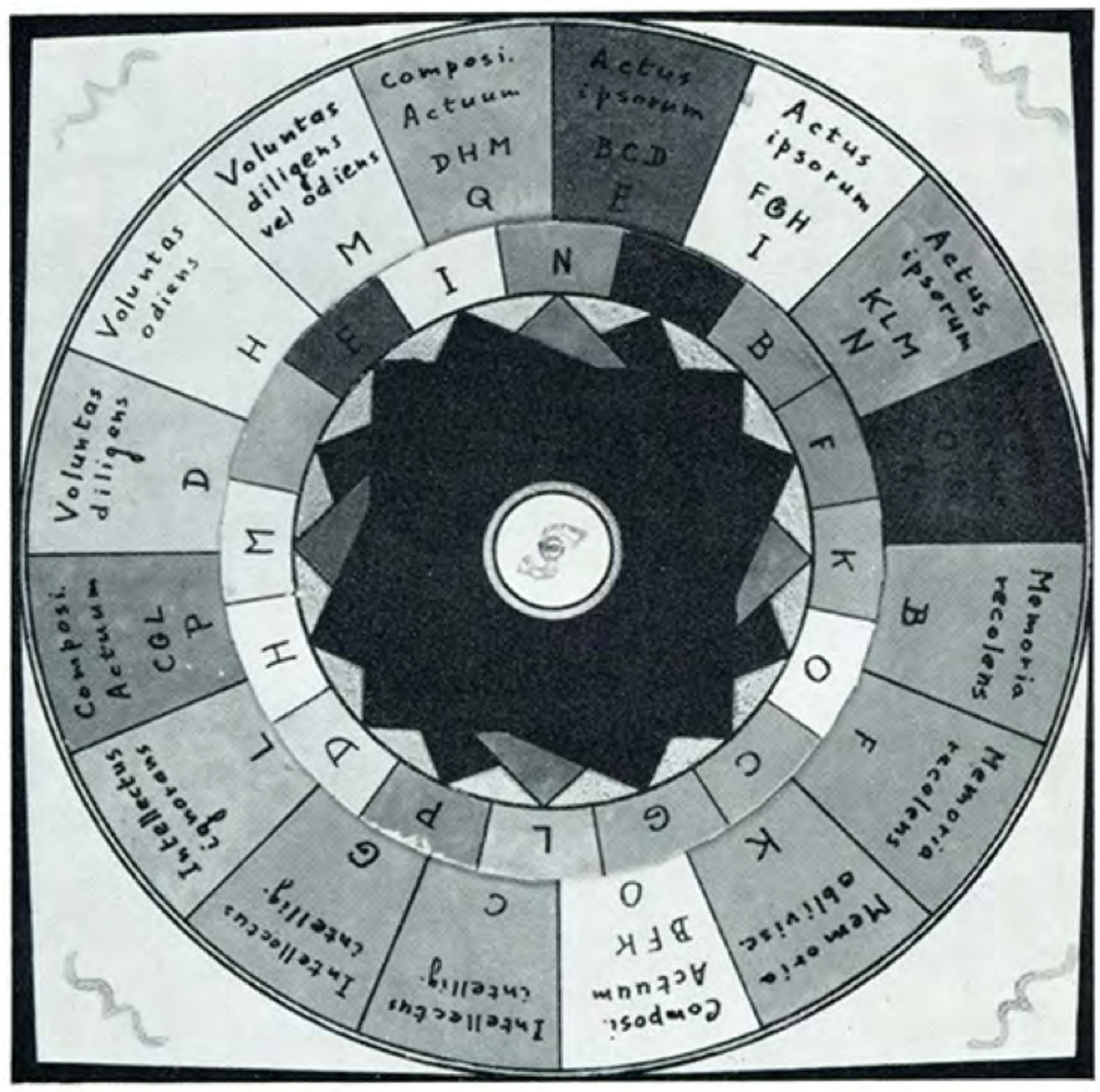
The blue square, with corners marked B C D E represents a normal, healthy soul; B stands for memory that remembers, C intellect that knows, D will that loves, E union of these three faculties.

The black square F G H I, is the condition that results when the will hates in a normal fashion, e.g. when it hates sin; H represents this faculty, F memory that remembers, G intellect that knows, I combines H F G.

The red square K L M N denotes a condition of soul in which K is the memory that forgets; L the mind that is ignorant, M the will that hates in an abnormal fashion, N unites these three degenerate faculties.

The green square O P Q R is the square of ambivalence or doubt; P stands for mind that both knows and is ignorant, O memory that retains and forgets, Q will that loves and hates, R represents the union of the three. Lull, considered this last state the unhealthiest of the four.

If we superimpose the four coloured squares in such a way that their corners form a circle of sixteen letters, we find, in addition to the four corner letters E I N R which are unions of the three corners of their respective square, that the faculties O P and Q are unions of the three faculties that precede them as we move the inner circle clockwise around the figure. The circle of sixteen letters can be rotated within a ring of compartments containing the same faculties to obtain 136 combinations of faculties.



SAM

Stafford Beer

Patterns—rigid or chaotic—are the stuff of
the universe . . .

Therefore of both art and artifacts . . .

The rigid patterns do not change at all.
Wallpaper patterns, the triangle of the
Sistine Madonna,
the proportions of the Parthenon,
the shape of a fugue—
of a ballade—
are like the pattern of an engine,
of a computer,
of an aircraft.

Chaotic patterns change eternally:
A waterfall or a thunderhead,
The scurrying of ants,
Clouds, wind and sea—
Atonal music and action painting,
Mobiles and the Æolian harp
Are matched in science
By the alpha-particle,
The collision of gas molecules,
The noise of the radio star.

What lies between rigidity and chaos—
Which both have their art and their science?

It is change within order
which perhaps defines design

Variations on a theme, for art—
and for science the stochastic process.

A stochastic process generates a pattern
which is almost rigid in the long run
through a long series of apparently random
events.
It is defined by mathematical statistics.

Will the next toss yield heads or tails?
Nobody knows.
But in a long enough series of tosses
half will be heads, half tails.

Most economic processes are stochastic.
Random events conspire towards
particular patterns—
in the long run. They are complicated,

and they interact.

In the early 1950's, before it was clear that computers would eventually cope with this kind of calculation at a reasonable cost, Stafford Beer devised SAM–
the Stochastic Analogue Machine.

Here is his original mock-up of the machine.
Ball bearings fell from the top,
and were randomly delayed (1)
by falling through the slide at the bottom.

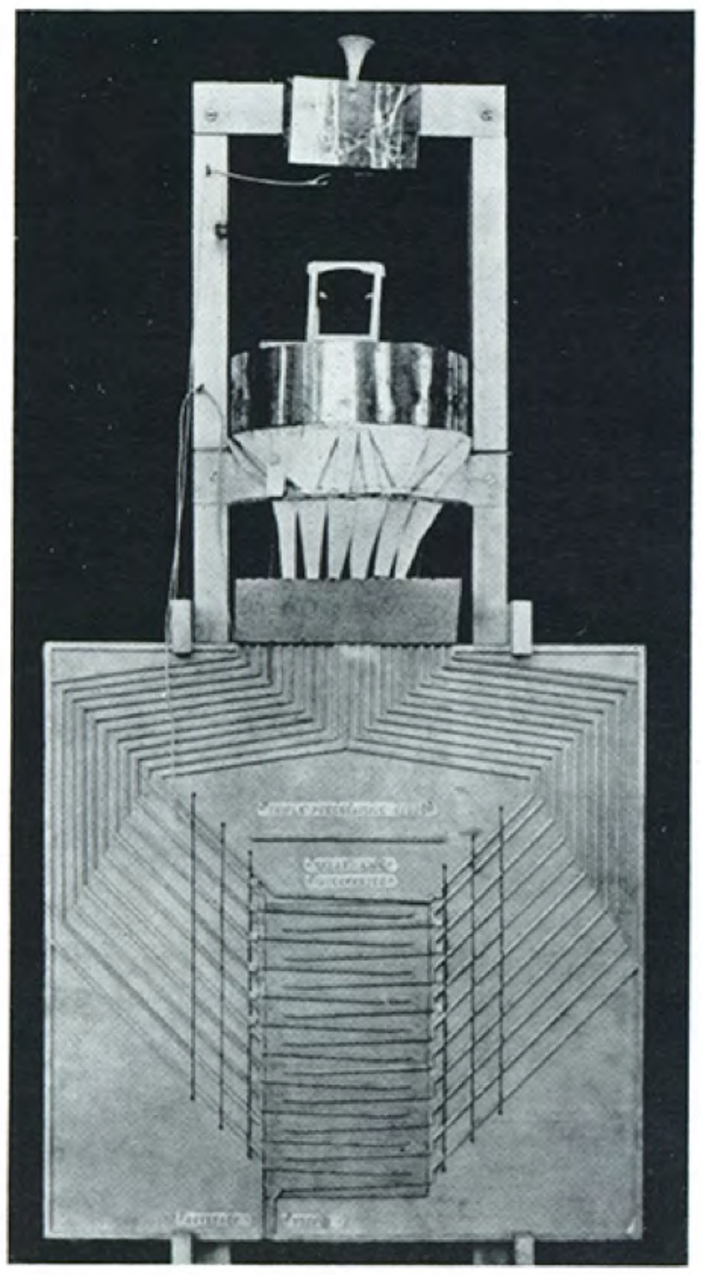
How long they took could not be predicted,
because each ball entered the slide at a different,
undetermined place,
How the ball got into this place was settled
by its falling through a sieve and running down a cone.
No one could say where the next ball would go
But the pipes connecting the randomizer to the slide
settled the *proportions* by which large numbers
of balls would be delayed.

So it was possible to generate a rigid pattern
By a random series of events.

When the pattern for one process could be generated.
It became necessary to generate the pattern
of the next process, and to use an event

Below, SAM mark I
Bottom left, SAM marks III & II
Bottom right, SAM final model

1



randomly put out by the first
to trigger off the second.
That is why two machines are joined together
in the second mock-up.

The design of these two machines reflects
the same stochastic system. (2)
Now it is possible to determine the interaction
between *two* processes by counting
the number of ball-bearings in the zig-zag
at the top of the second machine–
because the input to the second machine
is the output of the first.

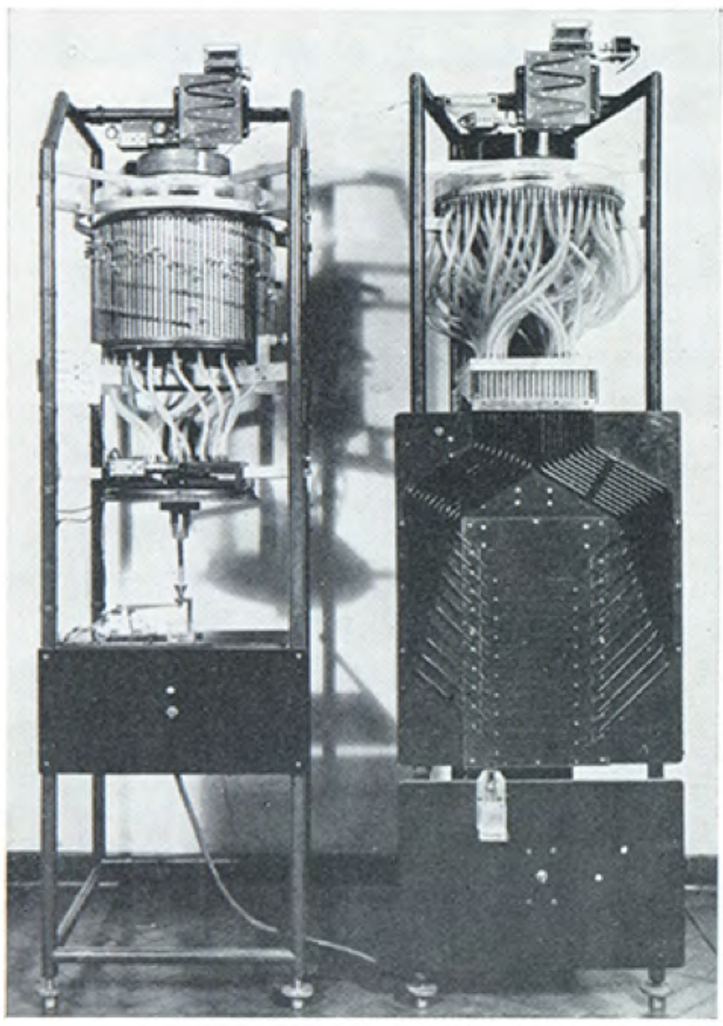
This reproduces the convoluted probability pattern, for instance,
of a stock held between two stochastic processes.

And here is half the completed SAM–
Five stochastic generators (3)
(There are five more behind the camera)
And a control console.

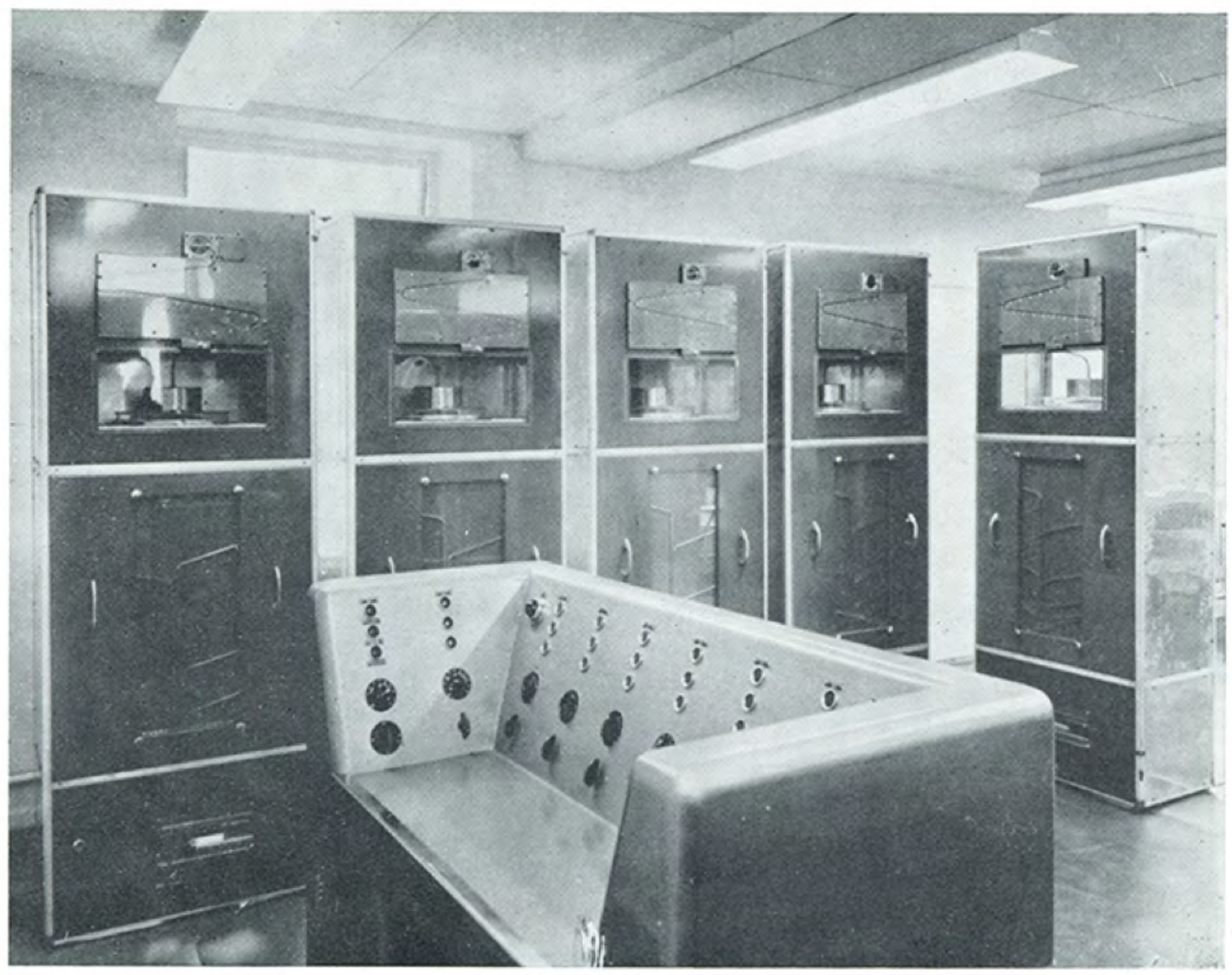
This total machine, soon superseded by electronic computers,
was used about 1955 to elucidate
the natural design of stochastic interactions
in a Sheffield steelworks.

It says something, in physical form and mechanism,
About the chaotic fulfilment of rigid patterns–
about DESIGN.

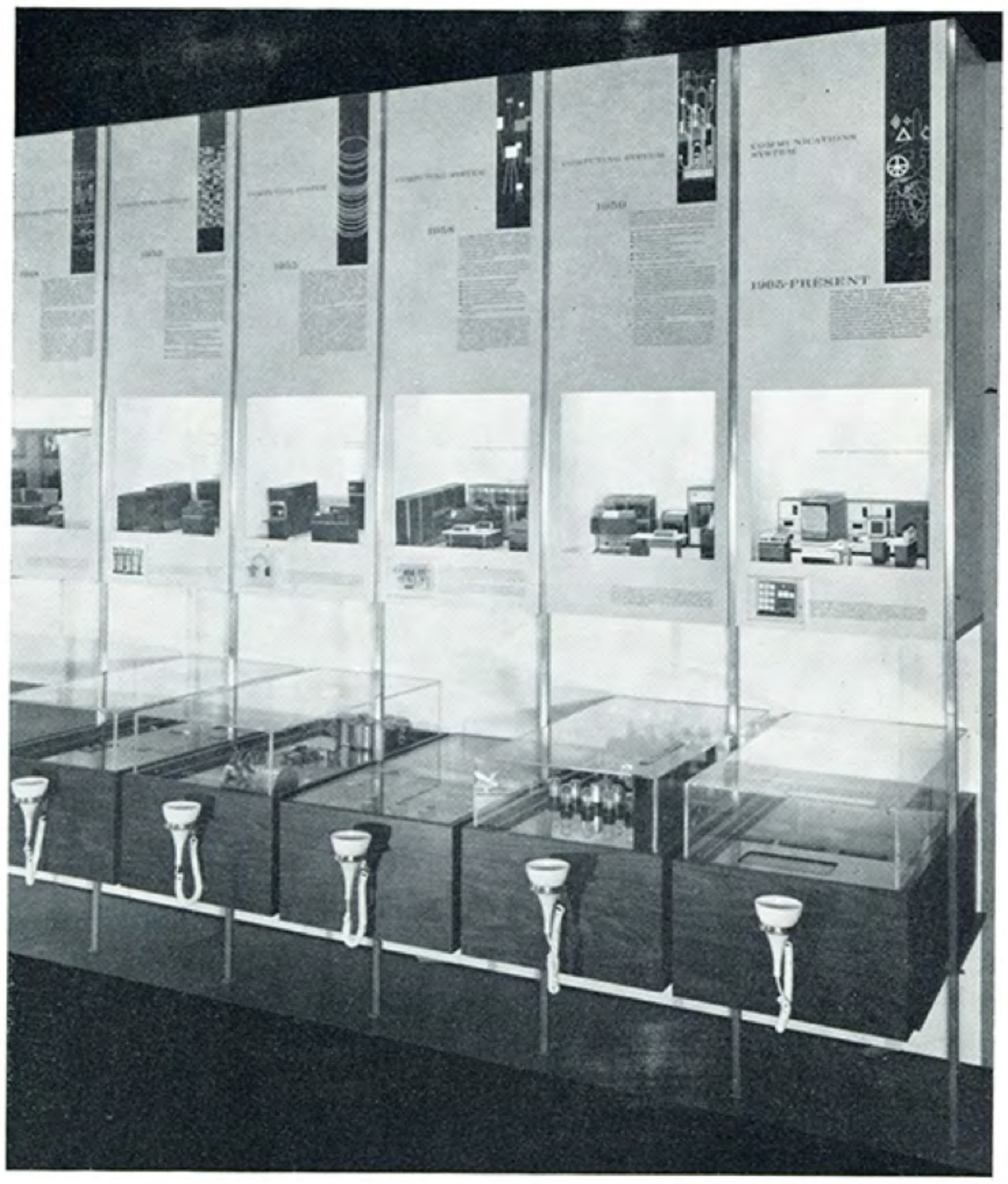
2



3



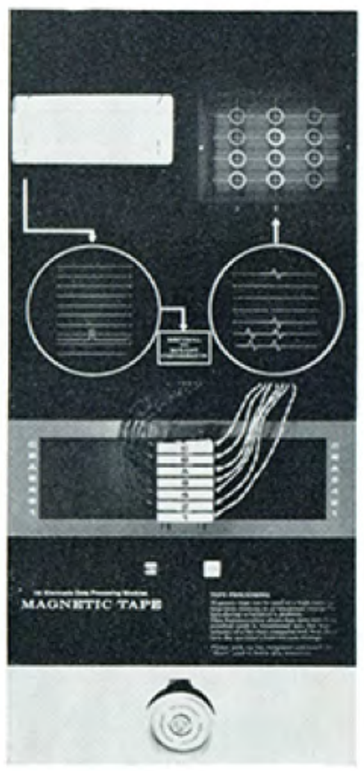
Highlights of the history and technology of computers from 1890 to the present

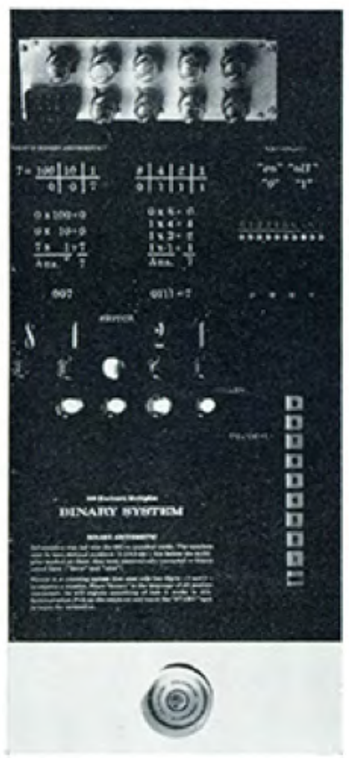


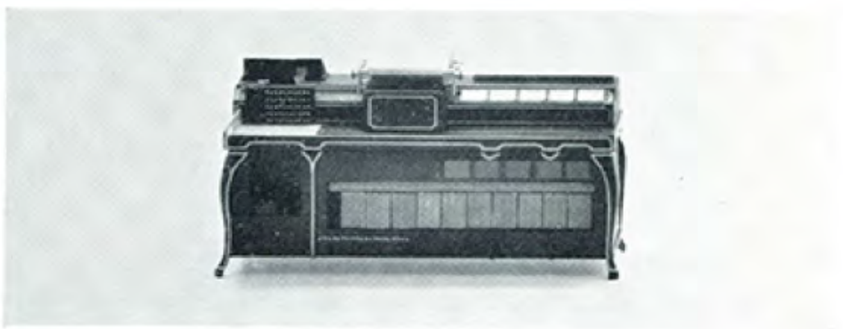
Each of the six display units consists of a scale model of a historical innovation in data-processing machines, and an audience-operated animation device which highlights the technological break-through represented by the machine—providing insight into some basic computer concepts. The machines shown here were selected because of their historical significance to the tabulating, calculating and computing industry. The six systems featured are the Hollerith (1890), Mark I (1944), IBM 603 (1946), IBM 701 (1952), IBM 7070 (1958) and System/360.

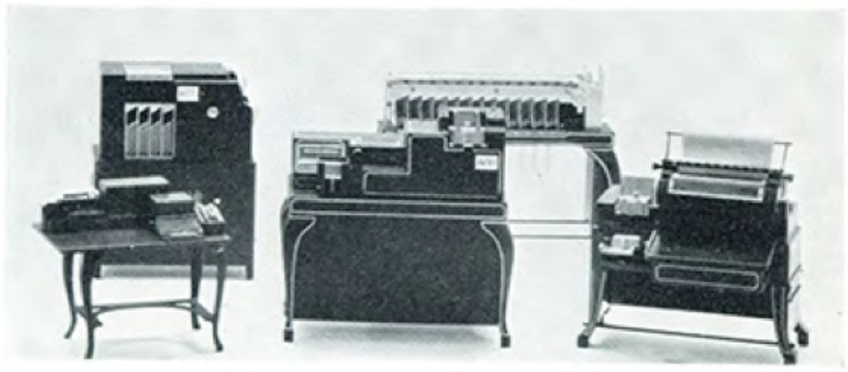
The audience-operated demonstrations include devices which help to explain punched-card data processing, programming, binary arithmetic, magnetic tape storage, core memory, and 'real-time' information handling.

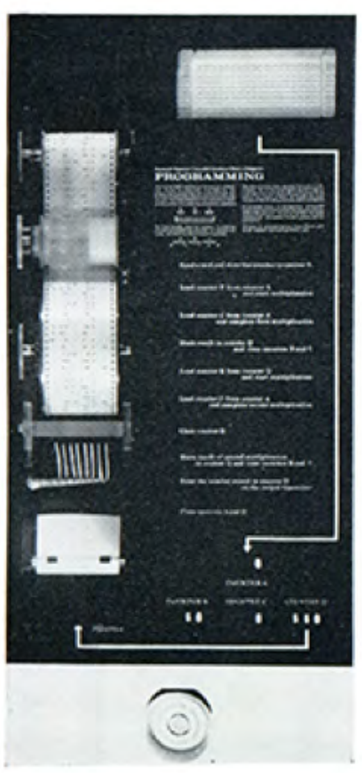
These six display units make up the travelling version of a section which IBM provided for an exhibition entitled 'History and Technology of Computers' which was held at the Smithsonian Institution in Washington. The IBM display section won the first place gold medal as the most outstanding exhibit of the year at the International Display World Competition of 1967.

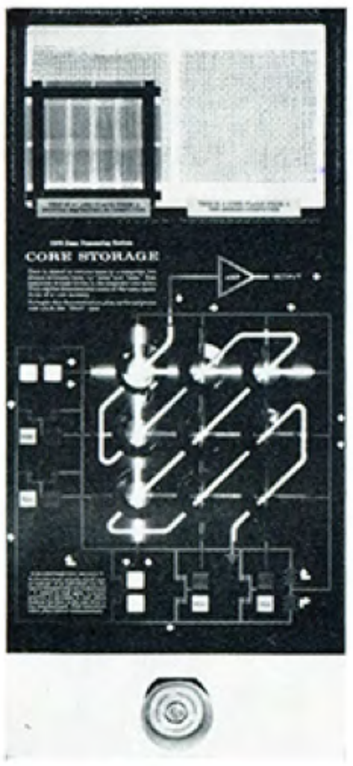


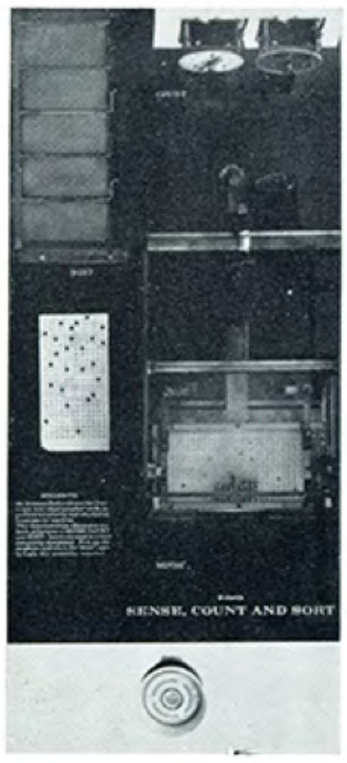












Top, A section of the IBM exhibit at the Smithsonian Institution

Above, Typical scale model

Far left, Six animation panels included in each display

Left, One of the six stands in the IBM display

Glossary

ADDRESS
In a digital computer; the name of a position in Memory where some piece of information is stored.

ALEATORY
Chance, random.

ALGOL
One of the most commonly used computer programming languages. Its name is derived from 'ALGOrithmic Language'.

ALGORITHM
A prescribed set of well-defined rules for the solution of a problem. Contrast – HEURISTIC.

ALPHABET
The symbols used in a language. A digital computer's alphabet is the two symbols '0' and '1'.

ANALOGUE
A physical, mechanical, electrical model (used for computation by analogous representation) corresponding in some respect to the original object or concept, with or upon which measurements or calculations are to be performed.

ANALOGUE COMPUTER
A device to perform calculations about real systems by constructing a (usually electrical) model or 'analogue' of a system and making measurements on it.

ARITHMETIC UNIT
That part of a computer performing arithmetic and logical operations.

ATTACK & DECAY
Wave forms opening and closing a sound or pulse.

AUTOMATON
A deterministic machine which applies an Algorithm to its inputs to find the appropriate output.

BINARY
A characteristic, property or condition in which there are two possible alternatives. The binary code used in computers is expressed in terms of one and zero representing on or off.

BINARY DIGIT
A binary number: 0 or 1.

BIT
Common abbreviation for binary digit; used also as a unit of measurement of information.

BIONICS
The science that studies biological mechanisms in order to construct machines using their principles.

BLACK BOX
A system whose inputs and outputs are known but with an unknown internal mechanism.

CATHODE RAY TUBE (C.R.T.)
A vacuum tube in which electrons emitted by a hot cathode are formed into a narrow beam or pencil and accelerated at high velocity toward a specially prepared screen which fluoresces at the point where the electrons strike; provides visual display of electronic signal information; can be used as a computer storage device.

CHANNEL
That part of a communication system along which messages are conveyed.

CODE
A system of symbols for representing data or instructions.

COMPILER
A special type of computer programme which will automatically translate programmes written in some universally-known programming language such as FORTRAN into machine language instructions suitable for a particular computer.

COMPUTER
Any system which operates on information to produce an output. See DIGITAL COMPUTER.

CORE
See FERRITE CORE.

CYCLE
A fixed period of operation.

DEBUG
To detect, locate and remove mistakes in programmes or malfunctions in a computer.

DIGITAL
System – one in which variables are represented by numbers (in analogue system, variables are represented by physical quantities).

DIGITAL COMPUTER
See page 10.

DIGRAM PROBABILITY
The probability of occurrence of a particular pair of symbols of an alphabet.

ELECTRONIC
Pertaining to the flow of electrons in vacuum, gas or semiconductors. Electrons are quantities of electrical energy which course from point to point in a computer making its high-speed operation possible.

ENSEMBLE
Set or collection. The ENSEMBLE of messages from a source is the collection of possible messages that the source can produce.

ENTROPY
Mathematical function rather than verbal description. A measure of the randomness, degree of disorder or chaos of a system.

FEEDBACK
Return of a signal to a controller indicating the result of an action taken by that controller and used to determine further actions.

FERRITE CORE
A minute (approx. 1mm. diameter) ring of magnetic material which may be used to store one bit of information in a computer memory.

FILTER
A device which transmits or suppresses a predetermined part of a signal going through it.

FINITE STATE MACHINE
A machine which has only a finite number of states or a finite memory.

FLOW CHART
A convenient diagrammatic method of representing the relationships among subroutines of a computer programme so that it might be more easily understood by human programmers.

FORTRAN
One of the most commonly used computer programming languages. Its name is derived from FORmula TRANslation.

BINARY

A toddler from a family refined
Alternatively giggled and whined
It is sad to relate
That the state of his fate
Was the binary state of his mind.

DEBUG

A hairdresser created a pouf
So high that it looked like a goof!
He said, while a-tugging,
'Madame, I am debugging!
This artless and curlycued roof!'

FOURIER ANALYSIS
A method of analysing any periodic signal into its harmonic components (pure sine waves).

FREQUENCY
The repetition rate which determines the pitch of a sound.

FREQUENCY MODULATION (F.M.)
A method of coding information so as to send it reliably. The frequency of a carrier signal is varied by the amplitude of the message to be transmitted.

GAME THEORY
A mathematical process of selecting an optimum strategy in the face of an opponent who has a strategy of his own. The forces of nature might be the 'opponent' in a planned space shot. The strategy to overcome these might be 'played' on a computer to ascertain an optimum launch date.

HARDWARE
The electronic and mechanical equipment comprising a computer, e.g. logic circuits, tape readers, power supply.

HEURISTICS
Techniques by means of which the individual (or machine) can be equipped to solve problems. If the heuristics are applicable, they will provide a short cut to the goal. However, heuristic methods cannot guarantee a solution and may lead to a blind alley. See ALGORITHM.

HOMEOSTASIS
The tendency of an organism – or an organism-like machine – to remain in and return to some stable state.

INTERFACE
An element of a computer system which connects its constituent parts.

'K'

In a scientist's jargon a 'K'
Is a thousand of be-what-it-may
From storage locations
To cycle durations
To the size of his annual pay.

A subfix meaning one thousand. Computer storage capacity can be stated in thousands of addressable locations, i.e. 64 K.

LASER

The light from the bulb overhead
Is white and pretty well spread
But laser-made light
Won't veer left or right
It's straight and as thin as a thread.

(Light Amplification by Stimulated Emission of Radiation.) A beam of light whose waves are coherent, differing from ordinary light as the effect of one pebble tossed into water differs from the effect of a handful.

LATENCY
In psychology, the interval of time between the presentation of a stimulus and the response to it.

MACHINE LANGUAGE
A vocabulary of 'words' meaningful to a computer; strings of binary digits acceptable to and manipulable by machine circuits.

MATHEMATICAL MODEL
Facsimile in mathematical terms; a body of mathematical statements describing a process, parameters, and their relationships to one another and to environments; useful for rigorously studying complex relationships, particularly with a computer. See also ANALOGUE.

MEMORY (OR STORAGE)
Any device into which units of information can be copied which will hold this information and from which the information can be obtained at a later time.

MESSAGE
Any string of symbols intended for transmission.

NANOSECOND
One thousand millionth of a second. Some computer operations are approaching nanosecond speed.

NOISE
Any undesirable signal interfering with the transmission of a message. Usually random.

ON LINE
The property of being connected to a real-time system.

PARAMETER
A discrete characteristic of a system; in conjunction with others it defines the state of the system.

PROBABILISTIC
A probabilistic process is one which is only statistically predictable.

PROGRAMME
A set of instructions either fed to or built into a machine which determines how it will act.

PROGRAMMING LANGUAGE
A language, e.g. ALGOL, FORTRAN, for feeding instructions or programmes into a digital computer.

RANDOM
A random process is one whose future is not predictable from its past.

RANDOM ACCESS
Storage characteristic in which the time required to access the next position from which information is to be obtained is in no way dependent on the position from which the piece of information was retrieved.

REAL-TIME
Computation controlling a physical process as it happens.

REDUNDANCY
Extra detail in a message which allows it to remain understandable in spite of noise and interference.

REGISTER
In a digital computer, a special memory unit for temporary storage of information.

RELAY
An electromagnetic device whereby a small electrical signal may switch on and off a larger one.

SAMPLE
The instantaneous value of some continuously varying quantity at a particular time.

SERVOMECHANISM
An automatic controller which uses information from its environment to control the environment, e.g. a thermostat.

SIGNAL
Any MESSAGE or part of a message.

SIMULATION

The coach on the blackboard did scrawl
His trickiest play of the fall
Though his simulation
Drew quite an ovation
The quarterback fumbled the ball!

The representation of the behaviour of a physical system by the execution of a computer programme or some other model.

SOFTWARE
The programmes and languages used to operate computer machinery.

STATE
A recognisable condition of a system.

STATISTICS
The branch of mathematics which prescribes the way in which large amounts of data may be summarised to detect averages and trends. Thus 'statistical'.

STOCHASTIC
Random, in whole or part.

STORAGE
See MEMORY.

SUBROUTINE
A unit of a computer programme.

SYMBOL
Any element of an alphabet.

TRANSDUCER
A device which converts energy from one form to another.

VALVE
A device whereby a small signal may continuously control a larger one. Contrast RELAY.

VARIETY
A measure of uncertainty or the amount of selection required to remove that uncertainty.

WORD
An ordered set of characters bearing at least one meaning and handled by a computer as a unit.

X-Y PLOTTER
The rule for a graph I have found
X is always westerly bound
And the thing about Y
Is, it points to the sky
(Or is it the other way round?)
A device in conjunction with a computer to plot co-ordinate points in the form of a graph.

Compiled by Mark Dowson, Humphrey Evans, IBM, Andrew Logan, Peter Schmidt.

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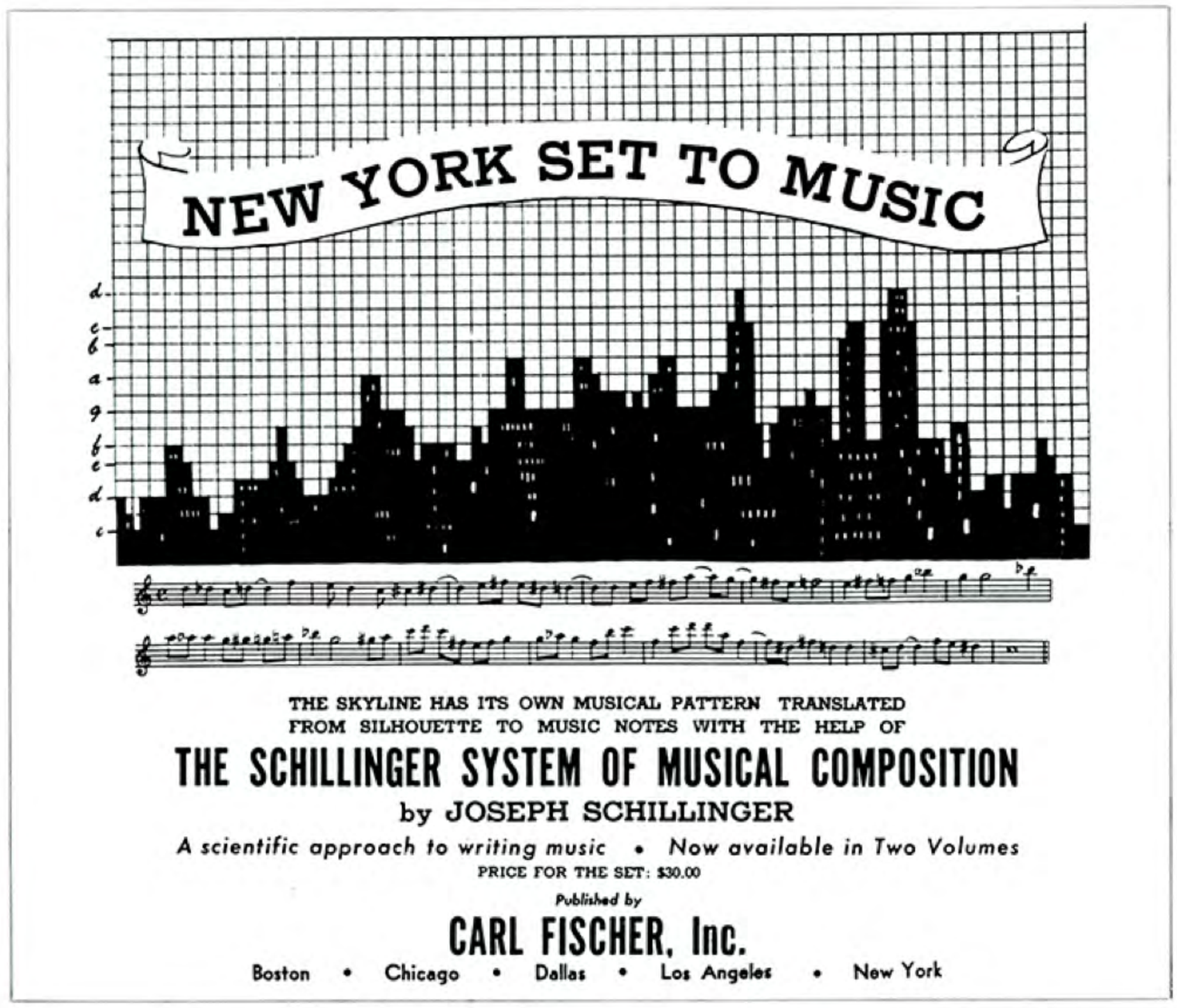
The computer and music



Poster for 'The Schillinger System of Musical Composition' (1946). *New York Skyline* was composed as a piano piece by Heitor Villa-Lobos. The System was also used by many other composers, notably by George Gershwin in writing *Porgy and Bess*

Coordinate expansion

Joseph Schillinger

[Schillinger's views on the mathematical basis of various musical styles were formulated before digital computers were developed (the book was published in 1948), but they could be used as a basis for experiment on the production of music in various historical styles generated by a computer.]

'As each coefficient of expansion is applied to music, the original is translated into a different style, a style often separated by centuries. It is sufficient to translate music written in the 18th century by the coefficient 2 in order to obtain music of greater consistency than an original of the early 20th century style. For example, a higher quality Debussy-like music may be derived by translation of Bach or Handel into the coefficient 2.

'The coefficient 3 is characteristic of any music based on $\sqrt[4]{2}$ (i.e. the "diminished 7th" chord). Any high-quality piece of music of the past exhibits, *under such projection*, a greater versatility than any of the known samples that would stylistically correspond to it in the past. For the sake of comparing the intuitive patterns with the corresponding forms of geometrical projection, it is advisable to analyse such works as J. S. Bach's *Chromatic Fantasy and Fugue*, Liszt's *B Minor Sonata*, L. van Beethoven's *Moonlight Sonata*, first movement.

'The coefficient 4, being a multiple of 2, gives too many recurrences of the same pitch-units since it is actually confined to but 3 units in an octave. Naturally, such music is thereby deprived of flexibility.

'But the 5p expansion is characteristic of the modern school which utilizes the interval of the 4th—such as Hindemith, Berg, Krenek, etc. Music corresponding to further expansions, such as 7p, has some resemblance to the music written by Anton von Webern. Drawing comparisons between the music of Chopin and Hindemith, under the same coefficient of expansion, i.e., either by expanding Chopin into the coefficient 5, or by contracting Hindemith into the coefficient 1, we find that the versatility of Chopin is much greater than that of Hindemith. Such a comparison may be made between any waltz of Chopin and the waltz written by Hindemith from his *Piano Suite*, 1922.

'Comparative study of music under various coefficients of expansion reveals that often we are more impressed by the raw material of intonation than by the actual quality of the composition.

[From Schillinger's book, *The mathematical basis of the arts*, Philosophical Library, New York, 1966.]

Computers and music

Dr J. R. Pierce

The application of electricity to the production, as contrasted with reproduction, of music goes back to the early years of this century, when an effort was made to bring signals from a primitive electric organ into homes over wires. This project was abandoned, partly because of the interference it caused to the telephone system.

With the invention of the vacuum tube and the development of the science and art of electronics, a number of electric musical instruments have come, and most of them have gone. The Theremin is no longer with us and the Novachord has vanished into limbo, but there are a surprising number of electronic organs in churches and in homes, aod there have been lively experiments with more esoteric instruments.

Indeed, there are in all countries centres of electronic musical art, in which the squawks, squeals, and other outputs of electronic apparatus are mixed with reversed, speeded-up and otherwise processed natural sound, which are the basis of *musique concrète*.

The proponents of electronic music have found themselves plagued with two chief problems. One of these has been the terribly time-consuming process of setting up equipment that generates or processes electronic sound and the hours spent adjusting and using the equipment and in piecing bits of tape together to achieve an over-all result. The other limitation has been one of variety of sound. However strange electronic music may sound, it seldom sounds anything but electronic.

A great deal of skill, on the part both of instrument-makers and of composers, has gone into making conventional instruments and ensembles produce extremely various sounds. Still, the writer of music for conventional instruments is limited to the sounds which conventional instruments can be made to produce. Another limitation which plagues the composer for conventional instruments is his reliance on the skill of the performer in executing his intentions. Haydn had instruments and an orchestra at his beck and call, but today's composer must often wait a considerable time for an experimental verification of the effect he conceives and intends.

As long as the maker of electronic music simply creates new but limited instruments, he suffers the limitations of all particular instruments, whether they be mechanical or electronic. He may or may not rely on a performing artist, according to the techniques he uses, but he certainly has not escaped challenges of manual skill and dexterity. A partial escape is illustrated by the RCA music synthetiser, now in use by Milton Babbit and others at the Columbia-Princeton Electronic Music Center, which can be controlled by a punched tape.

The coming of the digital computer has, in principle, changed the situation. In 1936 the English logician, Turing, showed that a certain rudimentary type of computer, which we call a Turing machine, can compute any computable number. In simpler words, this means that a Turing machine can carry out any numerical process that one can specify explicitly. While modern digital computers are not Turing machines and have limitations which the idealized Turing machine, with its infinite memory, does not have, they are much more flexible and capable in a practical way than the machines Turing envisaged. In a very real sense, electronic computers are universal machines which can do anything that any machine can do. Limitations lie in the insight and skill of the programmer, not in the digital computer itself.

Digital computers produce numbers, not sounds. However, information theory, which C. E. Shannon launched on its course in 1948, tells us, even in its most elementary aspects, that the world of messages is a universal world, amenable to numerical representation and interpretation. The electric wave which, by means of a microphone or a pickup, goes from an instrument or a recording into the speaker of a high-quality sound system can be specified with complete accuracy as a sequence of numbers. These numbers specify the amplitude of the wave at regularly spaced instants of time.

The number of numbers required per second is twice the bandwidth of the sound, or about 20,000 numbers per second for high-quality music. Furthermore, the numbers themselves need not be infinitely accurate, for the ear cannot detect small errors in amplitude. Thus, 20,000 three-digit numbers a second can describe not only any music that has ever been played, but any music that ever could be played, if only we are able to choose the right numbers.

Here is a powerful resource. A digital computer as a source of a sequence of numbers, together with not very complicated equipment for turning this sequence of numbers into an electric wave that can drive a loudspeaker, is truly the universal musical instrument—the instrument which can, in principle, create any sound that can be created, any sound that can be heard by the ear. A composer equipped with a digital computer has no limitations except his own.

Over the past few years, workers at both the Massachusetts Institute of Technology and the Bell Telephone Laboratories have been experimenting with the digital computer as a source of musical sound. More recently, this work has been extended to Princeton University, and similar work is being carried on at the Argonne National Laboratory. Related studies of the analysis and synthesis of conventional musical sounds are being carried out at Yale.

What are the results? They are surprising and promising in some ways and discouraging in others. One discouraging aspect is that even the IBM 7094, which is a very fast computer, takes about five seconds to produce one sound of music. Time on the 7094 costs several hundred dollars an hour. This is a limitation that will be overcome as computers become faster and more economical.

The other discouraging aspect is that, while the sounds produced are often wild and weird, they lack the richness which we are accustomed to hear in conventional instruments, and more especially in large ensembles of instruments. Something is missing and, while we can guess at its nature, we cannot point to it in a precise and quantitative enough way so that we can tell the computer to produce the effect we seek.

Helmholtz made great strides in musical acoustics in the 19th century, but the science has not progressed at the same rapid pace as others. The user of a computer is free to specify the wave form or frequency content of the sound he produces; he can make these random or regular in any degree; he can introduce regular or random vibrato. He can control the 'attack' and the duration of the notes. But, unlike the composer who has used a symphony orchestra as one huge instrument, he has neither years of tradition nor the skill of instrumentalists to rely on.

A little experimentation shows clearly that, while the harmonic content or frequency spectrum of the note has a strong influence on its quality, the attack has an even stronger influence. A rapid rise and gradual fall gives a plucked quality to a sound. A moderate rise, a sustained sound, and a moderate fall simulates a woodwind quality. A vibrato enhances the musicality of the sound. However, many things escape us. The brazen summoning of the trumpet is not easily evoked. Massed strings or voices must gain their effect through some degree of randomness in pitch or in attack. Yet, introducing randomness into computer music in simple ways makes it sound merely wobbly or noisy, rather than rich.

In all, the user of the computer is in somewhat the position of a musically talented savage when confronted with a grand piano. Certainly, wonderful things can come out of

this box, but how is one to bring this about? Tuition, intuition and practice are required, but there is no teacher and no one to guide the practice.

We are faced with an intriguing challenge. In principle, the computer *can* become the universal musical instrument. All that stands between us and all that was previously unattainable is an adequate grasp, scientific and intuitional, of the relevant knowledge of psychoacoustics. Both by experimentation, and by careful measurement and analysis of musical sounds, we must find among the bewildering complexity of the world of sound what factors, what parameters are important, and in what degree, in achieving the effects at which we aim: all the variations of sound that we hear from a skilled instrumentalist, all the characteristic sounds of instruments, the rich massed sound of the orchestra, and everything that can possibly lie beyond these familiar elements of music.

Men who are scientists or engineers only will never solve this problem. Its solution can come only through co-operation between those who understand something of the mechanism of hearing and psychoacoustics, those who understand the use of computers, and those who have real musical talent and creativity. Here is a chance for fruitful co-operation between science and the arts, rather than the phoney invocation of scientific formulae and jargon which so often satisfies artists in the present.

It is heartening to know that the work at Princeton and at MIT is carried out in the departments of music by people who are musicians and who are knowledgeable about computers, and who have the full co-operation of computer-oriented people. It is also heartening to know that the computer study of the analysis and synthesis of musical sounds which is being carried out at Yale is supported by a grant from the National Science Foundation.

The worry which is perpetually raised about the status and support of the arts in our society seems, in this instance, to be met in an unexpected way. If good art can embody a valid contribution to good science, as it can in the relation between music and psychoacoustics (and also, for that matter, in the relation between music and architectural acoustics), then art can validly share, not only the fruits of science, but the support which society so rightly gives to science, for the practical contributions that science makes to our welfare as well as the intellectual and philosophical value of science itself.

[This article first appeared in *New Scientist* of 18/2/65, No. 431.]

Extract from notes on 'Mikrophonie I'

Karlheinz Stockhausen

[While he is very interested in indeterminate and aleatory methods of composition, Stockhausen does not use computers. Nevertheless, his recent compositions show analogies to computer methods, in the way that different systems react to each other, enhance each other, and cancel each other out.]

It was on the basis of this experiment that *Mikrophonie I* was composed. With various materials, two players excite the tamtam; two other players pick up the vibrations with directional microphones. Distance between the microphone and tamtam (which influences the dynamics and timbre), relative distance between the microphone and the point of excitation on the tamtam (influencing pitch, timbre, and above all determining the spatial impression of the sound, ranging between distant, echoing and extremely close), and rhythm of microphone movement are prescribed in an appropriate notation. Each of two more players activates an electronic filter and potentiometer. They again shape the timbre and pitch (through a combination of filter adjustment and volume control) and the rhythm of the structures (through the metrically notated alteration of both instrument settings).

In this way, three independent, interacting, yet, at the same time, autonomous sound-structuring processes are bound together. These were then composed to function synchronously or independently, homophonically or as polyphony of up to six parts.

The score consists of thirty-three independent musical structures which may be combined for a given performance by means of a prescribed 'connection scheme'. This scheme determines the relationships between the structures. There are two groups of players; three musicians (one tamtam player, one microphonist and one filter and potentiometer player) form a group, and at a given time play one of the thirty-three structures. At a particular point, they give the cue for the second group to begin with the next structure. After a specific interval of time the second group returns the cue for the first group to begin with the next structure, and so forth. The relationships between structures are determined in three ways: 1) with respect to a given structure, the ensuing one is either similar, different, or contrary; 2) this relationship either remains constant, increases, or decreases; 3) the ensuing structure (which usually begins before the end of the given structure) either supports, is neutral to, or destroys that structure.

Thus, the 'connection scheme' determines three relationships for every connection between two structures. For example, a structure may be followed by one that is *similar* to it, *and* whose relationship remains *constant, and* that *supports* it; or a structure may be followed by one that is *contrary* to it *and increasingly destroys* it; or by one that is *different* and becomes *decreasingly neutral*, etc. According to these criteria, the musicians choose the order of the structures, which are themselves composed in respect to these same characteristics. Although the relationships (between structures) composed into the 'connection scheme' remain fixed for all versions (in order to guarantee a strong and directional form), the *order* of structures may vary considerably from version to version.

Composition with computers

Herbert Brün

During several years of experimental research in computer-assisted musical composition many problems have been solved and new problems discovered. The general approach to the field under investigation may grossly be described as following three modes:

1. Structural analysis and synthesis of compositional logistics and logics and their reduction to, or expansion into, computer programmes.
2. Analysis and synthesis of acoustical phenomena and their controlled and recorded production by a combination of A/D and D/A conversions processed and executed in computer systems.
3. Attempts at an evaluation and the application of thoughts and ideas with regard to musical aesthetics and forms created by the confrontation of the composer with technological conditions.

At various stages of this project the information already gained by that time was applied to specific purposes. The results are musical scores to be performed by musicians, tapes containing synthetic sound, and additions to the academic curriculum in musical education. Every one of these results reflects on and illustrates the state of work in progress on any one or all of the modes of investigation mentioned above.

Sonoriferous Loops 1964

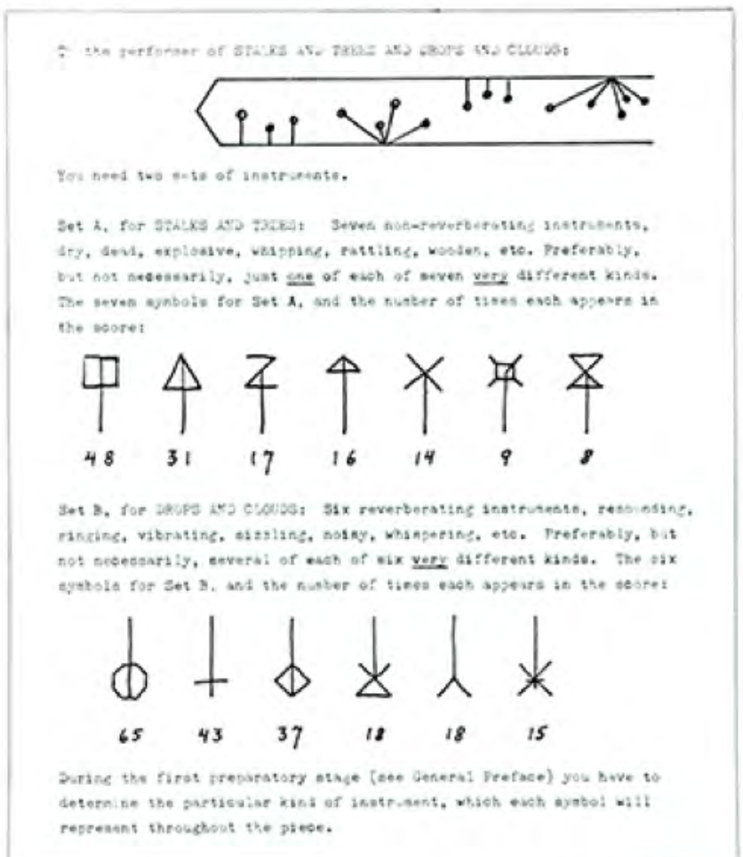
For flute, trumpet, double bass, xylophone, marimba, percussion and two-channel stereo tape. First performed 1965, at the University of Illinois, then in Darmstadt, Paris, London, Munich, Chicago, Bloomington, and several European broadcasting stations.

The structure of the composition defined by elements and rules, together with an algorithm which operates in and on the structure as a looping generating function, was translated by the composer into two programmes, one for the instrumental section and one for the tape section. Both programmes call on MUSICOMP, were written in SCATRE and executed by the computer IBM 7094. The 'instrumental' output, a print-out, thus had to be recoded by the computer into a score and parts legible for live musicians. The 'tape' output, a punch-out, was converted into actual sound by the computer CSX-1 and stored on audio tape. The final performance tape is the result of extensive modifications on the CSX-1 sound, achieved with the analogue equipment of the Experimental Music Studio.

The composition and programming of this work represent an attempt at coming to musical terms with two possibilities first offered to the composer by the computer:

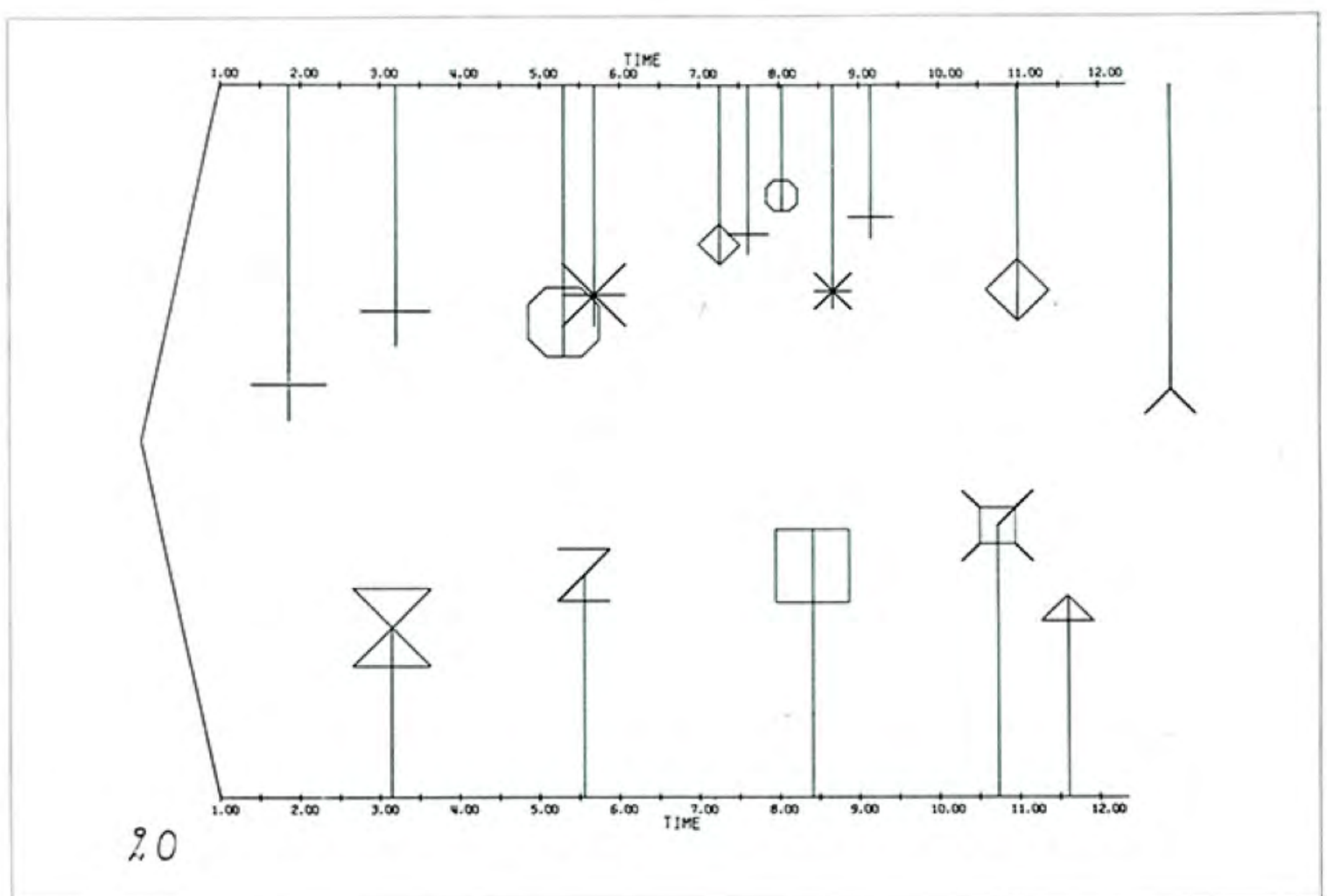
(*a*) random sequential choices channeled and filtered under the control of form-generating restrictive rules; this process created the shape, density-fluctuations and parameter-details of the instrumental sections.

(*b*) the transformation of speed of sound sequences into colour and timbre of sound; this method was used for the production of the tape sections.



Instructions to the performer and a part of the score from Herbert Brün's *Stalks and trees and drops and clouds* (1967). The complete score consists of 31 pages, and would last about 7½ minutes in performance. It was composed on an IBM 7094 computer.

The 'notation' in the scores makes use of a selected set of symbols provided by the Calcomp Library in the installed system. The 'language' consists in the distribution, size, and position of symbols on the page, in various modes of connectivity between the symbols, and a few rules prefacing each piece. The 'language' aims at eliciting from the musician a 'musical' stimulus response, which combines instrumental action and coherent interpretation. With the help of faculty and students of the Departments of Computer Science, the composer is now developing a system of symbols specifically designed for musical requirements and to be incorporated into the Calcomp Library.



Extracts from: Computer music experiences 1961-4

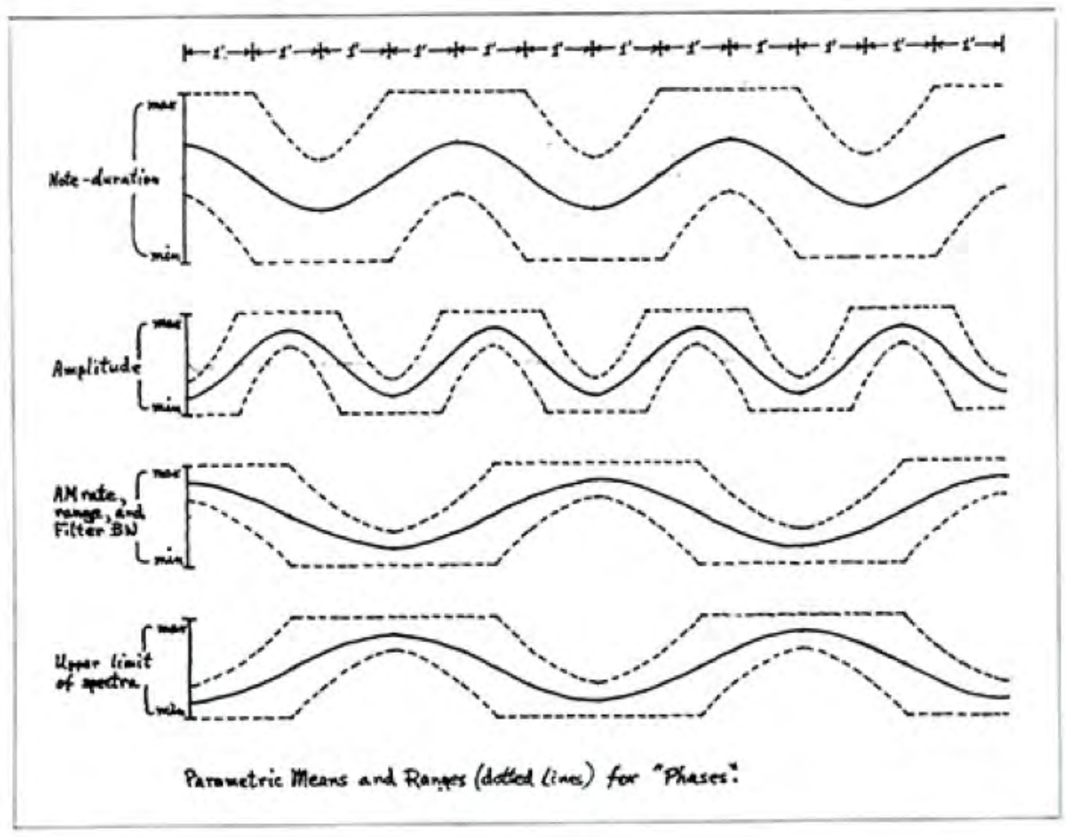
James Tenney

I arrived at the Bell Telephone Laboratories in September, 1961, with the following musical and intellectual baggage:

1. Numerous instrumental compositions reflecting the influence of Webern and Varese;
2. Two tape-pieces, produced in the Electronic Music Laboratory at the University of Illinois—both employing familiar, 'concrete' sounds, modified in various ways;
3. A long paper *(Meta Hodos, a phenomenology of 20th century music and an approach to the study of form*, June, 1961), in which a descriptive terminology and certain structural principles were developed, borrowing heavily from Gestalt psychology. The central point of the paper involves the *clang*, or primary aural Gestalt, and basic laws of perceptual organization of clangs, clang-elements, and sequences (a higher-order Gestalt-unit consisting of several clangs);
4. A dissatisfaction with all purely synthetic electronic music that I had heard up to that time, particularly with respect to timbre;
5. Ideas stemming from my studies of acoustics, electronics and—especially—information theory, begun in Hiller's classes at the University of Illinois; and finally
6. A growing interest in the work and ideas of John Cage.

I leave in March, 1964, with:

1. Six tape-compositions of computer-generated sounds—of which all but the first were also composed by means of the computer, and several instrumental pieces whose composition involved the computer in one way or another;
2. A far better understanding of the physical basis of timbre, and a sense of having achieved a significant extension of the range of timbres possible by synthetic means;
3. A curious history of renunciations of one after another of the traditional attitudes about music, due primarily to a gradually more thorough assimilation of the insights of of John Cage.



Graphic description of the most important variable parameters used in the piece *Phases* by James Tenney

In my two-and-a-half years here I have begun many more compositions than I have completed, asked more questions than I could find answers for, and perhaps failed more often than I have succeeded. But I think it could not have been much different. The medium is new and requires new ways of thinking and feeling. Two years are hardly enough to have become thoroughly acclimatized to it, but the process has at least been begun.

Noise study

From this image, then, of traffic noises—and especially those heard in the tunnel, where the overall sonority is richer, denser, and the changes are mostly very gradual—I began to conceive a musical composition that not only used sound elements similar to these, but manifested similarly gradual changes in sonority. I thought also of the sound of the ocean surf—in many ways like tunnel traffic sounds—and some of the qualities of this did ultimately manifest themselves in the *Noise study*. I did not want the quasi-periodic nature of the sea-sounds in the piece, however, and this was carefully avoided in the composition process. Instead, I wanted the aperiodic, 'asymmetrical' kind of rhythmic flow that was characteristic of the traffic sounds.

The actual realization of this image in the *Noise study* took place in three stages: first, an 'instrument' was designed that would generate bands of noise, with appropriate controls over the parameters whose evolution seemed the most essential to the sonorities I had heard; second, the large-scale from the piece was sketched out, in terms of changing *mean-values* and ranges of each of the variable parameters; third, the details—the actual note-values in each parameter—were determined by various methods of random number selection, 'scaled' and/or normalized in such a way that the note-values fell within the 'areas' outlined in step two; fourth, these note-values, in numerical form, were used as the input 'score' for the music programme, containing the 'instruments' designed in the first step, and a digital tape was generated and converted into analogue form; fifth, this tape was mixed with the same tape re-recorded at one-half and double speeds.

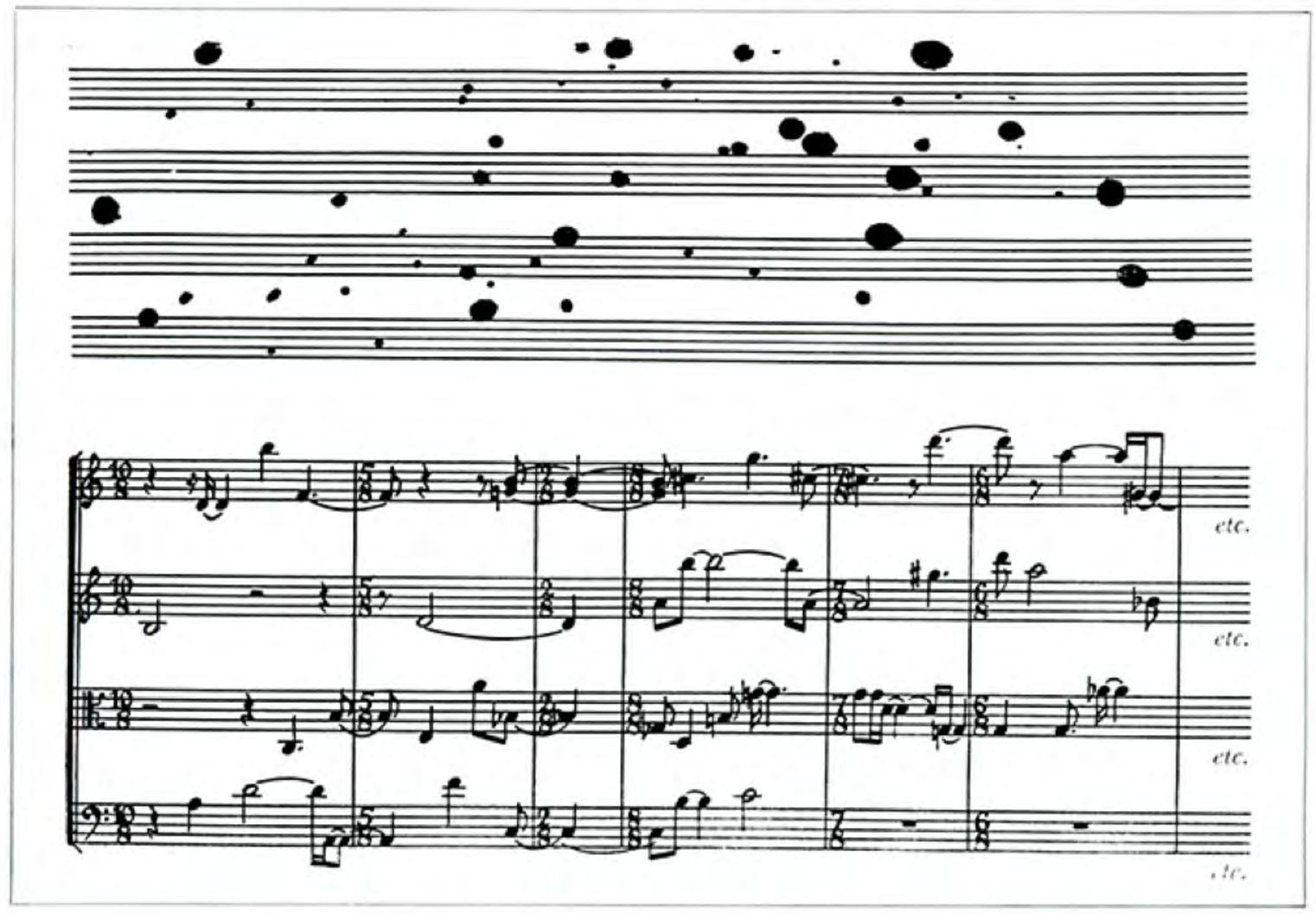
Computer music

Lejaren A. Hiller, Jr.

Can a computer be used to compose a symphony? As one who has been engaged in programming a large digital computer to produce original musical compositions, I can testify that the very idea excites incredulity and indignation in many quarters. Such response in part reflects the extreme view of the nineteenth-century romantic tradition that regards music as direct communication of emotion from composer to listener—'from heart to heart,' as Wagner said. In deference to this view it must be conceded that we do not yet understand the subjective aspect of musical communication well enough to study it in precise terms. The appreciation of music involves not only psychological needs and responses but meanings imported into the musical experience by reference to its cultural context. On the other hand, music does have its objective side. This can be defined as existing in the score as such, quite apart from the composer and the listener. The

Right. One of the ways of producing random music, from an article by Lejaren A. Hiller in *Scientific American*, December 1959. The ink spattering of this example is a physical approximation to the random number devices used by a computer.

Below, Lejaren A. Hiller



information encoded there relates to such quantitative entities as pitch and time, and is therefore accessible to rational and ultimately mathematical analysis.

In recent years the 'physics of music' has disclosed much that is mathematical in music. It reveals how sound waves are formed and propagated, how strings, membranes and air columns vibrate and how timbre depends upon complex wave-structure; it has provided universal standards of frequency and intensity, and clarified the rationale of musical scales. In its most compact form, acoustics reduces the definition of musical sound to a plot of wave-form amplitude versus time. The groove of a phonograph record, for example, contains only this information and yet yields a believable reconstruction of an original musical sound.

Acoustics, however, deals primarily with isolated elements of music and has thus far said relatively little about how these elements may be combined in a musical composition. Musicians have devised various nonmathematical systems for analysing the structure of compositions. More recently they have begun to draw upon a new branch of applied mathematics known as information theory as a means of clarifying this aspect of musical communication.

Information theory relates the 'information content' of a sequence of symbols (be they letters of the alphabet or musical notes) to the number of possible choices among the symbols. Information content thus resembles entropy or the degree of disorder in a physical system. The most random sequence has the higesht information content; the least random (or most redundant) has the lowest. The apparent paradox in this statement derives from the definition given the term 'information' in the theory. As Warren Weaver has observed, the term 'relates not so much to what you *do* say as to what you *could* say' (see 'The Mathematics of Communication,' by Warren Weaver, *Scientific American*, July, 1949). Information in this sense is not the same thing as meaning, and information theory is concerned more with the reliability of communication systems than it is with problems of meaning. Thus, it can be seen, the general enquiry into communication is confronted with the same dualistic question of form and meaning that faces the study of musical communication.

Music, sometimes defined as a compromise between chaos and monotony, appears to the information theorist as an ordered disorder lying somewhere between complete randomness and complete redundancy. This viewpoint accords well with much of traditional musical aesthetics. As early as the fourth century B.C. the Greek writer Aristoxenus noted that the voice...does not place the (musical) intervals at random... for it is not every collocation but only certain collocations...that distinguish the melodious from the unmelodious.' The composer, employing what Stravinsky has called 'the great technique of selection,' introduces redundancy into his relatively random materials in order to organize them into a 'meaningful' pattern.

To be sure, meaning is as different to define in music as it is in every other kind of communication. But musical sounds are not, as words are, primarily symbols of something else; the meaning of music is peculiarly dependent upon its own structures as such. The study of musical structures by information theory should open the way to a deeper understanding of the aesthetic basis of composition. We may be able to respond to Stravinsky's injunction and cease 'tormenting (the composer) with the *why* instead of seeking for itself the *how* and thus establish the reasons for his failure or success'.

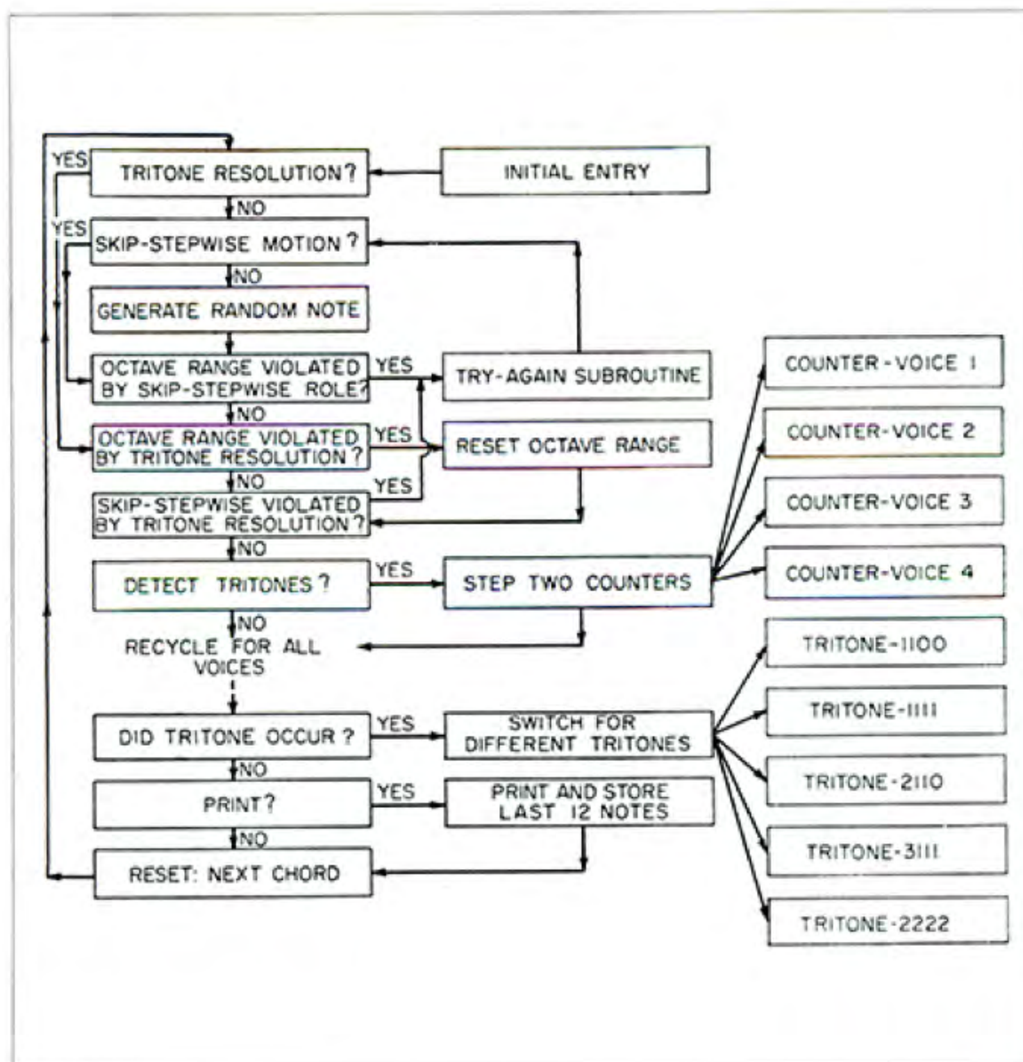
From the analytical standpoint, the aesthetic content of music can be treated in terms of fluctuations between the two extremes of total randomness and total redundancy. The significant fluctuations manifest themselves not only between one composition and another but also among elements or sections of the same composition.

Structural devices characterising various historical styles

The stylistic device of modulation (key-shift) shows a fairly steady decrease in redundancy over the past 200 years. Mozart employed a limited number of rather standardized modulations. In Chopin and Brahms the modulations are more extreme and occur more frequently and less predictably. Wagner and Debussy modulate so freely that the listener often loses any immediate and unequivocal sense of key. Many modern composers have abandoned the concepts of key and modulation altogether and in this dimension approach complete randomness.

By standards such as these it is possible, at least in theory, to construct tables of probabilities describing a musical style, such as

Block diagram for chromatic writing, used in section 3 of *Illiac suite for string quartet*, composed in 1957 by Lejaren A. Hiller and Leonard M. Isaacson on the ILLIAC computer.



Baroque, Classical or Romantic, and perhaps even the style of an individual composer. Given such tables, one could then reverse the process and compose music in a given style. The task of composition would start from the random condition with choices among musical elements all equally probable. The introduction of redundancy in accordance with a particular scheme of probabilities would extract order from chaos. It is not to be thought, however, that order is the sole criterion of beauty; as the musicologist Leonard B. Meyer has observed, 'Some of the greatest music is great precisely because the composer has not feared to let his music tremble on the brink of chaos.'

Series of short quotations about techniques used in the composition of 'Computer Cantata'.

'The concept of mathematically programmed music easily leads to the notion of composition by computer. In 1955 Leonard M. Isaacson and I began a series of experiments in composition with ILLIAC, the high-speed digital computer at the University of Illinois. In due course we completed four groups of experiments, the results of which we have sampled, in the *Illiac suite for string quartet*.

'As our first step we set the computer to composing simple melodies. To this end we programmed the machine to generate random integers by a technique borrowed from the "Monte Carlo" method, which physicists have devised to solve certain problems involving multiple probabilities.

'For our second experiment we devised additional screening instructions embodying the entire set of fourteen rules of strict first-species counterpoint. The machine was first set to turning out random "white-note" music in four voices; randomness was then made to yield to redundancy in small increments by feeding in the screening instructions one by one. The complete set of instructions yielded counterpoint of fair quality, strongly reminiscent, if one ignores a certain monotony in rhythm, of passages from Palestrina.

'In *Experiment III* we sought to find ways of producing the rhythmic and dynamic variety that the earlier compositions lacked.

'Since the object was to produce a type of music less imitative than strict counterpoint, the machine was first permitted to write entirely random chromatic music (including all sharps and flats). The result was music of the highest possible entropy content in terms of note selection on the chromatic scale, and thus it was strongly dissonant. With the minimal redundancy imposed by feeding in only four of the fourteen screening instructions, the character of the composition changed drastically. While the wholly random sections resembled the more extreme efforts of avant-garde modern composers, the later, more redundant portions recalled passages from, say, a Bartok string quartet. The experiment concluded with some exploratory studies in Schoenberg's twelve-tone technique and similar compositional devices.

'In *Experiment IV* the objective was the synthesis of music from purely mathematical rules—a style of composition peculiarly appropriate to a computer. To this end the computer was programmed to select the intervals between successive notes according to a table of probabilities instead of at random. Moreover, the probabilities themselves were made to shift in accordance with so-called Markoff probability chains.'

[Extracts from *Scientific American*, December, 1959.
Mathematical basis of music, information theory, use of computers in composition.]

	I		II		III			IV		V	
Section	Prolog to Strophe I	Strophe I	Prolog to Strophe II	Strophe II	Prolog to Strophe III	Strophe III	Epilog to Strophe III	Strophe IV	Epilog to Strophe IV	Strophe V	Epilog to Strophe V
Primary Organizational Principle	Percussion study: Density-intensity vs. time	Zeroth-order stochastic process	Total organization study	First-order stochastic process	CSX-1 sound synthesis of 9 through 15-tone tuning	Second-order stochastic process	CSX-1 sound synthesis of 9 through 15-tone tuning	Third-order stochastic process	Total organization study	Fourth-order stochastic process	Percussion study: Density-intensity vs. time
Instruments:											
Voice		•••••••		•••••••		•••••••		•••••••		•••••••	
Flute		•••••••••••••••••••••••		•••••••••••••••••••••••		•••••••		•••••••		•••••••	
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Snare Drum	•••••••••••••••••••••••			•••••••		•••••••					•••••••

Tambourine	•••••••••••••••••••••••			•••••••		•••••••					•••••••
Castenets	•••••••••••••••••••••••			•••••••		•••••••					•••••••
Cymbal	•••••••••••••••••••••••			•••••••		•••••••					•••••••
Tabor	•••••••••••••••••••••••			•••••••		•••••••					•••••••
Maracas	•••••••••••••••••••••••			•••••••		•••••••					•••••••
Bass Drum	•••••••••••••••••••••••			•••••••		•••••••					•••••••
Tam-Tam	•••••••••••••••••••••••			•••••••		•••••••					•••••••
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Theremin		•••••••		•••••••		•••••••		•••••••			
Sine tone		•••••••		•••••••				•••••••			
Sqr. wave		•••••••		•••••••							
Saw-tooth		•••••••		•••••••							
White N.		•••••••		•••••••							
Colored N.		•••••••									
CSX-1					•••••••		•••••••				

Organization scheme of *Computer cantata*, composed by Lejaren A. Hiller and Leonard M. Isaacson in 1963 with an IBM 7090 computer, using the MUSICOMP programming scheme. MUSICOMP (MUsic Simulator-Interpreter for COMpositional Procedures) is a completely generalized programming scheme for musical composition on the IBM 7090, and was completed during the composition of this piece. The score is for chamber orchestra, voice, and electronic tape.

Extract from 'A year from monday'

John Cage

[Cage's ideas have influenced experimental music very considerably, although he has only recently produced computer-generated music himself. Cage studied with Schoenberg, who commented that he was: 'not so much a composer as an experimenter, but an experimenter of genius'.]

Diary: Audience 1966
1. Are we an audience for computer art? The answer's not No; it's Yes. What we need is a computer that isn't labour-saving but which increases the work for us to do, that puns (this is McLuhan's idea) as well as Joyce revealing bridges (this is Brown's idea) where we thought there weren't any, turns us (my idea) not 'on' but into artists. *Orthodox seating arrangement in synagogues.* Indians have known it for ages: life's a dance, a play, illusion. Lila. Maya. Twentieth-century art's opened our eyes. Now music's opened our ears. Theatre? Just notice what's around. (If what you want in India is an audience, Gita Sarabhai told me, all you need is one or two people. *2.* He said: Listening to your music I find it provokes me. What should I do to enjoy it? Answer: There are many ways to help you. I'd give you a lift, for instance, if you were going in my direction, but the last thing I'd do would be to tell you how to use your own aesthetic faculties. (You see? We're unemployed. If not yet, 'soon again 'twill be'. We have nothing to do. So what shall we do? Sit in an audience? Write criticism? Be creative?) We used to have the artist up on a pedestal. Now he's no more extraordinary than we are. *3.* Notice audiences at high altitudes and audiences in northern countries tend to be attentive during performances while audiences at sea level or in warm countries voice their feelings whenever they have them. Are we, so to speak, south in the way we experience art? Audience participation? (Having nothing to do, we do it nonetheless; our biggest problem is finding scraps of time in which to get it done. Discovery. Awareness.) 'Leave the beaten track. You'll see something never seen before.' *After the first performance of my piece for twelve radios, Virgil Thomson said, 'You can't do that sort of thing and expect people to pay for it.'* Separation. *4.* When our time was given to physical labour, we needed a stiff upper lip and back-bone. Now that we're changing

Part of John Cage's score of *Fontana Mix* (Milan, November 1958), showing the way the score is intended to be used. This score also provides the material for other compositions by the composer, namely *Water Walk* (1959), *Sounds of Venice* (1959), *Aria for M.Sop.* (1958), *Theatre Piece* (1960) and *WBAL* (1960). This score was also used by Cornelius Cardew as the basis of a guitar solo.

10 transparent sheets with points; 10 drawings having six differentiated curved lines; a graph (having 100 units horizontally, 20 vertically); and a straight line, the last two on transparent material. Place a sheet with points over a drawing with curves (in any position), over these place the graph, use the straight line to connect a point within the graph with one outside. Measurements horizontally on the top and bottom lines of the graph, with respect to the straight

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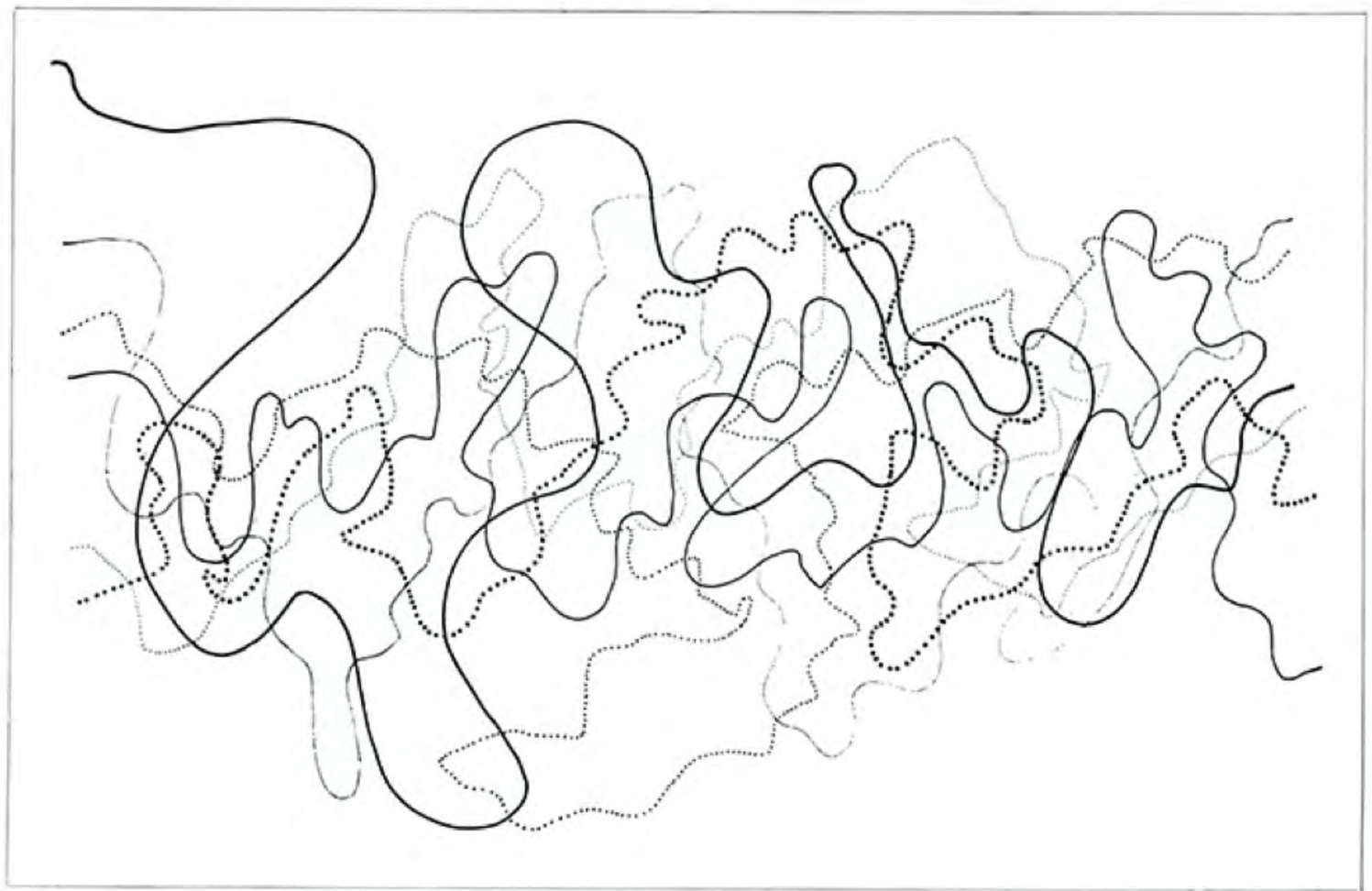

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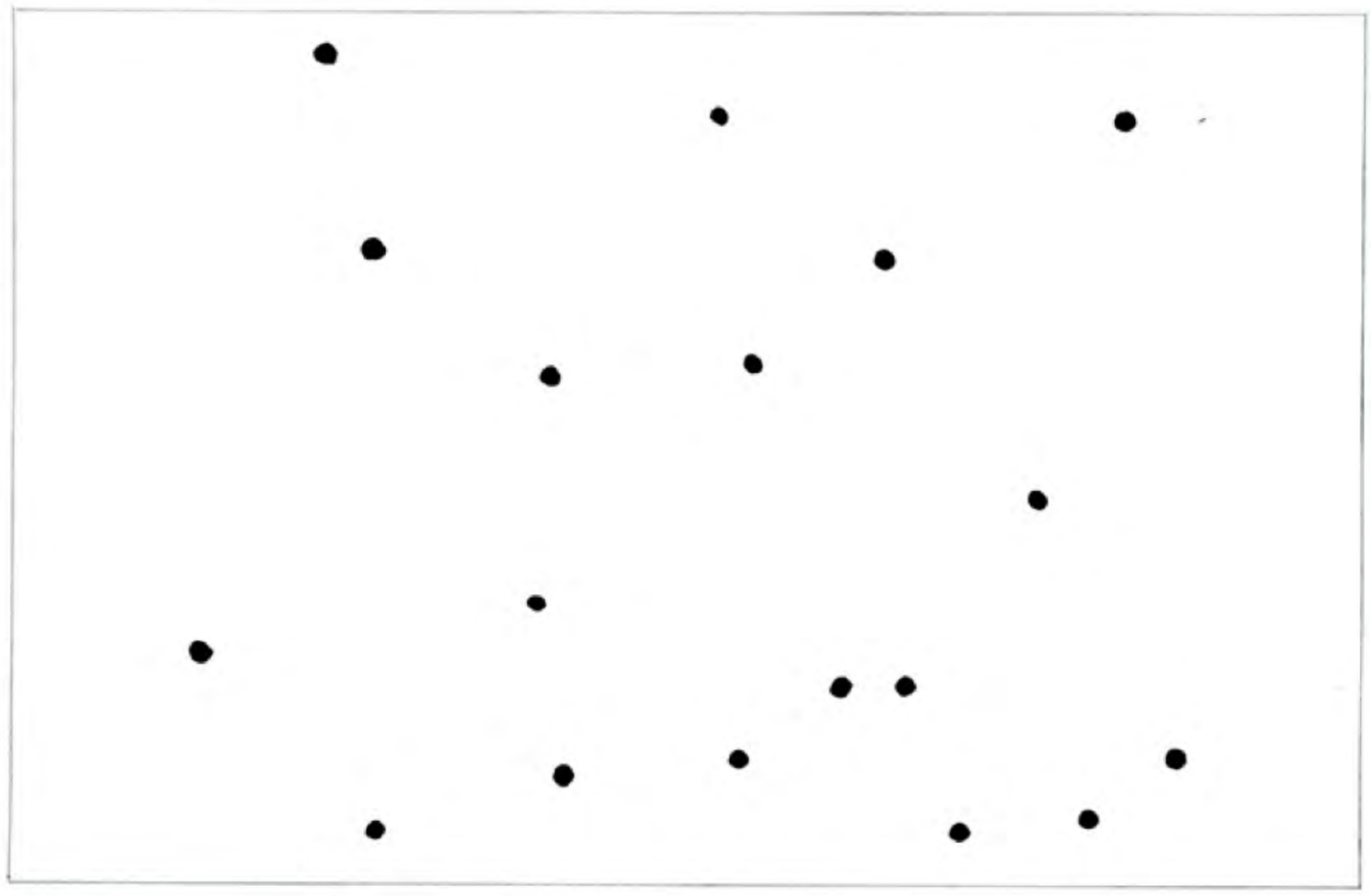

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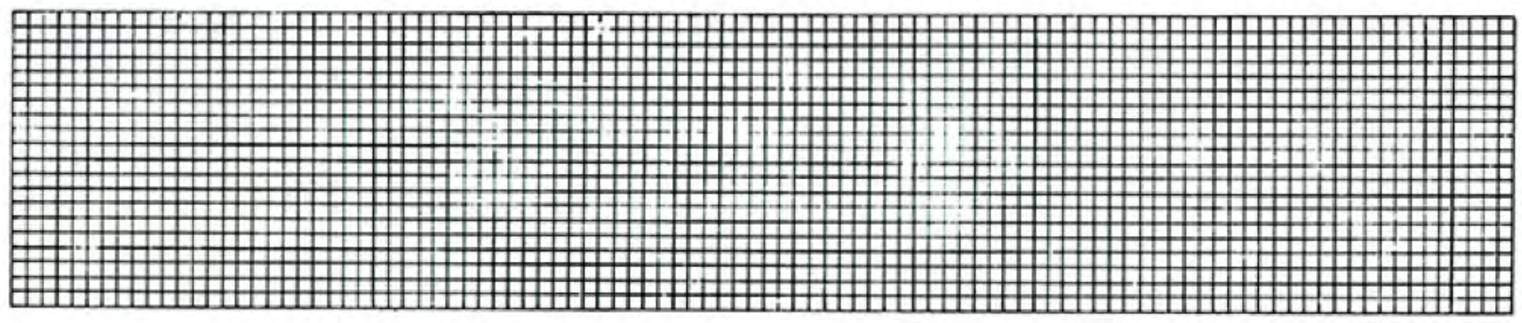
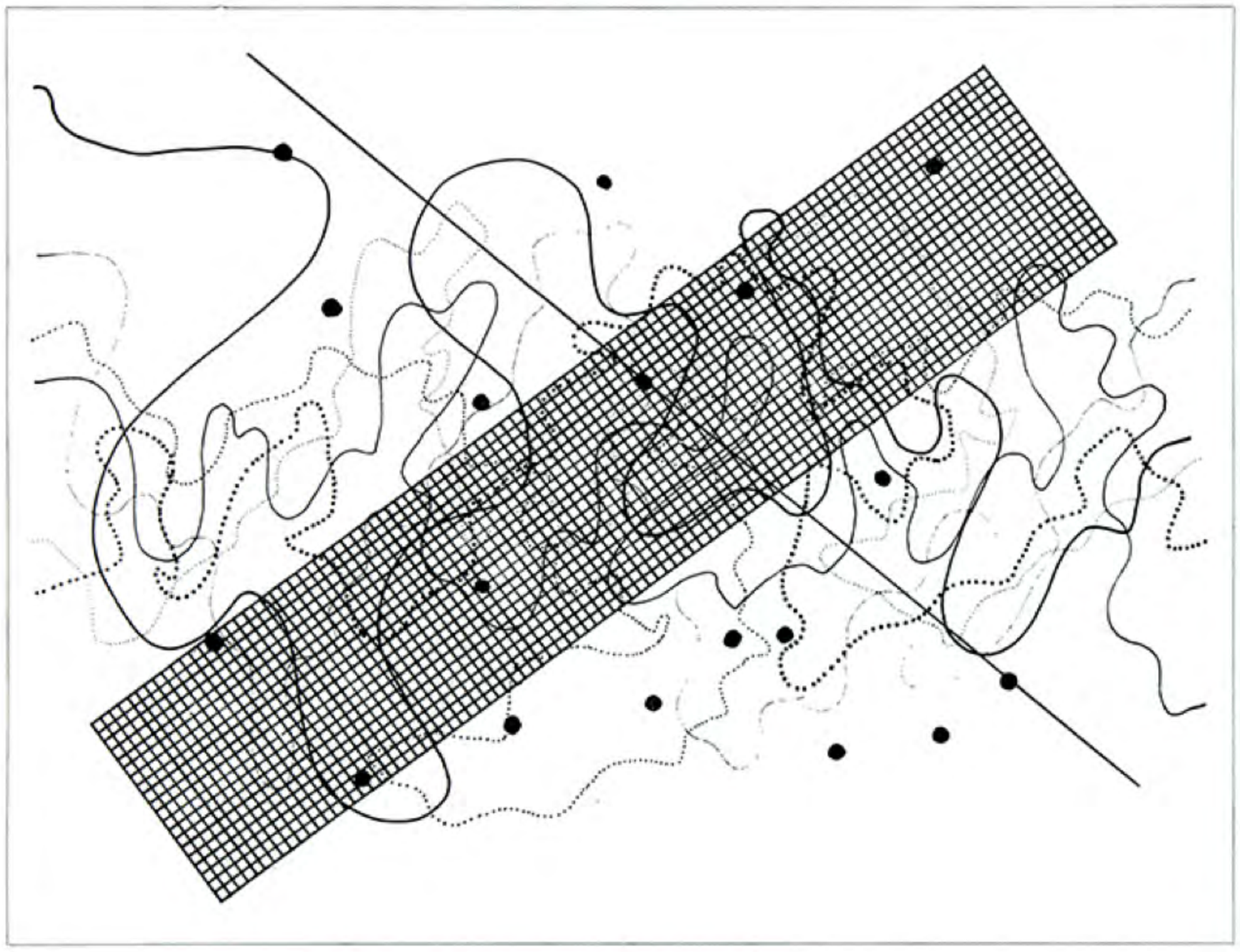


4

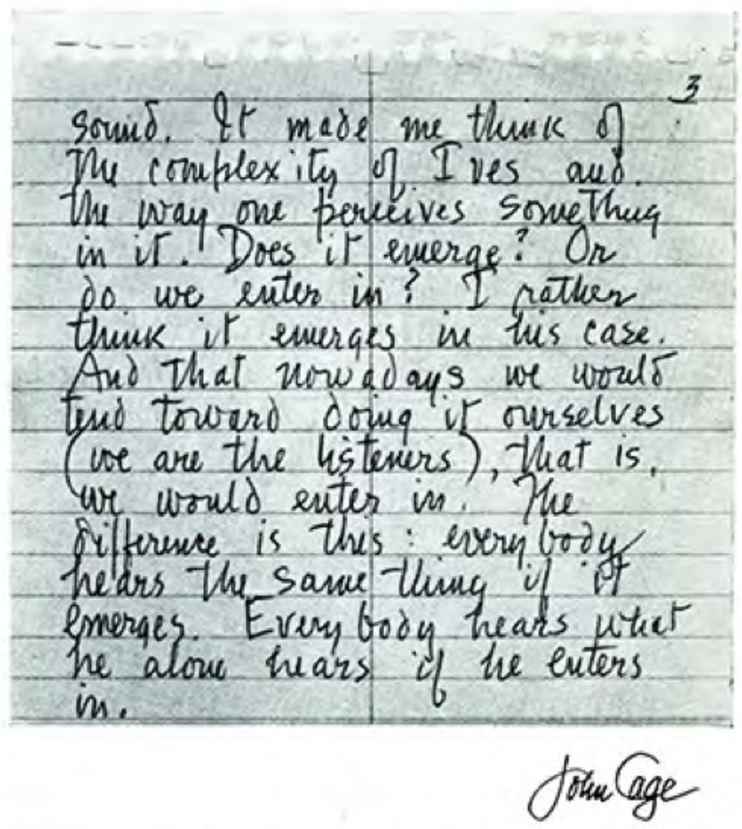
line. Give a 'time bracket' (time within which the event may take place) (graph units=time units). Measurements vertically on the graph with respect to the intersections of the curved lines and the straight line may specify actions to be made. Thus, in the case of (Fontana Mix) tape music, the thickest curved line may give sound source(s) where the latter have been categorized and related quantitatively to 20. (In this case, the 2 points connected by the straight line must permit the latter to intersect the thickest curved line.) Intersections of the other lines may specify machines (among those available) for the alteration of original material. Amplitude frequency, overtone structure may be changed, loops and specific durations introduced. Measurements made may provide one of a number of parts to be performed alone or together.
In making tape music, available tracks may be less in number than the time brackets given by measurements. Fragmentation is then indicated. The use of this material is not limited to tape music but may be used freely for instrumental, vocal and theatrical purposes. Thus, after a programme of action has been made from it, it may be used to specify a programme for the performance of the otherwise unchanging material. Where possible technically this can be not only simple changes of time (starting, stopping) but also alterations of frequency, amplitude, use of filters and distribution of the sound in space.

