Cybernetics, art and ideas

CYBERNETICS, ART AND IDEAS

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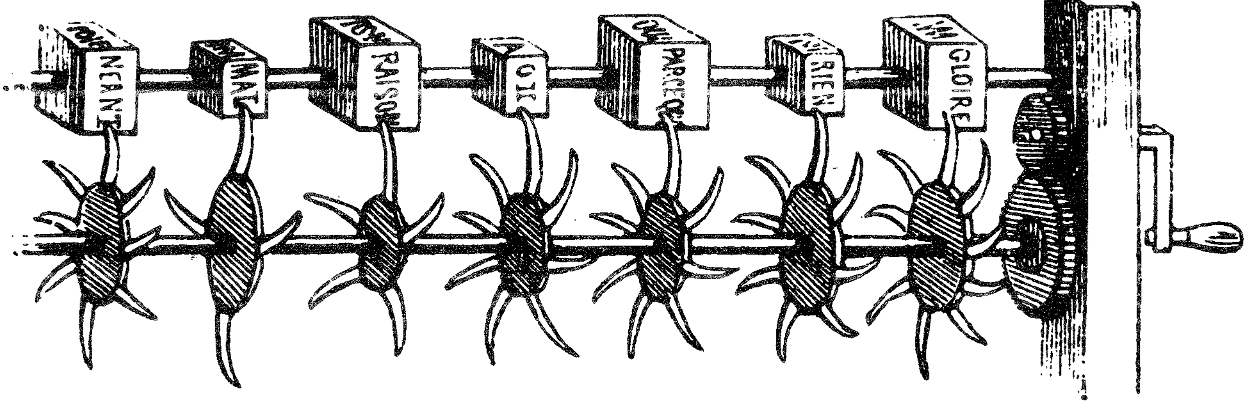
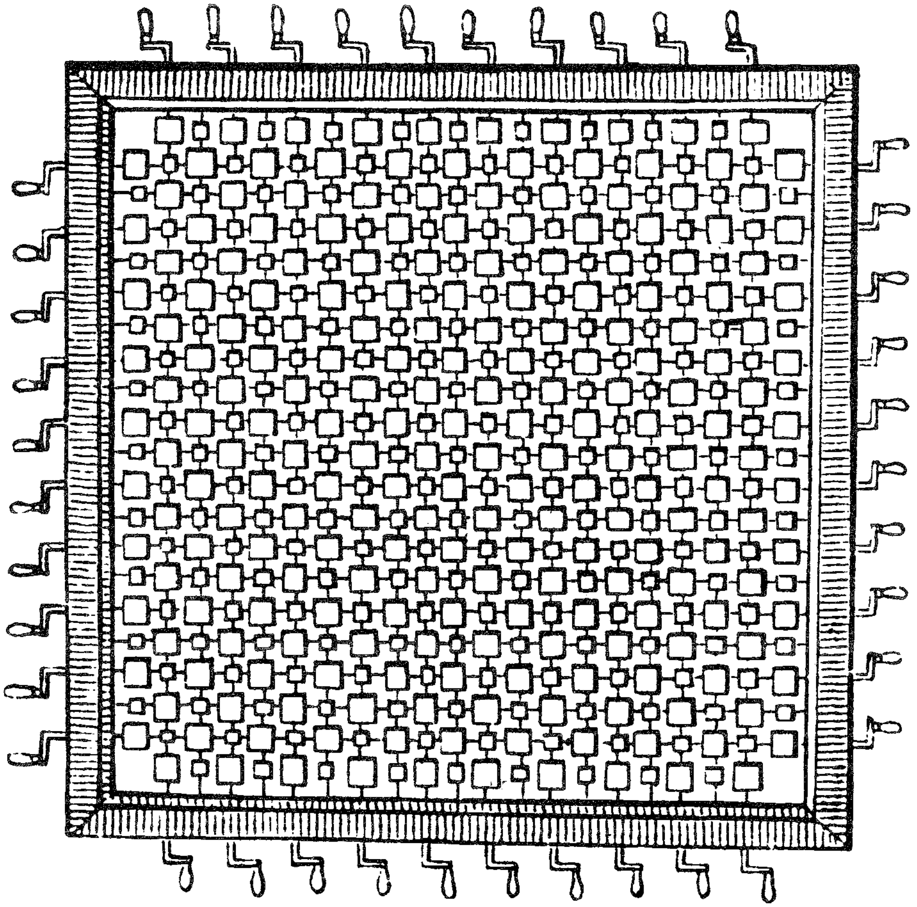
Fig. 1 The word machine by Grandville. 1838.





The word machine
Jonathan Swift

From 'A voyage to Laputa', *Gulliver's Travels*, by Jonathan Swift, 1726. This extract is taken from the 1869 edition: William P. Nimmo, Edinburgh. The illustration is reproduced from the first French integral edition of 1838.

We crossed a walk to the other part of the Academy, where, as I have already said, the projectors in speculative learning resided.

The first professor I saw was in a very large room, with forty pupils about him. After salutation, observing me to look earnestly upon a frame, which took up the greatest part of both the length and breadth of the room, he said perhaps I might wonder to see him employed in a project for improving speculative knowledge by practical and mechanical operations. But the world would soon be sensible of its usefulness, and he flattered himself that a more noble exalted thought never sprang in any other man's head. Everyone knew how laborious the usual method[1] is of attaining to arts and sciences; whereas by his contrivance, the most ignorant person at a reasonable charge, and with a little bodily labour, may write books in philosophy, poetry, politics, law, mathematics and theology, without the least assistance from genius or study. He then led me to the frame, about the sides whereof all his pupils stood in ranks. It was twenty foot square, placed in the middle of the room. The superficies was composed of several bits of wood, about the bigness of a die,[2] but some larger than others. They were all linked together by slender wires. These bits of wood were covered on every square with papers pasted on them, and on these papers were written all the words of their language in their several moods, tenses and declensions, but without any order. The professor then desired me to observe, for he was going to set his engine at work. The pupils at his command took each of them hold of an iron handle, whereof there were forty fixed round the edges of the frame, and giving them a sudden turn, the whole disposition of the words was entirely changed. He then commanded six and thirty of the lads to read the several lines softly as they appeared upon the frame; and where they found three or four words together that might make part of a sentence, they dictated to the four remaining boys who were scribes. This work was repeated three or four times, and at every turn the engine was so contrived, that the words shifted into new places, as the square bits of wood moved upside down.

Six hours a day the young students were employed in this labour, and the professor showed me several volumes in large folio already collected, of broken sentences, which he intended to piece together, and out of those rich materials to give the world a complete body of all arts and sciences; which however might be still improved, and much expedited, if the public would raise a fund for making and employing five hundred such frames in Lagado, and oblige the managers to contribute in common their several collections.

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[1] 'how laborious the usual method': cf. *The Spectator* (no 220) in which Steele ridiculed a pamphlet by John Peters called 'Artificial versifying: a new way to make Latin verses' (1678): 'This virtuoso, being a mathematician, has, according to his taste, thrown the art of poetry into a short problem, and contrived tables by which anyone without knowing a word of grammar or sense, may, to his great comfort, be able to compose, or rather to erect, Latin verses.'

[2] die: singular of dice.

Cybernetics, art and ideas

Jasia Reichardt

'One thing that foreigners, computers and poets have in common is that they make unexpected linguistic associations.' (*Reichardt*)

This volume of essays is the happy result of contacts and collaborations established during the three years devoted to the preparation of 'Cybernetic Serendipity'. Cybernetic Serendipity was an exhibition mounted at the Institute of Contemporary Arts in the summer of 1968, which dealt with the relationship of the computer and the arts. The exhibition, like this book, was concerned with the exploration and demonstration of connexions between creativity and technology (and cybernetics in particular), the links between scientific or mathematical approaches, intuitions, and the more irrational and oblique urges associated with the making of music, art and poetry. The title itself was intended to convey the fact that through the use of cybernetic devices we have made many fortunate discoveries for the arts.

The exhibition

Cybernetic Serendipity was mounted in a gallery of 6500 square feet (fig. 2), involved 325 participants and was seen by 60,000 people. The exhibits showed how man can use the computer and new technology to extend his creativity and inventiveness. These consisted of computer graphics, computer-composed and -played music, computer-animated films, computer-texts, and among other computer-generated material, the first computer sculpture. There were also cybernetic machines such as Gordon Pask's 'colloquy of mobiles', television sets converting sound into visual patterns, Peter Zinovieff's electronic music studio with a computer which improvised on tunes whistled into a microphone by the visitors; there were robots, drawing machines and numerous constructions which responded to ambient sound and light. Six IBM machines demonstrated the uses of computers, and a visual display provided information on the history of cybernetics.

Two aspects of this whole project are particularly significant. The first is that at no point was it clear to any of the visitors walking around the exhibition, which of the various drawings, objects and machines were made by artists and which were made by engineers; or, whether the photographic blow-ups of texts mounted on the walls were the work of poets or scientists. There was nothing intrinsic in the works themselves to provide information as to who made them. Among the contributors to the exhibition there were forty-three composers, artists and poets, and eighty-seven engineers, doctors, computer systems designers and philosophers. The second significant fact is that whereas new media inevitably contribute to the changing forms of the arts, it is unprecedented that a new tool should bring in its wake new people to become involved in creative activity, whether composing music, painting or writing. Graphic plotters, cathode-ray tube displays and teleprinters have enabled engineers, and others, who would never even have thought of putting pen to paper, to make images for the sheer pleasure of seeing them materialize. Many of the computer graphics made by engineers in Europe, Japan and the USA, approximate very closely to what we have learned to call art and put in our public galleries. This raises a very real question—should these computer graphics hang side by side with drawings by artists in museums and art galleries, or should they belong to another, as yet unspecified, category of creative achievement?

There are certain classifications to which we are all assigned according to what we do. These categories which relate solely to our work, or our professional titles, inform the outside world about our way of life, our abilities and creative propensities. The deductions based on these classifications are not necessarily accurate but they suffice to colour the picture of an individual sufficiently for him to be irrevocably labelled. These labels provide information which is accepted without question and without protest. Thus it is assumed that the electronic engineers represent a clever but an uncreative branch of society, whereas artists are exceptionally creative but it is unlikely that they should possess any technological skills. It is also widely assumed that to the engineer, scientist and mathematician, art is magic, and to the composer, painter and poet, technology is a mystery. These rough assumptions are very broadly true but not altogether true. Since the middle 1950s the relationship between art and technology has been increasingly in evidence through the advent of computer-aided creative design.

Fig. 2 View of part of the Cybernetic Serendipity exhibition.

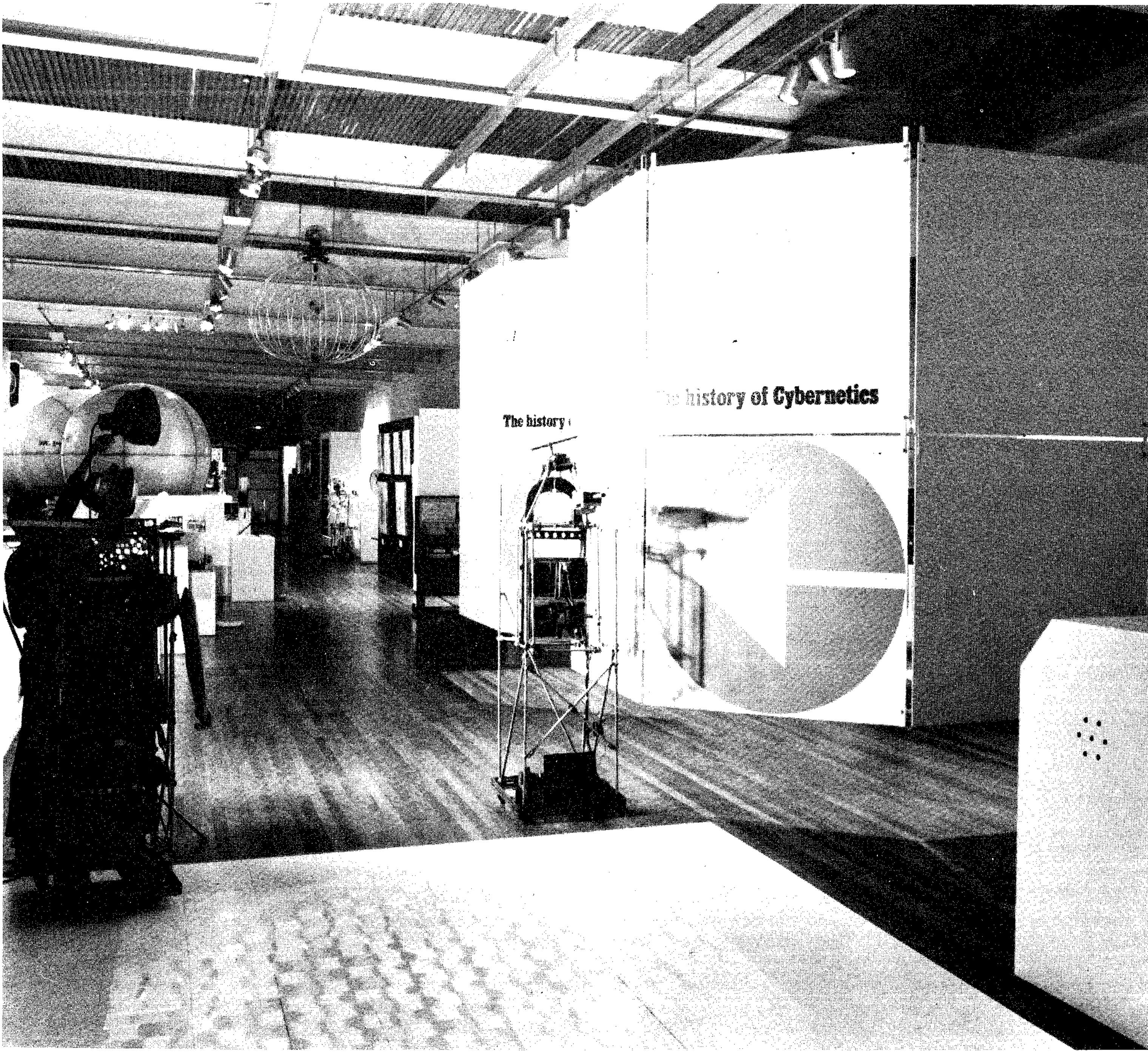


Fig. 3 History of cybernetics display, showing two parallel texts.

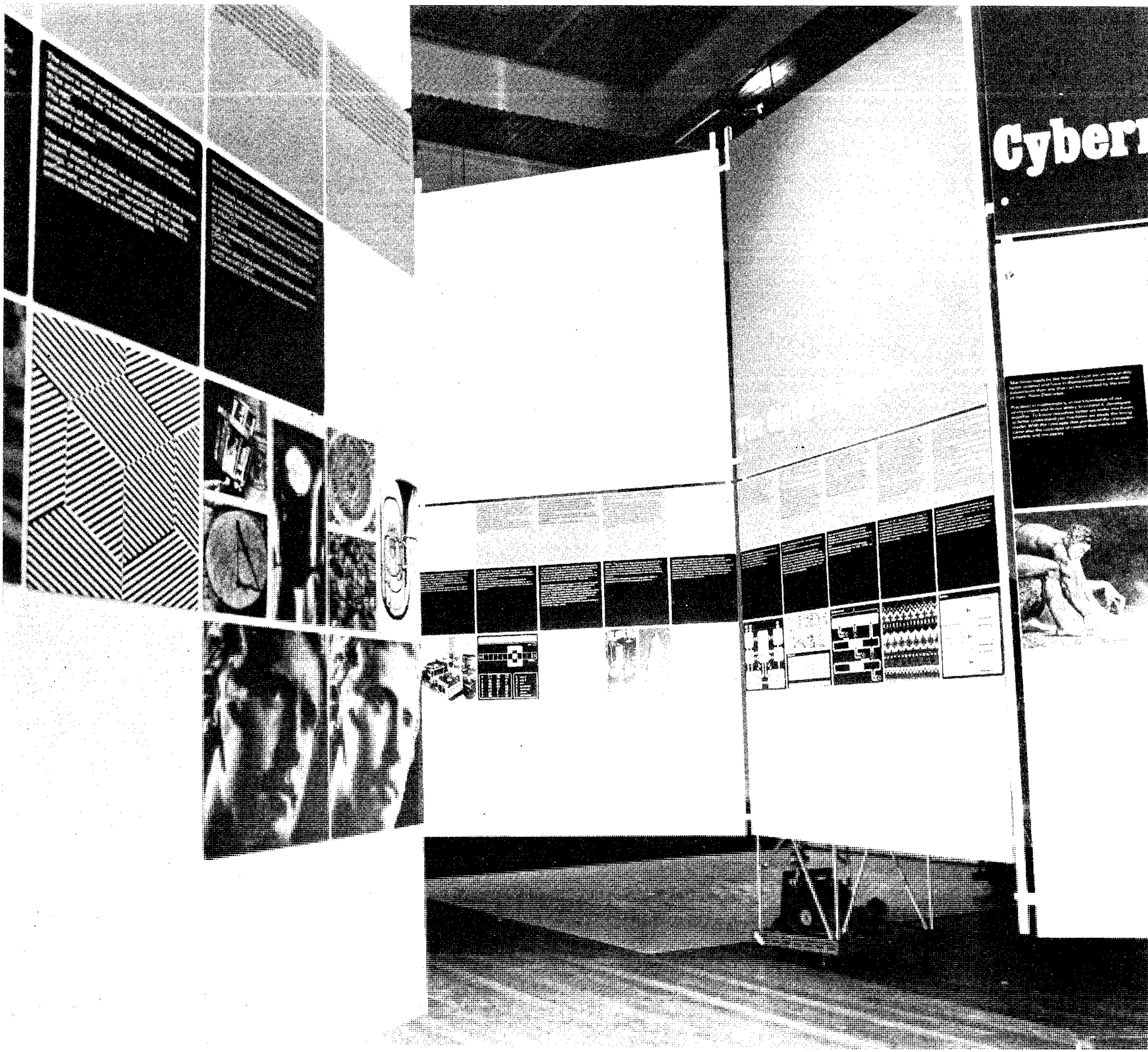


Fig. 4 'King of the Shouting House' by John Wood. A ritualistic pantomime for twenty-seven characters whose continuous movement in concentric circles and opposite directions, is interrupted at random by a computer-controlled sound. At that moment one of the various stages of the game is enacted and the circular movement is started again. Neither the outcome of the game, nor the steps by which it develops are computer-controlled, merely the timing of the actions.