5



John Cage Fontana Mix Use
1. sheet with curved lines only
2. sheet with dots only
3. graph only
4. straight line only
5. superimposed sheet with straight line added as shown

our minds, intent on things invisible, inaudible, we have other spineless virtues: Flexibility, fluency. Dreams, daily events, everything gets to and through us. (Art, if you want a definition of it, is criminal action. It conforms to no rules. Not even its own. Anyone who experiences a work of art is as guilty as the artist. It is not a question of sharing the guilt. Each one of us gets all of it.) They asked me about theatres in New York. I said we could use them. They should be small for the audiences, the performing areas large and spacious, equipped for television broadcast for those who prefer staying at home. There should be a café in connection having food and drink, no music, facilities for playing chess. *5.* What happened at Rochester? We'd no sooner begun playing than the audience began. Began what? Costumes. Food. Rolls of toilet paper projected in streamers from the balcony through the air. Programmes, too, folded, then flown. Music, perambulations, conversations. Began festivities. *An audience can sit quietly or make noises. People can whisper, talk and even shout. An audience can sit still or it can get up and move around. People are people not plants.* 'Do you love the audience?' Certainly we do. We show it by getting out of their way. (Art and money are in this world together, and they need each other to keep on going. Perhaps they're both on their way out. Money'll become a credit card without a monthly bill. What'll art become? A family reunion? If so, let's have it with people in the round, each individual free to lend his attention wherever he will. Meeting house.) *6.* After an Oriental decade, a Tibetan Bikku returned to Toronto to teach. He told me that were he to speak the truth his audience would drop to six. Instead he gives lectures transmitting not the spirit but the understandable letter. Two hundred people listen on each occasion, all of them deeply moved. (Art's a way we have for throwing out ideas—ones we've picked up in or out of our heads. What's marvellous is that as we throw them out—these ideas—they generate others, ones that weren't even in our heads to begin with.) Charles Ives had this idea: the audience is any one of us, just a human being. He sits in a rocking chair on the verandah. Looking out toward the mountains, he sees the setting sun and hears his own symphony: it's nothing but the sounds happening in the air around him.


3
sound. It made me think of
the complexity of Ives and
the way one perceives something
in it. Does it emerge? Or
do we enter in? I rather
think it emerges in his case.
And that nowadays we would
tend toward doing it ourselves
(we are the listeners), that is,
we would enter in. The
difference is this: everybody
hears the same thing if it
emerges. Everybody hears what
he alone hears if he enters
in.

John Cage

Part of a letter written by John Cage in 1964 on Charles Ives.

The computer in musical composition

Gerald Strang

'The computer is extraordinarily fast and extraordinarily accurate, but it is also exceedingly stupid and therefore it has to be told everything.'

There are two main aspects to computer experimentation in musical composition. One is the use of the computer to aid the composer in the production of a score. The other is the use of the computer to generate actual sounds.

The production of a musical score

For the first aspect, the centre of principal investigation today is at the University of Illinois. It began with Hiller and Isaacson's work in 1955 and 1956, which produced a piece called the *Illiac suite*. Hiller and his colleagues have continued their investigation and recently put out another computer work called the *Computer cantata*.

Essentially their composing programme is a system allowing the computer to make some of the choices which a composer has to make. They have experimented with random processes, probability tables, etc., and have codified the whole procedure into a programme which they call (with a typical programmers' acronym) MUSICOMP. The programme is essentially a way of simplifying the process by which a composer may specify what choices the computer may make on his behalf.

The Illinois investigations have dealt with producing computer output which could then be transcribed into musical notation and performed by musical instruments. Recently they have developed an experimental computer called the CSX1 which can convert digital output to give sound of a limited variety. But for the most part, they have not investigated this phase of the process.

The production of actual sounds

Many people prefer to do their own composing and make their own choices. However, in the generation of the actual sounds chosen, there are a great many detailed tasks for which the computer is a well-qualified assistant. The computer can, of course, do repetitive tasks with great ease and with great speed; and the sound of music is essentially repetitive. We deal with cyclic repetitions of sound waves, which may range anywhere from say 20 cycles per second to say 15,000 cycles per second.

The calculation and execution of such repetitive patterns is made to order for the computer. The computer can also do many other types of manipulation with great ease. It can, for instance, elaborate a pattern of accompaniment. Given certain parameters it can then adapt such a pattern to various keys, various harmonies, etc.

The sound-producing programme started with the work of Max Mathews at Bell Telephone Laboratories about four years ago. The first public output of this was in the form of a record called *Music from Mathematics*. Here the samples were mainly the work of engineers, and composers naturally are interested in doing rather different things than engineers. The BTL Programme is now in its fourth version; there is even a programmer's manual for 'Music IV'.

Instruments

The composer who wants to use this programme invents certain types of computer operations which are called 'instruments.' For this purpose, Mathews has designed a group of unit generators which are similar to the unit generators of an electronics laboratory. There are filters, envelope generators, shapers, oscillators, etc. These units can be linked together, as in electronic circuit building. In fact, experimentation with simulated electronic circuits undoubtedly affected the development of this system.

An instrumental circuit of almost any degree of complexity can be drawn; it will provide almost any sort of sound manipulation desired. It corresponds to an instrument, in that its subroutine is one through which data is passed and from which it acquires certain characteristics. But this is exactly what a musical instrument does. If I write a series of notes and I say this passage is to be played *mezzo forte* by the oboe, with certain particular kinds of attacks and certain phrasing patterns and certain expressive devices, I am really saying that certain raw data shall be processed and modified by passing through this instrument, coming out as acoustical sound waves.

Orchestra

Under the BTL Programme, once the composer has designed his instruments, he can specify that these shall form an orchestra. This then is compiled by the computer through the use of an elaborate set of instructions which form the compiling programme.

At this point a binary deck comes out which can be put into the final operation. Meanwhile the composer writes a score expressing his choices in musical composition with his computer-simulated 'orchestra'. The score needs to be presented in numerical form. Moreover, the computer is extraordinarily fast and extraordinarily accurate, but it is also exceedingly stupid and therefore it has to be told everything. You cannot assume that it is going to decide what kind of 'tonguing' or 'bowing' to use, or what interpretive characteristics are to be selected. So the composer specifies different kinds of data. On the other hand, his instruments can be so designed that a single instrument routine can produce a number of different kinds of tone quality and any number of different kinds of attack and decay pattern. These timbres, attack and decay patterns and the like, can also be designed by the composer. They are stored in arrays to which the computer can make reference as demanded by the score.

The composer can write his score in any fashion he wishes. He can also put in conversion functions so that he can specify his data in any form he wishes. If he prefers to specify loudness by the usual musical means, the equivalent of *mezzo forte, mezzo piano, fortissimo*, he can set up a numerical scale and a conversion function which says, 'If in this particular position on the card I punch 1, this means pianissimo; if I punch a 6, it means fortissimo.' If he prefers to specify loudness in decibels, he uses a different conversion function.

And so on with all the other parameters. One can, for instance, very easily generate a tempered scale. Not necessarily a twelve tone tempered scale, but eleven or nine or thirteen or twenty-one tone tempered scales. One can also allow the computer to make random choices of pitches or loudness or envelopes or anything else.

In short, the score can specify in as much detail as you choose, whatever types of parameter you choose. Other parameters can be specified as constants.

The orchestra and the score

When the data which form the score have been punched on IBM cards, it is fed in with the already compiled orchestra. You can feed in data for as many instruments as you like simultaneously, and you need not insert the cards in any particular order within sections.

In the execution phase of the programme, the computer accepts the data and stores it. It then processes that data according to your instructions and sorts it in such a way that all of the events are now ordered according to the beginnings of the events.

So you now have your score sorted and ordered. At this point, if you wish, you can put in instructions to generate new notes (e.g., to modify, invert, reverse, or permutate stored data); to create accelerandos, crescendos or diminuendos; to perform any large scale manipulation of the ordered data.

Sampled output

The computer now calculates values for the

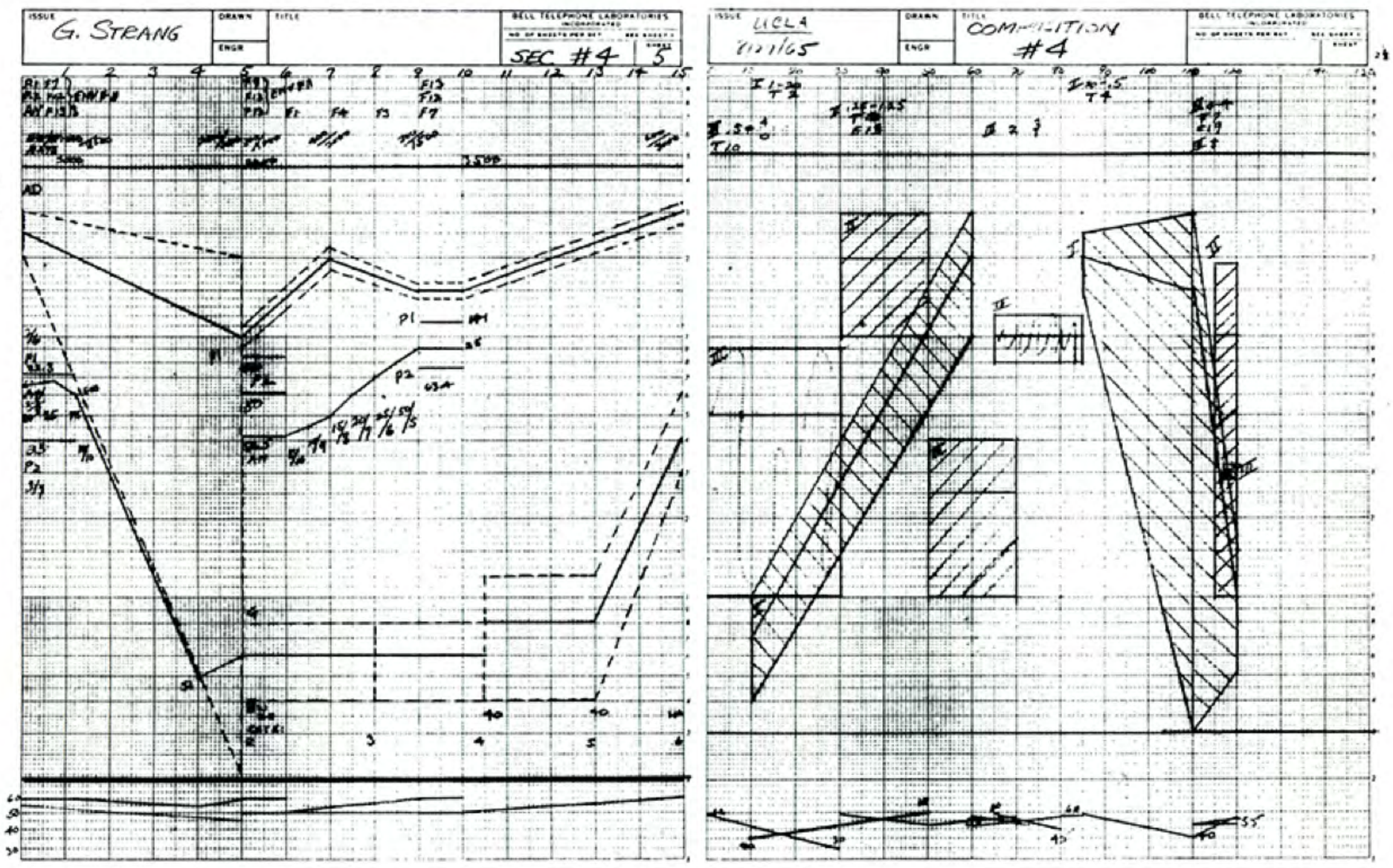
combined output at a fixed sampling rate. The Bell Telephone Labs Programme uses a sampling rate of 10,000 samples per second of musical output. That is an enormous output; in fact, since each value may be the result of a large number of cycles required to process several different instruments and several different units within each instrument, this represents a considerable task for the computer. It is a sufficient task so that on the IBM 7090 at Bell Labs in 1963, our time factor was about 10 to 1: it took us 10 seconds of computer time to generate the samples for one second of music.

Digital-to-analogue conversion

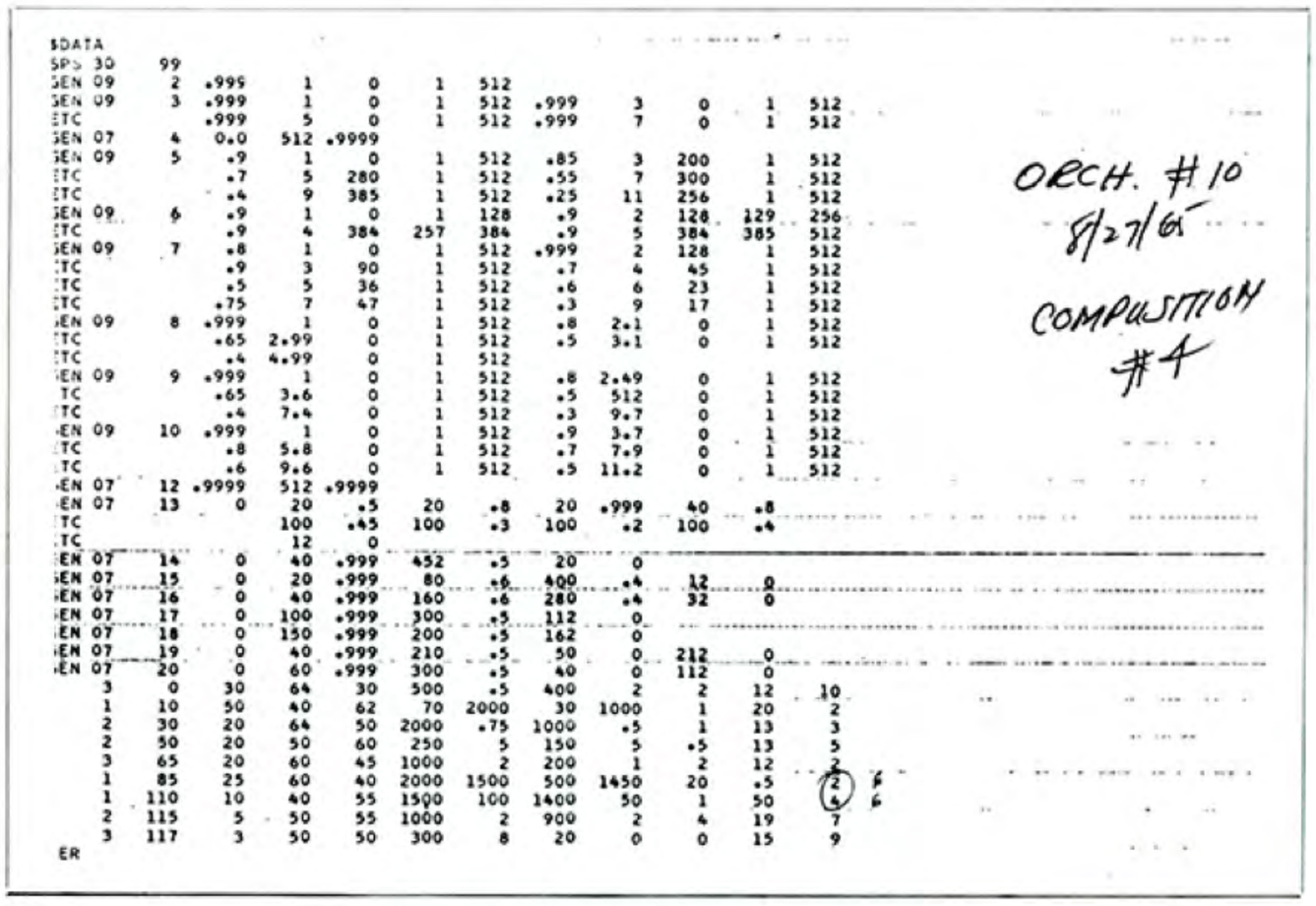
The computer output is in digital form – a string of binary numbers. It has to be processed further in order to get sound out of it. Essentially this is done by passing the digital output through a buffer into a digital-to-analogue converter. The digital-to-analogue converter takes the numerical output of the computer and converts it into voltage values which correspond in scale to the numerical values on the computer tape. This output has to be filtered. A low-pass filter is used, which usually cuts off at half the sampling rate. At Bell we were using a 5 kilocycle cut-off with a 10 kilocycle sample rate. The result of the low pass filter is to smooth the stepped aspect of the digital output. The resultant smoothly varying voltage is essentially what happens to voices in microphones. A voice is picked up by the microphone, converted into a varying voltage, amplified, and applied to the loud-speaker voice coil. At that point it is reconverted from electrical to acoustical energy. It becomes a series of pressure waves and is carried to the ears of the audience.

Sound

Once the computer output has been con-



Computer print-out and parts of the score of Gerald Strang's *Compusition 4*. The computer sound synthesis programmes used by Strang in this piece were developed by Mathews and Pierce at Bell Telephone Laboratories; the piece was produced at UCLA.



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SPS 30    99
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SEN 09     3  .999     1     0     1   512  .999     3     0     1   512
ETC           .999     5     0     1   512  .999     7     0     1   512
SEN 07     4   0.0   512 .9999
SEN 09     5    .9     1     0     1   512   .85     3   200     1   512
ETC             .7     5   280     1   512   .55     7   300     1   512
ETC             .4     9   385     1   512   .25    11   256     1   512
SEN 09     6    .9     1     0     1   128    .9     2   128   129   256
ETC             .9     4   384   257   384    .9     5   384   385   512
SEN 09     7    .8     1     0     1   512  .999     2   128     1   512
ETC             .9     3    90     1   512    .7     4    45     1   512
ETC             .5     5    36     1   512    .6     6    23     1   512
ETC            .75     7    47     1   512    .3     9    17     1   512
SEN 09     8  .999     1     0     1   512    .8   2.1     0     1   512
ETC            .65  2.99     0     1   512    .5   3.1     0     1   512
ETC             .4  4.99     0     1   512
SEN 09     9  .999     1     0     1   512    .8  2.49     0     1   512
ETC            .65   3.6     0     1   512    .5   512     0     1   512
ETC             .4   7.4     0     1   512    .3   9.7     0     1   512
SEN 09    10  .999     1     0     1   512    .9   3.7     0     1   512
ETC             .8   5.8     0     1   512    .7   7.9     0     1   512
ETC             .6   9.6     0     1   512    .5  11.2     0     1   512
SEN 07    12 .9999   512 .9999
SEN 07    13    0    20    .5    20    .8    20  .999    40    .8
ETC            100   .45   100    .3   100    .2   100    .4
ETC             12     0
SEN 07    14    0    40  .999   452    .5    20     0
SEN 07    15    0    20  .999    80    .6   400    .4    12     0
SEN 07    16    0    40  .999   160    .6   280    .4    32     0
SEN 07    17    0   100  .999   300    .5   112     0
SEN 07    18    0   150  .999   200    .5   162     0
SEN 07    19    0    40  .999   210    .5    50     0   212     0
SEN 07    20    0    60  .999   300    .5    40     0   112     0
     3     0   30    64    30   500    .5   400     2     2    12    10
     1    10   50    40    62    70  2000    30  1000     1    20     2
     2    30   20    64    50  2000   .75  1000    .5     1    13     3
     2    50   20    50    60   250     5   150     5    .5    13     5
     3    65   20    60    45  1000     2   200     1     2    12     2
     1    85   25    60    40  2000  1500   500  1450    20    .5     2
     1   110   10    40    55  1500   100  1400    50     1    50     4
     2   115    5    50    55  1000     2   900     2     4    19     7
     3   117    3    50    50   300     8    20     0     0    15     9
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ORCH. #10
8/27/65
COMPUSITION
#4

verted into a varying voltage, it is simple to apply it to a tape recorder head, or directly to a speaker, thus producing sound.

Some variations of the BTL programme are being worked on at Stanford, at U.C.L.A., at my college, and elsewhere. In addition, various experimentation is going on with other composing programmes. The main centres for work with composing programmes are Illinois and to some extent Yale.

From the standpoint of the composer, learning to programme in this way is formidable, but it is still quite possible for a composer to learn rather rapidly to present his data in this form and even to anticipate what kind of sound is going to come out of the computer.

A Sample Musical Piece

Let's describe a sample of output from the programme. In this sample, there are five separate voices, and a mixture of features. One voice consists of noise, filtered in such a way that the bandwidth and centre frequency can be shifted continuously between set limits.

One instrument makes use almost exclusively of gliding tones of various sorts. There are two tempered scales, one of nine tones, the other of twenty-one tones. There's another instrument in which the pitches are chosen by the random number generator, whose limits can be set. For the random number generator a centre frequency and a bandwidth can be set; then the numbers chosen will be translated into sound frequencies within the specific range. The rate at which random numbers will be generated can be set. If I generate these random numbers at, say, 2,000 per second, I get a kind of brittle noise. If I generate them one or two or five or twenty per second, I get a set of separate pitches.

It is characteristic of electronic music that a tremendous amount of dubbing, patching, snipping, putting pieces of tape together and so on, goes into it. But in this sample, no editing is necessary. The whole thing is put together in the computer. All the drudgery, all the manual manipulation, all the incredibly time-consuming fussing around is avoided, and this eliminates the noise build-up completely. This sample indicates that with this kind of a programme you can do almost anything you can do in an ordinary music lab. But you can do it more accurately, more easily, and certainly with far more variety.

There are still limitations, and other difficulties, but they are being overcome. For instance, at present the filtering produces a 5,000 cycle ceiling. The resulting sound is a little bit like a Hammond organ. But that is not a necessary result. We can very easily increase the sample rate and increase the complexity of the sound colour to any degree that we wish.

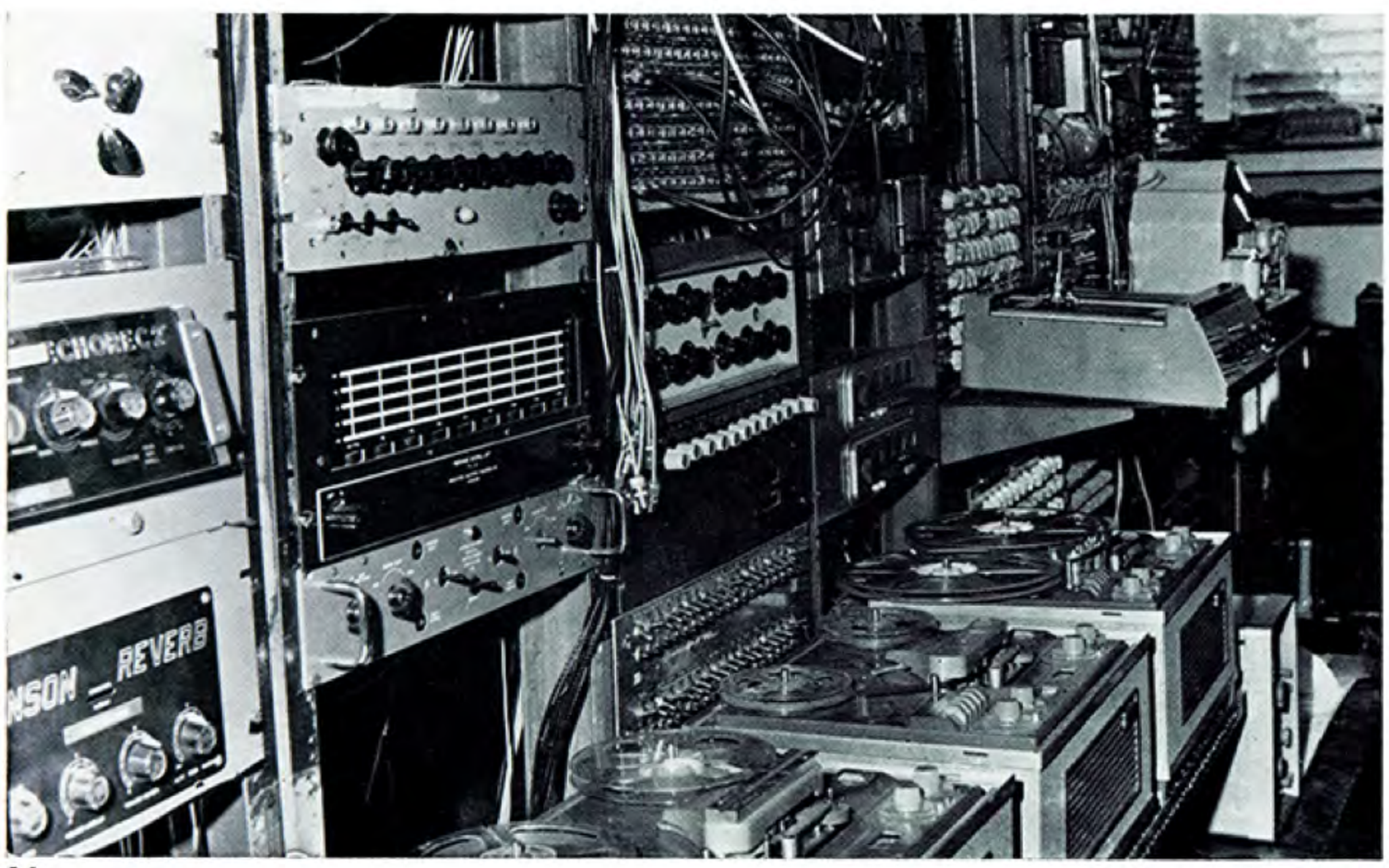
Two electronic music computer projects in Britain

Peter Zinovieff

My studio is now dominated by a computer, and my computer is dominated by other computers. My music tends to be at least partly composed by my machines and entirely realized by them.

This state has gradually arisen over the last few years, because of my deep distrust of the nostalgia and maladroitness of the old techniques of electronic music production, the manipulation by hand of magnetic tape and control knobs, in fact a distrust of recording altogether, and with the idea that there should ever be a finished, once and for all, piece of music. It is preposterous that one should be expected to stick pieces of tape together and to collage simple recordings together by these techniques. The arrogance is extraordinary, and it is only because of this marvellous first flush of arrogance in others that I have acquired an attitude of arrogance to these techniques themselves.

Digital computers and new electronic circuits can make possible the direct translation of scores into music, and the control produced is the result of compositional rather than technical skill. Elements of this probably exist in all music. Another way of putting it is that with computer techniques you may control the lack of control and you may have choice or no choice. Simple tape montages and complicated random multi-channel compositions can be produced from the computer, the production taking as long as the

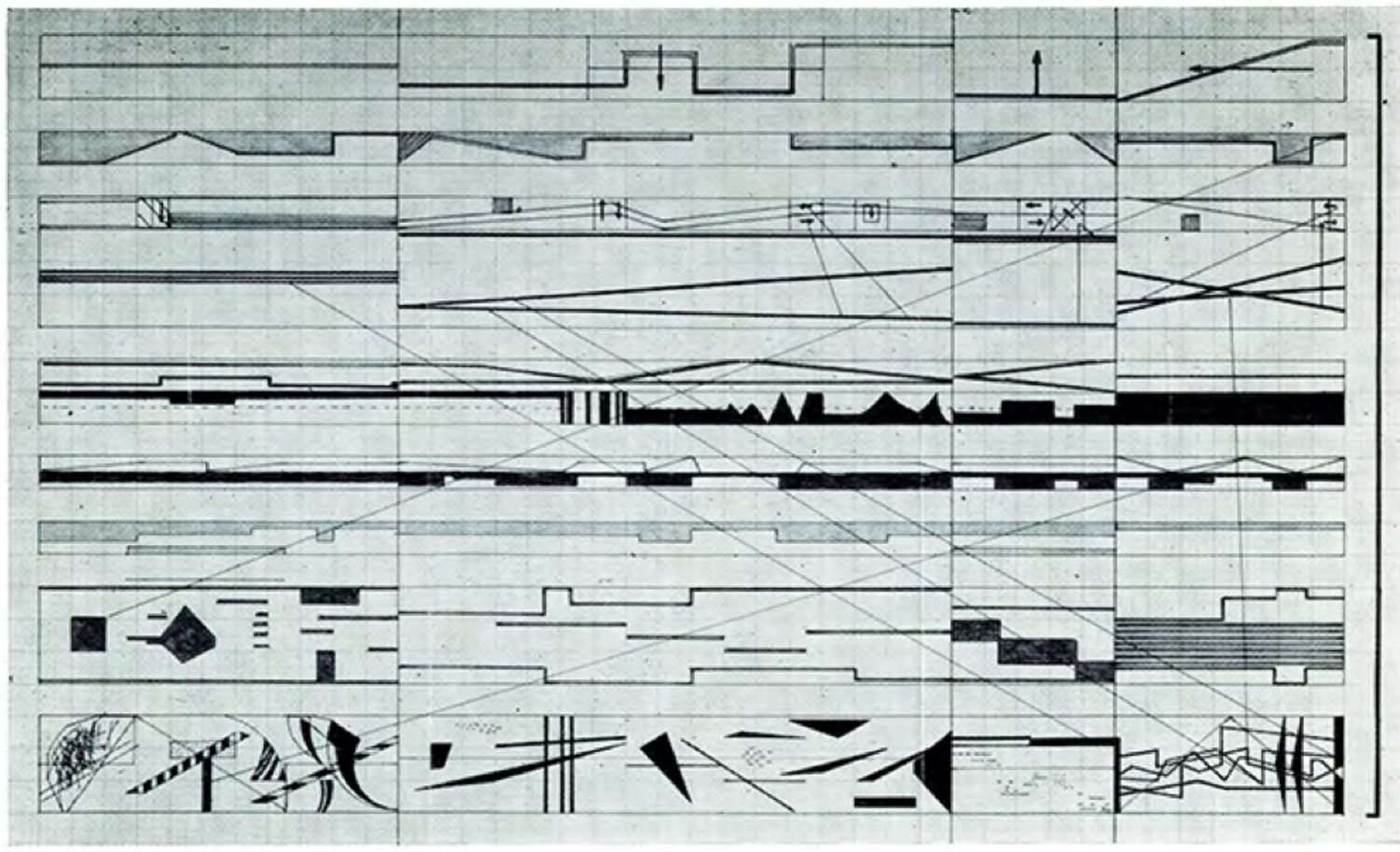


Left, View of Peter Zinovieff's studio

Facing page, top, Score for *Four sacred April rounds* by Peter Zinovieff, currently being realized at the composer's studio in Putney. The top line of the large block indicates the pitch sequences to be used in the realization by the computer. Reading downwards, the remaining horizontal lines refer to timbre, waveform, loudness and crescendo, probable ratio of sound to silence, probability of modulation, and probability of interference by previous events.

final piece. Numbers are equivalent to some aspect of sound which is finally heard, and codes and words are replacing numbers. A new grammar which is easily learnt will be the result. The communication between man and electronically-produced sounds become more and more efficient and the techniques easier to use. Certainly the field is not confined to mathematicians and engineers, but it is designed for composers of new music. This then is one experiment – a versatile electronic music computer installation with one main input, a typewriter keyboard, and one main output which is the final composition.

The composer remains in one sense, but in another he becomes an arbiter of form, the specifier of art. 'What is music?' he might ask the machine, and the machine will respond with endless examples, but the composer must ask the question or else nobody will. And this is what another computer project is about. Alan Sutcliffe at ICT has programmed an ICL 1900 to compose general compositions where the computer makes all the decisions about the outcome of a piece or even if there is a piece. The programme is sophisticated enough to allow a random determination of form, specific notes and the development and inter-dependence between movements and parts of movements and parts of notes. One output is in the form of punched paper tape, and the other is a tabular score informing us of what has happened. Such tapes have been fed into my computer, which in turn has been programmed to give free choice of electronic realization and treatment of this score, as well as recording it or merely playing it as it goes along. A product composed by a machine realized and automatically edited by another should perhaps be judged by a third.



Music from paper tape

T. H. O'Beirne

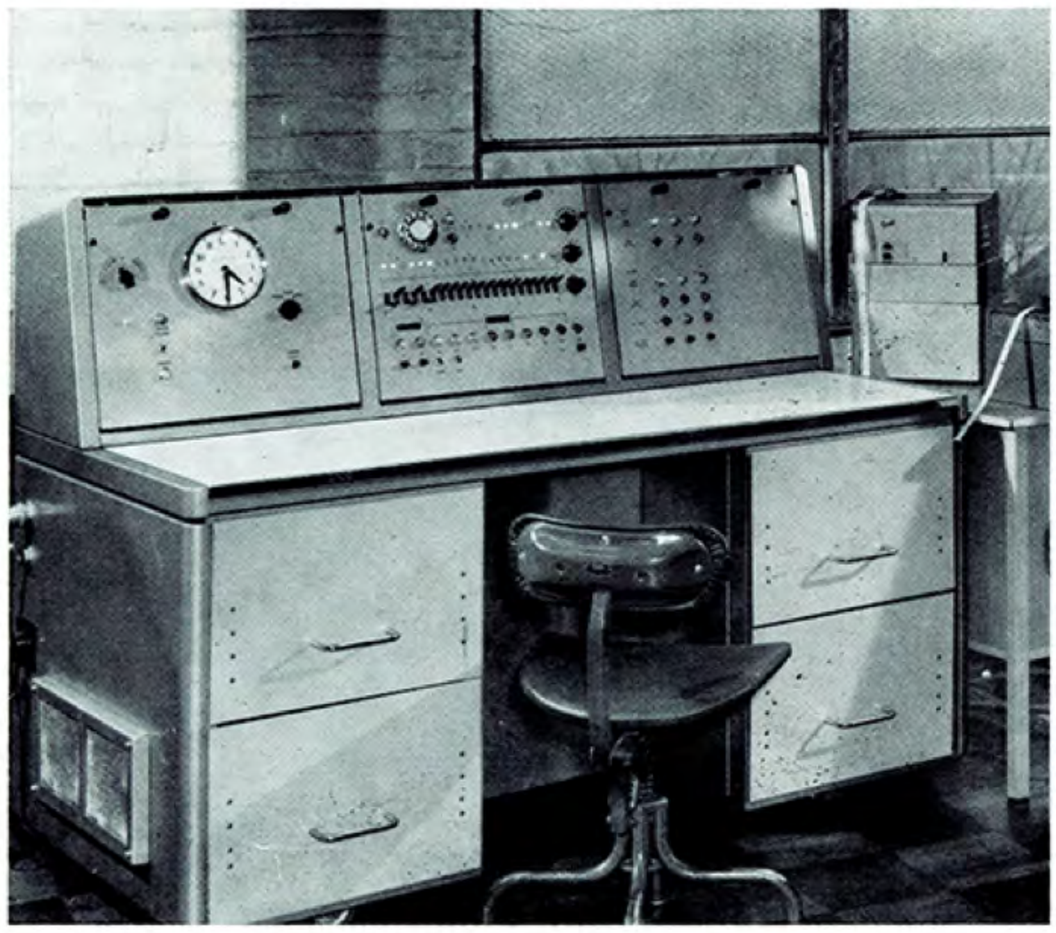
Some work with computer music has made advantageous use of a small computer built and for the most part designed by Barr and Stroud Ltd. for Glasgow University.

The design, dating from 1959, provides storage only for 1024 words of twenty bits, and a pulse rate of only 30,000 Hz. (Many computers of 1968 are about 100 times larger and faster.) Input is by five-hole paper tape. Musical potentialities–not at first appreciated–derive from shift orders which can vary loop-lengths by single pulses.

Suitable programming makes an internal (function-decoder) circuit have a rectangular pulse once in each passage of a loop. Amplified and fed to a loudspeaker, these pulses provide notes which have good harmonic overtones, somewhat suggestive of a clarinet. (Loop lengths determine pitch, and loop counts can then specify duration.)

A computer is preferably–and more easily–tuned to give many exact-ratio truly consonant intervals, rather than the equal-temperament compromises of keyboard instruments. True intervals give better scales for music of limited modulation. 'Solidac' can provide a just-intoned (major or minor) scale up to a 750-Hz note about one-and-a-half octaves above middle C, with some enharmonic alternatives useful for improving scales based on other notes.

As with an organ, each note has a fixed volume-level. Score-notations allow fine distinctions of duration (and very short rests), which are desirable and valuable for improve-



'Solidac' experimental computer made by Barr & Stroud Ltd, for Glasgow University

ment of musical expression. Suitable pieces can be given some simple two-part (and even three-part) harmony, by programming to produce multiplexing loops, cycled with the frequency of a fundamental bass.

Change ringing as for church bells—by authentic methods, up to full peals, if desired—can be specified in condensed notation. Bells are simulated by slightly staccato octave chords, given added realism by small random-number variations of timing.

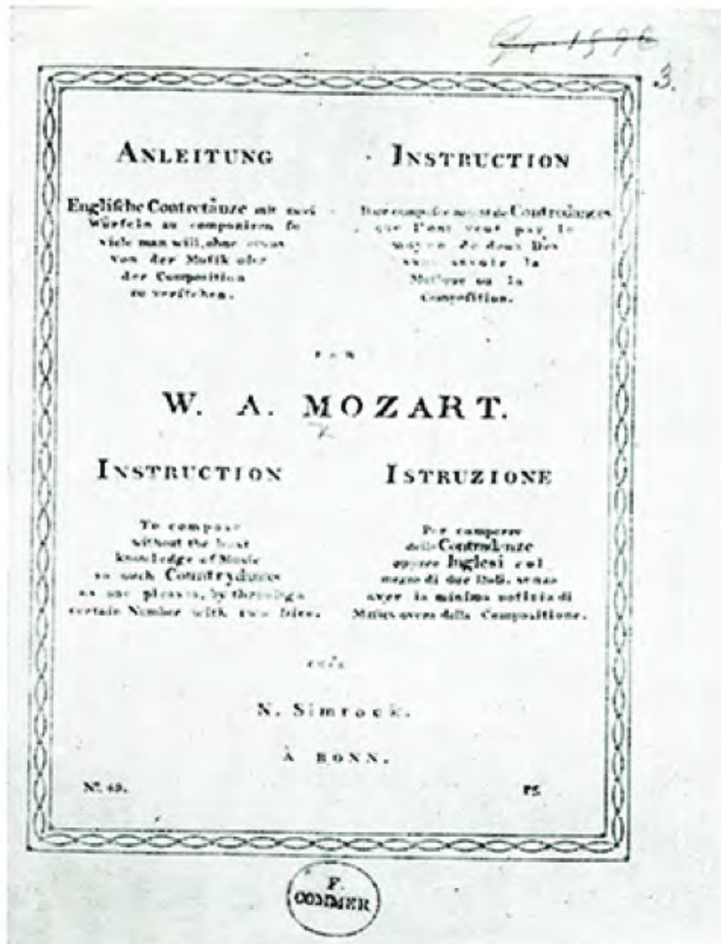
Random-number facilities can also provide for the continuous play of eighteenth-century dice-composition pieces in which an overall plan ensures compatibility for all choices made within sets of alternatives (usually eleven, for two dice, sometimes six, for one), given separately for each of sixteen successive bars.

The computer has arbitrary entry to cycles of some 100,000 variations for each of four scores of this type—Mozart scores for waltzes and contredanses, a Haydn score for minuets, and what is claimed as a newly-found Haydn score for trios (almost a billion different trios).

The dice-music master programme has been applied to give simultaneous composition and play of some forms of stochastic music. A first effort gave variants for four-bell clock chimes, Westminster (or Cambridge) style. Later work has been done within limits imposed by keeping to the nine notes of the (correctly tuned) Highland bagpipe—recently shown to have a unique and appropriate special-feature scale all of its own.

The computer can play a continuing succession of 256-bar pieces, each a variant in some selected genre suitable for this instrument. There are programmes for ten genres, some traditional and some novel. Restrictions can be imposed upon rhythms and note-selection, with provision made for progressive speed-changes, for some modulation and repetition features, and for authentic grace notes. Ten-movement suites of forty-minute duration can be formed by assemblies of complete sets of selected variants. (Direct play requires tape to be read between movements.)

Ready access to the computer gave a welcome opportunity to make many successive improvements by alterations to programmes and to their data.


ANLEITUNG · INSTRUCTION

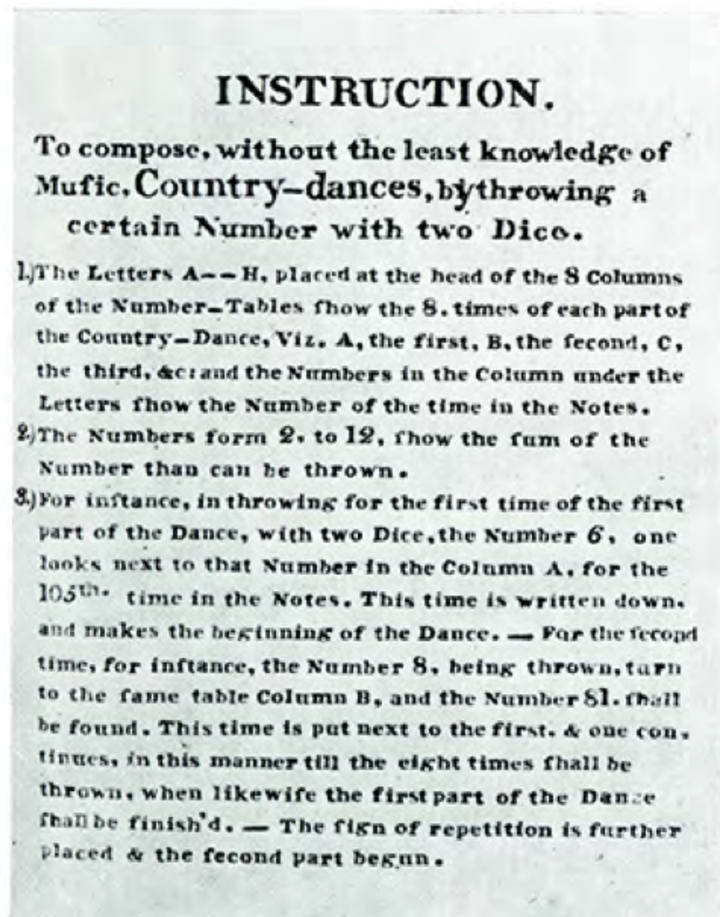
W. A. MOZART.

INSTRUCTION ISTRUZIONE

N. Simrock.

À BONN.

In 1795 Simrock published a system of composing waltzes and contredanses using chance operations, which have been attributed to Mozart. Two dice are thrown, and the resulting number is referred to the table to determine sequence of bars in the composition.

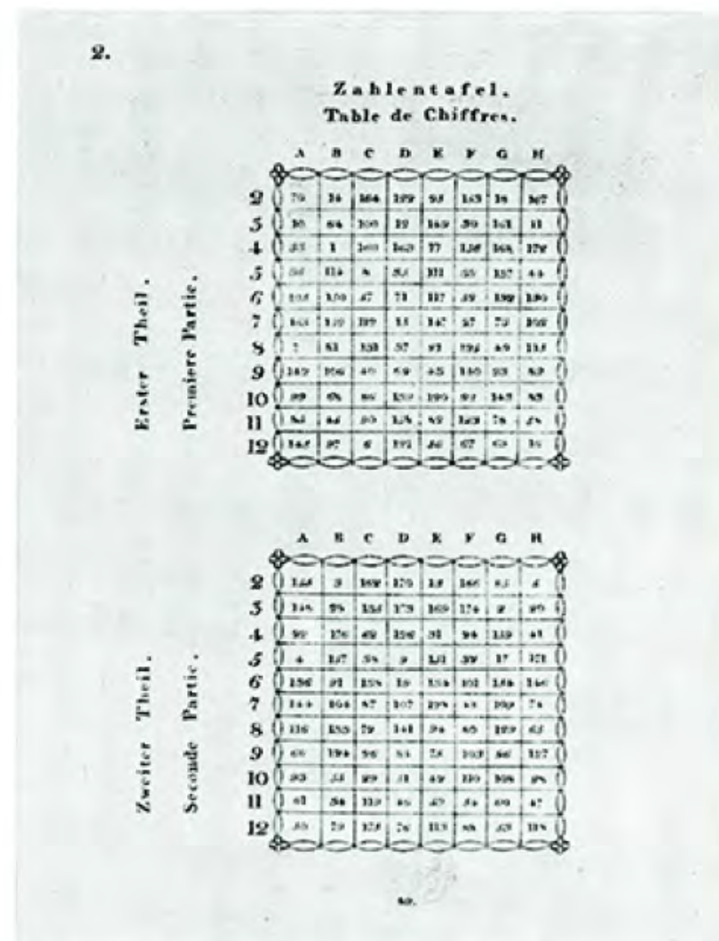

INSTRUCTION.

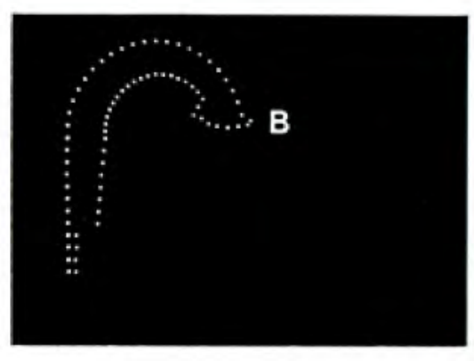
To compose, without the least knowledge of Mufic, Country-dances, by throwing a certain Number with two Dice.

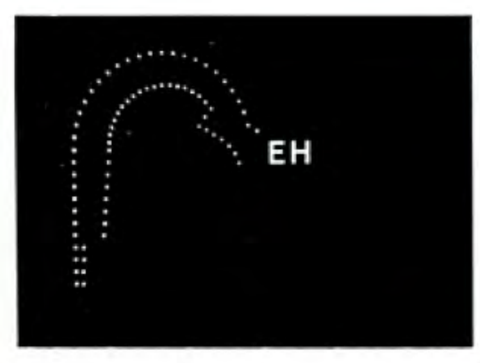
1.) The Letters A—H, placed at the head of the 8 Columns of the Number-Tables fhow the 8. times of each part of the Country-Dance, Viz. A, the first, B, the fecond, C, the third, &c: and the Numbers in the Column under the Letters fhow the Number of the time in the Notes.

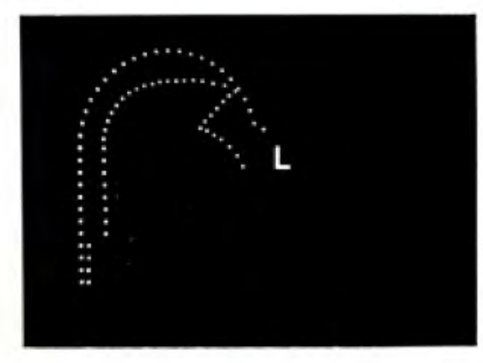
2.) The Numbers form 2. to 12, fhow the fum of the Number than can be thrown.

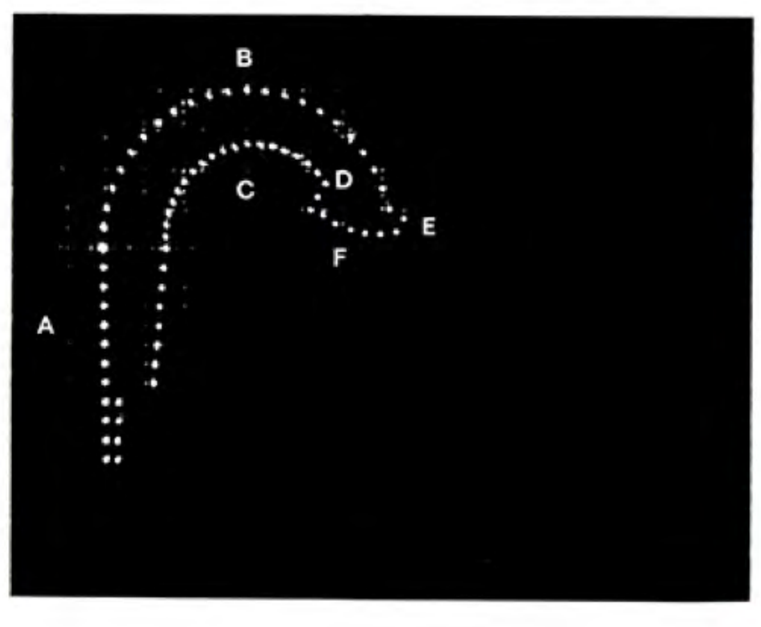
3.) For inftance, in throwing for the first time of the first part of the Dance, with two Dice, the Number 6, one looks next to that Number in the Column A, for the 105th. time in the Notes. This time is written down, and makes the beginning of the Dance. — For the fecond time, for inftance, the Number 8, being thrown, turn to the fame table Column B, and the Number 81. fhall be found. This time is put next to the first. & one continues, in this manner till the eight times fhall be thrown, when likewife the first part of the Dance fhall be finish'd. — The fign of repetition is further placed & the fecond part begun.











Computer-generated display of the vocal tract

Above, The changes in the position of the tongue, lips, and pharynx shown on an oscilloscope as the word 'Bell' is spoken. (Model developed at Bell Telephone Laboratories.)

Left, Vocal tract on an oscilloscope screen. Shown in the geometric side view is: (*a*) pharynx, (*b*) palate, (*c*) tongue, (*d*) tongue tip, (*e*) lips, and (*f*) lower jaw. The lips, pharynx and tongue are positioned to synthesize basic sounds.

Five screens with computer

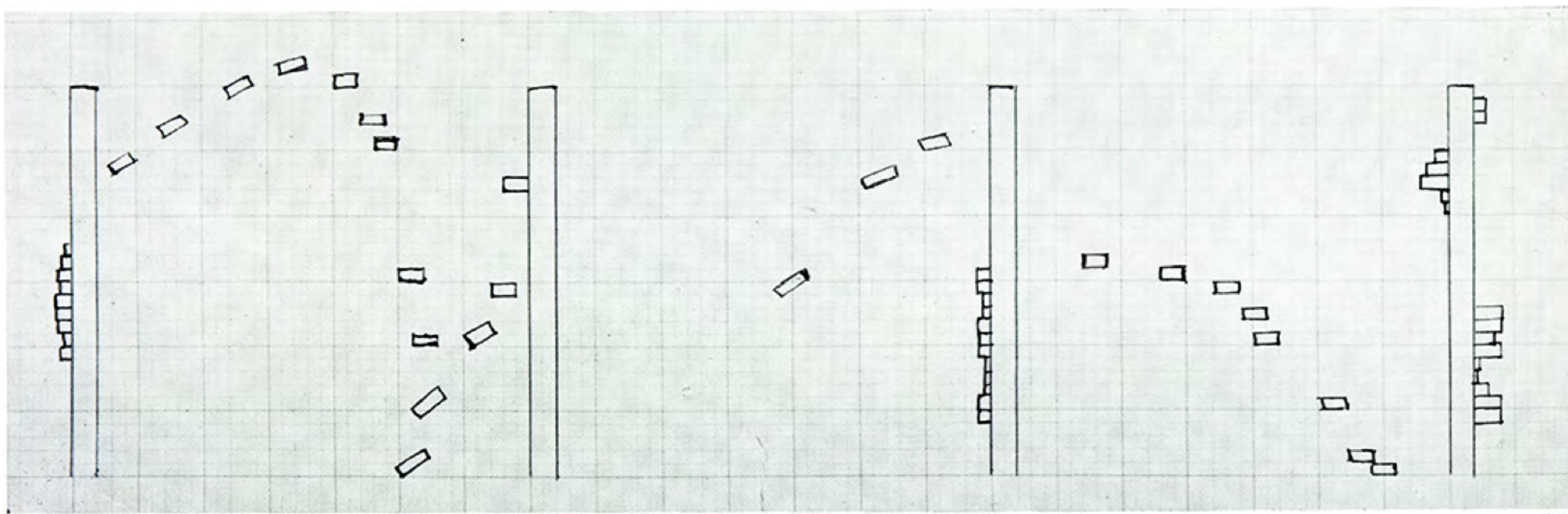
Gustav Metzger

'Five screens with computer,' is an elaborate project for auto-destructive art composed of five screens made of stainless steel, about thirty feet high, forty feet long and three feet deep. These are arranged thirty feet apart, staggered in plan, and sited in a central place between large blocks of flats. Each screen consists of ten thousand *uniform elements* three feet in length, whose section is either square, rectangular or hexagonal. The elements are tightly packed, and ejected one by one. The elements lying on the ground are removed periodically. After a ten-year period, only the empty site remains to be turned over to another use.

The artist prepares the programme for the ejection of the elements and disintegration of the frame. Numerous factors determine the programme. Technical demands and limitations. Day and night. Views of the screens, singly and in relation, from the ground and above. Shadows on the ground and screens at different seasons. The direction and velocity of ejections will be programmed. The frequency of ejections on holidays may reach 600 a day. One or several computers will exercise direct control over the activity of the screens. As suggested by Beverley Rowe, a computer programmer who assisted with the project in 1964, random ejections determined by atmospheric conditions can be incorporated in the programme. The computer is used for a variety of reasons. One is the complexity of ordering the movements of 50,000 elements over a period of ten years.

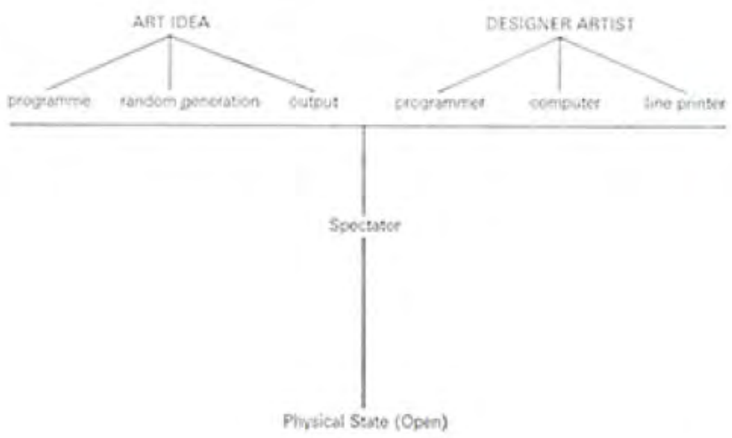
[These ideas were discussed by Gustav Metzger in his lecture at the AA in 1965.]

Elements spilling out from four of the screens at different speeds and in different directions. The entire activity is controlled by a computer.



Computer structures

Johan Severtson



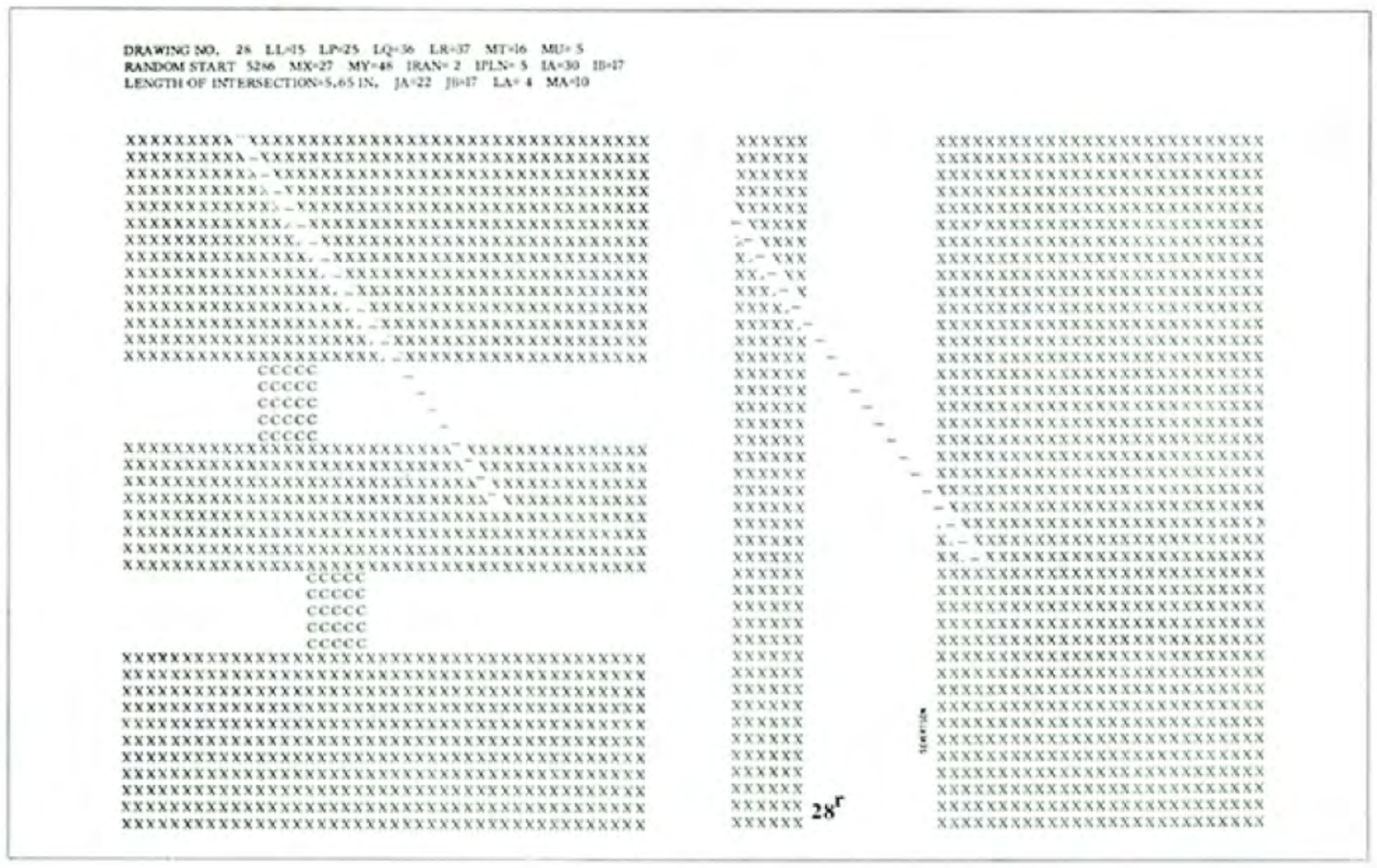
These structures have been simulated by the output of a general purpose digital computer. The computer served as a memory extension and thought manipulator, and was programmed to generate visual elements consisting of a finite entity such as shape, proportion, line and colour.

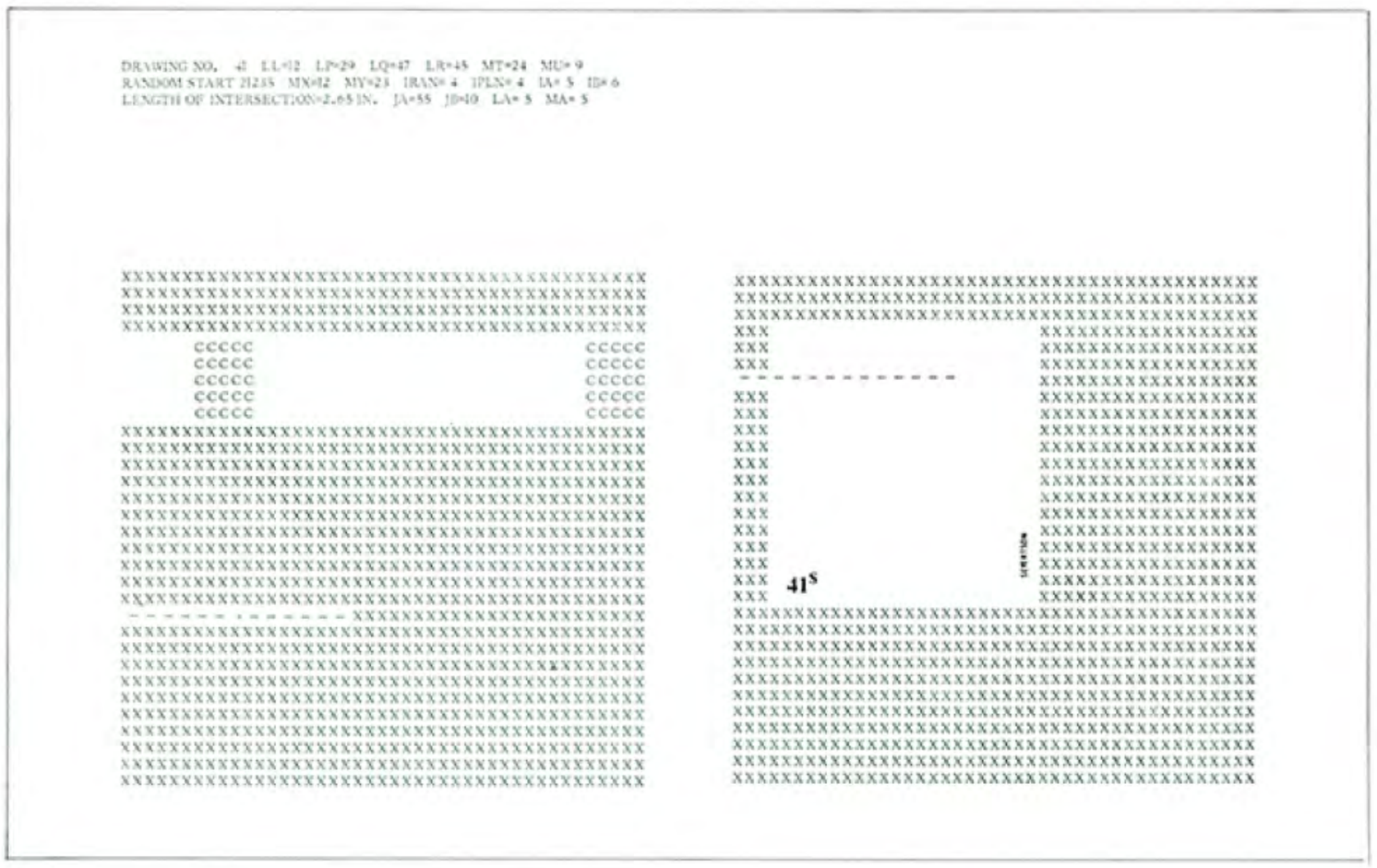
These elements are to be chosen by the spectator from a random list of elements available. The elements are manipulated by the computer to form a large number of random arrangements. It is up to the spectator to decide which elements he wishes to use. An example of the spectator specifications given to the computer might be as follows :-

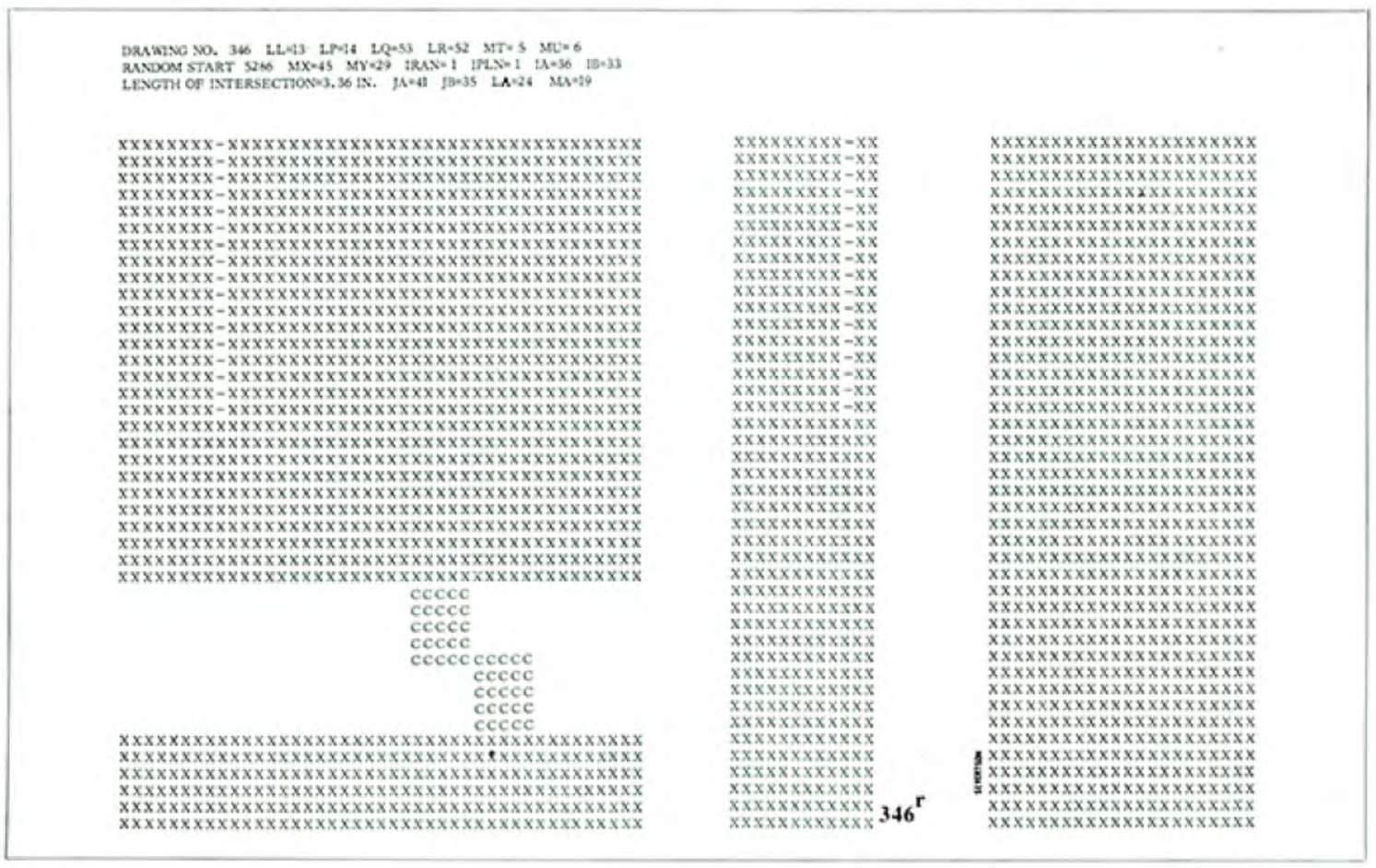
1. the structure must consist of two flat planes.
2. each to be rectangular in shape.
3. in a proportion of three to four.
4. the first plane to intersect the other.
5. on the first plane there may be one or two parallel bands of varying width.
6. each containing a block or two of colour.
7. the second plane will also contain a bank of constant width in varying positions.

A programme is then written to show the spectator the possible ways in which specifications could be met. Five hundred to a thousand permutations can be taken from one set of elements. When the output is produced the spectator chooses those he finds most interesting. The work of art exists in many physical states: electric impulses in the brain of the artist, verbal dictations to the programmer, flow chart on paper, punched on cards, printed as output, displayed on cathode ray tube, and translated to some other physical state determined by the spectator and artist.

Thus the computer is used as a tool for the spectator and artist, it does not produce art, but is used to manipulate thoughts and ideas which could be called art.







Computer Dance

Computer-programmed choreography

Jeanne H Beaman started work on computer dance in 1964, in collaboration with Paul Le Vasseur of the Computer and Data Processing Center at the University of Pittsburgh.

The first dances, all solos, generated three specific types of command, those of tempo, movement and direction. Three lists of such commands were given to the computer which selected from these at random. Since 1966, Mrs Beaman and Dale Isner have continued their explorations, generating choreography from duets to large groups and adding directional controls. For example, in the film *Stationary dance* the computer picked at random the place on the grid where each dancer starts. All successive space areas remained the same in this particular dance. Other possibilities are revealed by the titles to dances such as *Cluster at the centre, Once off stay off, Circling counter-clockwise* in which each new command moves the dancer around the stage grid, and *Front and back,* for which there are no lateral space commands.

Movement directions come spilling out of a computer very much like so many beads without any string to hold them in line. If the dancer responds in a mechanical way, the result is an aggregation of separate movements. The question of how to relate the movements or to emphasise their separateness remains an area of decision for the dancer and not for the machine. Two dancers, therefore, working from the same computer directions, may end up with dances which differ not only in skill but in the whole emotional import. The random character of the computer directions gets rid of long-held habits.

In England, at least one group of dancers has tried out computer dance under the direction of Ann Hutchinson.

STAGE LAYOUT

	13	14	15	
12	1	2	3	16
11	4	5	6	17
10	7	8	9	18

NUMBER OF DANCES	1
NUMBER OF DANCERS	2
STEPS PER DANCE	10
TITLE OF DANCES	STATIONARY DANCE

Random dances computer output
Dancer 2 at 4
Dance 1

Stationary dance

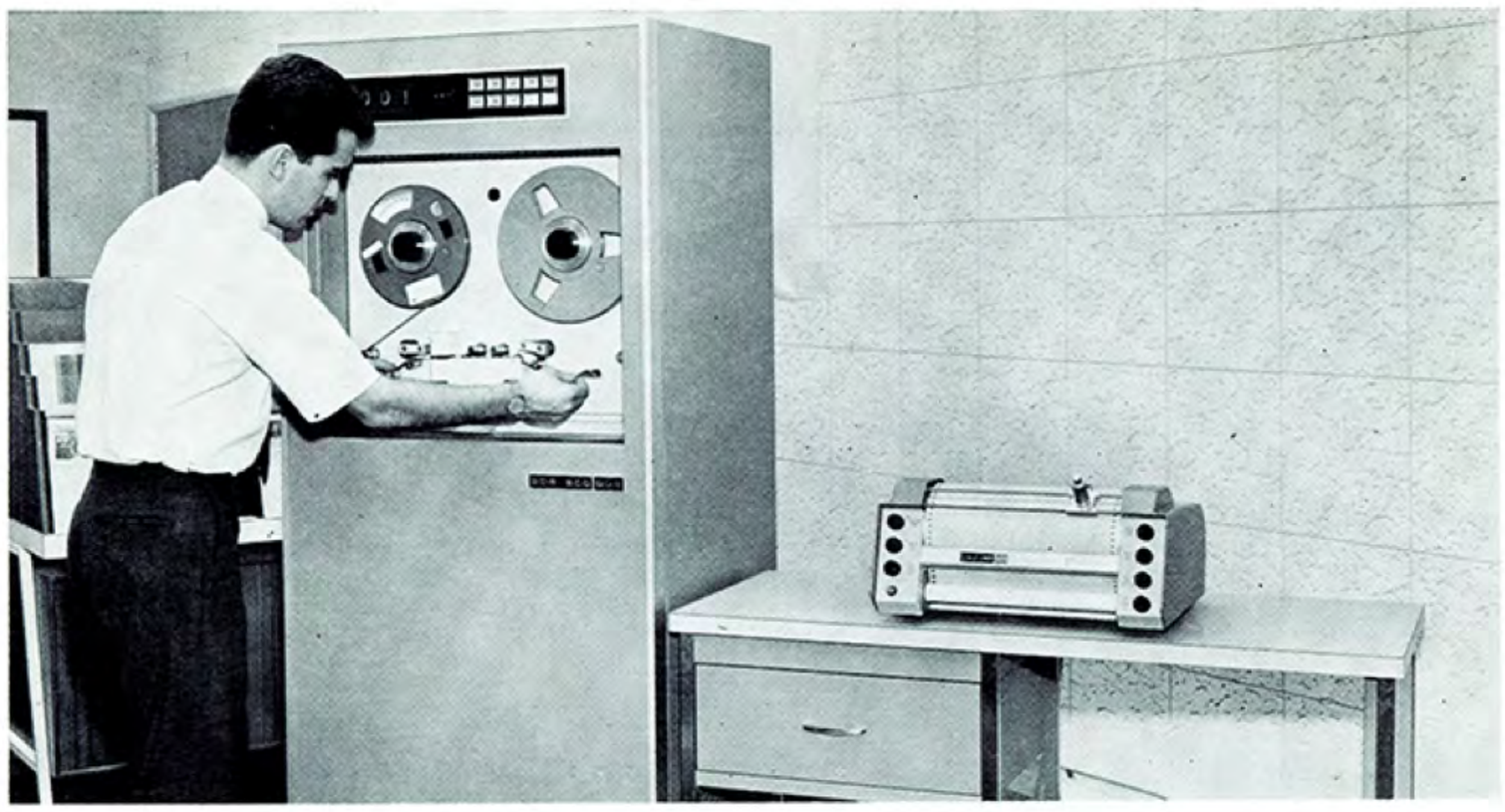
1. Stay at 4, nine medium beats, rotate left shoulder clockwise, diag rt bkwd then return then diag left bkwd.
2. Stay at 4, five medium tempo triplets, rotate both shoulders clockwise, make a pentagon.
3. Stay at 4, three medium beats, leap then run, diagonally right backward.
4. Stay at 4, eight beats S to F to S, run as many as desired, no change in space.
5. Stay at 4, three slow beats, plie in second position and rise, alternate diag rt forwd and diag left bkwd.
6. Stay at 4, three slow beats, fall land do not rise until next line, diagonaly left backward.
7. Stay at 4, seven medium beats, move left arm only, arc forward.
8. Stay at 4, ten beats S to F to S, quarter turn counterclockwise, make a hexagon.
9. Stay at 4, fifteen beats fast to slow, walk with legs bent, choose your movement direction.
10. Stay at 4, four medium beats, flex left knee and rotate lower leg CW, make a pentagon.

Random dances computer output
Dancer 1 at 9
Dance 1

Stationary dance

1. Stay at 9, four medium tempo triplets, walk heel toe, zig-zag left.
2. Stay at 9, three slow tempo triplets, stand on right leg, arc side left.
3. Stay at 9, ten beats F to S to F, walk on tip toe, choose your movement direction.
4. Stay at 9, eight slow beats, flex right knee and rotate lower leg CCW, arc forward.
5. Stay at 9, six medium tempo triplets, run then leap, forward.
6. Stay at 9, five fast beats, fall and do not rise for two lines, alternate diag rt forwd and diag left bkwd.
7. Stay at 9, three slow tempo triplets, fall and do not rise for two lines, diagonally left backward.
8. Stay at 9, four slow tempo triplets, full turn clockwise, side right.
9. Stay at 9, eight beats slow to fast, fall and do not rise for five lines, zig-zag right.
10. Stay at 9, ten beats fast to slow, rotate left hip counter-clockwise make a triangle.

Machines and environments



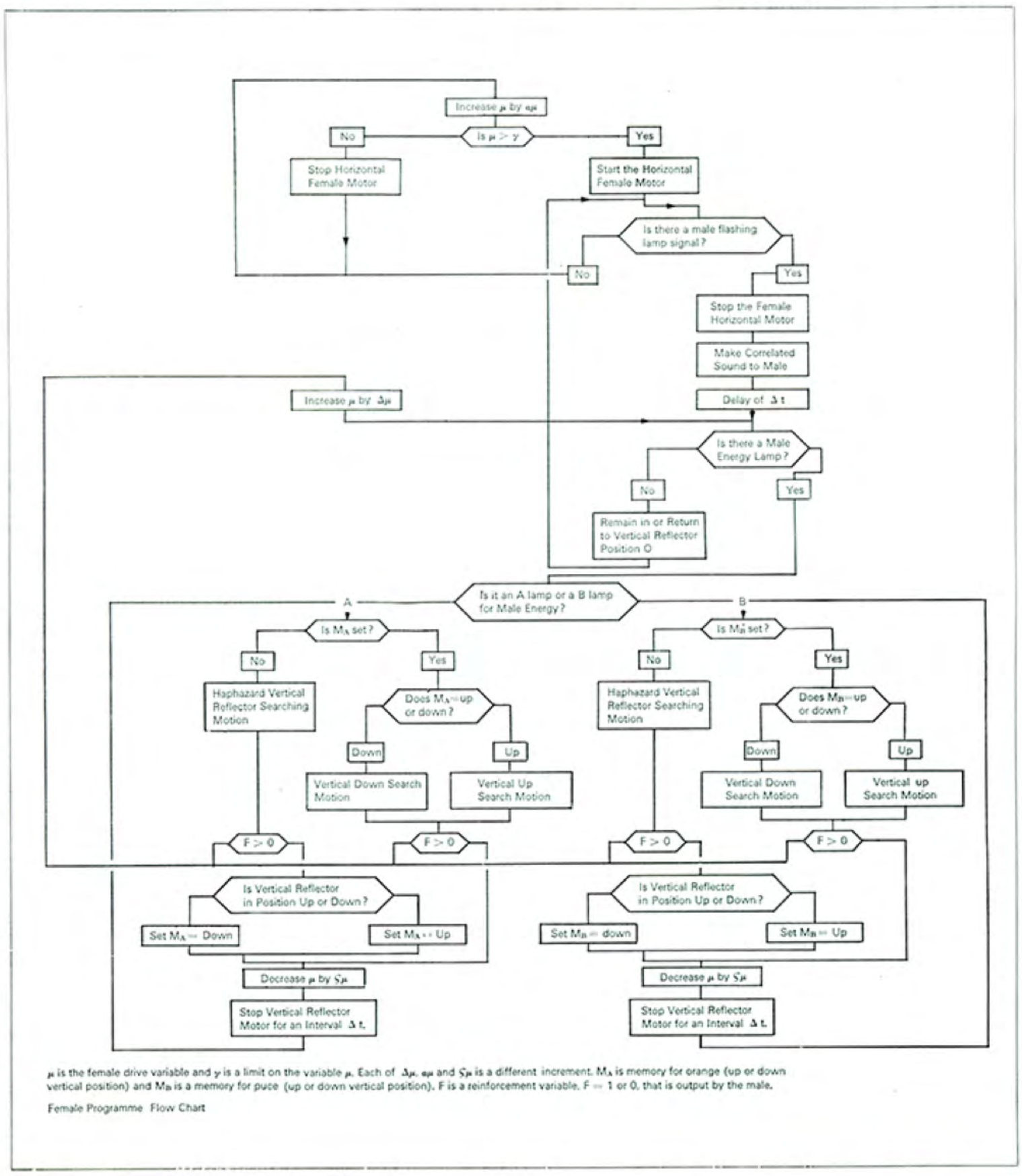
Calcomp's model 760 magnetic tape plotting system
One of four systems in the 700 Series—is compatible with all Calcomp 500 Series Digital Incremental Plotters. The precision-engineered tape transport and logic circuitry provide all the advantages of off-line digital plotting and include a number of special features for maximum plotting flexibility. Also shown is Calcomp's Model 565—one of several models in the 500 Series, suitable for automatic digital plotting with virtually any standard computer.

The colloquy of mobiles

Gordon Pask

An 'aesthetically potent' environment is an environment of any sort (auditory, as in music, verbal, visual, tactile perhaps) that people are liable to enjoy and which serves to shape their enjoyment. An artist can certainly manufacture and mould such an environment (as he does by writing music, building a house or painting a picture), and, in so doing, he may communicate a message. But the quality of 'aesthetic potency', although it determines the framework in which artistic communication can take place, is primarily attached to a relation between the environment and the hearer or viewer. An aesthetically potent environment encourages the hearer or viewer to explore it, to learn about it, to form an hierarchy of concepts that refer to it; further, it guides his exploration; in a sense, it makes him participate in, or at any rate see himself reflected in, the environment.

Physically (though not psychologically) passive environments of this sort are familiar enough (music that bears repetition, paintings worth seeing twice). Active and even reactive environments have been fabricated with this property. The *colloquy of mobiles* is an attempt to go one step further in the same direction.



μ is the female drive variable and γ is a limit on the variable μ. Each of Δμ, αμ and δμ is a different increment. M_A is memory for orange (up or down vertical position) and M_B is a memory for puce (up or down vertical position). F is a reinforcement variable. F = 1 or 0, that is output by the male.

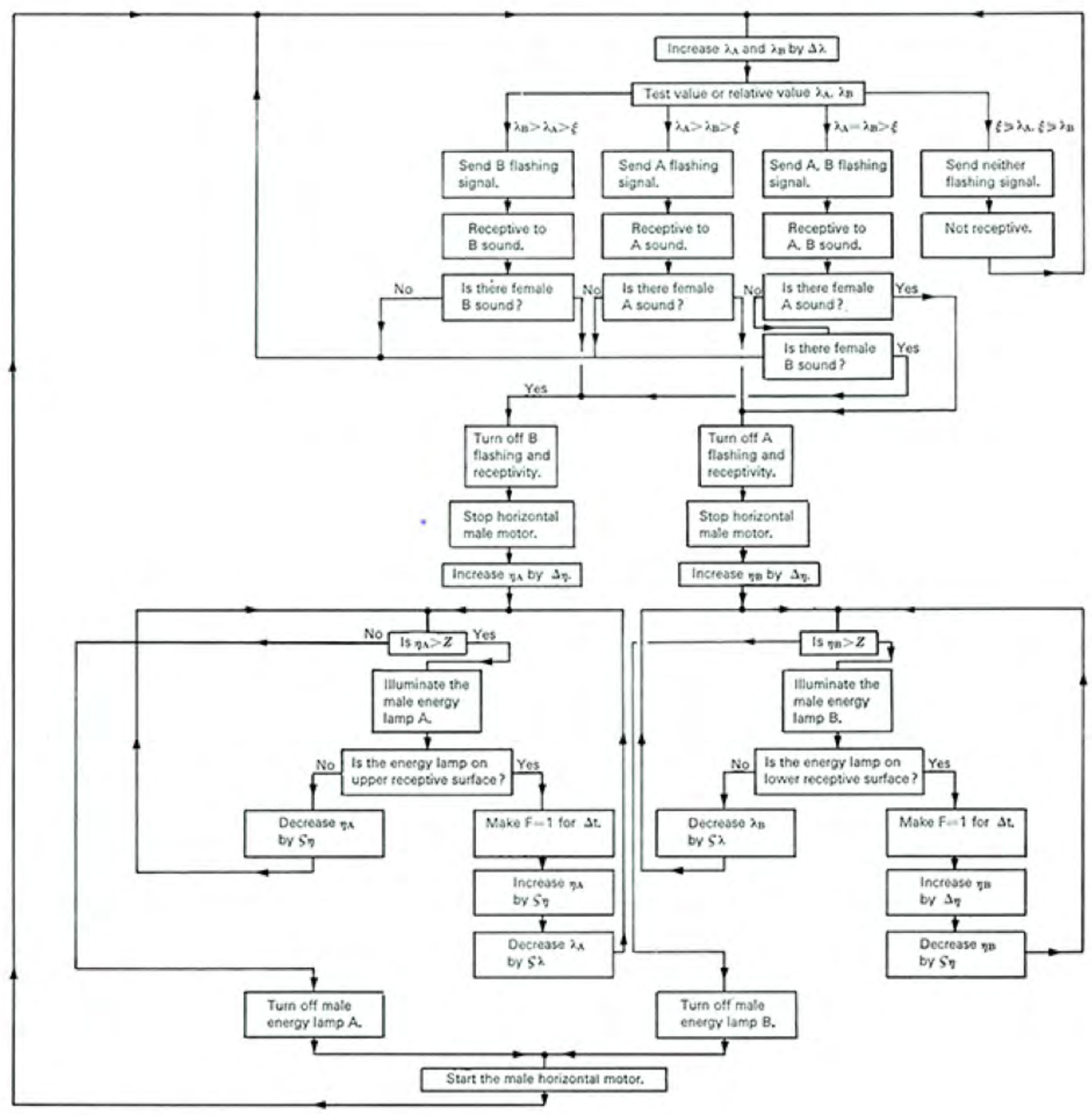
Female Programme Flow Chart

It is a group of objects, the individual mobiles, that engage in discourse, that compete, co-operate and learn about one another. Their discourse evolves at several levels in a hierarchy of control and a hierarchy of abstraction. The trick is that if you find them interesting then you can join in the discourse as well and bring your influence to bear by participating in what goes on. It is a crude demonstration of an idea that could be developed indefinitely.

Each individual mobile has a set of programmes that determine its motions and its visible state. Each individual learns how to deploy its programmes in order to achieve a goal; namely, to reduce an inbuilt drive. Its level of 'satisfaction' is reflected partly in its behaviour and partly in a visual display. The mobiles are of two sorts. As a whimsy, we have called one sort male, the other female.

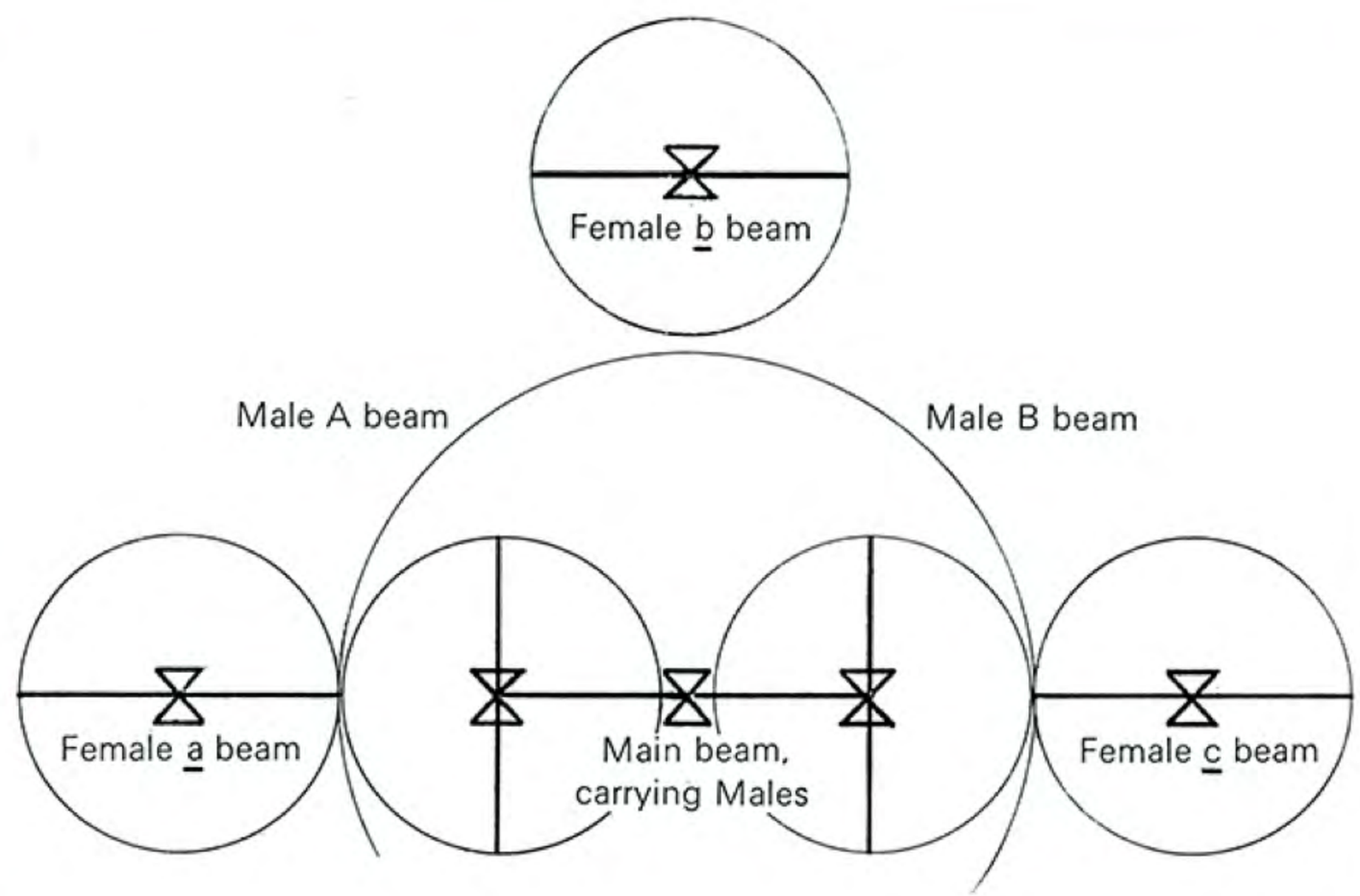
Whereas males compete amongst themselves and so do females, a male may co-operate with a female and vice-versa, for one possesses programmes that are not in the repertoire of the other and jointly a male and female pair can achieve more than both individuals in isolation. Ironically, this property is manifest in the fact that a male can project strong beams of light but it cannot satisfy an urge to have them play on its periphery, whereas a female (who cannot shine light) is able to reflect it back to a male (and, when she is competent, to reflect it upon the right position). To co-operate or even to orient themselves and to engage their programmes, the mobiles must communicate. They do so in a simple but many-levelled language of light flashes and sounds You may engage in this discourse if you wish to, though your goals may be alien to the goals of the mobiles; for example, you might be trying to achieve a configuration that you regard as pleasing.

For *Colloquy of mobiles:*
System and Males by Gordon Pask
Females by Yolanda Sonnabend
Electronics by Mark Dowson and Tony Watts
Patron of the project – Maurice Hyams in co-operation with System Research Ltd.



Lamp A = Orange Lamp B = Puce
Flashing Signal is male female communication signal. λ_A and λ_B are the drive variables in the male. η_A and η_B are the internal state variables for the male. ς is a limit on λ and Z is a limit on η. It is assumed that this male is reinforced if the A male energy lamp is on its upper receptive surface or if the B male energy lamp is on its lower receptive surface. The variable, F, is a reinforcement variable, F = 1 or 0, the value of which is conveyed also to the female.

Male Programme Flow Chart



Plan of Mobiles

Analogue feedback projection system

John Lifton

The projection system is a stage in a series of experiments started in autumn 1966 and working towards building an environment in which all the senses would be involved in an integrated way.

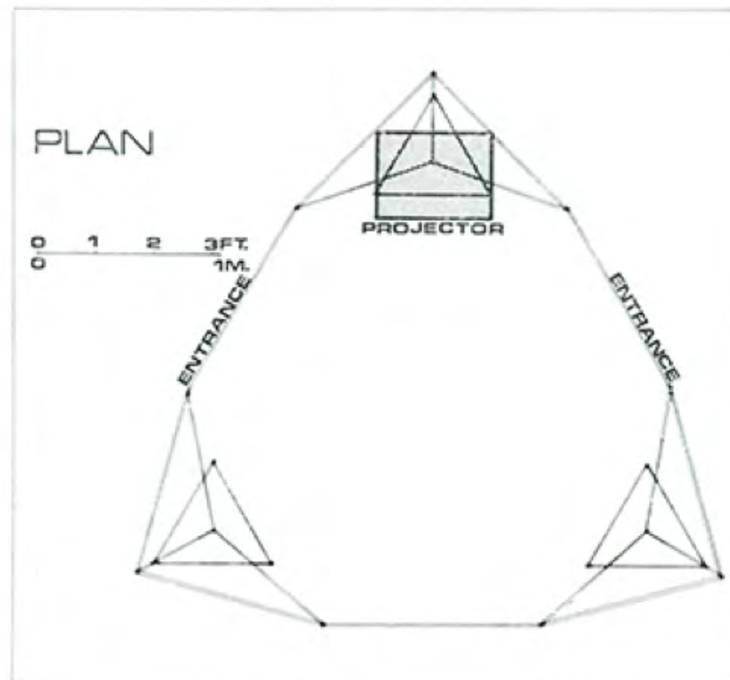
In earlier stages a combination of visual, aural, tactile and olfactory elements was used. Despite making the visual parameter indistinct, dark and intermittent, it still tended to dominate the experience, so I decided to concentrate on the visual side and try to find a way of making a visual image that involved the viewer in it rather than make him feel that he was observing it.

The functional criteria evolved for the system were–

1. The image should not be projected onto a fixed screen within the space but onto the whole surface of the space so that the viewer is within the projection.
2. The image should be constantly moving over the whole surface.
3. The image must be complex but not of high definition.
4. The image should respond to a sound stimulus as the aural sense is more 'immediate' than the visual.

The basis of the system, completed in April 1968, is multifaceted blocks of glass or optical plastic, placed in front of the projection lens, and mounted on low-inertia d.c. servomotors which are the output units of an analogue computer. When a sound is made in the projection space the computer sends a signal to a servomotor which causes the rotation of the glass or plastic block in the projector's light beam so that the projected image is moved on the surface of the projection space in accordance with the signal. The way in which the light movement responds to a sound depends on the programming of the computer.

The projector is mounted in a geodesic dome about 3m. wide and 4m. high internally, which combines for the viewer a sense of enclosure and a continuous projection surface. A tape loop provides intermittent music as the rhythmic response of the light to it is particularly interesting. Microphones pick up sound generated by viewers within the space.



Sidebands 1968

Hugh Riddle and Anthony Pritchett

Image size: 10 in high x 12 in wide

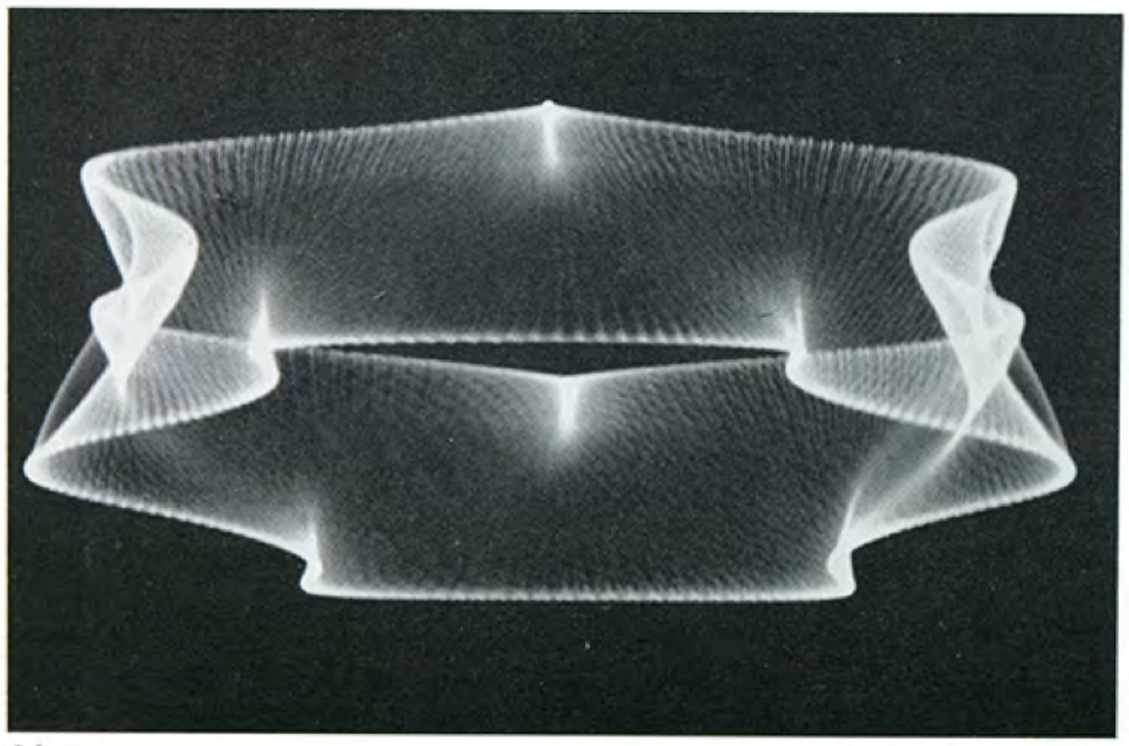
These forms are stills of a kinetic sequence produced by an analogue system and are essentially an elaboration of the Lissajous figure oscillographic technique used by engineers for frequency measurement. The most important difference is that surfaces have been substituted for the lines of the classic Lissajous figure. These surfaces are generated by a complex of high frequency sideband signals, which also give an impression of varying texture.

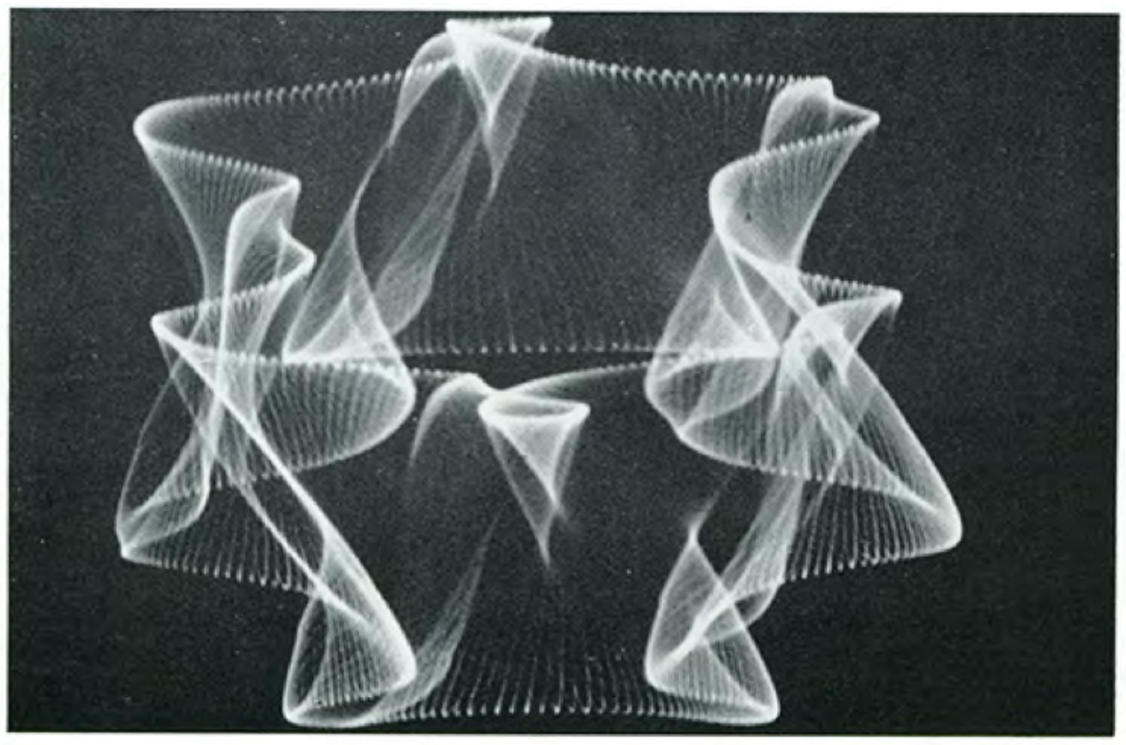
Harmonically-related sinusoidal waveforms originating from electronic signal generators are processed by analogue circuits and fed to the X and Y deflection coils of a cathode ray tube. The very large number of different graphic forms are achieved by varying the ratio of the frequencies of the waveforms.

For the purpose of this exhibition, the waveforms have been recorded on a loop of magnetic tape to provide a continuously changing display which repeats every ten minutes.

Analogue techniques are used to amplify and process signals in a continuous rather than quantised manner and the idea of using this approach arose when digital computer methods proved too expensive for the animation of even simple forms, when surfaces were involved. The system was originally designed to generate a Möbius strip for a television title sequence, of a BBC 2 science fiction series, *Out of the unknown*, but revealed unexpected graphic properties even at the testing stage.

Development followed a quite different path to that for most electronic applications,

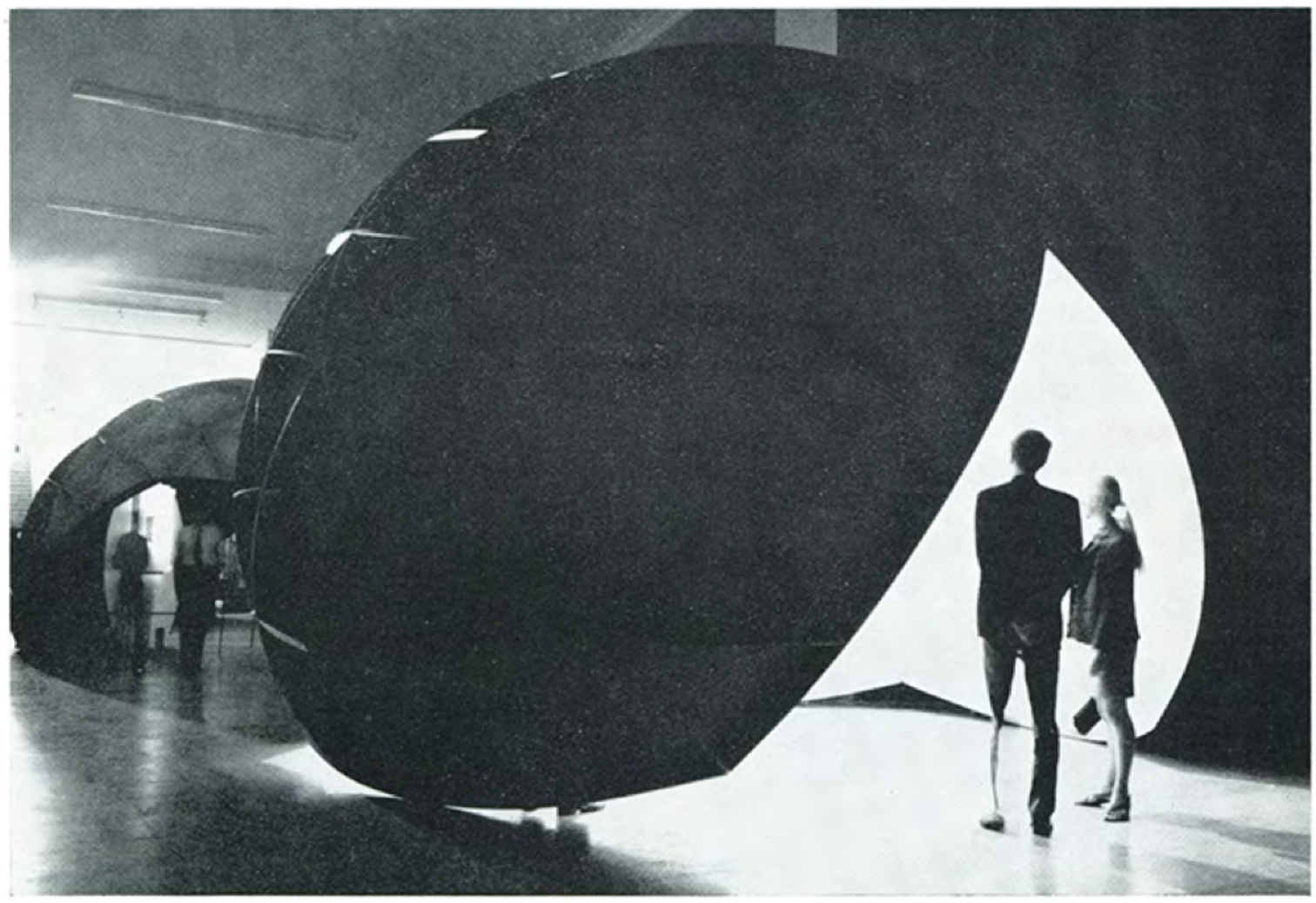




because the visual impact of the various analogue processes was so unpredictable. Many of the most significant steps were taken by accident. Even after an interesting effect had been found, it was not easy to see how to modify the circuit design to increase the interest, so that a free-wheeling, empirical approach had to be adopted. It is an interesting experience to work with an electronic system in such a subjective way, often exploring conditions that would be treated as faults in, for instance, an industrial system: very different from the cerebral preplanned approach usually necessary for digital computer graphics.

Que la lumière soit by Yaacov Agam

This dome was shown in the Museum of Modern Art in Paris in 1967. The slightest sound affects the bare bulb inside which responds in light intensity to the variety of ambient sounds.



Carm-O-Matic

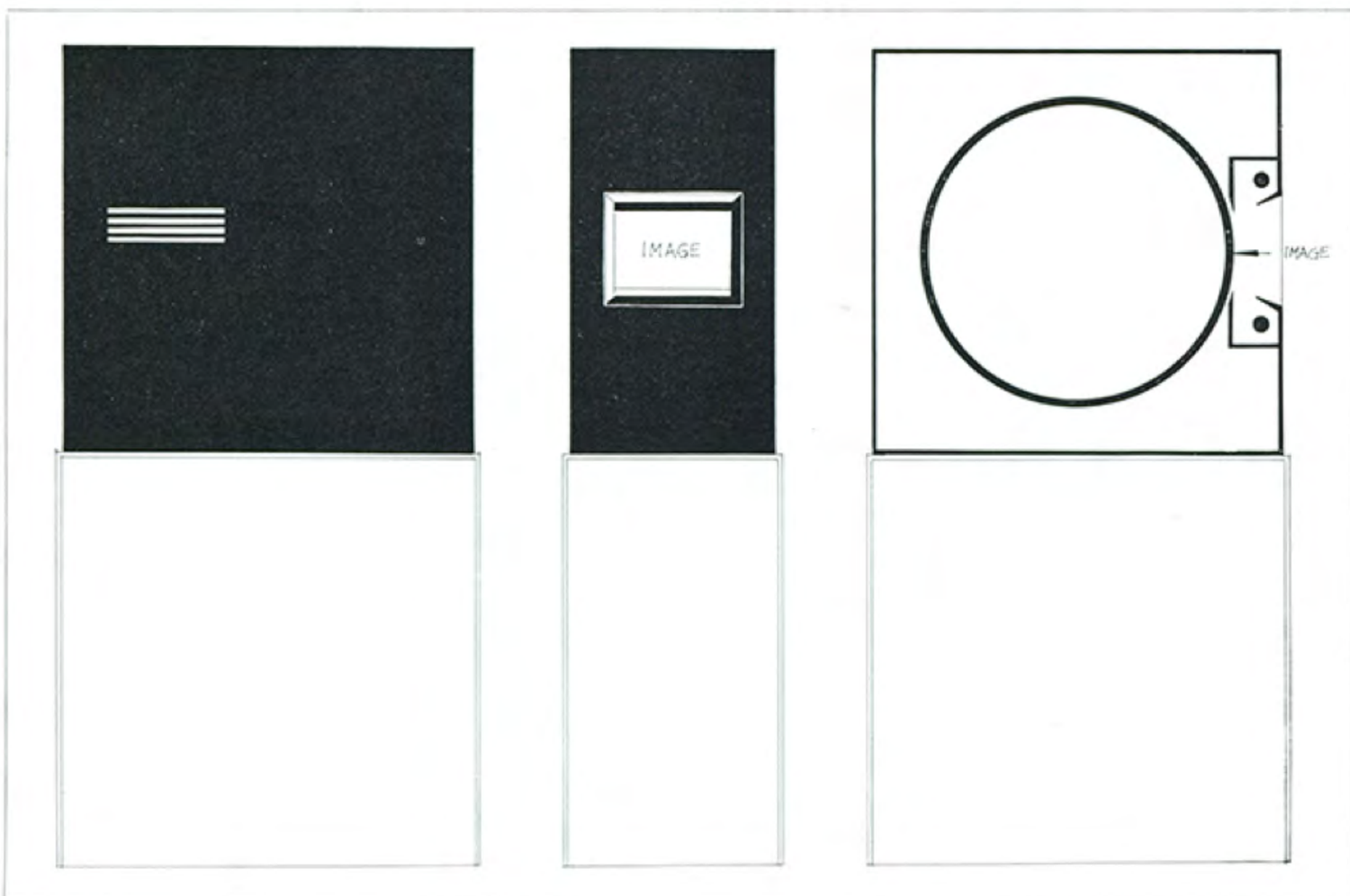
Eugenio Carmi

The Carm-O-Matic is a picture generator, with visual effects obtained by the overlapping of simple images, which build up on the retina of the spectator with the aid of stroboscopic flash. Starting with a set of elementary images, it is possible to obtain numerous combinations of considerable complexity.

The system incorporates an interchangeable set of images which appear on a cylinder at a speed of 1500 revolutions per minute.

What we see is the result of a combination of two chance elements, the moving images on the cylinder and the frequency of the stroboscope flash. The possible combinations run into millions. The apparatus is sensitive to sound in the environment, which effects its random function.

This work has been realized with the collaboration of Ing. Gianni Colombo of Borgoticino, Italy, and the patronage of Olivetti Company, Ivrea, Italy.



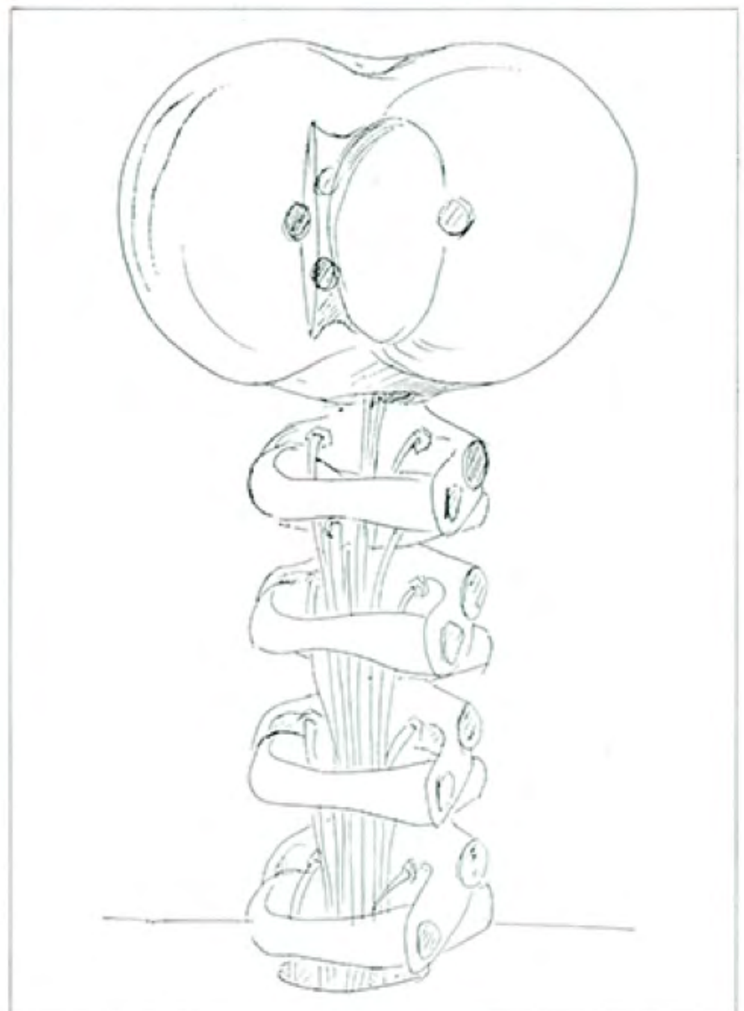
Sound-activated mobile

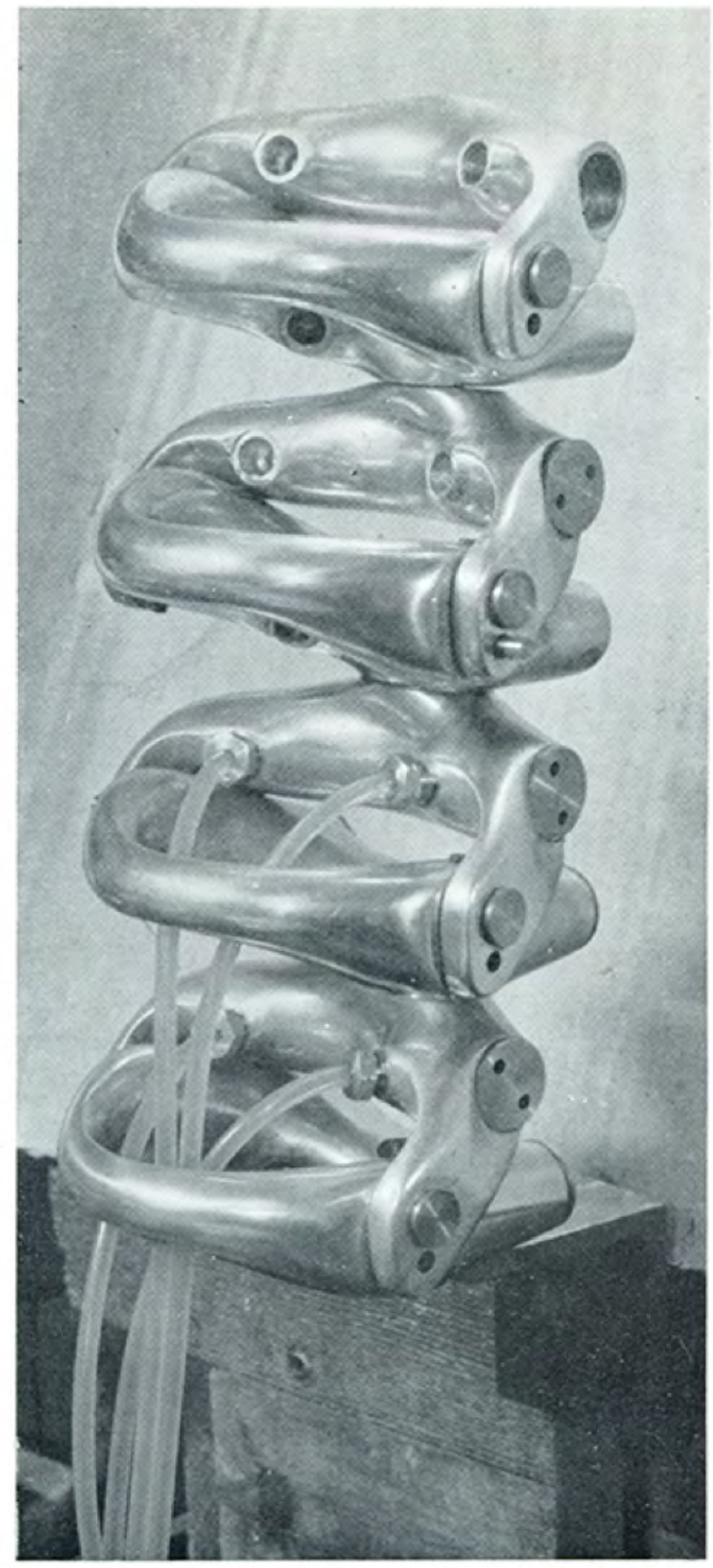
Edward Ihnatowicz

This electro-hydraulically operated, environment-sensitive mobile is my first attempt at an articulated structure capable of being controlled by an electronic system.

It was also an exercise in developing shapes by following a strictly functional discipline, in the hope that the final appearance would become a reflection of the motive as well as of the method.

I am currently working on a large structure to be operated by a computer and designed to explore the possibility of a much more subtle and varied movement, as well as more complex reactions to the environment.



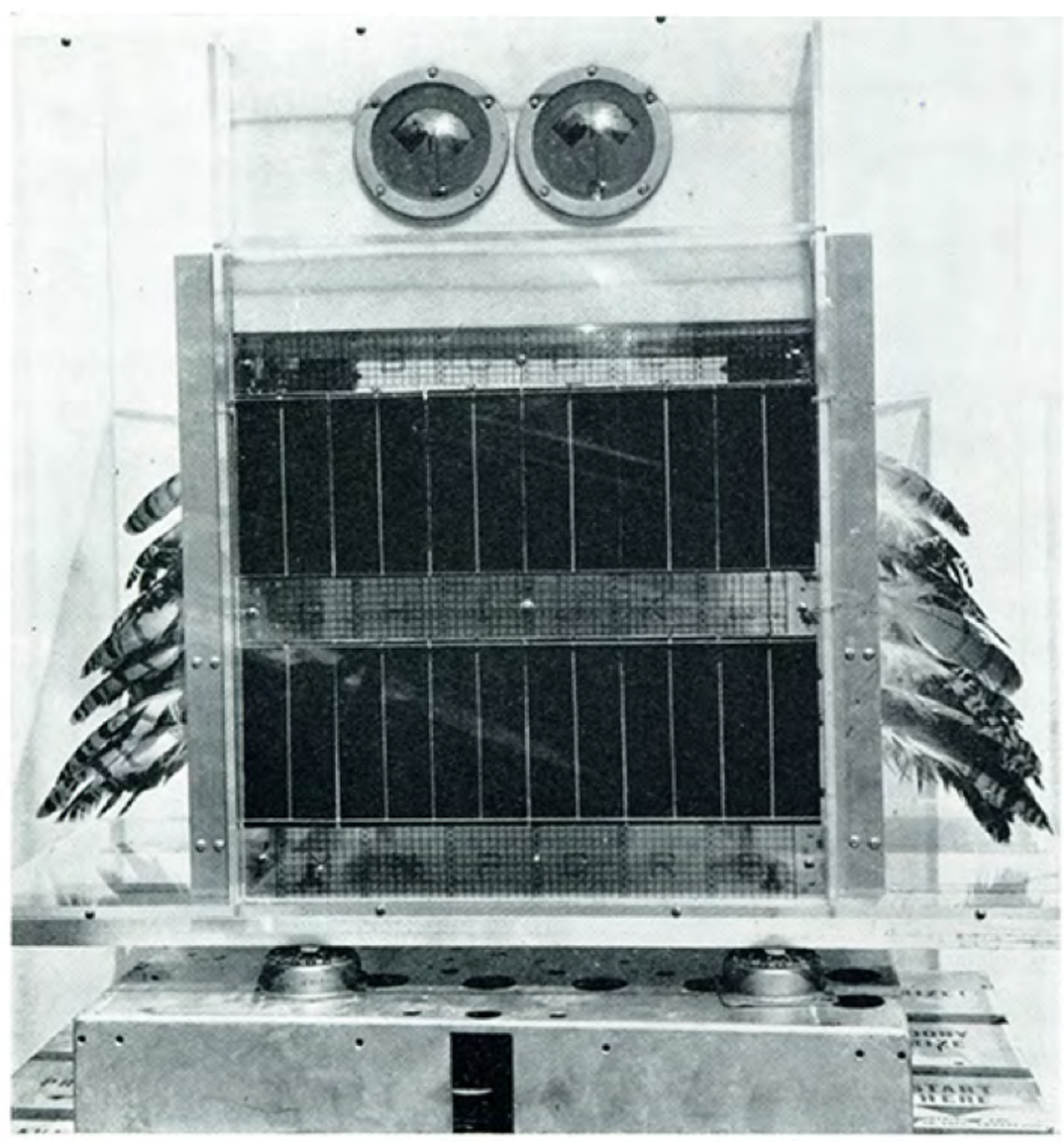


Top right, Edward Ihnatowicz in his studio workshop; right, a drawing of the mobile; far right, the partially-completed mobile.

On the human predicament

Bruce Lacey

Given a brain, man has the possibility of developing into a sublime, happy, creative, and unique creature, but he is prevented from realizing this potential by the severe limitations imposed on him by the environment he has created for himself in order to survive physically. Having to adapt psychologically to his environment, and if the environment has been too hostile, religions have stepped in to offer a pleasanter one after death. If man has resisted external pressures, he has either been put to death, put into prison, or put into a mental home. To survive in the future, he must rebuild his cities, rewrite his laws, and re-educate himself and his



Owl, 1967
plastic, selenium cells, feathers, 21 × 24 × 12 in. collection Deighton Duffy Productions Ltd.

When subjected to sunlight or artificial light, selenium cells emit electricity which operates sensitive motors which in turn activate feathers on either side of the body. Brooks Radiometers function as eyes revolving when heat is detected by them.

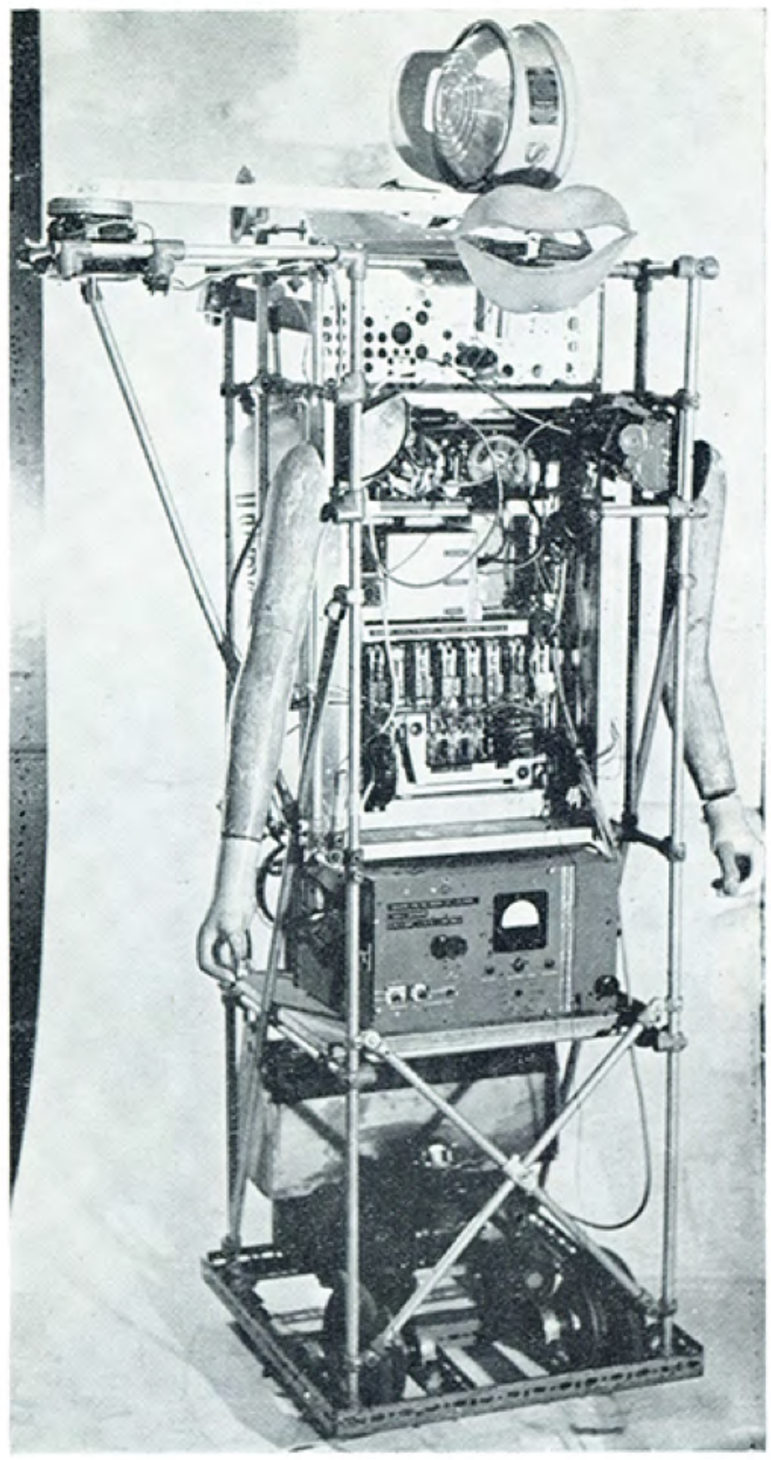
children. He must do all these things to suit his emotional, sexual and psychological needs. In other words, he must change his environment and his society to suit himself and not change himself to suit his environment or society.

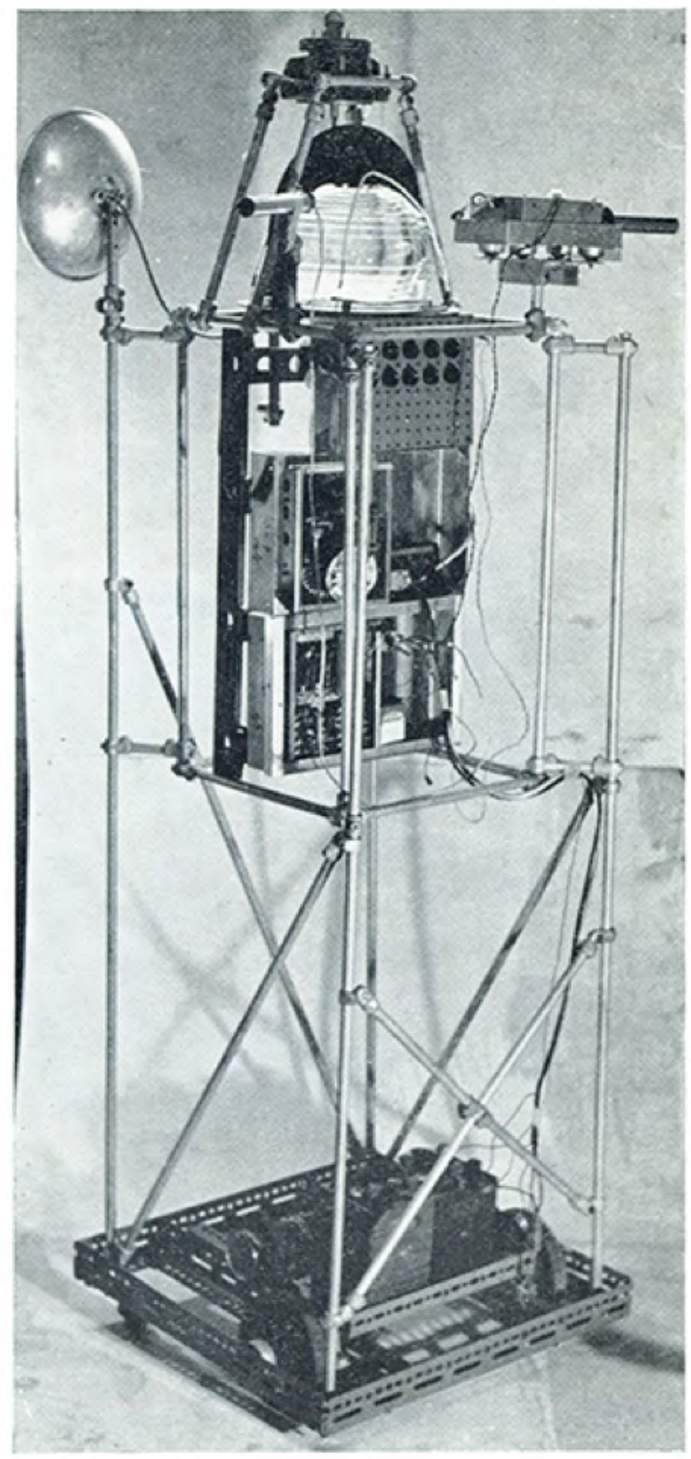
In my robots and humanoids I attempt to present this predicament. In my events I attempt to ask questions. And in my simulations and environments I attempt to point direction towards the answer.

In attempting to solve these problems I use all advances in technology, electronics, psychology, market research, medicine and mathematics at my disposal. Using, in fact, the very hardware that has brought about these problems in the first place.

Right, *Rosa Bosom (R.O.S.A.–Radio Operated Simulated Actress)*, 1965
Electronic parts, aluminium, batteries, motors, etc.
24 × 36 × 72 in.
Originally designed as an actress to integrate with live performers in production of *Three Musketeers*, at the Arts Theatre 1966, where it played the Queen of France.
Method of control: radio; programmed; environmental.

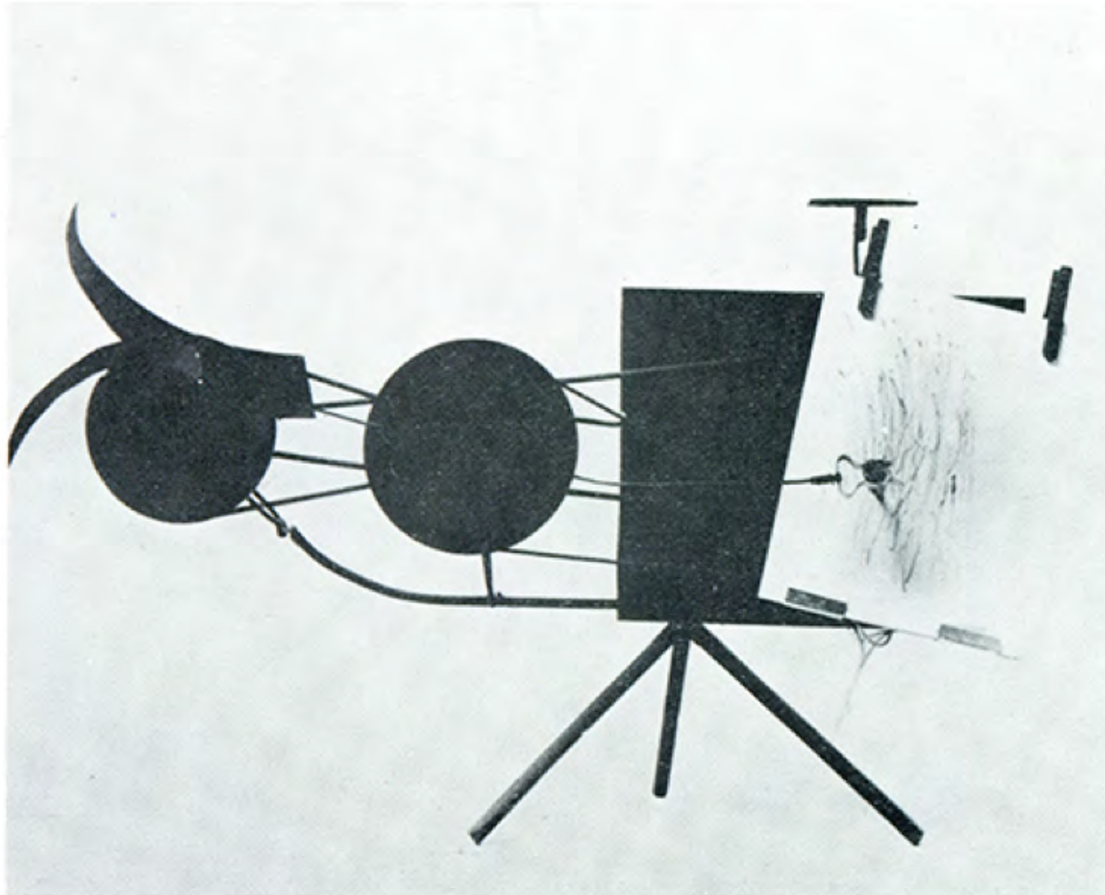
Far right, *Mate*, 1967
Electronic parts, aluminium, batteries, motors, etc.
24 × 24 × 72 in.
Built as companion to R.O.S.A., which it follows automatically and generally interacts with.
Using ultrasonics, infra-red and sonic signals.

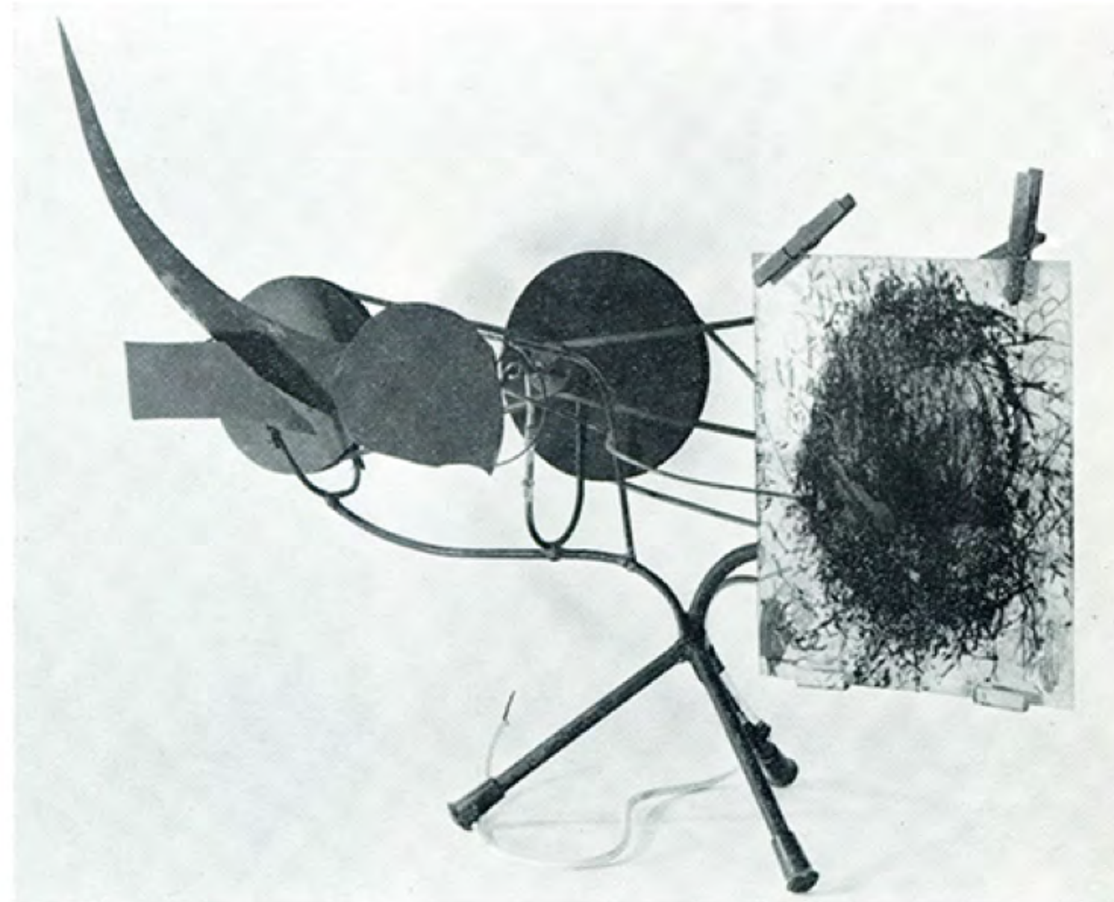




Machines by Jean Tinguely

Painting machine or *Metamatic* 1959, welded steel and rubber, painted black, 31½ × 19¾ × 17¾ in. collection: Pontus Hulten, Stockholm; *Painting machine*, or *Metamatic*, 1961, welded steel and rubber, 21¾ × 30 × 15 in. collection: Stedelijk Museum, Amsterdam





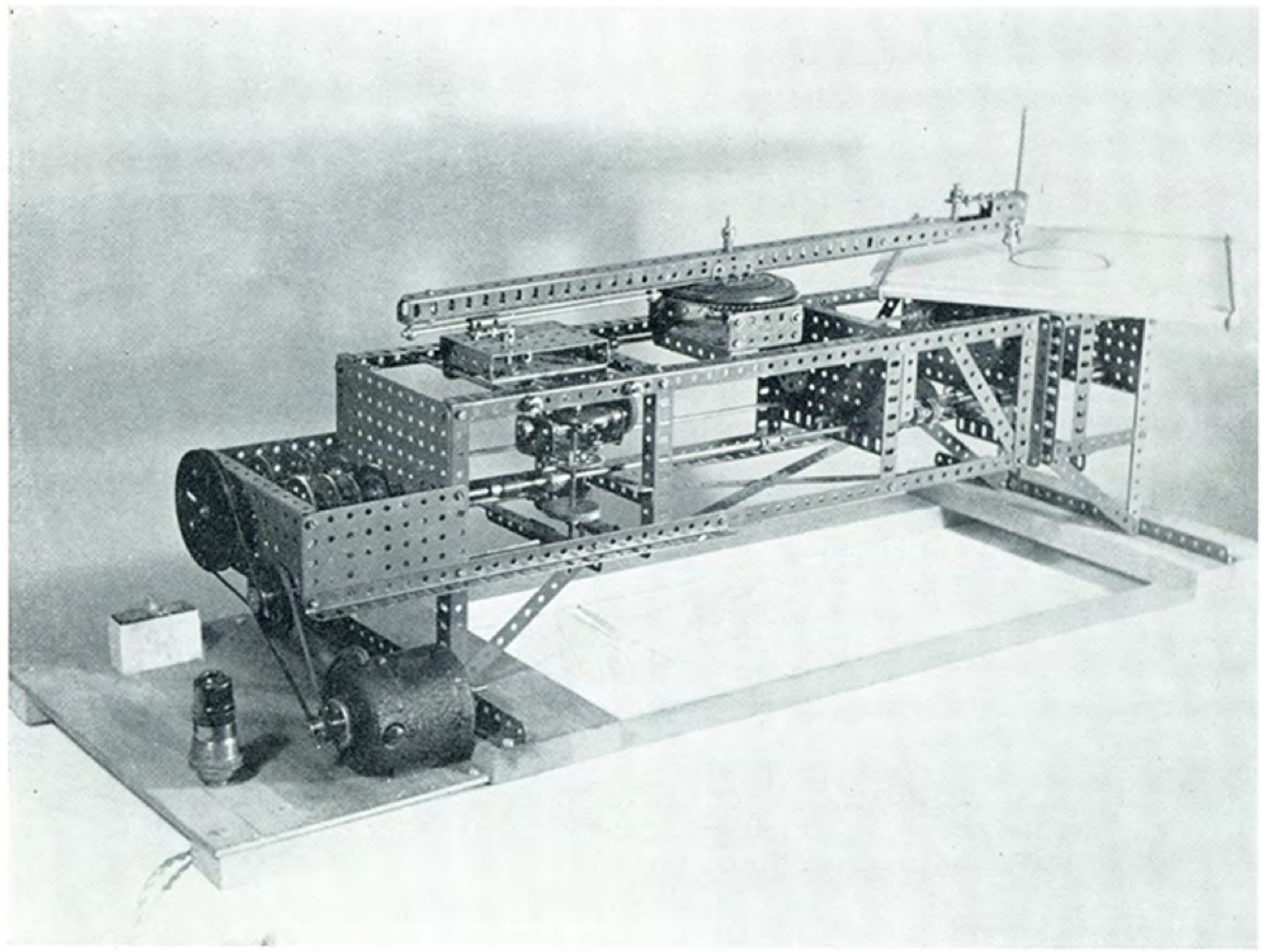
Mechanical patternmaker

Roy E. Allen

This machine controls the movements of a piece of paper, and a pen in contact with it. By varying the manner in which the pen and paper move, relative to one another, different patterns are produced. There are four independent motions incorporated in the machine, two concerned with the pen and two with the paper. The pen may be moved backwards and forwards and also from side to side.

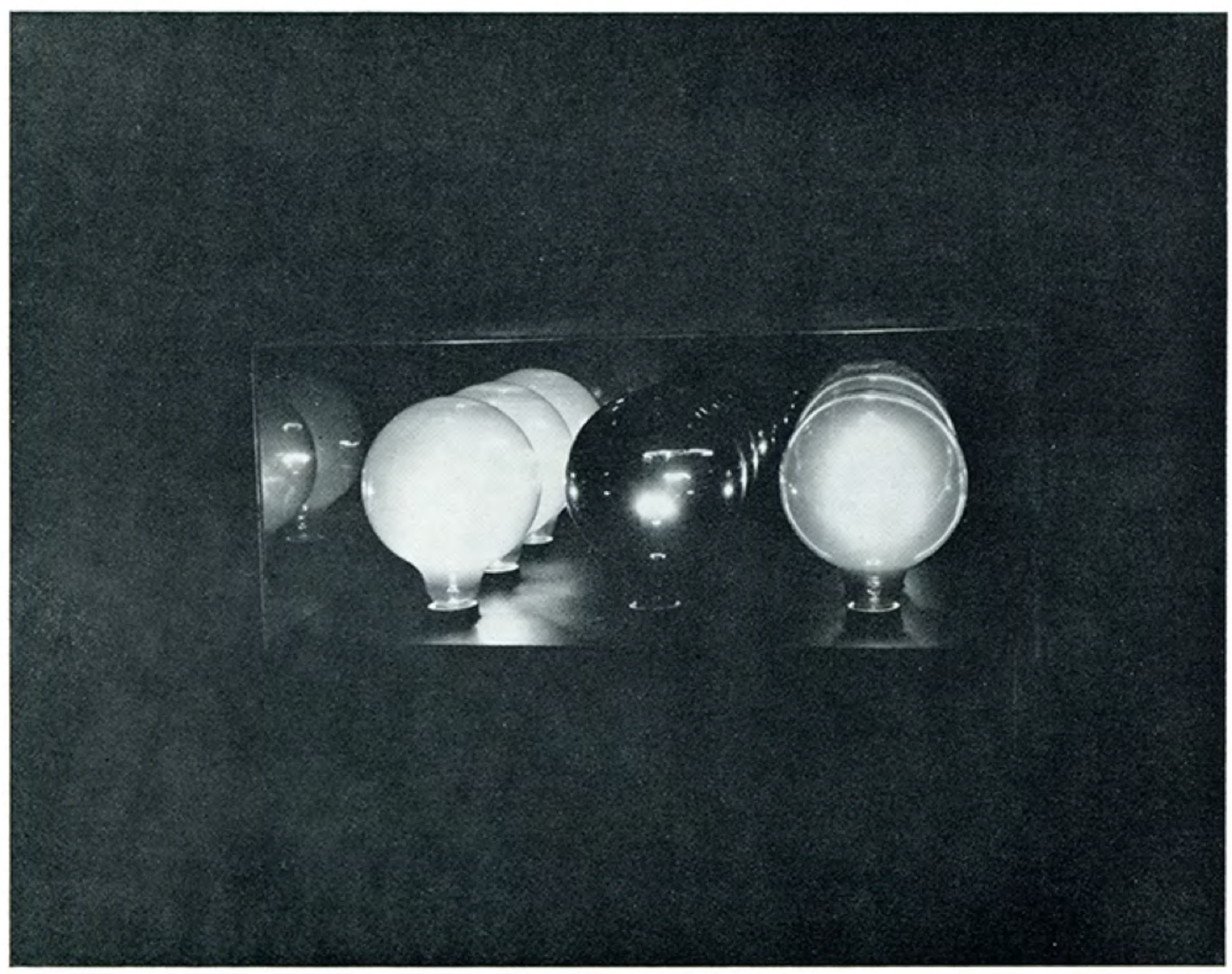
The paper (which is supported on a small wooden table) can be rotated about an axis which can also be rotated about a further axis. These four independent motions are driven by an electric motor via a series of gear chairs. By varying the gear ratios different patterns may be produced. In theory, all the patterns are regular and can be repeated. However, in practice, if all four motions are used at once for a pattern, it becomes so confused that the pattern appears to be random.

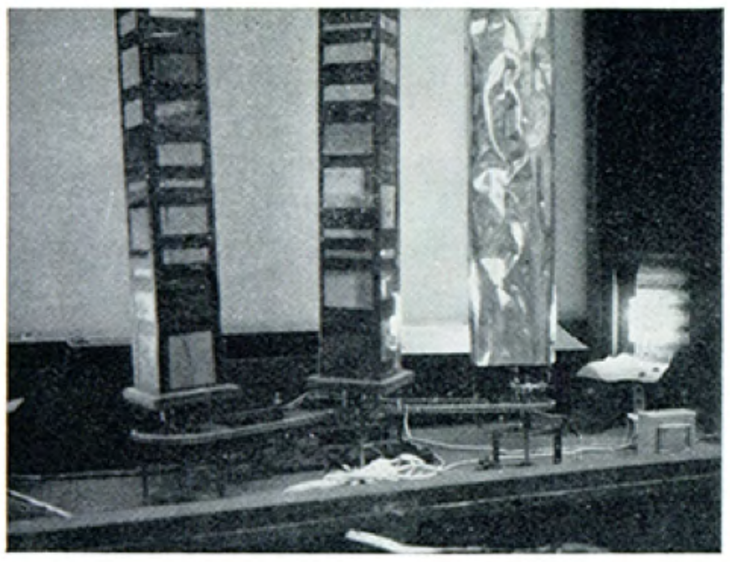
The machine is made from 'Meccano' and because of this, is not so precise as a properly engineered machine could be.

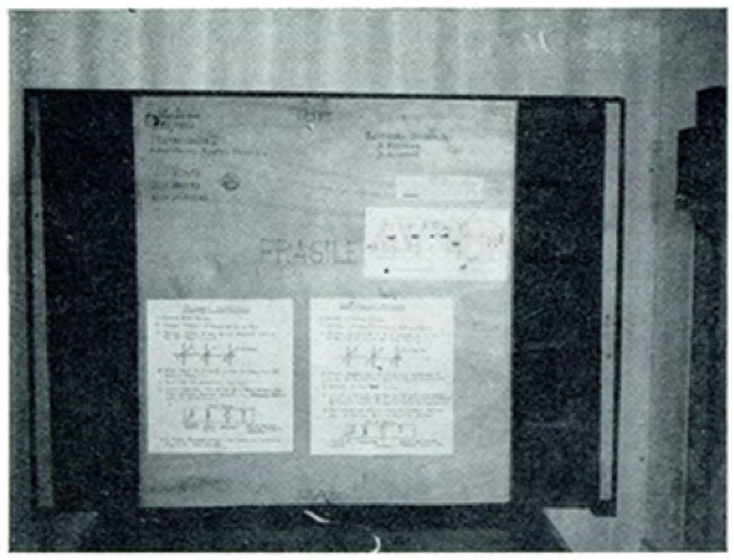


Hogle-Burdick organ

Richard Hogle's *Hogle-Burdick chromoluxite organ*, 1967, $16\frac{1}{4} \times 20 \times 14\frac{3}{4}$ in.
This work, which consists of three rows of bulbs, is sensitive to sound. The different bulbs respond to different pitches of the voice. Men have two rows of bulbs responding—women one.

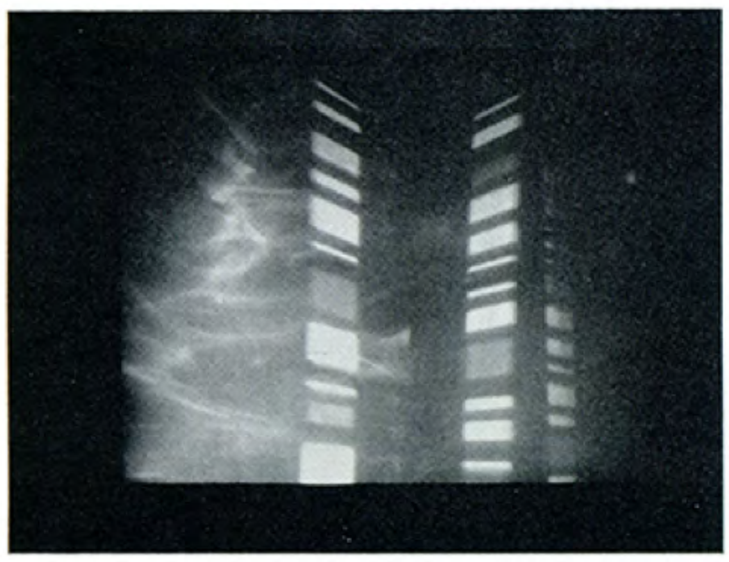


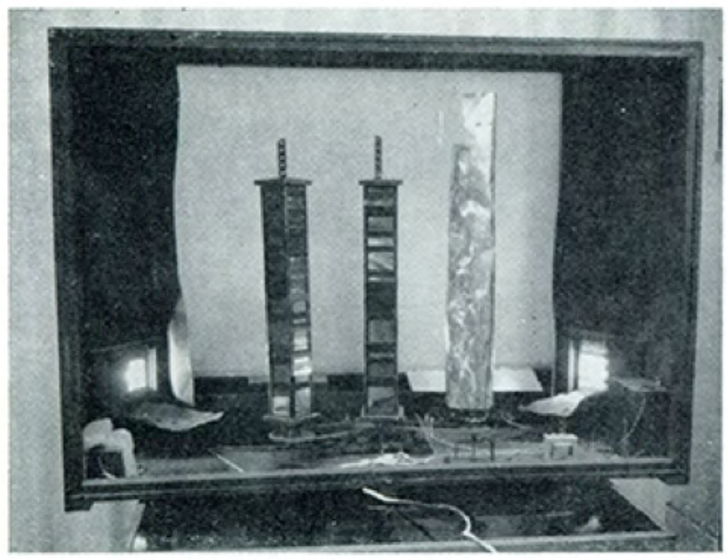


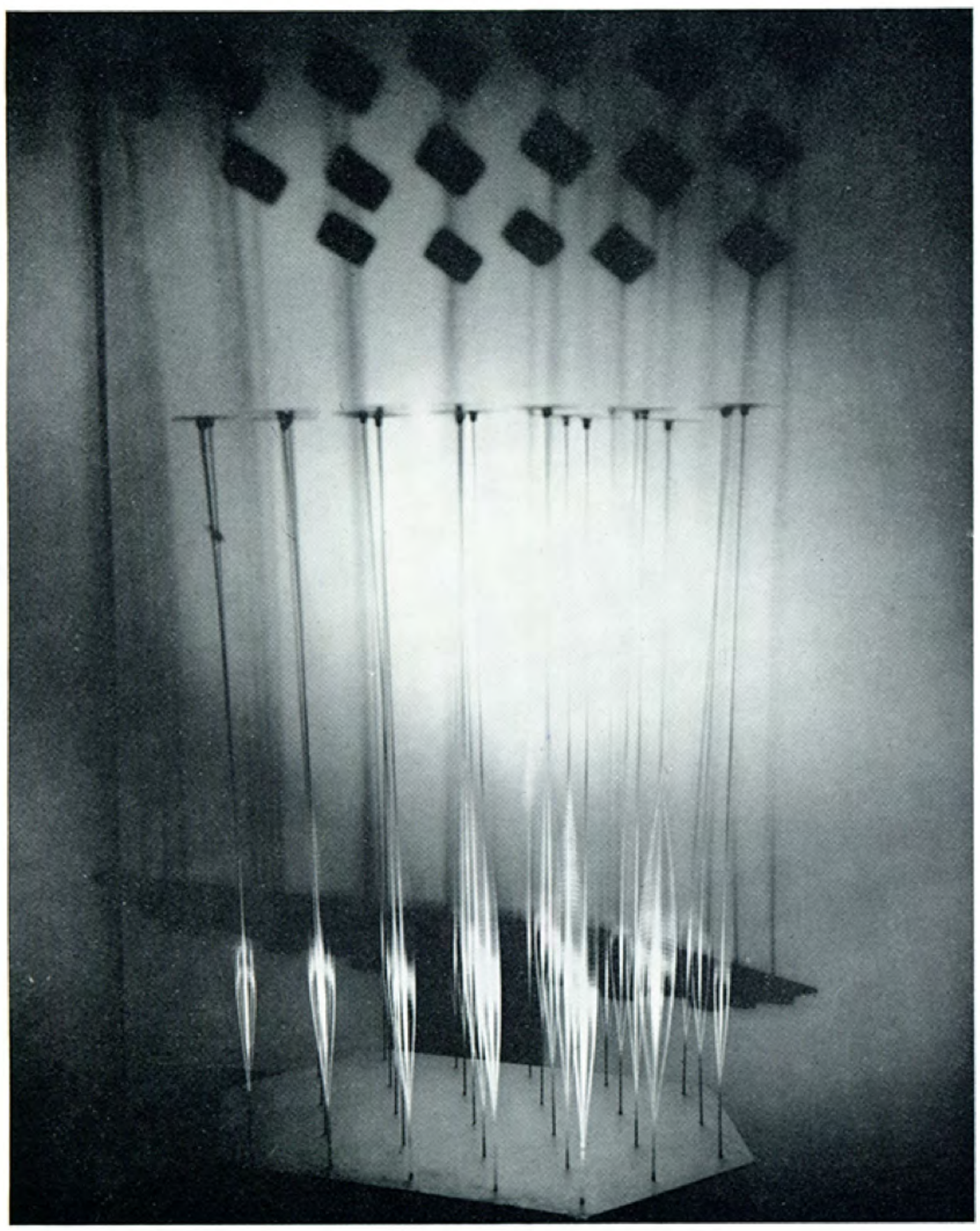


Entrechats II by Frank Malina

Entrechats II by Frank J. Malina was made at Boulogne sur Seine, France, in January 1966. It is Malina's 177th work since 1955 utilizing electric light either in static or kinetic form. It is the second work designed so that the motion of light forms on a translucent screen is determined by the variation of ambient sound intensity. The forms on the screen are produced by rotating light-reflecting surfaces. The electronic system, constructed by D. Bouffier and D. Bouchet, consists of a microphone, amplifier, two-way relay and a reversible electric motor.







Cybernetic sculpture by Wen Ying Tsai

Like many of Wen Ying Tsai's works, this sculpture consists of vibrating stainless steel rods surmounted by polished metal plates. It is in constant harmonic motion in an electronically-activated environment consisting of high frequency lighting. The frequency of the strobe flash, which is linked to an external stimulus such as the proximity of the viewer or ambient sound, appears to alter the motion of the rods ranging from gentle undulations to rapid vibrations.

Wen Ying Tsai studied both mechanical engineering and art, and has been making cybernetic sculptures in New York for the past four years.

Five-year guaranty

Norman Bauman

'What is this?' Bzzzz. 'Oh, isn't that marvellous!'
That was the universal reaction to a one-man show by artist and composer Nam June Paik, a student of John Cage and University Fellow, whose colour television sets were on display in the Humanities Art Gallery at Stony Brook University in March 1968.

A television set contains a cathode gun, which sprays the screen with electrons from the back, just like a gardener watering his lawn with a hose. When the electrons hit the screen, they excite the coating to glow. The television tube has little magnets which deflect the spray back and forth, until the screen is covered with about 250 lines. A signal controls the intensity of the glow, and that is how we get the picture.

Television sets today transmit pretty much a faithful reproduction of what is in front of the camera. There is no reason to be satisfied with this. Men should be able to control their environment, rather than be satisfied with making faithful reproductions of it. Mr. Paik has reworked the television sets to give the viewer a bit of control. He takes a large electromagnet and places it over the tube. He presses a switch. Bzzzzz! Yogi Bear gets squashed into a corner of the screen, his eye grotesquely enlarged. Mr. Paik releases him. Bzzzzz! Yogi Bear gets turned into an infinity sign.

Mr. Paik takes a huge horse-shoe magnet, straining under its weight. He places it on top of the television set. The original image is completely destroyed and turned into unique electronic shapes. He turns on an electromagnet. Bzzzzz! The shapes dance. Here and there a disembodied hand is visible, a vestige of the original programme.

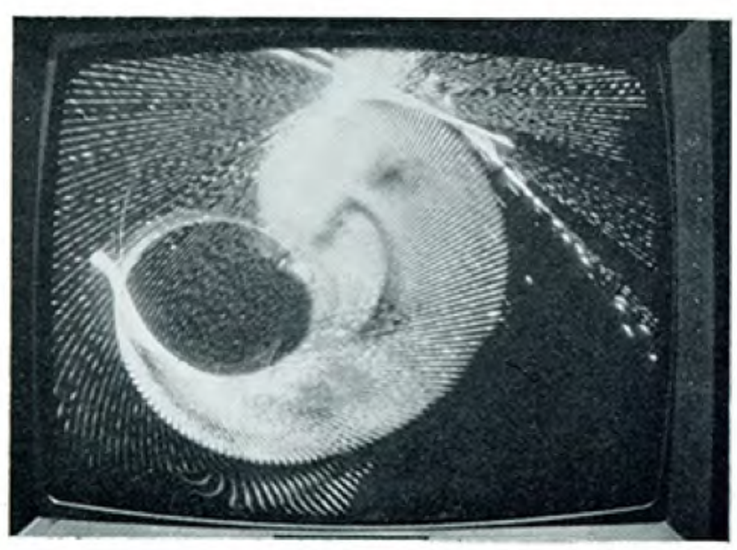
He gets stranger effects by re-wiring the sweep controls of the sets. One is rewired to give a symmetrical double image, like a reflection in a lake. In another, the image is completely obliterated; the screen shows only a collection of soft, round colours. Mr. Paik hands you a small magnet, which you move towards the screen. The screen bursts into brilliant colours. A third, called *Tango Electronique*, has shimmering coloured lines. You turn a knob, and the screen explodes into patterns. After a while, you get a feel for it, and are able to control the image.

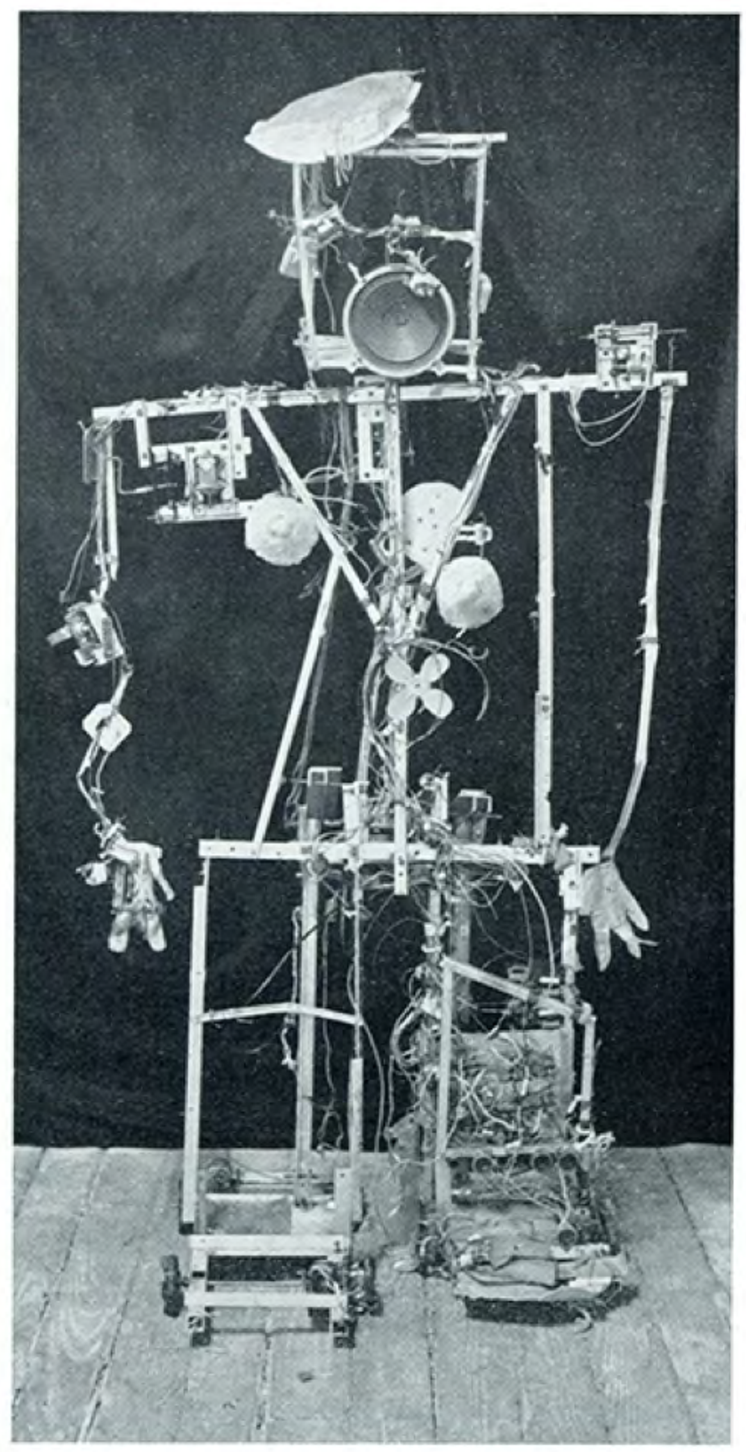
'Okay, what does it all mean?' This was the question that the more intellectualized types asked, those who weren't content to let the exhibit rest simply on its beauty. While there is no answer beginning with 'The meaning is . . . ', a few observations may make this kind of art more comprehensible.

In the first place, it is a responsive environment. Unlike ordinary art exhibits and ordinary television sets, here the observer can actually touch things and make it the way he likes it. Americans love to touch things, as museum curators and display designers know. At a Russian trade show I attended when I was in high school, the exasperated guards kept telling us, 'Why do you have to touch everything?' Presumably our more passive Russian counterparts would have stood back a respectful distance from the exposed computer and chemical glassware, but we turned switches and broke things. 'Let them play around,' said Mr. Paik. 'That's what it's there for. If something breaks, the Art Department will pay for it.'

Some of his more complicated machines, such as *Tango Electronique*, are more like musical instruments than art works. You don't watch it, you play it. The mass media is essentially passive. Watch a six year-old in front of a television set, or a 40 year-old baseball fan with a can of beer and a bag of potato chips. Passive art is a real threat to our culture. If the viewer does not enter into art, he cannot possibly hope to understand it. A major part of the thrill of Mr. Paik's exhibit is pushing the button yourself, and knowing that you made that little blip there.

Why television sets? 'Nobody else was doing it,' says Mr. Paik. And why not? If we paint with paint, and get one set of shapes, and paint with light, and get another set of shapes, and paint with sound, if the analogy





Above left, Nam June Paik

Above, *Robot K-456* by Nam June Paik (a female robot known for her disturbing and idiosyncratic behaviour)

Left, *McLuhan caged* by Nam June Paik, or, in other words, a transformed television image, which the artist has specialized in for some years.

may be extended, to get a different set of shapes, why not paint with magnetic fields, the working stuff of our technology, to get a completely new and completely different feel? The beautiful patterns of

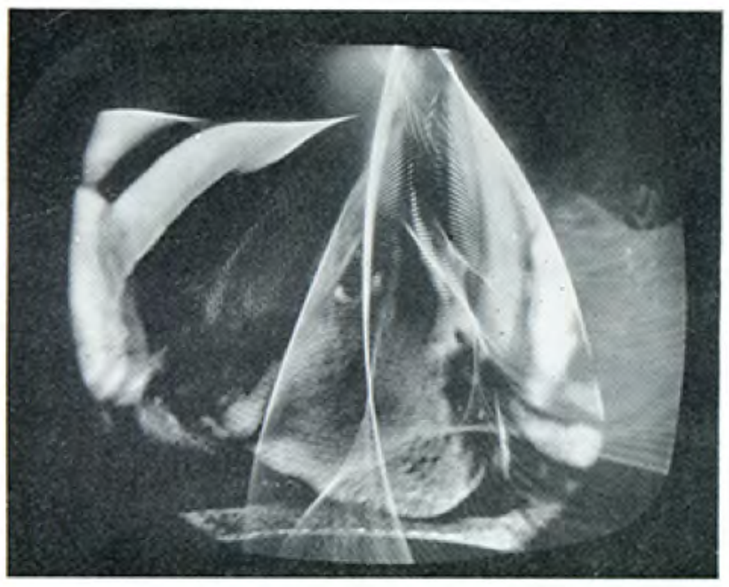
'loga Cage – 3.5$\sqrt{}$McLuhan = $\pm$ sorry'
Norbert Wiener

the black and white pattern which is generated from a single vertical white line, would be extremely complex for a graphic artist, but among the simplest of statements in Paik-television. Simple statements in this medium are quite penetrating.

Get the feel of magnetic fields! What are magnetic fields? Something that everybody knows about from textbooks, but that nobody has a feeling for. Before I used a Paik TV, I did not believe, despite all my physics, that magnetic fields really deflected electrons. A television set was one more black box: WARNING! Do not remove this cover! The feeling of holding a magnet in your hand, and seeing a visible, striking result, must be experienced to be appreciated. This is not chickenshit iron filings, but a real, living, breathing MAGNETIC FIELD, that you can really use to deflect real, live, glowing electrons.

It is fairly straightforward to analyze the images of an oscilloscope; a sine wave gives a certain pattern, a ratio of sines another. It is extremely difficult to apply the same analysis to these reworked television sets. While I played *Tango Electronique*, I noticed that one signal generator seemed to affect primarily one diagonal axis, and the other generator controlled the other axis, in a general way, but even when I disconnected both generators, the signal danced madly on the screen. It was affected by extraneous signals given out by its own control signals, the AC hum in the room, and the myriad signals of the other sets in the room. While it is possible to completely analyze these patterns in the traditional way, I would expect such effort to end in either frustration or in such complexity that it is impossible to observe any relation between the analysis and the feeling you get when you look at it. Nikolai Rashevski once described the inconvenience of describing an animal in cartesian equations. 'When the dog wags his tail; what happens to your equation?' When you learn to play a Paik TV, you are forced to see these patterns of technology in terms that are different from those you learned in physics. Your electronics will make it more enjoyable, but perhaps you will learn that you can't impose a traditional scientific order upon everything. In art as in the world.

Electronic TV images by Nam June Paik 1965



Simulated synasthesia

Roger Dainton

Colour and movement transposed from sound

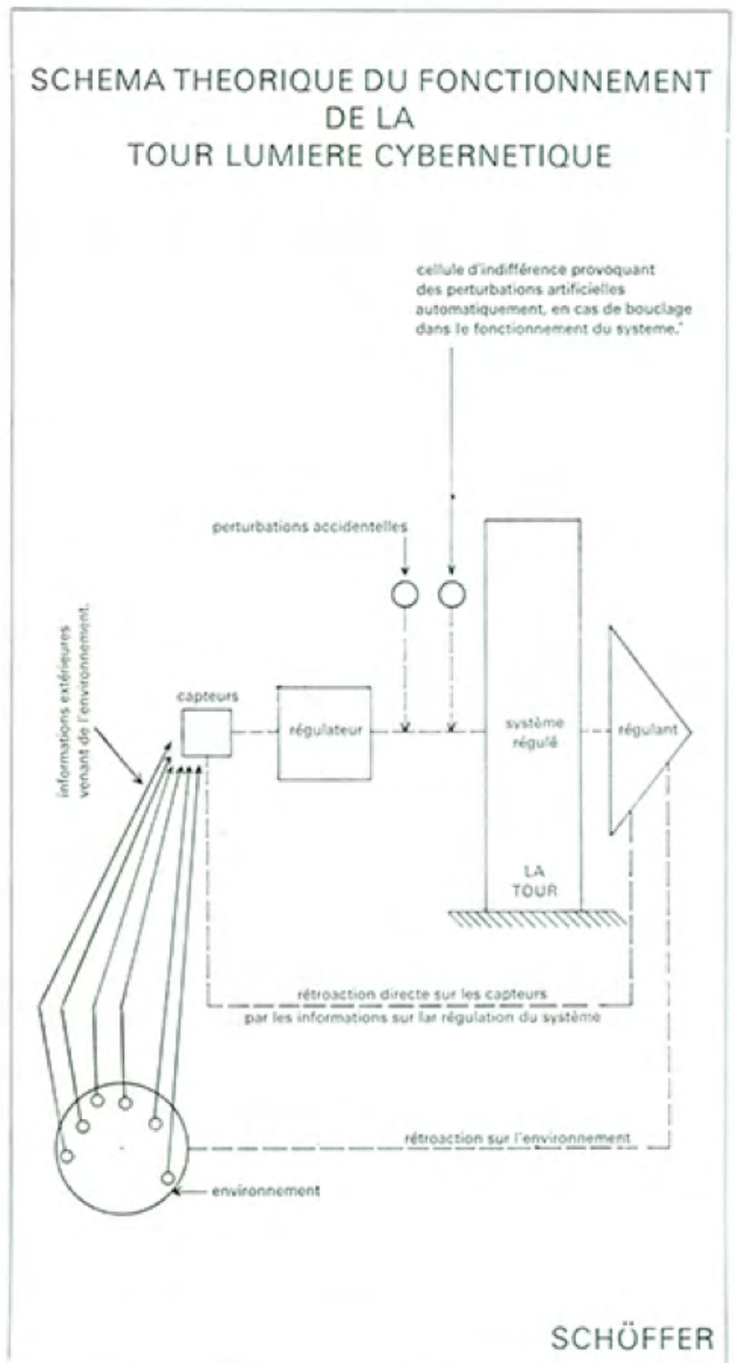
Most of my life I've been fascinated by machines; eventually I chose colour television machines because they had filled many of my waking hours in the past three years, but mostly because they represented for me one of the most subversive facets of technology—a means of creating a 'euphoria in unhappiness'. Essentially a means of conveying persuasive images to the viewer—other peoples' images, I wanted to explore effects as a means of trans*forming* from one medium to another, from sounds in time to light in space and time. I am beginning to see a new role for these machines—helping us to reveal ourselves to ourselves—not to impose ourselves on each other.

Visual patterns form and change as they do in sound. These patterns are not random, I have simply arranged them this way. The colours and the patterns could be very different.

From the frequencies of the music, all the colours of the spectrum are reproduced. Some patterns appear to be stationary, or float very slowly. This is because the music at this moment has a close relationship in frequency to the display, thus the structure and texture of the coloured patterns is formed. The sound is being transposed from one medium into another.

This system is still very much in its infancy, but with further development, and the use of computers, I hope to explore further the transposition of sound into colour and movement in space and time.

Cybernetic light tower



A project by Nicolas Schöffer, intended for the Rond-Point de la Defense in Paris

An open structure 307 metres tall, having an average span of 59 metres, is built of square steel tubes filled with reinforced concrete, based on the same techniques as a skyscraper frame. The structural elements of this skeleton will be covered either with polished stainless steel sheets, or with polished aluminium. Within this structure, 15 curved mirrors are placed at different heights between the 180 parallel arms protruding in four directions, 100 revolving axes are installed, on which 330 mirrors are fixed. The relationship between the curved mirrors and the revolving plane mirrors produce a great number of reflected and diffused rays around the sculpture.

Each of the 100 axes will be driven by electric motors at variable speeds. The combined controls for these motors are connected to a central computer.

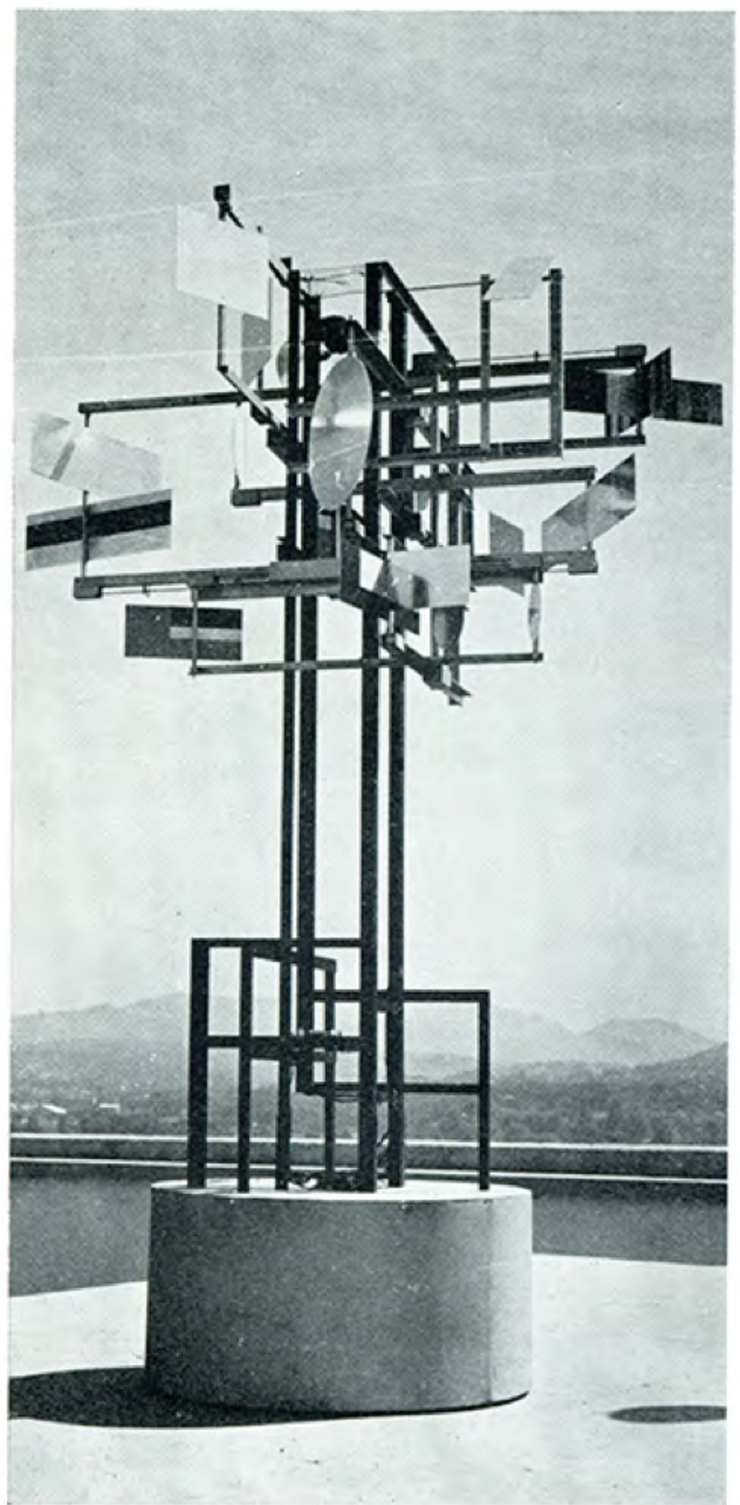
The sound, temperature, traffic flow, and humidity will affect the movement and luminosity of the tower.

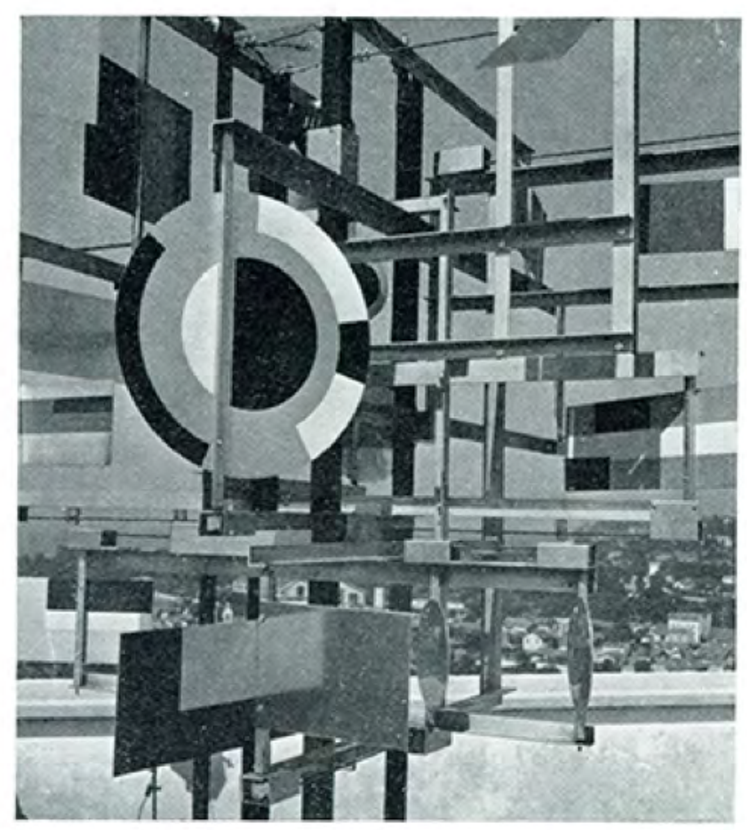
But on certain days and at certain hours, the tower can serve as a barometer, announcing bad weather, for example, through emission of red beams, and fine weather by the slowing up of its movements and the predominance of blue.

It will also be able, say at 1 p.m., to give the stockmarket trends: increasing brightness for a rising market, a more or less accentuated slowing-up for a falling market.

For road traffic, every evening from 5 to 8 p.m., it can be made to serve as the coordinator and broadcaster of information for car-drivers, communicating data by radio, and also by conventional visual signals, indicating the directions to take or to avoid.

In certain urgent cases, it will be able to broadcast warning sounds or orders.





CYSP 1

CYSP 1 (a name composed of the first letters of cybernetics and spatiodynamics) is the first 'spatiodynamic sculpture' having total autonomy of movement (travel in all directions at two speeds) as well as axial and eccentric rotation (setting in motion of its 16 pivoting polychromed plates).

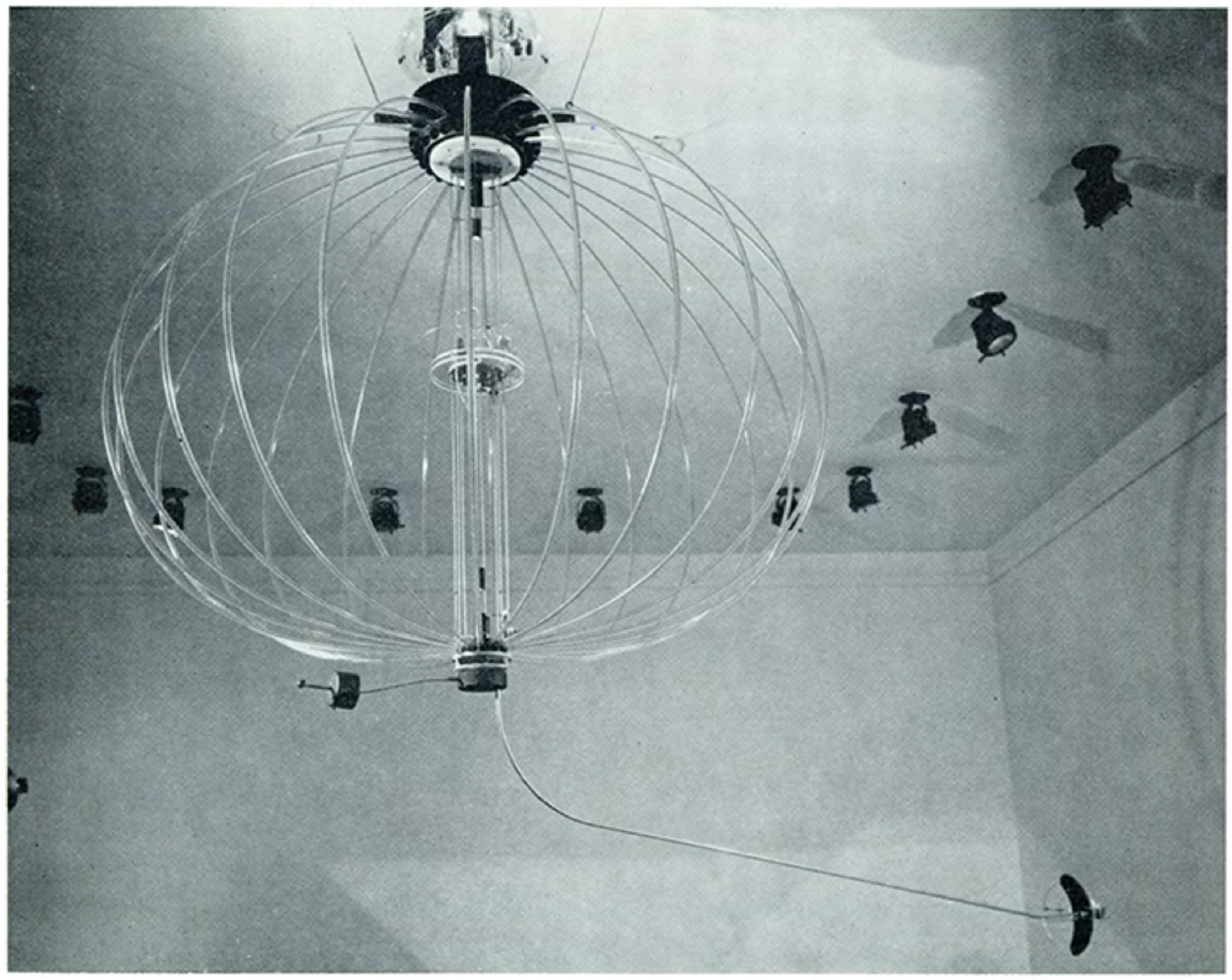
Nicolas Schöffer has executed this spatial composition in steel and duraluminium, into which an electronic brain, developed by the

Philips Company, has been incorporated.

The whole is set on a base mounted on four rollers, which contains the mechanism and the electronic brain. The plates are operated by small motors located under their axis. Photo-electric cells and a microphone built into the whole catch all the variations in the fields of colour, light intensity and sound intensity.

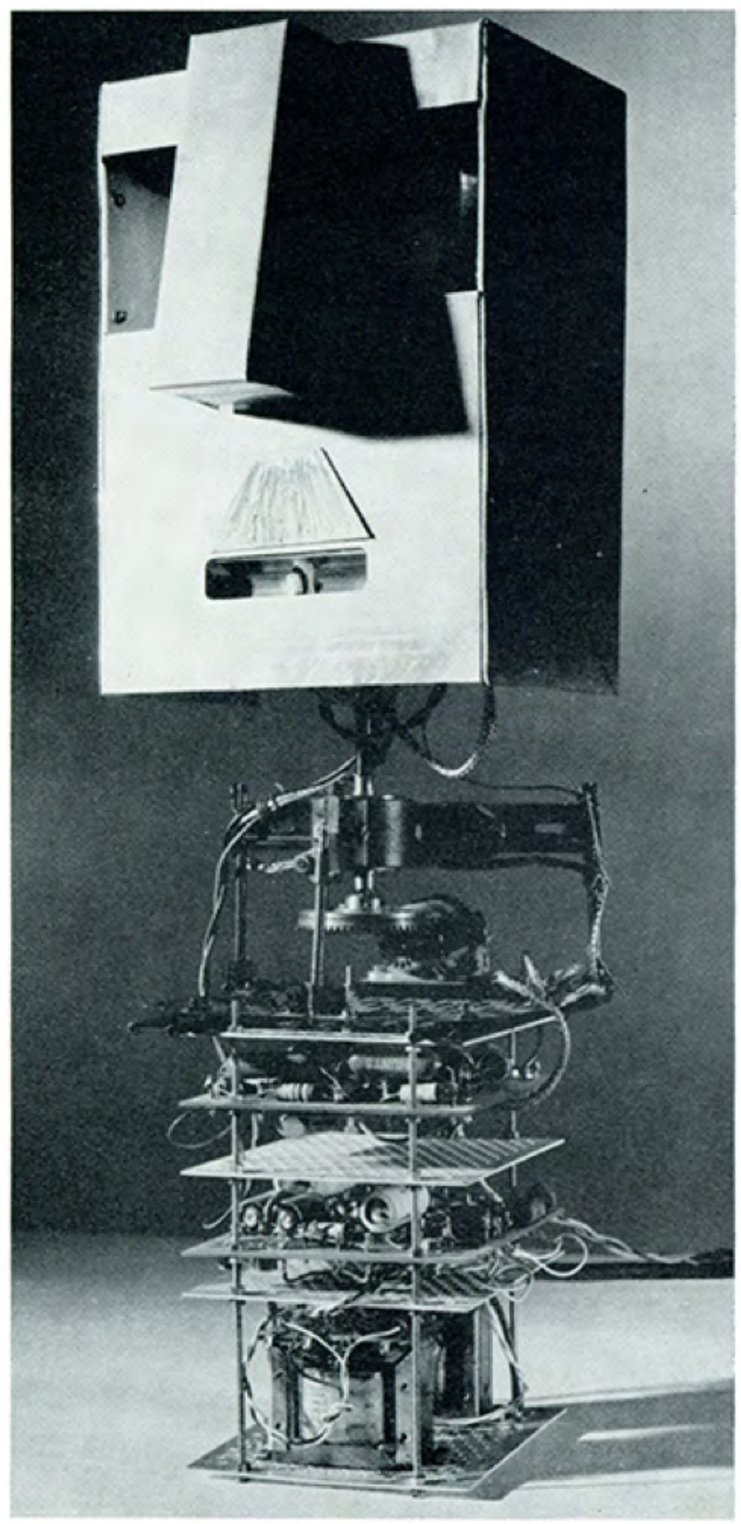
All these changes occasion reactions on the part of the sculpture consisting of combined travel and animation. For example: it is excited by the colour blue, which means that it moves forward, retreats or makes a quick turn, and makes its plates turn fast; it becomes calm with red, but at the same time it is excited by silence and calmed by noise. It is also excited in the dark and becomes calm in intense light.

Inasmuch as these phenomena are constantly variable, the reactions are likewise ever changing and unpredictable, which endows the mechanism with an almost organic life and sensitivity.



Scanner by James Seawright

A cybernetic sculpture, which Seawright made in New York in 1966. It is 70 inches high and 105 inches wide. It is constructed with metal, plastic and electronic parts.



Albert 1967 by John Billingsley

The sensing mechanism uses modulated light to obtain a 'turn left' or 'turn right' signal. The eyes are made to flicker in antiphase, and the reflected light is picked up by a photocell in the mouth. The signal is then amplified, filtered and demodulated, and used to drive the motor. If more 'left hand' light than 'right hand' light is seen by the photocell, the motor turns the head to the left.

The Honeywell-Emett 'Forget-me-not' (peripheral pachyderm computer)

The *Forget-me-not* computer, built in 1966 in accordance with Livingstone's Law (Memory *may* hold the door but elephants never forget) is of pleasing outward appearance, being delicately constructed of bamboo so that it may be placed in any executive suite without offence. Among its many worthwhile features are a mass-memory, where a number of miniature minds can think instantly in a clockwise direction (influenced by even tinier minds which only oscillate); a closed-circuit of activated Heavy Water boosts the Main Brain via fluid technology, while wrong numbers and unworthy thoughts are washed away into the Brain Drain. A single Billicycle (instead of a tiresome one billion cycles) ferries Messages from side to side.

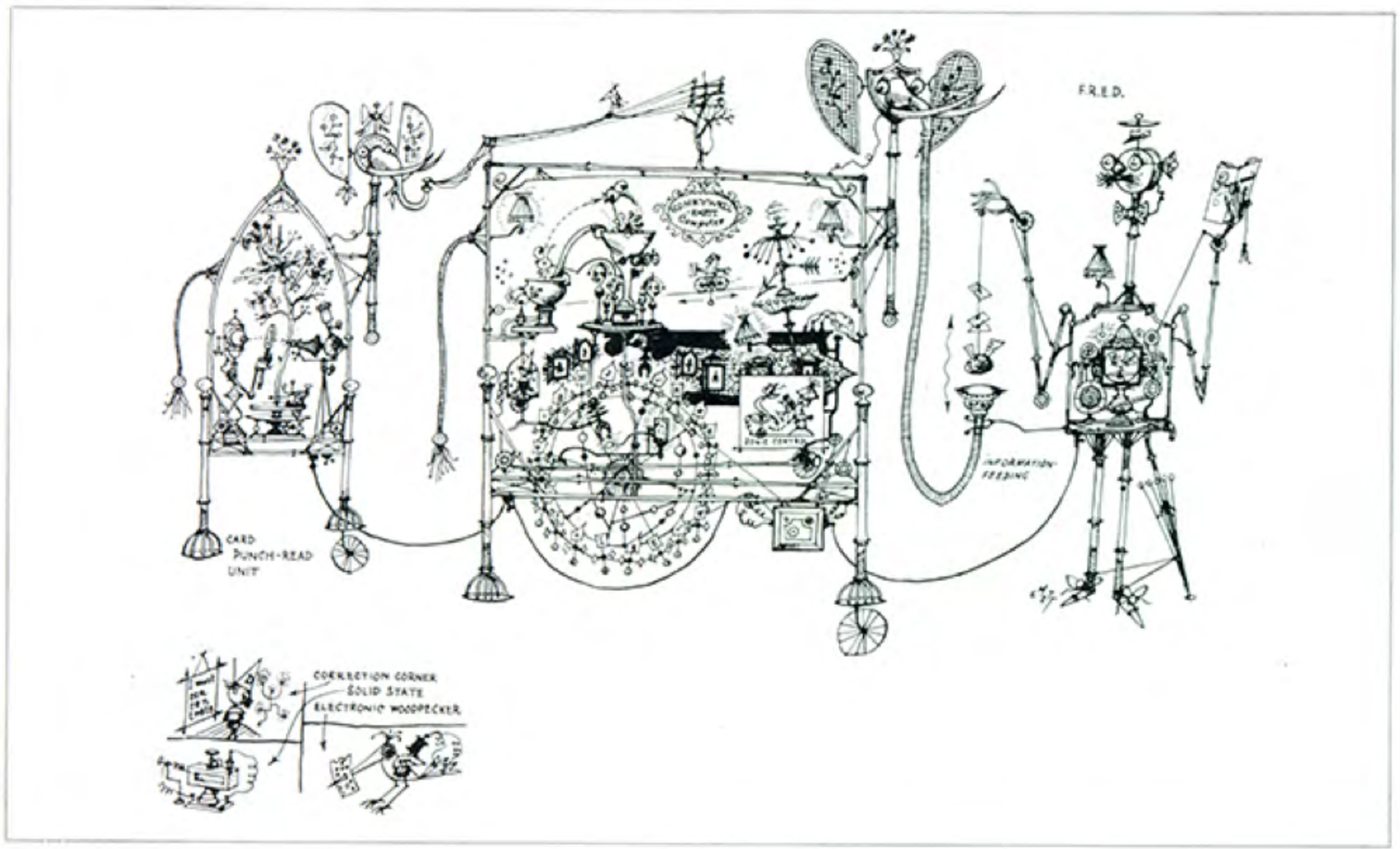
Two floating electro-magnets, weaving among a frenetic fluctuation (or controlled mish-mash) of BITS, effect floating point Arithmetic. The whole is assisted by a kind of inspired snake-charming in the form of especially silenced Sonic Control.