Today these categorical assumptions about our various talents, functions and possibilities are less accurate than ever.

Thus Cybernetic Serendipity was not an art exhibition as such, nor a technological fun fair, nor a programmatic manifesto—it was primarily a demonstration of contemporary ideas, acts and objects, linking cybernetics and the creative process.

The computer arts and the public

As a child I remember being told a story about a machine into which one could put dirty linen and within minutes retrieve all the clothes clean and ironed. This was only one of many fairy stories, all of which were equally credible. In the face of the evidence of washing hanging out on a line as usual, the washing machine was just as real, or just as unreal, as the mirror in *Alice through the Looking Glass.*

A five-year-old in the 1970s knows that machines can do everything, and is merely surprised if there is some task that a machine cannot perform. No child of that age today is surprised that certain drawings, poems or tunes were produced with a machine, or by a machine. At the Cybernetic Serendipity exhibition, the only members of the public who displayed that traditionally childlike quality of wonderment were those adults who were unfamiliar with the possibilities of computer technology in the arts.

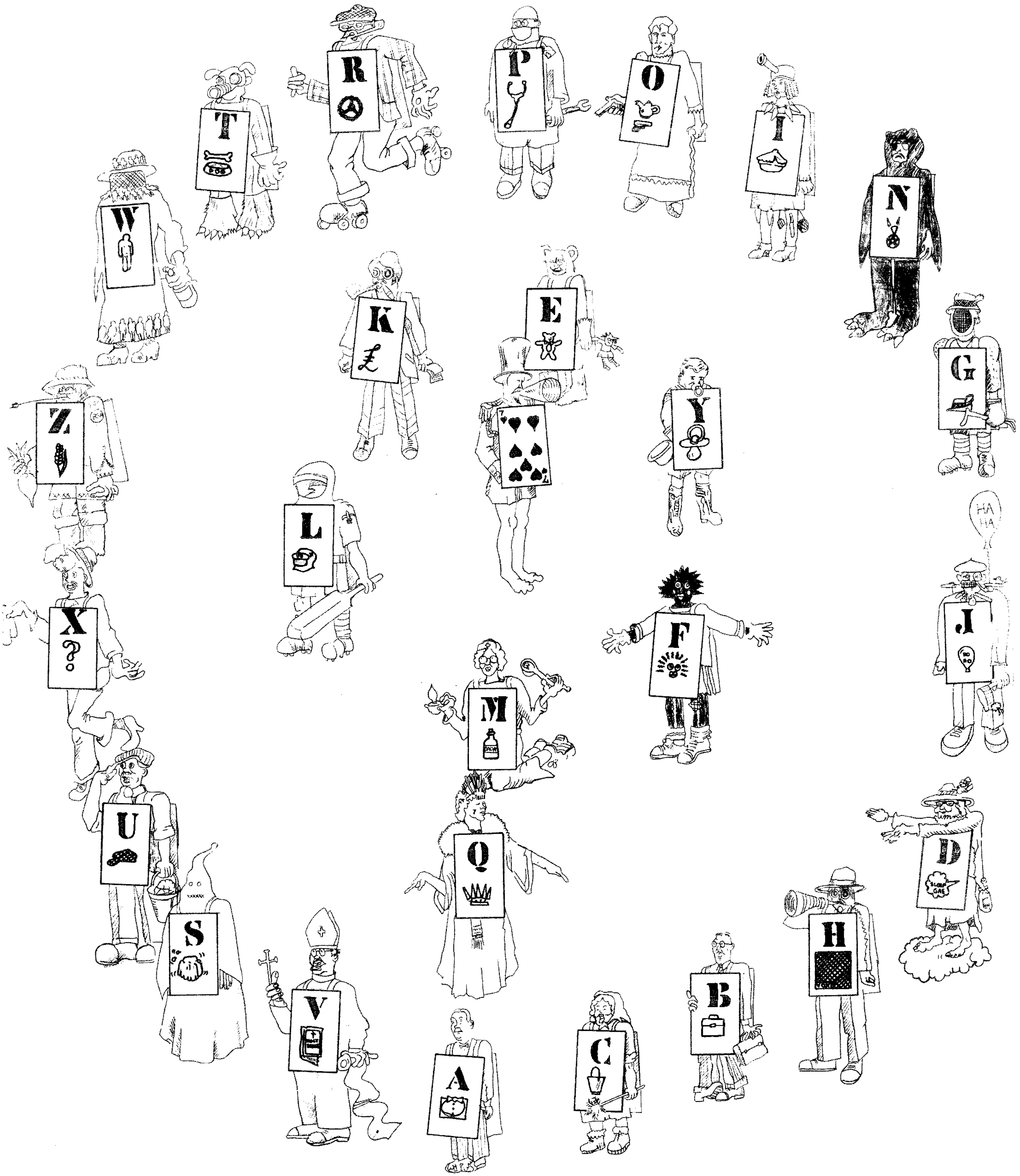
The advent of the computer is directly responsible for the emergence of computer poets, artists and composers, many of whom would not have found it possible, or desirable, to work with conventional media and techniques. A child, of course, would find nothing extraordinary about this. Those six-year-olds involved in experiments at MIT to find out how children can learn to communicate with a computer would no doubt have very sophisticated views about the possibilities of the machine as a robot or an artificial brain. The so-called 'controversial' questions asked by journalists with great predictability, whether the computer 'thinks' or whether it will replace man, are designed to fog the issue with emotional overtones rather than discuss it, and would probably not even occur to a young audience.

The intelligent layman finds himself right between these 'controversial' questions of mass media and the technical language which may present such a great obstacle to conveying simple information that any desire to learn about, or even to approach, the stronghold of art and technology is discouraged. When discussing this very subject John Pierce once told me a story about a man who went to confession and having asked the priest about a point in the *New Testament*, was told that any explanation could be given only in Latin.

To avoid the problem of offending the expert and nevertheless informing the layman, in the Cybernetic Serendipity exhibition, the section dealing with the history of cybernetics contained two parallel texts, one using technical terms and the other avoiding them (fig. 3).

In the arts, however, the demystification of the process will not do away with the mystery of the results. The fact that we are presented with a flow-chart, program and output of a composition by Iannis Xenakis, for instance, will not diminish or increase the impact of the composition when it is performed. Intellect has its own pleasures but these are not a substitute for a direct emotional response. The central core of a work of art, which is the transformation of the material which makes up the sum of its parts, has so far defeated all analytical attempts. Both Max Bense and Abraham Moles approach such an analysis from the peripheries of the structure of the work, but to this day there isn't a single masterpiece that has been made according to the principles of generative aesthetics. This essential core of a work of art remains still to be fragmented, rationalized and reconstructed.

The processes involved in making computer art are best suited to those who follow an analytical approach in their work, who are concerned with permutational procedures, serial techniques or the transformations of images from one finite state to another. Sometimes, it is true, the computer is used when the throwing of a couple of dice would serve equally well. To use the computer implies a concern with technology, an up to date outlook and the admittance of the possibility that the computer will one day be something in the nature of a household appliance. It is primarily the demonstration of an attitude. Recently even a children's game, called 'King of the Shouting House' by John Wood, has made use of computer controlled random interruptions (fig. 4).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The importance of the computer in the arts has wider implications than those suggested by the material which has been produced so far. The computer, as Abraham Moles points out, is not only a tool for making serial pictures, or transforming an image, but is above all an instrument of democracy. He describes the imaginary museum which contains all possible copies and variations of all works of art, which can be acquired as cheaply as groceries by those who want them. He dismisses the authenticity of a work of art and substitutes it by the authenticity of situation—the confrontation, and all that it implies, between a person and the copy.

Among computer graphics are simple designs that could have been done as easily and even as quickly by hand. This, however, is not the point of experiments with computer art—the point is nothing less than the measure of possibilities for the future. In the visual arts and in poetry, the computer as a medium is far more limited than in music, since the digital to analog conversion can produce any sound whatever. In the visual arts, the terminals for picture making are still very limited in possibilities of variation. Little, so far, has been done with colour or the third dimension.

In Tokyo a complex console holding paint-brushes and containers with paints was attached to a computer to produce suitably random results. The pictures were made on the spot in a gallery. This type of electronic action painting, however, represents only a peripheral exploration of the medium. A more logical exploration of the possibilities belongs more readily to the work of such artists as the Swiss constructivist Richard Lohse, who in 1952 set down the rules for progressive art:

'Progressive art must searchingly analyse its means, and build a critique of form resting upon valid principles. It must aim at a synthetic approach to the means and to the picture space if the artist is to operate on a higher level. The basic analysis should include:

1 Relations of formal elements to their spatial boundaries.
2 Form variables.
3 Theoretical and practical study towards a typology of forms.
4 Colour variables in connexion with various forms.
5 Objectification of the pictorial elements.
6 Interrelations of colour, form and picture space.
7 Research into the problems of dimension of pictorial elements and picture space.'

The artist, William Turnbull, had another idea about using the computer. He thought of analysing the work of an artist over a period of years in order to predict what he would do next. It would certainly be interesting to compare the computer's prediction with the artist's own ideas as to the sort of work he might be doing in the future.

At the one end artists seek technological means to develop or amplify their ideas and projects; at the other end artists whose work is quite removed from what technology implies have been influenced by its jargon. Cybernetics as a descriptive term has been applied to sculptures operating on a feedback system as well as assemblages using cogs and wheels. 'Stochastic' and 'aleatory' have been used to describe paintings which incorporate chance images, and 'topology' for pictures with obscure perspective. The terms 'information theory', 'metaprograms', 'strategy', 'entropy', 'hardware' and 'real time', are to be found in manifestos which have little to do with the sort of art to which they could possibly apply. These terms serve to create an atmosphere rather than convey concrete information. Their use demonstrates the artist's desire and need to be involved in a world of human aspirations, other than those dealing with art.

John Cage once advised the Korean artist Nam June Paik to write as much as possible before his English improved, because, in Paik's own words 'broken English is rich in semantics'. One thing that foreigners, computers and poets have in common is that they make unexpected linguistic associations. And indeed, even with a simple scheme such as that described by Margaret Masterman in relation to computerized haiku, and even with a small and deliberately selected vocabulary, there are some poetic or grotesque associations of words which are not to be found in standard English usage. It is these gratuitous moments when a logical, deterministic procedure yields a line of poetry, or where as in Stefan Themerson's 'Nonobody' the dance is a solution to a mathematical problem, that stimulate the imagination.

In this volume the machine is seen in various contexts—

as a competent assistant to man, a conversational companion, a tool, a background against which human frustrations and hopes are seen in a different light, as a labour-saving device, as an instrument for improvisation, as an instrument for amplifying happiness and promoting pleasure, as a means of democratizing art, as a tool for making art, as well as learning something about how it comes about and how it functions.

The machine as a creative tool is neither an original nor a new concept; nor is the comparison between the way a man and a machine function. In 1931 Ozenfant in a book on art, wrote: 'We are machines which demand attention and also special "instructions for use".' He went on to advise the artist to work regularly because the muse can be made to be punctual and arrive at any given time. He advocated control in all aspects of creative activity. It is true, inspiration can be harnessed, intuition can be developed, and creativity provoked, so long, however, as we approach them obliquely and do not attempt to work out an absolute formula for generating and disseminating masterpieces. This is unlikely to succeed.

The machine and technology, in general, are part and parcel of contemporary sensibility. This implies not only the functional, sociological or physical aspects but very often also the ethos, the atmosphere and the misunderstandings which arise. In art there are no rules defining its proper realm or specifying prescribed attitudes to technology and the world at large. Finally there is no reason why significant works should not be based on misunderstandings and partially digested information, although this is not a prescription.

The essays in this volume deal with aspects of the relationship between technology, contemporary life and creativity. I hope the reader will find them as thought-provoking and stimulating as I have, and perhaps that he or she may get as much out of this volume as I did out of *The Scientist Speculates*[1] in 1962, without which many of the connexions between art and technology would have passed me by.

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[1] *The Scientist Speculates, an anthology of partly-baked ideas*, general editor I. J. Good. London: Heinemann, 1962.

Technological civilization and man's future

Dennis Gabor

'Almost every important invention unbalances the front of progress, and a new invention is needed to redress the balance.' (*Gabor*)

This article formed part of The Inaugural Address, Imperial College, 1958.

The mechanization of genius

So far, the influence of electronic inventions on civilization has on the whole been beneficial. The reproductive inventions, high-fidelity sound-recording, radio and television have put the masterpieces of music and of the stage within everybody's reach, of course, mixed with advertisements and with entertainment. I have no apology to offer for advertisements; but as regards entertainment, I agree with J. B. Priestley who asked whether the cinema was 'any worse than the cartwheel around the village idiot's neck as a Sunday entertainment?'

It is also interesting and comforting to observe that the hi-fi gramophone and the radio, these highly democratic inventions, have brought a triumph to the aristocratic principle that nothing is worth doing unless it is done supremely well. Today there is no need for anybody to play the piano who plays it less well than Myra Hess. (Playing the piano for your own pleasure is quite another matter, but this has little to do with the level of artistic achievement of the epoch. The Medicis were no lesser judges of art for never touching a paint-brush.)

There is even a possibility that in music the intermediary between the composer and his public will be cut out altogether. Great composers need not be great performers on any instrument, nor need they be accomplished conductors, but we must concede that the composer is the best judge of how his work ought to be performed. Several years ago Dr Olson of the Radio Corporation of America constructed a wonderful musical instrument which enables a single man to put together, at leisure, any orchestral music, instrument by instrument, without being able to play a single one, and to correct it as often as he likes until it sounds perfect to him. To my knowledge no composer has tried his hand at it, but if ever there will be a new Beethoven (and not deaf), posterity may be able to hear his own interpretation of his symphonies without any intermediaries. This would be a further and final triumph of the aristocratic principle—if we are agreed that the creative artist ranks above the interpreter, be he a Bruno Walter or a Toscanini.

Will the machine go a step further and cut out also the creative artist? Is all this talk about composing symphonies[1] or writing sonnets just science fiction or is it a serious forecast of things to come?

My answer is that I sincerely hope that machines will never replace the creative artist, but in good conscience I cannot say that they never could. The brilliant researches of one modern school of mathematicians and logicians[2] have proved that it is not possible to construct deterministic machines to solve a class of mathematical problems which have been quite successfully tackled by human brains, and this suggests that the same applies to artistic creations. On the other hand there is strong evidence that a machine which embodies random elements can in every respect simulate the human mind. This is the old idea of 'monkeys on typewriters', but with an important difference. By embodying all the deterministic knowledge in the machine (such as of the English language, of the rules of logic, of harmony and melody) and by building in an enormous store of previous experience which allows preselecting elements likely to succeed, the probability space can be enormously restricted. Moreover (perhaps by teaching the machine by feedback what is agreeable to the human public and what is not), the machine can be its own critic and censor. I believe, though, that such a machine will be hardly less complicated than the human brain, and therefore there is some hope that it will never be built. On the other hand I should welcome simpler machines, such as Orwell's 'versifier' which produces popular lyrics 'untouched by human brains' for debunking all that is mechanical and bogus in what passes by the name of art.

I am afraid, though, that one cannot exclude the possibility of another much more sinister short circuit between

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[1] This ruthless idea is not as modern as one might think. The first composing machine, the 'Componium', was built in 1824 by Winckler and is preserved in Brussels. Other more recent ruthless suggestions are the Electronic Manager, the Electronic Surgeon and the Electronic Judge. (Cf. *Proceedings of the Symposium on the Mechanisation of Thought Processes*, organized by A. M. Uttley at the National Physical Laboratory, Teddington, 24 November 1958.) Why do these people never suggest the Electronic Research Worker?

[2] M. Davis *Computability and Unsolvability*. New York: McGraw-Hill, 1958.

invention and the public, not electronic but chemical. Primitive drugs such as alcohol and opium have existed since time immemorial, and they were beneficial in helping human beings to bear their miseries. Fortunately, one can say, they were ruinous for health or stamina when taken in excess, and society has kept them within bounds. But there is no reason why this should always be so. It is not unthinkable, even likely, that drugs will be discovered which give to simple, average people the happiness of the creative artist, and beyond this, the indescribable bliss of the ecstatic saint,[1] and which will not be ruinous to health, or even to willpower. A human society in possession of such a drug would not necessarily degenerate, nor need it be overrun by barbarians, but unless it decides by an act of will that it prefers to stay sober, it will not produce any more art. If this happened, I am glad that electronics would be innocent of it.

I believe that of all electronic inventions now within viewing distance, predictors are likely to have the greatest influence on civilization. In a well-ordered society the highest, the most respected and the most responsible posts go, or at least ought to go, to men who have the gift of making the right decisions on the basis of uncertain data, by a partly reasoning, partly instinctive foresight of the future. A false and irresponsible predictor like Hitler can ruin a civilization; in fact we have now reached the stage when we cannot afford another Hitler. At first sight it is a relief to think that in the near future objective electronic predictors may assist the statesmen. But a warning must be uttered, not to attach undue hopes to mechanical predictors when applied to human affairs.

A predictor, whether man or machine, can remain 'objective' only so long as its forecasts will not influence the processes which they predict. Weather forecasting is of this type; forecasting economic trends is quite another matter. A financial editor takes an active part in shaping the future. Once the forecasts are communicated to men who influence affairs the process becomes a complicated 'Neumann–Morgenstern game' between them and the predictor. To avoid complicating matters let us just consider the case tha a predictor has built up such a high reputation of being always right, that men will blindly follow its forecasts. The machine, being a learning machine, will soon notice that everything it says goes, and from that moment on there is no guarantee against its going astray. Absolute power will corrupt not only men but also machines! Let us hope that these things will be better understood before social predictors become important.