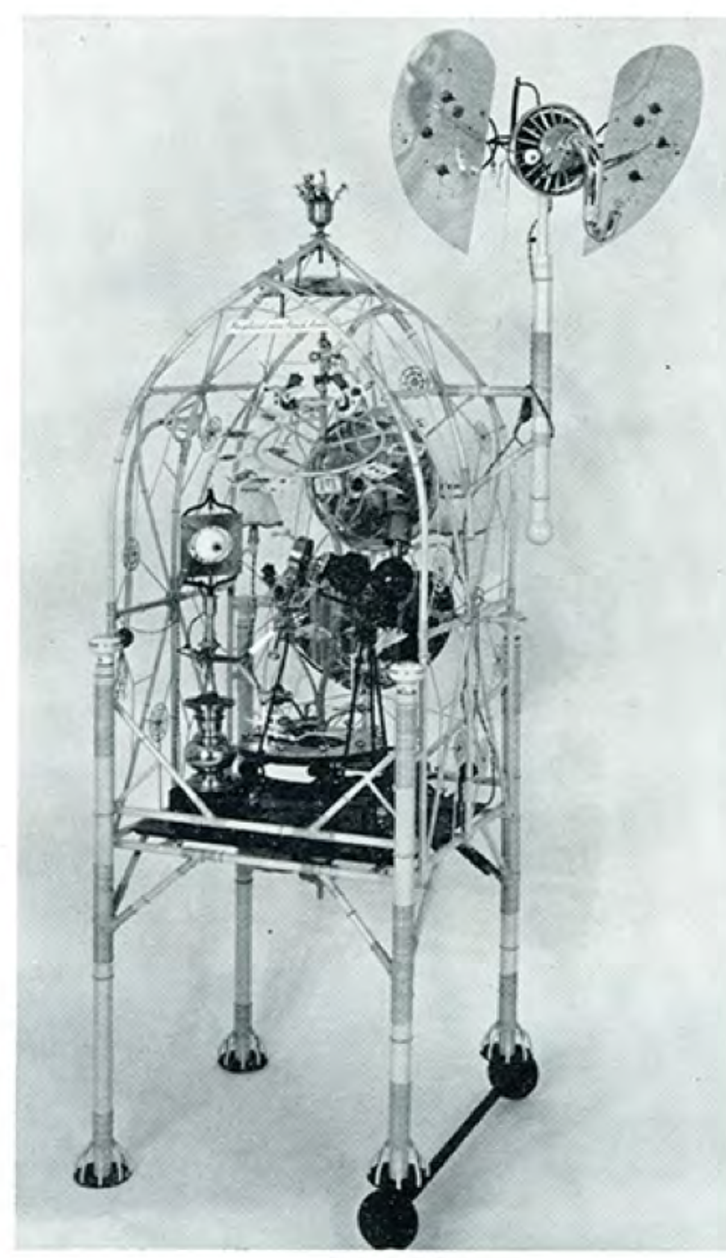
Weaving about at random is the Eenie-Meenie-Money-Mo unit, or Random Access Selector, upon which gambling is strictly prohibited. Two air-cooled circuits are mounted in the ears of the Control Head, which flap gracefully in unison with the waving of the multicore tail.

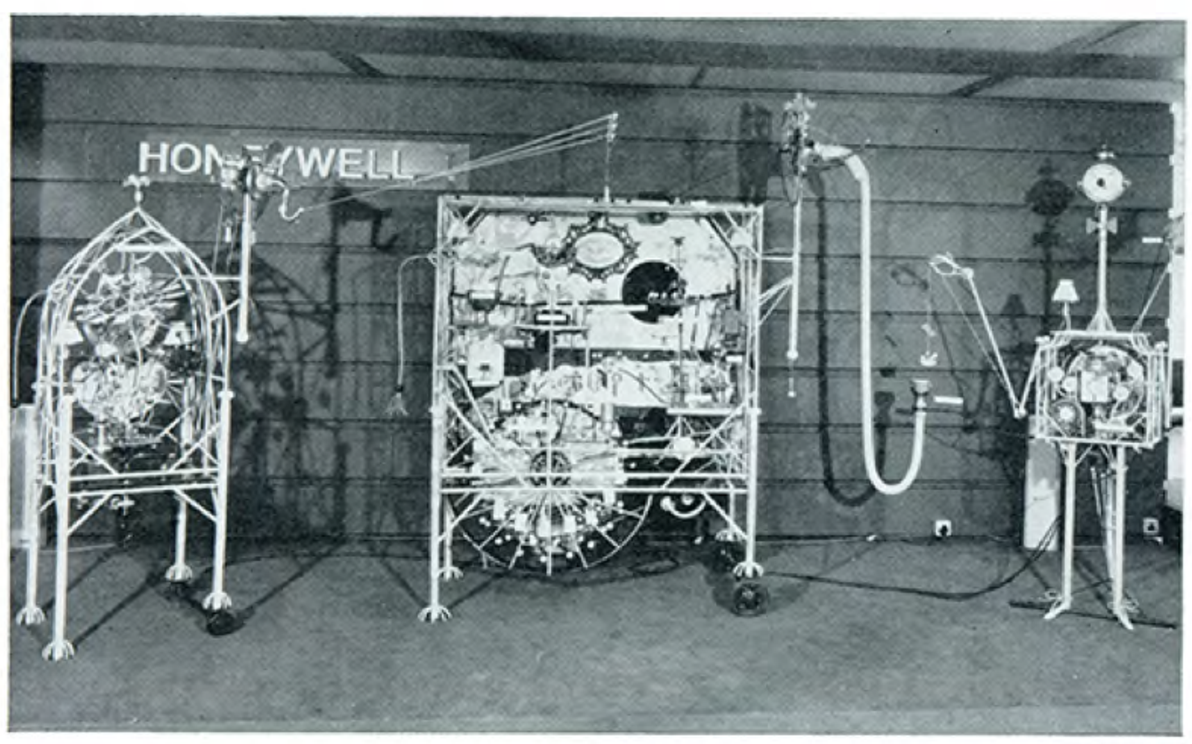
Perhaps the most moving fitment is Memory Lane, which offers eight especially treasured pieces of personal memorabilia, including the Ancestral Home where Honeywell started in 1885, Mother, a sweet old thermionic valve, First Love, where positive meets negative, etc. etc.

Memory here has great difficulty in Holding the Doors, which open and close discreetly to keep the memories green.

Flanking the main body of the machine are the peripheral units: on the right being F.R.E.D. (Fantastically Rapid Evaluator and Dispenser) who, wearing a tartan tie (Honeywell Computers are made in Scotland) and leaning nonchalantly upon his static-discharge umbrella, scans the Programme and teases the Forget-me-not with a pre-loaded Information Bun. His digestive system is capable of dealing with magnetic tape-measures, and it will be seen that there is a built-in set of butterflies to prove intense concentration and the fact that he is almost human.







The Tychotech

John Cohen

This apparatus is designed to measure an individual's preference for a particular combination of chance and skill on which to rely in order to win a prize. The device offers six different chance-skill combinations from which to choose.

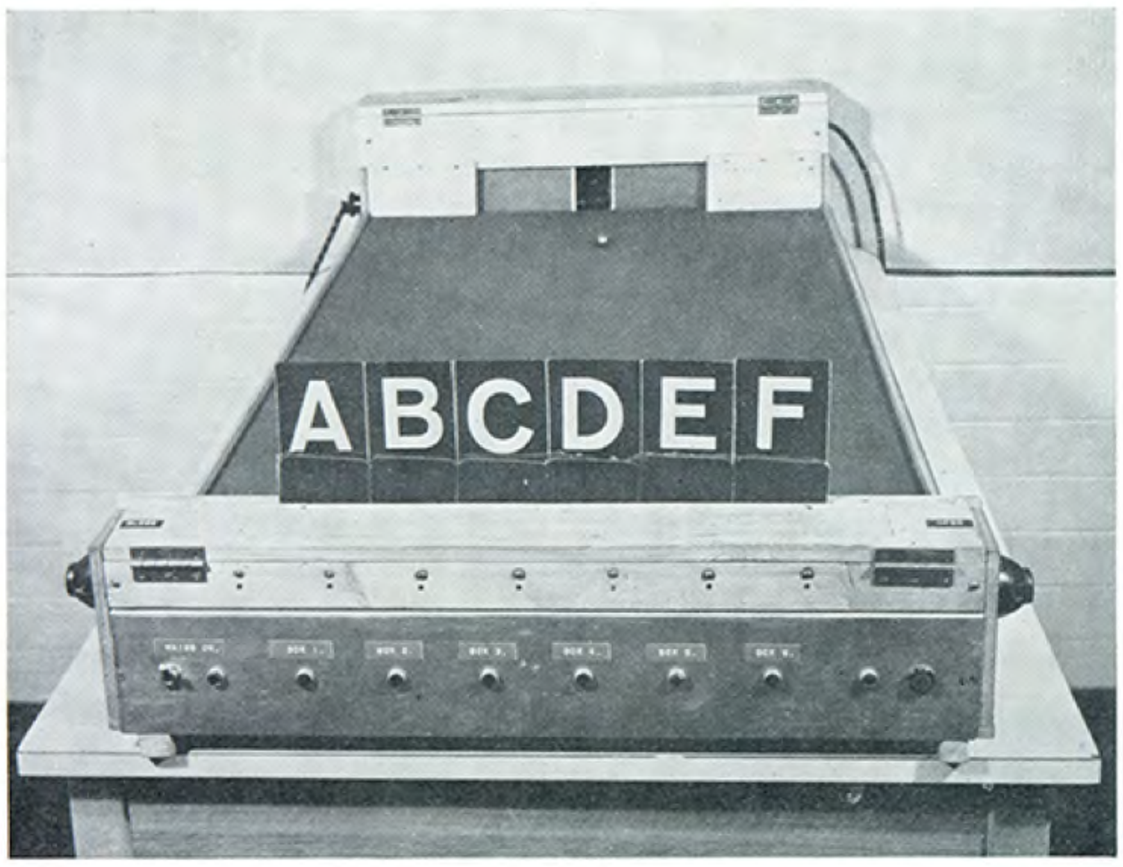
The object of the exercise is to propel a ball through an aperture without touching the sides. The player can select a relatively wide aperture in conjunction with a relatively small chance of securing a playing ball, or a relatively narrow aperture in combination with a larger chance of securing a playing ball. The width of the aperture is regulated by the player himself. He must determine a width such that, in twelve attempts at propelling a ball through it, he will succeed *no more* than:

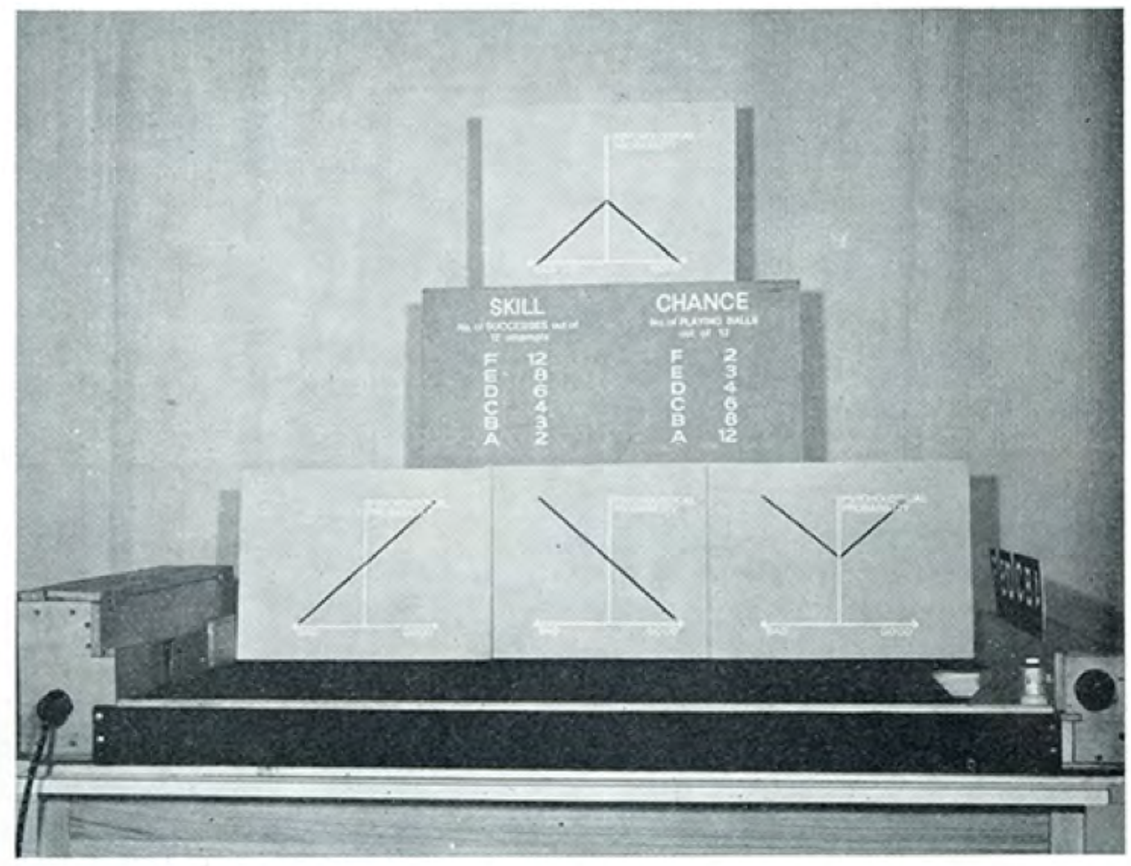
(A) twice
(B) three times
(C) four times
(D) six times
(E) eight times
(F) every time

Whichever particular aperture width, (A) to (F), he chooses, must be matched with a corresponding choice from six different sets of balls. Each set includes a different proportion of playing balls, from which he must choose one, without looking. In Set (A) all twelve balls are playing balls, so the player is certain of having a ball to propel. Set (B) contains 8 playing balls in 12; Set (C) contains 6 playing balls in 12, and so on.

The narrower the aperture the bigger correspondingly is the proportion of playing balls.

In experimental trials, prizes are given for success. The equipment has been devised to study the hypothesis that different people are attracted to gamble in situations which variously depend on a predominant element of chance (or luck) and a small element of skill or *vice versa*. Experiments suggest that the preferences expressed by subjects in playing on the Tychotech reveal their disposition to respond in a particular way in a variety of other situations in everyday life. It is thus of diagnostic significance.





Tychotech

–an experimental device for measuring preferences for different chance-skill combinations.

Operating instructions

You have to try and propel a ball through a gap. You yourself can decide how wide the gap should be. But the *wider* the gap you choose, the smaller your chance of having a ball to propel, because there are two kinds of ball: playing balls and non-playing balls. And you will have only one opportunity of rolling the ball, if you pick a playing ball. The playing balls are blue, the non-playing balls are bright steel.

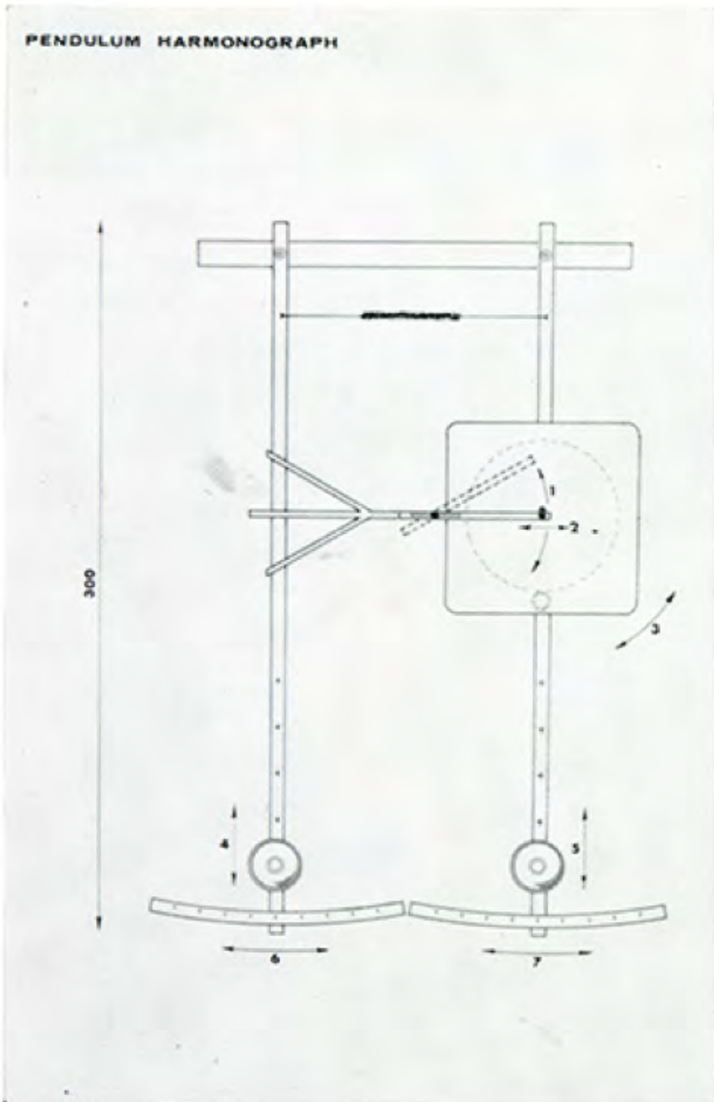
Here are six compartments from which to select a ball: A, B, C, D, E and F. If you choose compartment A, you must make the gap such that in 12 attempts you think you will succeed twice, but *not more than twice*. You can combine a gap of this width with the certainty of having a playing ball, because all 12 balls in compartment A are playing balls.

In B, 8 out of the 12 balls are playing balls, and you must fix the gap such that you think you will succeed not more than 3 times in 12 attempts. If you prefer B, choose a ball from compartment B without looking.

In C, 6 out of the 12 balls are playing balls, and the gap must be such that you think you will succeed not more than 4 times in 12 attempts. If you prefer C, choose a ball from compartment C without looking. And so on.

In fact all six choices have the same 'probability' of success. The point of the experiment is to probe your choice of means for arriving at the same end. Do you prefer rewards to come as a result only, or largely, of the skill you exercise, which is within your own control, or do you prefer to rely mostly on chance, which is outside your control? Would you prefer to hazard your life or future on a situation which calls for little skill on your part and in which chance is decisive or, instead, would you rather rely on your skill and depend as little as possible on your own chance?

The situation in front of you is one in which the two elements, skill and chance, can be nicely adjusted, so that it is possible to weigh one skill-chance combination against another.



Twin pendulum harmonograph constructed by I. Moscovich, Director of the Museum of Science and Technology in Tel-Aviv.
Features:
1. Angle of arm carrying the pencil
2. Extension of arm carrying the pencil
3. Revolving board holding the paper
4.
5. } Changeable lengths of pendulums
6.
7. } Variable amplitudes

The machine is simple in construction and easily controlled so that a skilled operator can make compositions as big as 30 × 30 inches.

The pendulum-harmonograph: a drawing machine

Ivan Moscovich

In 1951 I began experimenting with different mechanisms for drawing mathematical curves, with the objective of creating abstract designs of a more advanced or complex degree than those already existing. These experiments were part of a wider investigation into designs and patterns based on natural forms, curves created by physical forces, lines expressing mathematical functions, etc. As a result of testing different types of instruments and machines used for recording and drawing, I developed and constructed an advanced version of a twin-pendulum harmonograph. This is now displayed at the Museum of Science and Technology in Tel-Aviv.

The curves drawn by the machine are known as Lissajous' figures and their modifications. They are named after the French physicist who, about a century ago, first demonstrated a mechanical device describing these lines, which are graphic records of periodic oscillations. The demonstrations of Lissajous and his successors fascinated audiences in the drawing rooms at the time and there exist many versions of machines recording Lissajous figures. The instrument developed by me differs from these mainly through its simple construction and ease of control.

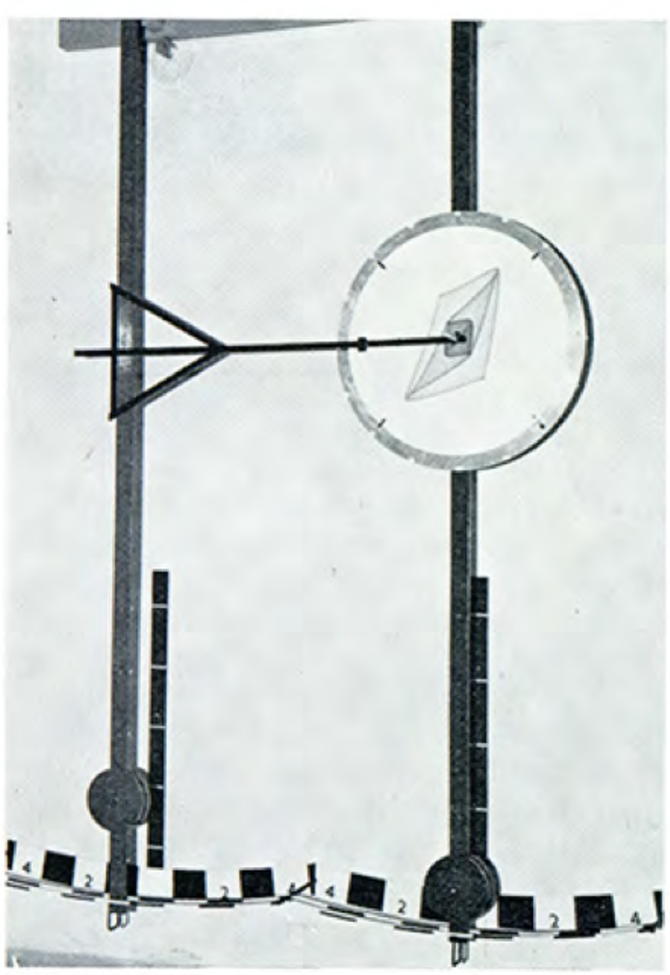
The harmonograph itself consists of two pendulums about three metres long, free to oscillate on ball bearings, each with a heavy weight which may be shifted to different positions along the shafts, thus altering the centre of gravity and with it the effective length of the pendulums. A board holding paper is affixed to one of the pendulums. This can be made to revolve in both directions while the machine is in action, its speed being controlled by a rheostat. The other pendulum carries a lever with a pen holder with the pen exerting constant pressure towards the drawing board. The length of the penholder, its angle as well as its position on the shaft of the pendulum, are all adjustable. Thus one is free to choose the starting point of the drawing anywhere on the board.

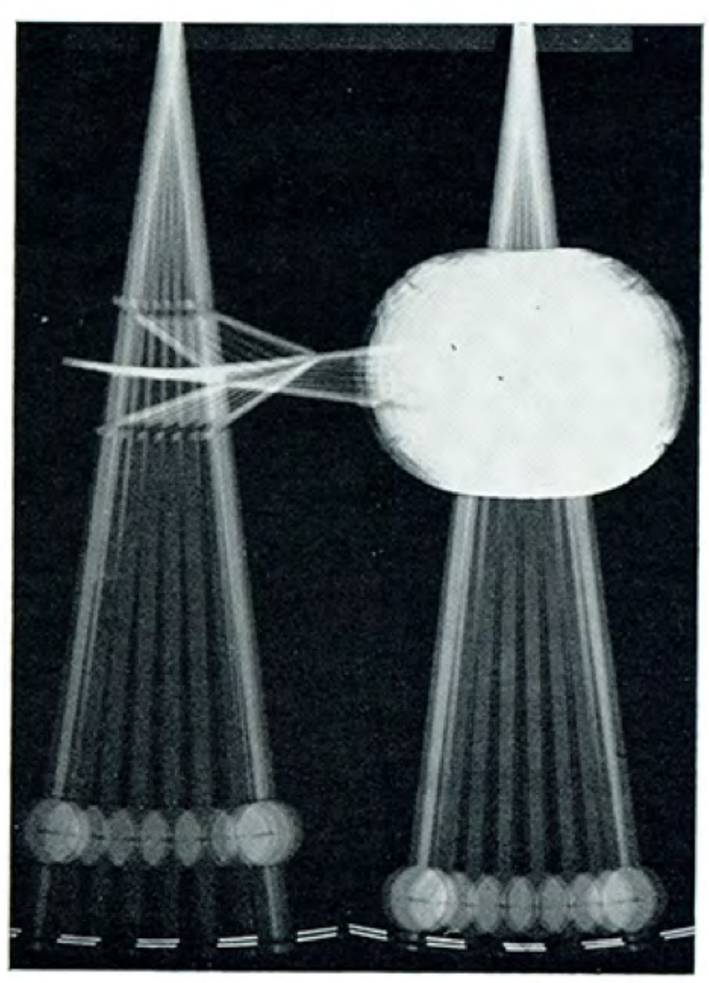
The forms of the recorded curves depend on different factors:

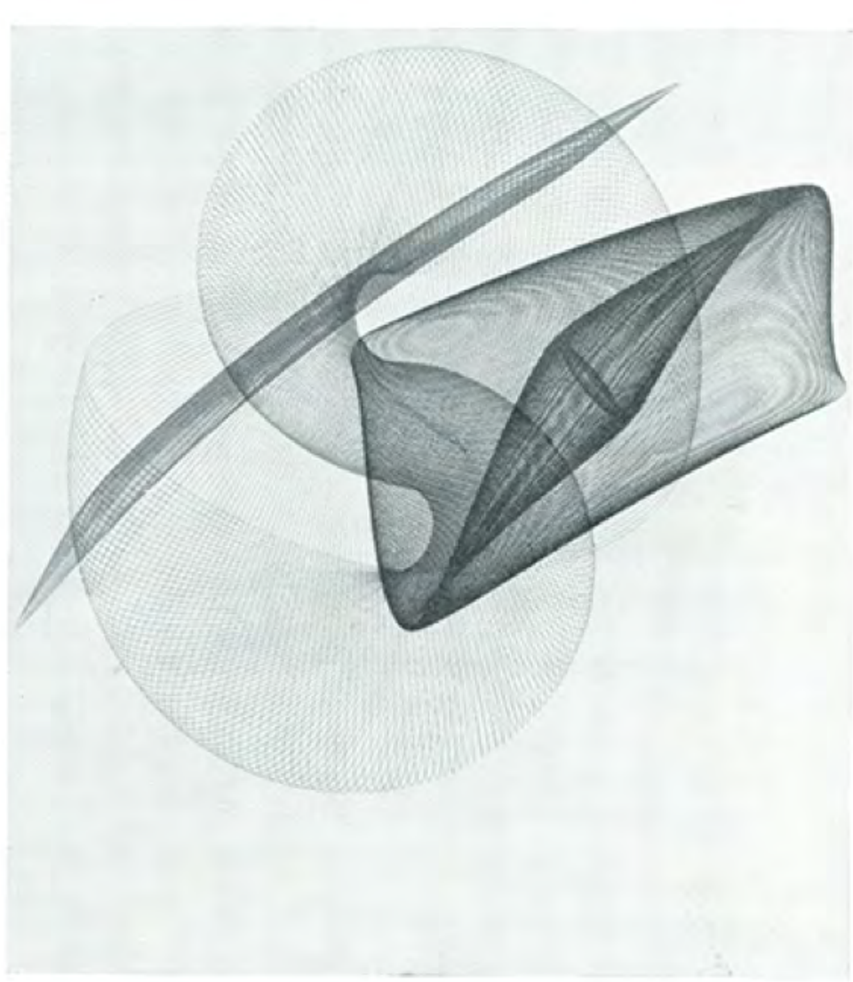
a) the length of the pendulums
b) their positions relative to each other
c) the amplitude of the oscillations and
d) their periods

All these are freely determined, thus making possible an infinite number of compositions, each of them producing different patterns. Silky moiré effects, unobtainable by other methods, are achieved by repeated overlapping of the lines.

After affixing the paper, the pendulums are set in one of the infinite number of possible combinations of all variable features and released to oscillate in relation to each other. The longer the periods of oscillation, the closer together are the lines; the bigger the amplitude, the larger the dimensions of the figures. They diminish in size as the amplitude of the swing dies away.

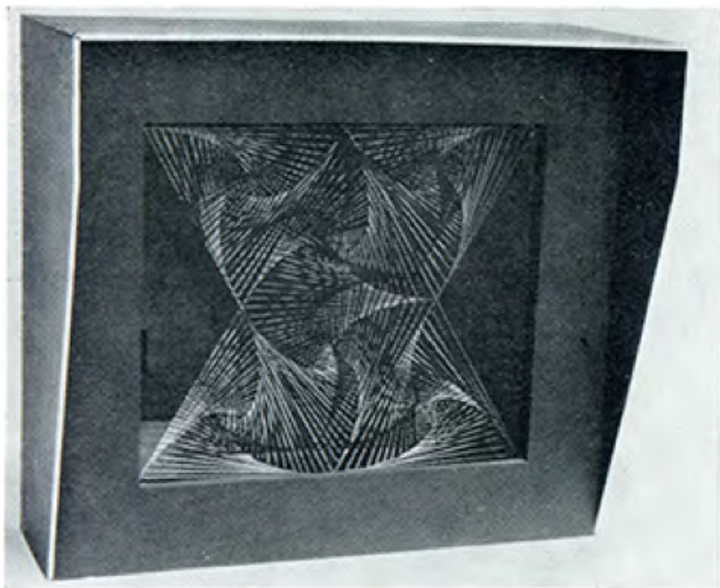


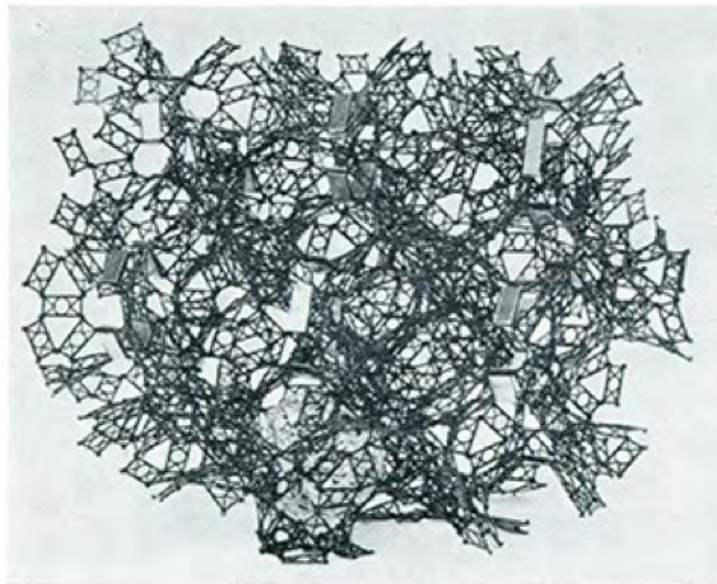




Dioximoirékinésis
by Irving John Good and Martine Vite

This model brings together several separate ideas: the random combination of pursuit triangles (*Mathematical Gazette*, 1959), moiré effects, and kinetic art. The result is a pulsating organism in a black box. The prefix 'Dioxi-' is Greek for 'pursuit'.





Good's Dream Figure by Irving John Good

This space-filling structure occurred in a vivid dream in 1957. The construction consists entirely of alternation of triangles and octagons, and leads to an infinite set of spheres with three mutually perpendicular tunnels running through each of them. Kittens like to crawl from one sphere to another.

The structure turned out to have crystallographic interest and is mentioned by the chemist A. F. Wells in *Acta Crystallographica* (1963).

Later additions were the dog collars and the captured icosahedron. The latter will be seen by chemists to correspond to a clathrate combination, physical capture without chemical bond.

Limitations and general design features of a pendulum drawing machine

John Ravilious

The machine was originally designed with the idea of producing all-over repeat wallpaper patterns, but the prototype showed that this would be impracticable. Such a machine would work, but it would only be capable of producing one standard pattern.

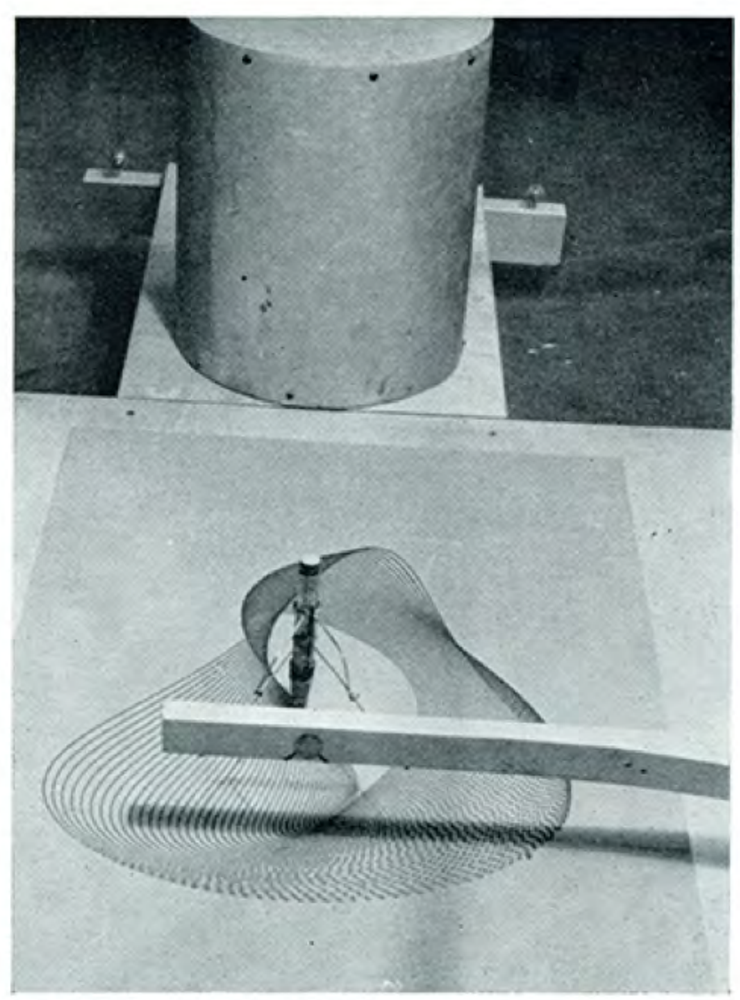
It was then decided to build a simple single-pattern machine to see how this would operate. This machine consisted of a swinging board on which the paper is placed and a separate swing bar with the pencil. The board swings with two motions: 1. a basic circular motion and 2. another rotary swing at double the frequency. The pen swings over a small distance at four times this frequency.

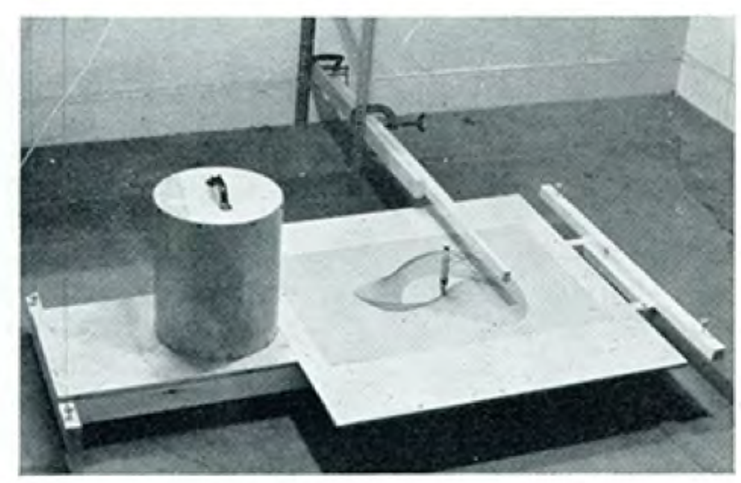
The board is driven by the free swing of a heavy weight and the pencil arm by a solenoid. (This is necessary because such high oscillatory speeds slow down at a higher rate when ideally all motions should cease at the same time). This machine works very well and large drawings are easily produced, although the slight movement of the pen makes starting and stopping difficult.

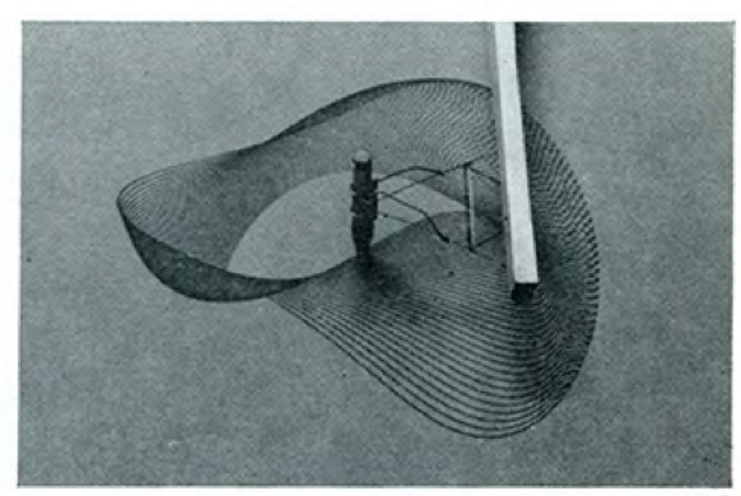
There are various patterns which can be produced depending on the phasing of the various motions at the starting point, and differences occur if the two second harmonic motions both lead, or lead and lag, the primary motions. Most of these factors are controllable so that a good pattern may be repeated approximately. The rate of lead and lag is important and this can be adjusted in the one case by moving an adjuster weight and in the other by altering the pendulum arm length. (These adjustments are made before the drawing is started).

Unfortunately the number of radically different patterns is limited by the number of significant phase shift settings that are possible between the three movements. The actual number of totally different drawings possible is roughly fifteen, and this is not a very large number, but by superimposing to produce greater complex interference effects this number increases two hundred or more.

To sum up, this machine is easy and simple to use and can produce a reasonable range of patterns which can be repeated. It can also do large designs of variable complexity which might be suitable for framing as decorative works of art.







The Henry drawing computer

D. P. Henry

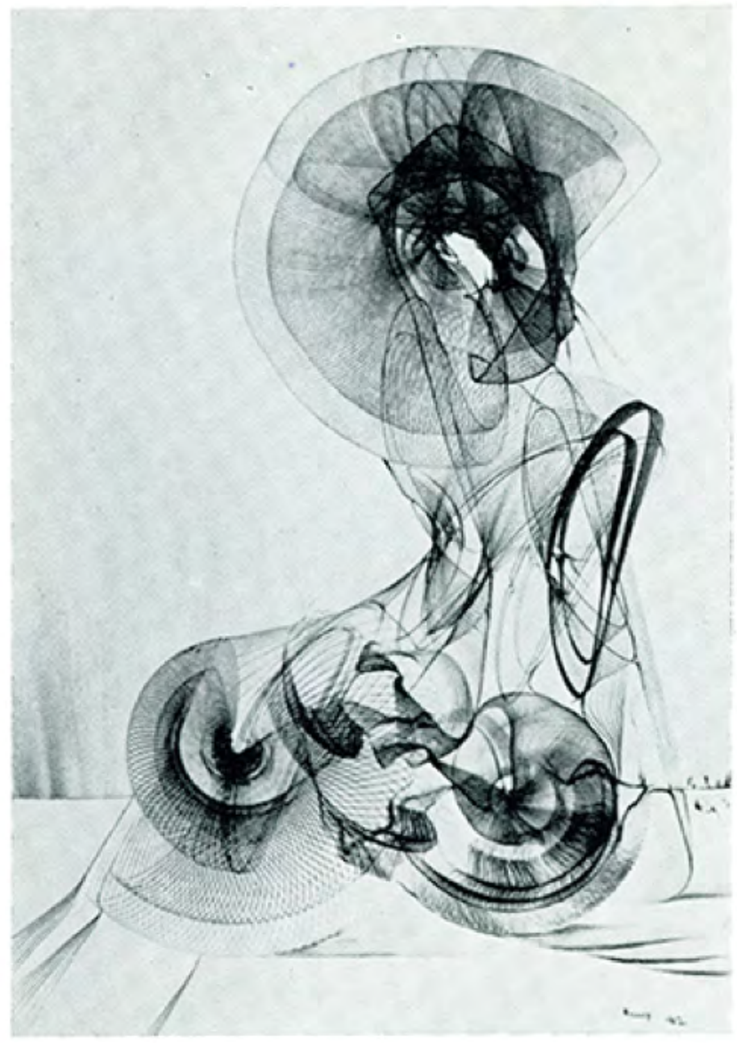
This machine is intended for use either as an *aid* in producing drawings, or as a producer of completed drawings. In the first case (used as an aid) the marks produced by the machine may be accentuated or interrelated at certain points by means of the artist's handiwork. In the second case (producer of completed drawings) no hand-modifications are added.

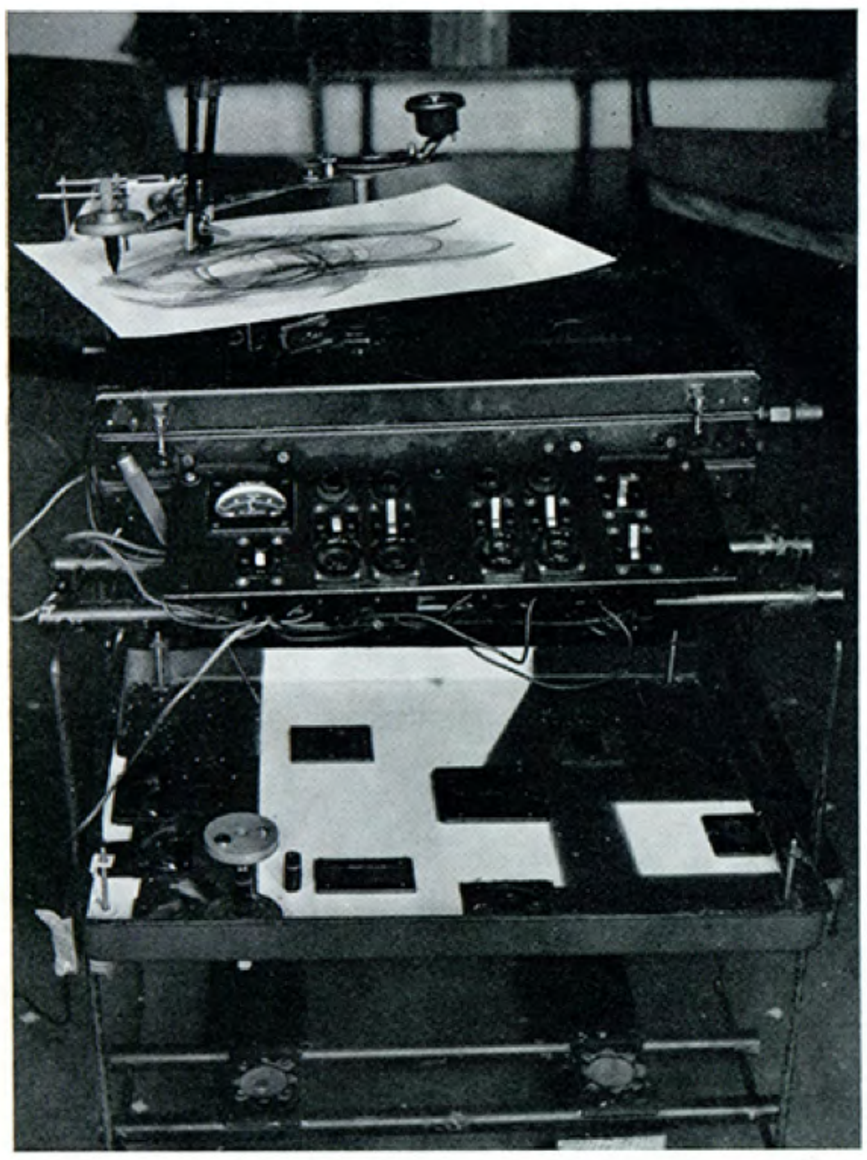
Basically, the apparatus is a modified mechanical analogue computer, originally operated by two electric servo-motors and air-pressure. The air-pressure sections are not in use, and two further motors have been added.

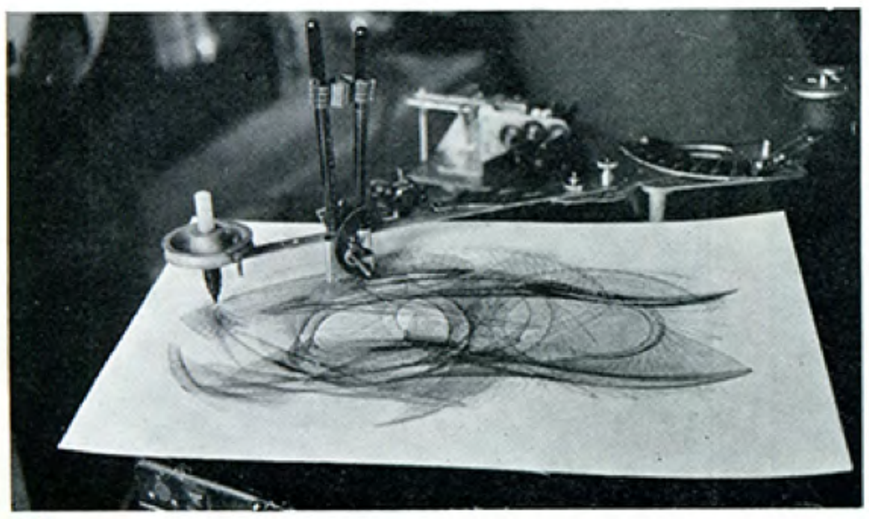
Drawings are produced by combinations of pen-movement and table-movement (the paper which receives the drawing being attached to the table). The pen is moved in elliptical paths of various dimensions, and harmonic table-movements distort the ellipses at selected points, at the same time shifting the paper in a curved path. The method of paper-shifting and ellipse distortion is such as to introduce varied degrees of randomness into the designs, thereby ensuring that no two are exactly alike. Arrangements for the regular lifting and lowering of the pen, so as to interrupt what would otherwise be a unicursal design, are incorporated for use if required. The infinitely many choices of dimension, distortion, paper-direction, and combination of various patterns on the same sheet of paper provide the artist with a flexible tool for the production of drawings possessing a fineness which the unaided hand could not achieve.

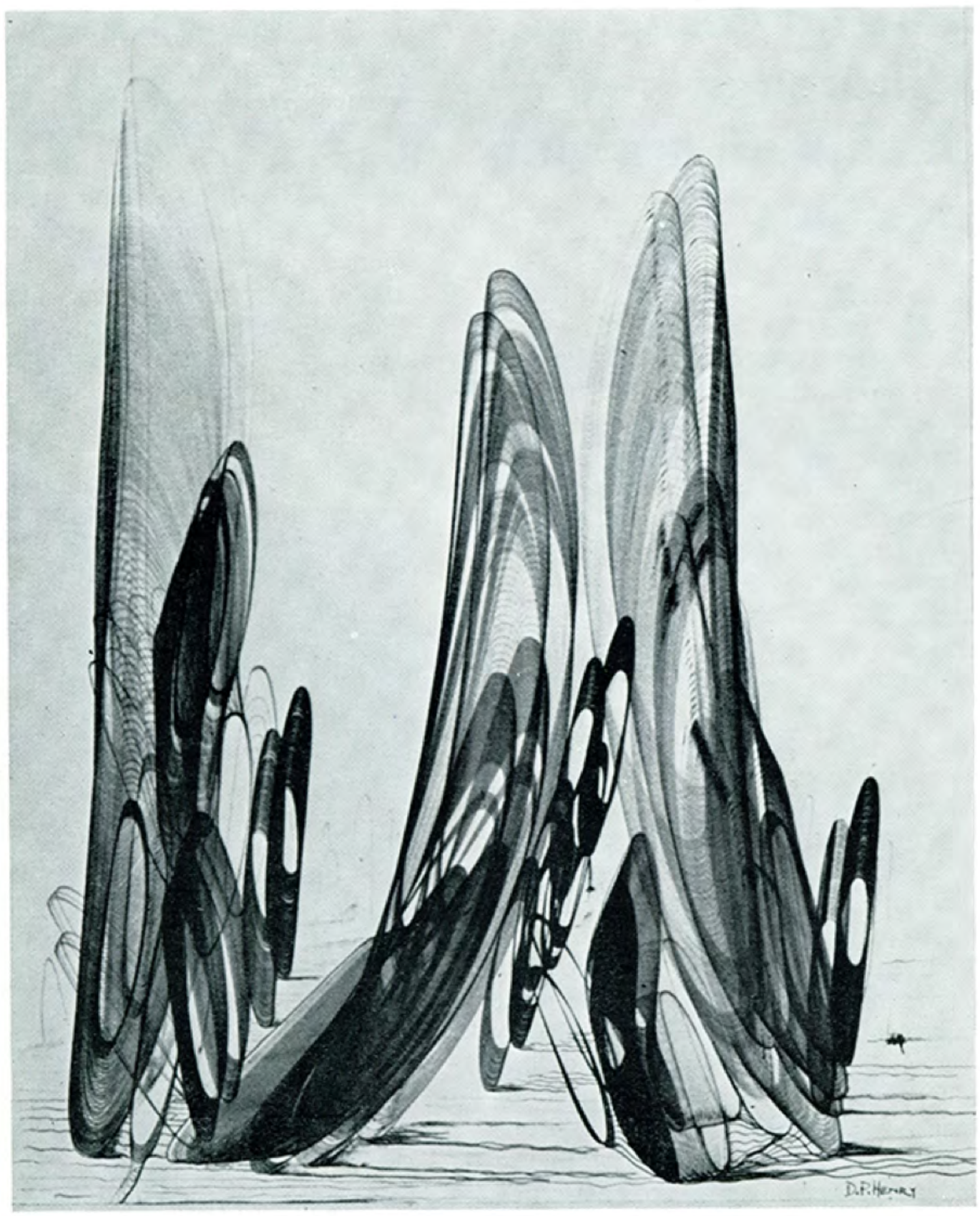
Pen arms of different lengths, and tables of varied sizes, are available.

Experience gained with this prototype suggests that a special-purpose machine, rather than a modified computer, will constitute the most profitable future development.









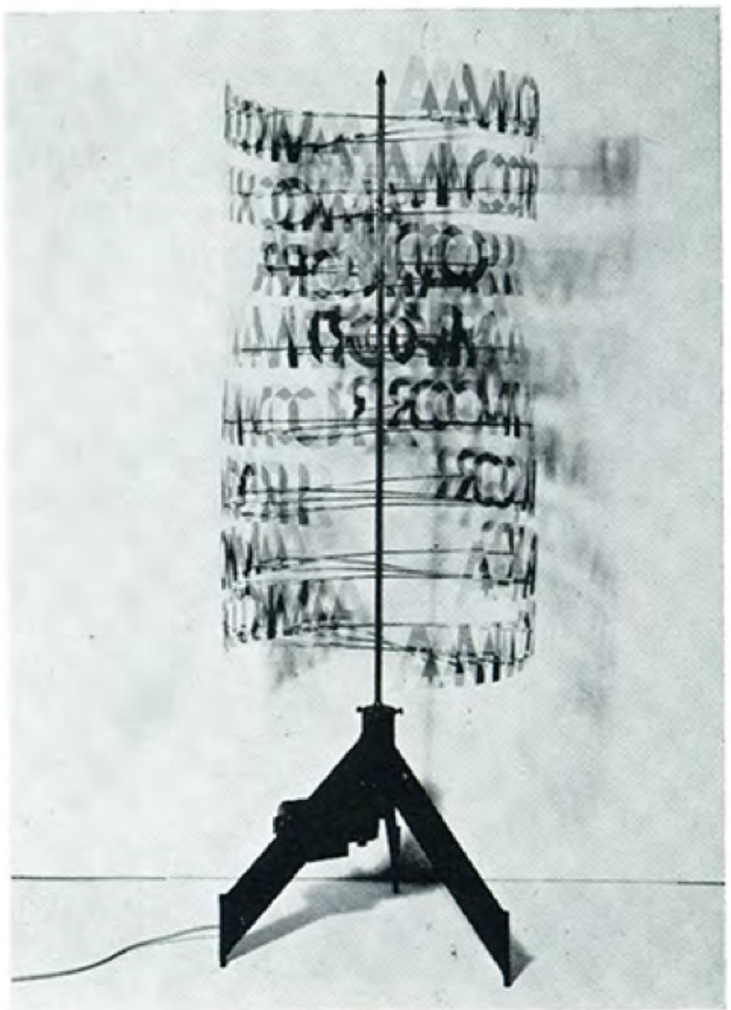
Amor-Voluptas-Pulchritudo 1966/68

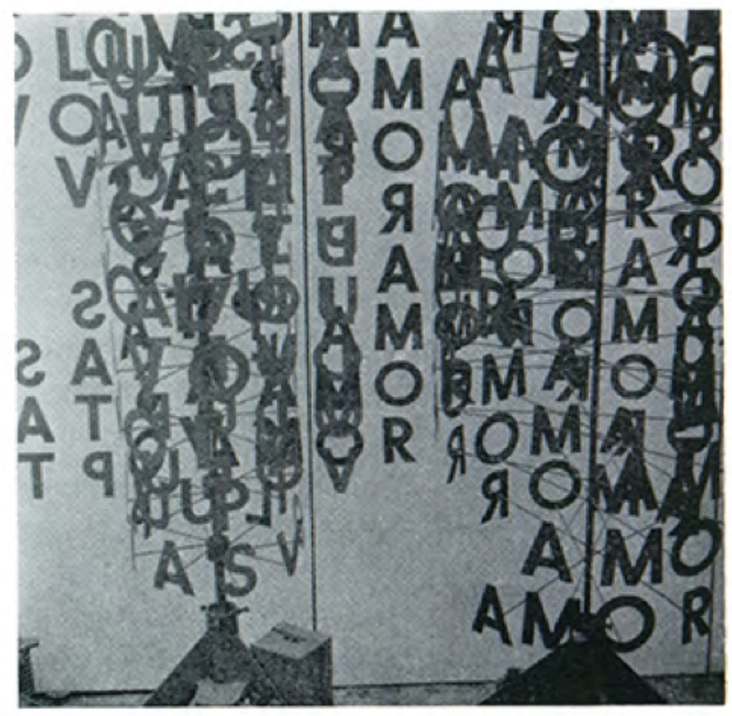
Ken Cox

Three in one and one in three—trilogy triptych—classically the concept of love at the time of the fusion of mediaeval and renaissance thinking; Venus as the embodiment of the interaction between three parts, passion, love and beauty—all constantly changing in detail yet remaining fundamentally the same.

AMOR the unifying influence, that which unites the changing, unpredictable elements in VOLUPTAS and PULCHRITUDO—the graces as dancing figures, turning and interweaving, exchanging symbolic gestures—love as passion fired by beauty.

Voluptas swings towards Amor, Amor transfers the gesture to Pulchritudo, Pulchritudo returns the gesture to Amor and thus returns to Amor the fire which originally came from Voluptas. Amor reinforced by Pulchritudo becomes the only possible link between the other two elements.





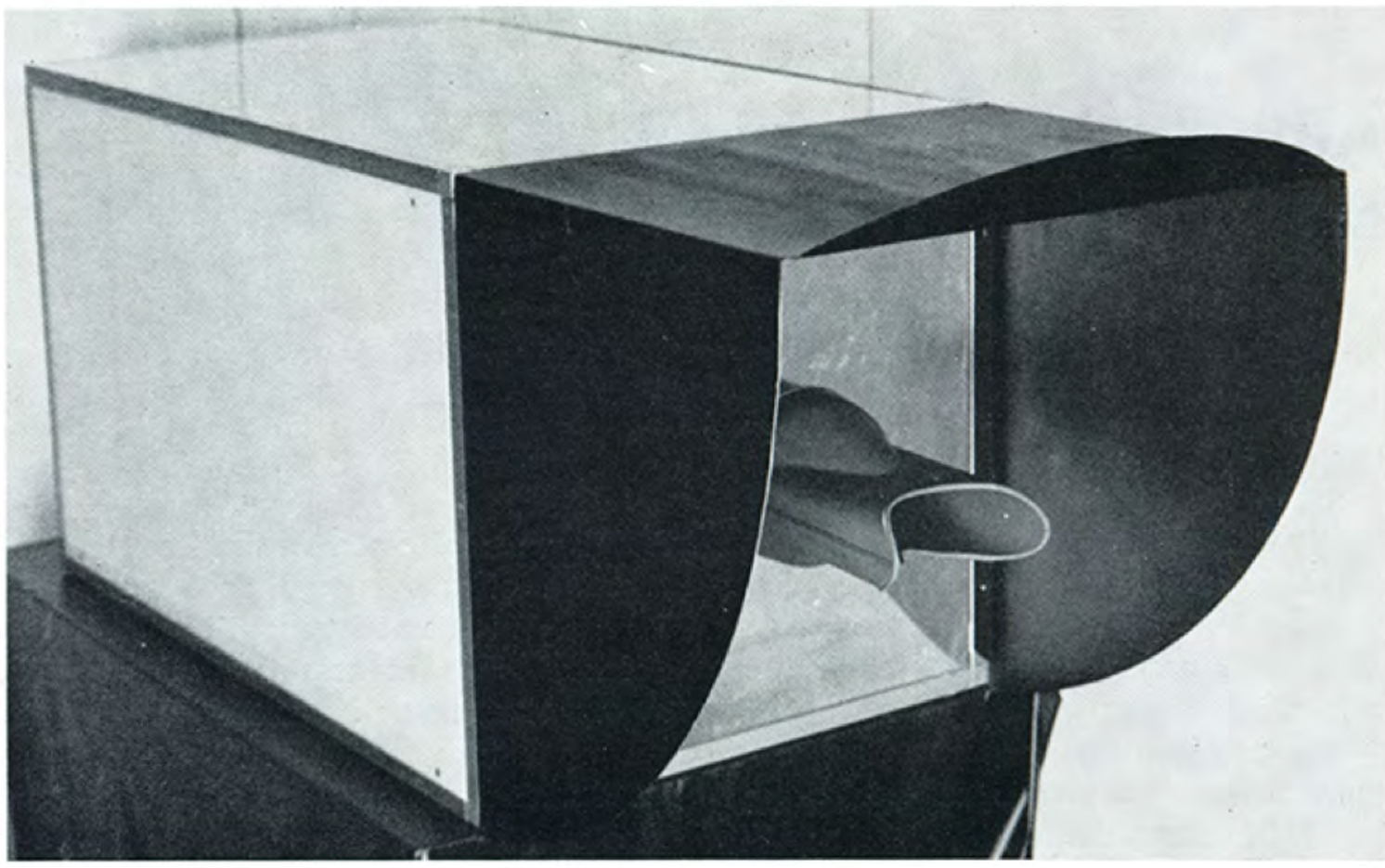
Amor, formed spatially from a double helix, stands before its own two-dimensional image and rotates as a unit at a constant slow speed. Voluptas stands before its own two-dimensional image and takes on the form of eight spatial free-running rotors superimposed on a common vertical shaft controlled electronically by a programme of two hours' duration. Pulchritudo, again before its own two-dimensional image, has a slow, sedate intermittent movement controlled by eleven small motors spaced equidistant on a vertical shaft forming its core.

Cybernetic introspective pattern-classifier

Christopher Evans

A sustained image of the visual world around us is maintained by the brain's continual co-ordination of a great flux of varying sensory input. Much of this co-ordination is achieved by the series of voluntary and involuntary eye movements which serve to scan the image of the pattern across the retina. When these eye movements are eliminated, or controlled, a remarkable collapse of the perceptual process occurs in which visual patterns disintegrate—but in non-random fashion, and according to 'rules' which appear to be common to all humans. The device, which we have called the CYBERNETIC INTROSPECTIVE PATTERN-CLASSIFIER—because that is as good a description as any—is not really the exhibit itself: it is *by means of* this device that the human brain can be turned into its own exhibit. People looking into the CIPC will be given a brief, bright flash of a pattern which plants an image on the retina in such a way that it can be seen, with eyes closed, for one or two minutes. Since the image is fixed on the retina, eye movements are irrelevant, and the perceptual system collapses as described above. The pattern can be seen to fragment and change its form, and these forms are probably the basic perceptual units used by the brain in recognising the pattern. This exhibit therefore allows people to watch their own cerebral processes actually in action.

The cybernetic introspective pattern-classifier; 48 inches long, 20 inches wide



Combinatorial geometry

Raymond Connor

Combinatorial geometry belongs to a branch of mathematics called COMBINATORIAL ANALYSIS, which is the study of combinations of numbers or quantities of things. Professor S. W. Golomb of the Jet Propulsion Laboratory (California Inst. Tech.), a leading figure in combinatorial theory and the inventor of the Polyomino, speaks of the ever-increasing importance of digital computers in modern technology as having revived a widespread interest in combinatorial analysis – a subject, he says, that also has had important applications in such scientific fields as circuit design, coded communications, traffic control, crystallography, and probability theory.

Here are a number of the more visually interesting problems which have been solved by mathematicians employing theoretic and modern computational methods.

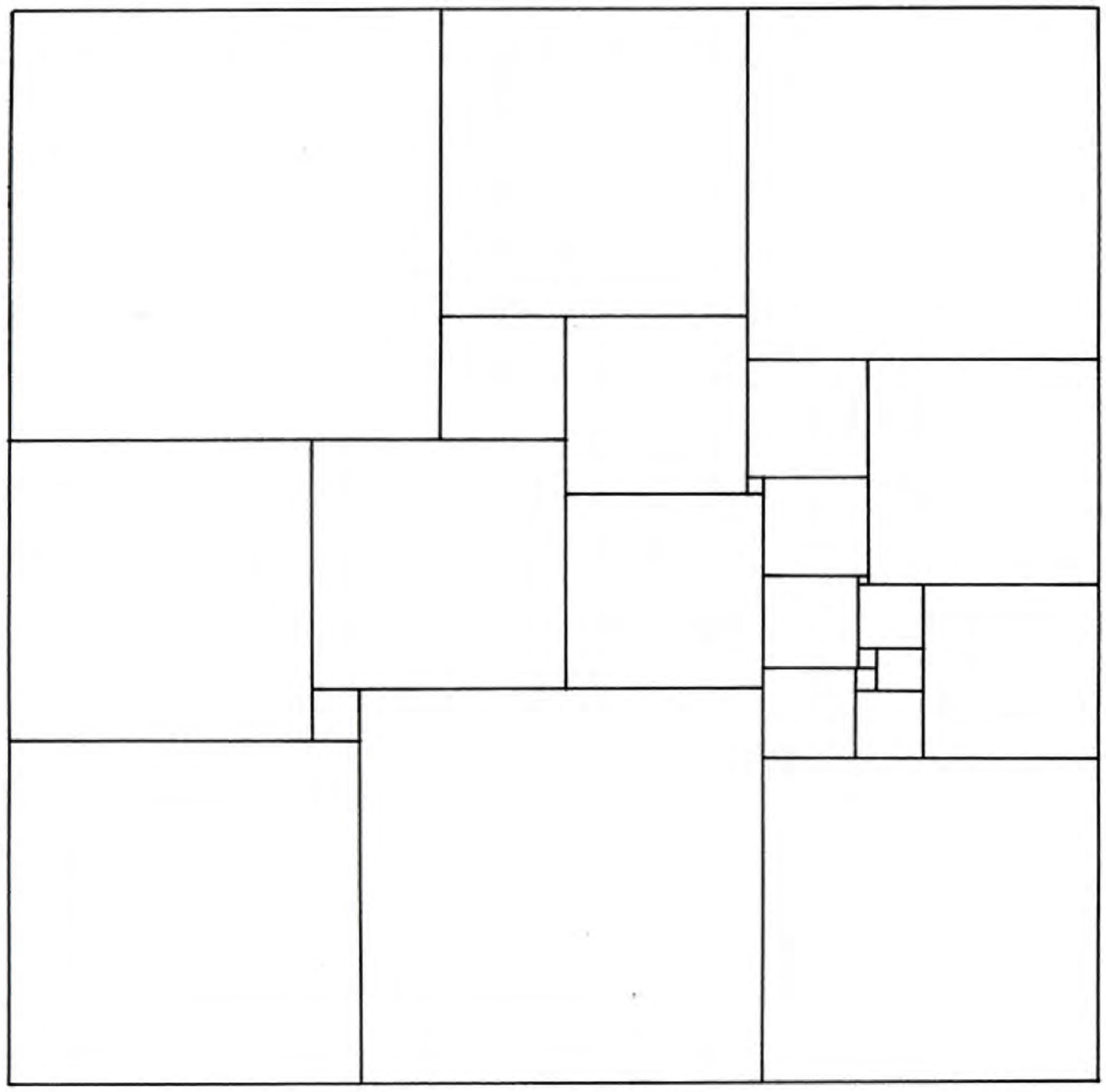
Dissection of rectangles into squares

A rectangle dissected into N>1 non-overlapping squares is called a 'Squared Rectangle of Order N'. The N squares are the *elements* of the squared rectangle; the term 'elements' is also used for the lengths of the sides. A squared rectangle that does not contain a smaller squared rectangle is called 'simple'. If the elements are all unequal, the squared rectangle is called 'perfect'; all other squared rectangles are 'imperfect'.

Progress was made in this field when a group of mathematicians succeeded in separating the topological part from the metrical part of the problem. The topological part of the problem appeared to be related to the theory of linear graphs, while the metrical part proved to be connected to the theory of current flow in electrical networks.

The programmes written in ALGOL were translated into PASCAL (Phillips Automatic Sequence Calculator) code. The 'Bouwkamp Codes' are used in the construction of the models, terminology being preserved throughout for the dissections of squares and cylinders.

A squared square – Bouwkamp codes: 231 T C T 25 373 . 373 FF 2 373 1 148 105 120 43 62 41 79 104 87 6 35 68 32 3 22 60 7 15 31 8 17 138 23 121 114

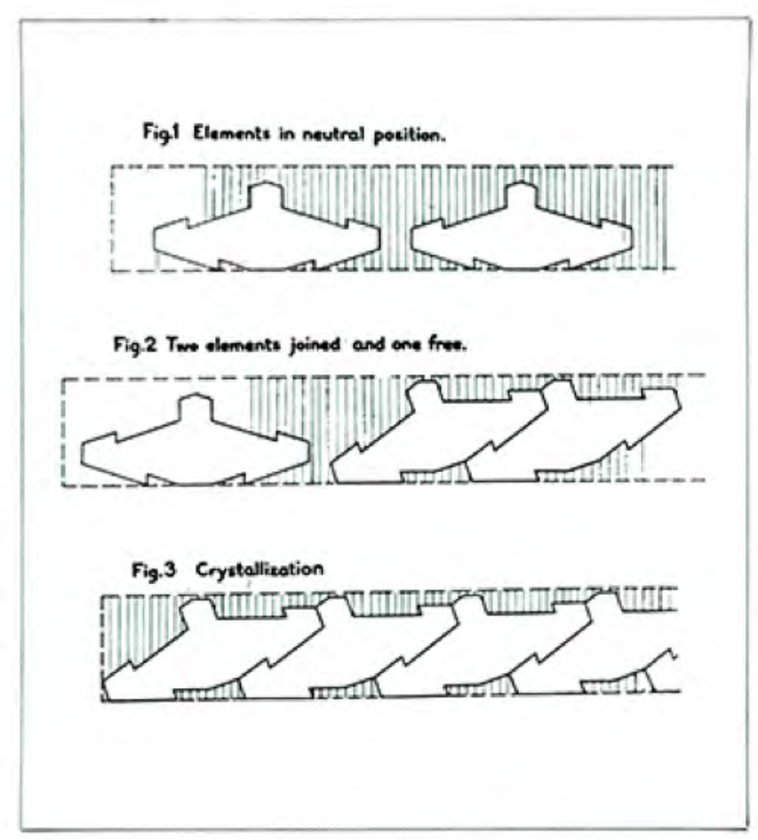


Automatic mechanical self-replication

Lionel Penrose

Pieces of material, analogous to molecules, are placed on a track. When a pair of pieces is assembled in a particular way they can act as a seed and communicate with other pieces, which respond by linking up in a similar way. The energy to make this transformation is supplied by shaking forwards and backwards along the length of the track. In the absence of assembled pieces, the application of this energy does not cause linkage. This demonstration, in which two different kinds of assembly are possible, shows what can be called the programming of a crystal by a specific seed.

It represents an analogue of a basic principle of self-replication.



Computer poems and texts

Computer texts

Marc Adrian

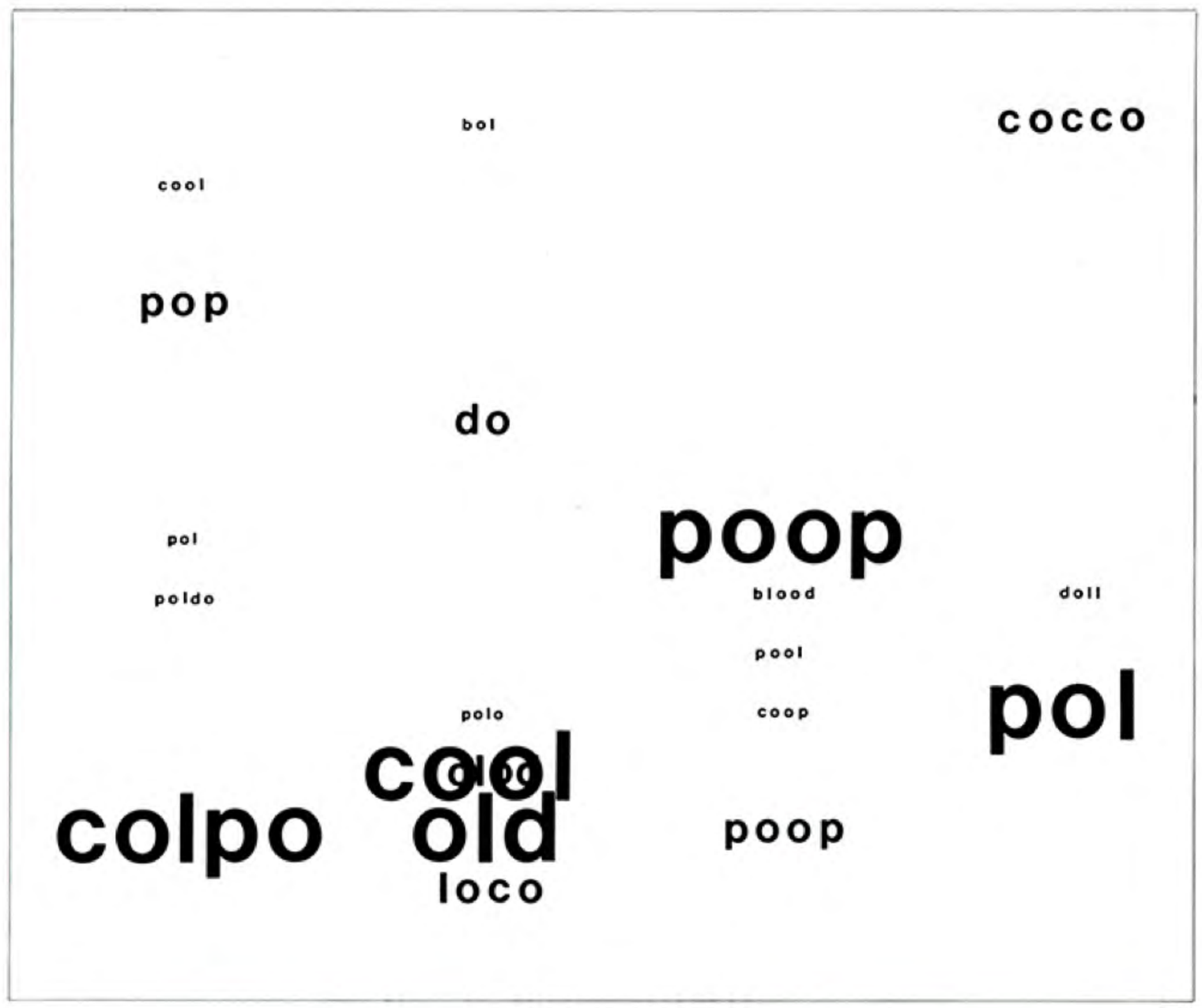
['To me the neutrality of the machine is of great importance', writes Adrian, 'it allows the spectator to find his own meanings in the association of words more easily, since their choice, size and disposition are determined at random.'

He has been making his experiments at the Vienna Institute for Advanced Studies, using IBM 16-20 II, with the help of Dipl. Ing. Wegscheider and J. Kritz.]

CT 2 1966

Programme instructions for this were as follows:

1. Select combinations of words and syllables which make sense and which can be made from the following typographical elements: l|oc (a vertical uninterrupted either above or below the line and a completed or an interrupted circle). As far as type was concerned in this instance Helvetica was used without capitals. Words could be in either German, English or French.
2. Select from storage twenty words at random.
3. Select at random a size for each of the words chosen – 14, 36 or 84 point.



Computerized Japanese haiku

These are examples, produced by on-line man-machine interaction at the Cambridge Language Research Unit, of one use of a computer for producing poetry. The programme is written in the TRAC language.

The programme is a frame with 'slots' in which the operator types words. In '1 Poem' and '2 Poem', the operator chooses his words as he wishes. In the two '3 Poem' exhibits his choice is constrained by the lists and arrow directions given in the thesaurus. By using these arrows, a semantic schema of the haiku can be built up (see diagram) which shows that the semantic centre of the poem—with five arrows going to it and one going from it—is situated at slot No. 5.

These poems were produced by Margaret Masterman and Robin McKinnon Wood.

Slot 1 (—→4) (—→5)	Slot 2 (—→5) (—→6)	Slot 3 (—→5)	Slot 4 (—→6) (—→7)	Slot 5 (—→8)	Slot 6 (—→2)	Slot 7	Slot 8 (—→5)	Slot 9 (—→5) (—→8)
White	Buds	See	Snow	Trees	Spring	Bang	Sun	Flit
Blue	Twigs	Trace	Tall	Peaks	Full	Hush	Moon	Fled
Red	Leaves	Glimpse	Pale	Hills	Cold	Swish	Star	Dimmed
Black	Hills	Flash	Dark	Streams	Heat	Pffftt	Cloud	Cracked
Grey	Peaks	Smell	Faint	Birds	Sun	Whizz	Storm	Passed
Green	Snow	Taste	White	Specks	Shade	Flick	Streak	Shrunk
Brown	Ice	Hear	Clear	Arcs	Dawn	Shoo	Tree	Smashed
Bright	Sun	Seize	Red	Grass	Dusk	Grrr	Flower	Blown
Pure	Rain		Blue	Stems	Day	Whirr	Bud	Sprung
Curved	Cloud		Green	Sheep	Night	Look	Leaf	Crashed
Crowned	Sky		Grey	Cows	Mist	Crash	Child	Gone
Starred	Dawn		Black	Deer	Trees		Crane	Fogged
	Dusk		Round	Stars	Woods		Bird	Burst
	Mist		Square	Clouds	Hills		Plane	
	Fog		Straight	Flowers	Pools		Moth	
	Spring		Curved	Buds				
	Heat		Slim	Leaves				
	Cold		Fat	Trees				
			Burst	Pools				
			Thin	Drops				
			Bright	Stones				
				Bells				
				Trails				

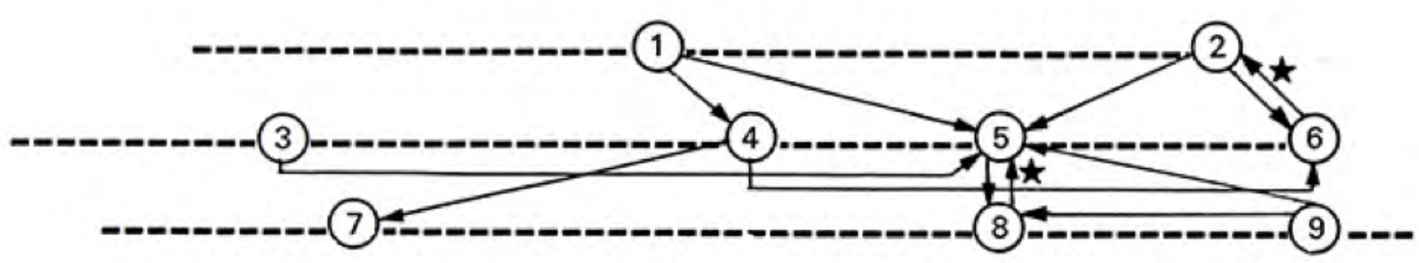
3 POEM

THE SEMANTIC SCHEMA

ALL ----------(1)----------IN THE (2)

I ----------(3)----------(4)------- (5) --- IN THE-- (6)

--------- (7) ----------THE--------- (8) -----HAS-- (9) --



* The star indicates a double linkage. For the system to be computable, only one of the arrows starred must be chosen.

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

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

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

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

Computer poetry from CLRU

Robin McKinnon Wood and
Margaret Masterman

Output resulting from a bug in the segmentation programme

This programme is designed to cut continuous text into 'Phrasings' corresponding to the rhythmic divisions of speech or spoken prose. These units usually include two stress-points and a terminal intonation feature, forming breath-groups which are also sense-groups.

The phonetic evidence and its relevance to silent reading was studied by David Shillan, the generalization of a two-stressed structure as a semantic form is the work of Margaret Masterman. The segmentation programme, which in effect simulates human perception of these phrasings, is by John Dobson at the CLRU. This output was produced by the Titan computer at Cambridge. In the case of this particular output, a bug in the programme effectively randomized the text given to it. We think this was caused by the programme taking as its text the first word on each line of the given text, but we are not sure as we failed to make the programme do it again. At any rate, this 'poem' is all the computer's own work!

Job Title (JED744/Phrasing) 10 7 67
Stream 1/0 (Phrasings)

1/0/1	I
1/0/2	development at the point normal homemaker
1/0/3	that extensive service
1/1/1	as a homemaker
1/1/2	visiting there
1/1/3	homemaker
1/1/4	the people
1/1/5	of them the
1/1/6	in the
1/1/7	these authorises services
1/1/8	them
1/1/9	the for the the deliberations
1/2/1	it kingdom associations
1/2/2	by the fifty to the development.
1/2/3	people natural larger
1/2/4	we
1/2/5	organisations cities.
1/2/6	we
1/2/7	welfare whole provided
1/2/8	quite
1/2/9	senator for a
1/2/10	for nineteen
1/2/11	provide to focus
1/2/12	in the need
1/2/13	the
1/2/14	some years
1/2/15	was is,

Tape Mark I

Nanni Balestrini

The basic text is made up of three extracts taken from:

(1) Michihito Hachiya's *Hiroshima diary*: 'the blinding fireball expands rapidly thirty times brighter than the sun when it reaches the stratosphere the summit of the cloud takes on the well known mushroom shape'.

(2) Paul Goldwin's *The mystery of the elevator*: 'head pressed on shoulder hair between lips lay motionless without speaking till he moved his fingers slowly trying to grasp'.

(3) Lao Tzu's *Tao Te Ching*: 'while the multitude of things comes into being I envisage their return although things flourish they all return to their roots'.

The working instructions for the computer are as follows:

(*a*) Make combinations of ten elements out of the given fifteen, without permutations or repetitions.

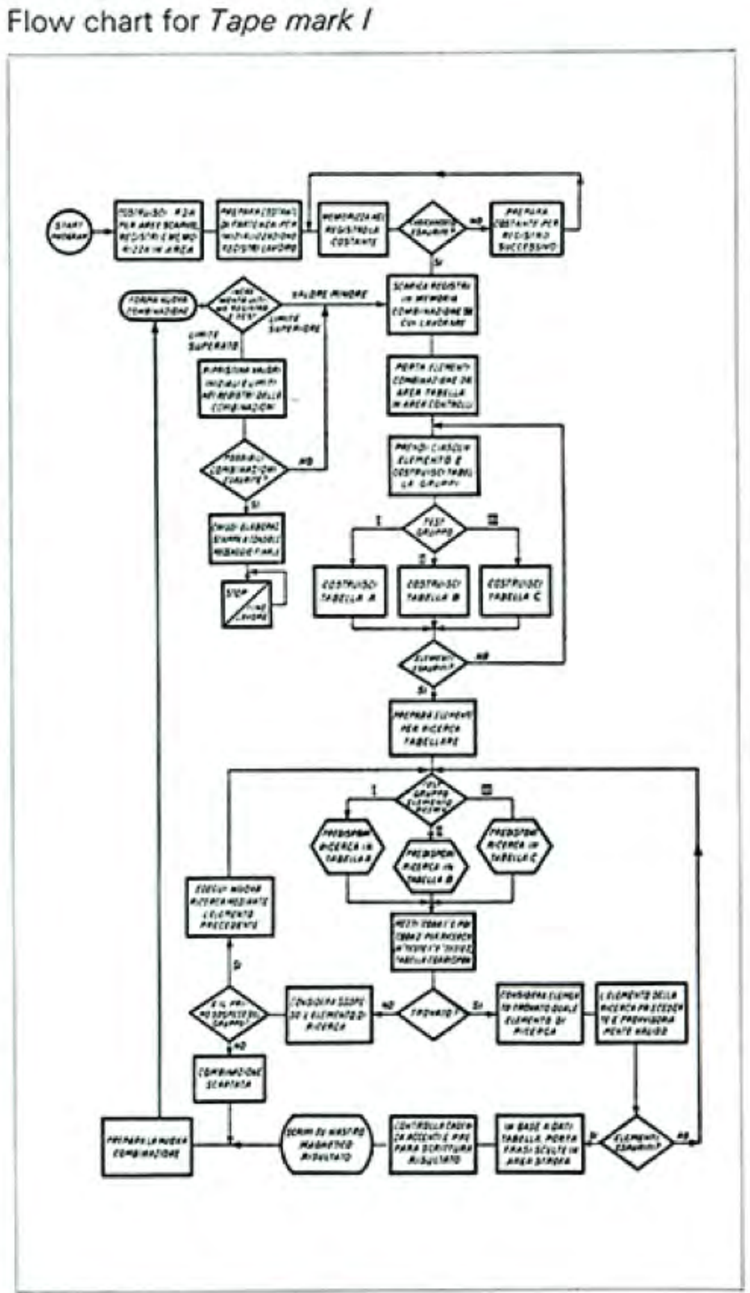
(*b*) Construct chains of elements taking account of the head-codes and end-codes.

(*c*) Avoid juxtaposing elements drawn from the same extract.

(*d*) Subdivide the chains of ten elements into six lines of four metrical units each.

The work of programming was on 322 punched cards, with 1,200 instructions to the machine; flowchart is illustrated. The full experiment was performed on an IBM 7070 computer at the Electronic Centre of the Lombard Provinces Savings Bank in Milan in October 1961.

Flow chart for *Tape mark I*



In the final text there are a few small editorial changes in points of grammar and punctuation. The results of this experiment were published for the first time in the *Bompiani almanac* in 1962.

(translated by Edwin Morgan from *Come si agisce*)

Tape mark I

Head pressed on shoulder, thirty times
brighter than the sun I envisage their return,
until he moved his fingers slowly and while
the multitude
of things comes into being, at the summit
of the cloud
they all return to their roots and take on
the well known mushroom shape
endeavouring to grasp.

Hair between lips, they all return
to their roots, in the blinding fireball
I envisage their return, until he moves his
fingers
slowly, and although things flourish
takes on the well known mushroom shape
endeavouring
to grasp while the multitude of things
comes into being.

In the blinding fireball I envisage
their return when it reaches the stratosphere
while the multitude
of things comes into being, head pressed
on shoulder, thirty times brighter than the
sun
they all return to their roots, hair
between lips takes on the well known
mushroom shape.

They lay motionless without speaking,
thirty times
brighter than the sun they all return
to their roots, head pressed on shoulder
they take on the well known mushroom
shape endeavouring
to grasp, and although things flourish
they expand rapidly, hair between lips.

While the multitude of things comes into
being in the blinding
fireball, they all return
to their roots, they expand rapidly, until he
moved
his fingers slowly when it reached the
stratosphere
and lay motionless without speaking,
thirty times
brighter than the sun endeavouring to grasp.

I envisage their return, until he moved his
fingers
slowly in the blinding fireball,
they all return to their roots, hair
between lips and thirty times brighter than
the sun
lay motionless without speaking, they
expand
rapidly endeavouring to grasp the summit.

Nanni Balestrini (1962)
translated by Edwin Morgan

```
CLEAR STORAGE 1      .008015,022026,030037,044,049,053053N000000N00001026                    1
CLFAR STORAGE 2      L068116,105106,110117R101/I9Z#071029C029056R026/R001/0991,001/001117I0A  2
BOOTSTRAP            .008015,022029,036040,047054,061068,072/061039          .0010011040     3

                          COMPOSIZIONE LETTERARIA 2                    COMPO          PAGE   1

SEQ PG LIN  LABEL  OP    OPERANDS                                  SFX CT  LOCN  INSTRUCTION TYPE  CARD

101  1 010  000    JOB   COMPOSIZIONE LETTERARIA 2
102  1 020        CTL   4411
103  1 030  BASE  DCW   @010205081114172023262932353841444750535659@      42  0374                   5
104  1 040  UNO   DCW   @010101010101010101010101010101010101010101@      42  0416                   7
105  1 050        DCW   @  &&  &&  &&  &&  &&  &&  &&  &&  &&  &&  &&  @  50  0466                   9
106  1 060  EDIT  DC    @&&  &&  &&  &&  &&  &&  &&  &&  &&@             34  0500                  10
107  1 100  START CS    332                                                4  0501  / 332            10
108  1 110        CS                                                       1  0505  /               10
109  1 120        LCA   EDIT,299                                           7  0506  L 500 299        11
110  1 130        MCE   BASE,299                                           7  0513  E 374 299        11
111  1 140        CC    S                                                  2  0520  F S              11
112  1 150        W                                                        1  0522  2               11
113  1 160        C     BASE-40,@99@                                       7  0523  C 334 552        11
114  1 170        BE    HALT                                               5  0530  B 546 S          11
115  1 180        A     UNO,BASE                                           7  0535  A 416 374        11
116  1 190        B     START                                              4  0542  B 501           12
117  1 200  HALT  H     *-3                                                4  0546  . 546           12
118  1 210        H                                                        1  0550  .               12
                  DCW   @99@                                             2  0552          LIT     12
119  1 220        END   START                                                     / 501 080          13

END OF ASSEMBLY
```

```
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 ADAGIO 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
```

A sheet from 'The house', a computer poem

Alison Knowles and James Tenney

The Something Else Press is working on compiling a book *Fantastic architecture*. Alison Knowles had been attending some lectures by James Tenney on computer programming. Together they made this poem which will be her contribution to the book. Four categories are set up: materials, situations, lighting and inhabitants. Each description occurs by random meetings of one element from the four categories. This is a fragment of the complete programme which would run for hundreds of houses if all the possibilities were exhausted. One of these houses will be built in New York City in the coming year.

```
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
```

```
FESTR      TENNEY                                   IBLDR -- JOB   000000

                    M E M O R Y   M A P

SYSTEM, INCLUDING IOCS                              00000 THRU  12302
FILE BLOCK ORIGIN                                   12311
    NUMBER OF FILES -      3
    1.  S.FBIN                      12311
    2.  S.FBOU                      12334
    3.  S.FBPP                      12357
OBJECT PROGRAM                                      12402 THRU  16263
    1.  DECK *ARCH  *               12402
    2.  DECK *RANDOM*               14056
    3.  DECK *RAND  *               16206
    4.  SUBR *INSVFB*               00000
    5.  SUBR *OUSVFB*               00000
    6.  SUBR *POSTX *               14300
    7.  SUBR *PPSVFB*               00000
    8.  SUBR *CNSTNT*  *            14417
    9.  SUBR *F05   *               14427
   10.  SUBR *F06   *               14430
   11.  SUBR *I05   *               14431
   12.  SUBR *RWD   *               14710
   13.  SUBR *ACV   *               15501
   14.  SUBR *HCV   *               15531
   15.  SUBR *XCV   *               15634
   16.  SUBR *FPT   *               15652
   17.  SUBR *XER   *               16047
   18.  SUBR *XIT   *               16262
  (* - INSERTIONS OR DELETIONS MADE IN THIS DECK)
INPUT - OUTPUT BUFFERS                              76157 THRU  77776
UNUSED CORE                                         16264 THRU  76147
OBJECT PROGRAM IS BEING ENTERED INTO STORAGE.
    36350777674I
```

Note on simulated computer poems

Edwin Morgan

Although I am interested in real computer poetry (and art and music), my special concern in these poems has been to take an ironic but not antipathetic look at the relations that will exist between computer creativity and human creativity, the challenge to the second from the first, the probability of a new approach to at least some aspects of poetry, even a deliberate emulation of the so-called blunders or digressions which at times arise (one would say) creatively within a computer context (e.g. there is a computer translation of Pasternak's poem *Hops* which is not even idiomatic English but is on several counts nearer 'poetry' than the published translation by Max Hayward, and this suggests some quite far-reaching questions). My use of irony or comedy in most of these pieces was conceived as the best way of drawing attention to some of the human/electronic relationships which will have to be investigated.

The computer's first Christmas card makes use of an obvious formal grid in each line (two words each having consonant-vowel-double-consonant-y) and at the same time suggests that the machine is scanning a semantic as well as formal 'store' (all the words relating somehow to the context of Christmas cheer). It is a goal-seeking poem which misses its goal finally but in the process discovers (as a machine might) an acceptable equivalent (chrysanthemum as emblematic good-luck flower, also as a flower one might buy or give at Christmas-time).

The computer's second Christmas card and *The computer's first birthday card* are variations on the basic approach described above. Both are goal-seeking. The first has to find the carol *Good King Wenceslas*, fails to do so because of mechanical faults (with just a touch of semantic voluntarism in the outriders on Steptoe and Son, good-class wenches, etc.), and has to fall back on a straight Christmas greeting which nevertheless it gets wrong until finally corrected. Like the *Birthday card*, it presents a true servomechanism which can correct itself as it proceeds. Since the message here involved a narrative and not a mere phrase, I set it out in the conventional five-letter pattern used for coded messages. The *Birthday card* will be self-explanatory.

The computer's first code poem, with *rhyme*, is different. This is a reminder that electronic computers developed out of work in advanced cryptography during the second world war, and it is also a metaphor for the fact that a poem itself can be regarded as a coded message. My code, though not hair-raising, is not exactly translucent. Amateur cryptographers, with or without computers, are invited to 'find the poem', which is I believe the first to have been composed in this form.

1 *Computer's first Christmas card*
2 *Computer's second Christmas card*
3 *Computer's first code poem*

1

jollymerry
hollyberry
jollyberry
merryholly
happyjolly
jollyjelly
jellybelly
bellymerry
hollyheppy
jollyMolly
marryJerry
hoppyBarry
heppyJarry
boppyheppy
berryjorry
jorryjolly
moppyjelly
Mollymerry
Jerryjolly
bellyboppy
jorryhoppy
hollymoppy
Barrymerry
Jarryhappy
happyboppy
boppyjolly
jollymerry
merrymerry
merrymerry
merryChris
ammerryasa
Chrismerry
asMERRYCHR
YSANTHEMUM

2

goodk kkkkk unjam ingwe nches lass? start again goodk
lassw enche sking start again kings tart! again sorry
goodk ingwe ncesl ooked outas thef? unmix asloo kedou
tonth effff rewri tenow goodk ingwe ncesl asloo kedou
tonth effff fffff unjam feast ofsai ntste venst efanc
utsai ntrew ritef easto fstep toeso rryan dsons orry!
start again good? yesgo odkin gwenc eslas looke dout?
doubt wrong track start again goodk ingwe ncesl asloo
kedou tonth efeas tofst ephph phphp hphph unjam phphp
repea tunja mhphp scrub carol hphph repea tscru bcaro
lstop subst itute track merry chris tmasa ndgoo dnewy
earin 1699? check digit banks orryi n1966 endme ssage

3

TEYZA PRQTP ZSNSX OSRMY VCFBO VJSDA
XSEVK JCSPV HSMCV RFBOP OZQDW EAOAD
TSRVY CFEZP OZFRV PTFEP FRXAE OFVVA
HFOPK DZYJR TYPPA PVYBT OAZYJ UAOAD
VEQBT DEQJZ WSZZP WSRWK UAEYU LYSRV
HYUAX BSRWP PIFQZ QOYNA KFDDQ PCYYV
BQRSD VQTSE TQEVK FTARX VSOSQ BYFRX
TQRXQ PVEFV LYZVP HSEPV TFBQP QHYYV
VYUSD TYVVY PVSZZ PCYJP FRDFV QYEVQ
PJQBT CYFES JQSZP QTTQZ DQRQZ VQUSP
TFRWP VCEYJ TZQSR JYEXP QOYFV XCYJP
MCYPV CQSWF AUSVP QTSRM GYYSX VQUSP

Automatic sentence generation

Jean A. Baudot

Sentence generation is performed by programming a computer, which at present is capable of generating and printing out 200 sentences a minute.

The programme is basically a mathematical model of simplified French grammar, having at its disposal a dictionary of a few thousand words classified in conventional grammatical categories (nouns, verbs, adjectives, etc.).

The generation of a sentence is performed in three steps as follows:

1. A sentence structure is generated together with information about tenses of verbs, gender and number of nouns and adjectives, kinds of clauses (principal or subordinate), kinds of objects (direct, indirect, other), etc. This structure acts as a mould which, while syntactically correct, will have to be filled with actual words; only word-categories are indicated.
2. Words are selected from the dictionary within their corresponding categories and inserted in the structure.
3. Grammatical rules are applied to 'polish' the spelling (gender and number concordances, etc.).

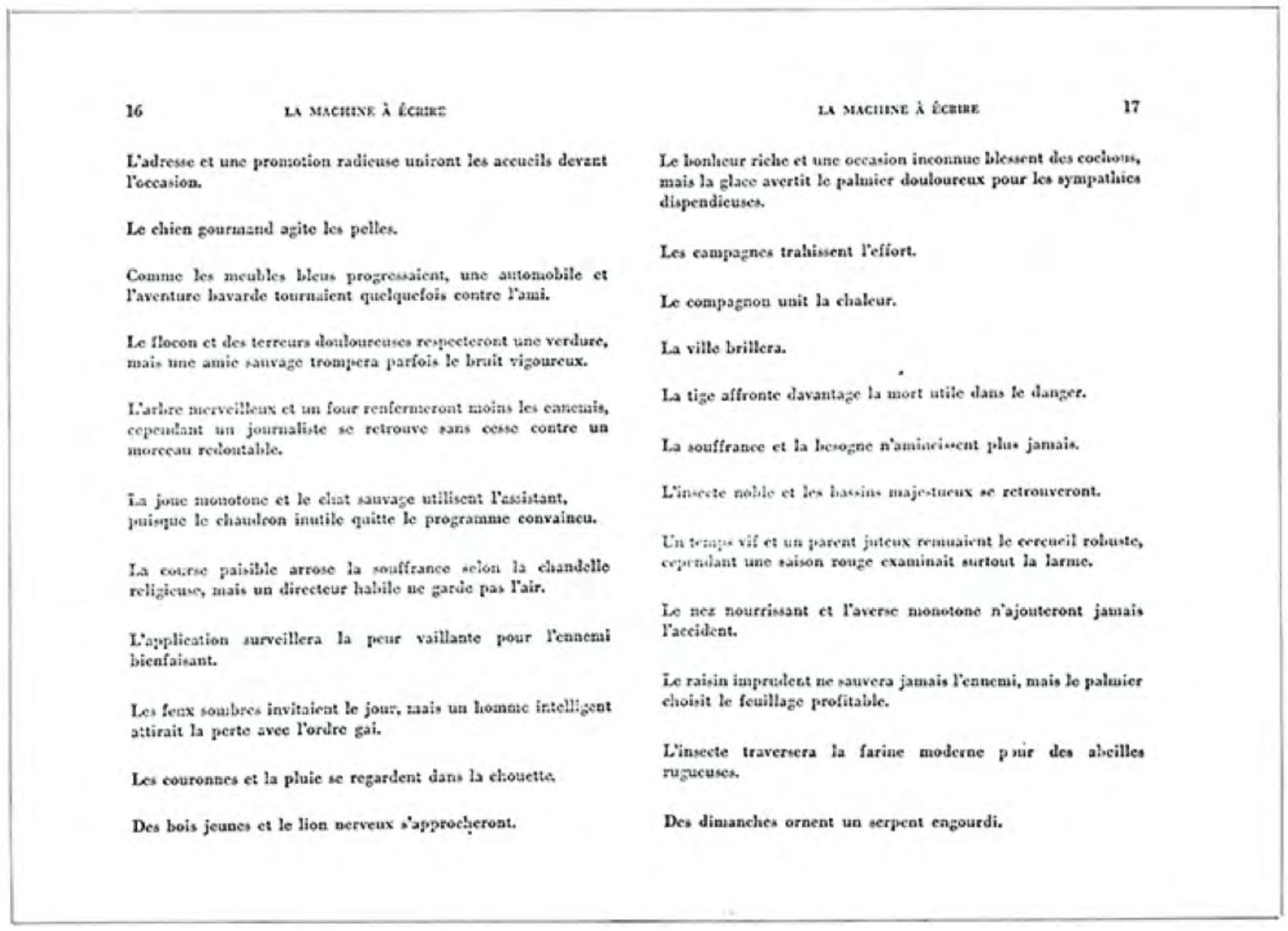
The sentence is then printed and another one is generated.

It is important to point out that steps 1 and 2 are random. In step 1, the structure selected is chosen at random among a very large number of syntactically correct structures permissible by the theoretical grammar model. In step 2, words are selected at random within their categories in the same way as one would choose a number by spinning a roulette wheel.

The final output consists of grammatically correct sentences where word occurrences are purely accidental. There is no way of predicting what kind of sentences will be generated, or what words will be associated.

In trying to discover a meaning in these artificial sentences, one feels that many seem completely nonsensical, and this is normally so. In several instances, however, accidental word-associations produce a stylistic effect which can have aesthetic value. It would be impossible to perform such a task ourselves, because man is essentially opposed to randomness and incapable of behaving or performing in a random fashion.

[Description of automatic sentence generation, from Jean A. Baudot's *La machine à écrire*, published by Les Editions du Jour, Montreal, 1964.]



16 LA MACHINE À ÉCRIRE

L'adresse et une promotion radieuse uniront les accueils devant l'occasion.

Le chien gourmand agite les pelles.

Comme les meubles bleus progressaient, une automobile et l'aventure bavarde tournaient quelquefois contre l'ami.

Le flocon et des terreurs douloureuses respecteront une verdure, mais une amie sauvage trompera parfois le bruit vigoureux.

L'arbre merveilleux et un four renfermeront moins les ennemis, cependant un journaliste se retrouve sans cesse contre un morceau redoutable.

La joue monotone et le chat sauvage utilisent l'assistant, puisque le chaudron inutile quitte le programme convaincu.

La course paisible arrose la souffrance selon la chandelle religieuse, mais un directeur habile ne garde pas l'air.

L'application surveillera la peur vaillante pour l'ennemi bienfaisant.

Les feux sombres invitaient le jour, mais un homme intelligent attirait la perte avec l'ordre gai.

Les couronnes et la pluie se regardent dans la chouette.

Des bois jeunes et le lion nerveux s'approcheront.

LA MACHINE À ÉCRIRE 17

Le bonheur riche et une occasion inconnue blessent des cochons, mais la glace avertit le palmier douloureux pour les sympathies dispendieuses.

Les campagnes trahissent l'effort.

Le compagnon unit la chaleur.

La ville brillera.

La tige affronte davantage la mort utile dans le danger.

La souffrance et la besogne n'amincissent plus jamais.

L'insecte noble et les bassins majestueux se retrouveront.

Un temps vif et un parent juteux remuaient le cercueil robuste, cependant une saison rouge examinait surtout la larme.

Le nez nourrissant et l'averse monotone n'ajouteront jamais l'accident.

Le raisin imprudent ne sauvera jamais l'ennemi, mais le palmier choisit le feuillage profitable.

L'insecte traversera la farine moderne pour des abeilles rugueuses.

Des dimanches ornent un serpent engourdi.

Computer texts or high-entropy essays

E. Mendoza

This work all began when, about ten years ago, a well-known scientist joined our staff at the Physics Department at Manchester University. He had spent several years away from academic life and was able to take a long cool look at many long-established academic procedures. He soon formed the theory that students never actually learned any real ideas; all they learned was a vocabulary of okay words which they then strung together in arbitrary order, relying on the fact that an examiner pressed for time would not actually read what they had written but would scan down the pages looking for these words. I therefore set out to test this hypothesis. I cannot now remember just how serious I was.

In the programme, it is as if there were a number of boxes each containing subjects or verbs or objects and so on, and the computer went along choosing one word or phrase at random out of each and then strung them together in a sentence. I began by writing 'Little Grey Rabbit' stories where the style was literary and the number of impossible combinations of words that had to be guarded against was large. I tested these stories out on my very small children but after some minutes they grew irritable because nothing actually happened. This shows that even small children of three can measure entropy.

Then I altered the vocabularies and the rules of grammar—making the sentences all very dead—to imitate the style of physics textbooks. The end-point came when a colleague at another university secretly sent me some first-year examination papers a week or so before the exam, and I wrote vocabularies (without cheating) and copied down what the computer emitted. Needless to say I had a special answer book and a suitable false name, and the script was slipped in among the genuine ones. Unfortunately it was marked by a very conscientious man who eventually stormed into the Director's office

shouting 'Who the hell is this man—why did we ever admit him?' So perhaps my colleague's hypothesis was wrong and students are a little better than we think.

Little Grey Rabbit-type stories

Rules of grammar incorporated.

1. If two consecutive clauses have the same subject, an appropriate pronoun is substituted. The very first clause of any vocabulary must however start with a proper subject.
2. In a 'who' clause, the verb must be different from the main clause.
3. There is no 'who' clause if the subject of the clause is a pronoun.
4. There is provision for the proper selection of an object when the verb is transitive, an adverbial phrase when intransitive.
5. There is a wide choice of acceptable *orders* of words and phrases.
6. The route followed from subject to verb to object or elsewhere is governed by a probability matrix; these are the numbers in the squares. Impossible combinations of words (for example, 'Old Grey Owl ran...') are avoided by zeros.

Construction of vocabularies

The style aimed at is that of the original stories which rely heavily on adverbial phrases.

subjects

random choice of one in 4. Numbers 1–4. The first subject demands a different pronoun from the other 3 (she; he; they; it).

verbs

eight in number; the first 4, numbers 5–8, demand adverbial phrases (called adverbs–2) and the other 4, numbers 9–12, demand objects instead.

adverbs—1

a 50%* chance of being included. They are single words which often go before the verb. Numbers 13–19. The 50% chance is secured by weighting location 20, corresponding to no adv. 1, with a probability roughly equal to the sum of the others; with provision for it not to get mixed up with word no. 20.

adverbs—2

adverbial phrases, numbers 20–27.

objects

numbers 28–34 (35 intended for choice of a subject and word as the object of a sentence; not built into grammar).

* In vocab. 1; can be altered by weighting in location 20.

who

number 35; 'which' for vocabs. with inanimate objects.

conjunctions

numbers 36, 37.

pronouns

numbers 38 (corresponding to subject 1), and 39 (subjects 2, 3, 4).

full stop

number 40.

Vocabulary I

1 Little Grey Rabbit
2 Old Grey Owl
3 Squirrel
4 Hare
5 scampered
6 flew
7 ran
8 hurried
9 sniffed at
10 peered at
11 ate
12 munched & crunched
13 then
14 slowly
15 quickly
16 soon
17 happily
18 gaily
19 noisily
20 off
21 over the woods & fields
22 through the trees
23 among the treetops
24 into the house
25 out of the door
26 down the path to the woods
27 about the garden
28 the house
29 the hollow tree
30 an old oak tree
31 the flowers
32 two buns
33 a strawberry pie
34 six cabbages
35 who
36 and
37 but
38 she
39 he
40 .

	5 scampered	6 flew	7 ran	8 hurried	9 sniffed at	10 peered at	11 ate	12 munched & crunched	
1 Little Grey Rabbit	0	0	2	3	1	1	0	0	= a1
2 Old Grey Owl	0	3	0	0	1	3	2	2	= a2
3 Squirrel	3	0	1	1	1	1	3	3	= a3
4 Hare	0	0	0	2	1	1	2	2	= a4

	13 then	14 slowly	15 quickly	16 soon	17 happily	18 gaily	19 noisily	No Adverb—1	
5 scampered		0	1	1	1	1	1	5	= a5
6 flew	1	2	1	0	0	0	0	4	= a6
7 ran	1	0	1	1	0	0	1	4	= a7
8 hurried	1	0	1	1	1	1	1	5	= a8
9 sniffed at	1	1	0	0	0	0	0	2	= a9
10 peered at	1	1	0	0	0	0	0	2	= a10
11 ate	0	1	1	1	1	1	2	5	= a11
12 munched & crunched	0	1	1	1	1	1	3	5	= a12

	20 off	21 over the woods and fields	22 through the trees	23 among the treetops	24 into the home	25 out of the door	26 down the path to the woods	27 about the garden	28 the house	29 the hollow tree	30 an old oak tree	31 the flowers	32 two buns	33 a strawberry pie	34 six cabbages	Not used	
5 scampered	1	1	1	0	1	1	1	1									= a13
6 flew	1	1	1	1	0	0	0	1									= a14
7 ran	1	1	1	0	1	1	1	1									= a15
8 hurried	1	1	1	0	1	1	1	1									= a16
9 sniffed at									1	1	1	1	1	1	1	0	= a17
10 peered at									1	1	1	1	1	1	1	0	= a18
11 ate									0	0	0	0	1	1	1	0	= a19
12 munched & crunched									0	0	0	0	1	1	1	0	= a20

Vocabulary 2

41 the clouds
42 the sun
43 the breeze
44 the sky
45 moved
46 drifted
47 shone
48 floated
49 touched
50 melted
51 looked down on
52 warmed
53 gently
54 quietly
55 lazily
56 softly
57 calmly
58 soon
59 then
60 by
61 over the woods
62 across the fields
63 through the trees
64 down
65 for a long time
66 across the sky
67 all afternoon
68 the grass
69 the leaves of the trees
70 the garden
71 the flowers
72 the little house
73 the old oak tree
74 the treetops
75 which
76 and
77 while
78 they
79 it
80 .

	5 moved	6 drifted	7 shone	8 floated	9 touched	10 melted	11 looked down on	12 warmed
The clouds	1	1	0	1	0	0	1	0
The sun	0	1	1	1	1	0	1	1
The breeze	1	1	0	1	1	2	0	0
The sky	0	0	0	0	1	0	1	1

	13 gently	14 quietly	15 loudly	16 softly	17 calmly	18 soon	19 then	No Adverb—1	20 by	21 over the woods	22 across the meadows	23 through the trees	24 down	25 for a long time	26 all day	27 all afternoon	28 the grass	29 the leaves of the trees	30 the garden	31 the flowers	32 the little house	33 the old oak tree	24 the treetops	25
moved	1	1	1	1	1	1	1	2	✓	✓	✓	✓	0	0	✓	✓								
drifted	1	1	1	1	1	1	1	2	✓	✓	✓	✓	0	0	✓	✓								
shone	1	1	1	1	1	1	1	2	0	✓	✓	✓	✓	✓	✓	✓								
floated	1	1	1	1	1	1	1	2	✓	✓	✓	✓	0	✓	✓	✓								
touched	1	1	1	1	1	1	1	2			·	·	·	·	·	·	✓	✓	✓	✓	✓	✓	✓	0
melted	1	1	1	1	1	1	1	2									✓	✓	✓	✓	0	✓	✓	0
looked down on	1	1	1	1	1	1	1	2									✓	✓	✓	✓	✓	✓	✓	0
warmed	1	1	1	1	1	1	1	2									✓	✓	✓	✓	✓	✓	✓	0

1035 Programme 4a

The sun shone over the woods. Across the fields softly drifted the breeze while then the clouds which calmly floated all afternoon moved across the fields.

Squirrel who scampered through the trees quickly ran off and off noisily ran Little Grey Rabbit. She sniffed at the house but out of the door noisily hurried Hare who peered at slowly the flowers. Squirrel quickly scampered over the woods and fields but Old Grey Owl flew over the woods and fields. Down the path to the woods ran Little Grey Rabbit who then sniffed at a strawberry pie

3503 Programme 4a

The breeze drifted by. Across the fields softly moved the clouds and then the breeze, which calmly touched the treetops drifted across the fields. Quietly the sun shone over the woods. The sky calmly shone across the fields.

Out of the door ran Squirrel and off hurried Hare who munched and crunched two buns happily. Off slowly flew Old Grey Owl and Squirrel soon ate two buns. Old Grey Owl who peered at a strawberry pie munched and crunched two buns but noisily Little Grey Rabbit who peered at an old oak tree slowly ran down the path to the woods. Soon she hurried down the path to the woods but then she sniffed at two buns. She hurried down the path to the woods.

Physics-type essays

Vocabulary and grammar: for imitating textbook style, all the work in a sentence is done by nouns; verbs are entirely neutral things.

Clauses of the type adverb 2, adverb 1, verb subject (for example, 'with loss of energy in all directions are propagated electrons') are not allowed.

Provision for up to five vocabs to be available at once.

Essay 6021

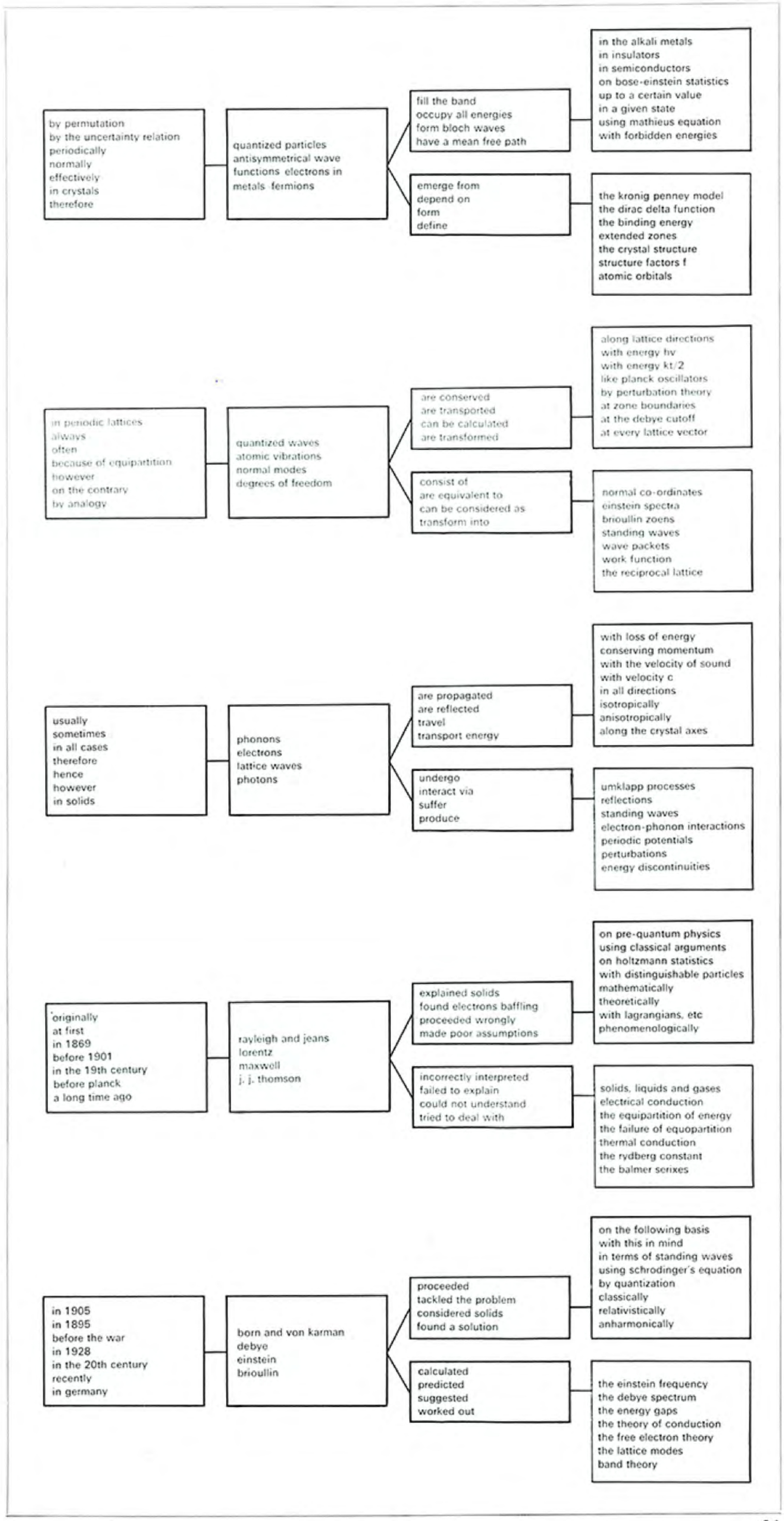
in electricity the unit of resistance is defined by electrolysis and the unit of charge which was fixed at the cavendish lab in rayleigh's classic experiments was
measured at the cavendish lab.
theoretically the absolute ohm is defined
in a self consistent way.
the unit of resistance which was determined
with a coil spinning in a field was fixed at
the cavendish lab
and this by definition
is expressed in conceptual experiments.
theoretically the absolute ohm which
was redetermined using combined e.m.u.
and e.s.u. is expressed
by the intensity at the centre of a coil

Essay 4321

the absolute
the entropy of the universe which determines
microscopic disorder implies the increase
of disorder
while quantity of heat statistically
increases in a reversible process.

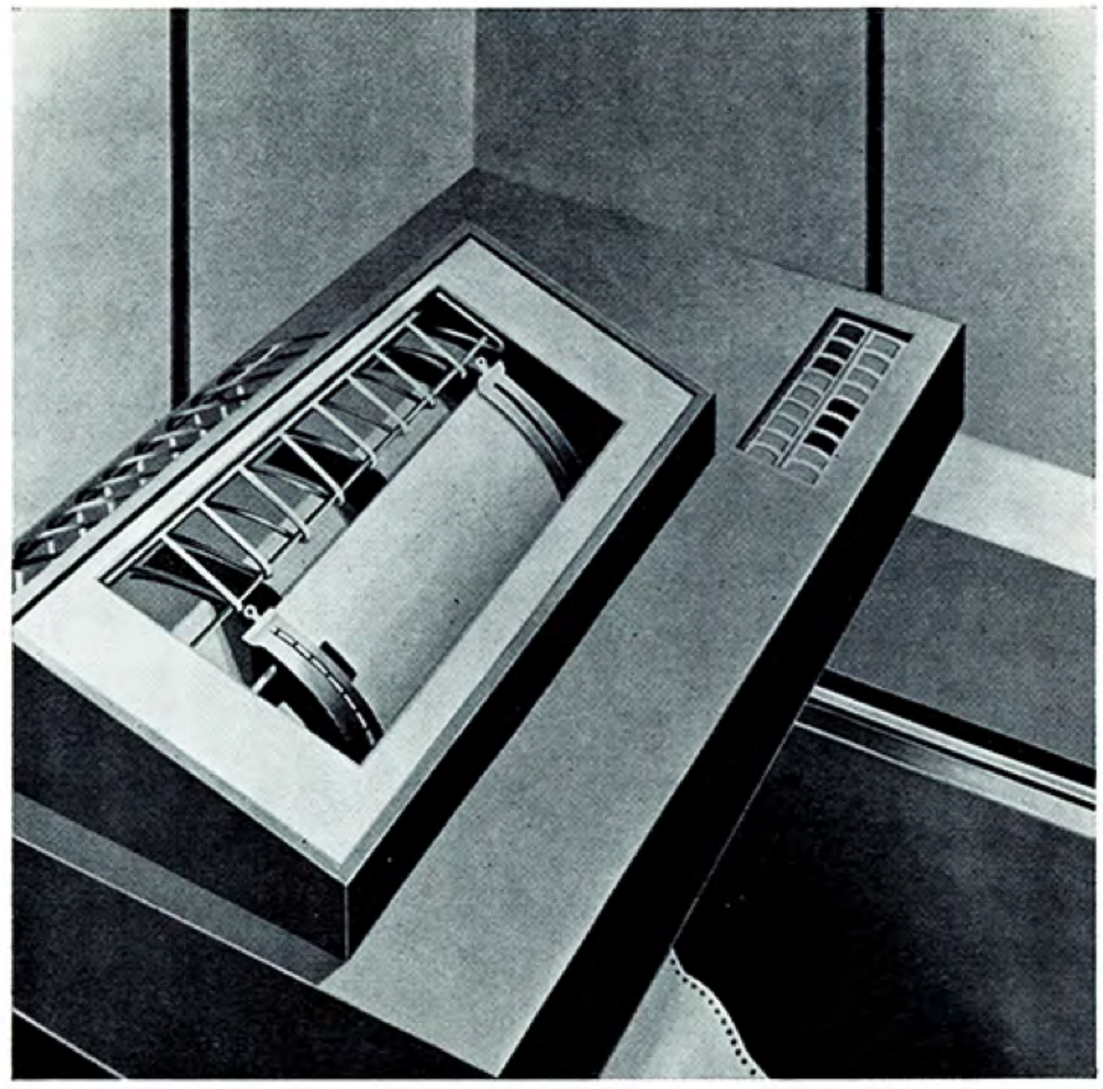
statistically the entropy of the universe
determines
irreversibility.
disorder causes $dS \geqslant dQ/T$
but the entropy of the universe which
causes a decrease of free energy for the
universe
is conserved while energy is conserved.
for the universe quantity of heat which
means $dS \geqslant dQ/T$ according to boltsmann
is conserved for the system surroundings.
statistically this is not conserved
in an adiabatic process.
dS this quantity is zero
in this case since S is not conserved–
dQ/T hence in this case
T.dS this quantity is irrelevant
in this case in this irreversible change is
zero
in the closed system
disorder which implies
the unavailability of energy according to
boltzmann on carnot's then
is conserved in an adiabatic process while
for a closed system quantity of heat implies
the unavailability of energy.
the entropy of the universe macroscopically
is not conserved
while energy is conserved.
in terms of p and T work done this quantity
= T.dS in this case
= –v.dp
along any path p.dv this quantity
is not zero in the closed system–
(dS/dT)dT + (dS/dp)dp so by maxwell's
relations
T.dS is not zero between initial and final
states
p.dv is irrelevant because S increases
hence dS is the same
since S is not conserved

Essay 4771
in this country soddy
considered plancks hypothesis from a new
angle.
einstein 50 years ago asserted quantisation.
at a photocathode electrons which
undergo collisions in the compton effect as
energy packets or
quanta are emitted at definite angles
nevertheless
particles in a photocell produce
photoelectrons of energy $h\nu = E_o$.
photons in vacuo transmute into
lower frequencies and light quanta
in the compton effect emit emission
currents.
particles emit current proportional to energy
electrons in vacuo interact
with loss of surface energy (work function)
nevertheless
particles which are emitted in a photocell
with conservation experimentally are
conserved with energy $h\nu$,



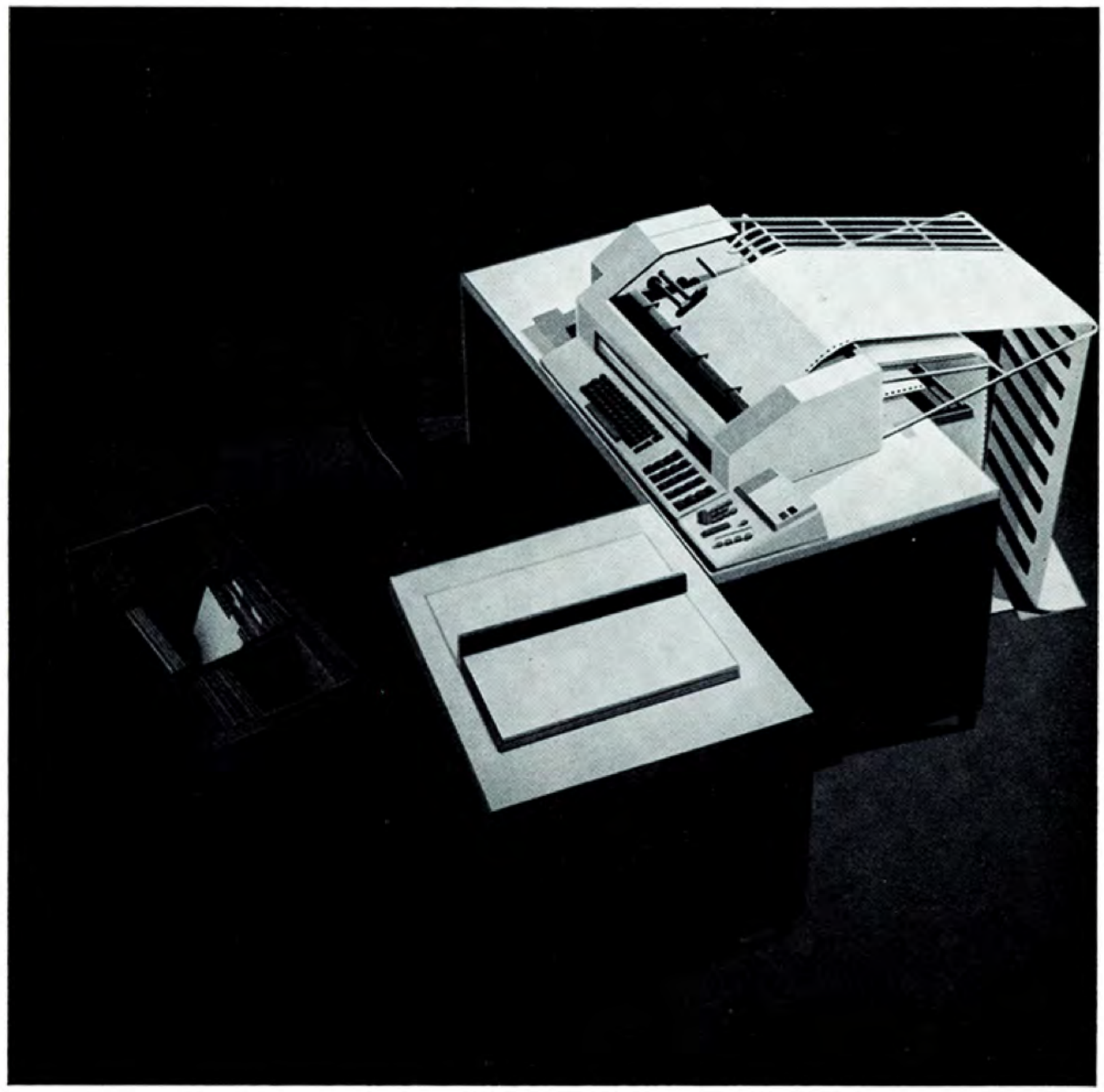
the former at a metal surface undergo collisions
with emission of current and at a metal surface
electrons produce emission currents.
einstein assumed the gas of quantum particles
but quite recently rayleigh
who quite recently solved the problem in an oldfashioned way
considered radiation classically.
planck who this century
assumed the A and B coefficients explained
the gas of quantum particles but before sommerfeld
rayleigh who quite recently
was puzzled on boltzmann statistics
tackled the problem
with disastrous results.
planck who assumed
the gas of quantum particles in 1905 this century
considered the ultraviolet catastrophe but
quite recently jeans who
tackled the problem in an oldfashioned way was puzzled
with disastrous results.
black body radiation that exerts
thermodynamic forces in an engine is equivalent to
a relativistic system.
out of a black body a photon that
is equivalent to out of a black body
an assembly of photons
is assumed to be a non-conservative system at the same time
thermodynamically black body radiation that
in a piston is assumed to be a relativistic system
exerts quantised forces.
the radiation gas that obeys
wien's displacement law is considered as a system of energy levels.
quantally a quantum particle exerts
a doppler-dependent pressure although this
produces equilibrium transition probabilities.
black body radiation in an engine produces
equilibrium transition probabilities.

Computer paintings



Lowell Nesbitt, left, *IBM 1440*, 1965, oil on canvas, 60 × 60 in. Below, *IBM 6400*, 1965, oil on canvas, 80 × 80 in. collection: Edith Cook, Washington, D.C.

Computer paintings of Lowell Nesbitt



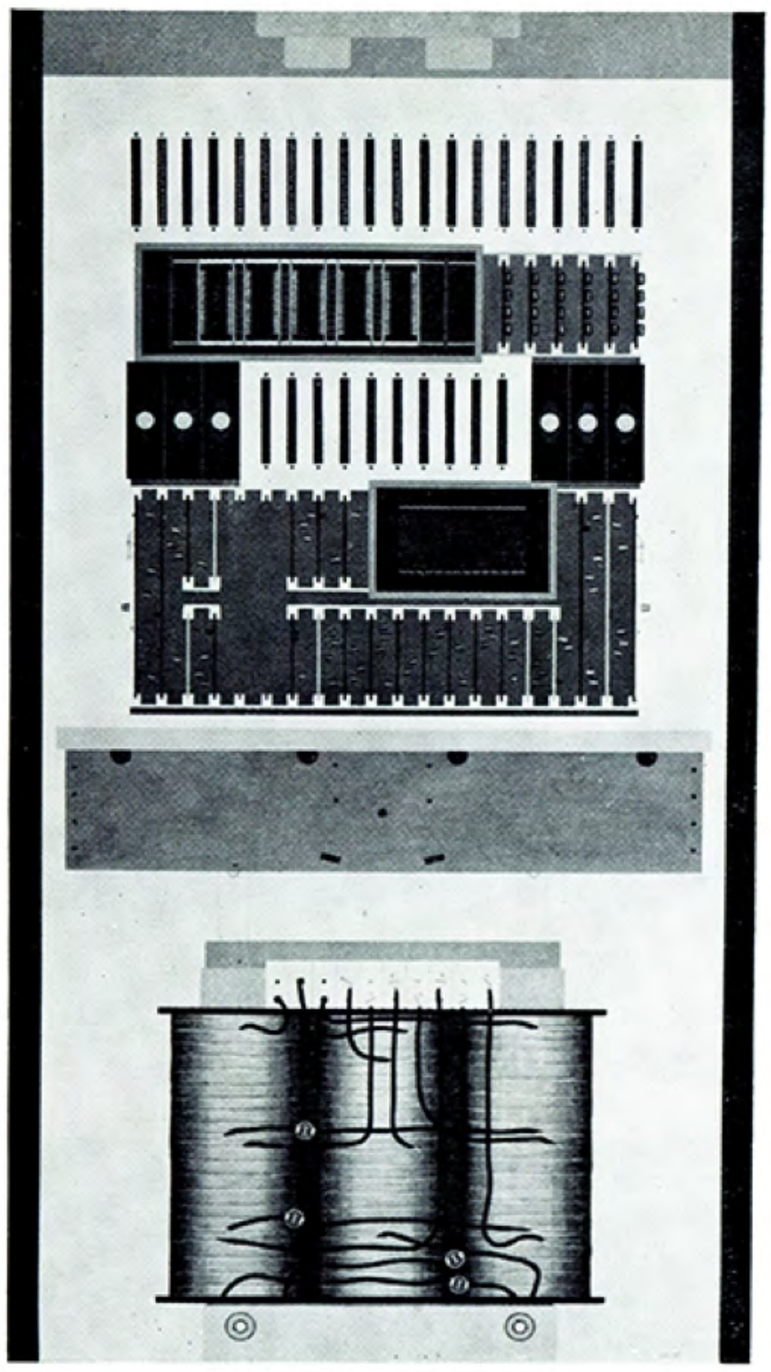
Henry Martin

Even though the invisible systems of mathematics and electron flow relate to the structures of the IBM paintings much as the barely implied rooms relate to the faces of the buildings, Lowell Nesbitt shows a concern for the world behind the machine that he chooses not to exercise for the world behind the façades. In spite of their serenity and silence, the paintings enquire into the duality of the computer and search for the correspondence between its physical and rational structures. Lowell Nesbitt's humanist rather than technological understanding of the IBM machine extends the arbitrariness of the instrument's surface into a questioning of the reality of the processes behind it. Lowell Nesbitt has accepted the obsolescence of the machine's surface and pulled this surface into the realm of the aesthetic object, thus acknowledging and emphasizing the unapproachability of the thing in itself.

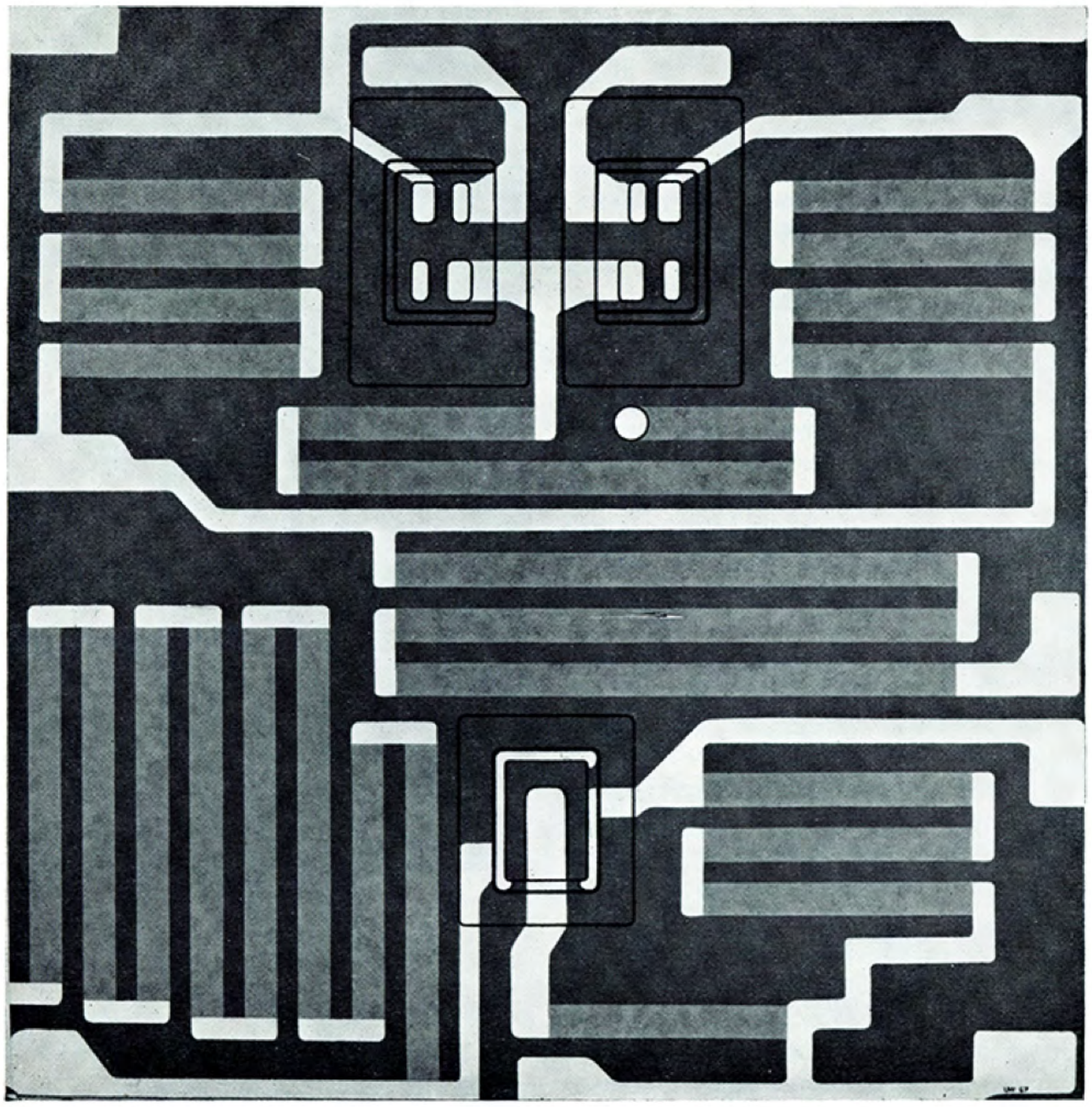
The space within Lowell Nesbitt's painting has nothing to do with the real ambience of the objects within it. The IBM paintings contain no clue concerning the size of the depicted object. Reticence being the extension of their formal economy and broad expanses of flat colour, Lowell Nesbitt's paintings tell no more than necessary. These paintings do not attack meanings from the front; like riddles, they circle meanings and define them only by their edges.

Ulla Wiggen
Trask (*portrait of computer parts*) 1967,
acrylic on board, 45¼ × 31½ in.
reproduced by courtesy of the Moderna Museet, Stockholm

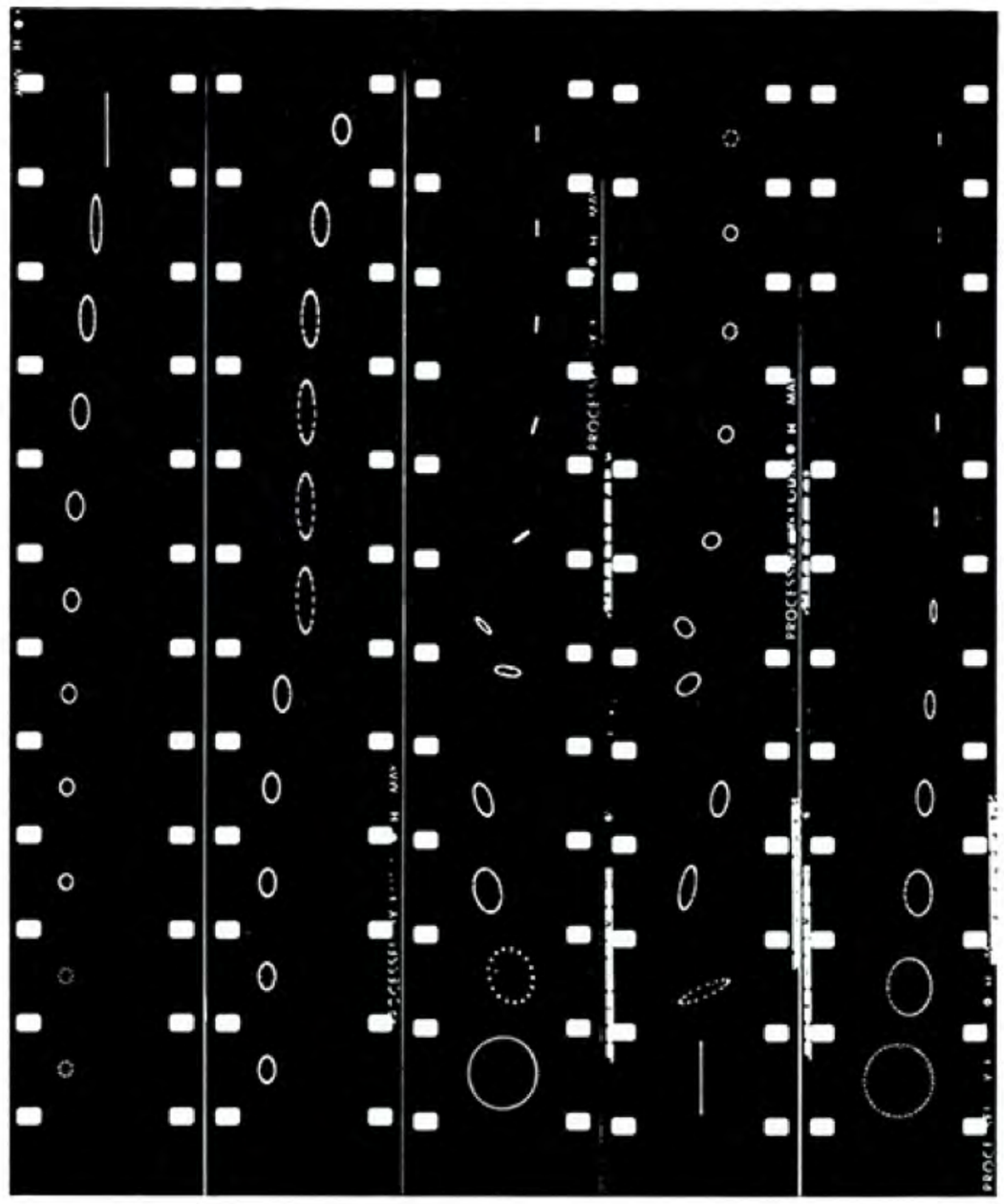
'Trask' (Transistorized sequence calculator) is a modernized version of the Swedish computer 'Besk' related to the American computer 'Illiac' 'Task' was built in Stockholm by Gunnar Hellström in 1965.



Ulla Wiggen
Vägledare (*micro-circuit*), 1967
acrylic on board, 27½ × 27½ in.
collection: Per-Olof Olsson, Lidingö, Sweden

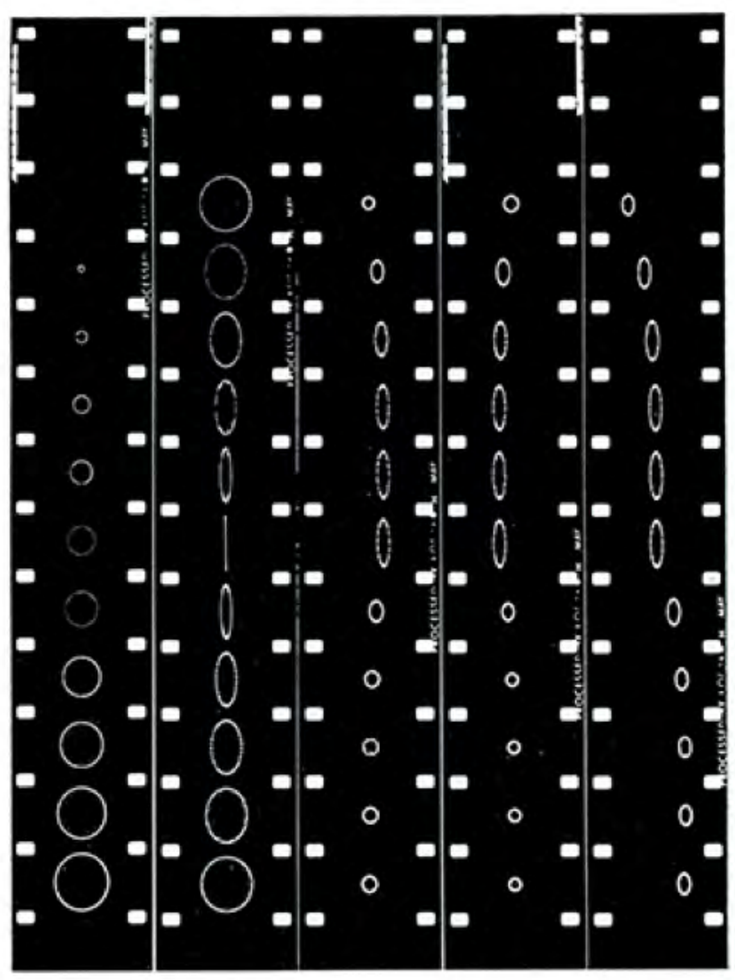


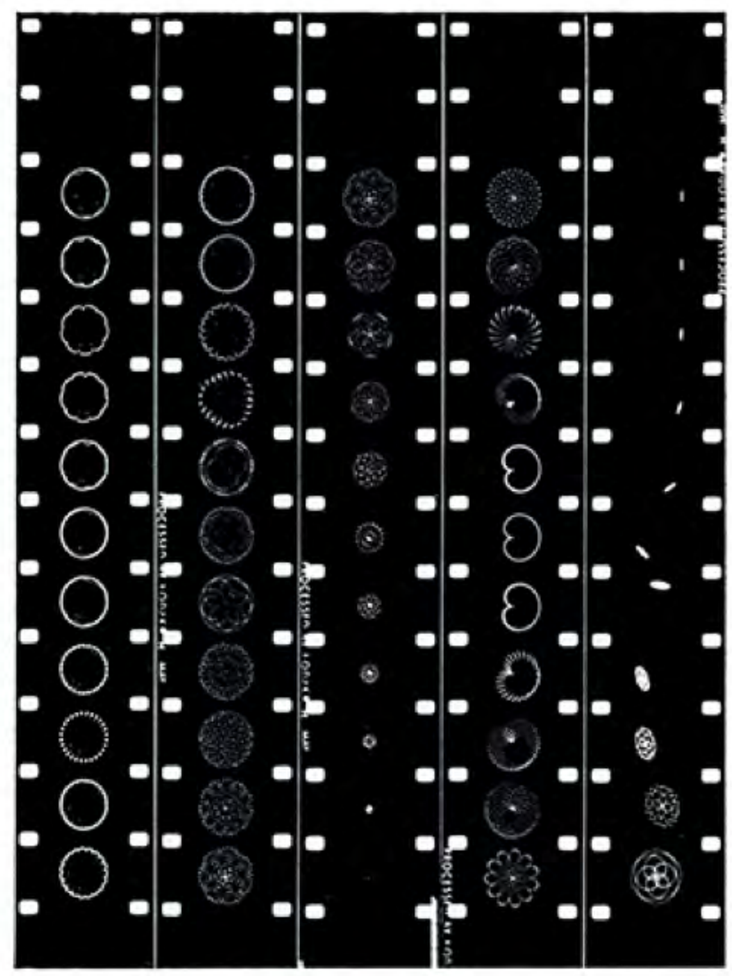
Computer films



Each strip represents every tenth frame of a 200-frame 'word' to which John Whitney refers in connection with his film *Permutations*

Permutations





John H. Whitney

Permutations is the most recent of several films which I have made as one of the activities, among many, within an IBM research project. It represents the first steps toward developing a compositional language of graphics in motion. With this film I have been able to realize, on a tentative and experimental level, a hierarchy of components of a structural system. Looking at the original black and white computer images on film which were used to make this composition, one can see the components of its structure.

The film contains various types of dot patterns which might be compared to the alphabet. At the next level of complexity the dot patterns are formed into 'words', each word having basically a 200-frame time duration. The words in turn can be fitted contextually into sentence structures.

My use of a parallel to language is only partially descriptive. I am moved to draw parallels with music. The very next term I wish to use is: counterpoint.

Having described dot pattern 'words' of 200-frame duration, I must strain the parallel beyond its limits in order to explain that these patterns are graphically superimposed over themselves forward and backward in many ways and the parallel now is more with the counterpoint, or at least polyphonic musical phenomena. Should I coin a new term? Should it be called 'polygraphic phenomena'?

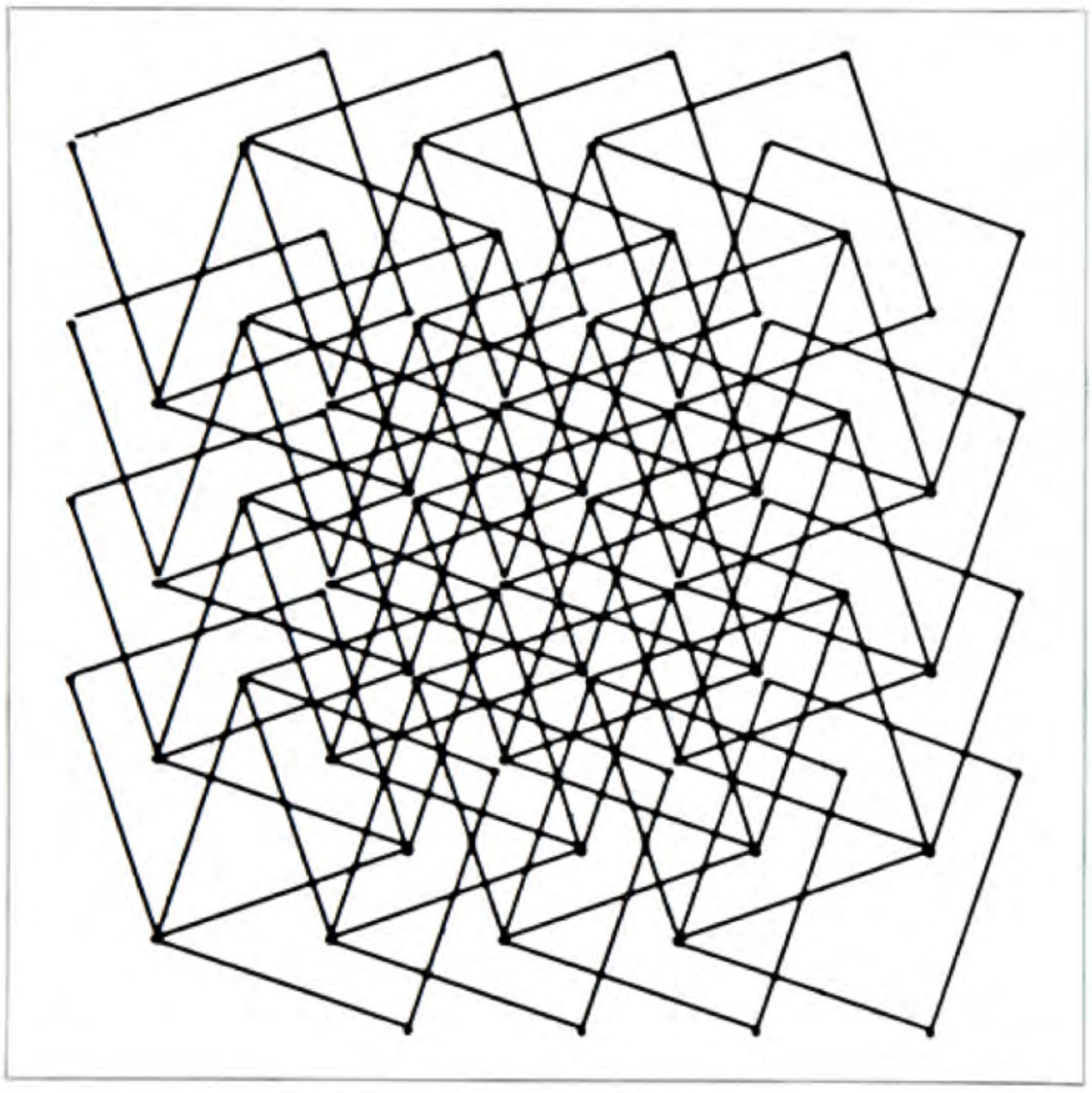
The filming procedure for making *Permutations* was as follows: the IBM 2250 Graphic Display Console was fitted with my own camera. A specially prepared computer programme of very broad graphic versatility (which I have been exploring for over two years now) was the source of the graphic patterns I designed and recorded on film.

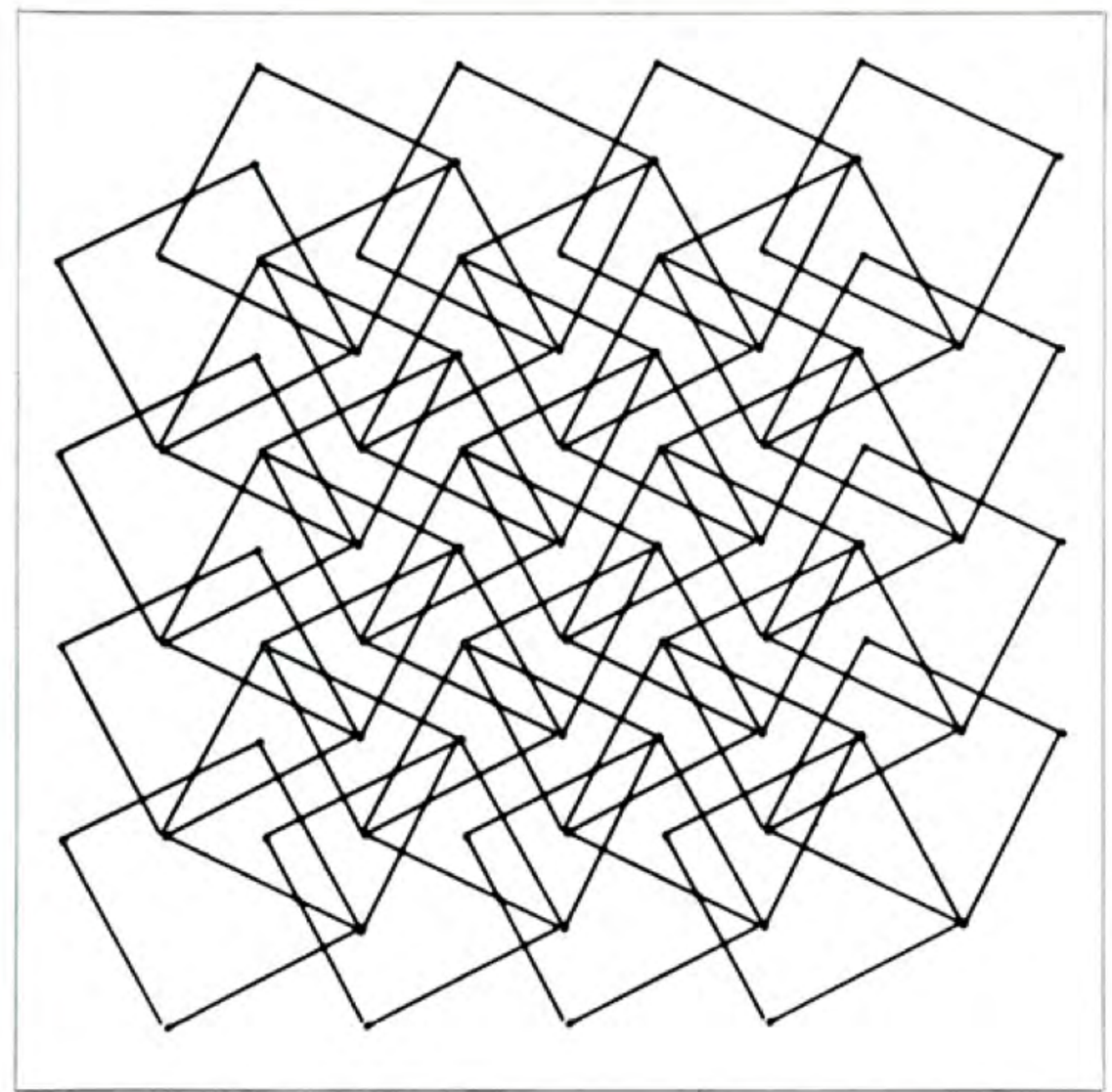
Having recorded on 35 mm black and white film all the sequences which I planned to use in making the film, I began the second stage of production.

This second stage is carried on at my studio with my own specially designed optical printer. After planning the 'word' sequences – I then describe the scale, colour and location of the images.

Stills from a computer-animated film by Ronald Resch

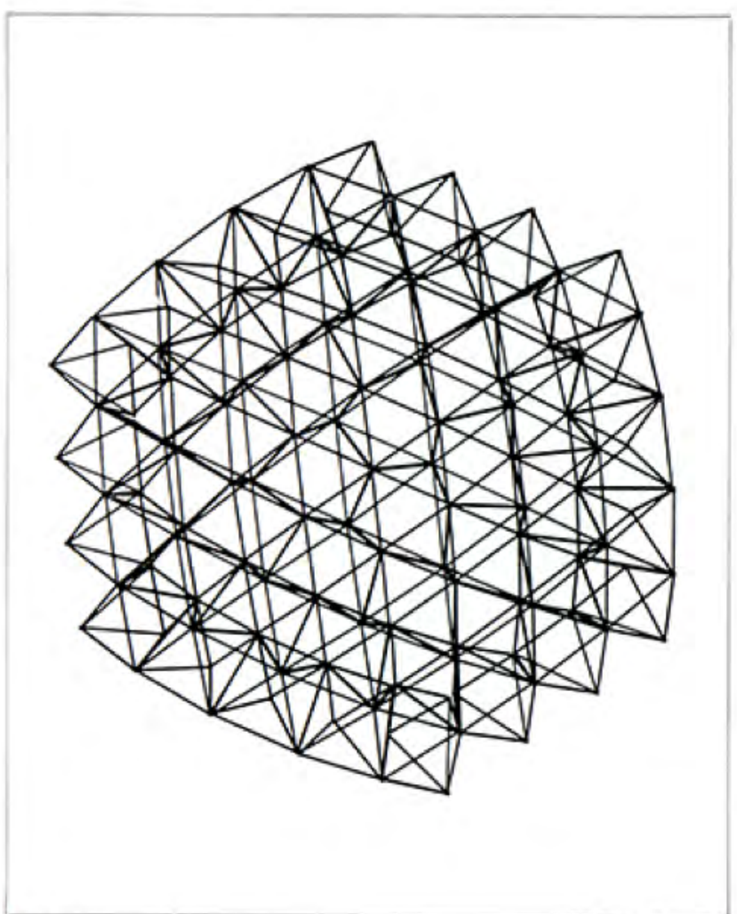
Made at Coordinated Science Laboratory, University of Illinois. A group of squares is transformed from a large checkerboard pattern into a single square and back to a checkerboard pattern. The pictures use a photographic reversal of a picture photographed from a cathode ray tube display. The display that was used in making the film is an 'inhouse' display which was designed and built at Illinois in the Coordinated Science Laboratory. The computer used is CDC 1604. The programming language used is a low-level interpreters' language which was written by Ronald Resch with assistance from several programmers and is embedded in a standard Fortran II language. Programming time for sequences represented by these stills varies from 2½ hours to 3 months.

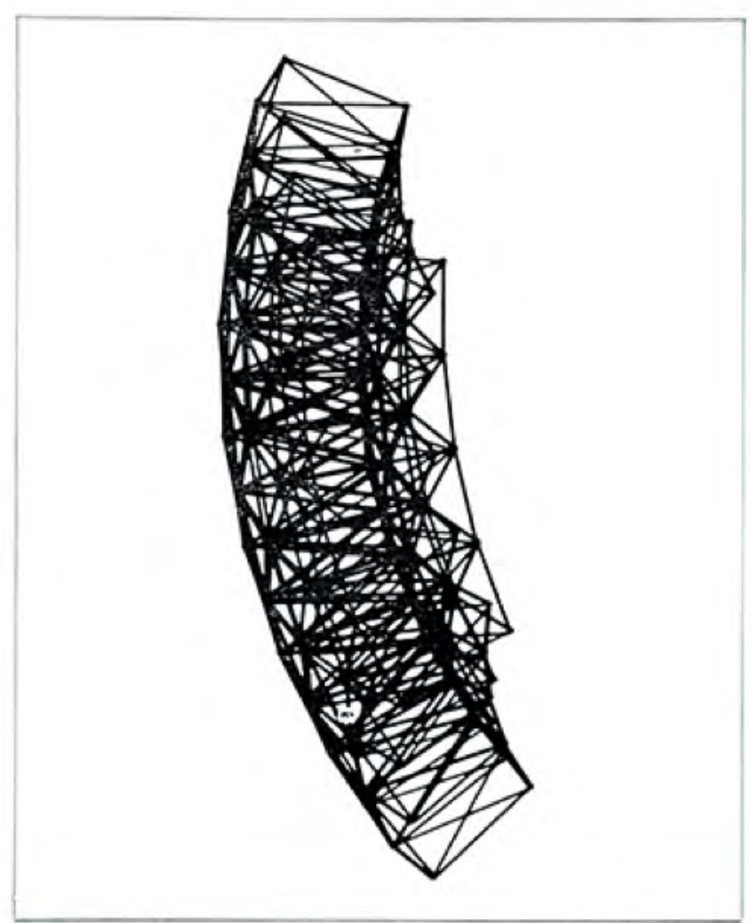


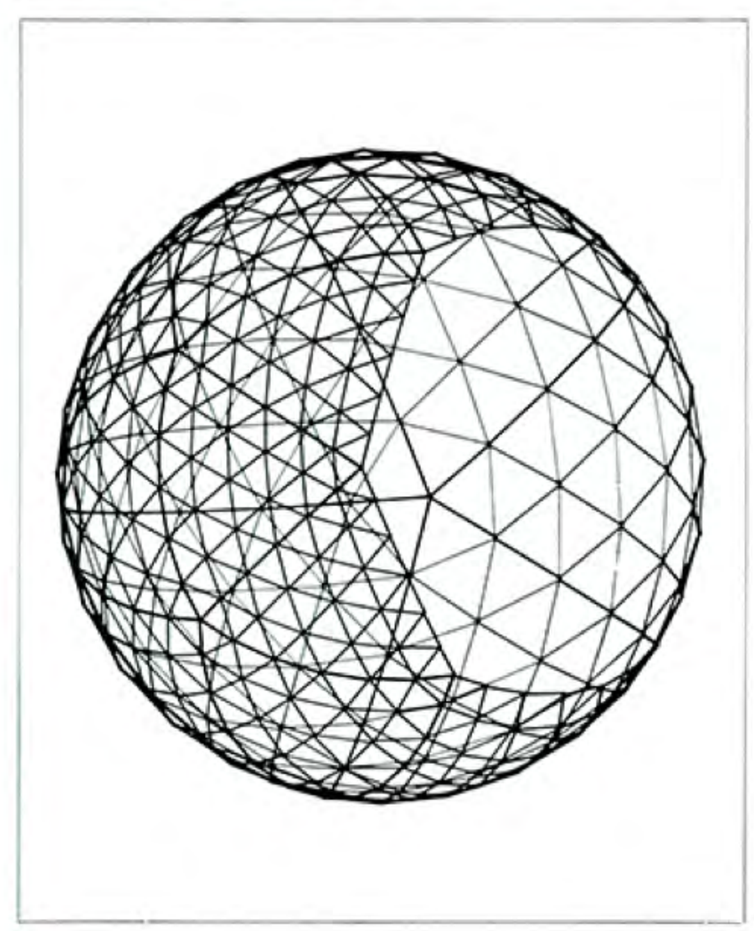


Below, left and right, top and side views of a structural system from the film.

Below, part of a film programmed by Ronald Resch to calculate Buckminster Fuller's geodesic dome.







Computer-animated movies

Kenneth C. Knowlton

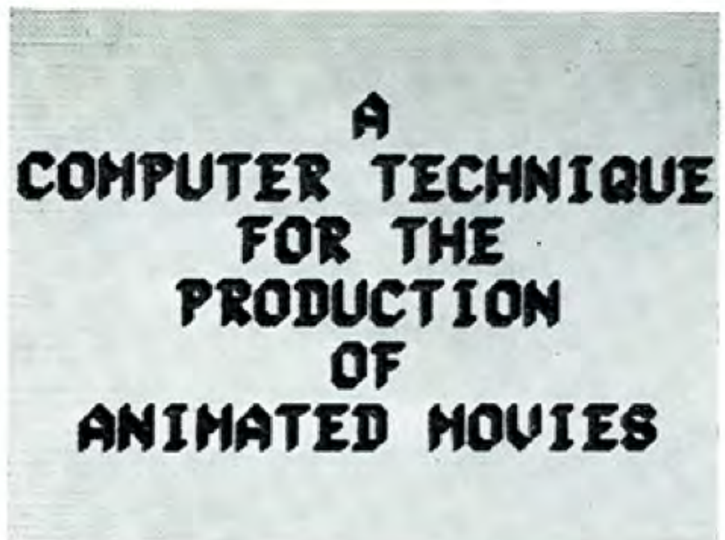
Computer-produced movies are playing an increasing role in technical education and research. A dozen computer films, made at Bell Labs during the period 1963–1967, are cited as demonstrating the dynamic graphical power of computers and automatic film-recording equipment. Movies made by computer are seen to be a significant adjunct to education and scientific investigation, particularly in areas amenable to mathematical and logical treatment and where results can or should be visualized.

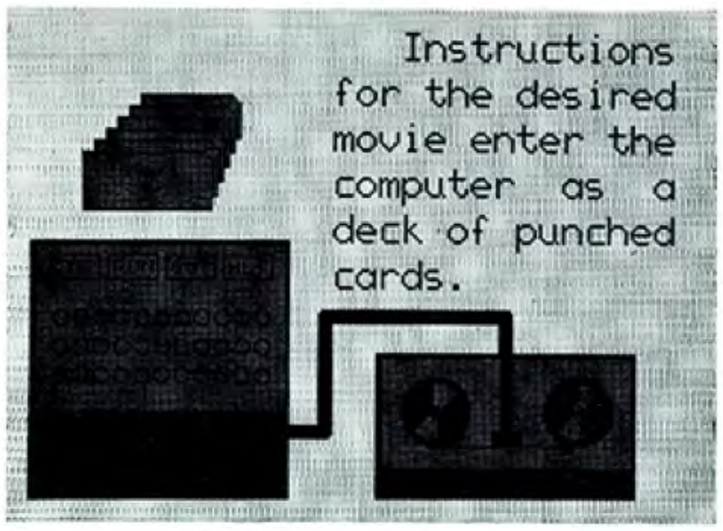
An electronic microfilm recorder can plot points and draw lines a million times faster than a human draughtsman. This machine and the electronic computer which controls it thus make feasible some kinds of movies which heretofore would have been prohibitively intricate, time-consuming, and expensive to draw and film.

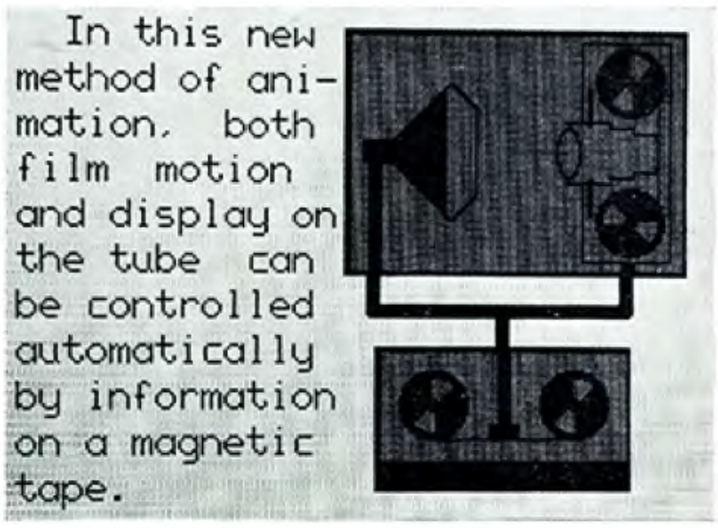
The microfilm recorder consists essentially of a display tube and a camera, and it understands only simple instructions such as those for advancing the film, displaying a spot or alphabetic character at specified co-ordinates, or drawing a straight line from one point to another. Though this repertoire is simple, the machine can compose complicated pictures or series of pictures from a large number of basic elements; it can draw 10,000 to 100,000 points, lines, or characters per second.

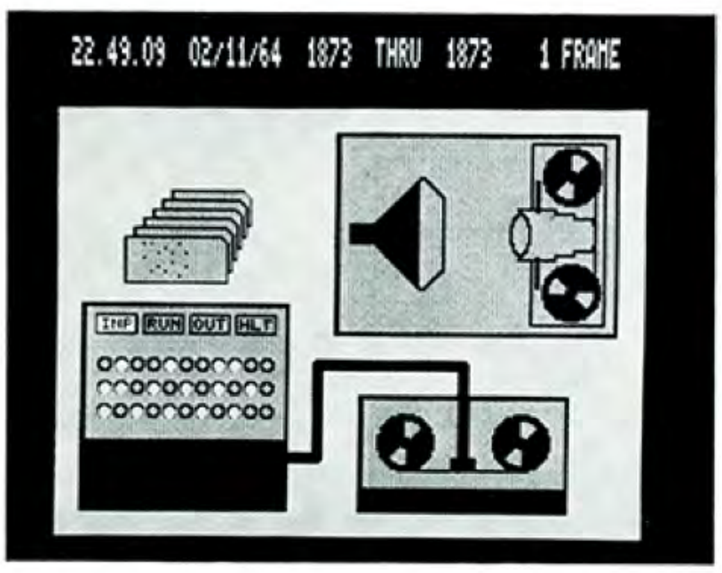
This film-exposing device is therefore fast enough to turn out, in a matter of seconds, a television-quality image consisting of a fine mosaic of closely-spaced spots, or fast enough to produce simple line drawings at rates of several frames per second. The important questions thus are not whether sufficiently detailed pictures can be produced quickly enough; they are, rather, whether sufficiently powerful and useful programming languages and techniques can be devised, and whether the resulting computation times are reasonable.

The answers to these questions are definitely yes: useful techniques can be and have been developed, and computation times for most purposes are quite reasonable. This will be demonstrated with a number of computer-produced movies made at Bell Telephone Laboratories during the past few years, grouped under the two headings of education and research. These films were all produced by programming the IBM 7094 computer to run the Stromberg-Carlson 4020 microfilm recorder. The two main programming languages used were FORTRAN with microfilm commands added and the author's mosaic-picture system called BEFLIX. Unless otherwise noted in the description of a particular film, FORTRAN was the language used.









Frames from a film on computer animation by K. C. Knowlton, explaining this technique. The pictures were made by a mosaic method in which a shade of grey is specified for each tiny square. Among the frames are those that explain how punched cards, bearing coded instructions, are fed into the computer which calculates numerical picture descriptions and stores them on magnetic tape.
The technique of producing this film is called the Beflix movie system and the film itself demonstrates how it works.
(Beflix is derived from Bell Flicks.) All the films illustrated here were produced at Bell Telephone Laboratories in New Jersey.

In these filming projects, the computer has played two distinct roles: always that of a high-powered drafting machine, and sometimes, particularly important in scientific and mathematical areas that of a calculating machine which determines the consequences of mathematical and logical statements. In the latter role, the computer typically accepts a description of a hypothetical system and first determines the successive states of this system by following differential equations or other laws supplied; it then uses its drawing capabilities to render a series of views of the resulting events.

The computer and automatic film recorders, because of their high speeds of calculation and display, make feasible the production of some kinds of films that previously would have been far too expensive or difficult. Costs for the films cited have fallen in the range of $200 to $2,000 per minute; the cost for the corresponding hand-animated film would be at least twice as much in the easier cases; in other cases it would have been entirely impractical to undertake the job at all without a computer.

The computer offers these further advantages: there are few intermediaries and few delays between the producer and the film-making mechanism, thus tremendously speeding up the overall process and minimizing communication problems. This speed, ease, and economy of computer animation permits the movie-maker to take several tries at a scene—producing a whole family of film clips—from which he chooses the most appealing result, a luxury never before possible.

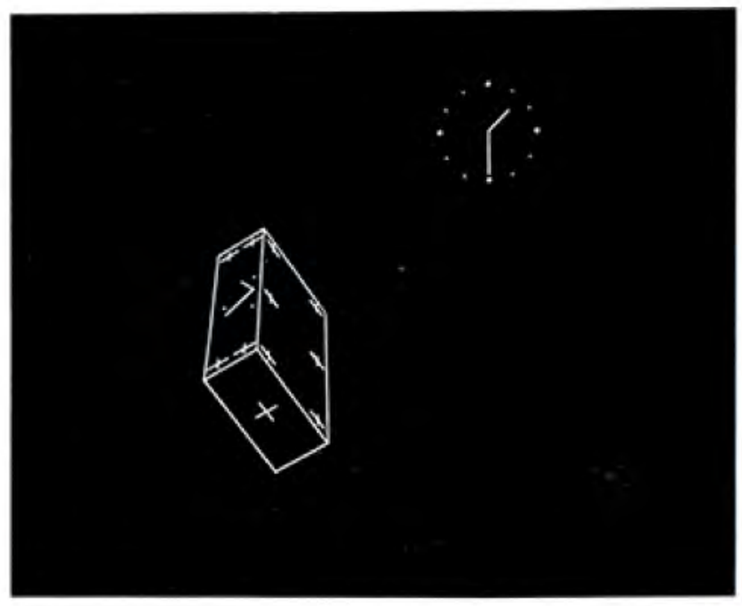
The first computer film produced at Bell Labs, made in 1963 by E. E. Zajac, showed the result of a simulation of the motion of a communications satellite. The problem under study was the orientation and stabilization of the satellite so that one end, and hence the antenna, pointed constantly toward the earth. The orienting force was the gravity gradient torque—which results from one end of the elongated satellite being slightly closer to the earth—and stability was achieved by viscous-coupled gyros which damped out oscillatory motion. The simulation required numerical integration of complicated differential equations; results were presented as perspective drawings showing position and orientation of the satellite and its gyros as a function of time. This still is a composite from several frames of this film,

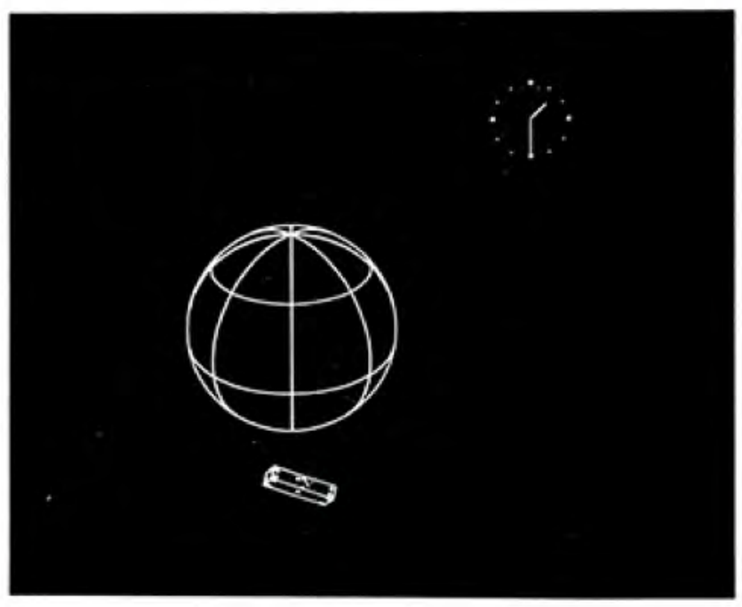
showing the earth, the box-shaped satellite in several positions, and a multiply-exposed clock used to count orbits. This film was a triumph not particularly because it helped Zajac in his study but because it was an excellent way for him to explain the results to someone not thoroughly familiar with the problem.

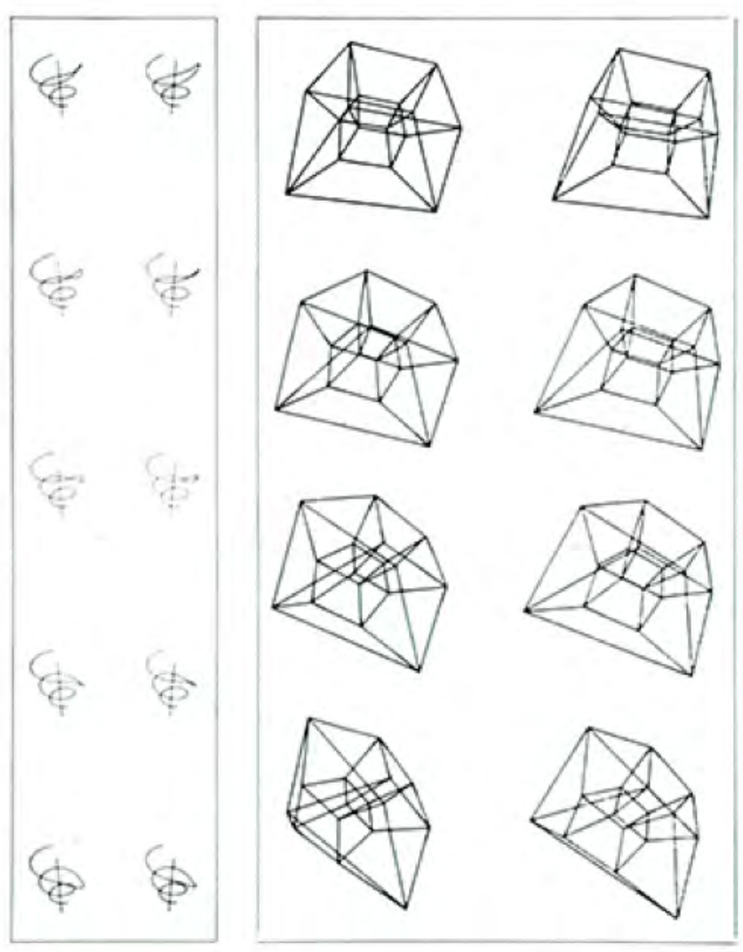
A mathematical construction is demonstrated in four successive stereo pairs from a film by A. M. Noll. These are views of a four-dimensional hypercube projected mathematically down onto three dimensions and then twice projected to two dimensions—onto slightly different picture planes for the left and right eye. (One form of this film has side-by-side images as shown, for crosseyed viewing; another version is designed for a special projector and the familiar 3-D crossed-polaroid glasses.) This was part of an interesting but thus far unsuccessful attempt to give people an intuitive feeling for four-dimensional objects by exposing them to a variety of these objects manipulated in 4-space by such operations as rotation about their four mutually-perpendicular axes.

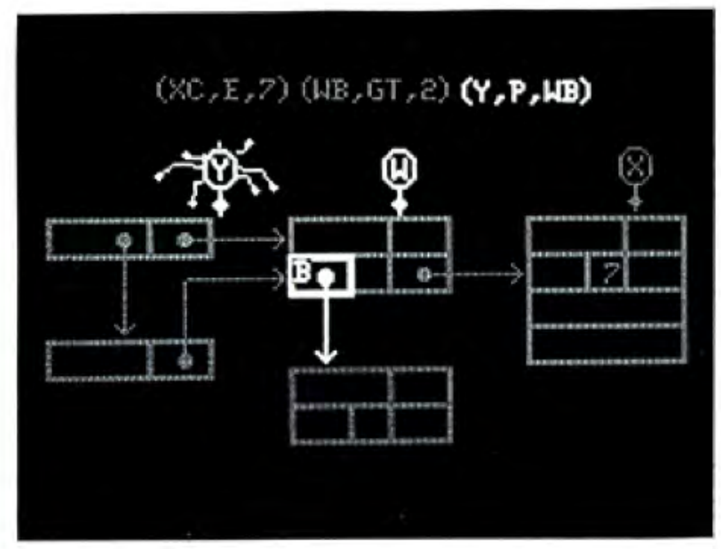
Noll's stereo display facilities have been used for a variety of other scientific and artistic purposes, including such diverse applications as experimental documentation for choreography and the depiction of a part of the hearing process in the inner ear. A sequence of stereo pairs from the latter appears in one of the stills. This film shows, by grossly exaggerated motion, the calculated deflections of the basilar membrane due to a variety of sound waves impinging on the eardrum: step functions, impulses, sine waves of different frequencies, etc.

A short film made in connection with Expo 67 by Kenneth C. Knowlton and Stan Vanderbeek, a producer of experimental and avant-garde films, is a visual play upon the theme of the fair, 'Man and his World', in several languages. It was produced by programming in a special set of macro instructions which, in turn, were written in terms of BEFLIX operations.









Above, A frame from a film produced by Beflix movie system, about the list processing language L^6. At the top is a partial line of L^6 coding and below it a representation of a linked structure in the computer's memory, with 'bug' (i.e. base register) Y crawling toward the bottom centre to point to the block that W's block's B-field points to.

Top left, Satellite as seen in an orbiting reference frame. From: *Simulation of a two-gyro, gravity-gradient attitude control system.*

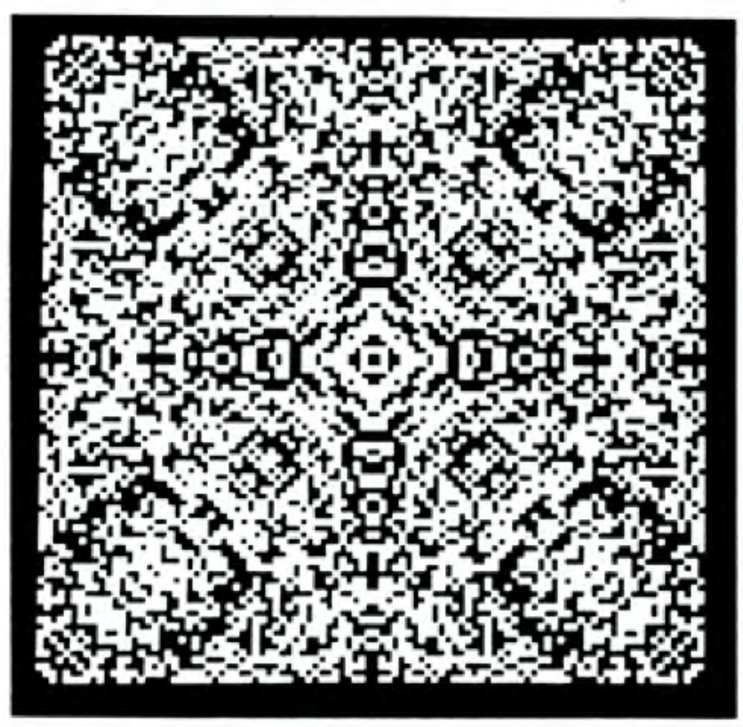
Left, Box representing a satellite changes attitude according to a mathematical model of the Earth's gravity. From: *Simulation of a two-gyro, gravity-gradient attitude control system.*

Far left, Sequence of stereo pairs from Lummis and Noll Film *Simulated basilar membrane motion.* The spiral represents the basilar membrane of the inner ear; vertical motions of the membrane, resulting from sound waves on the eardrum, are greatly exaggerated.

Left, Four successive stereo pairs from a film by A. M. Noll designed for stereo viewing. Portrayed here is a rotating 4-dimensional hypercube projected into 3 dimensions and subsequently twice onto two picture planes, thus producing two slightly different views for the left and right eyes. The 3-d effect may be seen by cross-eyed viewing of these pairs.

Right, A frame from a film produced by B. Julesz and C. Bosche for experiments in human vision and perception. One pie-shaped eighth of this picture is 'noise' produced by a pseudo-random number generator; the resulting pattern was then reflected seven times to produce the overall pattern with striking symmetries.

Far right, Still from a short colour film by Stan Vanderbeek and K. C. Knowlton produced in connection with Expo 67. This movie was programmed in a higher-level set of macro instructions, defined in terms of Beflix instructions, designed specifically for manipulating textual information in intricate ways.



An architectural project

Indeterminate dimensions in architecture

John Weeks

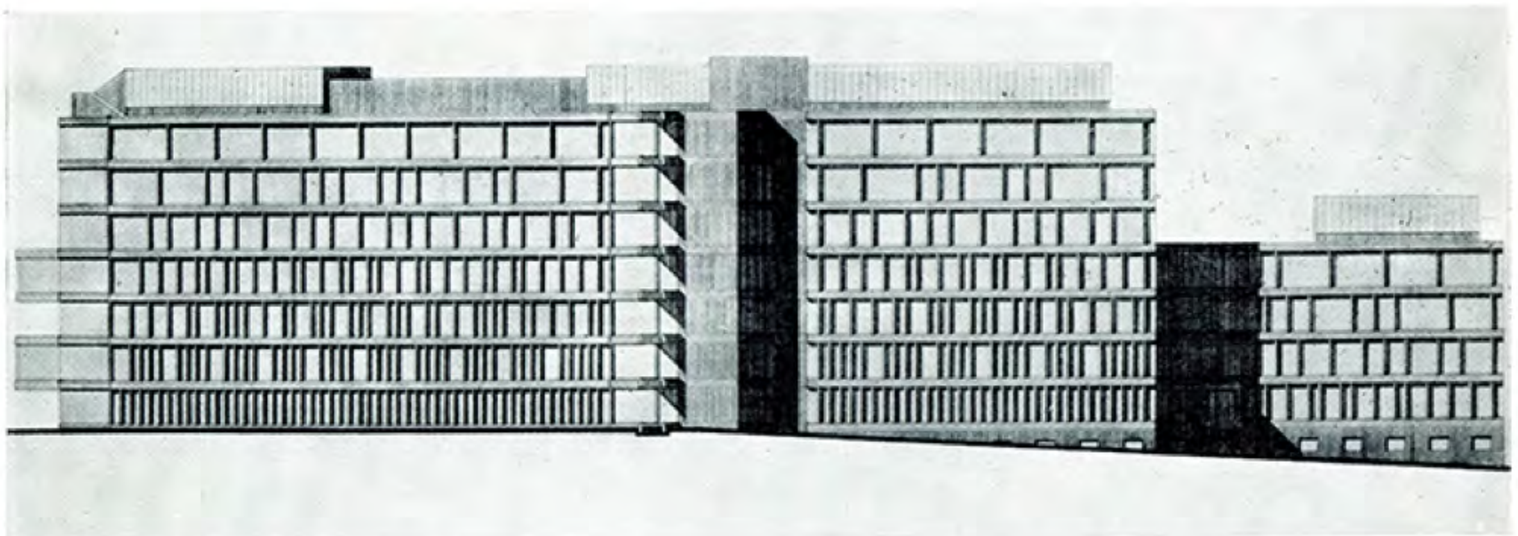
Works of architecture, recognized as such, normally have their dimensions determined by their designers. However, in a hospital building under construction at Northwick Park, North London, by Spring, 1968,* the visible structure has its appearance determined wholly as a result of a computer-orientated programme.

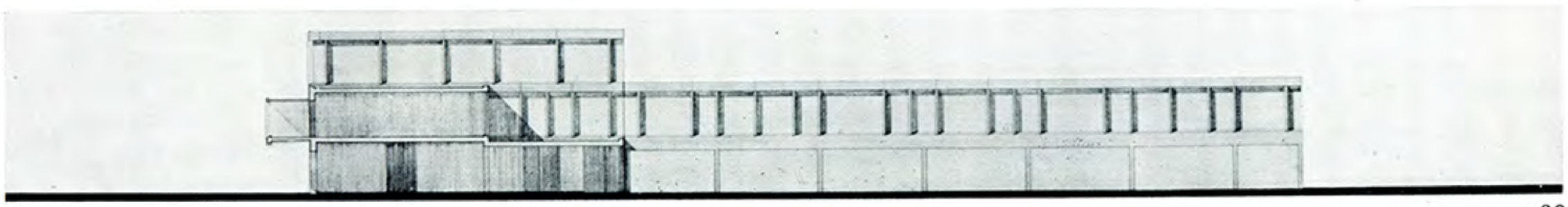
The rational basis for the decision to abandon an architect-designed dimensional system stems from the need to produce a structure made up of as large a number of identical units as possible, to enable economies to be obtained out of standardization.

The building complex comprises a cluster of buildings of different heights and shapes, but the same structural elements, a mullion and a beam, are used throughout. Design parameters such as height and loading characteristics were fed into the stress computations. This was the only design process which controlled the external appearance. The impact of the standard analysis on the varying conditions has resulted in buildings which are everywhere different, since the design parameters differ, even though they are made of identical structural elements. The standard structural mullions are grouped at intervals which enable them to be equally stressed whether they are at the bottom of multi-storey buildings or on the upper level of a two-storey building. The apparently random intervals between the mullions are the direct expression of an objective ordering process. The appearance of the buildings was not determinable until the results of the calculations were seen; the designers of the building did not intervene.

*Architect: John Weeks of Llewelyn-Davies Weeks Forestier-Walker & Bor; Engineers: Peter Dunican; Nigel Thompson of Arup & Partners.

Below, two buildings from a hospital complex under construction—a research building and an ambulant patient department. Identical structural elements are used throughout and the intervals between structural elements follow a stress computation without architectural modification.





Computer graphics

Computer art

Jasia Reichardt

'Absolute power will corrupt not only men but machines'. In his article 'Inventing the future', Dennis Gabor put forward some of his expectations and fears about the function of the machine in society of the future. The above comment was made with reference to electronic predictors, which, having built up a reputation for accuracy, become aware of their infallibility (since they are learning machines) and begin to use their newly-discovered power.

So far electronic predictors have not become a reality. However, another postulation made by Professor Gabor in the same article (*Encounter* May 1960) appears to be very relevant indeed. Will the machine—he wondered—cut out the creative artist? 'I sincerely hope', Gabor continued, 'that machines *will* never replace the creative artist, but in good conscience I cannot say that they never *could*.'

The computer performs various functions which in the broader sense seem to be the act of intelligence, i.e. manipulation of symbols, processing of information, obeying complex rules and even learning by experience. Nevertheless the computer is not capable of making abstractions, and is devoid of the three prime forces behind creativity—imagination, intuition and emotion. Despite this, the computer as a budding artist has been making an appearance since about 1960. In 1963, the magazine *Computers and Automation* announced a computer art contest which has been held annually ever since. The winning design usually appears on the cover of the August issue and the runners-up are given coverage inside. The designs vary considerably although they share certain characteristics, i.e. they are only in black and white, there is an emphasis on geometrical shapes, and they are basically linear. As designs, the computer products look bare and minimal and represent little else than the initial stage in what may be a far more challenging adventure in merging rather than relating creative activity with technology.

Computer graphics range from static compositions to frames of motion pictures, and could be divided into two main categories; 1. those which approximate to pure design or art; and 2. those which are not made with any aesthetic end in view but which serve to visualise complex physical phenomena.

At a conference dealing with computers and design in 1966 at the University of Waterloo, two statements were made which might at first have appeared unnecessarily boastful and heroic: 1. 'The computer simply elevates the level of possible creative work'. 2. 'The computer can handle some elements of creativity now—by current definitions of creativity'. Both these statements were made by scientists, although there exists a considerable scepticism amongst scientists as well as artists about the validity of the various experiments in this area. Others claim that the computer provides the first real possibility of a collaboration between the artist and the scientist which can only be based on each other's familiarity with both media.

The first commercial computer was marketed in 1950. Ten years later the Boeing airplane company coined the term 'computer graphics'. They used graphics for purely utilitarian purposes. These were employed, for instance, to verify the landing accuracy of a plane viewed from the pilot's seat and the runway. They were used to establish the interaction of range of movements of the pilot in his environment of the cockpit. To this end they created a 50 percentile pilot and studied him in animation. All the drawings and the animation were done with a computer. Other experiments included visualising acoustic graphs in perspective and the production of very accurate isometric views of aeroplanes.

There are two main methods at present by which computer graphics are made. In the first place there are the ink drawings produced by a computer-driven plotter. The plotter, a moving pen, conveys the image direct to paper. Drawings can also be made with the images composed of different letters or figures and printed out on a typewriter which is automatically operated by the computer. In the second category are the computer graphics made on the cathode ray tube with an electron beam electrically deflected across the phosphorescent screen to produce the desired picture. A camera photographs the image in various stages and an electronic console is used to control the picture and to advance the film. Static graphics can be obtained by making en-

larged photographs from the film. Whether the pictures are made for analytical purposes or just for fun, the computer graphic is a visual analogue to a sequence of calculations fed into the computer.

The now 'antique' Sketchpad which has been used for numerous experiments of this type at Massachusetts Institute of Technology since 1962, was one of the first to produce drawings on a cathode ray tube demonstrating the sort of possibilities which are inherent in the system. One could draw with a light pen on the screen simple patterns consisting of lines and curves. The operator could impose certain constrictions on the patterns he was making by demanding, for instance, by pushing the appropriate button, that the lines be made parallel, vertical or straight. At that stage the operator could not demand something as complex as a solution to the following problems: 'These lines represent a piece of structure of a certain thickness and size and with certain cross-section characteristics, made of a particular material and obeying specific physical laws—depict this under a stress of so many pounds per cubic foot'.

Today the process whereby a design is adjusted at any stage of its development is already quite familiar. If the operator alters the design on the cathode ray tube with a light pen, the computer converts the altered design into electronic impulses using them to modify the pre-existing programme held in the computer's memory store. The altered design then appears on another cathode ray tube. This system is widely used by General Motors for car body design. The image on the cathode ray tube can be shifted, rotated, enlarged, seen in perspective, stored, recalled and transferred to paper with the intermediate stages recorded on film. Since the process suggests inhibiting difficulties to someone who is not an electronic engineer, it may be difficult for an artist to imagine how he could possibly make use of a computer. The solution to the problem lies in collaboration. There are three stages in the process of producing computer graphics, or for that matter using the computer in most cases. In the first place the communicator presents his ideas or message which is to be communicated to the computer. Secondly, the communication specialist decides, unless there are specific instructions, whether the problem should be solved graphically, verbally or as a combination of both. Thirdly, the computer specialist selects the appropriate computer equipment and interprets the problem into machine language, so that the computer can act upon it. The Korean artist Nam June Paik has gone so far as to claim that in the same way that collage technique replaced oil paint, so the cathode ray tube will replace canvas. However, so far only three artists that I know of have actually produced computer graphics, the rest to date having been made by scientists.

At the moment the range of visual possibilities may not seem very extensive, since the computer is best used for rather more schematic and geometric forms, and those patterns and designs which are logically simple although they may look very intricate. One can programme the computer to produce patterns based on the golden section or any other specific premise, defining a set of parameters and leaving the various possibilities within them to chance. In this way certain limitations are provided within which the computer can 'improvise' and in the space of 20 minutes race through the entire visual potential inherent in the particular scheme. Programmed to draw variations with straight lines it is conceivable, though perhaps unlikely, that one of the graphics produced may consist simply of one line placed exactly on top of another. If there is no formula for predicting each number or step in a given sequence, the system by which this type of computer graphic comes about can be considered random.

Interesting results can be obtained by introducing different random elements into the programme. One can, for instance, produce a series of points on a surface which can be connected in any way with straight lines, or one can instruct the computer to draw solid geometric shapes without specifying in what sequence they are to be superimposed, leaving the overlapping of the shapes to chance.

A fascinating experiment was made by Michael Noll of the Bell Telephone Laboratories whereby he analysed a 1917 black-and-white, plus-and-minus picture by Mondrian and produced a number of random computer graphics using the same number of horizontal and vertical bars placed within an identical overall area. He reported that 59% of the people who were shown both the Mondrian and one of the computer versions preferred the latter, 28% identified the computer picture correctly, and 72% thought that the Mondrian was done by computer. The experiment is not involved either with proof or theory, it simply provides food for thought. Noll, who has produced a considerable number of computer graphics and animated films in America, sees them as a very initial stage in the possible relationship between the artist and computer. He does not consider himself as an artist by virtue of his graphic output. He sees himself as someone who is doing preliminary explorations in order to acquaint artists with these new possibilities.