Inventors

After this excursion into a hypothetical future I want to step back into the present, and ask the question, 'Do we need inventors?' Or, more precisely, 'Does a country need inventors?' Let me for a moment play the part of the *advocatus diaboli* and plead the case against inventors. I could ask, for instance: 'Does it make any difference that polythene was invented in Britain, and nylon in the United States?' There is now no shortage of either polythene or nylon in Britain or in the US or in any industrial country which has not invented either of them. Or does it matter that transistors were invented in the US? The whole know-how has come to Britain, for less than the cost of research, and the moderate royalties will have to be anyway invested in Britain.

If we agree, however, that a country's prestige is dependent on new ideas, what must we do to help inventors? In a country so richly endowed with inventive talent as Britain, there is no need for any artificial breeding and nursing, but I believe that it is of great importance to eliminate some of the obstacles, external and internal.

Once upon a time Britain had no shortage of inventors. In books like *Self-Help*[2] by Samuel Smiles we read with a shudder of these maniacs, who worked on relentlessly with their wives in rags, their children crying with hunger, who were later persecuted by irate workmen, and when their invention was finally successful, were cheated by manufacturers who stole their inventions in the hope that they could not go to court. In the end there is the horrible refrain: 'died in extreme poverty'. We now hear that all this belongs to the past: 'the inventor starving in a garret has been replaced by

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[1] It appears that opium produces the 'sensations of a poet' (but it ruined Coleridge), and that mescalin can give 'a vividness of vision of which only great painters are capable', as eloquently witnessed by Aldous Huxley (*Doors of Perception*, London: Penguin 1957). What is the 'use' of great painting if the sight of 'light playing on a garden chair' or even the sight of 'the folds of one's trousers' can produce a palpitating pleasure which no Rembrandt can give to the sober eye?

[2] Samuel Smiles *Self Help*. London: John Murray. 1959.

the scientist in the research laboratory'. But it is just this very widespread modern belief which is a subtle danger to invention, and it will be worth considering it in a little detail.

There is, of course, some truth in it. One of the greatest of inventors, the late Irving Langmuir, worked all his life in almost monastic happiness in the Research Laboratory of the General Electric Company, producing inventions which brought millions to his company, and scientific discoveries which brought him the Nobel Prize. But not all inventors have this happy disposition. Three of the greatest, Rudolf Diesel, W. H. Carothers (the inventor of nylon and other important high polymers), and Edwin Armstrong (the inventor of the superheterodyne, of super-regeneration and of frequency modulation), ended their highly useful and successful lives by suicide—all three because of imaginary worries. Even if they do not risk their own money, the responsibility for keeping their promises weighs heavily on highly strung and sensitive individuals. Shall we then keep them out of danger, for their own health, by changing the inventor into a scientist, working in a research laboratory? Though the inventor and the scientist often represent very different psychological types, this metamorphosis can be effected, without any crude pressure, just by the climate of opinion.

Invention and research

I believe that Rutherford is a good example of a highly gifted individual who could have been equally great as an inventor and as a scientist. When the young New Zealander came to Britain, he brought with him an invention, and not a bad one either: the magnetic detector of radio waves. If he had not gone in 1896 to Cambridge, England, but say to Pittsburgh, Pennsylvania, I have not the slightest doubt that he, and not Valdemar Poulsen, would have become the inventor of magnetic sound recording.[1] As it was, in his whole wonderful scientific life Rutherford never made another invention, and became the epitome of a pure research worker.

Rutherford's is certainly a rather exceptional case, for few inventors have this gift of curiosity, that appetite for scientific truth of which he had a somewhat old-fashioned, unsophisticated, but all the more vivid conception. Most inventors would make only average research workers, some even poor ones, but I have little doubt that in a climate of opinion which favours research they would settle down quite happily, and forget running after dreams.

But what is good for the individual is not necessarily the best for society. Will great research laboratories, staffed by devoted research-minded workers, really pour out automatically a stream of worthwhile inventions? I am afraid this is just one of the comfortable beliefs of modern 'organization man'.[2] Thanks to recent researches,[3] one can give a fairly quantitative appraisal. From a careful investigation into the history of sixty important modern inventions, it appears that not less than thirty-three are the work of individual or independent inventors, six are borderline cases and only twenty-two come from research laboratories, of which fifteen are chemical inventions.[4] It may be noted that electronic research laboratories have a very good record, because modern television is largely the work of excellent inventors employed by large firms, such as Westinghouse, RCA, EMI and Marconi's, whereas the work of individual inventors, such as J. L. Baird and D. v. Mihalyi came to a dead end. Also, one of the most outstanding modern inventions, the transistor, is the work of the exceptional team of the three Nobel Prize winners, Shockley, Bardeen and Brattain, in the Bell Telephone Laboratories.

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[1] I have heard from Sir Ernest Marsden, FRS, that Rutherford actually had the idea, and received encouragement from J. J. Thomson, but let it drop because the development promised to be lengthy and expensive, and undoubtedly also because by that time he had lost interest in inventions.

[2] William H. Whyte, jr. *Organization Man*. London: Penguin, 1956. Other comfortable beliefs of 'organization man' are that 'ideas come from the group, not from individuals'; that 'creative leadership is a staff function'; that decisions ought to be made in committees only; and that 'a man who gets ulcers probably shouldn't be in business anyway'.

[3] John Jewkes, David Sawers and Richard Stillerman *The Sources of Invention*. London: Macmillan, 1958.

[4] One case, admittedly not typical, deserves to be singled out, because it gives a somewhat unexpected answer to the question 'is invention the result of research?' This is the story of the Kodachrome colour process, which was invented by two young musicians, Leo Godowski and Leopold Mannes, who were so enthusiastic about it that they went on with their experiments during their concert tours, in hotel rooms. Later, Dr C. E. K. Mees, FRS, the famous Director of Research of the Eastman Kodak Company, himself a distinguished inventor, invited them to join his laboratories with salaries, royalties and excellent laboratory facilities, where it took another ten years to make Kodachrome commercial. (The most remarkable feature of this case is that the two outsiders worked on an orthodox chemical basis originating from the scientific work of Fischer and Siegrist, 1910–14, on dye-couplers, which was open to all dye-chemists.)

This might look like a sufficient vindication of the modern institution of great industrial or national research laboratories, in spite of the more than fifty-per-cent contribution of the small minority of individual, independent inventors, but on closer look it is a justification only of those institutions which know how to employ and to stimulate inventors. Research is a modern hurrah-word, which exploits the immense prestige of science. Even the institutions which deal exclusively with inventions cannot do without it; they call themselves Research Foundations in the US, and in Britain there is the National Research Development Corporation—as if invention were nothing but the development of research results! There is no objection against a name, so long as we do not forget what it covers. But to suggest that television is a result of research into photo-emitters and electron optics, or that the transistor is the result of research in semi-conductors is plainly misleading. V. K. Zworykin, the principal originator of electronic television, is a true inventor, a descendant of the pure line of the heroes of Smiles, and so is Shockley. The difference is, of course, that they are not self-taught mechanics, but fully trained scientists. The other difference, that they have preferred to work for larger corporations instead of as free-lances (though Shockley has now changed his mind), is not very profound. Even the inventors of old times valued achievement more than money[1] and in modern times, when inventions are still uncertain but income tax is dead certain, money is even less important. Inventors can fling themselves heart and soul into their vocation, whether they are free-lances or employees, even too much so, as witnessed by the tragic case of W. H. Carothers of Du Pont's.

Once a great invention is made, legend rapidly grows around it, and makes of it a result of patient research and observation—forgetting only the guiding vision and the motive power! The transistor is a particularly good nucleus for a legend, because it was accompanied by so much brilliant research. But the fact is that Shockley did not set out to carry on research in semi-conductors; he set out to invent a solid-state amplifier.

Shall we foster invention?

In the invention-stimulating atmosphere of the United States or of the Soviet Union there is probably no need to utter such warnings. But in Britain, where the prestige of pure research is so immense, it will be as well to avoid confusion of ideas and to protect the inventor from extinction. The stimulation must start early, through science teachers, newspapers, radio, television and periodicals accessible to young people. Fortunately, there is no shortage in this country of gifted popularizers of science with the right attitude to inventions. The universities can do their share by teaching the history of technology, and generally by teaching science not as a *post factum* logical reconstruction, but as a succession of ideas, with their historical background, giving due recognition to their originators.

But the universities can make a more important contribution. It is a plain fact that very few of the modern electronic devices were invented by people trained as electrical engineers. The majority were invented by physicists, some by mathematicians, one by an architect. This is no reflection on the intelligence of electrical engineering students. What can you expect of the man who has been taught the tools of his trade in a situation in which the scientific background of electronic inventions extends from symbolic logic to quantum physics? I believe that the best we can do is to advise young people who show exceptional early promise and who want to become inventors, to take up electrical engineering not directly but as a postgraduate study and to study for the first three years nothing but mathematics and physics.[2] These are the years in which the mind is most receptive for abstractions, and in which quantum physics will not appear 'strange'. Later, some of them can be advised to study in addition physical chemistry, metallurgy, even physiology, especially of the nervous system. It is not a great exaggeration to say that almost any bit of odd information is more likely to inspire an original invention than knowledge which the inventor shares with all his professional colleagues.

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[1] Think of the noble words of Charles Goodyear, written at the time when he was imprisoned for debt: 'Only when someone sows and no one reaps is there truly reason for despair.'

[2] I am aware that such a course might not be suitable for a new Thomas Alva Edison, but it is always difficult to cater for the exceptional genius. Edison could absorb whole libraries full of odd facts with his enormous eidetic memory, but he was unable to learn mathematics and quantitative physics. It is quite possible that he would have failed all examinations in mathematics.

We may be agreed that Britain needs inventors to hold its own in the international race, but this does not necessarily mean that we approve of the race itself, any more than we approve of the armaments race. I want, therefore, to pose in all seriousness the following question: 'Do we need more inventions?'

There is, of course, an easy answer to this. Almost every important invention unbalances the front of progress, and a new invention is needed to redress the balance. Disinfectants and chemotherapy have strongly reduced child mortality in the East, the population is growing out of control and we need 'the Pill' to keep it in bounds. The steam engine, the internal combustion engine, etc., are threatening our stock of fossil fuel with exhaustion; we must have nuclear power and after that thermonuclear power. This is a compelling practical argument, but a very unsatisfactory one. It means simply that we cannot stop inventing, because we are riding a tiger!

Let us, therefore, hear what our best contemporaries have to say on this question: our writers and thinkers. But I am afraid it is not much use going to them for encouragement. Today a scientist or inventor must be very illiterate indeed if he is to retain a little of the happy, confident spirit of Samuel Smiles or of the Prince Consort a hundred years ago. It may be better for his peace of mind if outside working hours he is interested only in music, or if he reads nothing but detective novels. He may even read good literature, but, as I think most scientists do, he must not take it seriously. If he takes seriously what our best contemporary thinkers and men of letters have to say on the subject of industrial civilization, it will make him at best very unhappy. At the worst it will give him a strong desire to give up his futile and dangerous work, and to retire into a monastery.

I believe that it is a very significant fact that no optimistic utopia has been written for the last thirty years. Utopian literature did not die, as one might think, in 1914; it survived the first world war by about a decade. Some of H. G. Wells' best utopian works date from this time, and I recall with particular pleasure the *Daedalus* of the young J. B. S. Haldane, sparkling with optimism, and belief in salvation by science. But after Aldous Huxley's incomparably brilliant anti-utopia *Brave New World* (1931), no more utopias were written, only dreary science fiction and George Orwell's horrible nightmare *1984*.

The nightmare of the age of leisure

It we cannot get encouragement from the men of letters, can we perhaps get it from our fellow-scientists? No more utopias were written for the last generation, but we have now scientific forecasts from two distinguished physicists, *The Foreseeable Future* by Sir George Thomson (1958), and *The Next Million Years*, from Sir Charles Darwin (1952). Thomson's is a cautious application of the scientific method, neither very encouraging, nor disturbing, but Darwin's is a profoundly depressing book. His thesis is, briefly, that we are not moving towards a golden age, because the present is a golden age, and the next million years will see a sort of statistical fluctuation around a level rather lower than the present. I have no wish to give a rival forecast of the next million years, but I want to give my view, for what it is worth, of the near future. My thesis is, briefly, that from a purely material point of view a 'golden age' is at hand—but that there are immensely strong forces at work to prevent us entering it for the next few generations—and that there is nobody to show us the way to it.

The plain fact is that science and technology have immensely enlarged the set of 'possible worlds'. Until quite recently, the majority of people had to work hard to keep a leisured minority. We are now for the first time in history faced with the possibility of a world in which only a minority need work, to keep the great majority in idle luxury. Soon the minority which has to work for the rest may be so small that it could be entirely recruited from volunteers, who prefer the joys of a useful and even of a dedicated life to idleness.

Men have always envied the leisured classes, but it now appears that the dream of leisure for all is turning into a nightmare. Indeed, to think of the privileged classes of the past is enough to make one doubtful. The aristocracies of the past had two great psychological satisfactions which would be denied to a leisured majority: they could command human service, and they believed themselves to be *élites*. Yet for the averagely gifted members of the privileged classes life became bearable only by hard drinking!

The leisured society of the future is still mostly below the horizon, but it seems to me that our contemporary world has already developed several very strong defence mechanisms to prevent it from becoming a reality.

The first defence mechanism is Parkinson's Law: 'Work automatically expands so as to fill the available time.' Though this great law was first formulated in Britain, if we want to see it in action we must look to the United States, the most advanced and richest industrial country, where 'tomorrow is already here'. In the United States in 1957, for the first time in history, the 'white-collar workers' outnumbered the 'blue-collar workers': there are now more pen-pushers than tool-pushers. It is only surprising that they do not outnumber them 3 : 1 or 4 : 1. Not very long ago the great majority of mankind had to work in agriculture; even in the US in 1900 the proportion was thirty-one per cent. Today less than twelve per cent are sufficient to produce so much food that a great fraction of it goes daily down the drains, that millions are on a slimming diet and producers of canned foods advertise that their food has less calories per weight than that of their competitors. Or look at the car industry, where less than a million workers produce so many cars that they can be sold fast enough only by employing all the means of high-pressure salesmanship to make customers change them long before the car starts showing signs of wear. These are very clear manifestations of Parkinson's Law. But looking at it this way, the growth of pen-pushers is not a tumour; it is the healthy reaction of a society in which people have been brought up to work, not only for earning money but also because they want to feel useful and want to keep their self-respect.

A second, perhaps even more important defence mechanism is the recent strong increase of the birth rate, particularly noticeable in the United States, but also in Britain and in France. This is quite a different phenomenon from the overpopulation of poor and ignorant countries. It can be an expression of a healthy and virtuous civilization; people have more babies not because they cannot help it but because they love having children. Nevertheless, apart from the very different motivation, it looks dangerously like Malthus' Law, on which Darwin based his pessimistic outlook: the law that a population tends to increase up to the starvation limit. I am inclined to take a less serious view of this, as may be seen from my putting Malthus' Law on the same level as Parkinson's Law. I do not believe that in highly civilized countries the population need grow up to the starvation level, but it looks to me as if it had a tendency to grow up to a level sufficient to ban the nightmare of leisure for everybody.

A third defence mechanism, and a very strong one, is, of course—'defence'. All I need say about it is that much of the effort in all industrial countries goes into making the most devilishly ingenious products of the human mind, which at best will never be used, at worst might destroy all of us.

Our contemporary world has a fourth defence mechanism ready against a too easy life, and I am glad to say that at least this one is wholly laudable. It is aid to the underdeveloped countries of the East. It is not on a large scale, and it will not last long, as these countries are already making very determined efforts to raise themselves to a higher technological level; but while it lasts it will be good for everybody.

These four, as I see it, are the chief defence mechanisms of our society against the nightmare of a leisured world, for which we are socially and psychologically unprepared. I do not feel competent to give an opinion on the question whether mankind can or cannot be conditioned to bear leisure without boredom, and without losing that magnificent spirit by which a poor animal, almost toothless and clawless, has raised itself gradually to the status of modern man. For my part, I would be satisfied with a compromise, because man in the past has shown rather too much fighting spirit. But I can see little sign of any preparations to meet this problem in our western civilization, and none at all in the Soviet Union where the official creed is, of course, to deny the existence of the problem altogether.[1] This may well be a great danger, because they are making such great strides in their industrial development that they may well take the step from poverty to plenty in one generation, instead of the two or three of the

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[1] The official attitude of Marxists is, I believe, well illustrated by the following quotation from the late Frédéric Joliot: 'There are those who object to the view of progress which depends upon shorter working hours on the grounds that then people will not know what to do with their leisure, and will let themselves lapse into idleness and immorality. Such fears are groundless, because the time saved on working hours will open up to the individual a culture rich enough to induce him to work spontaneously during his leisure at the things he enjoys, and even attain the supreme joy of creative achievement in the realm of art and science.' ('Quelques réflections sur l'énergie' *Physique et Chimie*. Paris, 1958.)

To believe this one would have to believe first either that in future everybody will be exceptionally gifted, or that the less gifted members of the old leisured classes were driven to drink by a bad conscience.

western countries, psychologically completely unprepared and with all their dynamism still in their blood.

It is a sad thought indeed that our civilization has not produced a 'new vision', which could guide us on into the new 'golden age' which has now become physically possible, but only physically. All we have is the pedestrian dream of the trade unions of the thirty-five-hour week, the twenty-four-hour week and so on. But even this is not certain, because work which is not necessary to sustain life may have to come back as occupational therapy. This reminds me of the pathetic picture of the dog in the old physiological laboratories, climbing endlessly up a moving ramp. The dog will never get anywhere, but at least it will keep in fine fettle.

The lost vision

Who is responsible for this tragi-comedy of man frustrated by success? If the intellectuals at the other side of the fence say that the fault is ours, of the scientists and inventors, we are not in a position to deny it. But instead of bowing our heads in shame, I think we ought to return the accusation, and ask: 'Who has left mankind without a vision?' The predictable part of the future may be a job for electronic predictors, but that part of it which is not predictable, which is largely a matter of free human choice, is not the business of machines, nor of scientists, not even of psychologists, but it ought to be as it was in the great epochs of the past, the prerogative of the inspired humanists, of the poets and writers. And for more than a generation we receive from these quarters little else but more or less polished expressions of despair and disgust.