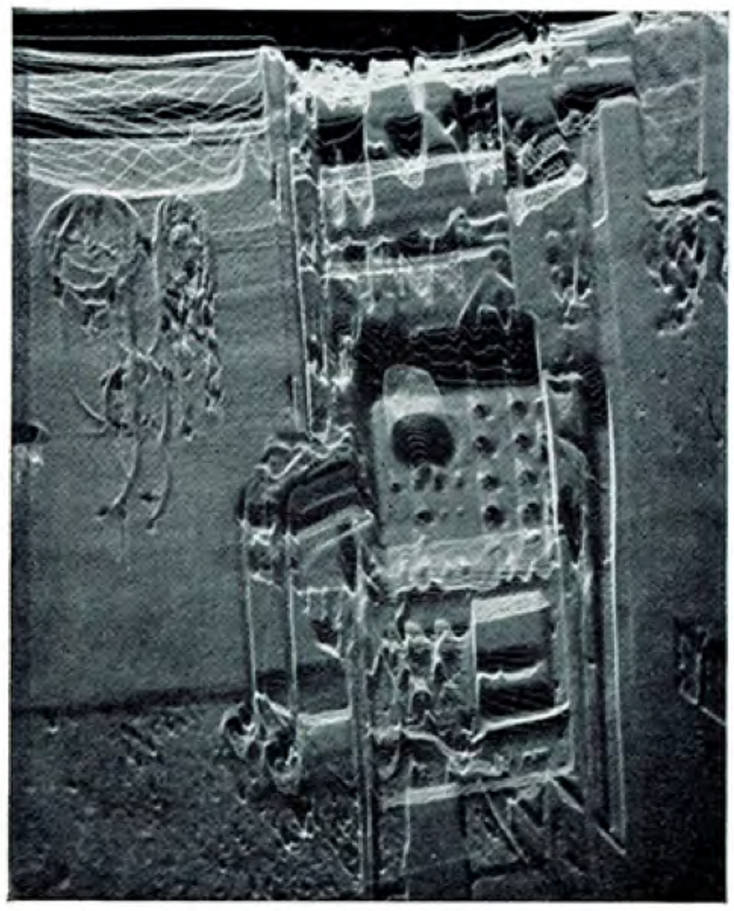
Perhaps even less credible than the idea of computer-generated pictures is the idea of computer sculpture. That too has been achieved. A programme for a three-dimensional sculpture can be fed into a computer—the three-dimensional projection of a two-dimensional design. It can be transferred via punched paper tape to a milling machine which is capable of producing the physical object in three dimensions.

The computer is only a tool which, at the moment, still seems far removed from those polemic preoccupations which concern art. However, even now seen with all the prejudices of tradition and time, one cannot deny that the computer demonstrates a radical extension in art media and techniques. The possibilities inherent in the computer as a creative tool will do little to change those idioms of art which rely primarily on the dialogue between the artist, his ideas, and the canvas. They will, however, increase the scope of art and contribute to its diversity.

Experiments with Data Processing

Experiments with data-processing equipment in visual design courses for science and engineering students conducted by Robert Preusser, Associate Professor of Visual Design, Department of Architecture, Massachusetts Institute of Technology.

Transformation of images is achieved by using electronic data-processing equipment. The forms are picked up by means of a digital TV camera and fed into a computer. The images are recorded, domains traded and the final designs displayed on a high-resolution oscilloscope. The digital TV system used in producing these designs was built at the Smithsonian Astrophysical Observatory for the celescope OAO satellite.

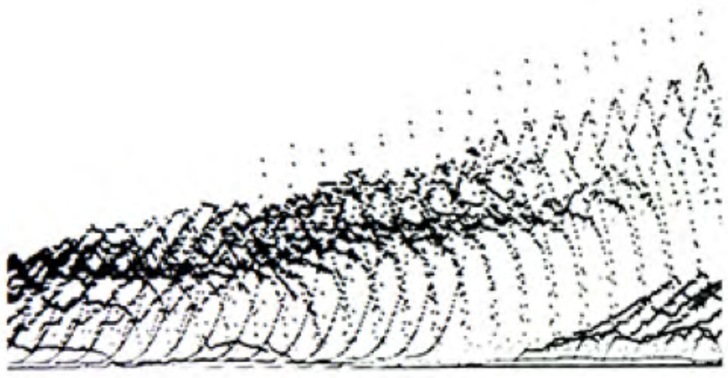


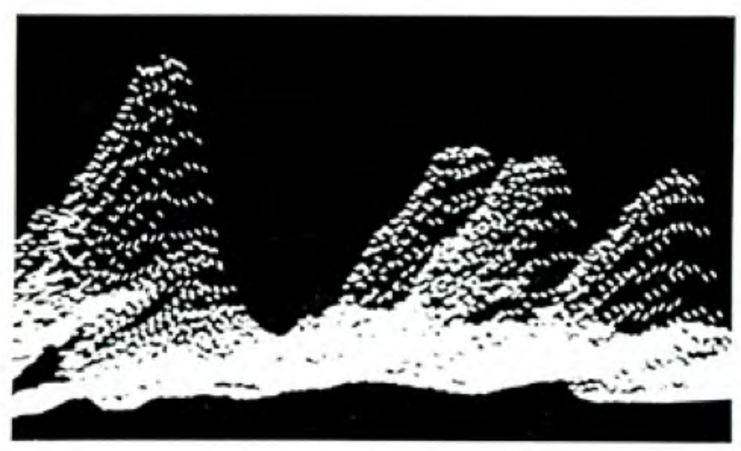
Left, *Self-portrait* by Efraim Arazi
The TV camera picked up the image of the oscilloscope which displayed a picture of itself

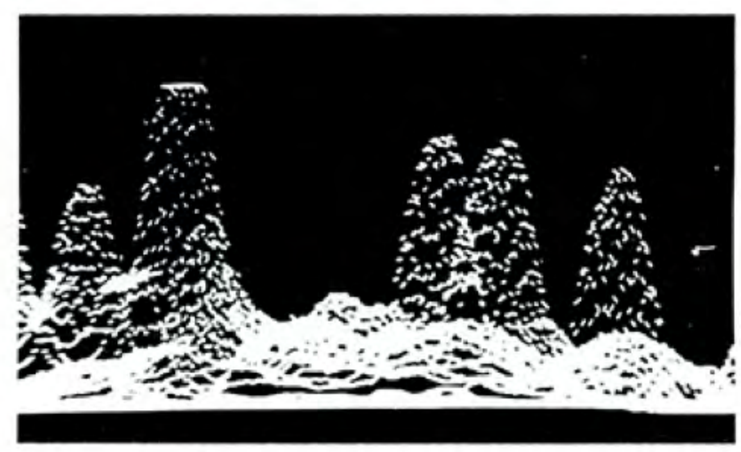
Below, Three random number generated patterns by Efraim Arazi

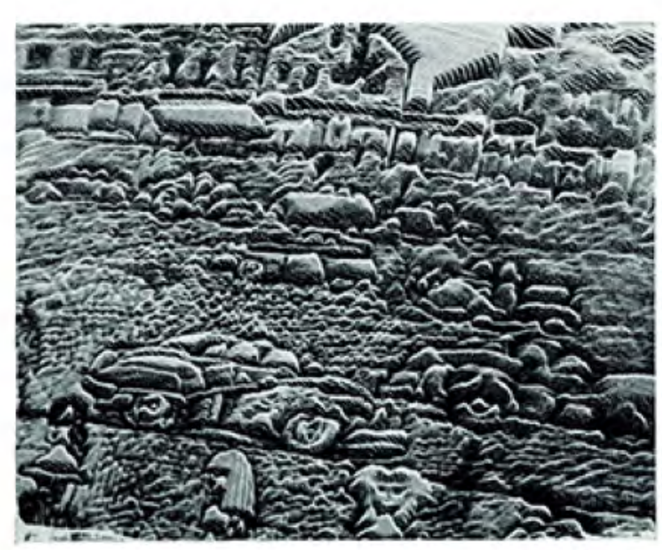
Bottom left, *Transformation of a relief surface* by Efraim Arazi

Bottom right, Two Steinberg drawings transformed by Efraim Arazi
Drawings were relayed from TV camera to oscilloscope and scanned photographically







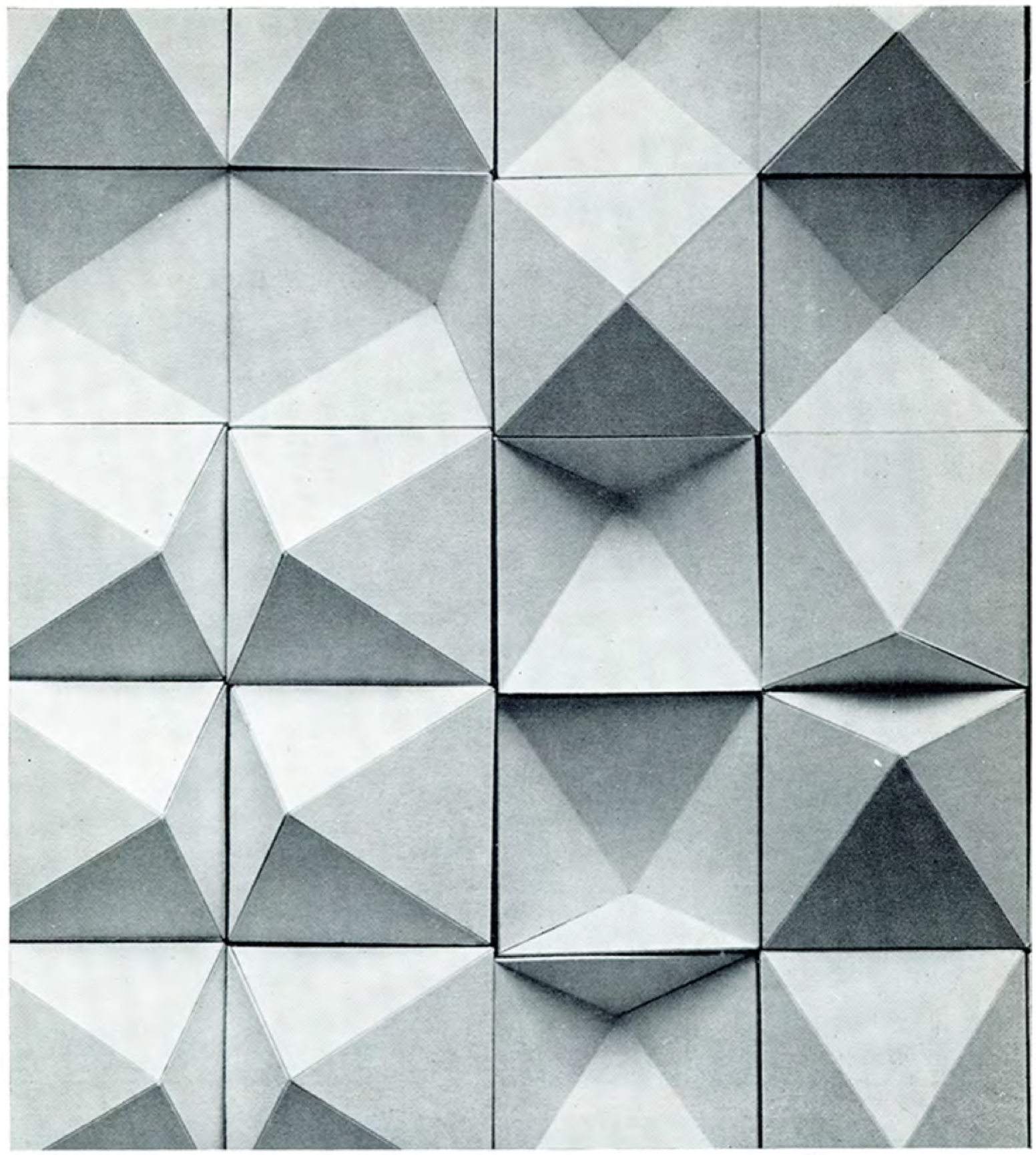


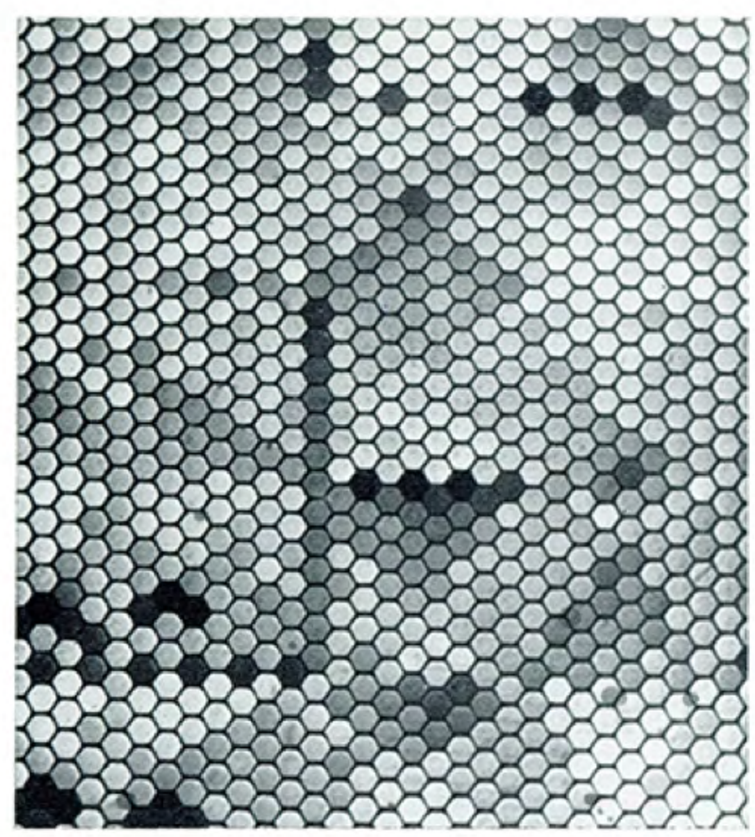
How the hexagonalized pictures were formed

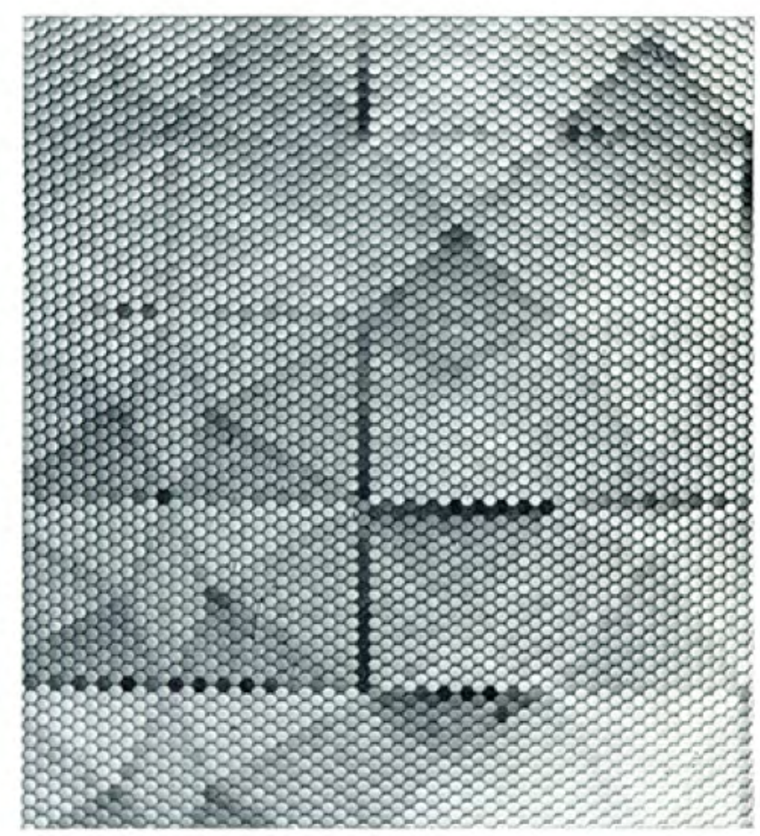
Robert Dick

A picture-to-magnetic tape conversion device was used to make the hexagons in the pictures. A cathode ray tube in the device displays an array of dots in sequence. A photocell behind the picture puts out a signal reporting the brightness of the point on the negative corresponding to the dot currently being displayed. This information is recorded on magnetic tape and can be played back so the tube displays the picture.

To make the hexagons the array was adjusted so that the dots formed equilateral triangles, the array which permits exact fitting together of hexagons. The brightness of the points on the picture corresponding to dots on the array was then read onto magnetic tape. For the playback, a camera was aimed at the face of the tube, slightly out of focus and with a hexagonal stop on the lens. The information on the magnetic tape was read out onto the tube face. Each dot throws a shadow of the aperture of the camera onto the film, forming an exposed spot on the film in the shape of the hexagonal stop. These hexagons are formed on the film at points corresponding to the points they were derived from on the original film. The focus of the camera was adjusted so the hexagonal array on the film just filled the space. Because each dot on the screen had to illuminate an area on the film, it was necessary to record the pictures several times and play them back several times per exposure.







Top, Relief surface used for brightness translation by Robert Dick

Above left, Hexagonalized value translation of a relief surface (small scale) by Robert Dick

Above right, Hexagonalized value translation (large scale) of a relief surface by Robert Dick

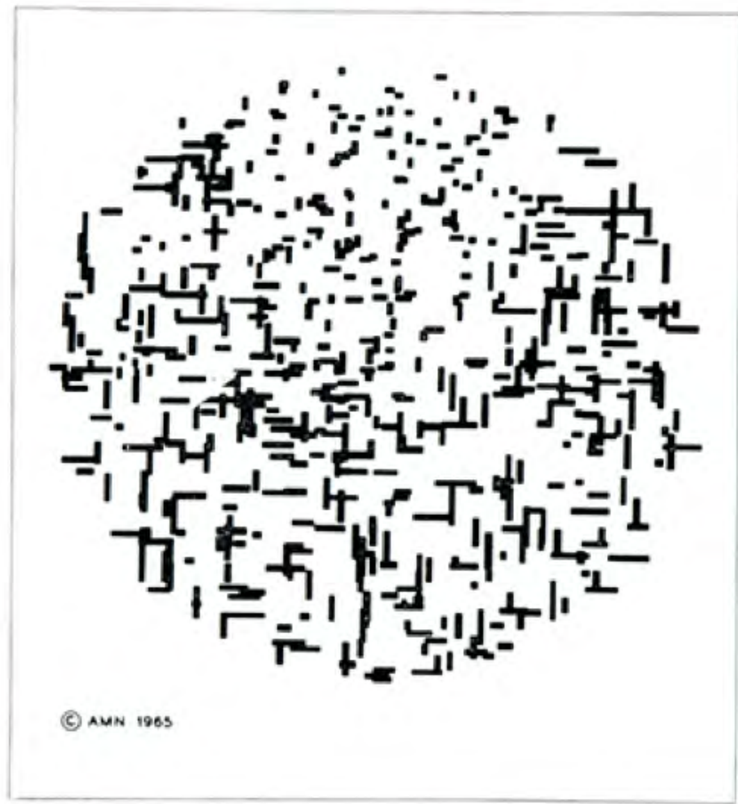
A subjective comparison of Piet Mondrian's 'Composition with lines' 1917

A. Michael Noll

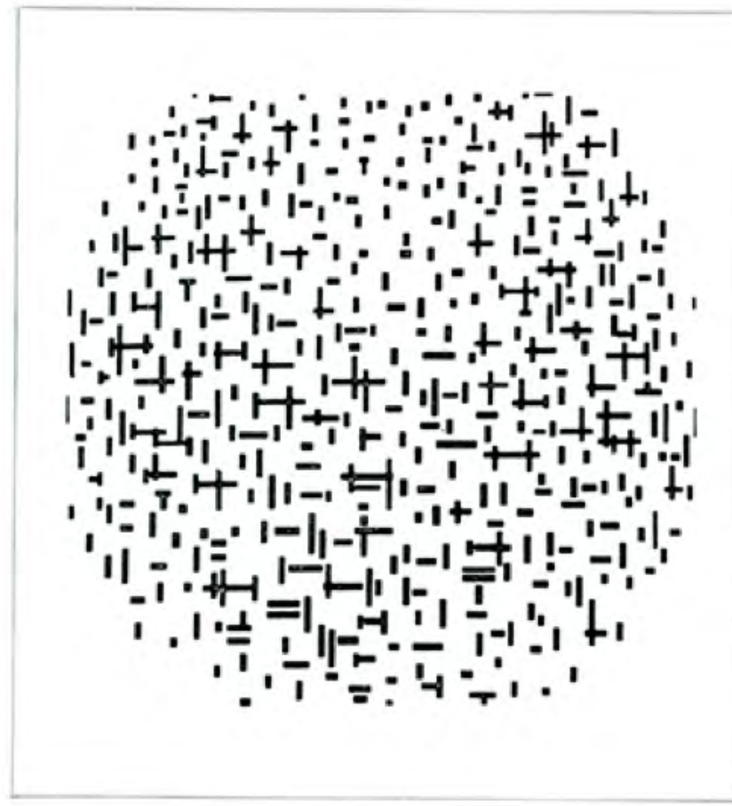
A digital computer and microfilm plotter were used to produce a semi-random picture similar in composition to Mondrian's painting *Composition with lines*. Reproductions of both pictures were then presented to 100 people who were asked to identify the computer picture and to indicate which they preferred. Only 28% were able to correctly identify the computer-generated picture, while 59% preferred the computer-generated picture. Both percentages were statistically different from selections based on chance according to a binomial test.

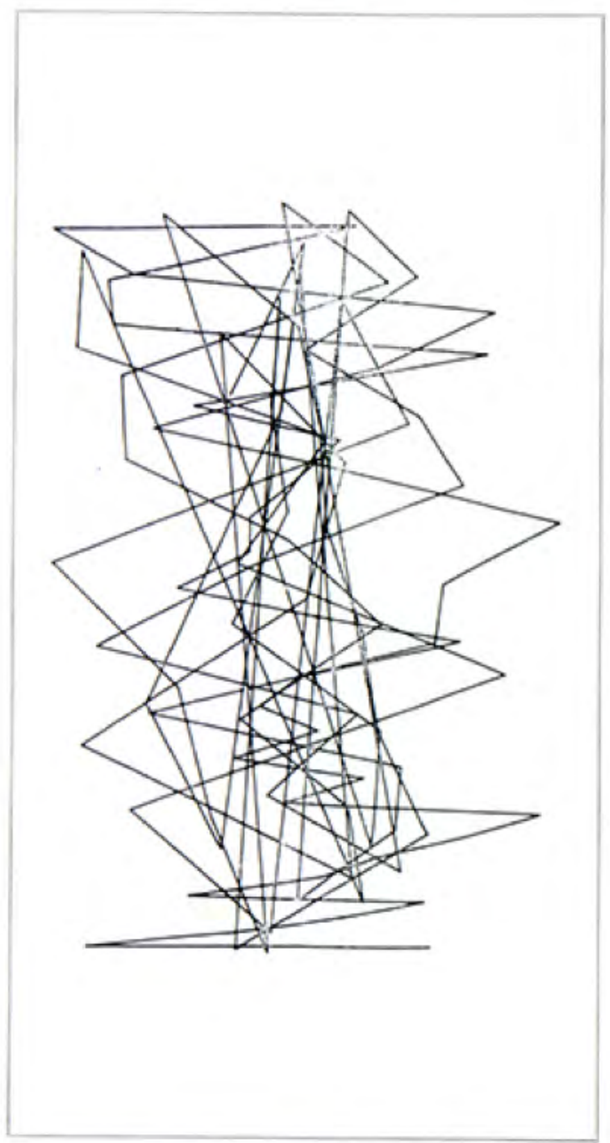
Below, a subjective comparison of Piet Mondrian's *Composition with lines*, 1917, and a computer-generated picture, by A. Michael Noll of Bell Telephone Laboratories, Murray Hill, New Jersey.

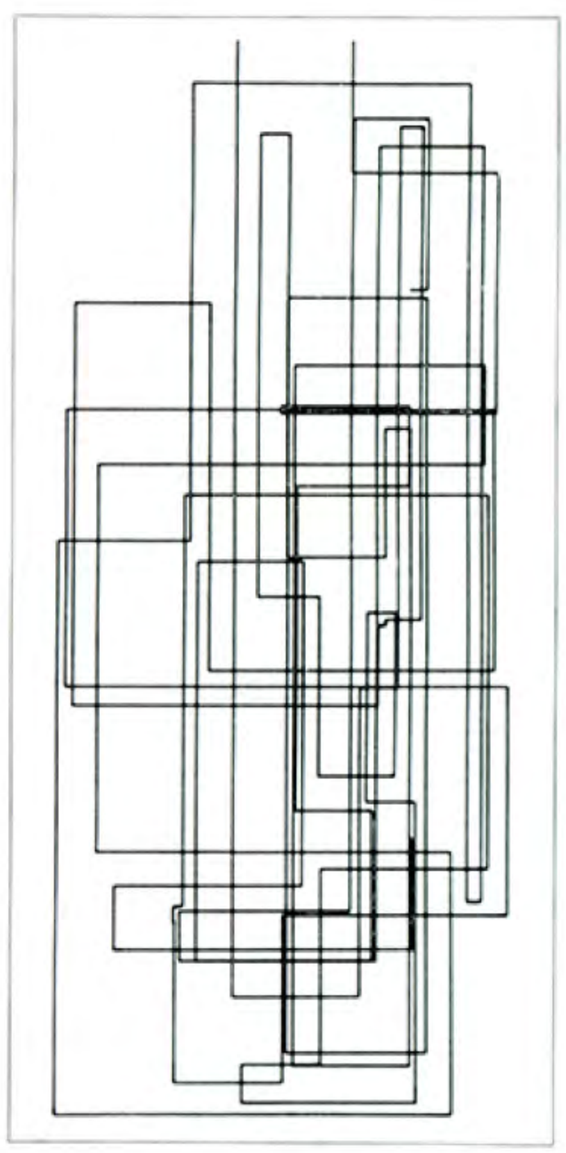
Below right, four further computer-generated pictures based on Mondrian's *Composition with lines*.
All works by A. Michael Noll © AMN.

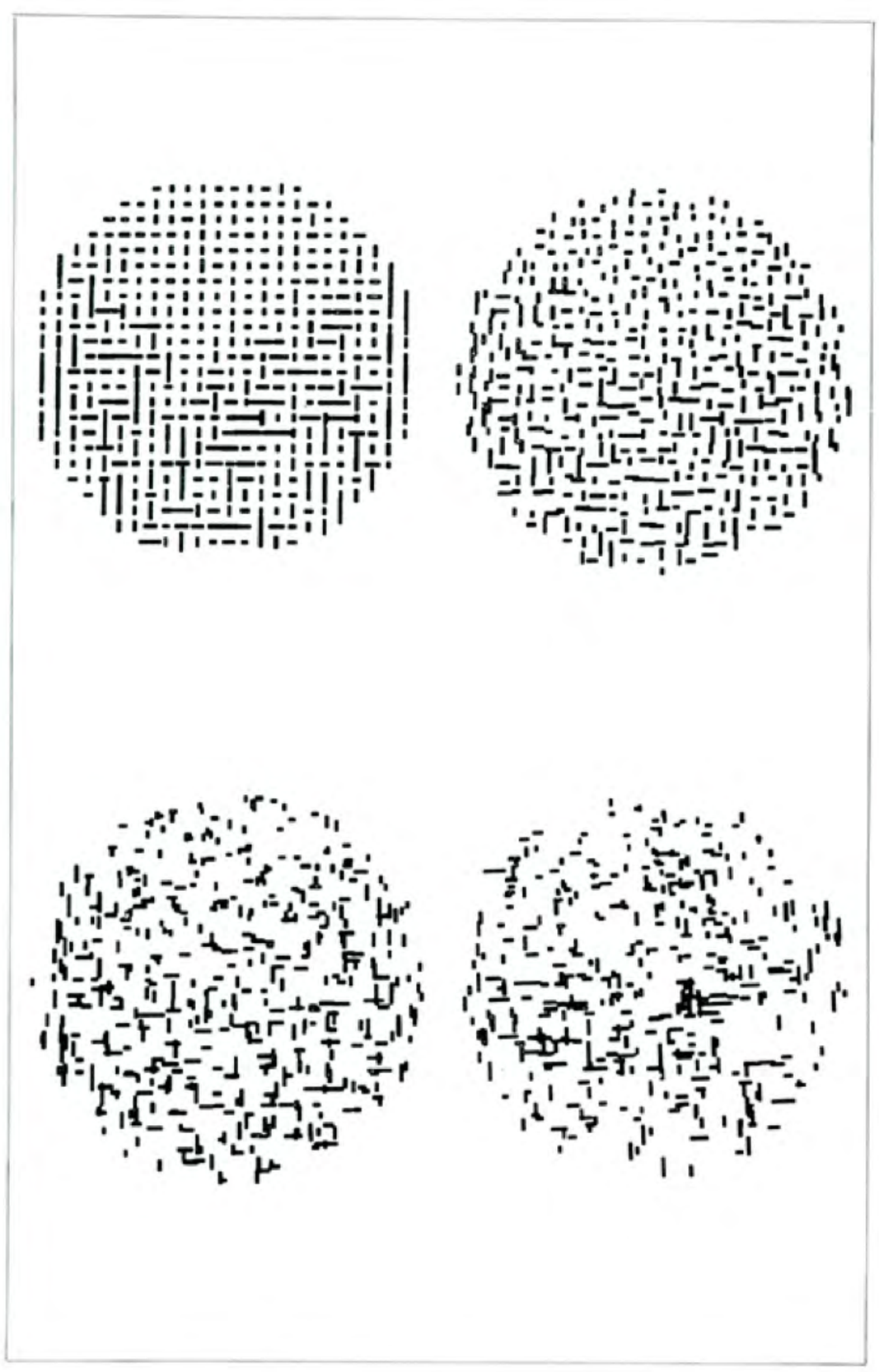


Piet Mondrian's *Composition with lines* 1917









Above left, *Gaussian Quadratic* by A. Michael Noll. The horizontal positions of the end points of the line segments have a Gaussian or normal curve distribution; the vertical positions increase quadratically until they reach the top, except that when any vertical position measured is greater than the constant height, then the constant height is subtracted. The result is a line that starts at the bottom of the drawing and randomly zigzags to the top in continually increasing steps. At the top, the line is translated to the bottom to once again continue its rises.
Above right, *Vertical-Horizontal No. 3* by A. Michael Noll. 101 randomly selected points (with x-coordinate less than the y-coordinate) were connected by vertical and horizontal line segments to form a single line. The lines were determined under the condition that only one of the two coordinates was changed (alternatingly) from one point to the next.

Computer Technique Group from Japan

[Members of CTG : Haruki Tsuchiya (systems engineer) ; Masao Komura (product designer) ; Kunio Yamanaka (aeronautic engineer) ; Junichiro Kakizaki (electronic engineer) ; Makoto Ohtake (architectural designer) ; Koji Fujino (systems engineer) ; Fujio Niwa (systems engineer).]

Their computer graphics were done at the end of 1967 and beginning of 1968 at IBM Scientific Data Centre in Tokyo, with the help of IBM Japan. Programmes were in FORTRAN IV. The computers used were IBM 7090 for computer graphics and HITAC 5020 for computer poetry. Computer graphics were executed on a Calcomp 563 plotter.

The Computer Technique Group believe that the computer as an artistic medium will increase in importance in the future, and that already today the computer-produced images appear to be relevant to the current preoccupations in the visual arts. They write: 'Computer art says something about time, space, and existence. An object in space is transformed via magnetic tape into a set of units of information, or bits, conveyed throughout via two simple statements, 1 or 0.'

Their graphics fall into four categories: Nos 1–7: Deformations; Nos 8–11: Metamorphoses; Nos 12–21: Improvisations; Nos 22–24: Variations on a cubic pattern.

1. Kennedy in the net

A photograph of the late President Kennedy has been subjected to a process of deformation developed by CTG. Through a process of scanning every element is turned into a section of a net pattern.

Idea and programme by Haruki Tsuchiya (CTG)

2. Shot Kennedy No. 1

Data from the photograph is converted into straight lines converging at one point at the ear. This deformation programme can be applied to any pattern.

Idea and programme by Fujio Niwa (CTG)

3. Shot Kennedy No. 2

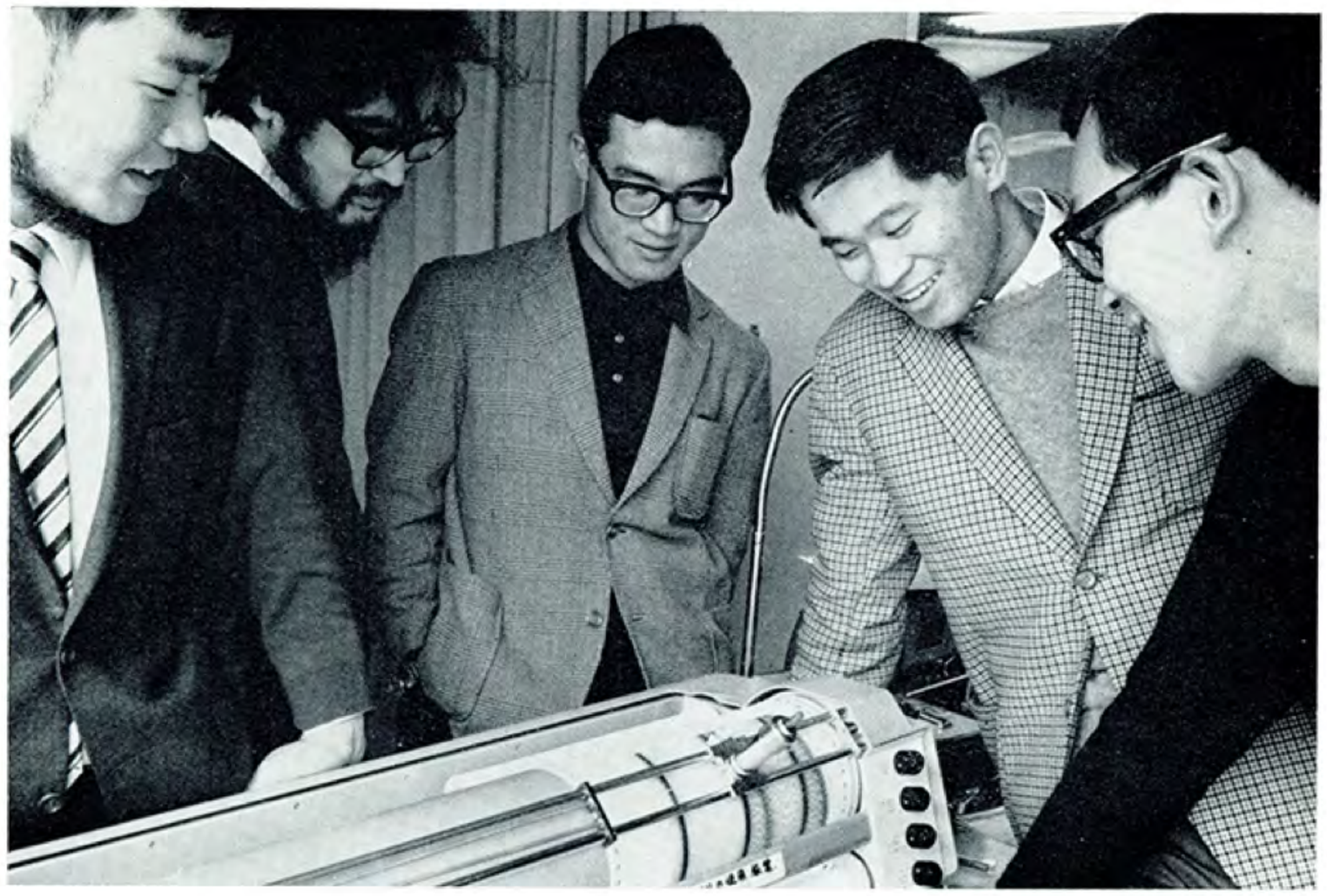
Data from a photograph of Kennedy is converted into straight lines converging at one of three points.

Idea and programme by Fujio Niwa (CTG)

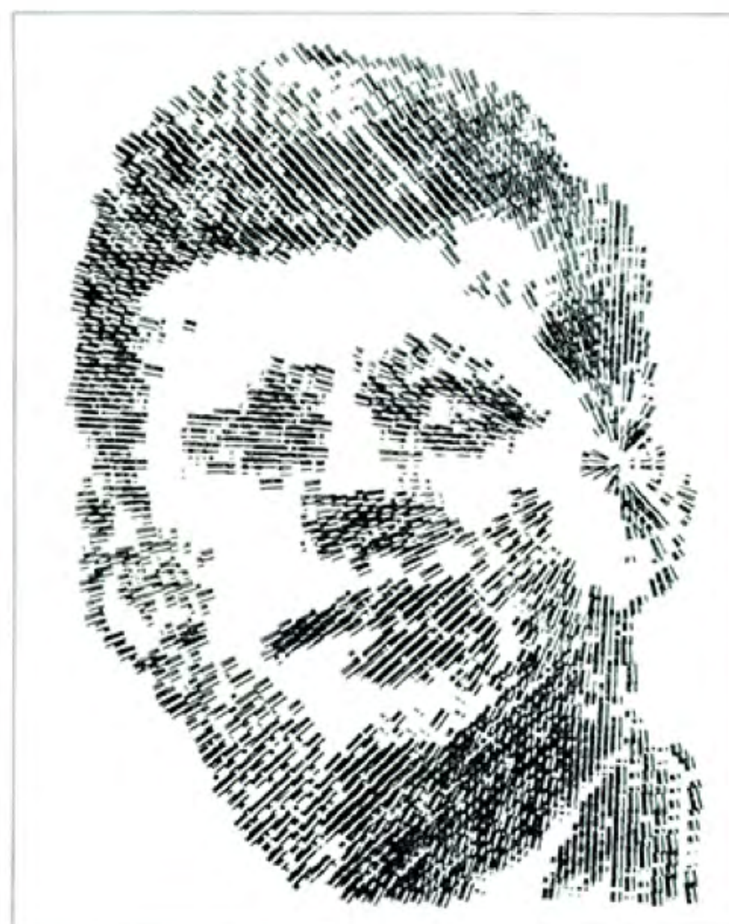
4. Diffused Kennedy

Data from a photograph of Kennedy is converted into a set of straight lines which are directed to one point, namely the eye.

Idea and programme by Masao Komura (CTG)



Members of CTG – Computer Technique Group, Tokyo:
left to right: Koji Fujino, Masao Komura, Kunio Yamanaka, Haruki Tsuchiya, Makoto Ohtake



Shot Kennedy No. 1

Diffused Kennedy

5. Kennedy in a rectangle

Data of a photograph of Kennedy is confined to a rectangle.

Idea by Masao Komura, programme by Fujio Niwa (CTG)

6. Kennedy in a dog

Data from a photograph of Kennedy is inserted into data from a photograph of a dog. The final output looks like the face of Kennedy in the shape of a dog's head. Thus there are three contributing elements: Kennedy, dog and the square which forms the element of the overall pattern.

Idea by Masao Komura, programme by Fujio Niwa (CTG)

7. Monroe in the net

The same deformation pattern which has been used in *Kennedy in the net* has been applied to a photograph of Marilyn Monroe. The process can be applied to any visual material, both two- and three-dimensional.

Idea and programme by Haruki Tsuchiya (CTG)

8. Return to square (a)

A computer metamorphosis. A square is transformed into a profile of a woman and then back into a square.

Idea by Masao Komura, programme by Kunio Yamanaka (CTG)

9. Return to square (b)

One of two works on this theme. *Return to square (a)*, however, is programmed according to an arithmetic series, and this one is programmed according to geometrical progression.

Idea by Masao Komura, programme by Kunio Yamanaka (CTG)

10. Running Cola is Africa

A computer algorithm converts a running man into a bottle of cola, which in turn is converted into the map of Africa.

Idea by Masao Komura, data by Makoto Ohtake, programme by Koji Fujino (CTG)

11. Deformation of Sharaku

Five separate techniques of co-ordinate exchange are applied to original data.

Idea by Masao Komura, programme by Koji Fujino (CTG)

12. Random flower

The programme indicated that the flower should have 3280 petals, but their distribution was left to the random selection of the computer.

Idea and programme by Haruki Tsuchiya (CTG)

13. Tragedy of seven

The programme here indicated the number of closed curves (i.e. 40) and the fact that these should extend in seven directions. The radii of the curves are determined by a random system, and the detail of the output could not have been predicted.

Idea and programme by Haruki Tsuchiya (CTG)

14. Miracle stones

Here the size and position are predetermined whereas the shape is decided by random means. No two stones are exactly the same.

Idea and programme by Haruki Tsuchiya (CTG)

15. March of polygons

In each polygon the number of vertices is predetermined but their distribution is random.

Idea and programme by Haruki Tsuchiya (CTG)

16. Individualization age

The distribution of elements has been arrived at deliberately, but the minute differences in the elements themselves are determined by random means.

Idea and programme by Haruki Tsuchiya (CTG)

17. The crystal space

This is a random distribution of symmetrical figures.

Idea and programme by Fujio Niwa (CTG)

18. Jellyfish in the cosmos

A series of asymmetrical patterns are distributed randomly in a predetermined space.

Idea and programme by Fujio Niwa (CTG)

19. Centripetal biological world

A random study on the theme of ellipses.

Idea and programme by Fujio Niwa (CTG)

20. Optical effect of inequality

An algorithm was employed to distribute the mathematical sign representing inequality to obtain an optical effect.

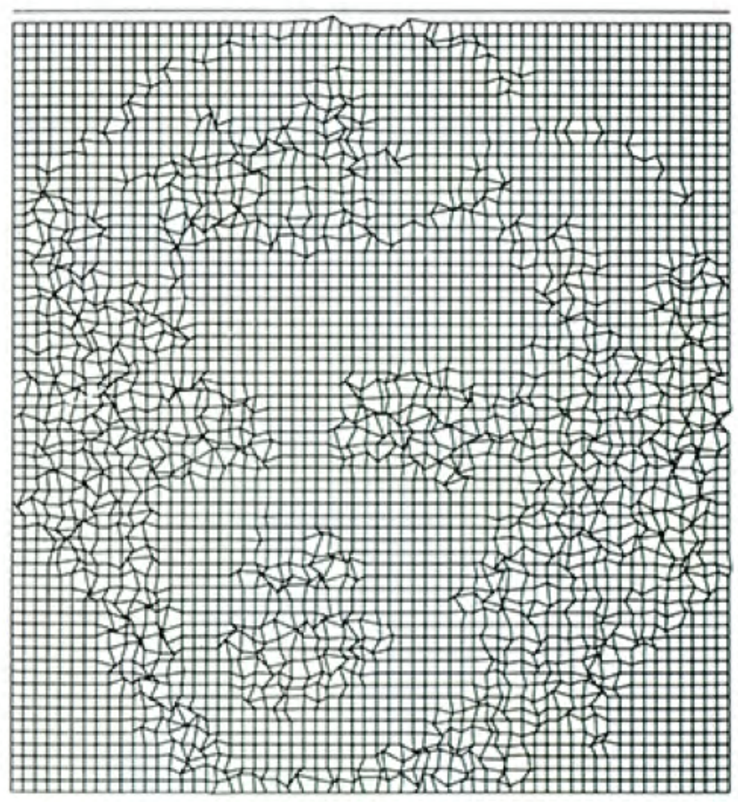
Idea and programme by Masao Komura (CTG)

21. Random collection by computer

Symbols are arrived at by random means – the mathematical values which the symbol represents appear above the box.

Idea and programme by Masao Komura (CTG)

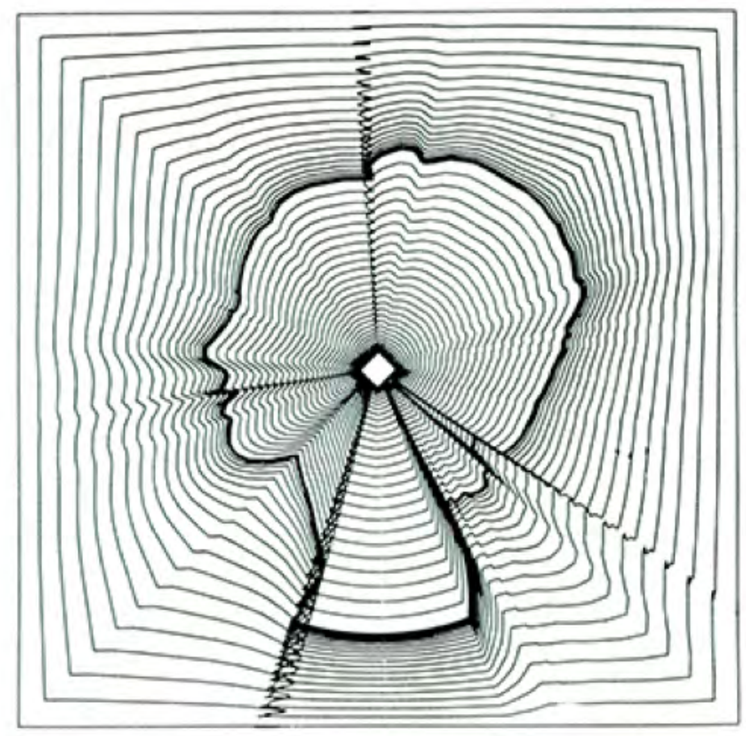
Kennedy in a dog



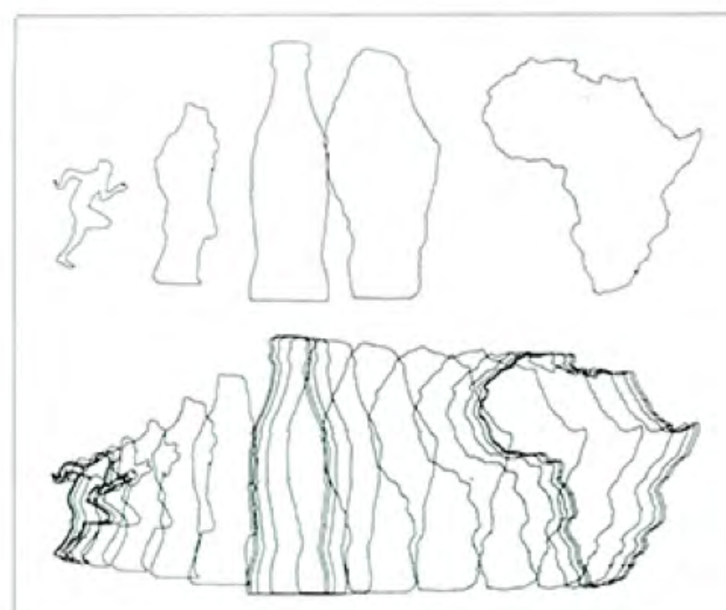
Monroe in the net

Upheaval collection (b)

Return to a square (a)



Return to a square (b)



Running cola is Africa

Deformation of Sharaku

22. Upheaval collection (a)
Stages of a star-form composed of a network of lines into a cube, by means of a random improvisation.
Idea by Masao Komura, programme by Junio Yamanaka (CTG)
23. Upheaval collection (b)
Further developments in the transformation of a two-dimensional star-form into a cube in perspective.
Idea by Masao Komura, programme by Kunio Yamanaka (CTG)
24. Hexagon involving cubes
The detail of the forms is established by random means.
Idea by Masao Komura, programme by Kunio Yamanaka (CTG)

Right, CTG Computer Poetry aims only at the effect of combining letters of the alphabet according to certain rules. Words and sentences are regarded only as a sequential development of the alphabet. The poetry is composed by using random procedures. Idea and programme by Haruki Tsuchiya (CTG), who writes: 'The poetry is hard to read at a glance. But if you read it you will find a wonderful experience in the unknown world of sound, word, language and letter.'

Notes on the programming of computer graphics

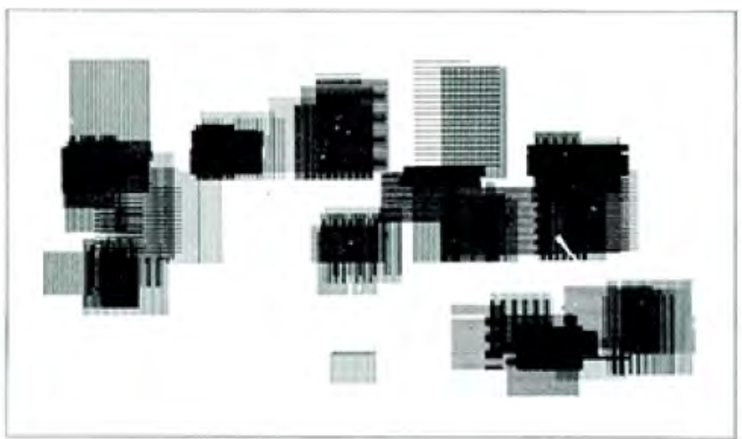
Frieder Nake

Computer graphics are diagrammatic forms, or figures, produced by means of a digital electronic computer and a drawing instrument which is either a direct component of the computer or connected to it, e.g. punch tape or magnetic band.

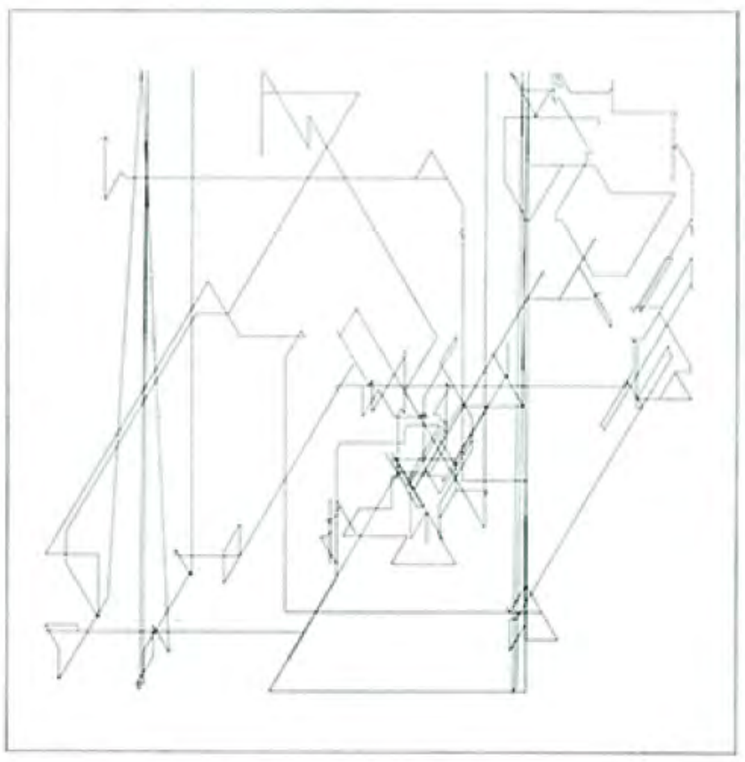
My first computer graphics were produced in Germany in December 1963 at the Computer Institute of the Stuttgart Polytechnic. Shortly afterwards, and independently, Georg Nees started making computer graphics in Erlangen.

In Stuttgart, I used the Graphomat Zuse Z 64 drawing machine controlled by punch tape. The machine has a drawing head guiding four pens, fed by Indian ink of different colours with nibs of varying thicknesses.

The production of computer graphics is a three-stage process:
1. setting up a programme for the computer;
2. automatic feeding of the programme into the computer;
3. automatic conversion of the information delivered. The latter is contained in a punch tape and is transposed by the drawing machine into the lines of the diagrammatic figures.



Rectangular hatchings by Frieder Nake



Computer graphic *Polygonal course No. 7*, 13.9.1965, random elements include:
1. number of polygonal angles
2. direction of each polygonal side
3. length of each polygonal side

The first and most important task is that of setting up a programme which should make it possible to produce an entire class of drawings ('aesthetic objects' as referred to by Max Bense) running through a specific pattern in all its variations. An analogy may be drawn here to the artistic process of pursuing a theme through all its possibilities guided by 'intuition'. Here the concept of 'intuition' refers to the choosing of possibilities from a given repertoire. The computer simulates intuition by the automatic selection of pseudo-random numbers.

It is best to explain the process with the programme used for producing a series of *Rectangular hatchings*; the common theme of these drawings is the spacing of horizontally or vertically shaded rectangles. For this purpose a programme was set up to produce a class of drawings consisting of rectangular-shaped hatchings parallel to the borders of the illustrations. Then all those elements of a drawing belonging to that class, which are arbitrary, must be determined. In this particular graphic the variable elements were;
1. N number of hatchings per illustration.
2. Position x y per hatching (i.e. determined by the position of the lower left-hand corner of the rectangle).

3. Length l and height h per hatching.
4. M number of strokes per hatching.
5. Direction of lines per hatching (vertical or horizontal being the only possibilities).
6. Style per hatching (line thickness, colour).

The size of the illustration is determined during each run of the programme, and cannot be altered in the middle of the run. The remaining elements (parameters) of the illustration are determined by the probability distributions, F. Or, in other words, it is indicated with what degree of probability each of these elements will coincide with the various possible values.

The programme could be formulated as follows:

– input of illustration format (width and height)
– input of probability distributions $F_1, F_2 \ldots F_8$.
– selection of N with the help of F_1.

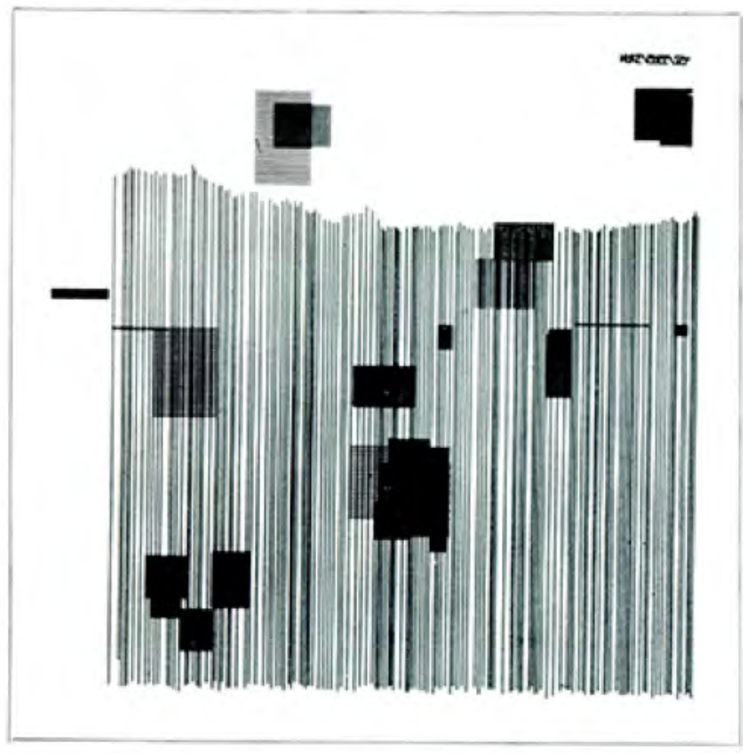
For $n = 1.2 \ldots, N$:

– Selection of x_n relative to y_n with the help of F_2 relative to F_3.
– Selection of l_n relative to h_n with the help of F_4 relative to F_5
– Selection of M_n with the help of F_6
– Selection of L_n with the help of F_7
– Selection of s_n with the help of F_8
– Output of hatching determined by x_n, y_n, l_n, h_n, M_n, L_n, s_n.

This main programme must be supported by subroutines which determine the pseudo-random numbers according to given probability distributions, F; and a programme that punches the tape responsible for the drawing of the hatching executed by the drawing machine.

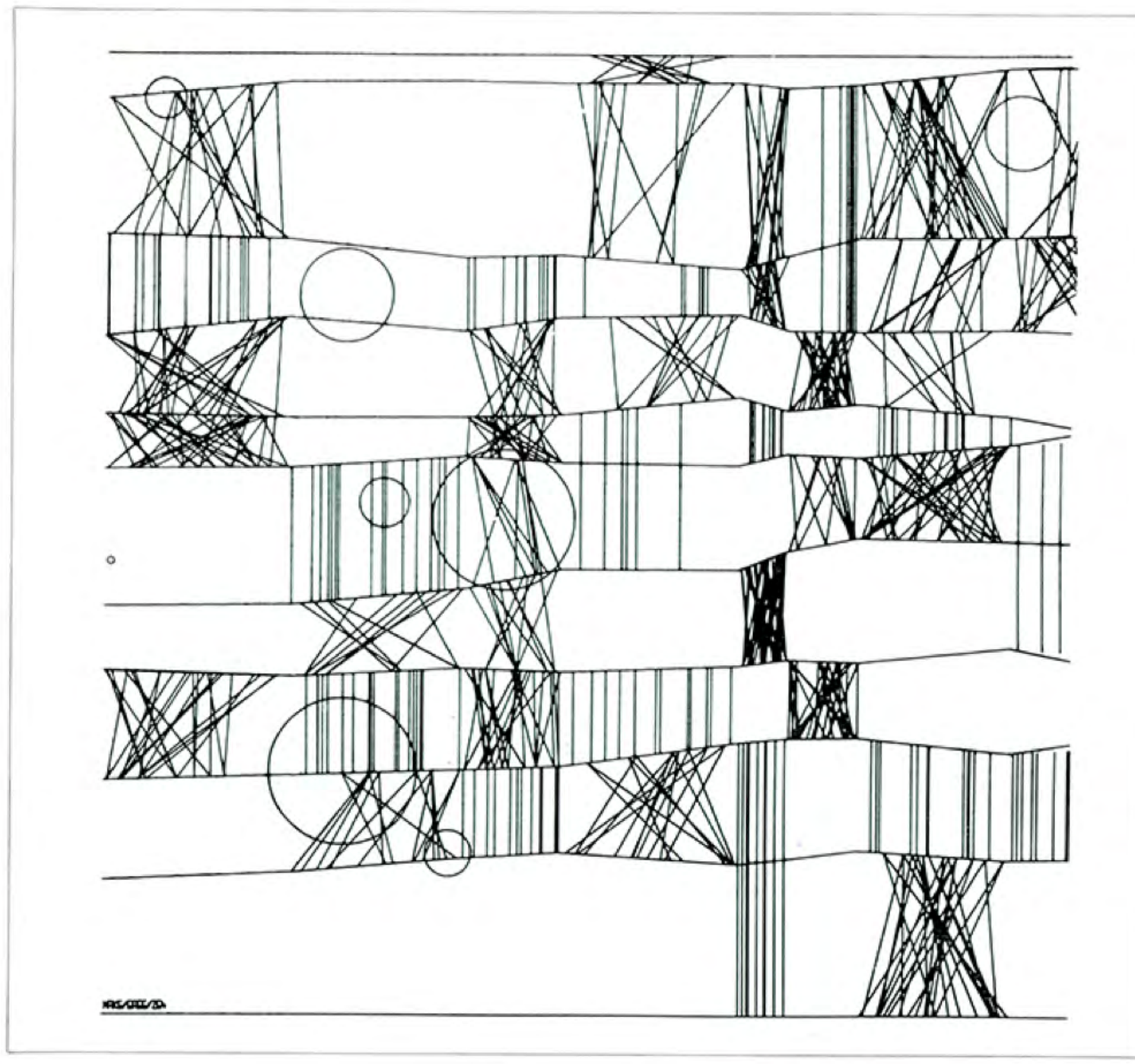
The graphics illustrated were produced by extending the *Rectangular hatchings* programme. In other words, here the entire picture-format is distributed over an imaginary grid area, and then the *Rectangular hatchings* programme may or may not be applied to a certain picture point or picture element.

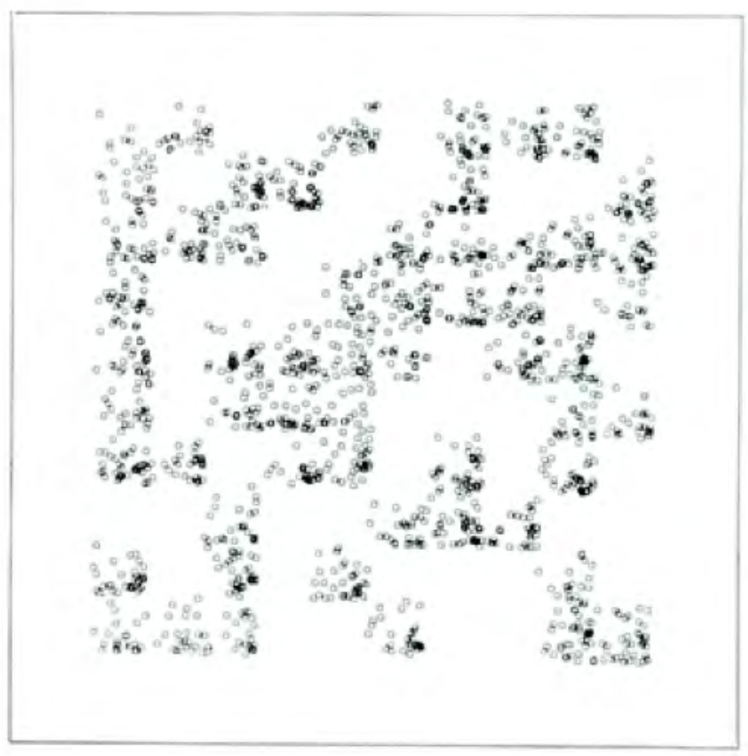
In a further stage of computer graphics it is possible to set up programmes which determine certain aesthetic proportions during the process of calculation, thereby influencing the course of the drawing. This type of production would fit into the framework of aesthetic theory as developed by Max Bense and his co-workers in connection with the work of G. D. Birkhoff.



Left, *Rectangular hatchings*

Below, *Klee No. 2*, Sept. 13, 1965, 40 × 40 cm
Random elements:
(1) variation in width from break of curve to break of the horizontal bands
(2) 'breaking' of the horizontal bands
(3) selecting of symbols for each square of a band – no symbol, vertical lines for triangles
(4) number of symbols per square
(5) position of symbols in the square
(6) number of circles
(7) position of circles
(8) radius of circles





Left, *Computer graphic*
The drawing is the result of producing uniform small squares with a kind of regular irregularity specifically suited to a computer's patience. Prize-winning entry of the annual Computer Art Contest organized by *Computers and Automation* in 1966.

Programming stochastic computer graphics

Georg Nees

To produce the graphics, I used a drawing-board controlled by a punch tape and a digital computer producing the pilot tape.

Each graphic has random parameters. The programme for each graphic repeats generative fundamental operations so that the mere repetitions, the aesthetic redundancy, produce the random parametric values of the aesthetic improbability of the graphic during each repetition.

The graphics *8-corner* and *23-corner* alter one basic figure each when programmed as follows:

8-corner

Distribute eight dots inside the figure-square and connect them with a closed straight edge line.

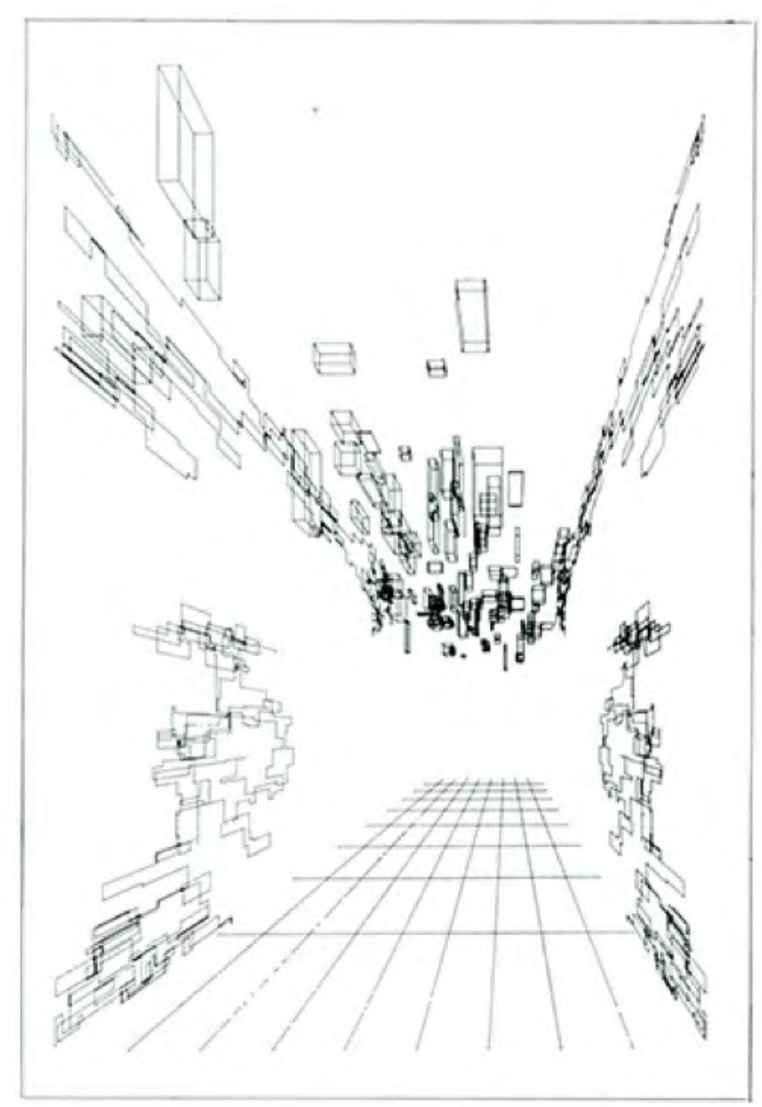
23-corner

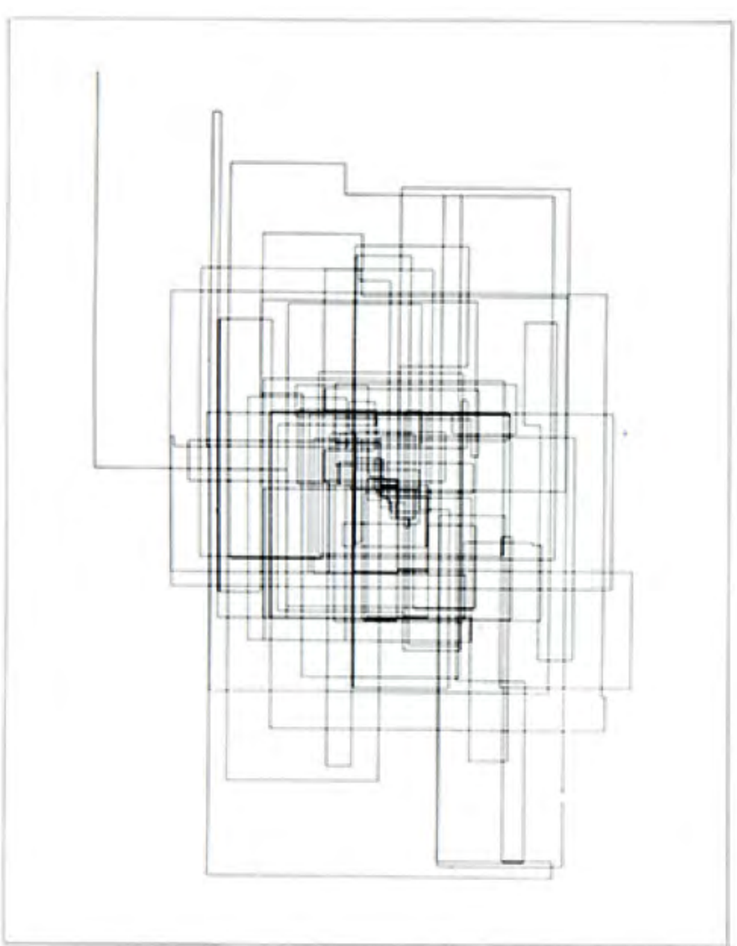
Beßinning anywhere within the figure-square draw a straight edge line with 23 sections inside the square, each section of random length, alternating horizontal and vertical lines. The horizontal lines may go right or left at random, the vertical lines up or down. Connect the starting and end points of the straight edge rectilinearly.

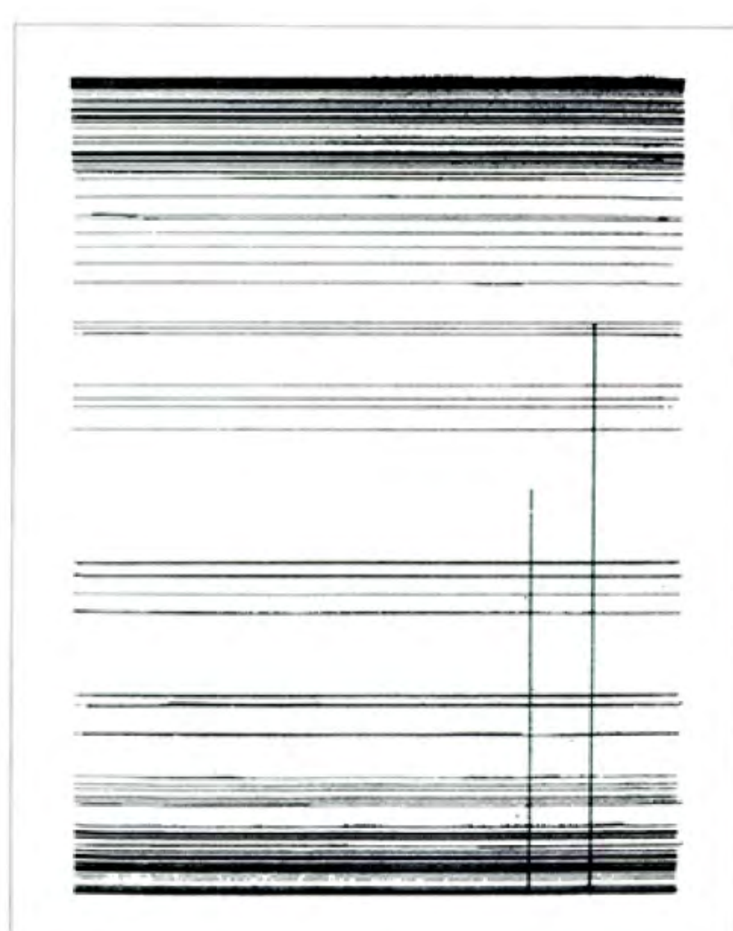
Axis-parallel maze

Beginning at one corner of the rectangular frame, draw a straight edge line within the frame. The line should consist of 4,000 sections of random length, each one under 15 millimetres long, alternating horizontal and vertical lines—the horizontal lines either to left or right at random, the vertical lines up or down. The programme produces a continuous shape or form.

The *Curtains* graphic was discovered through a programming error, thus it possesses improbabilities in a twofold sense. The programme may be described roughly as follows: Draw 60 parallel lines along the narrow side of the rectangular frame, so that the lines, together with the random abscissi, accumulate against the narrow side.







Top far left, Georg Nees, *23-corner graphic*

Top centre, *8-corner graphic*

Above, *Corridor*
Programme for this picture was constructed as follows:
Two separate linear-rectangular progressions were generated on the left wall. Then the pattern was copied symmetrically on the right wall. A set of cubes were spaced randomly on the ceiling and the floor pattern was drawn
The programme was written in Algol, run on a Siemens 2002 computer and plotted with a Zuse-Graphomat

Far left, *Axis parallel maze*

Left, *Curtains*, graphic discovered by error

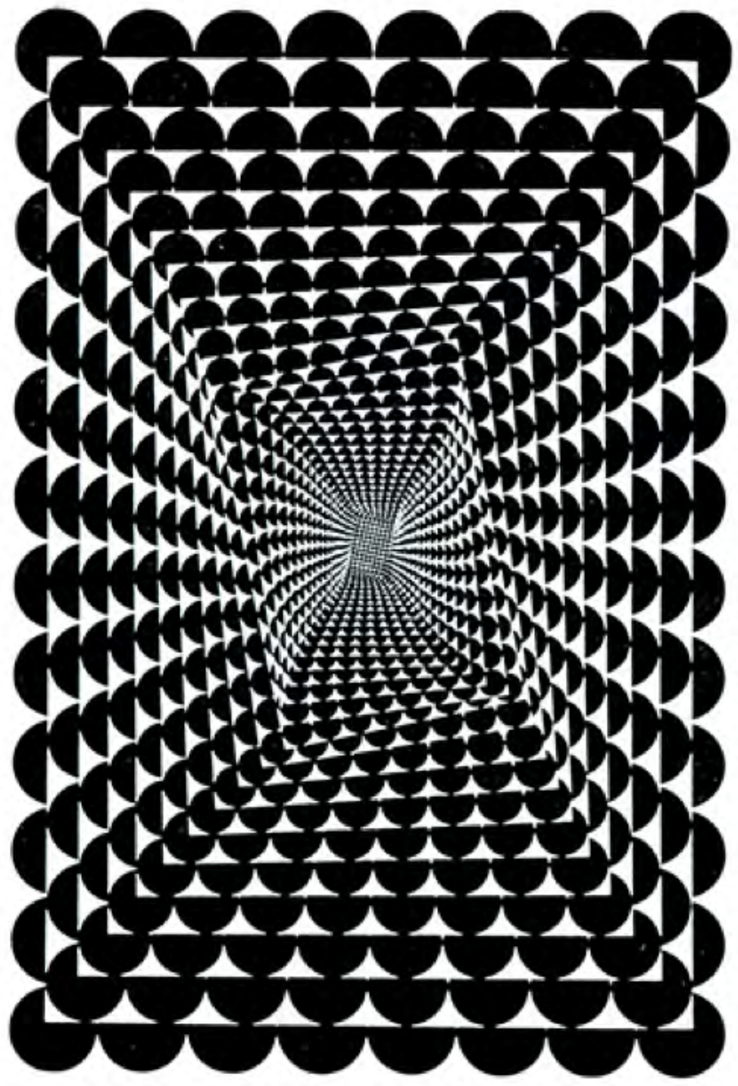
Bugs and patterns

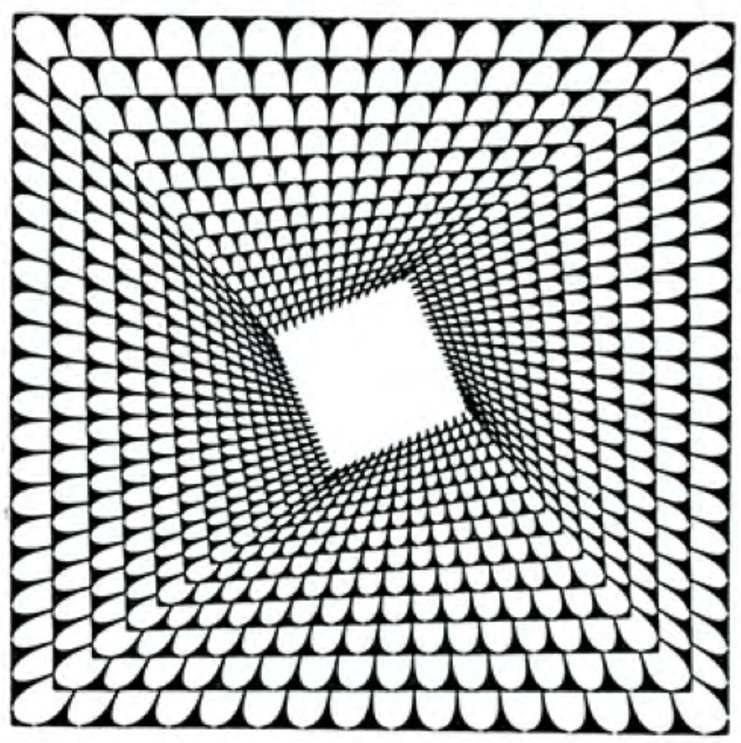
Donald K. Robbins and Leigh Hendricks

One of the traditional problems in calculus is the so-called bug problem. The problem can be stated as follows. If four bugs start on the corners of a square, and start crawling toward each other, what path will they follow? If in addition you took a picture of their lines of vision periodically, and drew lines to indicate this, you would get a spiral-looking picture. On a digital computer, it is easy to put the bug's path into a portion of the programme called a subroutine. This subroutine can then be manipulated. The checkerboard pattern shows a replication of the basic pattern. A further progression shows the checkerboard revealed as a three-dimensional entity, with the shape distorted (or perhaps made more real) by the perspective transformation. The computer, under the direction of the technological artist, can readily produce these pictures.

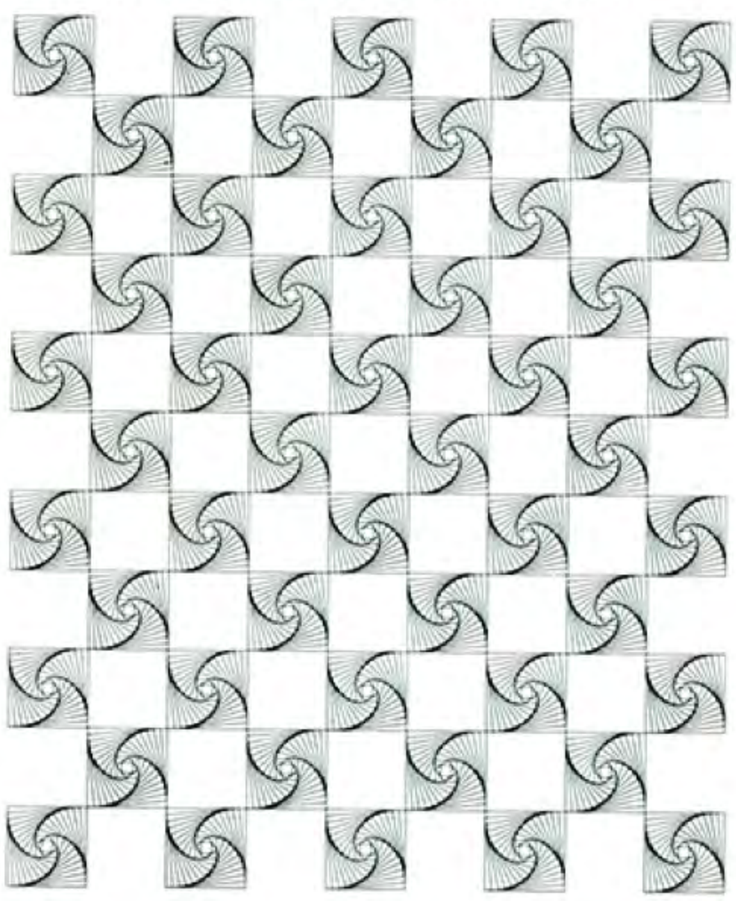
Taking the subroutine for the bug, and randomly selecting the co-ordinants of the vertices as well as the number of vertices, it is possible to produce a number of variations on a theme. Some figures may resemble a soaring strange winged creature, others stately space-ships, others merely regular geometric figures. The computer can produce an entire series of pictures united in a strange manner by a basic pattern, which allows every image to be different.

Once the basic subroutine is programmed for a digital computer, one can vary parameters at will, either consciously or randomly for effect. Examples of this process are the variations on themes from Jeffrey Steele and Bridget Riley. The latter has also been turned into a coloured movie, also produced on the computer.



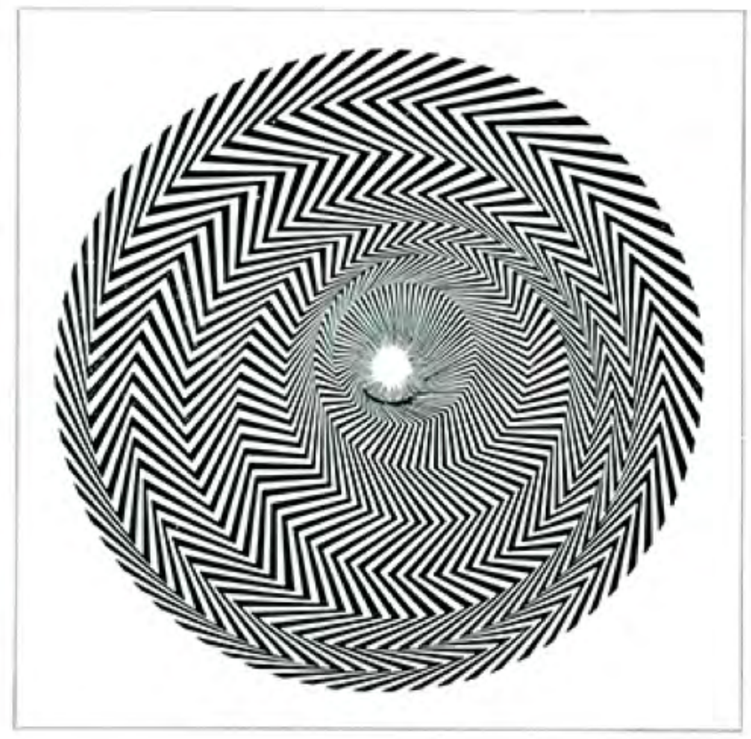


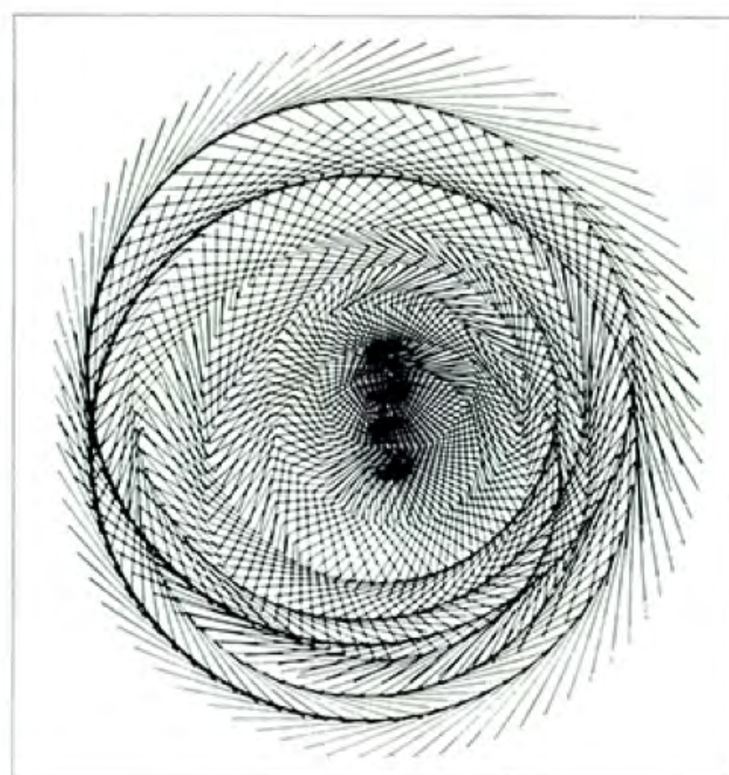
Checkerboard pattern by Donald K. Robbins

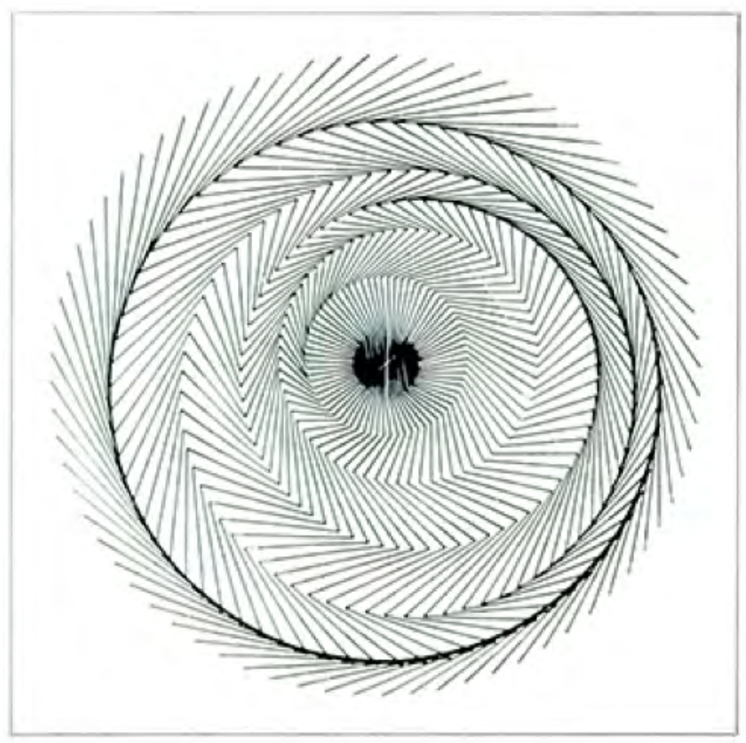


Left, Jeffrey Steele: *Baroque experiment—Fred Maddox* (sometimes known as *Harlequinade*), 1962/63, oil on canvas 60 × 40 in., collection: The Hon. Anthony Samuel, London, and, left centre, Variation on a theme from Jeffrey Steele by Donald K. Robbins, based on this painting.

Below, Bridget Riley: *Blaze I*, 1962, emulsion on board, 43 × 43 in. and, below centre and bottom, Variations on a theme from Bridget Riley by Leigh Hendricks, based on this painting.







An interview with Charles Csuri

Arthur Efland

For most of his professional career, Charles Csuri worked like any painter since the invention of easel painting. Then he discovered that computers could be programmed to produce images, and since that time his total effort has been devoted to exploring the artistic potentialities made available by these new means.

Arthur: What made the computer seem like a reasonable possibility for this kind of search?

Charles: Well . . . it's the potentiality that is offered by mathematics that is of special interest to me. . . . The type of mathematics one can use in, say, doing hand pictures—if you will excuse the expression—is restricted by how much time it takes to solve a problem, that is, normal methods of working are too slow. I think that if I were to deal with that question in a slightly different way it might be better. I am saying that the artist can now use complex mathematics and the digital computer in his work because its structure and characteristics may suggest different approaches to problems than would otherwise be considered, and this is especially true of problems involving the repetition of data and iterative procedures which can take advantage of the computer's speed of operation. That gets a little technical. What I might be saying is that mathematics offers new possibilities in the realm of the arts. One can use things like N-dimensional geometry or like a hundred-dimensional geometry rather than a three-dimensional geometry . . . which might give you a different idea of a form, a different idea of a structure. You can make use in a much more systematic manner of random-number generators that give certain kinds of distributions of points or lines that may be of great interest.

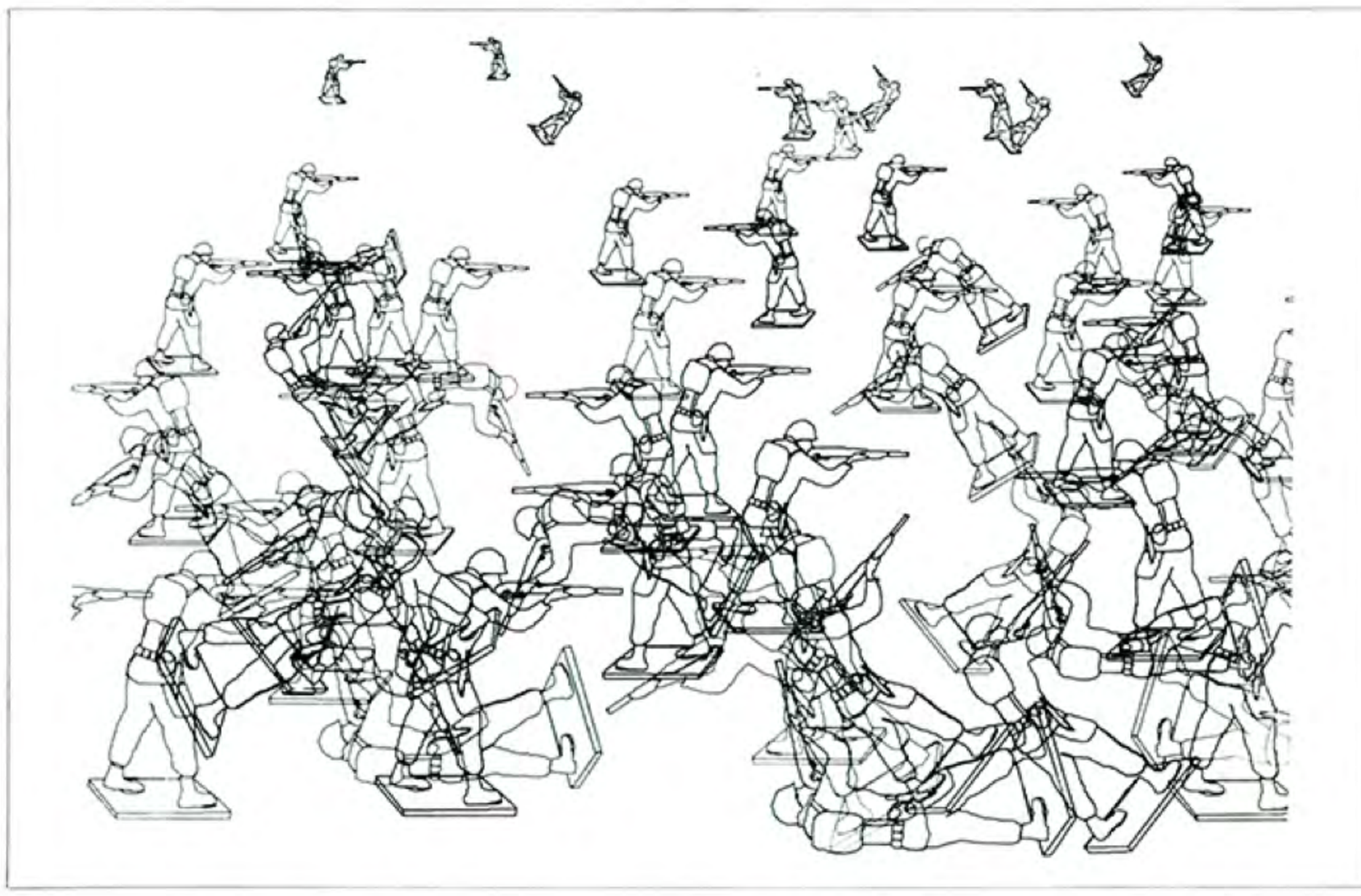
Arthur: You mean that you never would have thought of . . .

Charles: Right. I think when you deal with so-called structures or distribution of points, values, lines, or whatever, that you have a certain bias. This bias is based on past experience, pre-conceptions of what is structure in art, and one way of breaking away from this is to introduce a mathematical system that can't depend upon that kind of conception. This is a way of breaking the bias and perhaps getting to an interpretation that you ordinarily would not think of.

Arthur: Let me try out this analogy and see if this makes sense to you. You can think of some of the highly mathematical forms of art that some of the renaissance masters worked with in developing geometric perspectives, as being essentially systems dealing with two or three dimensions, and in a sense, modern developments in mathematics which can handle not only more complex problems but handle them more rapidly are really opening up another realm of possibility to the artist just as Euclid's geometry made perspective possible. . . .

Charles: Well, I think this is particularly true when you move into dimensional geometry. It is not ordinarily described as dimensional geometry but is called vector spaces. You have for instance thirty directions rather than three directions that you think of as ordinary dimensions. It's not a real space—it's a theoretical space. You take something which is in three vectors and put them into ten vectors, or into ten thousand vectors, or into a million vectors. And this in itself may or may not make it interesting but there is a possibility. Also what is connected to this, you can use an area of mathematics called the 'Fourier' series and actually take, for instance, a profile of a head, the line of a head, and construct a specific equation that describes the profile, and if you give this equation to the computer with a plotter (a device to draw with) it will come out the same shape. What you can do is take all the portions of that head and construct an equation that describes the character of the nose, of the eye, of the mouth, and so forth, and quite simply modify the coefficients and you begin to get changes and you get a different kind of structure.

Arthur: And so instead of going through the



Random war by C. Csuri and J. Shaffer, programmer.

Csuri made a drawing of one toy soldier, and this became the data deck.

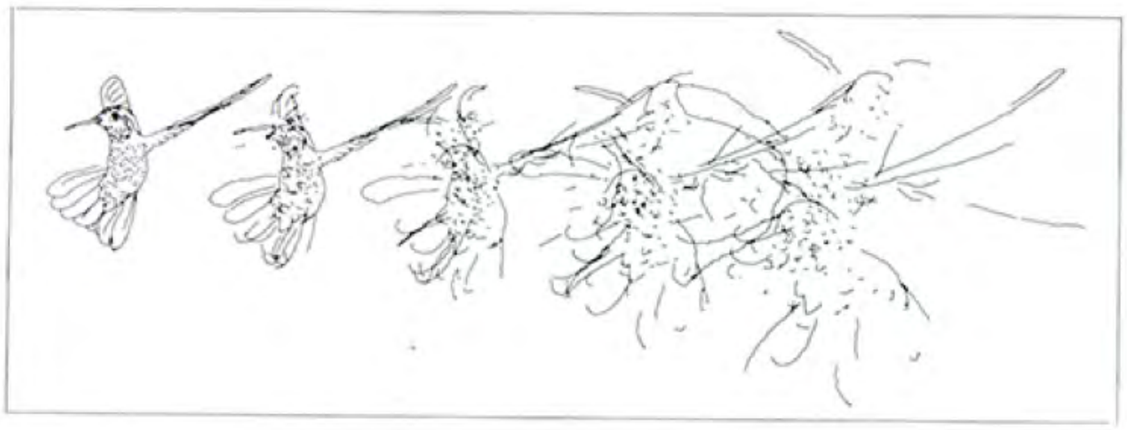
A computer programme which generates random numbers is called a pseudo-random number generator. Such a programme determined the distribution and the position of soldiers on the battlefield. One side is called the 'Red' and the other one the 'Black', and the names of real people were given to each soldier. Their military *ranks* were assigned by the random number generator. The random number generator also decided who is to die and who is to be wounded. The programme also has an automatic control for perspective. A picture 30 × 100 in. in colour of the battle was produced by the computer, and the 'print out' gave the following information:

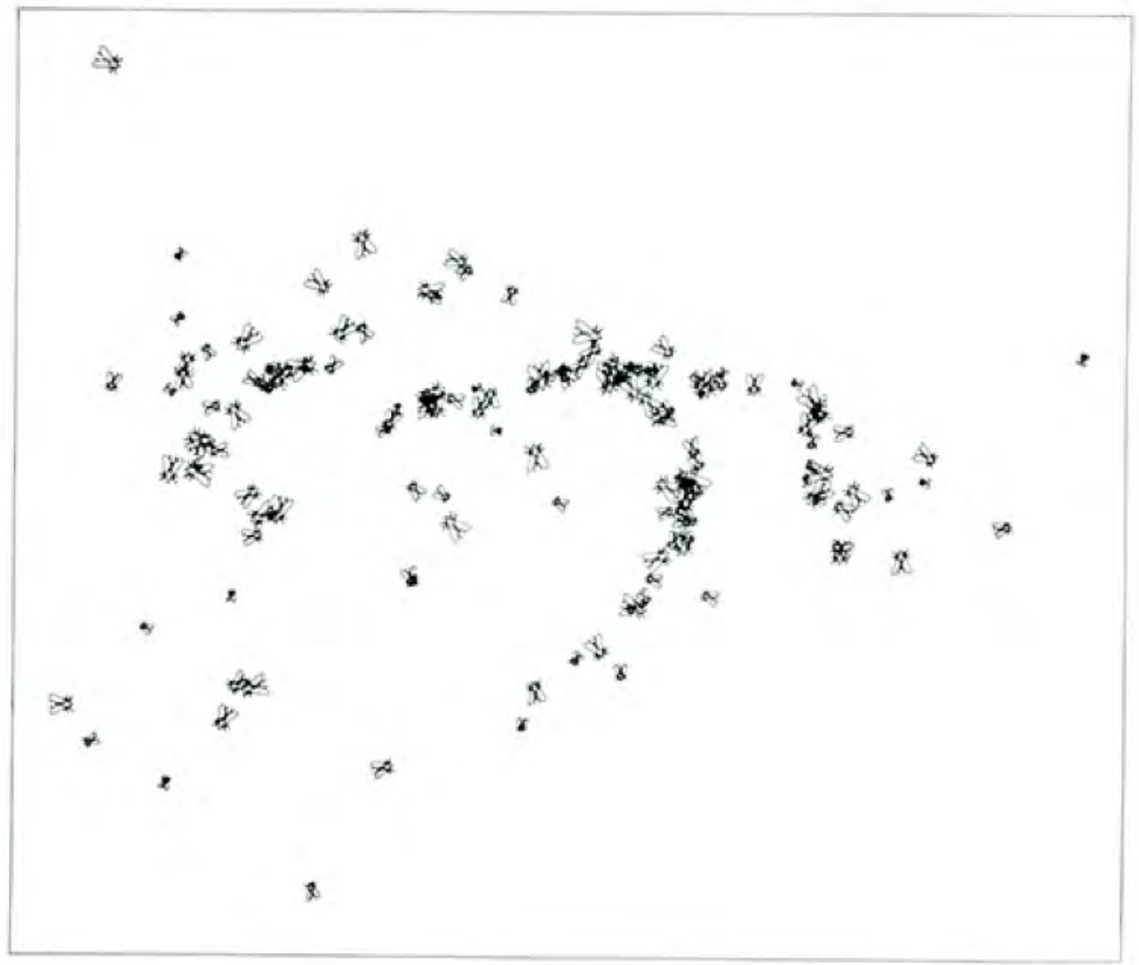
1. Total number of dead on each side
2. Total number of wounded on each side
3. The number of dead and wounded in each of forty sectors of the battlefield
4. Identification of the dead and wounded in alphabetical order
5. The survivors in alphabetical order.