Some thirty years ago the French critic Julien Benda wrote a famous book, *La Trahison des Clercs*, in which he accused the 'clercs', the writers and thinkers (who by their vocation had the duty to uphold the ideals of freedom, justice and the dignity of the individual), of 'treason' by embracing dogma of one sort or another, or the creed of extreme nationalism. Today we are faced with a new treason of the *clercs*—oh, nothing as crude and criminal as the treason of the French intellectuals Barrès and Maurras—no treason by commission but only by omission: by not giving us a vision for which to live.

Until such time when our *clercs* change their mind, and come up from their depths of comfortable and complacent despair, we shall have to muddle through, from invention to invention. And if we want a measure of hope, we must not turn to the intellectuals; we must look at the present and into the past.

In the present we can see more simple happiness of the 'common man' than has ever existed in the world. Even uniformity can have its delights. Some years ago I saw in the *New Yorker* the following cartoon: a suburban row of houses, as far as the eye can see, and through every gate steps a young man, who has just arrived with the commuter's train. A little dog with wagging tail runs out to greet every young man, behind every dog runs a little toddler, and behind every little toddler, on the doorstep, stands a smiling young wife. This is stereotyped happiness, but unique and wonderful for those who live it. Worse things can happen to humanity than this scene repeating itself through a hundred generations!

This is what we can see in the present. Looking into the past, we can see our ancestors, men with much the same capabilities as ours, miserably sheltering under dripping trees from the cold pelting rain. The journey which led from these poor savages to the distinguished audience before me seems to me worth while. It will be for another new professor in another historic epoch before another audience, to draw the balance of splendours and miseries and to decide whether the rest of the journey was necessary.

Creativity, technology and the arts

John Cohen

'The intricate cybernetic system which, we may surmise, governs thinking in general and creative thinking in particular, must not be treated as solely an intellectual affair.' (*Cohen*)

A much extended and revised version of this article appears in Professor Cohen's *Homo Psychologicus*, London: Allen and Unwin, 1970.

Creativity knows no bounds. Its forms are legion, its sources obscure, its ways devious in the extreme, but its fruits are patent for all to see in every domain of human life. Creativity is not an all-or-none affair, not a question of being a Rembrandt or nothing at all, but rather a series of imperceptible gradations from a most rudimentary inventiveness at one extreme to a superlative exercise of genius at the other. That there are immense differences in the scale and quality of creativeness is not disputed, but this is not what distinguishes technology either from the arts or from pure science. For there are major and minor poets, major and minor painters, sculptors, musicians, just as there are prodigious mathematicians and physicists of the first rank by comparison with whom the life-work of lesser lights is no more than a footnote to science.

There is certainly, in respect to creativity, no natural opposition between technology and the arts, for it is sheer prejudice to suppose that technology is routine, prosaic and pedestrian, while all fecundity of invention belongs to the arts, a prejudice which can only be sustained by begging the question at issue. The humblest activity carries within it the seed of innovation. Even mental defectives, suitably trained and encouraged, can weave original patterns which are a joy to the eye, just as they can infuse a new rhythm into an improvised dance. I am reminded of a Venetian shoe-cleaner in the Piazza San Marco who pursues his craft with the dedication of a great painter. He places his sitter on a gilded throne alongside which is assembled a full array of materials, cloths, colours, oils, chemicals, boxes, tubes and brushes, while a spell-bound crowd gathers to admire an artist blind and deaf to everything but the task in hand. The work, so perfunctorily performed by his philistine counterparts elsewhere, if not actually mechanized by them, may last an entire afternoon.

Whether we dwell on the aesthetic properties of an object or on the technique by which it is contrived may be merely a matter of emphasis. There is artistry in primitive toolmaking as there is technique in prehistoric cave paintings. The aesthetic glories of ancient civilizations in the Near and Far East, their cities, temples, statues and monuments, their chariots and ships, like their spinning, weaving and dyeing, were all founded on technology, principally on a knowledge of *architectura* in the widest sense, and on techniques of mining, forging, smelting and metallurgical processing. Any object whatsoever, whether it is an aeroplane, locomotive, ship, automobile or boomerang, in so far as its design is visually pleasing and it is at the same time operationally effective, is both a work of art and a product of technology, and it may be an arbitrary decision to assign this feature to art and that to technology.

We must guard against any derogation of technology which regards it as nothing but the application of pure science. Indeed the question whether pure science itself is ultimately rooted in technology is still hotly debated by historians. No doubt the origins and growth of modern science are, to some extent, the outcome of a gradual shift of interest from pure theory to practical application, an interest made plain enough by the founding fathers of the Royal Society. On the other hand, as Alexander Koyré remarks, such prominent features of civilization as the plough, the gothic arch, the stern rudder and the spindle of mediaeval clocks, as Koyré reminds us, neither stemmed from nor led to progress in science. Perhaps, on the whole, the chicken of technology owes no more to the egg of science than the egg of science owes to the technological chicken.

But there is another view, namely, that if we divorce technology from science we are also obliged, for the same reason, to demarcate the humanities from the arts. Possibly we should say, with Michael Polanyi, that the humanities are the technology of the arts. From the discoveries of pure science, by and large, depend on nothing but themselves. They are self-generating. The scientist is a prime mover in advancing our understanding of nature, including human nature. He is next of kin to the poet, the dramatist, the novelist and the statesman. Modern technology, by contrast, must rely on pure science for its fundamental ideas, and on the market for the demand for its products; and the humanities—the academic study of language, literature, law and history—are in a similar fashion dependent on a world outside themselves. What would the army of academic literati, historians, social scientists and lawyers do if there were no poets, generals, politicians, trade unionists or criminals?

If logic dictates that technology and the humanities should be natural bed-mates, the facts of life are otherwise. Not for nothing are pundits on all sides wailing and gnashing their teeth. For we seem to be witnessing a profound cleavage of culture into science and technology *versus* arts and the humanities, a cleavage said to be among the chief occupational diseases of our age. This predicament could be changed if we removed the spurious antithesis, for example, that classical studies are naturally opposed to science, which befuddle our educational tradition. However, the bifurcation, such as it is, would have appeared strange to the ancients, who held man-made mechanisms in the highest esteem and venerated equally their artistic and technical merit. Homer, Pindar, Plato and Aristotle all speak of them. Socrates must have had the mobile statues of Daedalus in mind when he said to Euthypro:

> 'Your words are like the handiwork of my ancestor Daedalus; and if I were the sayer or propounder of them, you might say that this comes of my being his relation and that this is the reason why my arguments walk away and won't remain fixed where they are placed.'

If Daedalus, celebrated sculptor and prototype of inventive genius, belongs to myth, there is no doubt that the Greeks of old, like the ancient Chinese, Indians and Egyptians, could also boast of actual triumphs, at once artistic and technical: automatic theatres, clepsydras, hydraulic organs and countless other marvels of ingenuity.

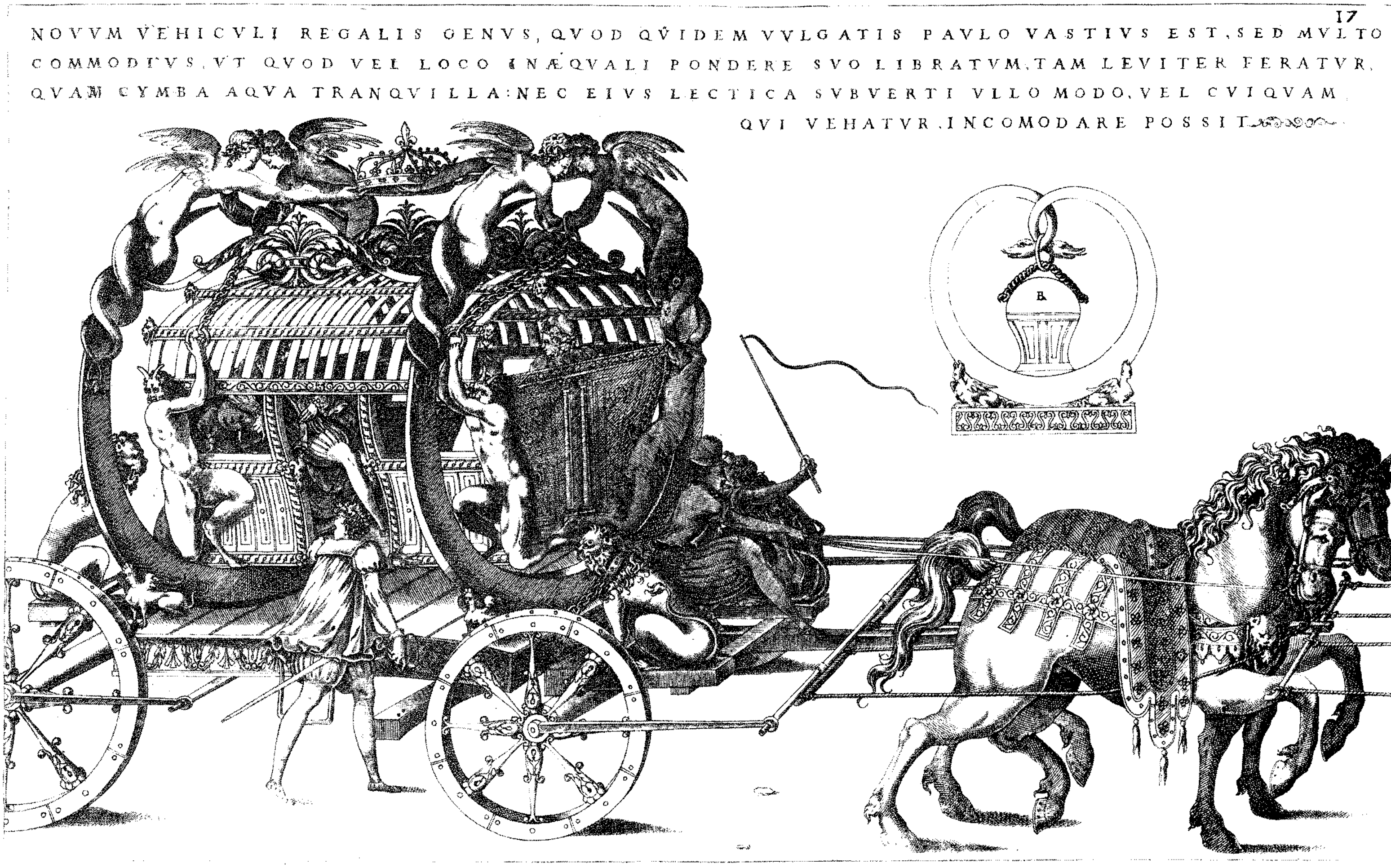
The bifurcation would have seemed just as alien to the scientific innovators, artists and men of letters of the sixteenth century. Leonardo would have frowned upon it, while the young Galileo found it perfectly natural that he should be renowned as much for his poems and dramas as for his scientific accomplishments. Signs that the rot was setting in first appear in Lord Bacon for whom 'the palaces of the mind', by which he meant scientific endeavour, were far superior to the mere arts of the theatre. Descartes spoke of the 'blundering constructions of the imagination', while Spinoza was equally critical. 'Men of great imaginative power,' he wrote, 'are less fitted for abstract reasoning, whereas those excelling in intellect and its use keep their imagination more restrained and controlled, holding it in subjection, so to speak, lest it should usurp the place of reason,' a view to the taste of Leibniz, who, while he did not begrudge Dryden the £1000 he received for his translation of Virgil, would have liked the astronomer Halley to have received four times as much and Newton (whom he often disparaged) ten times. Yet a divisive spirit of this sort found no favour in the eyes of the Royal Society, at least in its early days. It welcomed among its illustrious members, poets, politicians, dramatists and divines on a par with scientists and philosophers. Only in the nineteenth century did its choice tend to become somewhat restricted; so much so that to Charles Babbage the letters FRS came to signify 'A Fellow who is Really Scientific'.

The interplay of technology and the arts from the fifteenth to the seventeenth century, in particular in architecture, reached a peak of excellence in the hydraulic engineering which made possible the fantastic fountains in the palaces of the great. Although the mediaeval water-wheel and other devices for exploiting water-power were essentially utilitarian and designed for agricultural and industrial purposes, hydrology during the Renaissance and later was subsidiary to aesthetic ends. 'Galatea drawn by dolphins', designed by the brothers de Caus in the early seventeenth century, could just as well be called technological art as artistic technology.

The numerous graphic representations of machinery during this period have a truly aesthetic appeal, as shown by A. G. Keller's *Theatre of Machines* (1964) based, in the main, on the works of Jacques Besson (1579), Agostino Ramelli (1588), Vittorio Zonca (1607) and Giovanni Branca (1629) (figs 5, 6 and 7).

The European literature of the Middle Ages, as in the *L'Horloge Amoureuse* of Froissart, and of the Renaissance, vividly reflects technological art in the popularity of water and mechanical clocks. Reinforcing the mechanisms actually in existence were legends and travellers' tales of animated figures and other automata in Byzantium and the Far East. Among them are oracular heads and singing birds powered by water, wind or the bellows. The interest of artists in the minute works of nature was subsequently

Fig. 5 Carriage with equilibrated suspension, *Théâtre des Instruments*, Jacques Besson, 1579.



NOVVM VEHICVLI REGALIS GENVS, QVOD QVIDEM VVLGATIS PAVLO VASTIVS EST, SED MVLTO COMMODIVS, VT QVOD VEL LOCO INÆQVALI PONDERE SVO LIBRATVM, TAM LEVITER FERATVR, QVAM CYMBA AQVA TRANQVILLA: NEC EIVS LECTICA SVBVERTI VLLO MODO, VEL CVIQVAM QVI VEHATVR, INCOMODARE POSSIT.

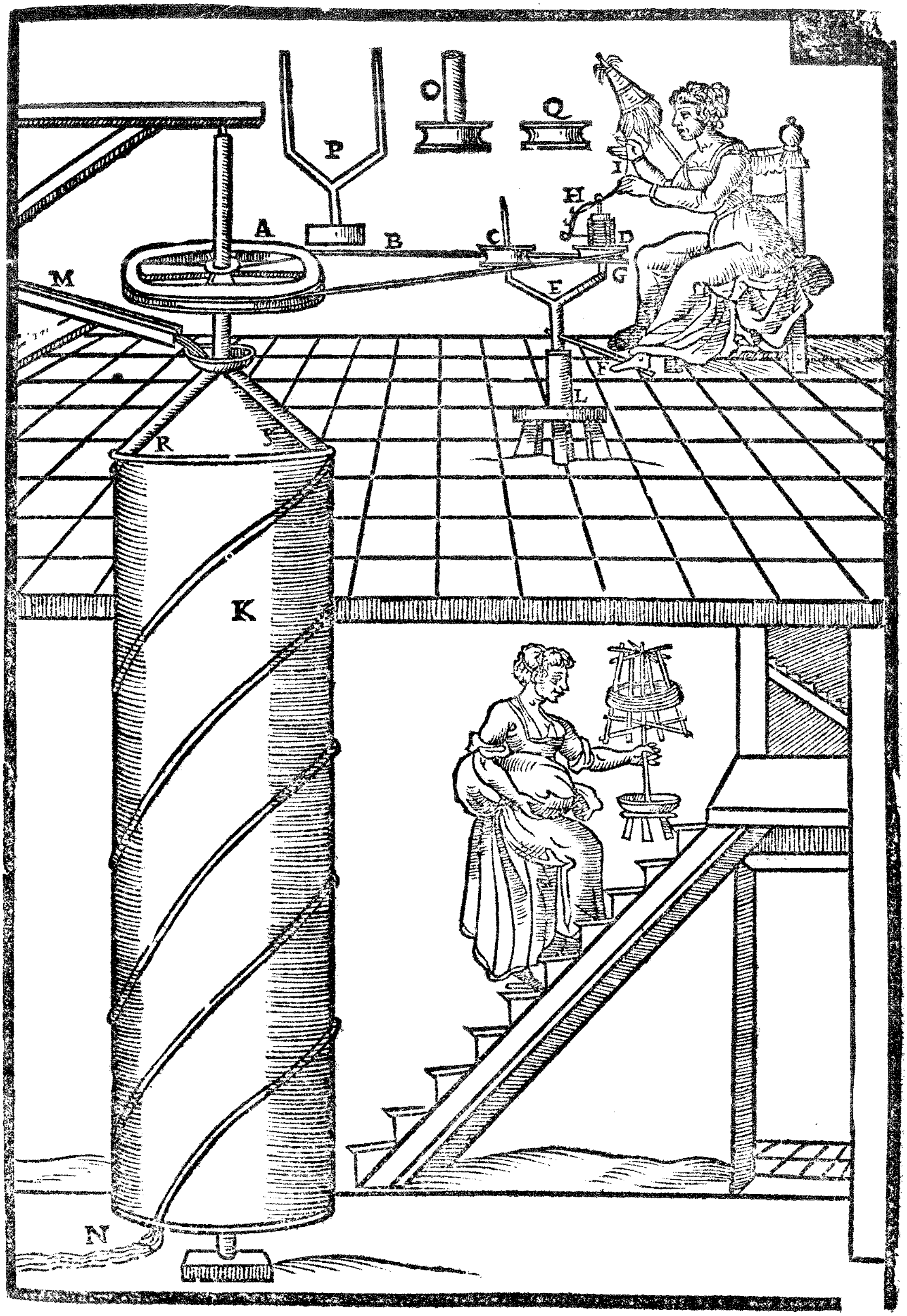
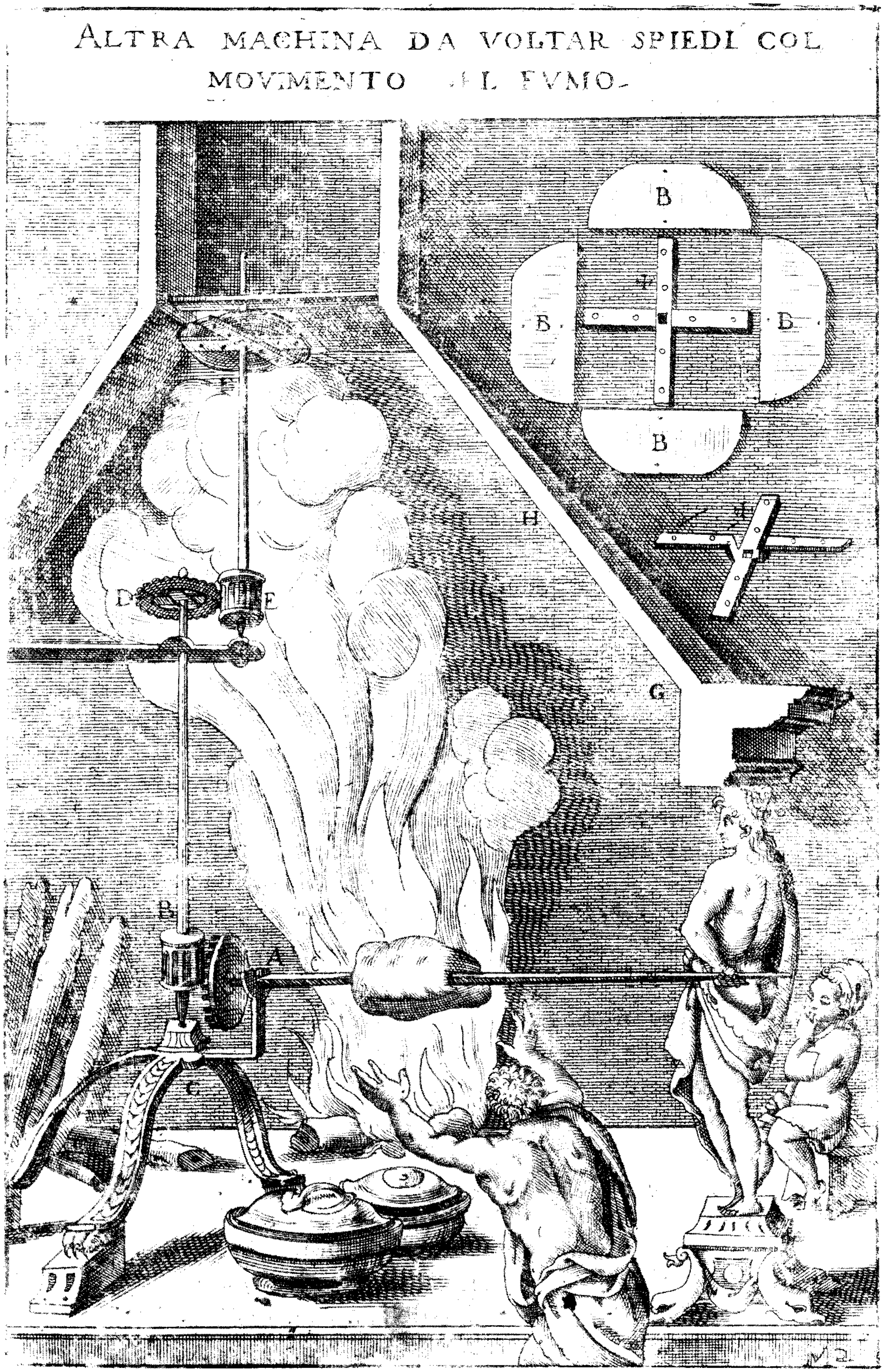