Random war is an imaginary war, one with few variables, but it is a short step to a real situation with the introduction of many more variables into the computer. One could introduce military intelligence reports into the programme with an estimate of the enemies' capabilities and the tactics they may use. The computer can handle information about the type of terrain, types and number of weapons, historical data which involved similar situations, weather conditions, physical condition of the troops and so forth. The battle can be simulated on the computer, and computer-generated movies would give a visual display of the contest. Then more decisions could be made before the event takes place in real time. Once the real battle starts, the computer can predict the outcome and its consequences many hours before the battle ends. It would show motion pictures as the battle progressed. The military computer could process one per cent of each of the variables and predict the outcome, much in the same way national television computers have recorded the final results of political elections.

Right, *Flies on the Miller transformation*
This is a problem which makes use of random points generated into the region of a triangle. Then these points or flies are mapped into the region of a half circle. The equation which deals with conformal mapping was developed for Charles Csuri by Prof. L. Miller of the Mathematics Department, Ohio State University.
C. Csuri and J. Shaffer, programmer

Below, *Chaos to order*
Random distribution of each line of the humming bird. The computer draws the chaotic version first and in progressive stages brings the bird back together.
C. Csuri and J. Shaffer, programmer





problem of cataloguing noses and eyes, à la da Vinci, you start with an ideal nose or an ideal mouth ... however you want to define it. ...

Arthur and Charles: A nose!

Charles: Yes, right.

Arthur: And by mathematical means, transform it so that you can predict the result but perhaps can't quite visualize until you come up with an infinite series.

Charles: Or, you approach this in such a way that it would be impossible to visualize what will happen, and perhaps this is the part that makes it interesting.

Arthur: I see. It gives art back some of the mystery.

Charles: Right. We put the mystery somewhere else now. But, I also like to feel that there is a very specific discipline involved here. What I am really saying is that there are certain ways to make decisions that I find more convenient, maybe there are certain patterns of thinking that are somewhat different than problem-solving in the past, and this in itself is interesting to me.

Usually, when I make a painting in the conventional sense, or a drawing, I have to worry about media. I have to worry about whether this should be grey, that should be black, or this should be white, and I find that by working with certain mathematical ratios I can play with numbers and end up with certain kinds of distributions, of colour, of value, and of line, that are just as interesting—possibly more interesting than if I worked in conventional terms and could anticipate exactly the result.

Arthur: And in a sense you are working just as hard as with hand pictures.

Charles: You've got to work hard in order to set the game up so that your output is interesting. You've got to set up strategies ... there are certain things you can do that would be obvious and quite predictable, but when you start getting into the fields of probability and statistics, you can't guess what is going on, and it is rather difficult to set up a sophisticated game. I mean you will still have a problem.

Arthur: A game that doesn't have enough combinations or if you can think through all the combinations, it loses its surprise value, let us say.

Charles: Well, to give you an example of something I've been working on recently which was rather fun. Maybe nobody else would think of it as being fun, but I made a drawing of a horsefly and managed to put this into the memory of the computer, and I decided that I wanted 250 horseflies distributed in a rectangular space. I didn't want to worry about drawing each fly and I couldn't possibly tolerate the responsibility of making a decision as to where to put it 250 times. So, I turned this decision over to a random number generator and let it decide its distribution throughout the space. Also, I let it decide the angle of orientation. Finally I decided it would make it more interesting if I had different sizes of horseflies. So, I introduced a game whereby the random number generator would give me four or five different sizes of horseflies. And, so, I had a combination of random distribution, random orientation, and random size, and I find the result quite interesting. In fact, I don't think that I would have the interest to draw the horsefly 250 times in different sizes. I'd lose my mind. That part of it is really great fun but there is another aspect of it here. I picked a horsefly, and it's not such a profound idea certainly, but on the other hand, this has a comment to make about the computer itself and the whole business of *bugs* and *debugging*. Maybe this is one sort of meaning. It's an absurd idea, you know, to use a horsefly. I somehow feel sorry for the flies. They're disappearing from our culture.

Arthur: Do I recall correctly that you told me that you minored in math?

Charles: No, I didn't minor in math. What happened was this—I was in art for three and a half years and then I was drafted into the army and in typical United States Army fashion they put me back in college to study engineering, and I covered two years of engineering in accelerated programme in one year and I took college algebra, trigonometry, analytical geometry, differential calculus and I had a couple of courses in physics and chemistry, and in my background I had a lot of technical training, a number of courses in drafting, for instance, so that, I suppose, without too much difficulty I could have got an engineering degree.

Arthur: I think that a fine arts background and the technical training on top of it was a blessing in disguise, although you probably didn't think so at the time.

Charles: Right. In trying to solve problems as an artist or an art student, I tended to think in terms of very broad generalities. At least the way I processed data is quite different than the way I have to approach the problem as I am confronted with the technology of the computer mathematics which this involves, and questions of programming. At one point in my work, I tried to make big general shapes and proceed from the general to the particular. I had a certain idea about

control of a painting and I worked with gross chunks of information, if you will.

Arthur: That was in the pre-computer days?

Charles: Yes. Now if I get very involved in a line drawing of a face, I think—I have 400 lines that made up this face. Now the question is, how many points do I have for each line in terms of computer technique? How many points make up this line? What can I do to these points? How can I change their distribution? What kinds of strategies can I use in mathematical terms to modify these points so that they make a new arrangement of lines which in terms of the total image gives me a different appearance to a head—gives me another point of view about it?

Let's take as an example the humming bird that was exploded. The first problem, a very simple one, was to put this into the memory of the computer. This is done by using a rectangular co-ordinate system. The programme tells you how many points you have, and adds up your points. It also tells you how many lines you have, e.g. 200 lines and 1,732 points. Then you must decide where to put these. We might decide to scatter these lines. Well, how far do you want to scatter them? Six inches? Four inches? Do you want to spread out that much? In the case of the humming bird, we decided to have up to six inches in radial displacement or in the distance, and plus or minus forty-five degrees in angular displacement, for each line. This was the maximum. Then we brought in the random number generator and let the random number generator decide where the point would fall, between 0 and 6″ and between ±45°. So, one time around the first line would be, say, 4″ and 12° out. The second line would be 3″ and 27°. And this was done for every line and the computations were made and put on a deck of cards. Then, we have what appears to be a scrambled image. Then, you must decide how many steps to take to return to the first image of the humming bird. We decided to do it in three steps, which is quite simple because once you have the scrambled information, then you have what we call a zero with the first image. Then on the basis of percentages you can bring it back 25%, 50%, 75% and finally to zero.

Arthur: In other words you drop out degrees of randomness this way?

Charles: Right. You pull the image back together again. It gets closer back to the representational image and what becomes the drawing or the so-called aesthetic object is, as far as I am concerned, not just scrambled or realistic image but this entire process going from what appears to be a disordered image back to progressively a more ordered one.

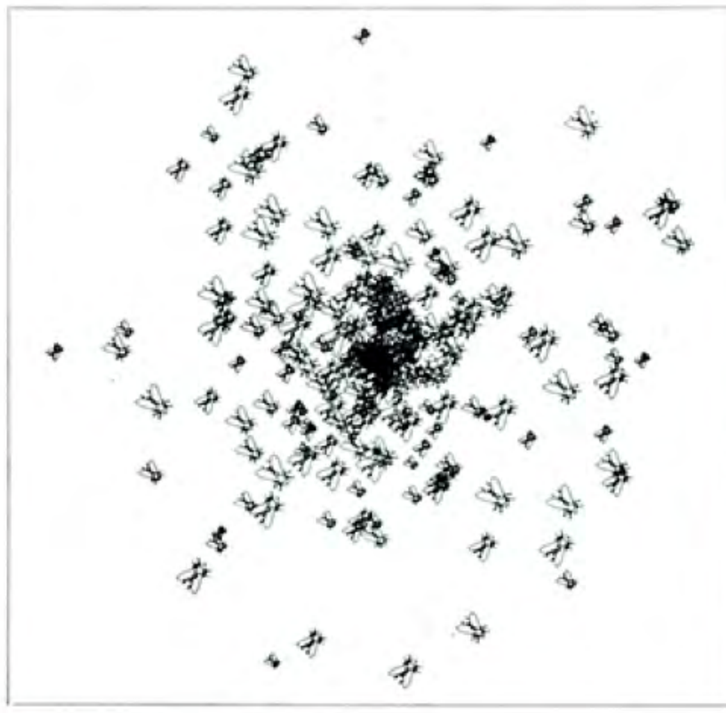
Arthur: You could programme a whole year's work this way.

Charles: Yes, and every time you get a different image.

Arthur: Suppose you did this, just to create a problem for the critics!

Charles: You could certainly do this by writing one programme and letting it run all year long.

Arthur: And then you have a one-man show with the output of, say, half the year, and in the second half of the year you have another show. And the critics will look it over and decide 'Well, Csuri is getting better'.



Flies in a circle 1966
A computer programme generates random numbers which determine the distribution of a specific number of flies in a series of 1 in. concentric rings. Within predetermined limits the random number generator also decides the orientation and the size of each fly.
Produced and directed by Charles Csuri and James Shaffer

Random light and shadow
A realistic line drawing was made of an old man. This line drawing was transformed mathematically into a shaded image. A spiral, rectangle, triangle and star were the character symbols used through each line segment. The random number generator determined the colour distribution, and the size of each symbol is a function of distance from a reference point outside of the picture space.
C. Csuri and J. Shaffer, programmer

Charles: What this would mean is: his random numbers are falling better for him. No, I think if you are a well-known artist you could pull it off, you really could. And you can do it two years in a row and go and live in the Hawaiian Islands, then come back and write another programme and take off once more. You know, it does become a little absurd to say the least.

May I introduce a very fanciful notion? It's something I've just thought of recently. I was talking to someone about the future of computers and what one might be able to do, and I simply said, well, I think that in time the artist will sit down and think about a picture and then a computer will translate his brain impulses into a picture. Actually draw a picture! And I thought this was sort of ridiculous, you know, sort of Buck Rogers type of thing—twenty-fifth century—and then several days later I sat down and started to think, I wonder how you would even approach the problem? And it occurred to me that there is a way of getting at it. And this has to do with the study of brain waves and the electroencephalogram, and what I thought I might do—in fact, I was on my way to the library when you called, to get this book. ... The brain waves are extremely complex, although most people are only familiar with the alpha or beta brain waves. Is that what they're called? I'm not really sure. But, there are certain patterns for being awake and asleep for normal men and for an epileptic, and so forth, but in addition to that, there are all sorts of other brain activities that are recorded. One of the difficulties in dealing with the problem is that there tends to be too much information. It's hard to sort out and really give it any value. What I thought I might do is put this output on magnetic tape. This has already been done, i.e. in what is called analogue form. There are processes which will convert analogue information into its digital equivalent, which can be fed into the computer, and what has occurred to me is that I would create an alphabet of drawing marks, which I have already done, and then have some way of having the brain signals trigger certain kinds of elements in the alphabet and see if we can make a picture. In recording the impulses you actually can affect, depending upon how you concentrate, the character of the brain waves. There can be a different phase, a different frequency, a different amplitude, etc. All this can be recorded on magnetic tape. Then you think 'circle', and you record that, and see if you can get the equipment to make you a circle or a square. It sounds pretty ridiculous, but I think there are certain things one might do, based on this.

Arthur: I can see the cartoons in the *New Yorker*, now. You see the artist on the couch—well, he's thinking! And the computer drawing away like mad.

Charles: That's right. Exactly, and at some point I'm going to do something with this idea.

Arthur: I don't think this is so improbable.

Charles: Oh, no, I don't think it is either. I thought it was when I first said it. But the more I thought about it the more I began to realize ... something along this line could be done. Very unlikely that you would end up with an image that is representational.

There is another aspect of this that I haven't really talked about that I think is quite important. I came across some research reports from M.I.T. trying to illustrate what happens to a mass when it approaches the speed of light. This is involved in the Lorenz Transformation. They took as a problem a drawing of two lines which give an impression of a road receding in the distance and then telephone poles of various sizes to give the impression of perspective. Then, they introduced the Lorenz Transformation. You have to think of this as if you were travelling down that road in a car approaching the speed of light, and the computer shows what happens to the telephone poles at one quarter of the speed of light, 50%, 75% and then .99 the speed of light, and the telephone poles start to bend, actually changing their shape.

Arthur: Becoming curved forms instead of straight?

Sine curve man
A realistic line drawing of a man is transformed into this image by means of a sine curve function. The colours are blue and green.
C. Csuri and J. Shaffer, programmer

Charles: Straight lines curving in. Now, what is very strange is that an unpredicted thing really happened. These telephone poles had cross members on them, rather like upside-down L shapes. It didn't go all the way across, but a line going out from a point, and the three sets on the inside turned in as you would expect them to but then one set turned out. They originally were in, but they turned out. The article doesn't explain what happened but a change did occur. Well, what I am going to do very shortly is to make a line drawing of a head and use the Lorenz Transformation to see what would happen to the appearance of that head, hypothetically, as it approached the speed of light. I like the idea because man cannot move at that speed. I'm interested in seeing what would happen. And, maybe I am also interested in introducing objects which we associate with slowness like a turtle and having it go at the speed of light, a strange sort of contradiction. I can use a well-known physical law as a point of departure and, then, quite arbitrarily, I can change the numerical values which essentially change the reality. I can have light travel five times faster than the speed of light. And in a sense put myself in a position of creating my own personal science fiction.

Arthur: There's almost a contradiction here though, because if you can make a drawing, and by means of the Lorenz Transformation show what man looks like as he approaches the speed of light, you're closer to reality than science has ever been.

Charles: I don't know yet how to deal with this. I just know that I like to play with the world. I like to have the possibility of modifying certain circumstances, certain conditions in the environment.

I think artists are going to be influenced by science in one way or another, and I think that this is going to force some new definition of art. This is inevitable.

How to draw a ball

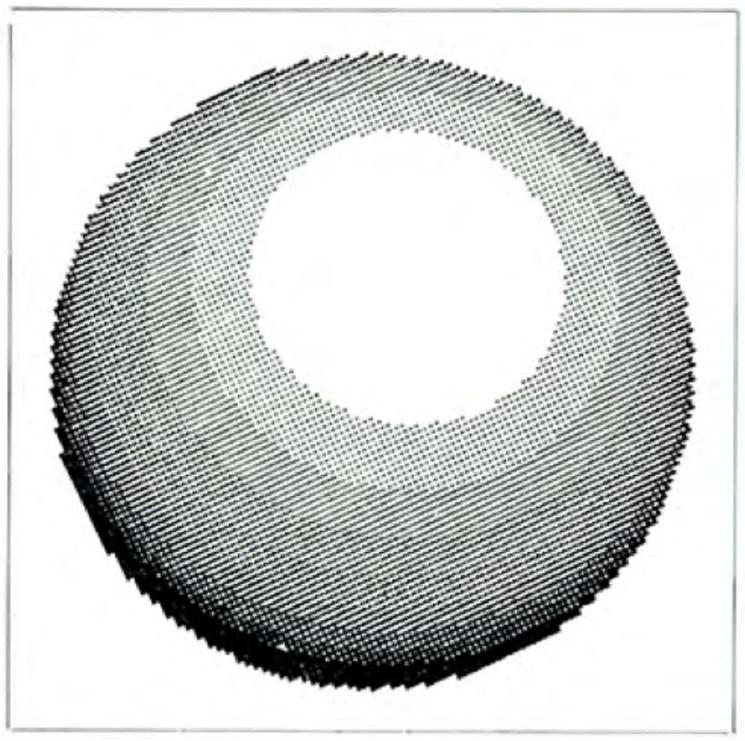
Alan Parkin

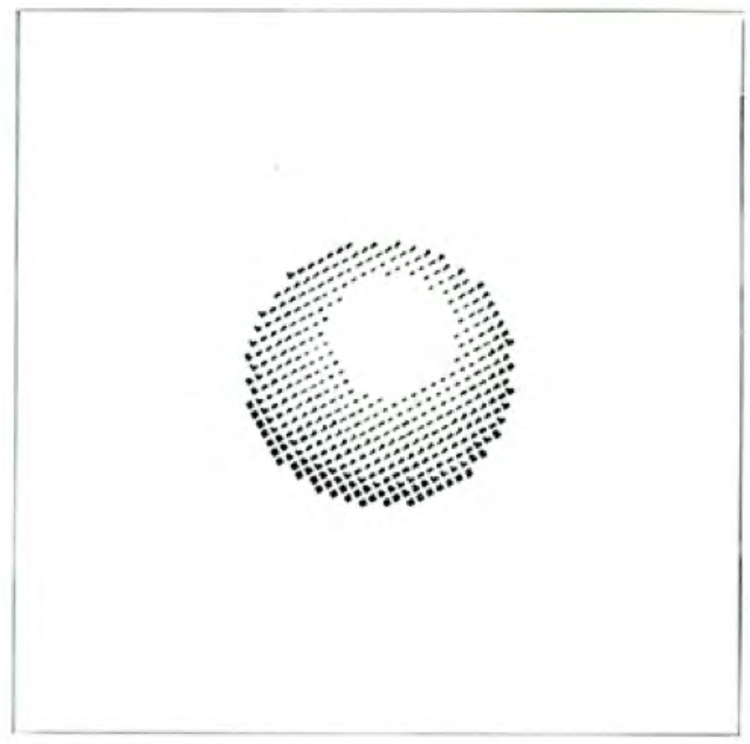
Simple and common
A ball is the simplest solid. It has the minimal surface for a given volume. It can be specified by one location (centre) and one length (radius). It is the fundamental shape of almost all large objects in the universe, such as the sun, moon and stars. We begin as a ball, we live on a ball, and a ball is one of the earliest and commonest toys.

Hard to draw
Notwithstanding its simplicity and ubiquity, a ball is quite hard to draw. This is because our drawing techniques are essentially linear. We can easily represent profiles (outlines) and sharp edges by lines, but curved

Algol programme *Spherelit* by Alan Parkin
run on Elliott 4120, at Greenford Computer Workshop 25 April 1968
Rapidograph pen 0.2
with the following data
Sphere data AAA
1300, —3600, 6, 304, 304, 0, 0, —4800, 400, 0.2419, 0.2419, 0.9397, 2, H

Sphere data DDD
400, —3600, 8, 104, 0, 0, —4800, 132, 0.2419, 0.2419, 0.9397, 2, H





surfaces are something of a problem. Their varying light and shade call for some additional tonal variation in the representation, such as hatching or painting. The problem is particularly acute in accurate measured drawing, which has been standardized in two main forms. There is orthogonal projection, as used for engineering and architectural plans and elevations; and central projection, as used for perspective pictures. In orthogonal projection, all points on a line perpendicular to the picture plane are represented by the point where the line meets the picture plane. In central projection the projecting lines all pass through a single point, the viewpoint. Traditional perspective method is a graphic technique for transforming orthogonal projections into central. It enables salient points to be plotted, which then have to be joined by lines. It is a satisfactory method for straight lines, but tedious or inaccurate or both for curved lines. And it is entirely unsatisfactory for curved surfaces, where there are no salient points and no sharp edges.

New conception of drawing

A new conception of drawing, of a general nature, arises from the combination of four possibilities:

1. Abandoning the linear convention and taking up a mosaic convention, as that used in halftone photo-engraving. The picture is built up from separate dots of varying sizes, arranged in a regular mosaic.
2. Abandoning the tedious and inaccurate graphic method and taking up numerical calculation. This is even more tedious if done by hand, but of virtually unlimited accuracy.
3. Removing the tedium from calculation by the use of a digital computer.
4. Using a digital plotter to produce the finished drawing from the numerical results, with great speed and precision.

Such a method would be especially suitable for drawing a ball, or any curved surface.

Mosaic elements

A typical plotter is capable of one basic operation, moving in a straight line to a new position, in either of two states, pen up or pen down. It can only move a whole number of steps in both directions across the paper. The step length is thus a quantum imposing a limit on resolution. But it is necessary to build up a range of plottable mosaic elements, which reduces the resolution further. If we take a typical step length of 1/200 inch, and choose a square 3×3 steps as the mosaic unit, and use a pen one step in diameter, then the square can contain any of nine different areas of black. In gross, the effect will be a tone, having any of nine values from white to black. The resolution of the mosaic will be $66\frac{2}{3}$ elements per inch. Alternatively, four tones could be used at 100 elements per inch, sixteen tones at 50 elements per inch, or generally n^2 tones at 200/n elements per inch.

Fundamental equations for mosaic elements

In coordinate geometry, points, lines, curves, planes and surfaces are represented by numbers, within some suitable frame of reference. It is convenient here to take the viewpoint as the origin, and three rectangular axes with x positive to the right, y positive upwards, and z negative in the direction of view. The unit of measurement is the plotter step. Then a point is specified by three numbers (x, y, z), which are steps along the respective axes. The picture plane is perpendicular to the z-axis at a distance d from the origin. It is therefore specified as the plane $z = d$. If the mosaic unit is a square m by m plotter steps, then the position of any mosaic element is specified by two numbers (p, q), where $p = \ldots, -2mx, -mx, 0, mx, 2mx, \ldots$; $q = \ldots, -2my, -my, 0, my, 2my, \ldots$; and $z = d$ is understood. Now any point (x, y, z) on the object is centrally projected into the picture plane in some element (p, q) of the mosaic. From the definition of the frame of reference, by similar triangles, we have the fundamental projection equations:

$$p = xd/z$$
$$q = yd/z.$$

The simplest lighting situation is a single source at such great distance that the incident light at object and origin can be taken as parallel (such as sunlight). The source is then specified by three numbers (alpha, beta, gamma), the angles which a line pointing at the source makes with the x, y and z axes. The unit normal at a point on the object is the line, one step long, which is perpendicular to the surface at that point. It is found by standard geometric procedures depending on the type of surface concerned. It is specified by three numbers (ux, uy, uz). Assuming that the surface is a perfect diffuser (matt white), the brightness at any point is given by Lambert's cosine law as the cosine of the angle between the normal and the direction of the source. Thus:

$$\text{brightness} = ux.\cos\text{alpha} + uy.\cos\text{beta} + uz.\cos\text{gamma}.$$

This is the tonal value of the appropriate mosaic element. Full colour work involves no new principle. Using a trichromatic set of colours with black, the colour of the source and the local colour of the object are specified. The brightness equation is used four times for each mosaic element, with weighting factors derived from the specifications.

Mathematical description of illuminated ball

A short way to refer to a point is by using a vector, written A, which is understood to have three components (ax, ay, az), measured along the three axes. The length of a vector, the distance from the origin to A, is written $|A|$. The line through the origin (viewpoint) and element A in the mosaic is

$$X = e.A \text{ (in full, } xx = e.ax,\ xy = e.ay,\ xz = e.az)$$

where e is a variable number, a parameter. The sphere with centre C and radius r is

$$|X|^2 - 2.C.X + |C|^2 = r^2$$

The intersection of the line and the sphere is therefore the point which satisfies both these equations. Substituting the first into the second we have

$$|A|^2.e^2 - 2.C.A.e + |C|^2 = r^2$$

This is a quadratic equation for e, whose solution is

$$e = (-b \pm \sqrt{b^2 - 4.a.c})/2.a$$

if $a = |A|^2$, $b = -2.C.A.$, $c = |C|^2 - r^2$

The two solutions for e are then substituted in the equation of the line to give two intersections. The visible one is the nearer of the two to the viewpoint. The normal at any point on a sphere is the line through that point and the centre. The unit normal is found by dividing by the radius. Thus if the line through the origin and mosaic element A intersects the sphere at point I, the centre of the sphere is point C, and the radius is r, then the unit normal is $(I - C)/r$. It then remains to use the brightness equation to find the tonal value of the mosaic element A.

ALGOL programme

These calculations, and the subsequent plotting instructions for the mosaic elements, have been written as an Elliott ALGOL programme. The programme has a range of ten brightness values. There are eight parameters to the programme, which are given values by a separate data tape. These are:

plotting origin
distance of picture plane from viewpoint
size of mosaic element
horizontal cutoff value for mosaic
vertical cutoff value for mosaic
centre of sphere
radius of sphere
direction of illumination.

The drawings were produced by the Elliott 4120 computer at Greenford Computer Workshop, using a Benson-Lehner 141 digital plotter and Rapidograph Variant pens.

So what?

A ball is a suitable test case, mathematically simple yet beyond the reach of traditional perspective methods. Clearly the same approach enfolds the whole of classical linear perspective by simple specializations. It is also clear that it can be extended to draw other forms which have been mathematically studied, placed in any position in any light. The next important step is to develop a

method for specifying natural forms in computable terms. The work in developing a programme is considerable. But once done, it provides a whole range of pictures of imaginary objects, of photographic standard but under various controls. The limit, as before, is the imaginative grasp of the user.

25 April 1968—programme
by Alan Parkin
Spherelit:

```
'BEGIN' 'REAL' CX, CY, CZ, R, DIX, DIY,
  DIZ, LAM, BRI, AX, AY, AZ, NOX, NOY,
  NOZ, T, U, V, MISS;
'INTEGER' E, J, K, S, D, N, M, Q;
'READ' E, D, S, N, M, CX, CY, CZ, R, DIX,
  DIY, DIZ, Q;
SETORIGIN (E, O);
'FOR' K:=M 'STEP' −S 'UNTIL' −M 'DO'
'FOR' J:=N 'STEP' −S 'UNTIL' −N 'DO'
'BEGIN' AX:=J;
AY:=K;
AZ:=D;
T:=−AX*CX−AX*CX−AY*CY−AY*CY
  −AZ*CZ−AZ*CZ;
U:=AX*AX+AY*AY+AZ*AZ;
V:=CX*CX+CY*CY+CZ*CZ;
MISS:=T*T−4*U*(V−R*R);
'IF' MISS<−0.0000001 'THEN' 'GOTO'
  RETURN;
LAM:=(−T−SQRT(MISS))/(U+U);
NOX:=(LAM*AX−CX)/R;
NOY:=(LAM*AY−CY)/R;
NOZ:=(LAM*AZ−CZ)/R;
BRI:=NOX*DIX+NOY*DIY+NOZ*DIZ;
'IF' BRI 'GE' 0.8888888 'THEN' 'GOTO'
  RETURN;
'IF' BRI<0.8888888 'AND' BRI 'GE'
  0.7777777 'THEN'
'BEGIN' MOVEPEN (J, K);
DRAWLINE (J+Q, K);
'GOTO' RETURN;
'END';
'IF' BRI<0.7777777 'AND' BRI 'GE'
  0.6666666 'THEN'
'BEGIN' MOVEPEN (J, K);
DRAWLINE (J+2*Q, K);
'GOTO' RETURN;
'END';
'IF' BRI<0.6666666 'AND' BRI 'GE'
  0.5555555 'THEN'
'BEGIN' MOVEPEN (J, K);
DRAWLINE (J+2*Q, K);
DRAWLINE (J+2*Q, K+Q);
'GOTO' RETURN;
'END';
'IF' BRI<0.5555555 'AND' BRI 'GE'
  0.4444444 'THEN'
'BEGIN' MOVEPEN (J, K);
DRAWLINE (J+2*Q, K);
DRAWLINE (J+2*Q, K+Q);
DRAWLINE (J+Q, K+Q);
'END';
'IF' BRI<0.4444444 'AND' BRI 'GE'
  0.3333333 'THEN'
'BEGIN' MOVEPEN (J, K);
DRAWLINE (J+2*Q, K);
DRAWLINE (J+2*Q, K+Q);
DRAWLINE (J, K+Q);
'END';
'IF' BRI<0.3333333 'AND' BRI 'GE'
  0.2222222 'THEN'
'BEGIN' MOVEPEN (J, K);
DRAWLINE (J+2*Q, K);
DRAWLINE (J+2*Q, K+Q);
DRAWLINE (J, K+Q);
DRAWLINE (J, K+2*Q);
'END';
'IF' BRI<0.2222222 'AND' BRI 'GE'
  0.1111111 'THEN'
'BEGIN' MOVEPEN (J, K);
DRAWLINE (J+2*Q, K);
DRAWLINE (J+2*Q, K+Q);
DRAWLINE (J, K+Q);
DRAWLINE (J, K+2*Q);
DRAWLINE (J+Q, K+2*Q);
'END';
'IF' BRI<0.1111111 'THEN'
'BEGIN' MOVEPEN (J, K);
DRAWLINE (J+2*Q, K);
DRAWLINE (J+2*Q, K+Q);
DRAWLINE (J, K+Q);
DRAWLINE (J, K+2*Q);
DRAWLINE (J+2*Q, K+2*Q);
'END';
RETURN: 'END';
MOVEPEN (0, 0);
'END';
```

Computer-generated pictures

L. D. Harmon and K. C. Knowlton

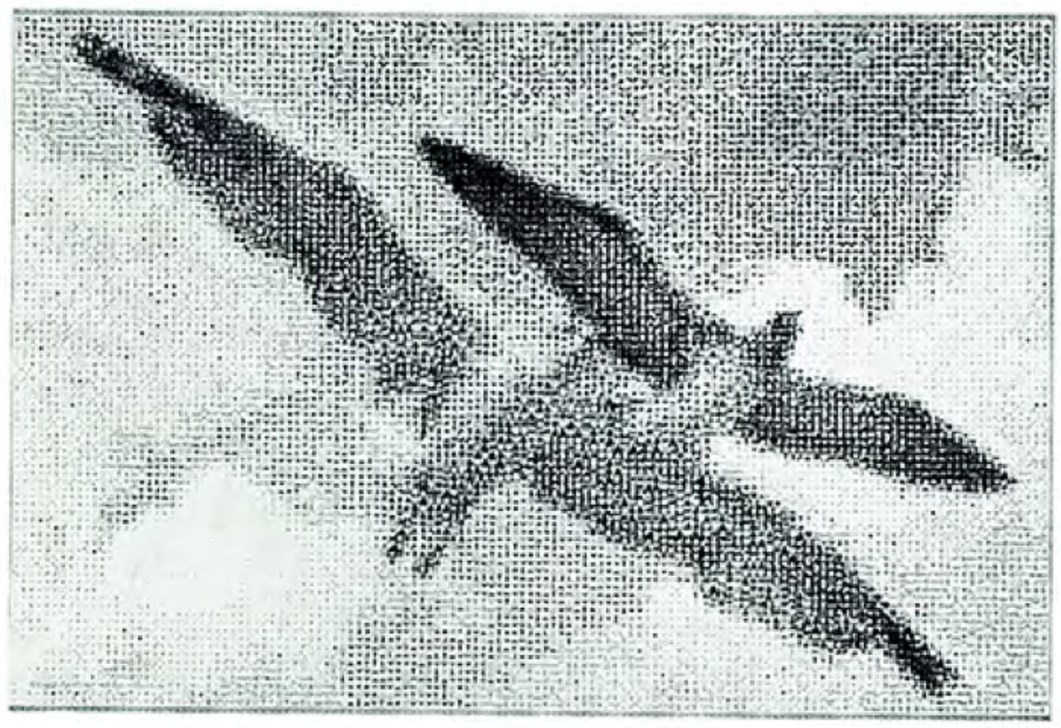
A 35-mm transparency is made from a photo of some real-world object and scanned by a machine similar to a television camera. The resultant electrical signals are converted into numerical representations on magnetic tape. This provides a digitized version of the picture for computer processing.

The first step taken by the computer is to fragment the picture into 88 rows of 132 fragments per row. The average brightness level of each fragment is computed; thus 11,616 (88 × 132) numbers are generated.

The brightness levels are encoded into numbers 0 through 15 which stand for white, black, and 14 intermediate shades of grey. The original picture is now represented by 11,616 numbers each one of which represents a small area having one of 16 possible density (brightness) values.

In the processed picture a given density is reproduced by the number of black dots occupying an 11 × 11 square, and this dot array is produced on microfilm by a Stromberg Carlson 4020 microfilm printer. Instead of randomly sprinkling black dots over the 11 × 11 square in the proportion called for by any given brightness level, the dots are organized into micropatterns which can be seen at close range. For example, a light grey (say brightness level 5) requires (ideally) 42 black dots. So approximately this number of black dots is structured to form either a house, or a cat, or a stop light, or an umbrella, etc. Similarly a nearly black element (say level 14, requiring 111 black dots) might be a lightning flash, a white division sign on a black background, etc. There are a total of 141 patterns. Some brightness levels have as many as 14 to choose from, while others have as few as 5.

When a particular brightness level is called for, the computer makes a random choice among the set which fits that level; different



K. C. Knowlton
and Leon D. Harmon
Gulls: studies in perception II

probabilities may be assigned to different patterns within a given level.

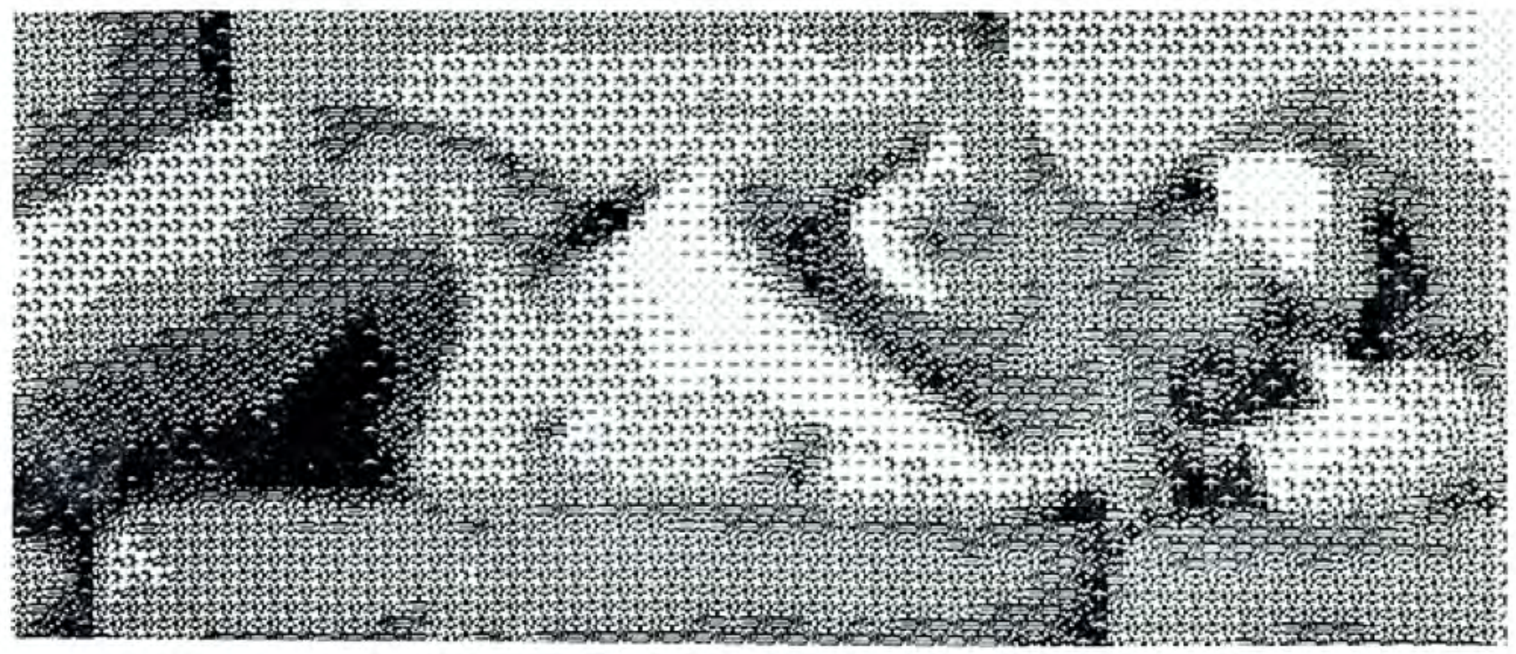
The overall picture is actually produced on 6 frames of microfilm because the resolution of the microfilm printer is only 500 separable dots horizontally, whereas we need 132 × 11 = 1452 dots along that dimension. The 6 microfilm frames are then enlarged photographically, pasted together, and rephotographed to produce a final high-contrast 8 × 10 inch negative. This negative is then used to produce a giant enlargement like the one shown here. At close viewing distances the 11,616 tiny patterns are clearly visible, but unless you know exactly what to look for, the large picture cannot be perceived. With increasingly great viewing distances the small patterns disappear, and the overall picture emerges.

There are several reasons for experimenting with these pictures:

To develop new computer languages which can easily manipulate graphical data;

To explore new forms of computer-produced art;

To examine some aspects of human pattern-perception.



Top, *Mural* 1966, 5 × 12 ft produced by Kenneth C. Knowlton of Plainfield New Jersey and Leon D. Harmon of Watchung, New Jersey.

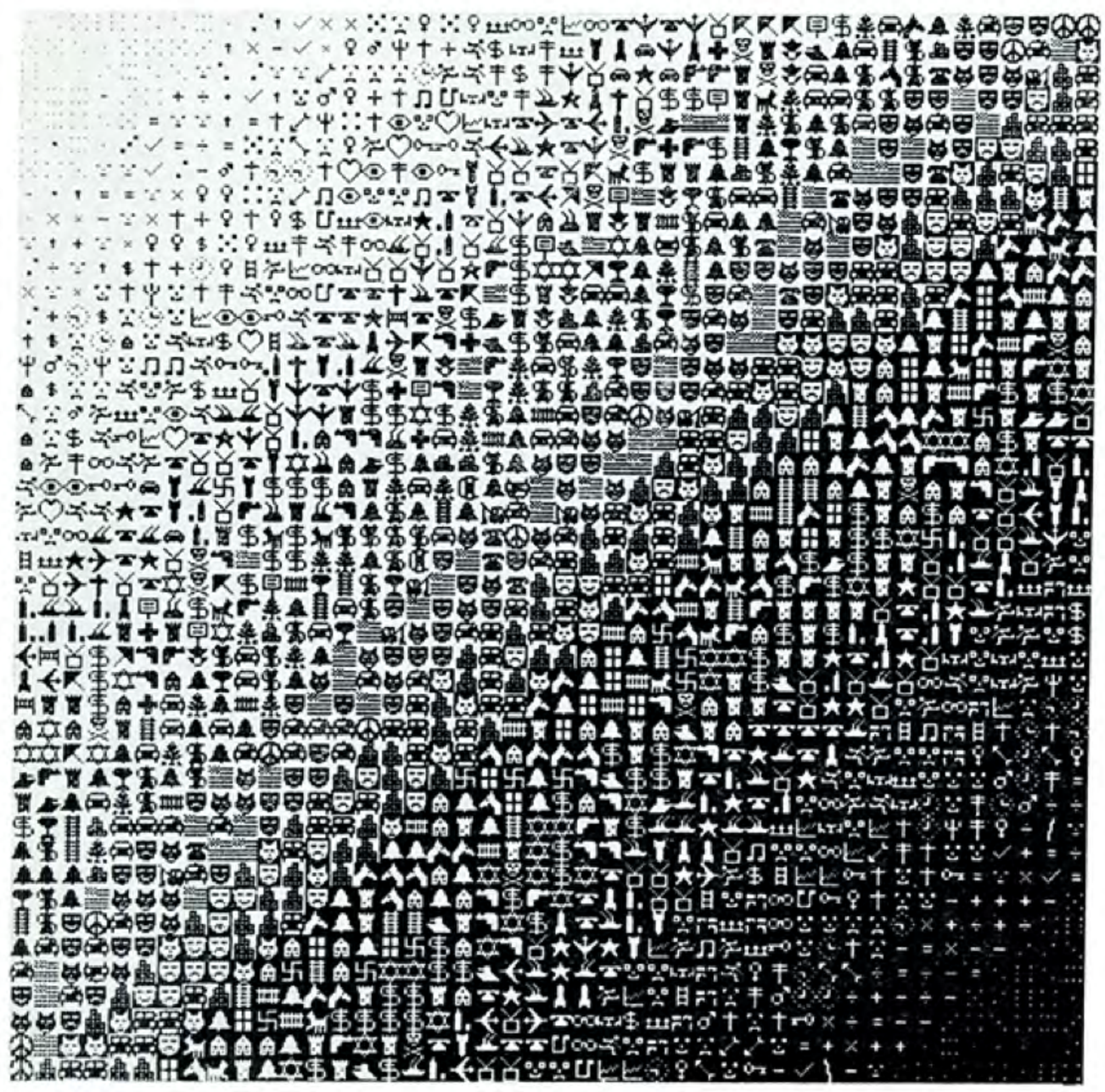
A conventional photograph was scanned, like a television picture, and the resultant electrical signals were converted into binary numbers (representing brightness levels at each point). These numbers were then written on magnetic tape which thus provided a digitized version of the picture for computer processing. It was required that brightness be quantized into eight levels (from all black to all white) to represent tonal value for local patches of picture (100 across, 40 vertically; i.e. 4,000 in all). Thus each 1/4000 of the picture area is represented by one of eight possible densities. A given density was reproduced in the processed picture by the number of primitive black points occupying a 10 × 10 square. Thus an all black region would have 100 *as* in it; ideally an all-white patch would be bare, but a few *as* were sprinkled in to avoid a washed-out appearance. The remaining six levels were obtained by varying the percentage occupancy by *as* of each 10 × 10 area. Actually twelve choices were provided, two at each level, to avoid monotony. These twelve sub-pictures were made to represent various appropriate patterns. They are Level 2 (nearest white): multiplication and division signs; Level 3; transistors, either normally oriented or rotated; Level 4: zener diodes, either normally oriented or rotated; Level 5: vacuum triodes or a random pattern; Level 6: resistors or a tape reel; Level 7 (nearest black): a wiring crossover or a random checkerboard.

When the computer found a quantized picture region of a particular level, the appropriated sub-picture was called up and printed by a microfilm output plotter at the proper location. The resultant microfilm was then enlarged photographically to produce the final mural. You will see that there are three viewing levels. At the closest view, one can see the individual *a* symbols. At the next level the sub-patterns are evident. Finally at sufficiently great viewing distance (20 to 30 feet is appropriate, but even more is better), the overall picture (original) becomes clear. The effect is very much like that of viewing a newsprint photo very close up at first, then stepping back.

[Patrons of the project: E. Arthurs; E. E. David jr; B. Julesz; M. V. Mathews; P. G. Neumann; J. R. Pierce; M. R. Schroeder; V. A. Vyssotsky.]

Above right, K. C. Knowlton and Leon D. Harmon
Telephone: studies in perception I

Above, far right, K. C. Knowlton and Leon D. Harmon
Gargoyle: studies in perception III

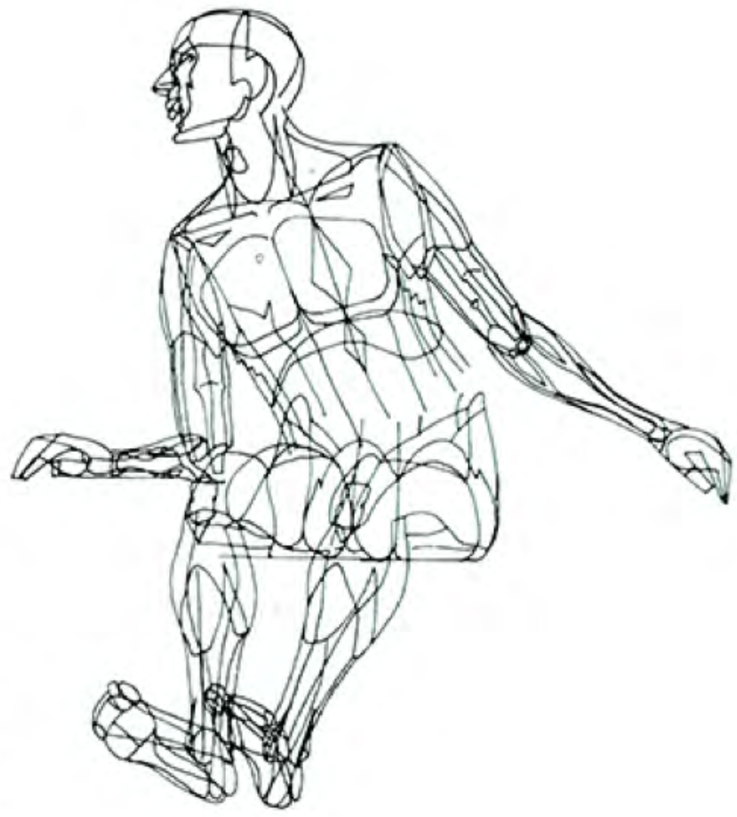


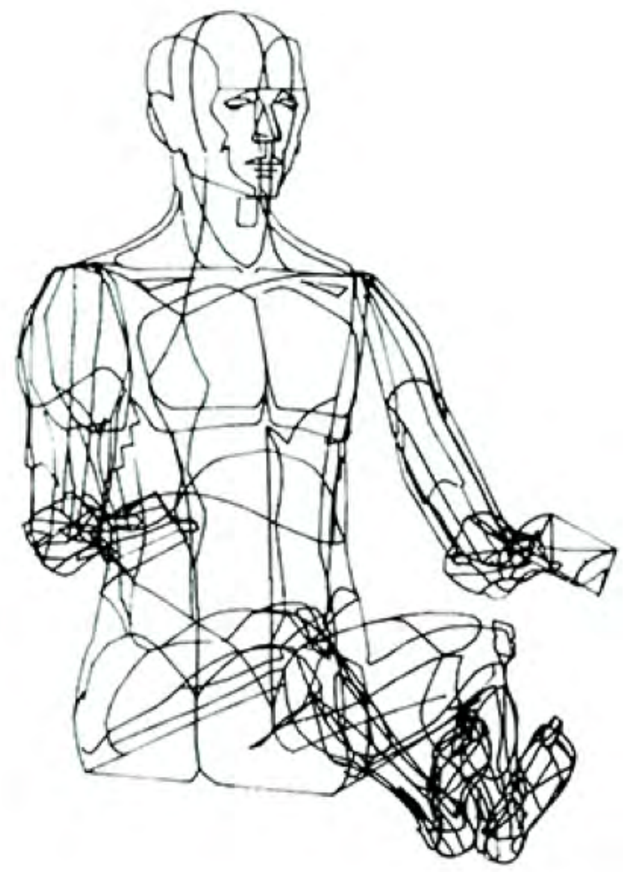
Right, Tone scale of symbols used in producing the *Telephone*. All the images are, in fact, communication symbols

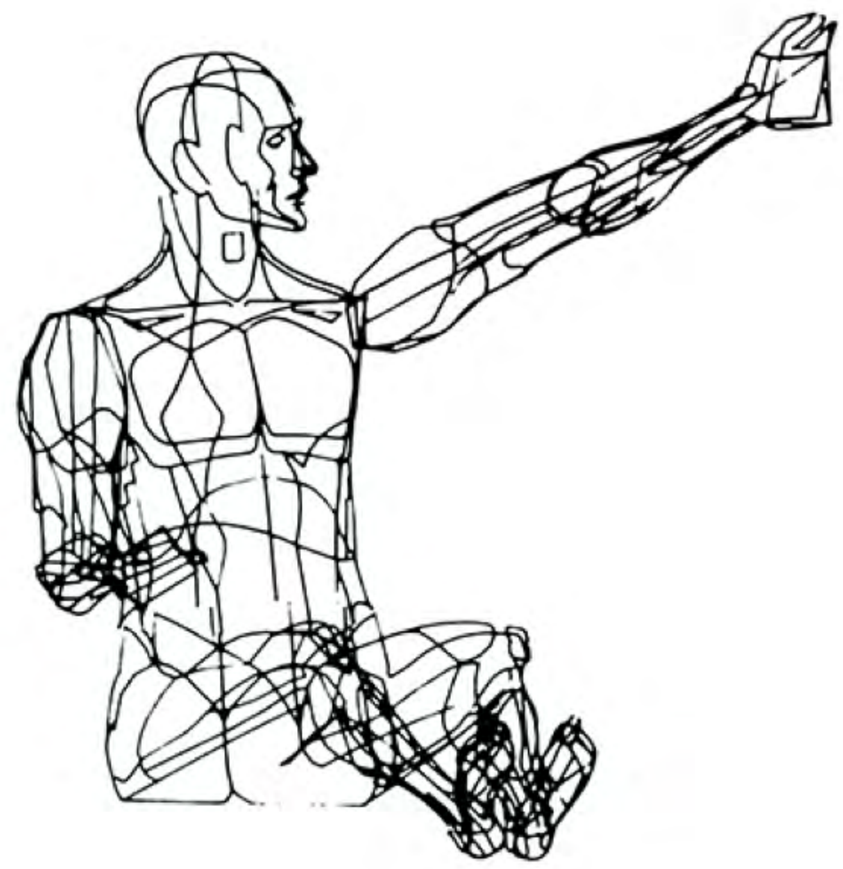
Boeing computer graphics

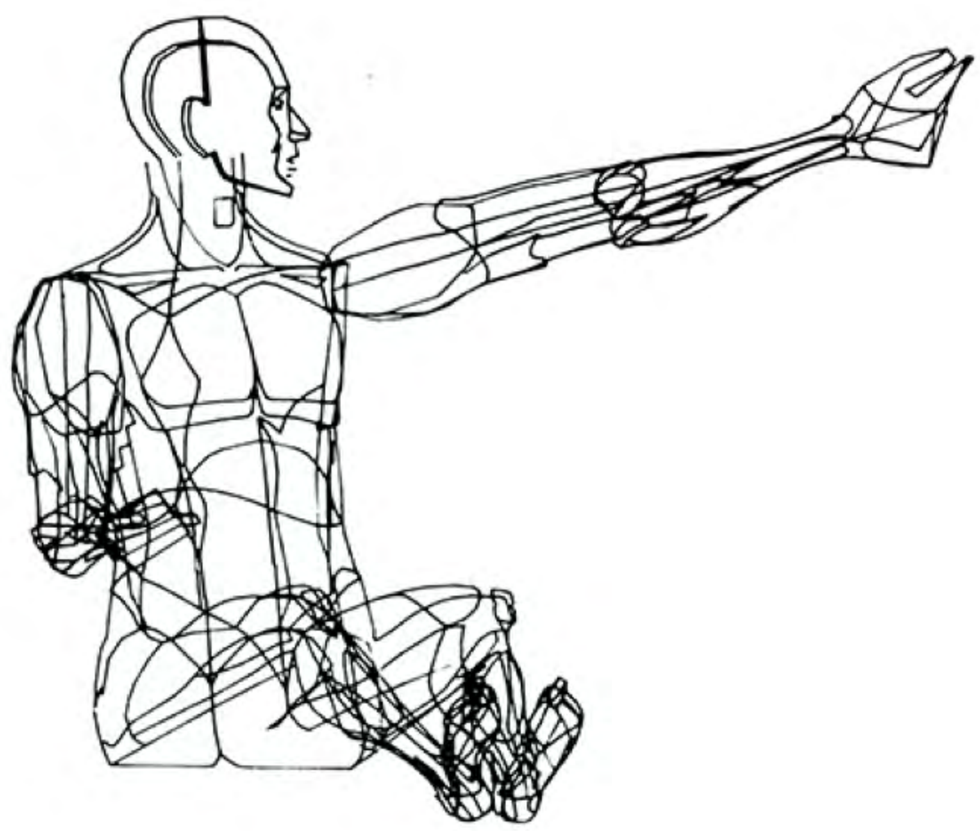
The Boeing Computer Graphics organization has been working on direct application of projects within the company. They produce a final product which is used by engineers and management to visualize specific problems. There are various studies involving Boeing aircraft and its immediate environment, such as airports, flight, etc. These are in the form of pilot visibility in cockpit configurations and various perspective and isometric drawings of aircraft done with a computer plotter. The equipment used was Keypunch, IBM 1400C reader printer, IBM 7094 computer, Gerber plotter.

One of the projects is the animation of the human figure by the computer including sequence of film showing movement of the various limbs. This man is a creation of Air Force data and the Boeing designers and he represents the fifty percentile pilot in the US Air Force.

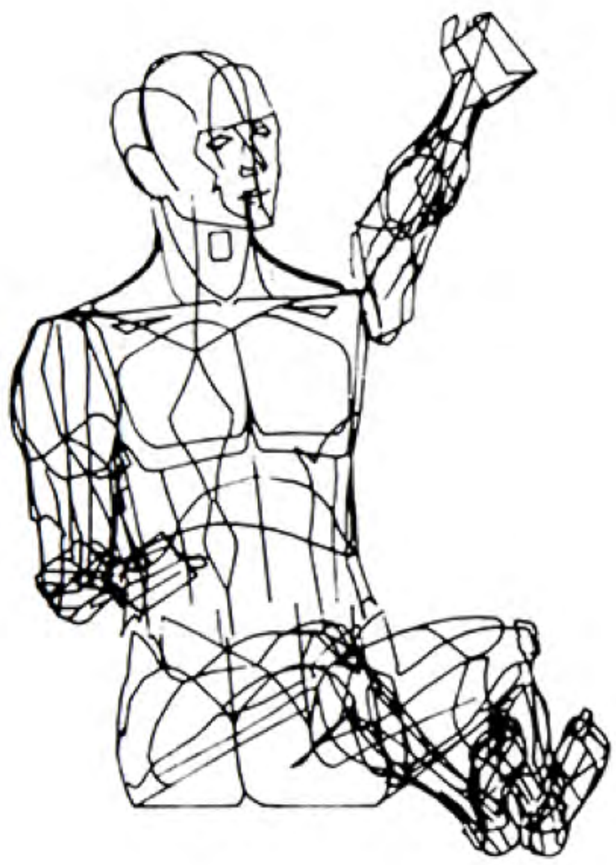


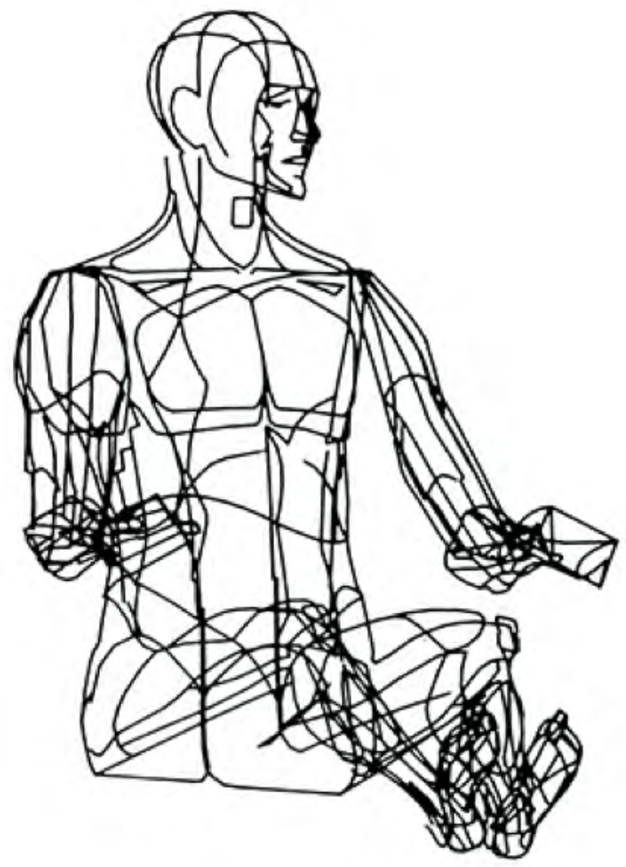


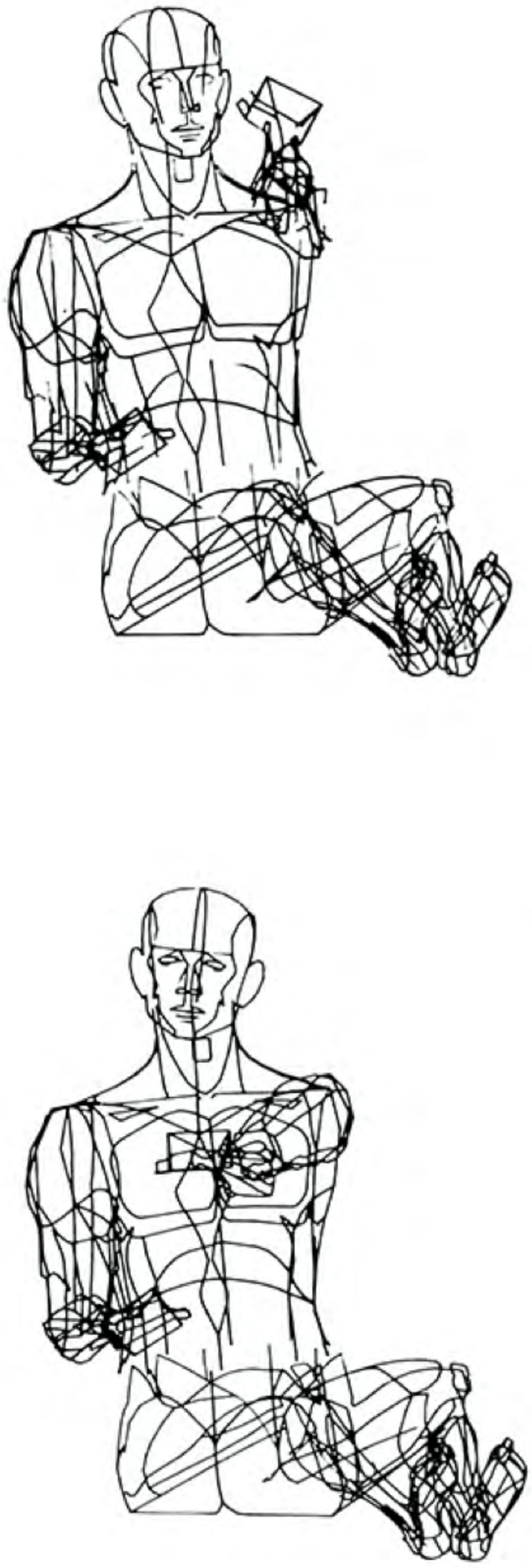




1. Human figure
This was the outgrowth of human engineering needs for a means of determining human capabilities in cockpit configurations. It is used for studies to determine cockpit instrument location and arrangement for easier use of control.
Top, centre column, front view – seated. Subject checkout plot.
Top, right-hand column, and reading downwards left to right in sequence, rear view sequence. Due to the inability of the programme to eliminate hidden lines at this time, we have a transparent figure. This figure is seated looking away from you with a movement to right and body movement toward the left.
This figure is now a seven-system figure. Each moveable part is a system – the head and neck, the torso, the legs, right upper arm, left upper arm, right lower arm, left lower arm. The aim is to have a 21-system man where the complete figure can be manipulated

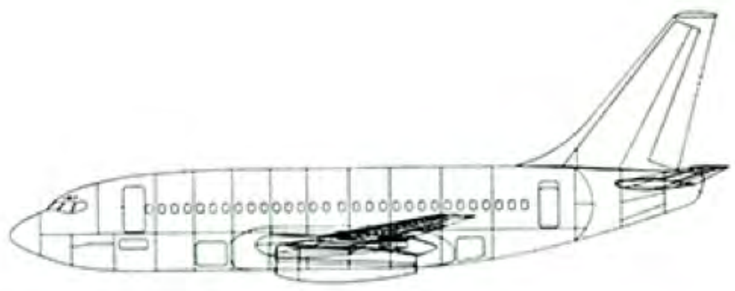






2. Boeing 737 project
This aircraft is a short-range commercial airliner which has gone into service in 1968.
a. Orthographic plot–front view
b. Orthographic plot–side view
c. Isometric plot
Figure a and b are check plots and are part of checkout programme. From them one can be sure that the information is correct. The plots are produced by an automatic plotting machine, the Gerber plotter, from tapes produced from the IBM 7094. The information is fed to the 7094 in the form of punched IBM cards.
The isometric view is produced by using the programme for the subject definition along with a computer graphics programme. The isometrics were used as a drawing base for manuals and publication work which involved pictorial representation of the Boeing 737

2a



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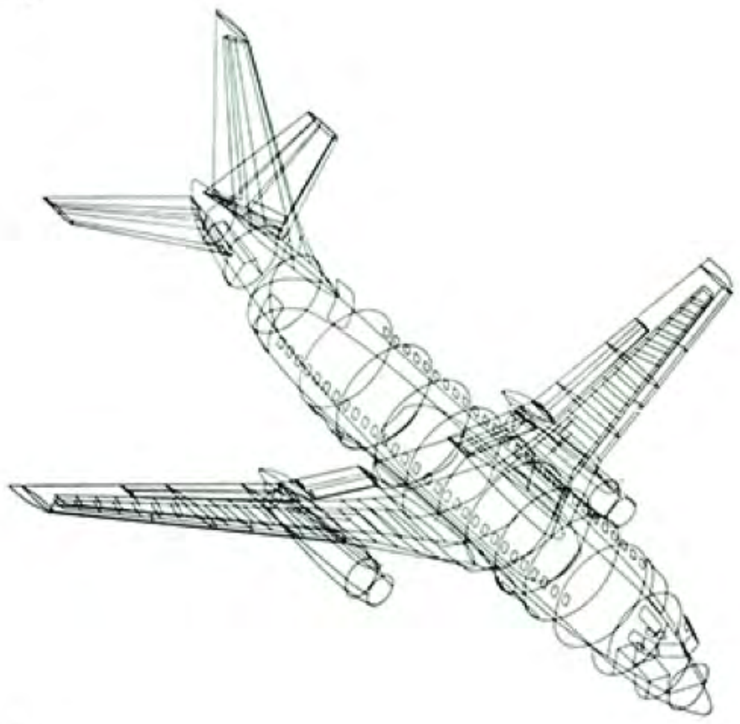
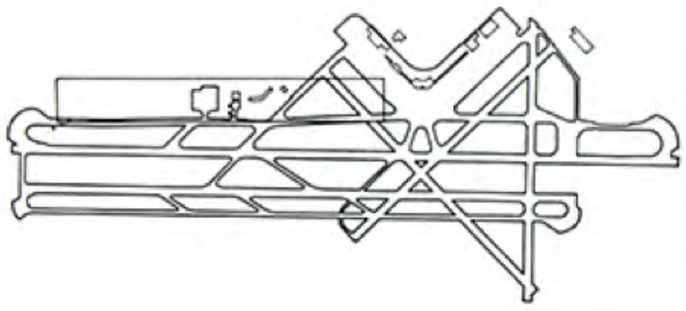
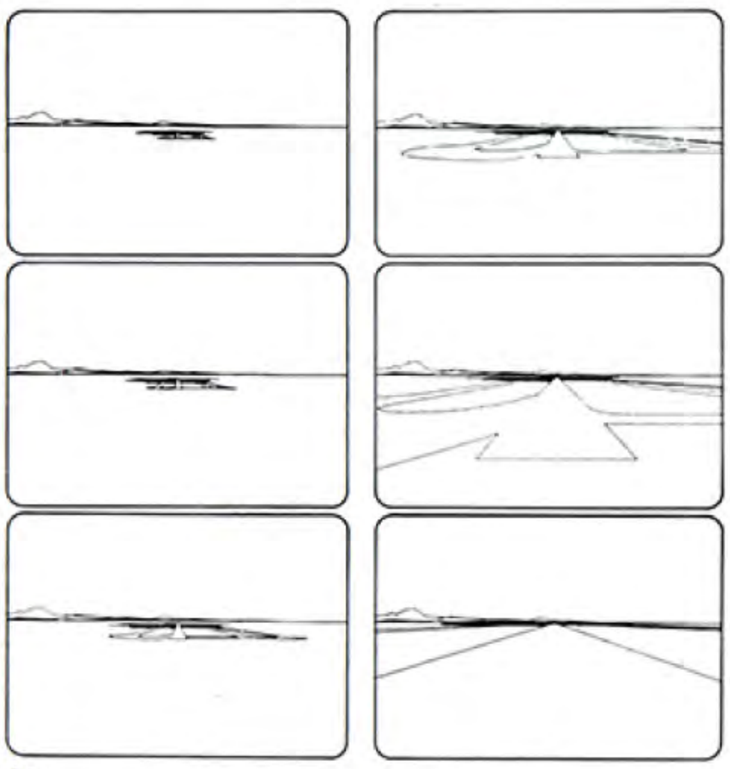


2c

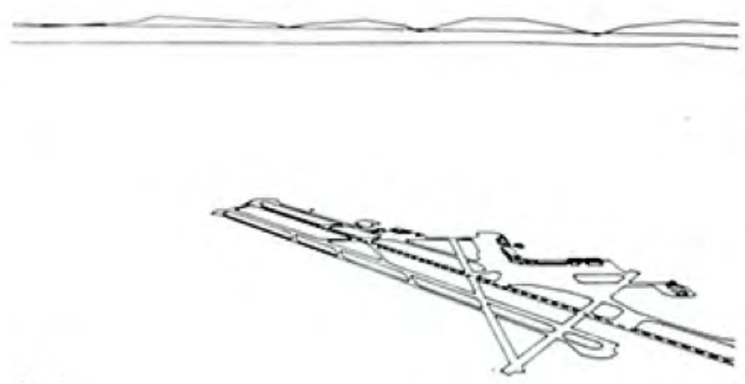


3a

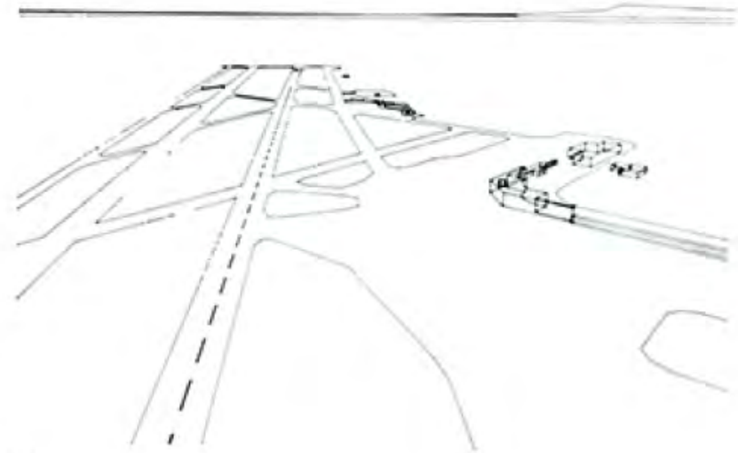


3b

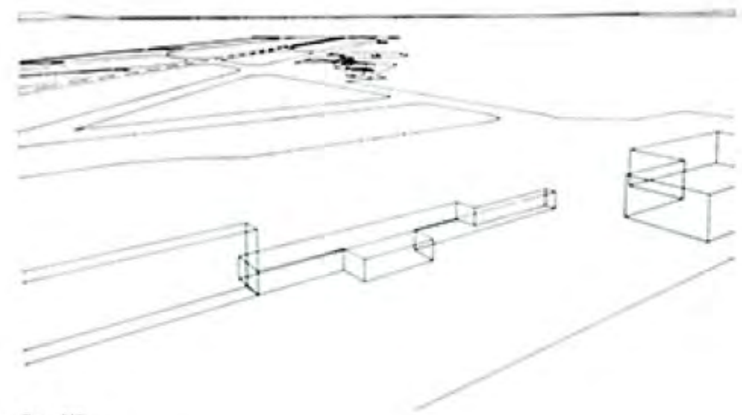
3. Seattle-Tacoma Airport
This was the first Boeing airport configuration for motion picture landing simulation. The data was taken from the Master Plan of Seattle-Tacoma Airport.
a. Orthographic view of Seattle-Tacoma Airport configuration.
b. Manoeuvre checkout plots with angle of descent and distance figured to aircraft speed–approach to landing. The main subject is an airplane in the middle of all the frames in the sequence.
c.i-iv. Zoom sequence from a height above the airport right up to the back of the primary object. The aircraft is not any one defined.



3c.i



3c.ii



3c.iii

3c.iv

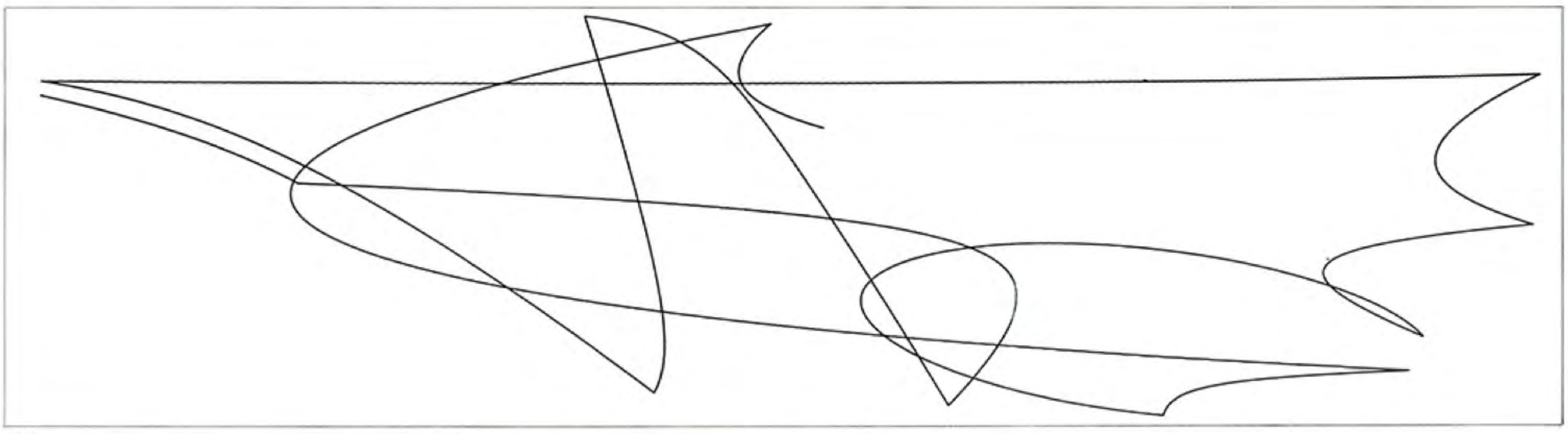
Computart panelling

Robert Parslow and Michael Pitteway

This demonstrates a combination of two separate research activities in the Computer Science Department at Brunel University. Robert Parslow has been active for a number of years in computer simulation work which involves the efficient generation of long sections of random or pseudo-random numbers. Professor Michael Pitteway developed an equally efficient programme for drawing conic sections, e.g. ellipses or hyperbolic arcs using the incremental graph plotter available with the Brunel University computer.

The two are here combined to produce computart originals of great simplicity. The computer is first given the dimensions of the required picture and is told how many curves are required in each colour–though only black has been used in this example. The machine then generates five random numbers, places the pen anywhere on the paper (two more random numbers required for this) and starts to draw a conic section chosen by the random numbers. The range of each number is scaled, however, so that, on average, the shapes drawn tend to fit the frame of the picture; round tubby curves are produced more often for a square picture while a long thin picture is covered with matching long thin shapes. When the pen reaches the edge of the picture, or if it is drawing a small ellipse when it has gone most of the way round, the computer suddenly generates five more random numbers and starts another curve. When enough curves have been drawn, the pen is lifted, the paper is moved on, and the computer starts a new picture. Every picture is an original. The computer never repeats itself, to the disappointment of an operator who on one occasion was unable to repeat a very effective surrealistic bull that was unfortunately produced under test conditions using a ball-point pen instead of the more effective coloured inks.

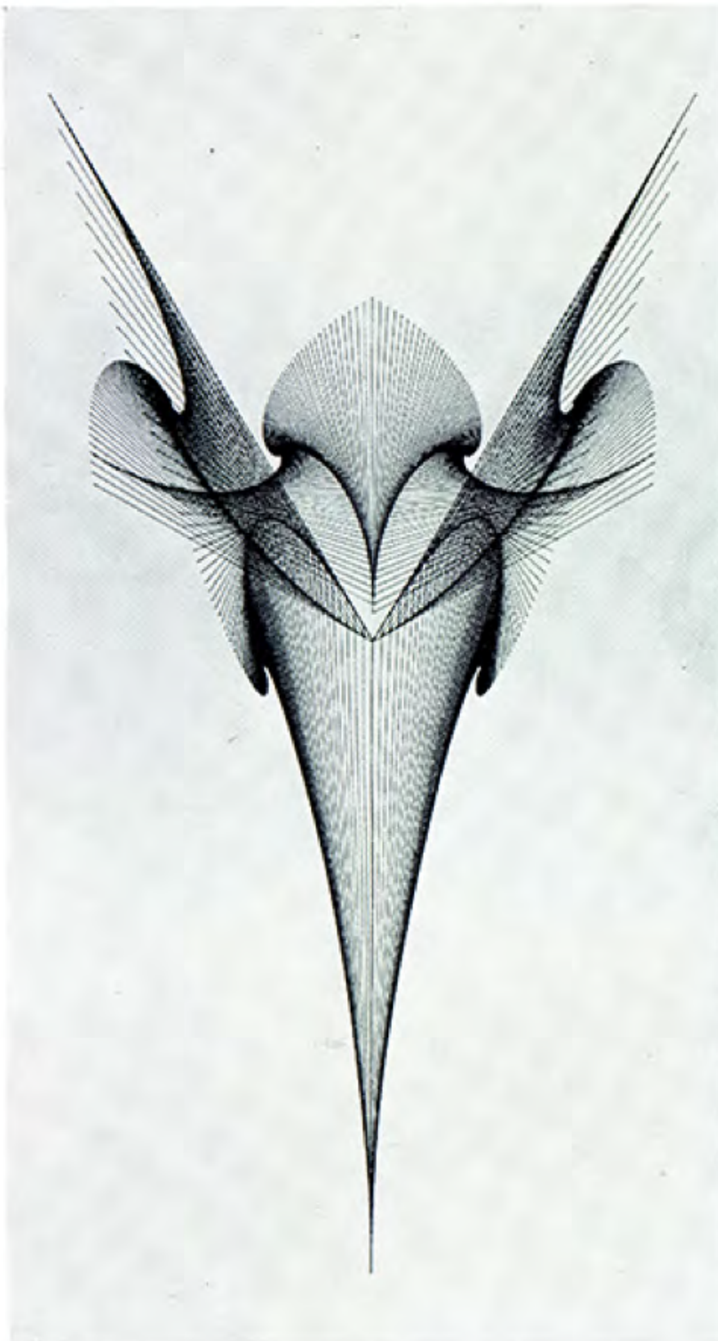
From an artistic standpoint, the programme is a genuine attempt to escape from the pretty geometrical and mathematical figures of conventional computer artwork, showing how the power and flexibility of modern equipment can be used to introduce a new freedom into the field of machine-associated art.



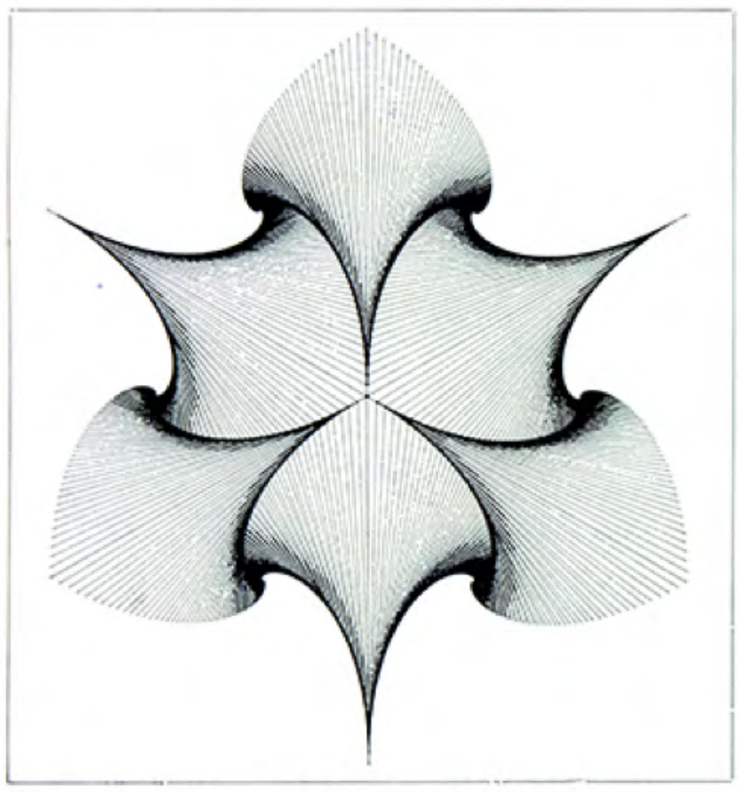
Calcomp plotting system

The Calcomp model 770 magnetic-tape system was used in conjunction with their 702 flatbed plotter to produce these computer graphics.

1 Hummingbird by Kerry Strand, produced on Calcomp 770 tape system and model 702 flatbed plotter. Plotting time took 30 minutes.



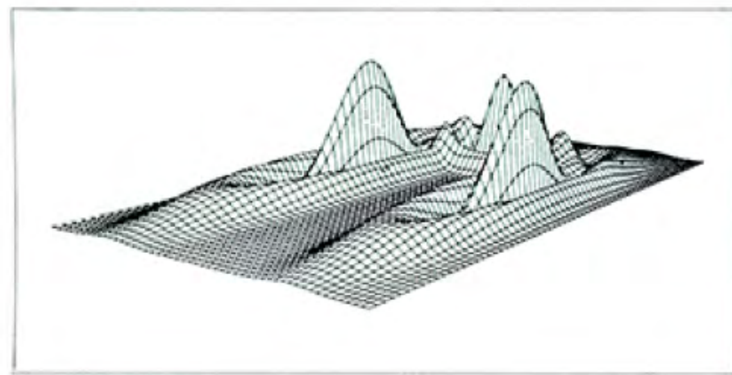
1



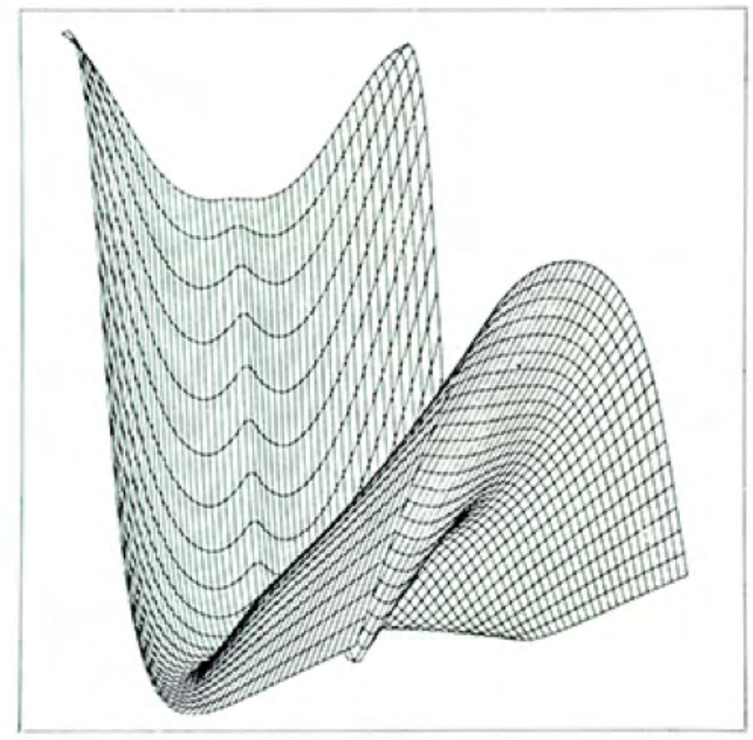
2

2 Crest by Kerry Strand, produced on Calcomp 770 tape system and model 763 drum plotter (zip mode). Plotting time took 5 minutes.

3 Three peaks by John Szabo, produced on Calcomp 770 tape system and model 763 drum plotter. Plotting time took 7 minutes.



3



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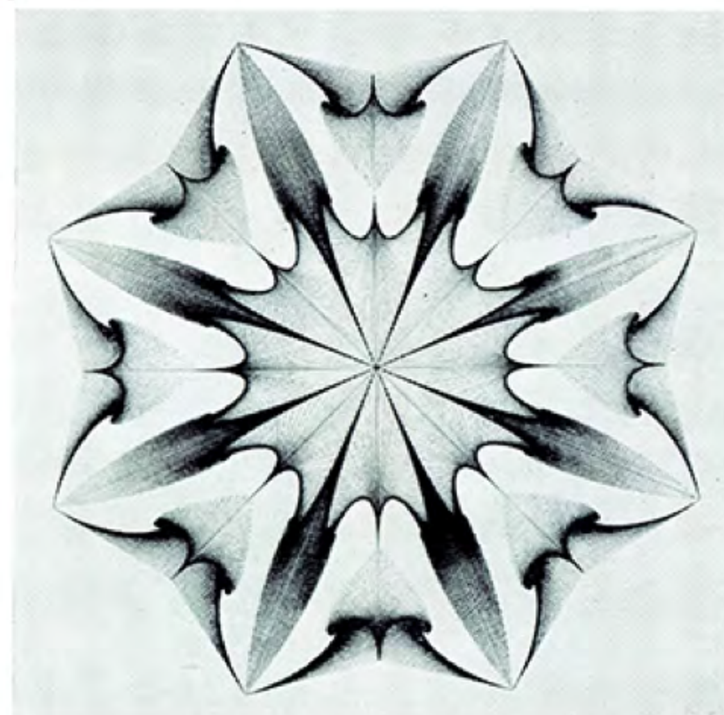

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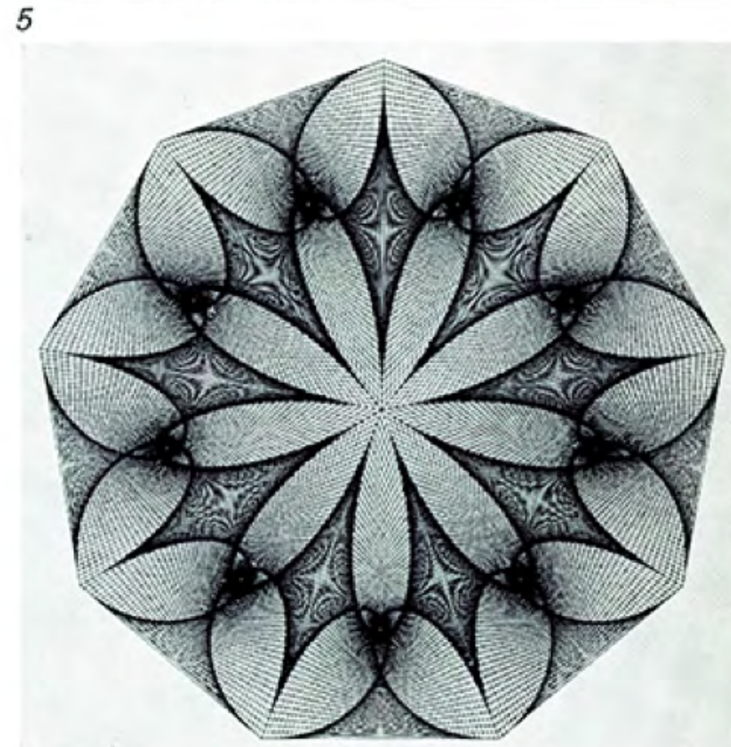

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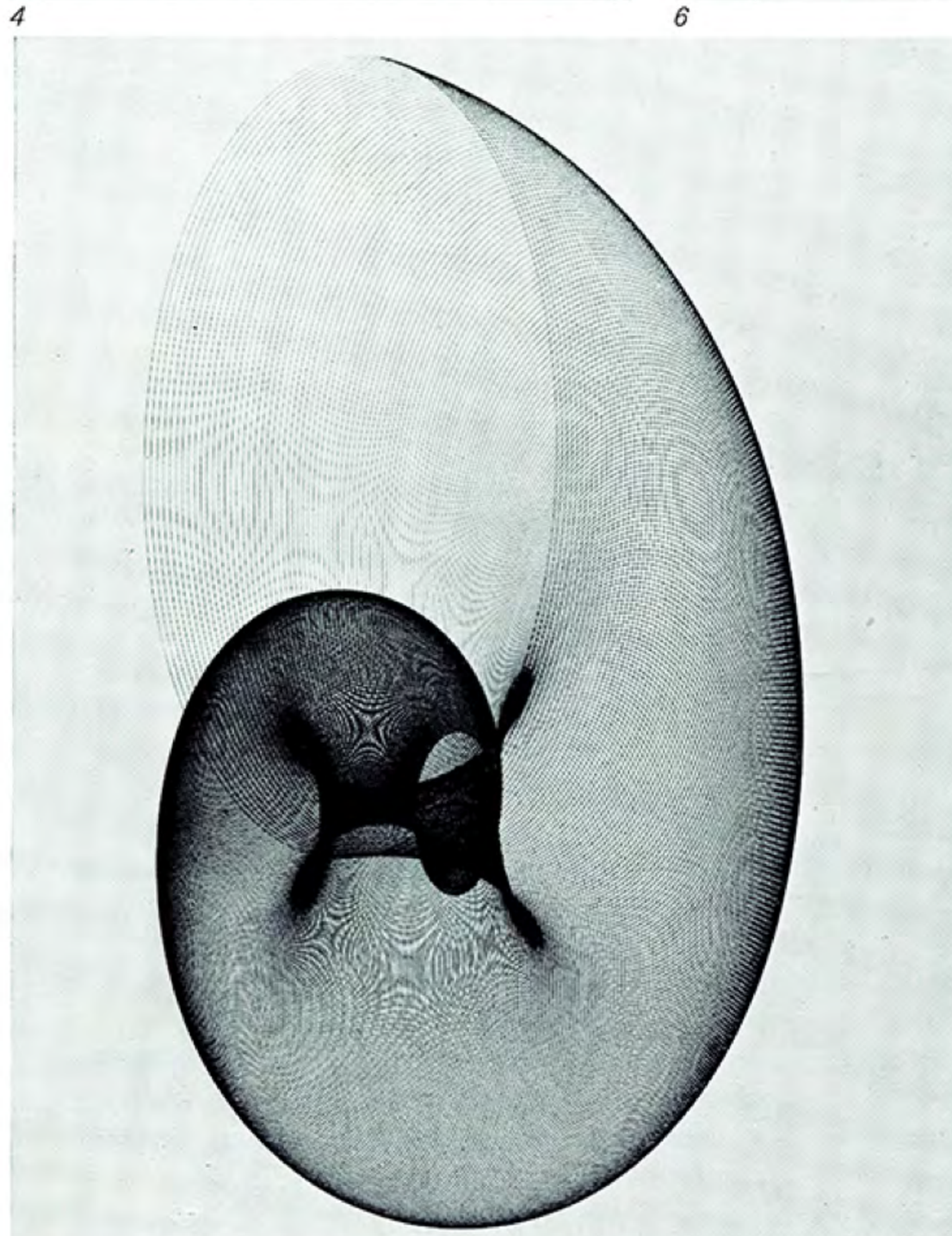


7

4 Krystallos

5 The bat by John Szabo, produced on Calcomp 770 tape system and model 763 drum plotter (zip mode). Plotting time took 7 minutes.

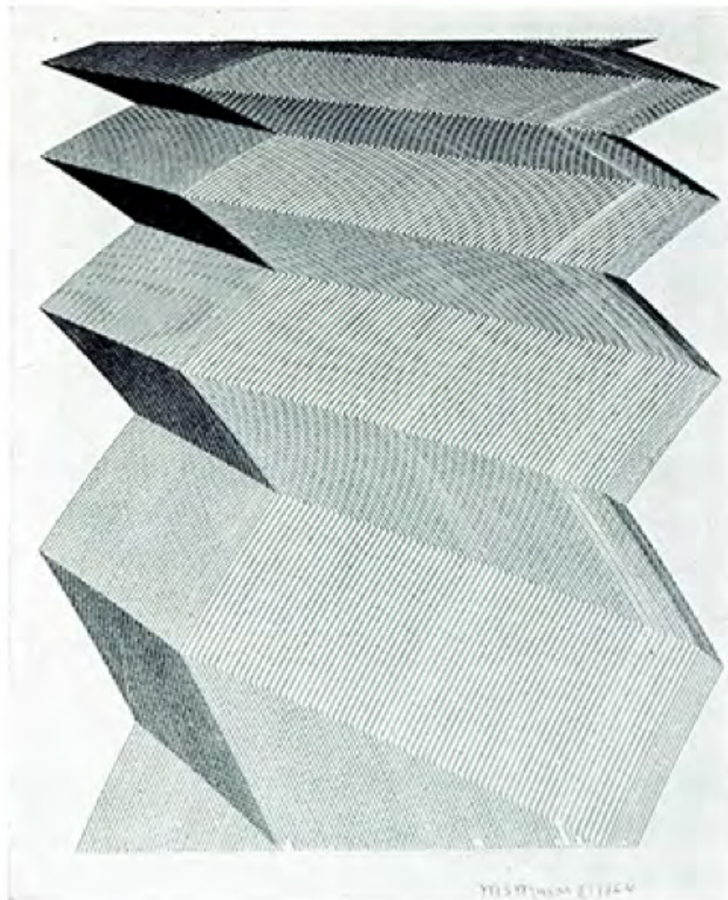
6 Symplexity by Kerry Strand and Larry Jenkins, produced on Calcomp 770 tape system and model 702 flatbed plotter. Plotting time took 1 hour.

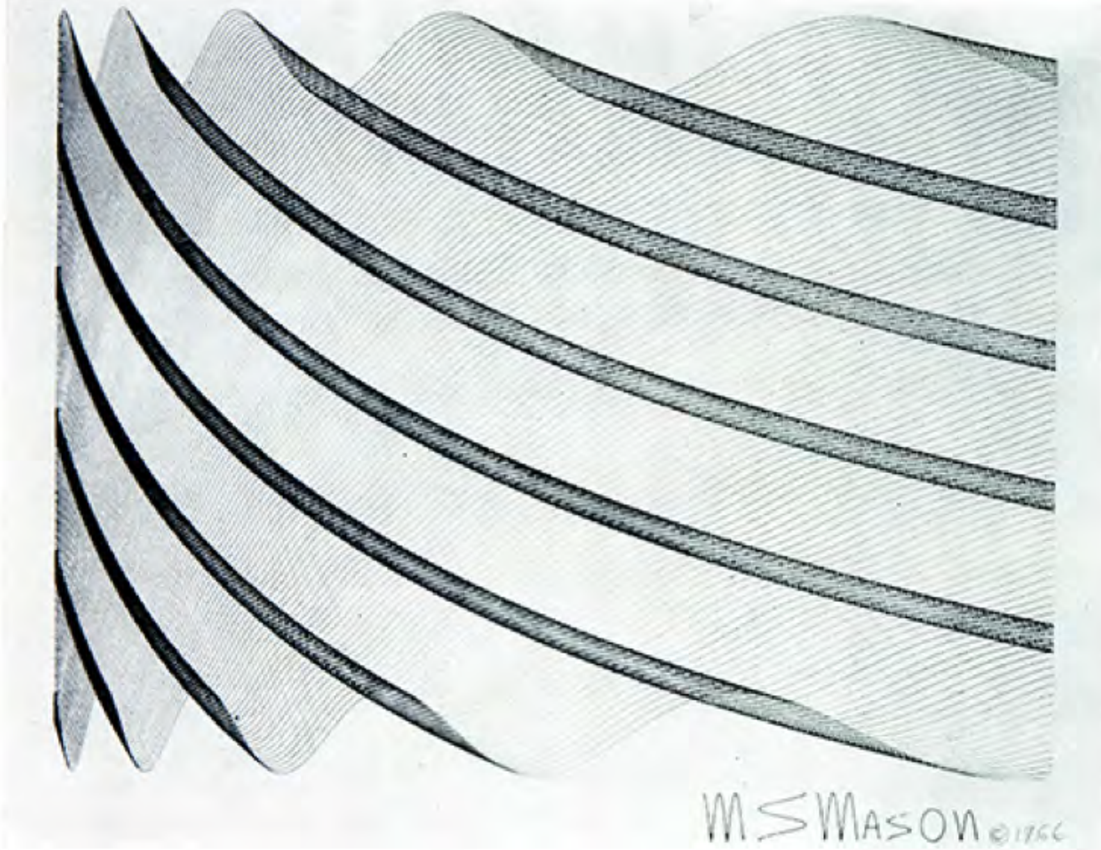
7 The snail by Kerry Strand, produced on Calcomp 770 tape system and model 702 flatbed plotter. Plotting time took 4½ hours.

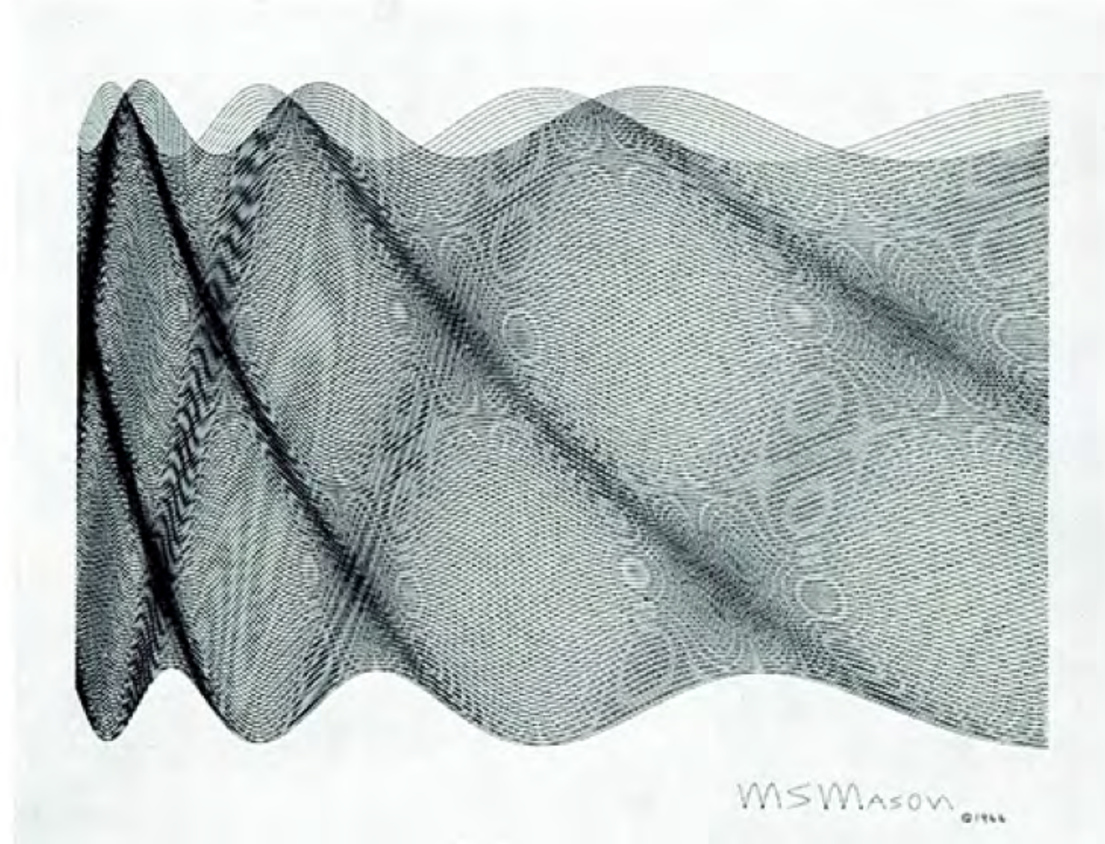
Computer-generated graphics

Maughan S. Mason

Mason visualizes the desired pattern and then conceives a circuit arrangement which will produce the effect. He works with an analogue computer in association with an XY plotter. The drawings are executed in black or coloured inks. They were previously shown at the Salt Lake Art Center, Salt Lake City, Utah.







Computer prints

Duane Palyka

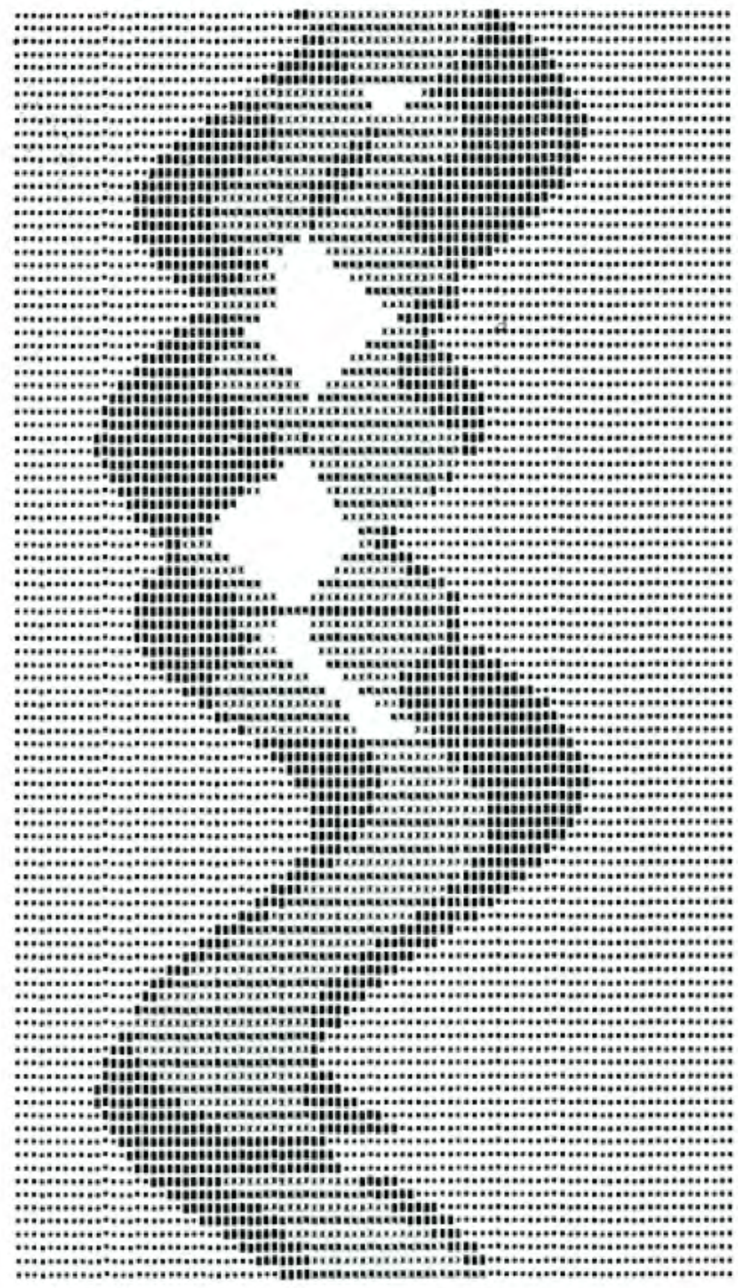
All my work was done on Carnegie-Mellon University's Bendix G-21 computer with a standard upper-case character set. The programmes were all written in ALGOL and utilized periods of three to fifty-nine minutes of computer time for each time my programme ran. I had no direct contact with the computer but had to submit my programme to an attendant to be run and then pick it up again afterwards along with the resultant output. The output contained the inputted code of my programme followed by a sequence of computer prints, each differing from the one before it. This variance results because of a random number generator which I call upon quite extensively throughout my programme.

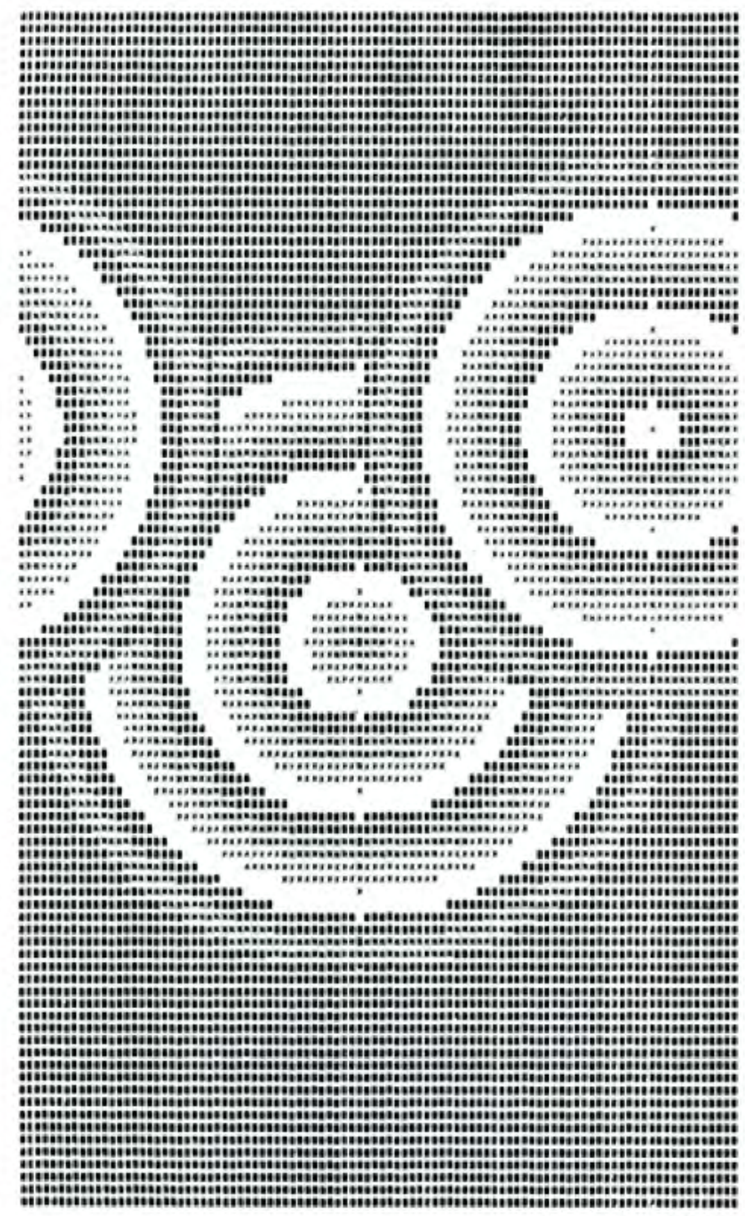
In originating my work two years ago, I developed several simple shapes that I felt would be exciting within a random grid arrangement. Since they were shapes that could easily relate to one another, I established some mathematical relationships that I would have liked to happen between the shapes. Then the computer, as I had programmed, generated random grid structures with my shapes allowing these relationships to occur in various positions of a 6 × 6 grid. The relationships are based on reflexive properties and negative variations of the original shapes designed.

Among my early prints, there are a few composed totally of reflexive triangular shapes. These shapes are designed to order a subtle radiating diamond structure beyond the viewers' immediate encounter with the print. All of the mathematical manipulations and calculations of each print are programmed to occur in the first part of my programme. Only when the computer has finished this phase of the operation does it print out the completed form of the print. Thus, in my more complicated pieces, the machine manipulates the design structure for one-half to three-fourths of an hour before finally printing it out. The value changes in the printing process are created by printing alphabetic characters upon each other, and range from the initial white of the paper to a total black character created by printing a 'T' upon an 'E' upon an 'N' upon a 'Z'. The increased time-length occurs in works where each design is considered to be composed of

10,000 variable point positions on the page instead of the 36 design blocks used in the earlier prints. I began transition towards this more complex point system in the third group. In this group the programme contains a shifting of grids and distortion of shapes until the original inputted shapes (still being used at this point) become lost in the more demanding structure of the print. I make a distinct effort here and in all of my work to allow chance to intervene at every possible phase of mathematical manipulations.

In the work which resulted in the latest prints, I introduced, as an initial phase of my programme, procedures to construct shapes and to construct them relative to the page upon which they would be placed. Increasingly, as my work progressed, the concept of pictorial space gained in importance. The shapes subsequently were designed more three-dimensionally and merged with a depth of enveloping space. Eventually I found myself working on many programmes at the same time and storing unfinished prints still in their mathematical state within the computer's memory—using them later in other programmes. As operations became more complicated, one phase of the computer's operation merged with other phases; and shapes which were usually created first in the programme were now being created in the middle of a print's construction. In some cases I had the computer analyse the finished print to determine its linear construction—having the linear analysis saved and used as a part of another print.

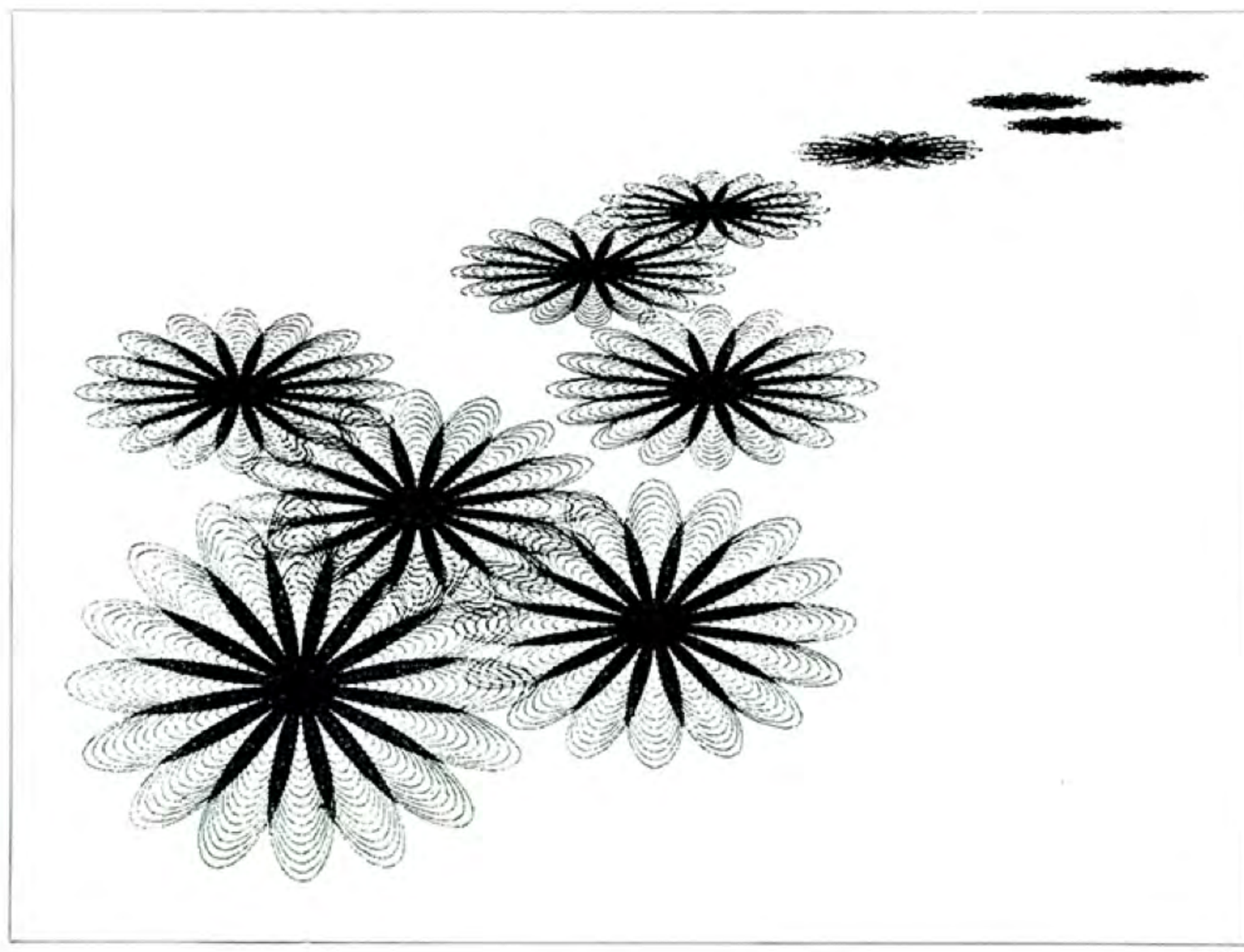




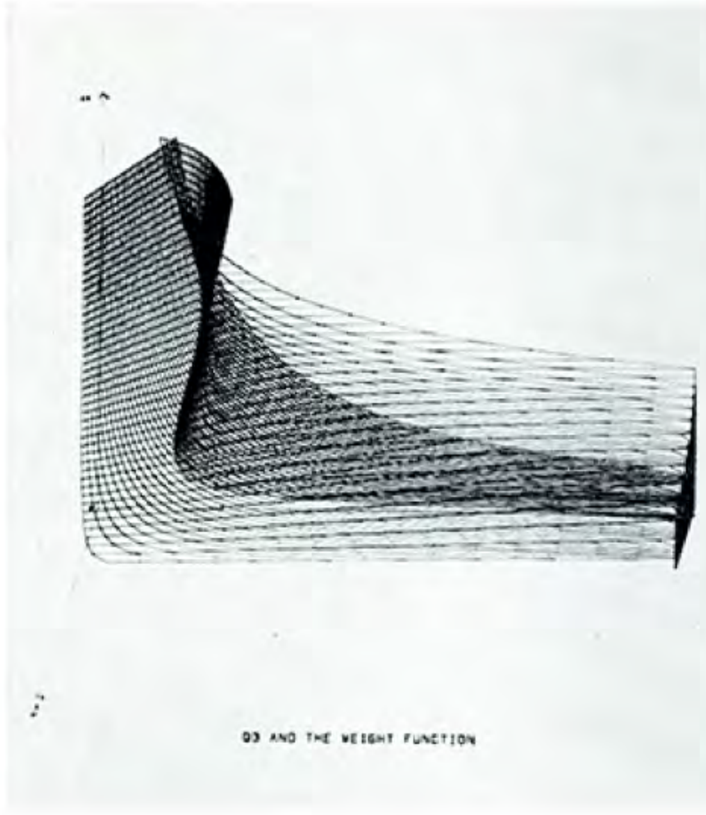
Computer graphics by Duane Palyka, Pittsburgh. The works were done on Carnegie-Mellon University's Bendix G-21 computer with a standard upper-case character set. The programmes were all written in Algol and utilized periods of three to fifty-nine minutes of computer time for each time the programme ran.
The output contained the inputted code of the programme followed by a sequence of computer prints, each differing from the one before it. This variety results because a random generator was used extensively throughout.

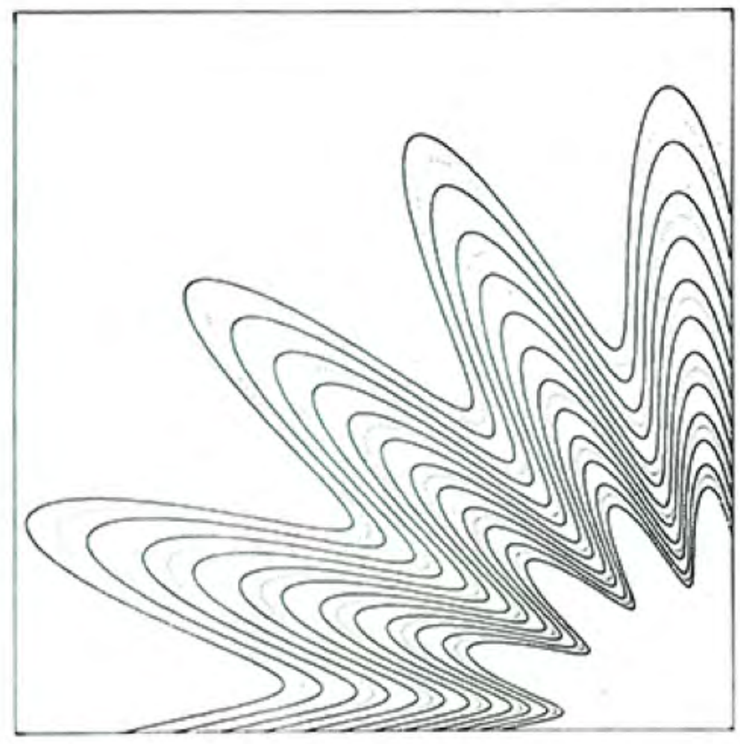
Lloyd Sumner

started experimenting with computer graphics in the early 1960s. He made them at the University of Virginia, using extended Algol for programming a Burroughs B 5500 and a Calcomp 565 plotter. He launched a firm called Computer Creations from which he sells computer graphics in red, blue, green, brown and black. His graphics are given romantic titles and the largest dimension is 28 × 12 in. This one is called *Friendly flowers of time and space.*



7 designs

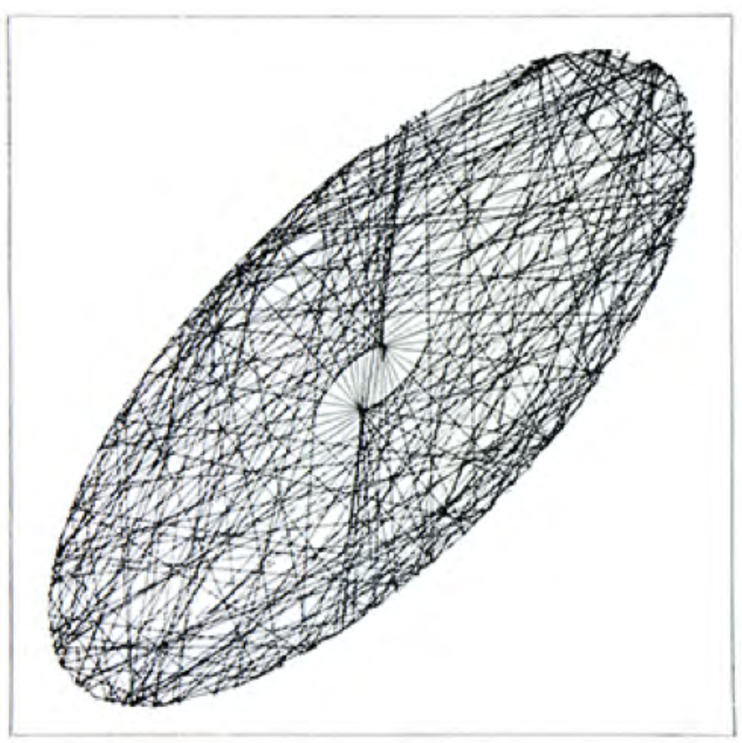




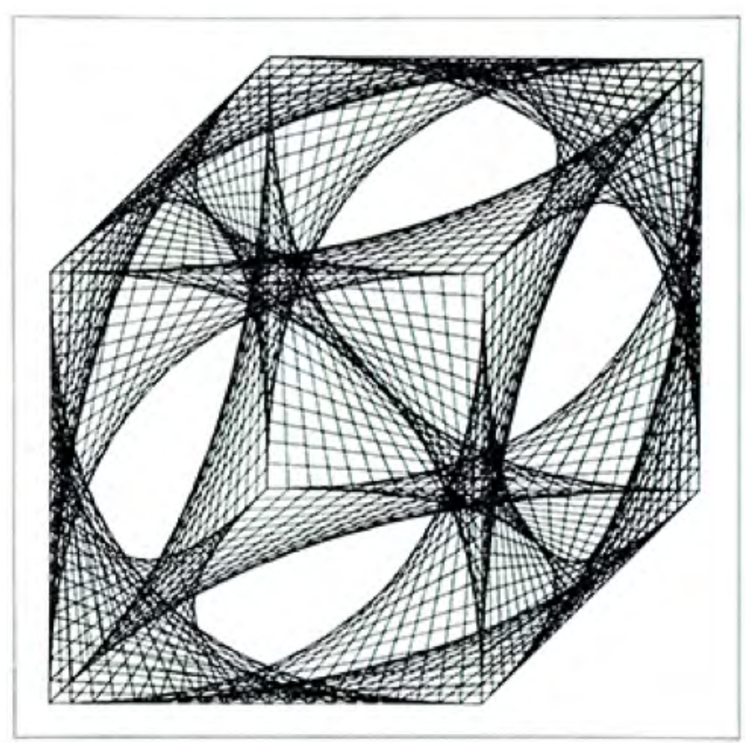
Far right, *Modulated logarithmic spiral* by C. T. Messinger (China Lake, California), computed on IBM 7094 digital computer and drawn on a Stromberg-Carlson 4020 display unit.

Right, *Weight function graph* by C. T. Messinger, computed on an IBM 7094 computer and drawn by a Stromberg-Carlson 4020 display unit.

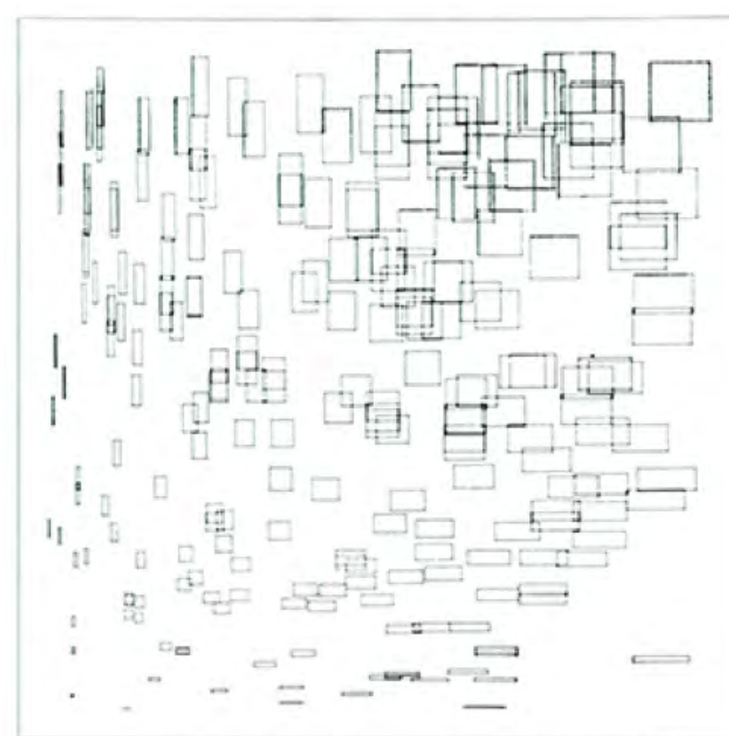
Below, *Ellipse by error* by L. W. Barnum E G & G, Inc. Las Vegas, Nev. 89101.
This elliptical figure was accidentally generated during a study of digitally-generated Lissajous figures. The figure should have been an ellipse caused by a 45 deg. phase shift, with sample points every 0.1 in. along the boundary of the figure. A Calcomp 565 driven by a CDC 106A, drew the figure.



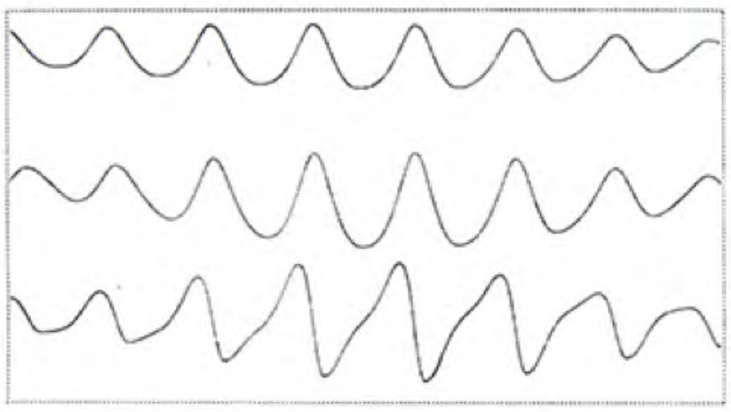
Below and bottom, *Computer graphics* by Petar Milojevic, McGill University, Montreal.
The programming was done in Fortran and processed on the IBM 7044. The figures themselves were done on the Calcomp 565 plotter. The cubic figures were obtained by connecting certain points on the sides of a cube, with the positions of the lines changed by translation or rotation.

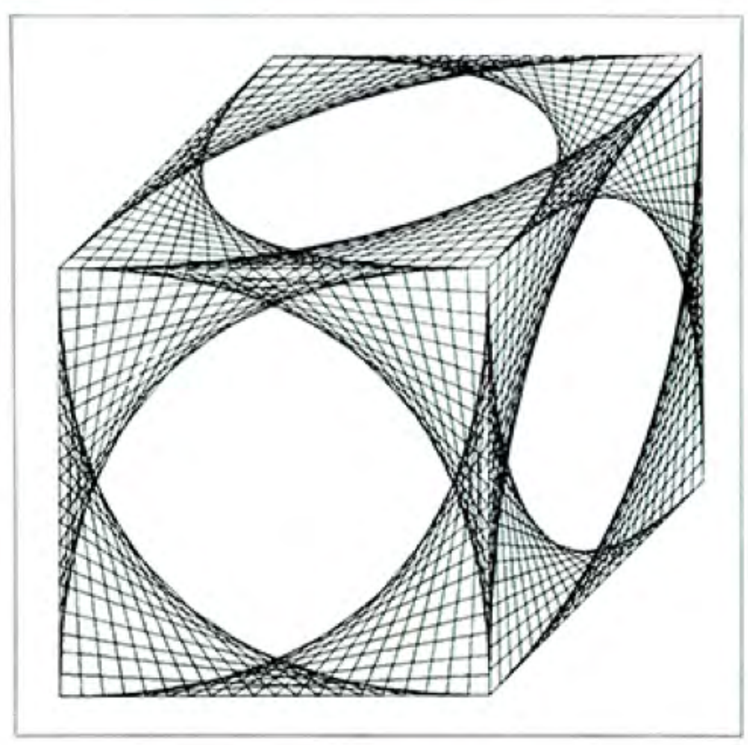


Below, *Boxes* by Darel Eschbach, University of Toledo, Ohio. The corner of each rectangle was generated by random numbers. The X dimension of the box was determined as 1.09 times the X co-ordinate. This produces a design which has squares on the diagonal and rectangles on each side as you move away from the diagonal. The design was made on an IBM 1620 with an IBM 1627 plotter, and was programmed in Fortran.



Below, *Computer graphic 3*, 1960 was executed by Kurd Alsleben together with Dr Cord Passow in 1960 in Hamburg on an electronic analogue computer which was linked to a graphic plotter. The differences in the configurations depend on the parameter changes of a differential equation. These and others from the same series were in Kurd Alsleben's book *Aestetische Redundanz*.





Computer pictures

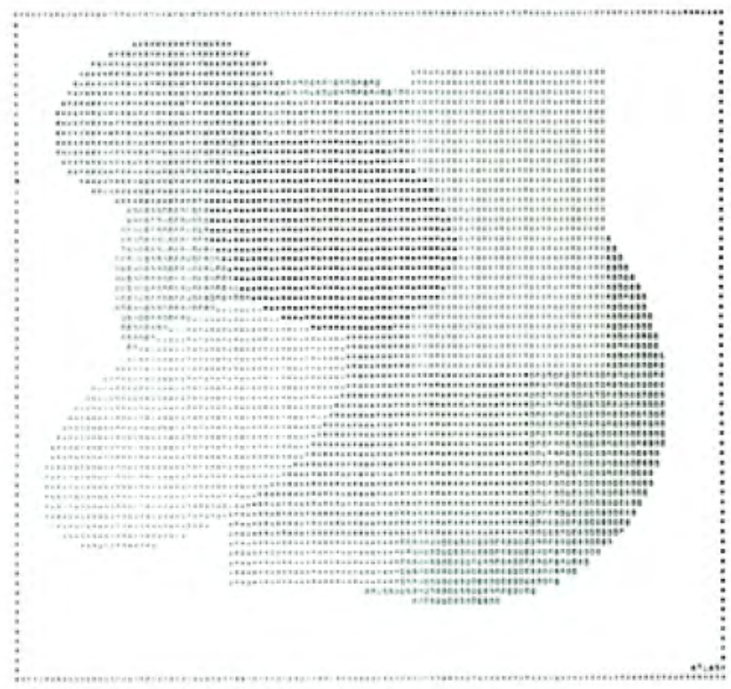
Andrew Colin

These pictures are essentially action paintings. The programme which generates them has a 'repertoire' of five standard shapes: the circle, the ellipse, the triangle, the square and the rectangle. Before generating any pictures, the programme selects subsets of these shapes at random. It then generates examples of each shape, assigns to them a random size orientation of position, and places them into a previously black frame. When the number of shapes, which have previously been selected at random, have been placed the entire frame is printed out. The different shapes are distinguished by the use of different symbols.

The pictures illustrate the effect of partially randomizing the process of selecting the components of compositions. Andrew Colin found that although the majority of pictures produced in this way had no value whatever a substantial minority were agreeable to look at.

Eventually, he hopes to continue this experiment by introducing some method of 'balance' between the shapes.

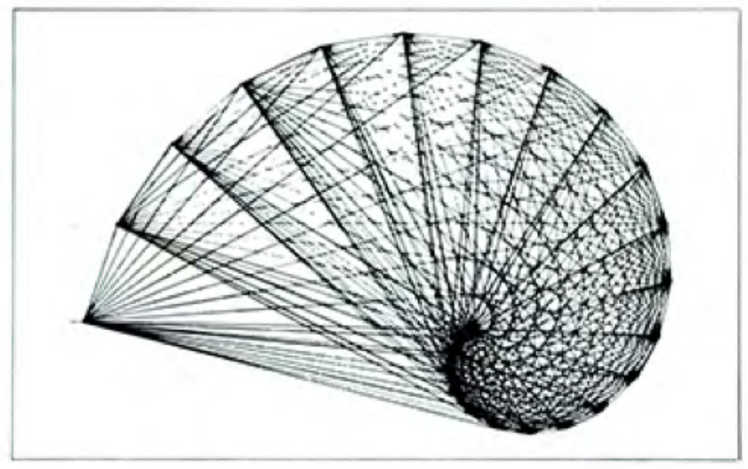
Computer-generated picture 1963, produced on the Atlas Computer at the University of London.

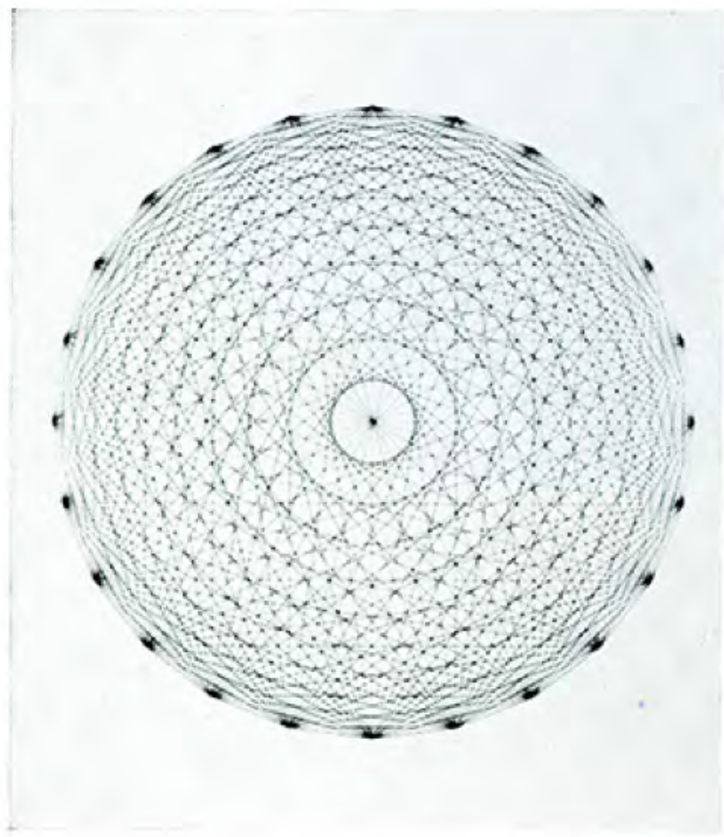


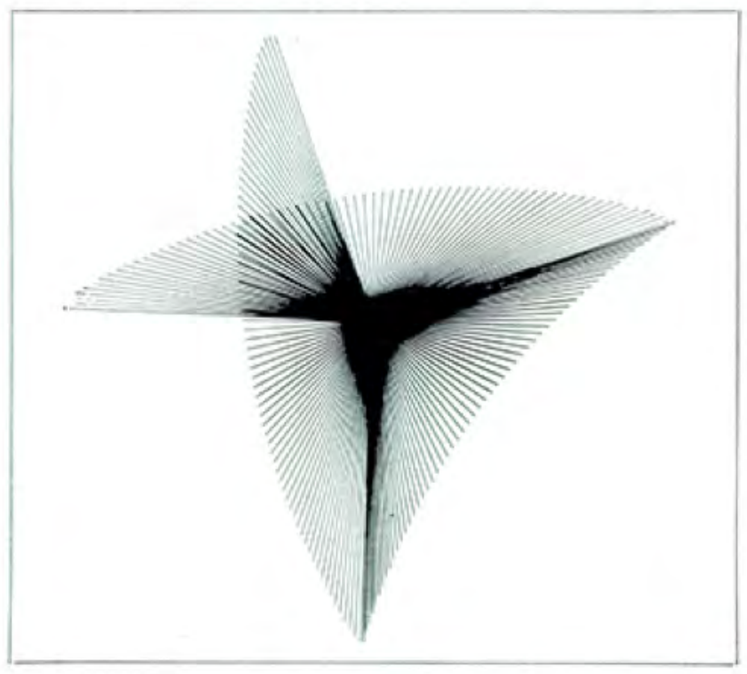
Geometric patterns

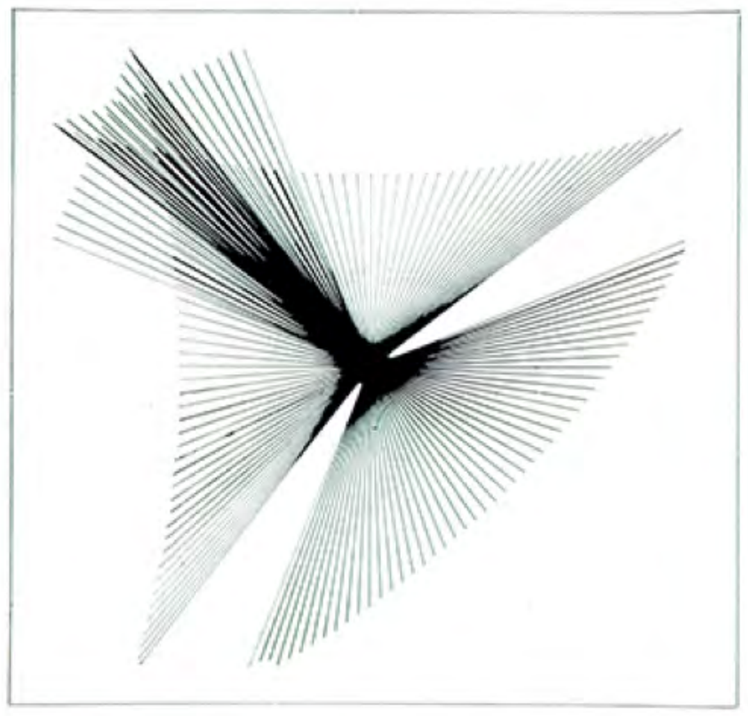
Five geometric patterns from the research aboratories of the General Motors Corporation which were part of a programme for checking image quality and general screen presentation on the cathode-ray-tube screen of the DAC graphic console. They also serve as a diagnostic tool to check the recorder electronics. More specifically, for each of these a mathematical expression was programmed into the computer; the computer then translated the mathematics into graphical representations and fed this information into the graphic console, presenting each expression as a series of straight lines: the resultant pattern was then automatically recorded on film by the CRT recorder, and these prints were made from the film. Donald W. Borland writes: 'In two cases we doubled up—purely for the artistry of it. The prints with the yellow and blue backgrounds were made by superimposing two negatives, in each case, and then printing the resulting combined pattern. The prints were then air-brushed to provide the tinted backgrounds.'

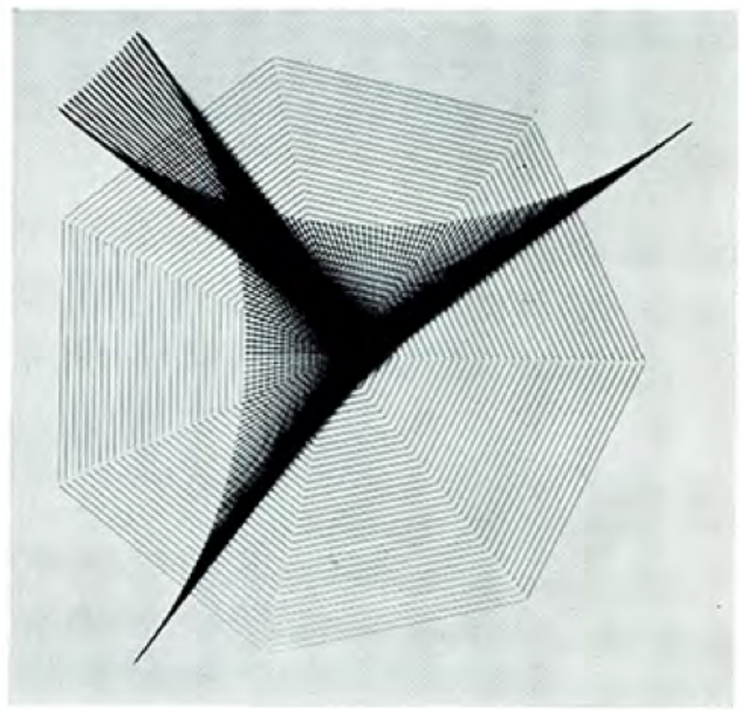
The automotive drawings show a use of the capability being checked in the other five prints. Briefly, the drawings that appear on the viewing screen come from a mathematical representation of the design stored in the computer's memory. By use of the electric 'pencil' and console keyboard, the designer is able to call for various views, enlarge, rotate, and examine them, change them if he wishes, and then store either the original or the modification (or both) back in the computer. All of this is part of the DAC experimental man-computer design system developed by the General Motors Research Laboratories.











Mathematically-defined surfaces

A. R. Forrest

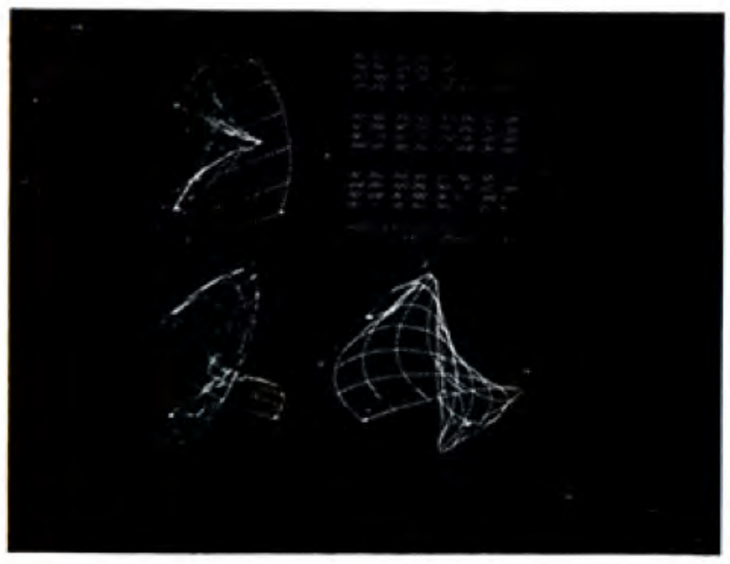
The three pictures show views of surfaces designed interactively on a computer-driven cathode ray tube display. The surfaces are defined mathematically by three matrices visible in two of the pictures—alteration of a term in the matrix changes the surface. Other information on the screen controls the programme.

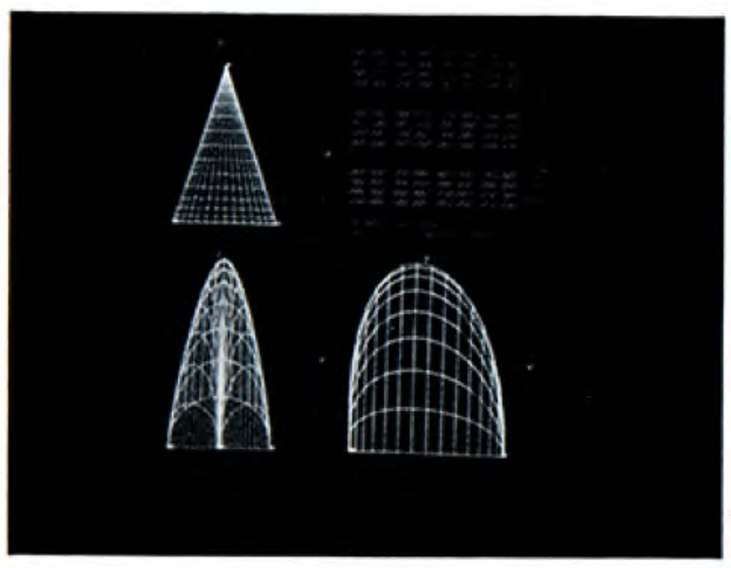
The surface design programme was written to aid research work on surface forms suitable for describing such shapes as car bodies and aeroplanes. The programme is not convenient for a designer to use, but despite this, several people have managed to construct shapes with considerable visual appeal.

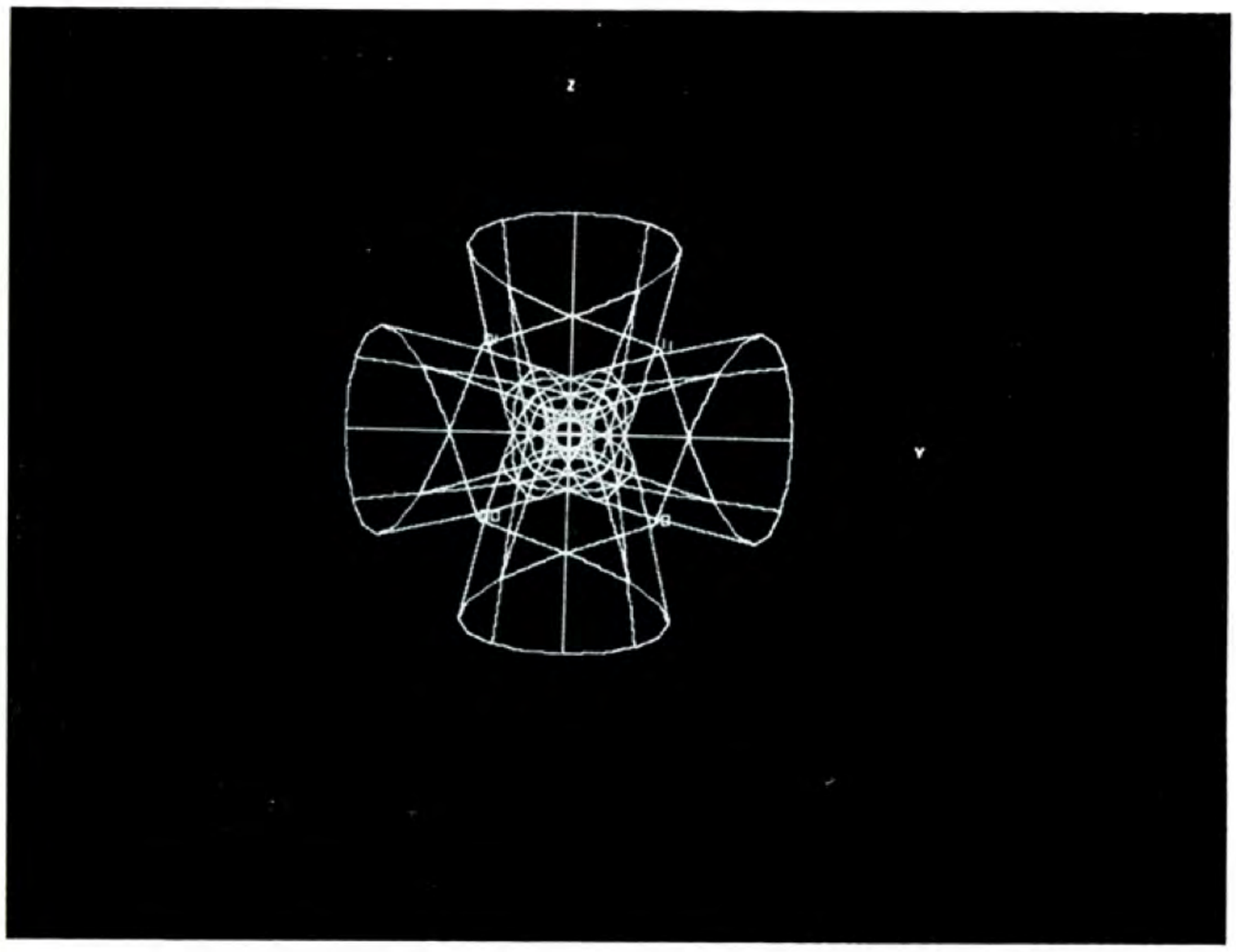
Warped surface No 1 arose from a demonstration of the programme when a portion of a sphere was progressively distorted until nothing remained of the original shape.

Distorted half cone started out as a cone, but the Z co-ordinate information was altered. One view remains as in the original. This surface was designed solely for the pattern in the Z–X view.

Stylized cross is in fact a plural surface, the normal projection of which is drawn. The surface was designed as a pattern—it has no other practical use.

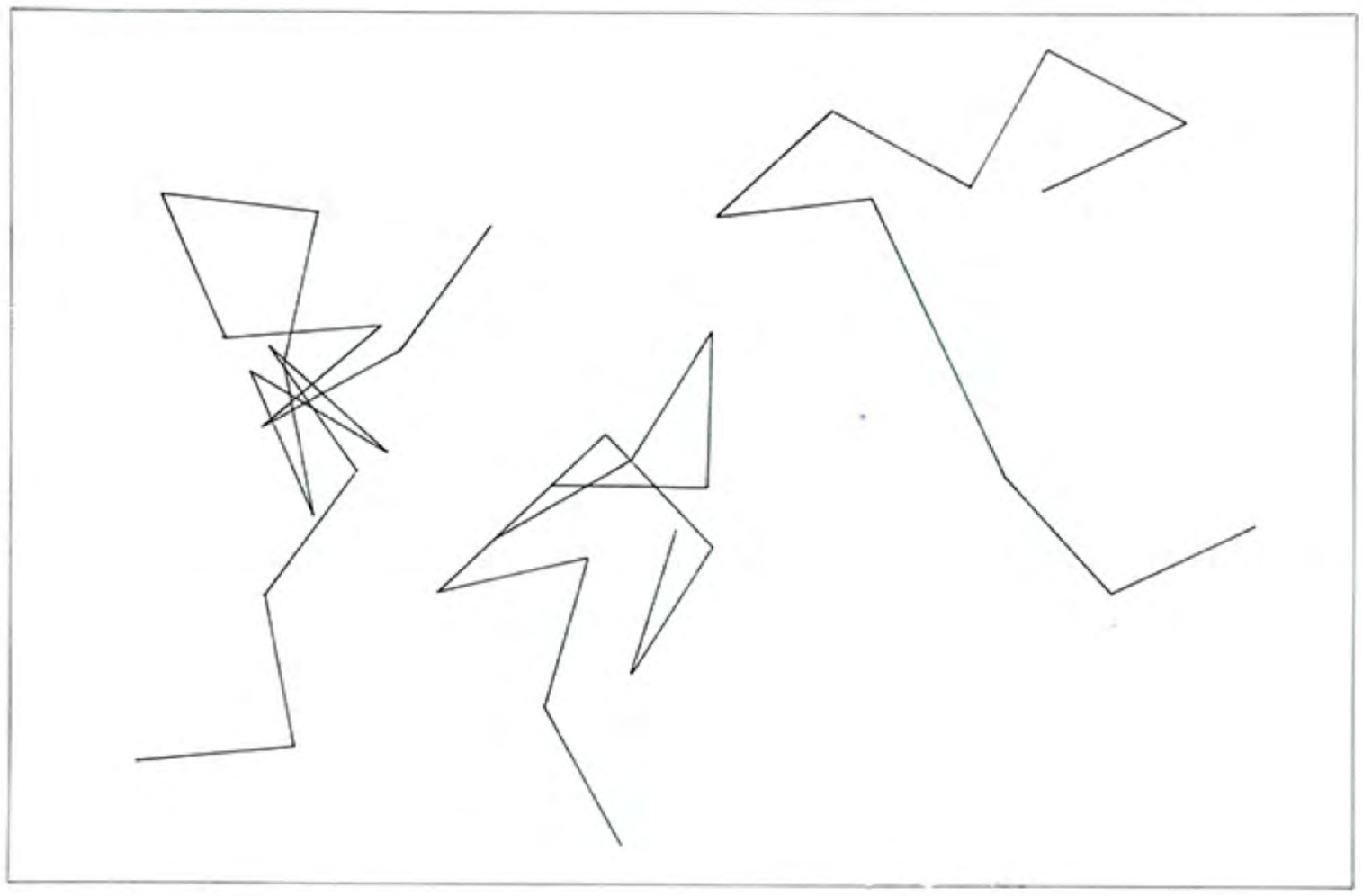




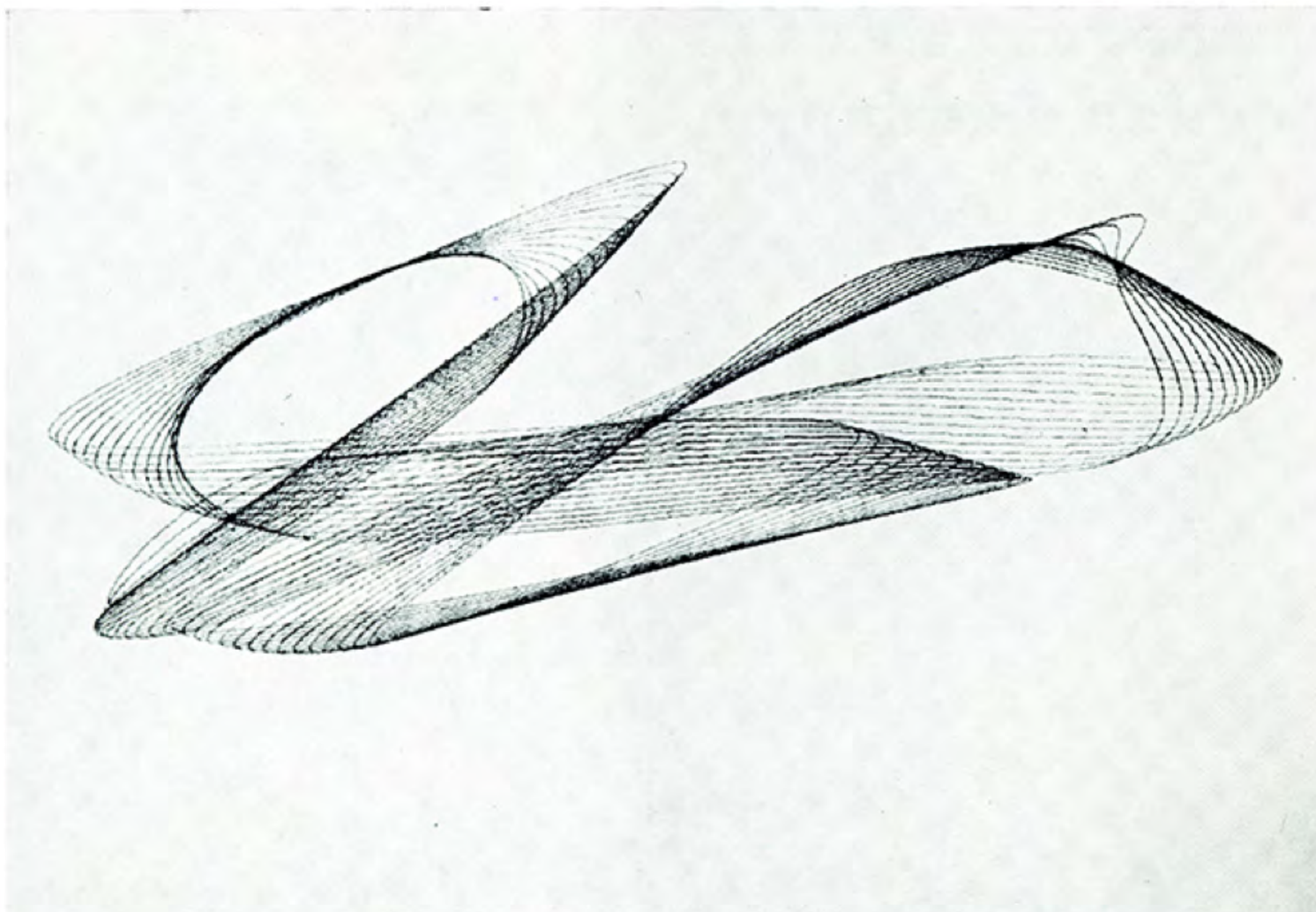


Joseph Stiegler

Transmutations
Transmutations are generated from number sequences or literary texts. Each digit or letter is assigned a vector—a line of fixed length and direction—which is then drawn at the end of the previous vector. The resultant line is a simultaneous representation of the sequential number or text.



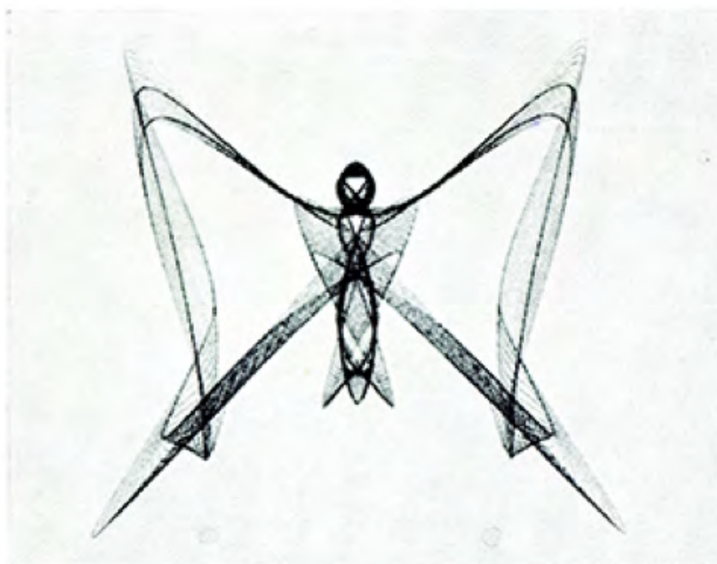
Cubic interpolations

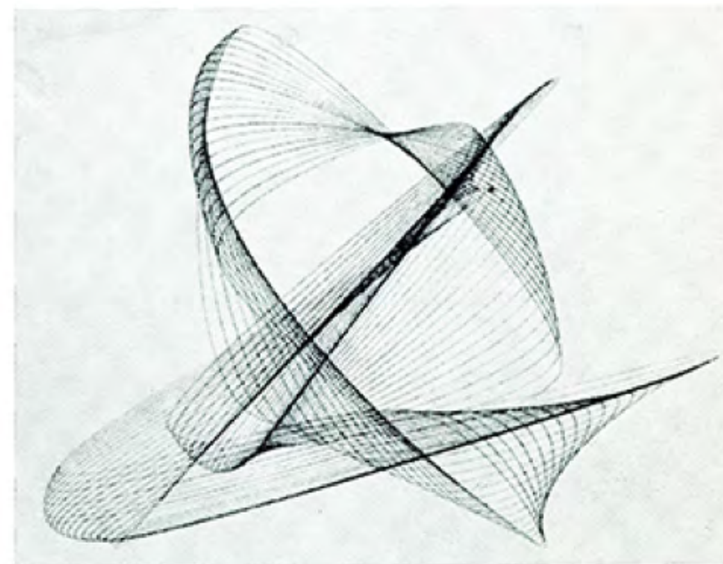


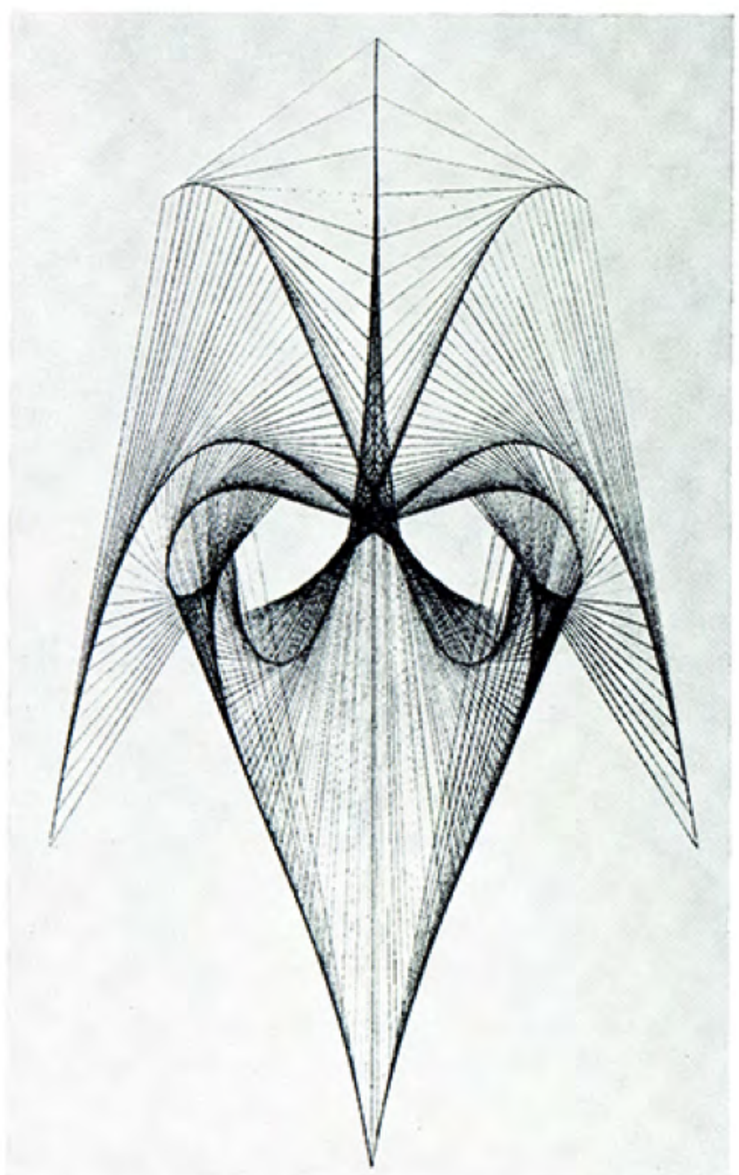
Sam Schmitt

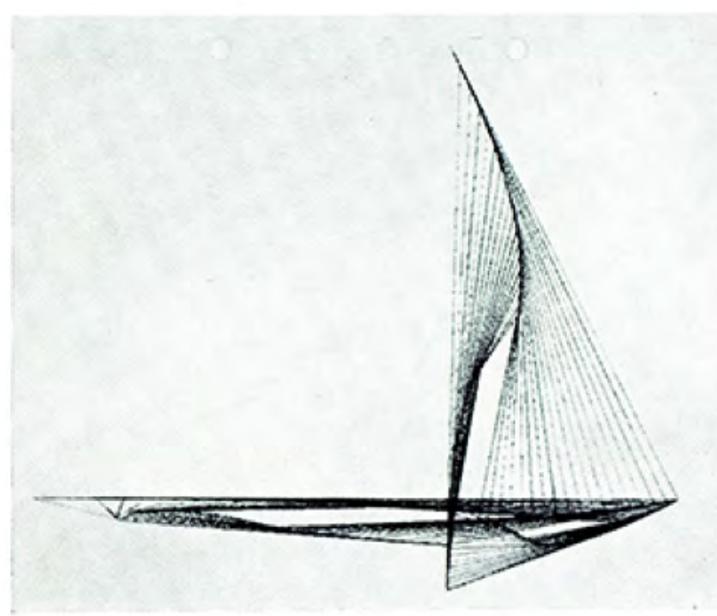
The smoothing of experimental data by polynomial interpolation is familiar in numerical analysis. Sam Schmitt of Princeton had the idea of using (cubic) interpolation on the abscissi and ordinates separately. This gives rise to smoothing in a peculiar sense since it can give rise to nodes and small loops, and this peculiarity is largely responsible for the artistic effects. These graphics were produced by Schmitt with the help of a CDC 1604. Further examples could be readily generated with the aid of the following precise descriptions:

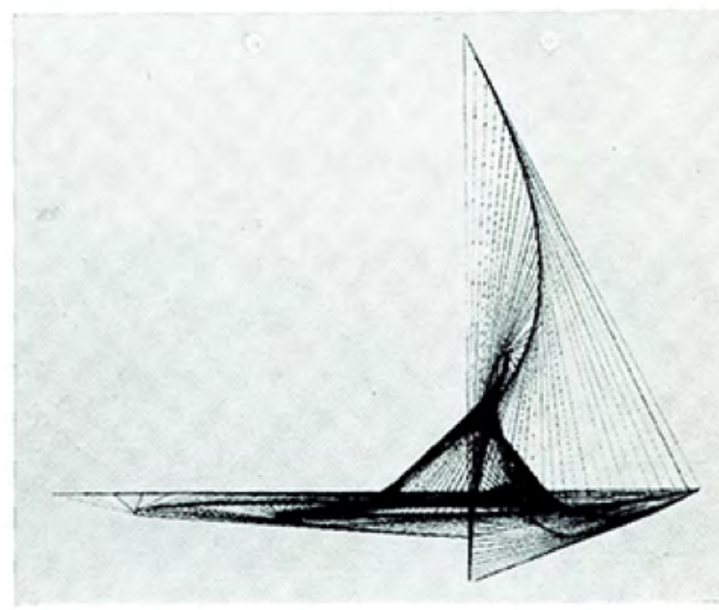
We select n points $P_r = (x_r, y_r)$ $(r = 1, 2, 3, \ldots, n)$ randomly or not. We define $P_{r+n} = P_r$, that is, we think of the n points as cyclically ordered. We now choose four consecutive points, P_r, P_{r+1}, P_{r+2}, P_{r+3}, and find cubic functions F_r and G_r such that $F_r(0) = x_r, \ldots, F_r(3) = x_{r+3}$, $G_r(0) = y_r, \ldots, G_r(3) = y_{r+3}$. We use this pair of cubic functions to draw an arc from P_r to P_{r+1}. Now replace P_r by the point $[F_r(0.1), (G_r(0.1)]$ say, and repeat the process for the points P_{r+1}, P_{r+2}, P_{r+3}, P_{r+4}. And so on round and round cyclically until the human operator decides to stop.











Top, *Cubic interpolation 1*, and centre, left and right, *Cubic interpolation 2* and *3*, by Sam Schmitt and Stockton Gaines

Above, and above right, *Sailboat* based on pursuit curves with random selection of initial positions of the beetles

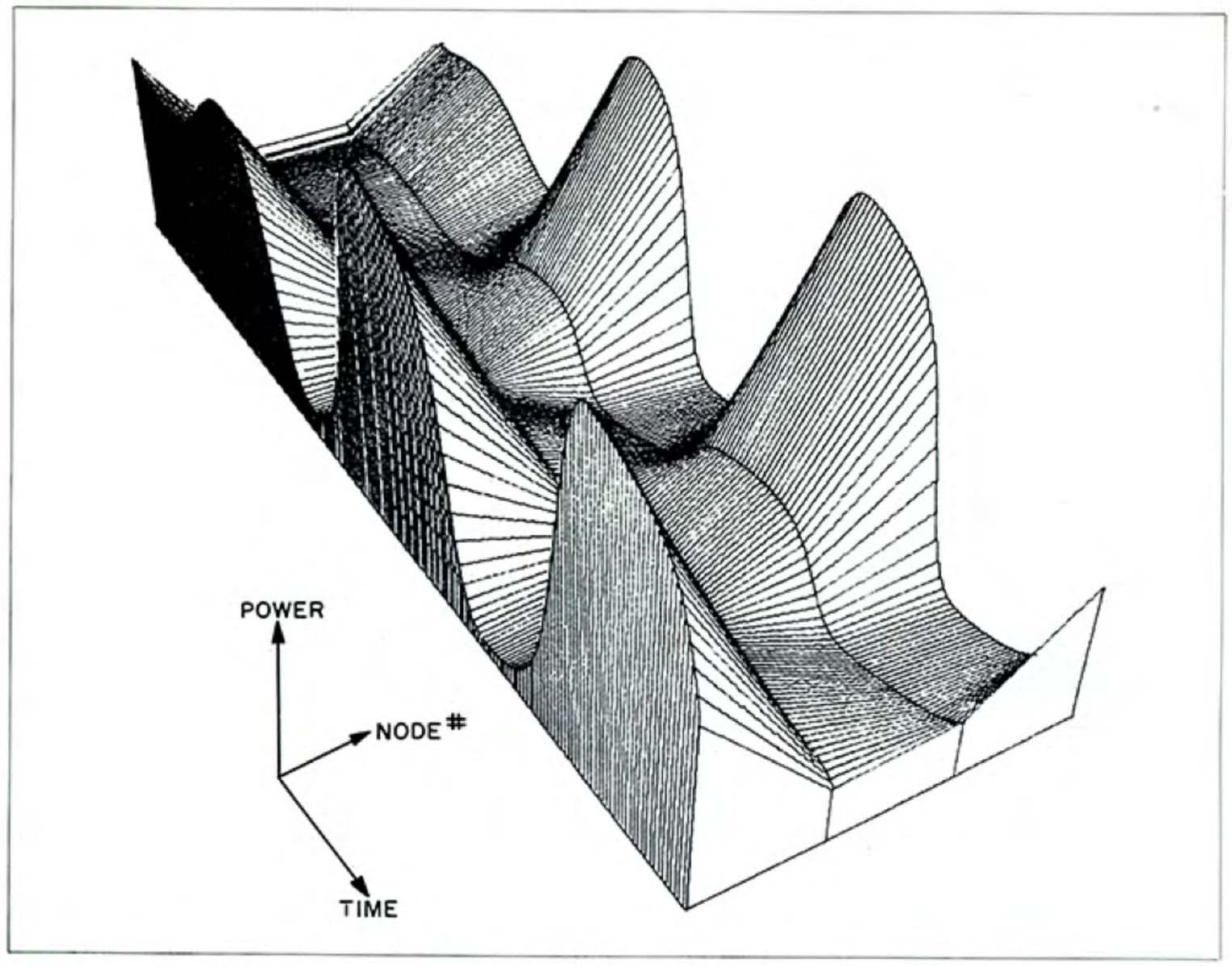
Left, *Mask*

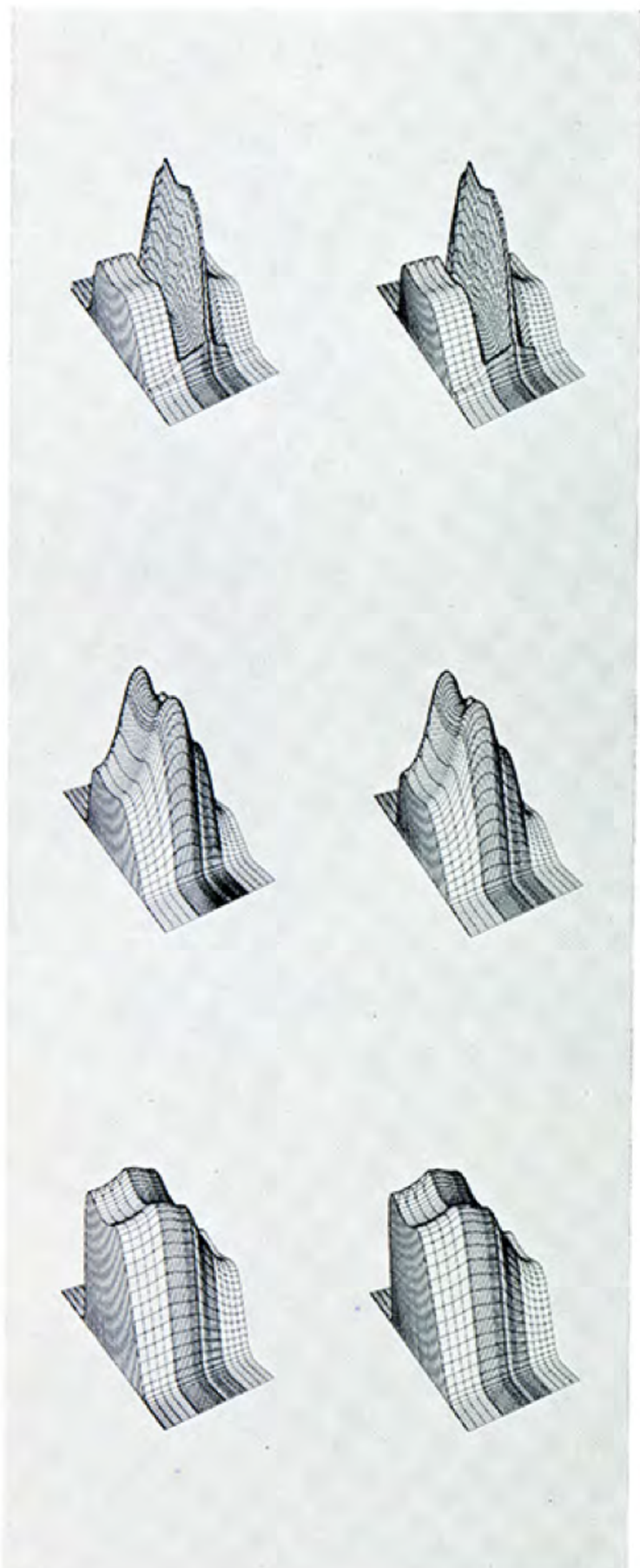
[All drawn by computer CDC 1604 at Princeton University, submitted by I. J. Good.]

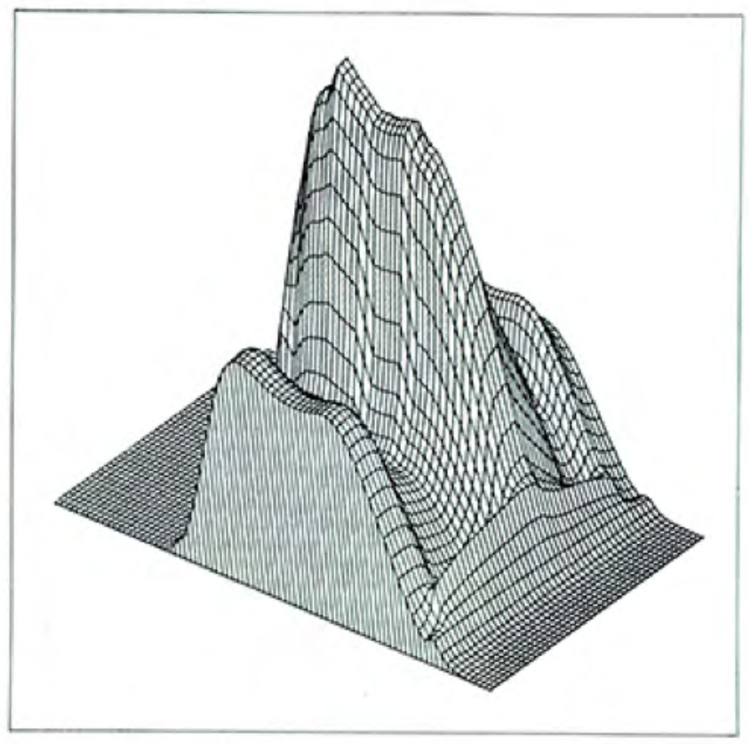
Isometric view of neutron distribution

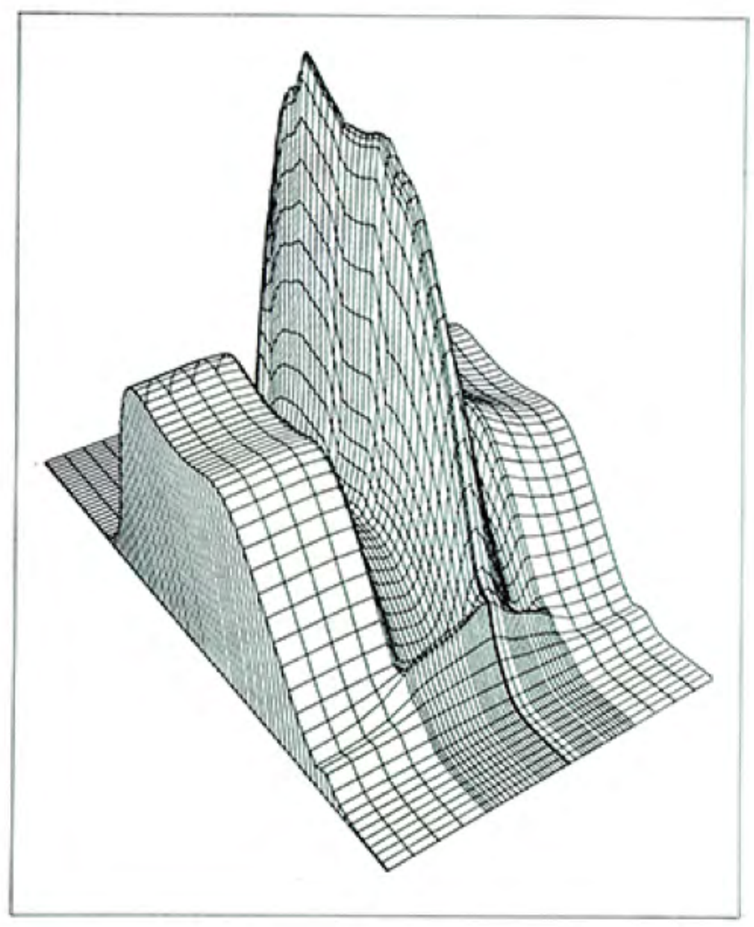
D. J. DiLeonardo

These isometric views were produced at the Westinghouse Electric Corporation, West Mifflin, Pennsylvania.









Above, Perspective view of the reactor power as a function of time at several reactor core locations.

Far left, These pairs of perspective views are actual stereo pairs. In constructing the pairs the viewing position was displaced a distance equal to the distance between a viewer's two eyes (about 2½ inches). By staring at the stereo pairs a middle view will materialize which will have a depth effect.

Left and below left, Perspective views of the neutron distribution in a reactor.

Shift-register derived patterns

D. H. Green

The shift register is one of the most fundamental elements of digital computer hardware. It finds many applications in storing and manoeuvering binary information within the central processor.

When used in an autonomous mode with feedback, the device provides a rich source of binary codes with many desirable properties. Such codes or sequences have many engineering applications especially in the field of digital communications. The study of feedback shift registers, or chain code generators as they are sometimes called, provides a valuable insight into the fundamental theory of more general sequential systems and brings together many aspects of higher mathematics and number theory.

The device itself mechanizes a logical recursion on a set of stored binary digits. On command from a 'shift pulse' each binary digit is moved one place down the register. The last digit in the register is lost but the vacancy created in the first stage is filled by a new digit computed from the stored digits by means of a logical circuit. Thus successive digits in the sequence are produced by the feedback of some logical combination of the digits previously held in the register. The set of digits in the register at any time between shift pulses constitutes the 'state' of the register and as successive shift pulses are applied the register progresses through a sequence of states.

The mathematics describing this sequential behaviour become complex unless restrictions are placed on the type of feedback logics used. One such restriction ensures that all states will lie on closed branchless cycles so that the shift register will be confined to generate repeating sequences of binary symbols. As the sequences generated by this means are strings of 0's and 1's the human observer may find difficulty in distinguishing between different sequences. A technique which has proved useful in overcoming this drawback involves the transformation of the digit strings into characteristic two-dimensional patterns traced out on a unit cellular lattice.

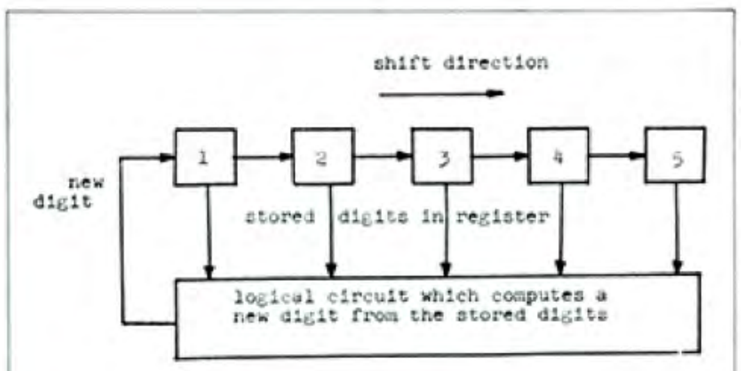
A simple conversion procedure is used whereby the binary sequence is inspected three digits at a time and to each of the eight possible combinations arising is allotted a direction of movement over the cellular lattice. Thus each of the 3-digit combinations causes the trace to move from a point on the lattice to one of the eight points immediately adjacent according to the coding system shown below. This procedure is repeated in a serial overlapping manner down the whole length of the sequence and as a result a pattern characteristic of the sequence is traced out on the lattice.

If, for each combination of 3 digits found in the sequence, there exists at some other position in the sequence another combination of 3 digits which is the logical inverse (0's and 1's interchanged) of the first combination, then the net movement over the lattice will be zero. This means that the trace eventually returns to its starting position and, as the sequence repeats, the pattern will be retraced in exactly the same position on the lattice. This property is satisfied by a large number of sequences.

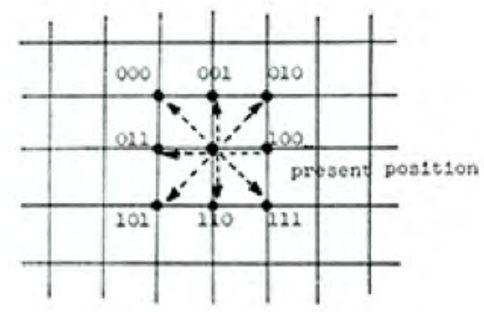
The patterns may be generated manually but long sequences are best generated and plotted by means of computer programme. Some typical results are shown here. It is also possible to construct digital hardware which will generate and display these patterns on a CRO screen.

The technique has been found extremely useful in the study of shift-register sequences. Many of the structural properties of the sequences are manifested as specific pattern configurations, e.g., skew-symmetrical sequences give skew-symmetrical patterns.

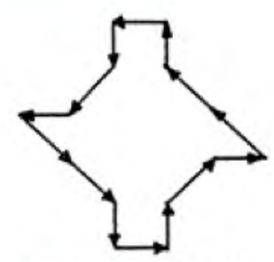
As the size and complexity of the shift-register becomes large the patterns produced in this way can take on astonishingly elaborate forms. Simple changes in the feedback logic or starting state of the generator can reveal a wealth of new structures, but the sheer determinism and inevitability of their logical derivation seems to endow each one with some undefined similarity.



A five stage feeedback shift register



Position codes used in transformation



Pattern produced by the repeating 14 digit sequence .... 11110010000110111100... etc.,

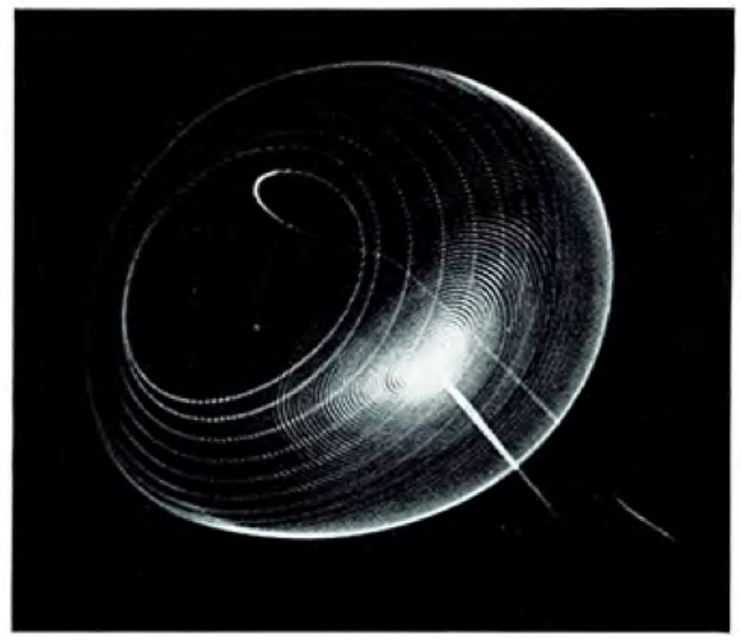
Oscillons (electronic abstractions)

Ben F. Laposky

Oscillons, or electronic abstractions, are compositions generated by means of electronic waveforms on a cathode ray oscilloscope. Oscillons are monochromatic, but colour effects may be added by the use of filters in front of the cathode ray tube.

The electronic abstractions are recorded photographically on paper, slides or film, or they can be displayed directly on a television tube. Many kinds of oscilloscope circuits and other input instruments, such as oscillators, amplifiers, modulators, are required to produce a wide range of forms in this medium.

Ben Laposky, from Cherokee, Iowa, has held exhibitions of his oscillons since 1953 and a number of them have been used in design and advertising.

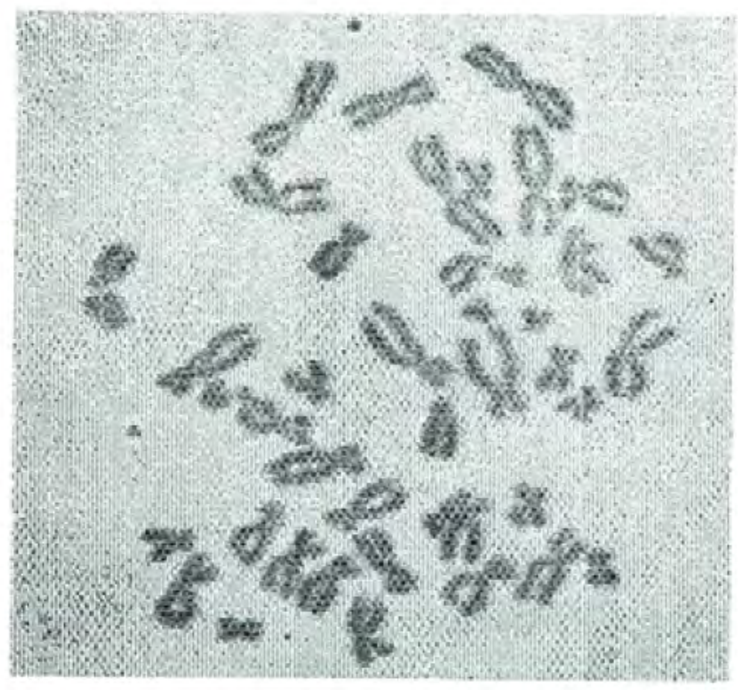


Cydac images

Mortimer L. Mendelsohn, Brian H. Myall, Judith M. S. Prewitt, Benson H. Perry, and Thomas J. Conway

Cydac is a device that converts the images of microscopic objects and photographs into a series of numbers suited to computer processing. The image is scanned directly through a microscope and is divided into 40,000 minute elements. The light passing through each element is measured and recorded as a number. These numbers are analysed by a computer (IBM 7040) programmed to recognize different types of cells and other objects of medical and biological interest. The computer can also generate pictorial representations of the original image, using combinations of letters and symbols to simulate different tones of grey, as is shown in these examples.

In some forms of analysis, the image is differentiated to find how rapidly the grey level changes between adjacent areas. In the differentiated pictures, dark elements correspond to large changes, giving a result that is somewhat analogous to a line drawing.



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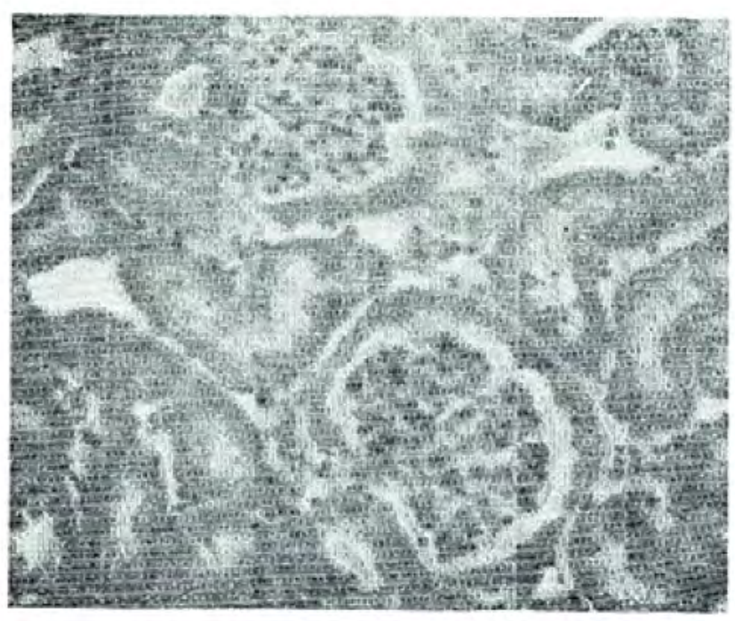

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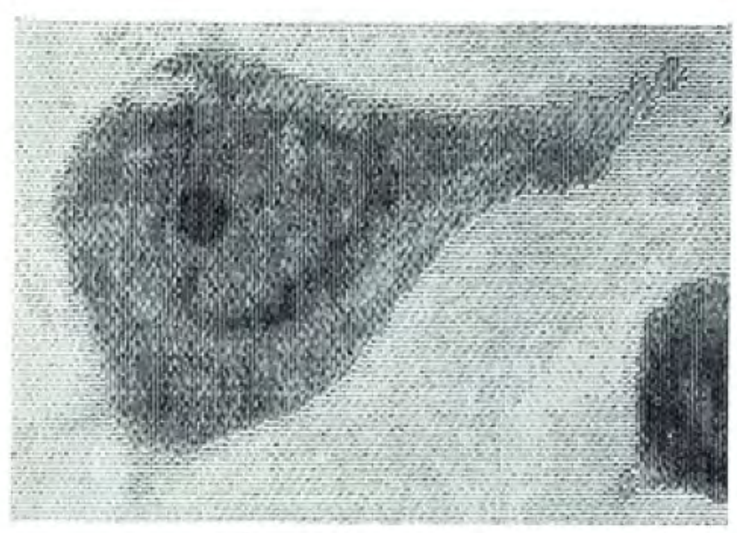

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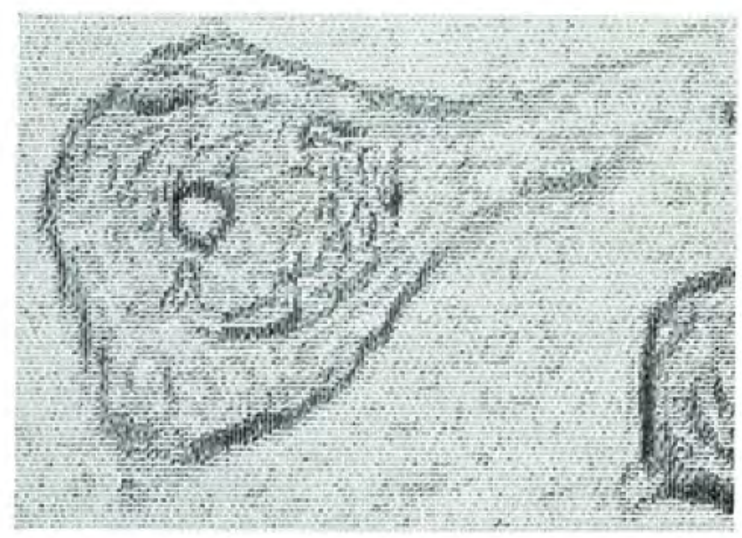

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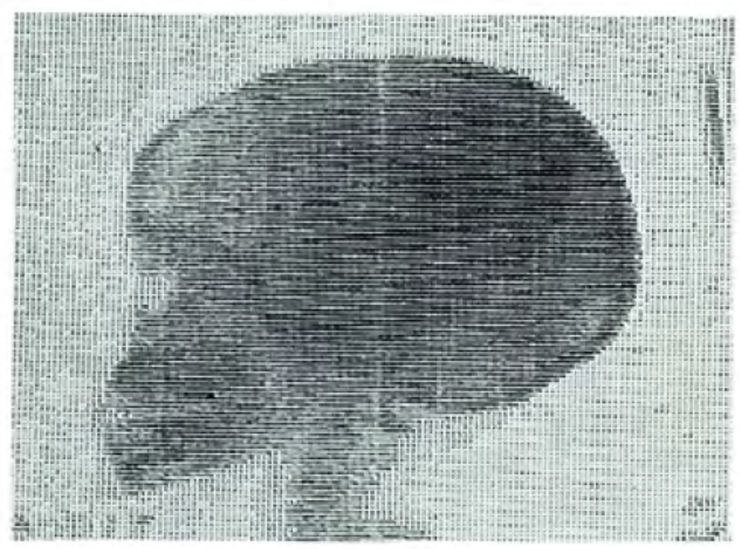

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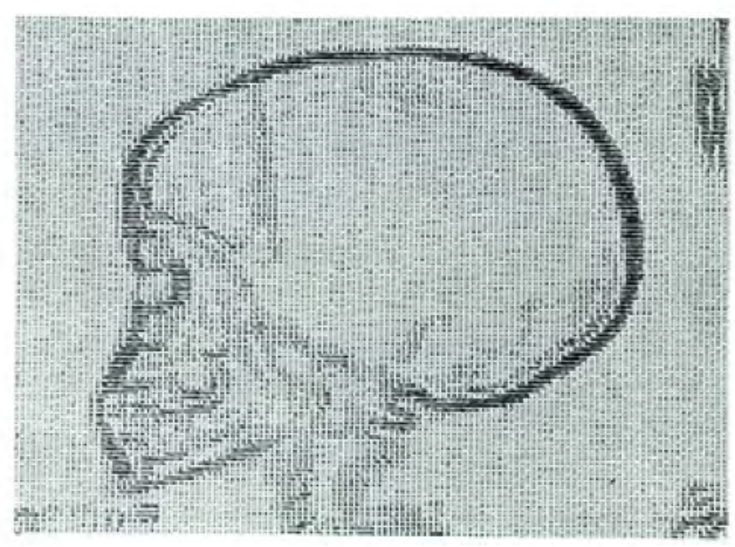

6

1. Human chromosome (magnified 20,000 times)
2. Mouse kidney (magnified 3,200 times)
3. Nerve cell from a monkey brain (magnified 20,000 times)
4. Differentiated nerve cell
5. X-ray of child's head
6. Differentiated x-ray of child's head

[Cydac images from Department of Radiology, University of Pennsylvania.]

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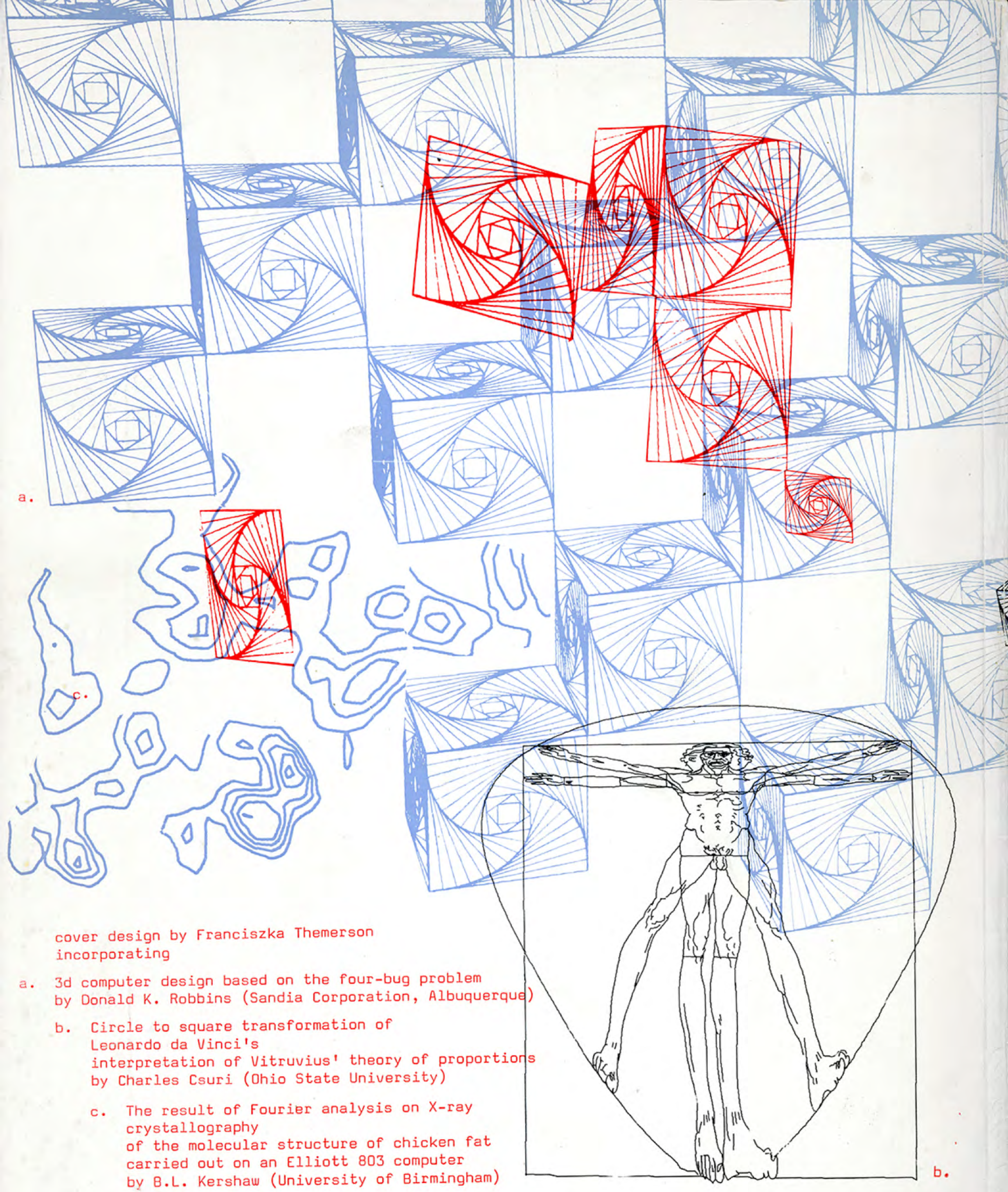

cover design by Franciszka Themerson
incorporating

a. 3d computer design based on the four-bug problem
by Donald K. Robbins (Sandia Corporation, Albuquerque)

b. Circle to square transformation of
Leonardo da Vinci's
interpretation of Vitruvius' theory of proportions
by Charles Csuri (Ohio State University)

c. The result of Fourier analysis on X-ray
crystallography
of the molecular structure of chicken fat
carried out on an Elliott 803 computer
by B.L. Kershaw (University of Birmingham)