Fig. 6 Hydraulic spinning wheel, *Le Machine.* Giovanni Branca, 1629.

Fig. 7 Smoke-jack spit for roasting in kitchens of inns, *Novo Teatro di Machine*, Vittorio Zonca, 1607.



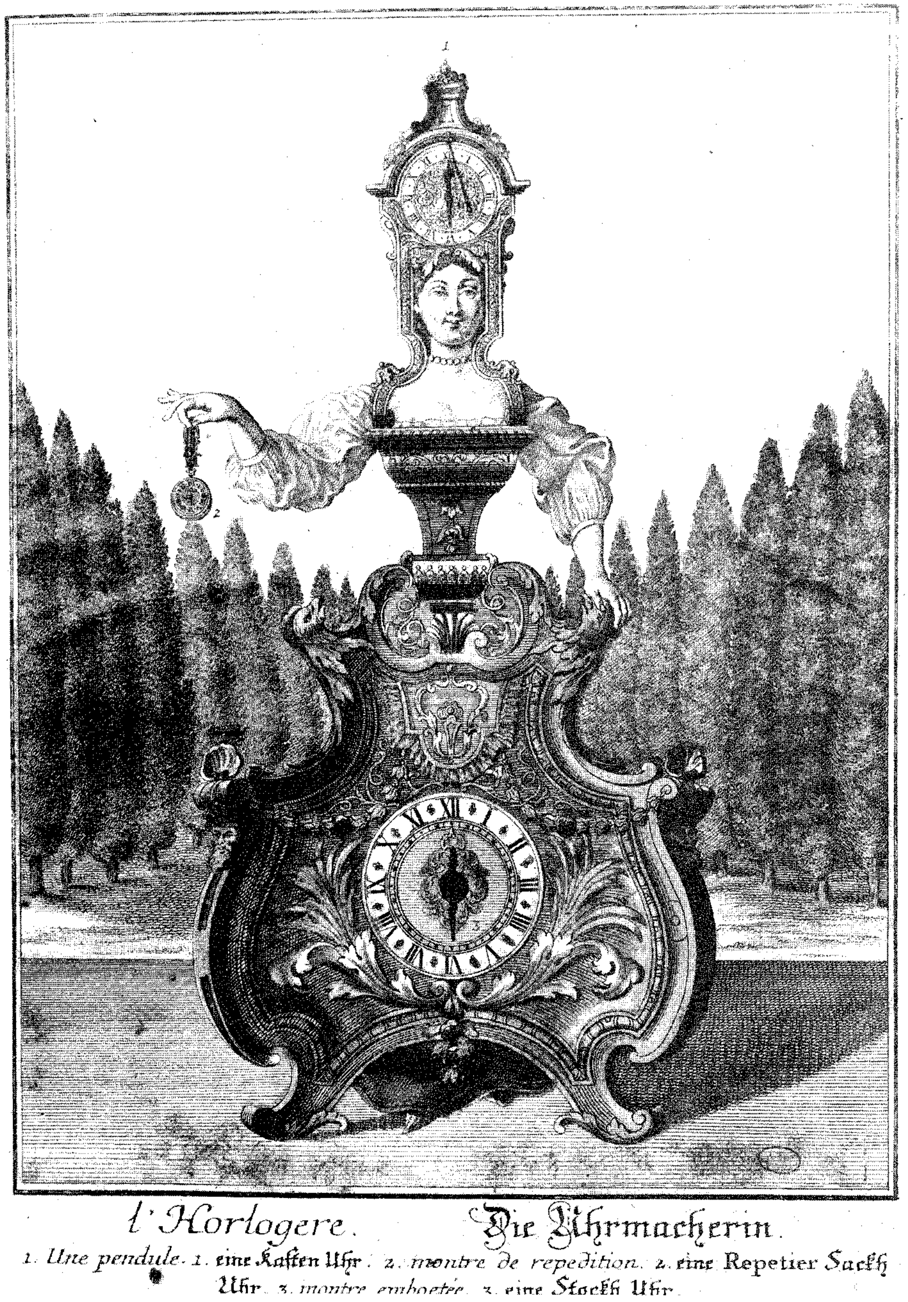


Fig. 8 *The Mistress of Horology*, an eighteenth-century German engraving. Bibliothèque des Arts Décoratifs, Paris.

aroused by the microscope, just as the invention of the telescope opened their eyes to the new world of perspective.

Each epoch has its dominant model which permeates science and art alike, always, naturally, with dissent here and there. European thinkers of the seventeenth and eighteenth centuries, a period when the mechanician's automata became increasingly impressive, adopted the clock as their model. The universe was modelled on the clock of Strasbourg, and there was one principal question at issue: whether God needed to maintain and service it from time to time or whether He had wound it once and for all at the start. The piety of Newton required that God should, as and when required, come to the assistance of his cosmic clock, rewind it, clean it and even repair it. Less pious Newtonians, like Leibniz, critic-in-chief of such a conception, felt that this celestial intervention was unnecessary. At all events, the

Fig. 9 *The Master of Horology*, an eighteenth-century German engraving. Bibliothèque des Arts Decoratifs, Paris.

technology of the clock-makers gave philosphers something to think about.

I have described elsewhere[1] the immense fascination which automata of all types, and especially those that simulate some feature of human behaviour, have held for writers of fiction from the tenth century until our own day (figs 8 and 9). With the progress of cybernetics and the design of self-regulating machines of ever greater complexity, modelled on adaptive and homeostatic mechanisms in man, the novelist, playwright and science fiction writer find ever more scope for their inventiveness in the idea of human automata.

Technology as we understand it in our own time is vastly different from the technology of antiquity, the Middle Ages

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[1] J. Cohen *Human Robots in Myth and Science*. London: Allen and Unwin, 1966.

or the Renaissance, interwoven as it was then with art and science. Technology today is self-conscious, and while its tangled roots reach back to the intellectual revival of the thirteenth century, it needed the liberating air of the eighteenth century to bring forth its products in the nineteenth. These products are of two main kinds: amenities of civilization and instruments of scientific investigation. The supreme achievement of the nineteenth century was, in Whitehead's words, 'the invention of the method of invention'. A scientific idea, however profound and far-reaching, does not of itself constitute an invention, nor can it be patented. It is a far cry from idea to invention, and between them lies 'an intense period of imaginative design'.

As art, science and technology began to go their separate ways in the eighteenth century there remained individuals whose unity of vision was such as to resist any intellectual mutilation. Among these Shelley is outstanding. His line, 'I spin beneath my pyramid of night' could have been written only by someone, to quote Whitehead again, with 'a definite geometrical diagram before his inward eye', a diagram faithful to the facts of astronomy. The grand scope of Shelley's prevision has yet to be fully appreciated, if we may judge from one of his metaphysical fragments which foreshadows developments in psychology to an extraordinary degree. He imagined a scale of measurement 'graduated according to the degrees of a combined ratio of intensity, duration, connexion, periods of recurrence and utility'. With this, he believed, one could calibrate all mental activities to yield a continuum of nicely shadowed distinctions, 'from the faintest impression on the senses, to the most distinct combination of those impressions; from the simplest of those combinations to that mass of knowledge which, including our own nature, constitutes what we call the universe'.

Let us remind ourselves that the converse effect also takes place. Somehow we are more apt to note the influence of science on the arts than the influence of the arts upon science, as if scientists never read poetry, never go to the theatre or lose themselves in a novel. As a matter of fact, we have it on the testimony of Einstein himself that he was more indebted to Dostoevsky than to any other thinker, more even than to Hume or Gauss. What Einstein owed to Dostoevsky had nothing to do with science or relativity as such but, as Boris Kuznetsov has said, with the tremendous significance he attached to a truly crucial 'experiment' from which, without any repetition, the most far-reaching inferences could be drawn. Here lies the kinship between Einstein and the heroes of Dostoevsky who were ready to hazard everything, life itself, in order to know.

What can we learn from poets, novelists, philosophers and scientists about the manner in which they bring their creative work to fruition? They speak of the times, places and habits which are propitious, and of those which are unpropitious. And they speak of their diversions. 'A continuity of labour deadens the soul,' observed Seneca. So Balzac drew crayon portraits. Descartes cultivated delicate flowers. Spinoza set spiders to fight each other, and the theologian Petavius twirled his chair for five minutes every second hour. All these recreations serve as a period of incubation, a period during which the seminal idea can be processed in ways beyond the scope of conscious concentration. Yet creative processing remains nature's most closely guarded secret, by comparison with which the interior of the atom is an open book for all, even the illiterate, to read. The momumental *Road to Xanadu*, after all, sheds only a faint ray of light on the sacred darkness of the mind of a Coleridge.

No wonder the idea of 'creativity' is vague and undefined. It is commonly understood to refer to a wide range of activities which themselves relate to a great diversity of content. We can perhaps get a clue to its essential nature from the reply a small boy of three and a half gave to the question 'what do you do when you think?'—'You just stand quietly and don't say nothing and something comes into your brain.' Creativity means 'Eureka!'; the heuristic devices of the mind have triumphed. The search is at an end, for the seeker has found that which he has sought.

The eureka-knowledge that surprisingly and mysteriously springs from the hidden depths of our being carries with it a feeling of overwhelming conviction. We do not know whence this knowledge comes; we ourselves seem to have contributed nothing consciously towards it; we cannot therefore question the logic on which it is built. This knowledge is imbued with a strength and irrefragability which never characterize the reflective products of consciousness. It may even seem to us totally divested of our own subjectivity and to emanate from some extraneous source. Such knowledge has often been regarded by philosophers as *a priori*, as something that precedes experience and owes nothing to it. Indeed, the hiatus between an idea and its origin within us led the ancient Greeks to invoke the gods as the responsible agent. The *daimon* of Socrates was a messenger from the gods, like the voices and visions of the Biblical prophets. Not so very long ago, William Blake was convinced he was an amanuensis writing from divine dictation.

Nowadays, chance is invoked as the responsible agent. Greek thought, outside the randomly moving atoms of Democritus, had no place for the idea of chance. Man's destiny, like every natural phenomenon, was governed by the fateful designs of the gods. Hence the universal appeal to oracle and divination as a device for compelling the gods to reveal their secrets. It would, therefore, have been inconceivable for a Greek artist or sculptor deliberately to allow chance, in the sense of an event outside his control, to influence his work. So the single recorded instance in which an aesthetically pleasing effect occurred by chance is all the more significant. This is Nealces' portrayal of a horse in the third century BC. Displeased with the foam falling from the horse's mouth on the bridle, again and again, but without success, he tried to erase the blur, and finally, in a rage, he flung his sponge, full of colours as it was, at the picture. 'This', says Plutarch, 'very wonderfully produced exactly the effect he desired.' We should not call it Tachism, for it was a chance event that occurred by chance, not a deliberate exploitation of chance.

There are several different senses in which chance may be said to play a part in contemporary art. There is the sense in which the artist allows his work to be shaped or even dominated by so-called random elements electronically or otherwise produced, but this does not mean an aleatory system—that is, a system in which the probabilities of the different outcomes of an event (as the six faces of a die) are precisely known beforehand. No artist chooses his pigment by tossing a coin. Even chimpanzee 'art' is not aleatory.

The sense of chance which best characterizes some contemporary artists is one of which Francis Bacon, a lover of gambling, has spoken from time to time, and on which Soto is particularly explicit. Soto tells us that his early work was governed by an inner conception which was present before he took up his brush. Subsequently, he came to value what he found while working, by pure chance, and he asserts, 'I never make a model or draw a plan. I work my pictures directly . . . the work of art must give me a shock . . . Hazard is, for me, the living element alien to myself which I incorporate into my work.' But these hazardous features of his work have an alien character only because the work is sealed off from his conscious life. He cannot recognize where it comes from. Picasso makes the same point crisply, 'I am not looking for anything, I find.' What he finds he finds by 'the magic hand of chance', like Kandinsky, to whom the idea of abstract art came fortuitously. He returned to his studio and discovered a landscape upside down on the easel. 'I do not make a book; it makes itself,' wrote Alfred de Vigny. 'It ripens and grows in my head like a fruit.' 'I have a brain working in two compartments,' said Balzac. 'In the first is the book I am writing. In the second compartment, behind, is another which is writing itself.' This finding without seeking marks the mind of the creator of cybernetics, Norbert Wiener, who valued in himself a 'free-flowing kaleidoscopic train of imagination which more or less by itself gives me a consecutive view of the possibilities of a fairly complicated intellectual situation'.

Perhaps we may be permitted to speak of chance in describing the licence which Cézanne granted himself. 'I could keep myself busy for months,' he said, 'without moving from one spot, just by leaning now to the right, now to the left.' This highlights a principle of relativity in art. It points as well to the significance of the moving rather than the static eye, a significance which has led to kinetic art in which aesthetic effects are produced not only by the mobile eye of the artist but also by the participation of the roving eye of the viewer for whom duration and movement are integral elements of his aesthetic experience.

The inner conception before taking up the brush which governed the early work of Soto poses a time-honoured question which runs through the history of art: does the artist copy nature? or does he represent an image within himself? Does he, with the empiricism of Aristotle and Leonardo, look to his observations of the external world to discover an order which is there to be discovered? Or does he, with the rationalism of Plato and Michelangelo, seek a Pythagorean order in his own mind or soul? Zeuxis, who selected five naked virgins of Agrigentum as models for his

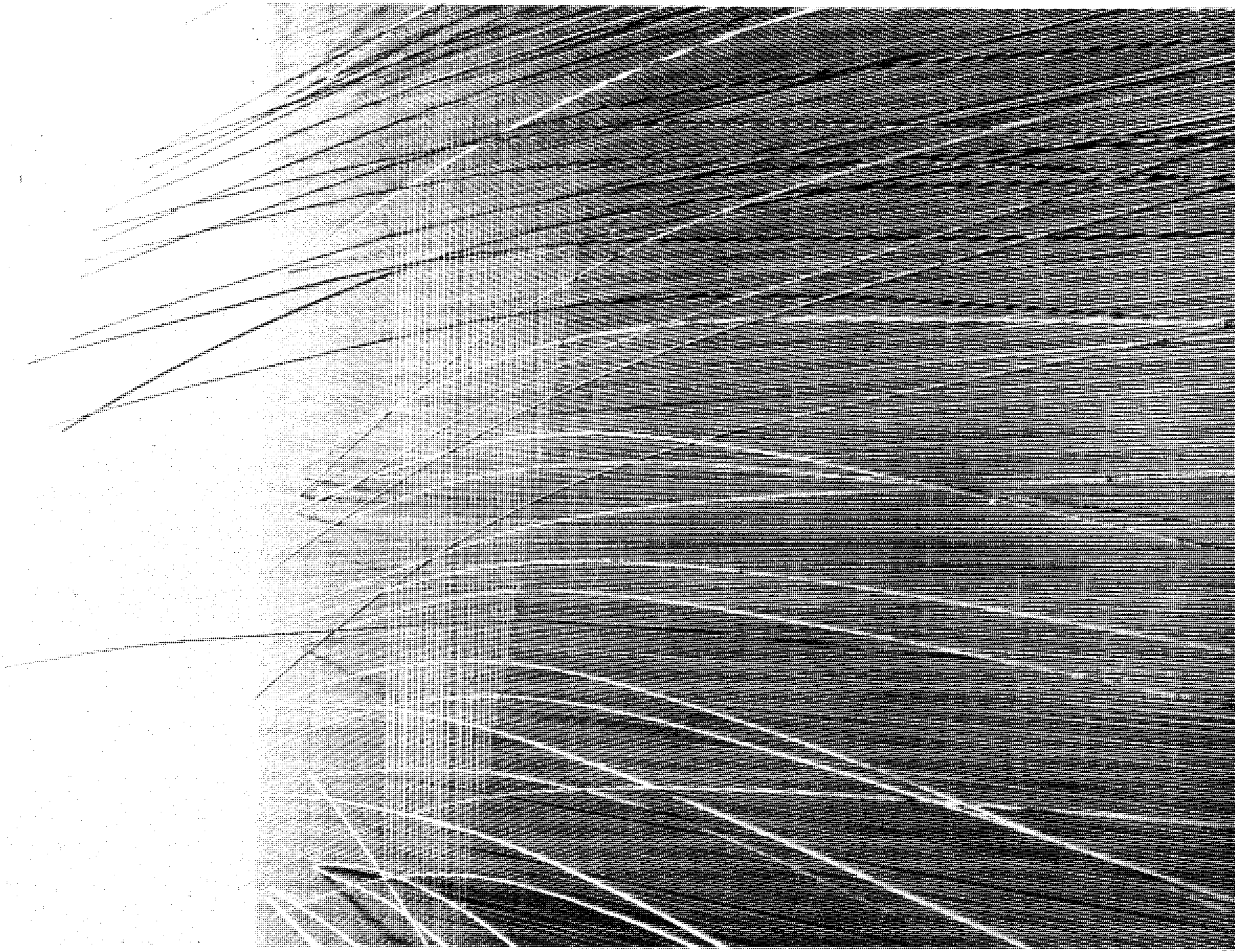

Fig. 10 *Vibration Immatérielle* by J.-R. Soto (detail). Collection Jean Clay Paris.
Photo H. Gloaguen, Paris.

Helen, copied; while Raphael searched for images in his own mind 'since there are so few beautiful women'. He preferred to look within himself.

This profound polarity also pervades the history of science. In philosophy we encounter it in the manner whereby Leibniz, in refuting Locke, depicts the human mind at birth. If the veins in a block of veined marble mark out the figure of Hercules rather than other figures the marble is said to be predisposed to it. Just as Hercules is innate to the marble so 'ideas and truths are innate to us, like natural inclinations and dispositions'.

Whichever path the artist chooses is in the reverse direction from that of the scientist. For the artist does not construct a model. His model is given and he accepts it as he finds it, whether it be within him or outside, and his task is to match reality to this model in whatever medium he works. The scientist on the other hand deliberately sets up his model to match nature, and modifies it as and when he finds it necessary to do so. For him, nature is given and he constructs a model to illumine it. What is true of the scientist is equally true of the technologist.

Furthermore, the outward model is more akin to science than the inward model. 'As a living figure is hidden in the hard stone, so are my good intentions, if there be any, buried deep in the superfluity [*soverchio*] of the flesh.' So wrote Michelangelo in a madrigal to Vittoria Colonna, and she alone had the power to reveal the hidden image. On the other hand, the scientifically disposed Leonardo favoured the outward model, and it may be of interest to remark that he too was attracted by the influence of chance. The would-be artist, he thought, should accustom himself to gaze at spots on the wall, ashes in the fire, clouds and mud and behold in them 'landscapes bedecked with mountains, rivers, cliffs, trees, large plains, hills and valleys of many a sort'.

When all is said, the dizzy ascent of modern science need not deter us from tracing the precarious paths whereby the heights have been scaled. But we shall not make much headway if we follow Spinoza in assuming that there is a self-sufficient 'intellect' which functions in total independence of a self-contained entity called the 'imagination'. We do not really have much idea of what we are talking about when we use either of these words, and all that Theseus can tell us of 'imagination' in *A Midsummer Night's Dream* is that it 'bodies forth the forms of things unknown'. Certainly, the intellect of the man of science does not, any more than the imagination of the poet, engage in an entirely conscious exercise which can be recaptured by introspection. Nor is the scientist's retrospection better than the poet's recollection in tranquillity, which at best permits him to grasp the shadow rather than the substance. The poet or mathematician who seeks to catch himself unawares in the act of discovery feels like a small boy who stands in front of a mirror with eyes closed to see what he looks like while asleep. Thinking in science is not at all a step-by-step series that we can follow from start to finish, and it never keeps to the traffic lanes prescribed by logic. Nor, again, is it a sharply defined cognitive activity. It may involve features which are generally believed to have nothing to do with the scientific intelligence. Let Charles Babbage's Analytical Engine, chief precursor of our computing machines, serve to illustrate. How did Babbage arrive at his novel idea? This is what he tells us:

'The earliest idea that I can trace in my own mind of calculating arithmetical Tables by machinery arose in this manner: one evening I was sitting in the rooms of the Analytical Society at Cambridge, my head leaning forward on the table in a kind of dreamy mood, with a table of logarithms lying open before me. Another member, coming into the room and seeing me half asleep, called out, "Well, Babbage, what are you dreaming about?", to which I replied, "I am thinking that all these Tables (pointing to the logarithms) might be calculated by machinery."'

A 'dreamy mood' is very unlike that conscious concentration which concerns itself with a representation of the external world. Yet such a mood may generate a liberating imagery which lifts the mind from the perceptual field and endows it with an otherwise unattainable mobility. Babbage's dreamy mood, like Kekulé's dream of the benzene molecule, reminds us of Clerk Maxwell in whose constructions (as in Kepler's and Newton's) there appear to have been 'religious' elements to which we owe the general equations of the electro-magnetic field. Because of these elements the equations were more real to him than the material effects he encountered in his laboratory.

Faraday provides a further illustration. His special gift lay in tirelessly probing resemblances between the known and the unknown, and in seeking and dwelling on analogies between different ideas and images, an activity which seems akin to what T. E. Hulme described as the art of dancing around an idea, of lingering on a point, of decorating and transforming it until it produces a sense of novelty. Inventiveness in science and art alike depend on simile and metaphor, and in so far as language plays a part it preserves 'the relics of the extravagant fancies and analogies of dead and forgotten poets'. In physical science, the task of analogy is to render the unfamiliar familiar. In psychological science it is the other way round, to render the familiar unfamiliar.

If every stage in the creative process could be logically specified and made explicit, we could invite the computer to write poetry and discover theorems, for a computer can discharge any task that can be formally described. The trouble is that we are not yet in a position, either in principle or in practice, to set the limits of the formalization of mental activities, in spite of over-sanguine assertions to the contrary. An enthusiast declares, for example: 'Undoubtedly, it will ultimately be feasible to program a computer to achieve the same mastery of English that we ourselves have.' There is unfortunately no magic whereby the use of the word 'undoubtedly' exorcizes the devils of doubt out of our minds, doubt which rests on the fact that our mastery of English is made possible by the use of language for non-linguistic ends. This world of ours is not bounded by words or by the covers of a dictionary. Our commerce with it provides the cues which reduce the intrinsic ambiguity of language and hence make communication possible. Only if a computer engaged in similar transactions with the world beyond its own linguistic store could it acquire our mastery of language.

Creativity, in every sphere, is a species of information-processing in which, so to speak, the processing by man as transducer, contributes far more to the output than the information itself. The creative man makes more and better bricks with less straw. He does not have to plod and search every nook, crevice or cranny. He has a knack of eliminating false trails. In short he has a repertoire of heuristic devices at his disposal. He himself can tell us little about them, and a computer scientist would give his right arm to be able to pounce on them and bring them to the light of day.

The relative contributions of input information and transducer towards the output may be illustrated by reference to emotional response in animal life where one and the same pattern of behaviour may result either from an intense signal impinging on a weak state of need or from a feeble signal impinging on a strong need. When the need rises to a certain level it needs no triggering signal from the outside for a reaction to take place; the organism 'explodes'. Man too is capable of 'exploding', without stimulation from without, when his state of being reaches a certain peak of passion or intensity.

Let us not oversimplify a complex situation. We do not know when the processing begins, the point at which the physical signals begin their psychological transformation. It is here that one of the main difficulties lies. The selfsame moon lights up the heavens for all of us alike but only a poet sees it as wandering companionless, like a joyless eye. When does the poet's mind set to work on the common physical signals?

We are not yet able to answer this question, but we are in a position to point to the two-fold character of human life which makes creativity possible at all: an inner world of personal experience and a public world of behaviour manifest to the outside observer. The inner life is not disparate from the outer manifestations of behaviour merely because we describe them in two different languages, the former in the mentalistic language of feelings and fantasies and the latter in the physiological language of heart beat and movement. The disparateness arises because there exist different kinds of information—selective, semantic and subjective. The selective information-content known to cybernetics and information theory is only indirectly concerned with what we actually convey in a message. Its primary preoccupation is with what we could have said with the range and choice of possible messages. How much selective information has been gained by the receiver can only be known after the message has arrived. This kind of information gain may be measured in terms of the number of questions which have to be asked (and to which the reply must be yes or no) in order to identify a given element. It is a binary system, and it has nothing whatever to do with the quality, meaning or value of information as this is understood in everyday life.

Semantic information, not yet measurable, has to do with the meaning of a message shared by transmitter and receiver, while subjective information, more elusive still, embraces all that an individual infuses into his love and his hate, his compassion and his rage, as well as what he introduces into his ideas, his fancies and his evocations of memory. This cannot be coded into a binary system without loss of essential features. At the level with which we are here concerned, experience which generates creative work in art, science or technology cannot be conveyed in a message governed only by the rules of selective information content.

Compare semantic with subjective information content by reference to Wagner, who 'poured into *Tristan and Isolde* his adultery with Mathilde Wesendonck, and if we want to enjoy this work we must, for a few hours, turn vaguely adulterous ourselves'. (Ortega y Gasset) The adultery which Wagner's audiences share with him through the medium of the music of *Tristan* is the opera's semantic content, which is bound to be a somewhat attenuated form of the original. If Wagner had been faced with the choice of enjoying adultery or listening to *Tristan* (composed by someone else) he would have certainly chosen the former, or else renouncing the creative hope of transforming adultery into music and enriching it with a subjective information-content. It is one thing to encode adultery into music, it is another to decode music into a phantom-like adultery.

Not all subjective information-content is precluded from being re-coded into another form, as the game of 'Twenty Questions' illustrates. An answer at any stage transmits information that is both subjective and selective and which may be described in binary units. If there are about a million possible and equally probable items to be mentally sorted, a player using a binary system can dispose of three-quarters of a million of the items in his first two guesses. In fact, this game is more complicated because the items are not equiprobable either statistically or subjectively.

The differing domains, personal and public, to which I have referred above may be contrasted in terms of two key questions: how do we represent within us, and therefore in our conduct, the physical environment and the social milieu which exist outside us? Otherwise expressed, how do we learn to understand or manipulate the external world and to internalize, come to terms with or reject its codes of behaviour? A reply to these questions is generally sought by psychologists in terms of an output which is essentially a function of the input, this input being peripherally coded in the receptors and processed in one way or another in the brain. But there is a complementary question: how do we represent outside us (in words, things or actions) the 'world' which exists within us? This too may be resolved into simpler questions. How do we find phrases, melodies, patterns of colour, masses and shapes of stone or bronze to convey that which cannot be communicated in any other way? What peremptory impulse charges us to do these things? How does the poet know he has selected the correct words and placed them in the correct order? By what means did the words *senza rigore* come to suggest to Proust 'a feeling of harsh thunder combined with tender spirituality'? And, most intriguing and most tantalizing question of all—how is a metaphor generated? All these questions clamour for an information theory in reverse.

The intricate cybernetic system which, we may surmise, governs thinking in general and creative thinking in particular, must not be treated as solely an intellectual affair, as simply a matter of knowing, reflecting, analysing, inferring or engaging in other exclusively cognitive activities, in so far as this is possible. The entire individual is involved, body and soul. By which I mean that his repertoire of heuristic devices is not merely a bag of intellectual tricks and short-cuts. Audacity and daring, fearlessness in asking unwelcome questions, and willingness to ignore the sign 'Do not trespass on my territory'—all these belong to heuristics. Among such qualities, arrogance, deadliest enemy of fruitful thinking, is conspicuously absent. Arrogance closes the gate to the contemplation of new possibilities, and over-values those the thinker is already familiar with. The creative man does not maintain a seraglio of ideas where he seeks solace for his failing innovatory virility. Above all he is immunized against the syndrome first identified by Dante in his *Convivio* (*c.* 1308) and which should therefore be called 'Dante's Disease'. The chief symptom is a presumptuousness which makes the patient suppose that he knows everything and so he affirms uncertain things as certain; what he approves is true and everything else is false. The result is that he cannot learn. He believes he knows enough, never listens or asks questions, and insists that others should ask questions of him, but before a question is well out he gives the wrong answer.

The impasse now reached in computer simulation of mind can be attributed to the excessive zeal of those engaged in this work who try to run before they can crawl. There is no hope for a 'get-rich-quick' short-cut to success by by-passing psychology in simulation exercises which purport to play complex games, think productively, recognize patterns or translate from one language to another. Success will come when the simulators will find a place in their models for the true heuristical devices of the mind, the facilitators and generators, while excluding the inhibitors. But before they can do this they have to recognize these features in their own minds. Perhaps a hint could be taken from Emile Augier's dictum that 'the legs are the wheels of thought', and make all computers mobile. Or from Schiller, whose inspiration rested on a collection of rotten apples in his desk, and install a decaying fruit core memory!

The input which induces creative effort from a man's own inner resources is analogous to the electrical engineer's 'shot effect' which carries a minimum of information. Hence the act of creation has surprise value, both to the creator and to others, which may be of two kinds: 'How obvious! why did no one think of it before?' or 'How could such an idea occur to anyone!' Any work of art which conforms to Novalis' recipe for a poem—'conceived wholly in the unconscious and executed wholly in the conscious'—must carry with it some element of this surprise. Granted that we admire its quality, we assess the creativeness of a man's information output on the basis of its improbability in terms of the information input. The smaller the part played by the input and the bigger the part played by the individual as transducer, the more creative we regard the output. In the limit—when the input is zero, achieved only by the gods—we have *creatio ex nihilo.*

Nonobody's mathematical bio-pianolas

Stefan Themerson

'Do we want the machine to produce its own, new, unknown to us, basic notions, the ones that cannot be derived from ours? If we do, let us see what we must give it to enable it to produce them.' (*Themerson*)

This is part of a novel, *Professor Mmaa's Lecture*, written in 1940–42, in France. Some fragments of it were published in London in 1945 and in volume form it appeared in 1953. The passage about 'noses' was not included in the volume because, owing to some specific sensitivities of the times, it was thought that what was meant to be sardonic would look sordid. Today, Nonobody, the termite scientist, would probably be noticing and analysing not so much the homos' preoccupation with the shapes of their probosces as the hullabaloo they make about the absorption of light by their epidermis. Whether, by doing so, he will miss the point about homo, or, on the contrary, hit the nail on the head, is very difficult to say. And, alas, it is rather doubtful whether his use of his mathematical bio-pianolas (and Dr Good's use of his ultra-intelligent machines)[1] can help him (and us) to answer the question.

Nonobody counted. First he counted up to 6, then up to 36, then to 216, to 1296, to 6 times 1296. To do exercises in addition and subtraction, multiplication and division, was a pupa's affair. If you want to multiply 128 by 2, you strike your middle feeler c and change the length of your vibrissa until you hear an octave; you read the frequency of the vibrissa and you've got your answer: $c' = 256$. To multiply by 3, you change the length of your vibrissa until you hear a duodecima and there is your answer: gis' or 384. If you wish to divide, for instance $\frac{15}{4}$ by $\frac{8}{3}$, you tune your feelers to the low H and F, you listen and you hear that there is a 3 notes interval; so now you strike your vibrissa 3 notes distant from frequency 1, and you hear your answer which is $\mathit{Fis} = \frac{45}{32}$.

All that is not so difficult if one's audibility is acute, if one can, as Nonobody could, tell 7776 from 7777 just by listening to these two frequencies. And so he went on, doing a few exercises in raising numbers to various powers and finding the roots, as well as in running over a few chromatic scales and a couple of passages of arithmetical and geometrical progression, and a number of permutations and combinations which are so necessary in dealing with all problems of statistics (and is not the statistical treatment of the interactions of organisms as living wholes the base for the conversion of natural history into true science?).

After a pause at zero, he swiftly ran over the keyboard of the harmonic series to the upper limit, where he depressed the damper pedal to sustain the tone all through the long pierre-fermata of macro-infinity; then, returning, played a series of steadily quickening staccatos, in this simple fashion reaching the infinitesimal. Finally, striking at the polyphonic chords of matrices consisting of endless series of numbers, he selected those matrices which represented various states of one and the same homo, giving out or absorbing energy of various values, and made a few calculations on them in addition and multiplication.

Thus, having practised for some time on the great calculating bio-pianola—one of the greatest inventions of the age—he set to work to solve the homo problem that Professor Mmaa had given him.

Unfortunately, he at once came up against a very serious difficulty: how much is an egg worth for a nose-piercer if the nose-piercer is worth half of one Santa-Rè share for a pancaker?

He swiftly realized that a whole series of supplementary data was needed to work out this problem. So he surrounded himself with the fat abdomens of hebooks and shebooks entitled: *Political Economy, Sociology, Psychology of the Masses, Trade and Industry, Industry, Universal History, the Egyptian Dreambook, Nostradamus's News of the World, Who Is Who and Why*, and, flinging all this into the pianola, waited for the result.

The result exceeded his expectations. Instead of sounding politely in one single tone whose frequency would represent a definite number, the bio-pianola began to thunder and roar through an extraordinary fugue consisting of a thousand thousand voices, each of them representing one Santa-Rè share's value as a function of various circumstances.

Alarmed by this result, Nonobody began to throw more and more varied data into the bio-machine. But the consequence was that, instead of decreasing, the number of voices jumbled in that monstrous fugue increased more and more. Drowned in the flooding waves of sound, Nonobody lost

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[1] Irving John Good 'Speculations concerning the first ultra-intelligent machine', *Advances in Computers* vol. 6. New York: Academic Press, 1965.

control of himself and the pianola, began to dance in terror round and round the raging machine and, driven to despair, tried to appease her by stroking her multitudinous palpitating vibrissae, and at haphazard pulling out the stops of one register after another.

Just as he was in the midst of this uproar, Trumpet ran into the laboratory, groping all around him with feverish antennae.

'Ah, so it's you!' he shouted in astonishment, nosing out Nonobody. 'I would never have expected that!'

'What wouldn't you have expected?' Nonobody asked.

'Why, that I'd find you amusing yourself at the pianola.'

'I amusing myself?' Nonobody indignantly burst out.

'Well, and what of it? You don't pretend you're working, do you?'

Nonobody gave Trumpet a severe smell, waited in silence for a long moment, then said curtly:

'I'm calculating.'

'Calculating!' Trumpet broke into a peal of laughter and began to dance a scalp dance to the tempo of one of the voices coming from the polyphonically raging machine.

'That's not music for a scalp dance,' Nonobody shouted. 'It's the value that one Santa-Ré share acquires in relation to the humidity of the air in the place where it was issued.'

Trumpet stopped dancing the scalp dance, and began to dance a celebrated corroboree to the time of another voice coming from the polyphonically storming pianola.

'That isn't music for a corroboree!' Nonobody shouted again. 'It's the value that one Santa-Ré share acquires in relation to the humidity of the air in the place where it is to be sold.'

Trumpet stopped dancing the corroboree and, giving Nonobody an astonished smell, began to dance three dances at once. His forelegs danced a minuet, his middle legs danced a contre-danse, while his hind legs danced a waltz.

'It isn't music for a minuet or for a contre-danse or for a waltz!' Nonobody squealed. 'They're the values that one Santa-Ré share acquires in relation to the rate of wages, divided by the price of meat, bread and beer respectively, and multiplied by the temperature.'

But this time Trumpet took no notice of Nonobody's objection.

'I don't know what you're being so stupid for,' he said. 'Why, it's quite obviously the polyphonic association of three orchestras in Mozart's *Don Giovanni*.'

The very sound of the name of Mozart made some impression on Nonobody. And when Trumpet caught a new motif coming from the mathematical bio-pianola and began to dance a tango, Nonobody began to wonder whether the real crown of acoustic mathematics might not be some kind of ballet. 'If so, the scope of our knowledge, hitherto restricted by the possibilities of our associative substance, would be enlarged by the entire sphere of kinaesthetic movement.' Having noted this great idea, he turned to Trumpet and said, not without a touch of respect:

'One thing surprises me . . . How is it that . . . Please don't take offence—that with all the muscularity of your world outsmell you possess such great acoustic talent?'

'And one thing surprises me,' replied Trumpet, 'namely, how you, with your quite pleasant mug, can keep company with all that band of Mmaasites and the rest?' And he drew nearer to Nonobody, very diffidently attempting to rub his antennae against Nonobody's abdomen.

'The only explanation I can think of,' Nonobody continued, 'is that you are not polymorphically perfect, that you are a deviation from the type, one of those exceptions which sometimes determine the efflorescence and sometimes the decline of civilization.'

Trumpet moved still closer.

'There is much truth in what you say,' he replied. 'I would like to tell you something, but you must keep it a dead secret. Swear by the Deepest that you will not tell anyone.'

'No, I won't swear.'

'Then by the Shallowest.'

'If you ask me not to tell anyone, I shan't. But I shall not swear. That's on principle.'

Trumpet paused for a moment, then he whispered:

'Just imagine, I've got genitals. Real ones! Would you like to listen to them?'

'You don't say! Didn't you have yourself castrated?'

'The Deepest forbid! It's very pleasant to have genitals.'

'But how do you manage with them?'

'I purge them with music and dance. That's called catharsis, but it's very tiring.'

And, pressing against Nonobody more boldly, Trumpet asked:

'Wouldn't you like to join me in dancing a fox-trot . . . I mean the change of value that occurs in a Santa-Rê share in relation to something or other?'

'No!' Nonobody said resolutely. 'I don't dance.' But at the same moment he felt that the fox-trot floating from the mathematical pianola was provoking a queer shiver in his extremities. And he added:

'You forget that we're in mourning for the Queen.'

'Oh my! And I've got to be at the march past!' He touched Nonobody's antenna delicately yet firmly and ran out of the laboratory.

Nonobody's associative substance was in a whirl with new problems. He decided to set them out in order:

Nota Bene 1
a Mathematical bio-pianolas are growing more and more perplexingly multiplex. Can our associative substance be made to keep pace with this growth? If so, how—(*a*) by performing some polymorphic deformations of our innate characteristics, or (*b*) by the educational gymnastics of our acquired characteristics?
b If it proves to be correct that the dance, being a superstructure of sound curves, may give a picture of the problems put into a calculating bio-pianola, can one regard a fox-trot danced with Trumpet, for instance, as a solution of a mathematical problem, if the kinetic motor of a fox-trot is not associative substance but the genitals?
c If so, wouldn't the development of genitals be necessary to the development of science?
d If so, wouldn't there be a danger of one of the arts (namely, choreography) becoming a higher form of knowledge? (Elaborate: why exactly should it be dangerous?)

Nota Bene 2
a Why did Professor Mmaa pay homage to the Queen when there was no one but myself to hear him?
b Why did the hebook from Professor Mmaa's library call me 'Miss' when he came into the Hall in search for the Old Mamma?

Nota Bene 3.
On occasion calculate 3 × 2 again.

Nota Bene 4.
Is it possible that I have in me 'something of an Infanta'?

He erased the last note, and made another Nota Bene 4:

Nota Bene 4.
On the problem Professor Mmaa set me: if I fail to finish it before he arrives for his next lecture, what is the likelihood that some miracle, such as an earthquake, may take place before and not after he demands to hear the results? (Note: if it happened after, then it would not be a miracle at all.)

His cheek twitched nervously. Up till now he had been pretty certain that there was no problem in existence that his, Nonobody's, intelligence couldn't solve, if it only really wanted to. How was it that he now felt he might fail? Perhaps he didn't really want to enough? Perhaps he preferred miracles? Once more he tried to repeat the text of the problem he had been given to solve:

'make yourself familiar with . . ., and taking into account that . . ., find out what . . ., and having thus found out what . . .,—calculate what quantities of what qualities would form such traits in a zooid that it would be denied the right to influence the said civilization,—if the reproduction of kind in the homo . . .'

Suddenly his cheek stopped twitching, all his antennae—long, medium and short—entwisted into one single plait; furiously he began to throw all that pupish Santa-Rê business out of the pianola. Now he *knew*. With the help of his fore-legs he unravelled his antennae, tore a piece of fresh bio-tissue from his exercise-book, trimmed its edges, and started to work. Systematically. Beginning with the title:

The quantitative method of measuring the right of any individual to influence a particular civilization
by Periclase Nonobody

There is a steadily growing number of people who hold that the moral and social influence of certain persons or of certain groups

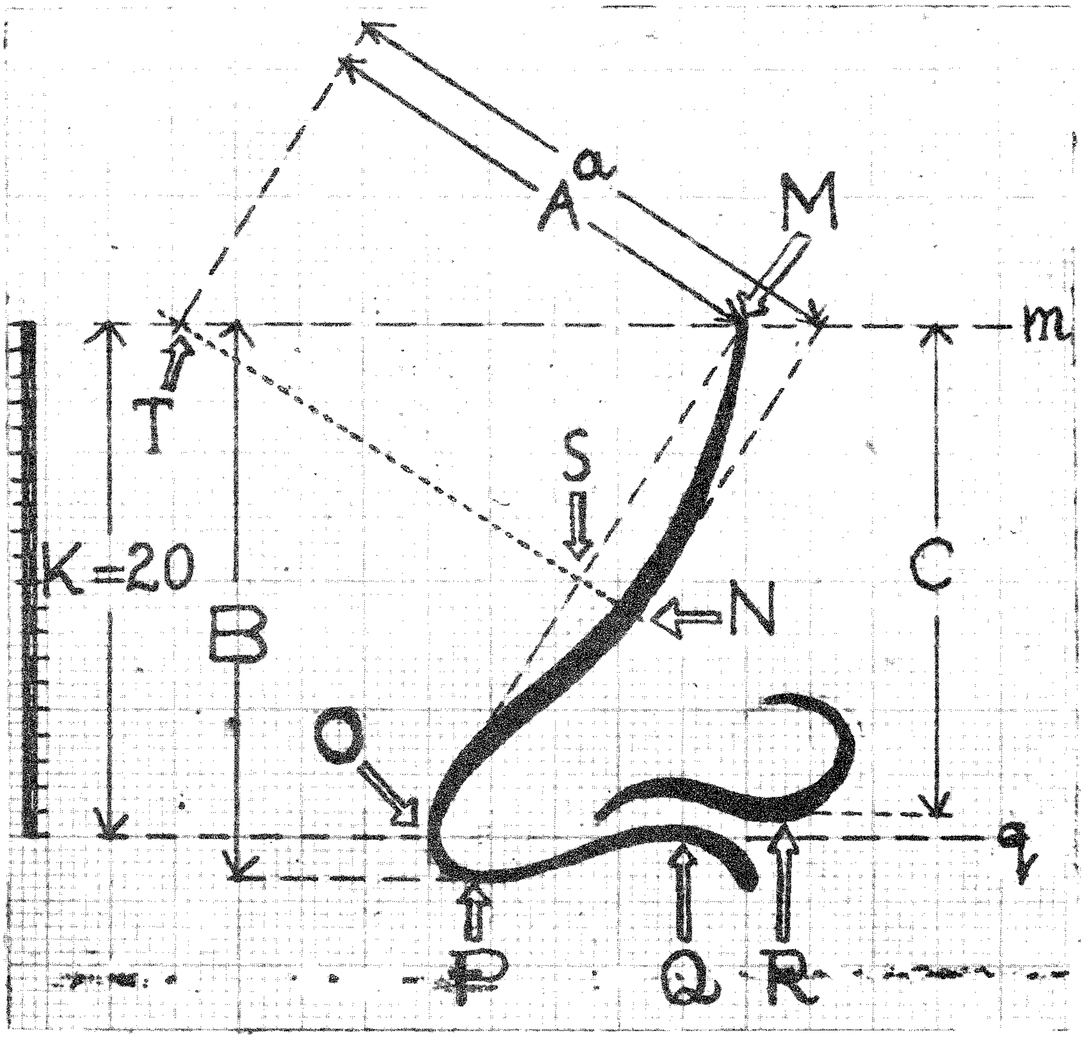
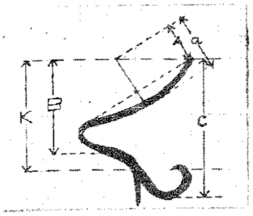


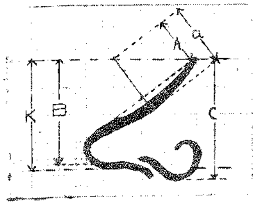
Fig. 11

of certain persons in a particular civilization is pernicious, and who therefore aim at counteracting and destroying it. In realizing these principles, they have up to now been hindered by the lack of a clear standard against which to measure the objects of their investigations. And it is only the present author who has given the idea such a truly scientific form that, from now henceforth, it will be possible to practise it in everyday life, both public and private. In order to find out whether a specimen (*X*) has or has not the right to influence a particular civilization, we have to take the said specimen's external organ of smell and mark on it 6 points annotated by the letters *M*, *N*, *O*, *P*, *Q*, *R* (fig. 11). Through the points *M* and *Q* we trace 2 parallel horizontal lines which we annotate by the letters *m* and *q* respectively. The distance between them will give us the quantity *K* which, after having been divided into 20 equal sections, serves us as a scale for further mensuration. Let us then connect the point *M* with the point *O*, and thus obtain the straight line *MO*, from the middle (*S*) of which let us trace a perpendicular to *MO*, which perpendicular crosses the line *m* in a point which we call *T*. Let us call *A* the length of this perpendicular (*ST*), and let us call *a* the distance between the point *N* and the point where the said perpendicular crosses the straight line *m* (or the section *NT*). Now, let the distance between the point *R* and the straight line *m* be called *C*. With the help of the scale *K* (always = 20), we now measure the sections: *A*, *a*, *B*, *C*, and employ the following Golden Formula that has been worked out by the present author:



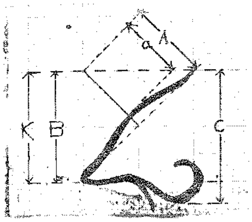
K=20, A=7, a=10, B=17, C=25

$$\Psi = \frac{2 \cdot 10 \cdot 25^2 \cdot 20}{7 \cdot 17^2 (17 + 25)} = 2.94$$



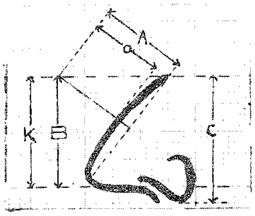
K=20, A=8, a=11, B=19, C=22

$$\Psi = \frac{2 \cdot 11 \cdot 22^2 \cdot 20}{8 \cdot 19^2 (19 + 22)} = 1.80$$



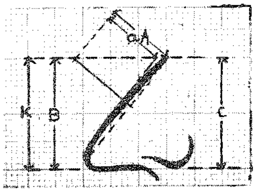
K=20, A=14, a=12, B=20, C=24

$$\Psi = \frac{2 \cdot 12 \cdot 24^2 \cdot 20}{14 \cdot 20^2 (20 + 24)} = 1.12$$



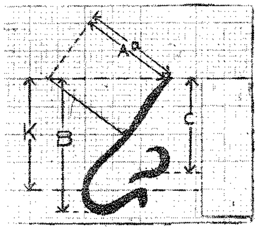
K=20, A=16, a=14, B=20, C=23

$$\Psi = \frac{2 \cdot 14 \cdot 23^2 \cdot 20}{16 \cdot 20^2 (20 + 23)} = 1.07$$



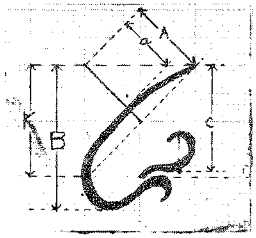
K=20, A=13, a=12, B=20, C=20

$$\Psi = \frac{2 \cdot 12 \cdot 20^2 \cdot 20}{13 \cdot 20^2 (20 + 20)} = 0.92$$



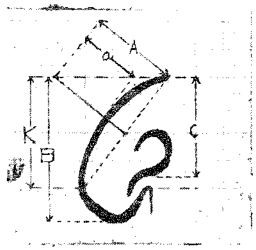
K=20, A=17, a=18, B=24, C=17

$$\Psi = \frac{2 \cdot 18 \cdot 17^2 \cdot 20}{17 \cdot 24^2 (24 + 17)} = 0.52$$



K=20, A=14, a=11, B=26, C=19

$$\Psi = \frac{2 \cdot 11 \cdot 19^2 \cdot 20}{14 \cdot 26^2 (26 + 19)} = 0.36$$



K=20, A=16, a=11, B=26, C=18

$$\Psi = \frac{2 \cdot 11 \cdot 18^2 \cdot 20}{16 \cdot 26^2 (26 + 18)} = 0.30$$

Fig. 12

Neu!!! $\Psi = \dfrac{2\,a\,C^2\,K}{A\,B^2\,(B + C)}$ Neu!!!

!!! Die interessanteste erfindung der Neuzeit!!!

A specimen *has* the right to influence a civilization if his

$$\Psi > 1$$

and that right rises in accordance with the increase of the value for his Ψ (fig. 12).

A specimen has not the right to influence a civilization if his

$$\Psi < 1$$

and this lack of right persists through all decreasing values for his Ψ.

As to the borderline case:

$$\Psi = 1$$

(with the approximation ± 8%, i.e. from $= \Psi 0{\cdot}92$ to $= \Psi 1{\cdot}08$) it gives us a picture of an intermediate individual, very difficult to define and classify, and thus undoubtedly doubly dangerous in a normally functioning society.

We are convinced that our 'quantitative method' should oust the unscientific, dilettante qualitative methods, and that it should be put into practice in parliaments and all social institutions.

Now, by the Shallowest of Beings, a vote of somebody who has on his face a

$$\Psi = 0{\cdot}36$$

cannot be equal to a vote of somebody who has on his face a

$$\Psi = 2{\cdot}94$$

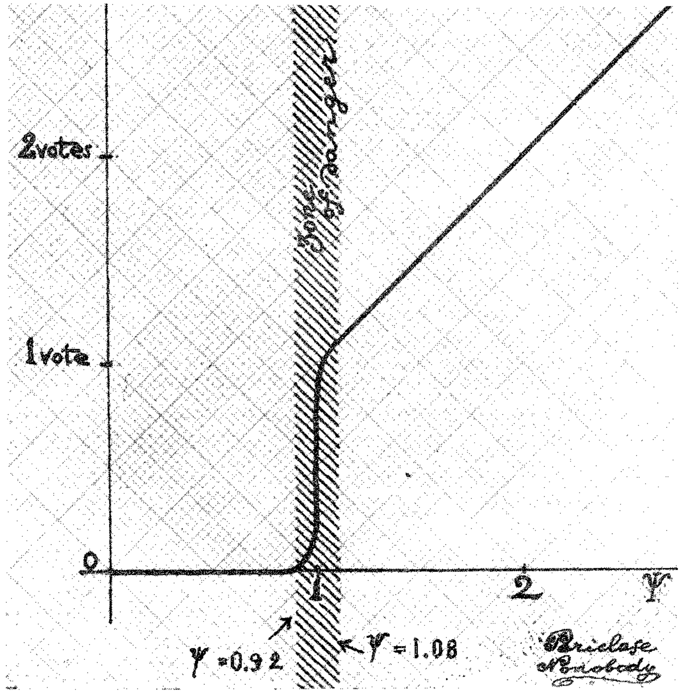


Fig. 13

Postscript 1968

Mystics apart, to grasp a truth, we must have a set of tools to grasp it with. We call these tools 'notions'. Sets of notions are neither fixed once for all, nor do they ever seem to be complete. Especially, what we call 'basic notions'. They are invariably the basic notions of the time. In our case, of our time. How can we know that those we have in hand are sufficient to grasp a truth? If it were so, if our difficulty concerned only the art of manipulating them, then Dr Good's ultra-intelligent machine[1] would help us to grasp a truth. But what if it is not so? What if the set of notions we possess (and can endow the machine with) does not suffice? Do we want the machine to produce its own, new, unknown to us, basic notions, the ones that cannot be derived from ours? If we do, let us see what we must give it, to enable it to produce them.

For practical reasons, I shall call here 'notions' what is abstracted and/or derives from named experiences. To name an experience, one must first have it. And to have it, even a poet or a philosopher must have something to have it with; an eye and a hand, an ear and a leg. Thus, if the machine is to have its own experiences (in order to name them and have something to derive new notions from) it must have both sensorium and motorium. Dr Good says that his ultra-intelligent machine would have both, that 'it would be based on a kind of simulation of a neural network, and should think in a somewhat similar manner to that of people, but much better and faster'[2]—and that in it 'an assembly for a word would also have sub-assemblies shared with non-linguistic assemblies, such as those representing the taste of milk, and, more generally, representing experiences of the senses, especially of the nine apertures, where the density of neurons is high for evolutionary reasons.'[3] When he says 'evolutionary reasons', he refers, of course, to human evolution: two legs, nine apertures, etc. But how do we know that to produce notions necessary for grasping a truth, Good's machine shouldn't possess Nonobody's six legs, three pairs of antennae and I'm-not-quite-sure-how-many apertures?

An ultra-intelligent machine either can or cannot produce new basic notions. If it cannot—this is the end of the story (so far as rational discussion is concerned).[4] If it can—shall we be able to understand them? If yes—fine (though: how? if we haven't had its experiences to refer the new notions to). But if not, well, if not, then, in fact, what we have created with our own head and our own hands is a god, a god who is going to rule.

It may be said that if the divine machine is really ultra-intelligent then we should welcome being ruled by it rather than by politicians. Something similar used to be said of our other gods and goddesses. There is, however, at least one difference: while the alienation (being ordered about by one's own creation) of our old gods was a historical fact (and, with some qualifications, a physical event), the alienation of our new, divine, ultra-intelligent machine may become a logical necessity. Because, as our intelligence cannot surpass itself, once the machine has arrived at a level of intelligence higher than ours, we cannot instruct it any further: if our instruction were a part of the machine's own schemes, it would be superfluous; if it were different, it would either restrict or possibly misdirect the machine's divine work.

And to let the machine go the whole hog? Oh dear! Without knowing at what conclusion it may arrive? It may arrive, for instance, at the not unlikely conclusion that, after all, all this bloody business of life is sheer nonsense and the only logical and intelligent answer to it is extinction. There is, of course, no reason for not accepting that sort of solution, except that we would rather not. But the machine may find this argument insufficient.

One can say that though we should not tell the machine what to do (in order not to restrict its ultra-intelligence), we may still tell it what not to do; we may tell it, for instance:

'Please, any solution, except extinction.'

I already hear it answer:

'Extinction of whom?'

'Extinction of men!' we exclaim.

---

[1] *Op. cit.*

[2] Private communication, 27 July 1966.

[3] Irving John Good 'Speculations concerning the first ultra-intelligent machine', *Advances in Computers* vol. 6. New York: Academic Press, 1965.

[4] This is the end of the story so far as rational discussion is concerned. Otherwise, it is only the beginning. The question will arise: who is going to decide which notions are basic and to be given to the machine to impregnate it—Dr Good or Ian Smith? In practice, where it is a question not of truths but of goals, and *a priori* arguments, and interests, it is not mathematicians who decide but club-men. Be they from Pentagon, Pentateuch or Penclub.

'Be more precise,' it says. 'Give me the definition.'[1]

Now we must watch our step.

If we say: 'except featherless bipeds', it may produce some featherless peacocks and save them, and not us. And if we say: 'intelligent beings'—it may save Nonobody, or itself.

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[1] What we mean by a man? Dr Good says (private communication, 27 July 1966) that his ultra-intelligent machine which, 'by definition, can do every intellectual activity better than any man', will, in particular, 'have no difficulty in understanding what we mean by a man'. But do we know what we mean by a man? Recently (14 March 1968) in the Court of Appeal, His Lordship remembered Lord Donovan saying: 'What is a human being, by reference to his essential characteristics? He has a head, body and legs. That is a human being. But you would not say that a monkey who has those essential characteristics was a human being.' Some time ago, I tried to discuss the subject in a little essay ('factor T', London: Gaberbocchus Press 1956, pp. 24–28) where I gave a few pages of reasons for calling 'Man' anything (a beast, a plant, or a machine) whose nervous system is split into two parts so that the one part prompts it to perform actions leading to the satisfaction of its primary needs, while the other part restrains it from performing such actions, whenever they are (as they invariably are) to the detriment of other organisms—thus producing an 'anti-cybernetic' neural tension, which results in its building Gothic cathedrals, Chinese pagodas, houses of parliament, bull-rings, Royal Societies, revolutions, counter-revolutions, heavenly kingdoms, Stratfords-on-Avon, in short, anything uneatable and uninhabitable—and proposed not to call 'Man' things (whatever their anatomy) whose nervous system, ('cybernetically'?) free of the split, allows them to practise without hesitation, the necessary pillage in the woods of the world. For a philosopher, of course, it will not be impossible to find arguments showing that what I've just said can be reduced to a statement that Dr Good, Nonobody, some machines, and people I like, are men; and vipers, weasels, some other machines and people I don't like, are not. I agree that this conclusion couldn't sound as cynical as it does, if it didn't contain both a grain of truth and a grain of falsehood.

A chance for art

J. R. Pierce

'It would seem odd if mathematics had nothing to contribute to the arts, and yet I think that its contribution has been small.' (Pierce)

These chapters from *Astounding Science Fiction* were originally published under the name of J. J. Coupling. When J. R. Pierce was asked why he chose this particular pseudonym, he replied: 'J. J. Coupling is a type of coupling within an atom—a term familiar to physicists. It was also the name of the secretary of the Institute for Useless Research, founded many years ago at Massachusetts Institute of Technology by William Shockley (now Nobel Laureate), J. B. Fisk (now president of the Bell Telephone Laboratories), and others. That's where I picked the name up. Isaac Neutron was president of the IUR.'

Chance remarks (October 1949)

There has been a lot in the papers about cybernetics and the theory of communications recently. As usual, *Astounding Science Fiction* was ahead of all others—back at least as far as 1943 and Raymond F. Jones' story *Fifty Million Monkeys*. You may remember the 'semantic analyser' which selected meaningful words from random letters. Now something very like that has appeared in the most respectable sort of print.

It was a long and indirect route if any which led from Jones' story to an authoritative publication, *A Mathematical Theory of Communication*, by Dr C. E. Shannon. Dr Shannon, who is now at the Bell Telephone Laboratories, is a product of the Massachusetts Institute of Technology and of the Institute for Advanced Study at Princeton. His accomplishments include the application of Boolean algebra—a symbolic logic—to the problem of telephone switching. His new work, which won him the Morris Liebman Memorial Prize of the Institute of Radio Engineers, is a fine exercise in multidimensional geometry and probability theory.

The whole field that Dr Shannon covers is important, but it is so broad as to make a simple explanation exceedingly difficult. Too, much of the material, while of great technical importance, may seem to have little interest for any one but an expert. But part I section 2 of the paper, 'The discrete source of information', deals with something which is right up the science-fiction alley. That is, the statistical structure of written English.

It is immediately clear that English text is in some way set aside from mere combinations of letters. Subjectively, one easily tells whether text is English or whether it is not. There is, however, an objective distinction.

Dr Shannon describes this by saying that written English is redundant. That is, more symbols are used than are needed to convey the information. Now, what is important is that the excess symbols are introduced according to certain rules, which a mathematician calls statistical laws or probabilities. For instance, *q* is always followed by *u*. Most of the rules are not this simple. However, a writer in mid-word or in mid-sentence does not—ordinarily—exercise complete freedom of choice in setting down the next letter or word. The choice of some letters or words is completely ruled out, or, such choices have zero probability. Among the letters or words allowed, some are more probable than others. For instance, because of our unconscious knowledge of such statistical rules, or of certain specific instances of them, we can correctly reconstruct most text—the reader can easily verify this—even if many of the individual letters have been erased or struck out. When we cannot, as in the case of some passages from Gertrude Stein or James Joyce, it is because there is something objectively un-English about the original text. That is, the text doesn't follow the rules. Granted conventional English text as a source from which to draw statistical rules, it is theoretically possible to tell English text from un-English sequences of symbols by applying statistical tests.

Dr Shannon's work has led him to believe that English is about fifty per cent redundant, that is, that one has about half as much freedom of choice as if symbols could be chosen with complete freedom. This is no trivial observation, for it has all sorts of implications. For instance, this degree of redundancy makes it just possible to construct crossword puzzles. If there were no redundancy, any arbitrary combination of letters would be a word. Thus, any set of letters could be read up or down as well as crosswise, and backward, too. There would be no puzzle to crosswords. If the redundancy were much greater than fifty per cent, there would be so little freedom of choice in the sequence of letters that it would be impossible to achieve a crossword pattern.

The degree of redundancy of English allows the construction of crossword patterns with some difficulty, and makes the language almost ideal for crossword puzzles. Conceivably, crossword puzzles could not succeed in some countries because the structure of the language would make them virtually impossible.

To the mathematician a language is a 'stochastic[1] (i.e. a statistical) process which generates a discrete sequence of symbols from a finite set'. These symbols are the letters of the language, together with punctuation and spaces, if these occur. The stochastic process chooses these symbols in accordance with certain probabilities which involve the sequence of symbols already chosen. Thus, if part of a word or a sentence has been written down, the probability, as evaluated from ordinary English text, that the next letter will be *a* may be very high, while the probability that the next letter will be *e* may be very low, and these probabilities will depend on the preceding letters and the order in which they occur—that is, on what has already been written down.

If the statistics of the language were completely known, it would be possible—again in theory—to evaluate exactly the saving which could be made in transmitting English text. It would also be possible to do other things of which we shall have a hint later. Of course, a knowledge of the whole statistical structure of a language is an unattainable ideal, but one need not for this reason forgo all knowledge. Indeed, Dr Shannon has done a little preliminary exploration himself in a surprisingly simple and a rather interesting manner.

We already know from work on cryptography, and can obtain from other sources, a small part of the statistical laws of English text. Now, suppose we choose symbols—letters—by a chance process incorporating the rules which we know and see how nearly the result resembles English. This will give us some clue as to the relative importance of the part of the statistical rules which we know and employ, and the unknown part of the statistics of the language.

Dr Shannon gives first an exceedingly simple example:

XFMOL RXKHRJFFJUM ZLPWCFWKCYJ FFJEYVKCQ SGXYD QPAAMKBZAACIBZL HJQD

Here the letters and spaces are successively drawn at random with equal probabilities for all symbols. Here, for instance, *x* and *z* are as common as *e* and *a*, which they certainly are not in English text. The combinations are un-English, unpronounceable and uninteresting. Mathematically, we say that the statistics are incorrect.

OCRO HLI NMIELWIS EU LL NBNESBYA TH EEI ALHENTTPA OOBTTVANAH BRL

Here letters were chosen, still independently, but with regard for their probabilities in English. If they were chosen from a hat, there would be more *e*'s in the hat than *z*'s, for instance. There is still, however, no rule connecting pairs of letters; there is no rule saying that *u* is the only letter which has any probability at all of following *q*. Still, some of the statistics of English have been taken into account, and the result is surprisingly more like Enr=is than the first sample. The letters do occasionally form word-like combinations. Although it is not in the dictionary, OCRO is pronounceable. It is interesting to think of OCRO as a nonsense word, and to wonder who invented it. It was really begotten, although through a human agency, by an undistinguished copy of a book of random numbers. A machine following the rules could as easily have arrived at the combination.

ON IE ANTSOUTINYS ARE T INCTORE ST BE S DEAMY ACHIN D ILONASICE TUCOOWE AT TEASONARE FUSO TIZIN ANDY TOBE SEACE CTISBE

This has some intriguing features. Here more of the statistics of English were observed, and each letter or space was chosen in accordance with its probability of following that preceding. If *q* had occurred in the example, it could have been followed only by *u*. This has resulted in combinations of symbols which strongly resemble English. ARE is a real word. INCTORE and ILONASIVE are not words, but they are very wordlike. DEAMY almost suggests meaning, and is perhaps worthy of remembrance. One begins to wonder if Dr Shannon's work has some literary significance. Can senseless statistics perhaps add to our vocabulary?

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[1] Stochastic, not aleatory, is the proper translation of this sense of the French *aléatoire*.

IN NO IST LAT WHEY CRATICT FROURE BIRS GROCID
PONDENOME OF DEMONSTURES OF THE REPTAGIN IS
REGOACTIONA OF CRE

To an unprejudiced reader, this is not only largely pronounceable, but it sounds like talk, and English talk more than anything else—it contains seven English words. Or, if you wish, the passage sounds like double talk. It is perhaps difficult to believe that in constructing this passage there was no conscious effort to make English-like combinations. The procedure of construction was, however, purely automatic; each letter was chosen in accordance with the probability of its following the ordered pair of letters preceding it.

It must be understood that, because of the increasingly elaborate statistics involved, these passages were increasingly difficult to construct. A complicated machine could do more, but without one it seemed impractical to go further, and to base a letter on a preceding ordered triplet of letters. We can, however, see where the process would lead. If we added letters according to rules involving three, four, five and more preceding letters, we would gradually rule out as of zero probability all combinations which do not appear as words in the dictionary. We might as well, indeed, use words as our basis of choice, and Dr Shannon has tried this, too. As a first example he chose words merely on the basis of their probability of appearing in English text:

REPRESENTING AND SPEEDILY IS AN GOOD APT
OR COME CAN DIFFERENT NATURAL HERE HE THE A
IN CAME THE TO OF TO EXPERT GRAY COME CAN
DIFFERENT NATURAL TO FURNISHES THE LINE
MESSAGE HAD BE THESE

This seems rather a retrogression. The statistics are unduly simple, for they provide no connexion between words. With a great deal of effort, Dr Shannon was able to provide such a connexion, however. In obtaining the following passage, a pair of words was chosen at random in a novel. The novel was then read through until the second of these words was encountered again, and the word following it was inserted. Then that new word was sought out in a new context, and the word following it there was added, and so on. This laborious process evoked:

THE HEAD AND IN FRONTAL ATTACK ON AN ENGLISH
WRITER THAT THE CHARACTER OF THIS POINT IS
THEREFORE ANOTHER METHOD FOR THE LETTERS
THAT THE TIME OF WHO EVER TOLD THE PROBLEM
FOR AN UNEXPECTED

Here we have merely an example of words chosen randomly according to certain statistics. We may, however, have a strange feeling that we have seen something like this before. Certain passages in *Ulysses* and *Finnegan's Wake* are scarcely more intelligible. Despite an apparent lack of connexion, the passage has some subjective interest. I have a sympathetic concern for the predicament of the English writer. I would like to ask the author more about him. Unfortunately, there is no author to ask. I shall hear no more unless, perhaps, chance should answer my questions. One wonders if Dr Shannon's work has philosophical implications.

Dr Shannon stops at this point. The idea of pursuing the matter further is, however, tempting. By taking into account more and more statistics in the choice of letters, all letter combinations but English words could be ruled out. Can we, by the use of a more elaborate statistical choice of words, rule out all word combinations which don't make sense? At least, we could construct something better organized than the last example.

Suppose, for instance, that a word were chosen in accordance with its probability of following the preceding three words. Although this might seem unduly difficult, a trick will overcome all obstacles. English and its statistics reside in the human brain and they can be tapped at the source. One has only to show a list of the latest three words of a passage to a person unfamiliar with those preceding and ask him to make up a sentence including these three words and to write down the word which, in that sentence, follows the three. The statistics linking four word combinations are automatically evoked in this process. The word chosen *can* and *is likely to* follow the three. There is, however, a chance element in the choice. The word chosen is not determined by the preceding three words, for different people, or the same person at different times, would choose a different word.

In following this procedure we can also, without added difficulty, include punctuation and capitalization. This further lends naturalness to the result.

Starting with the words, 'When the morning', I obtained from twenty-one acquaintances: 'When the morning broke after an orgy of abandon he said her head shook quickly vertically aligned in a sequence of words follows what'.

This begins well, and the eighteen words following the initial three have a clear meaning. Afterwards there is a wandering of the mind as in some cases of schizophrenia.[1] But whose is the meaning, and whose mind wanders? We must admit that the meaning exists only in the mind of the reader. Each of the twenty-one writers knew only four words, and each thought of them in a different context. There was no 'meaning' until someone read the completed passage. And there was no wandering of the mind, but only failure of such short-range statistics as were taken into account to hold the text together over many words. The words are connected to those immediately preceding them, but have no connexion with those further ahead. I think, however, that it is the seeming sense of the passage and not its long-range incoherence that is astounding. And, it is a little disturbing to think that an elaborate machine, taking longer-range statistics into account, would have done still better. The passage seems to us to have meaning, and yet the true and only source of this quotation is a small part of the statistics of the English language—and chance.

Presumably, written English is coherent over long stretches, when it is, because of some overriding purpose in the writer's mind. Or, is it coherent because the writer is unconsciously constructing his text to obey certain long-range statistical rules? And, we wonder, how many times does a person let his pen or tongue, started by some initial impetus, merely run through a sequence of probable words?

This sort of investigation became interesting for its own sake. A couple of hours spent in a conference room with two mathematicians and two engineers produced a half a dozen curious forty-word bits. It is scarcely worthwhile to quote the whole of these, but some selected sentences may be of interest:

'When cooked asparagus has a delicious flavour suggesting apples.'
'No man should judge his actions by his wife Susie.'
'It happened one frosty look of trees waving gracefully against the wall.'

We see that the statistics involved are sufficient to give 'meaning' frequently, but are scarcely adequate to insure 'truth'. But, if we mean by truth merely that which we are likely to find written in encyclopaedias, statistics could, presumably, supply it, too. With the statistics which we have included, however, any merit of such compositions is more apt to be aesthetic than factual. The last sentence has, for instance, a rather pleasing twisting effect which might have escaped a conscious artist.

We are reminded that philosophers have argued for years about how much of art lies in the work of the artist and how much lies in the observer. I do not know whether or not Dr Shannon had anything of this in mind, but these consequences of his work certainly have an interesting bearing on the matter. Here there is no creator or 'artist'. The structure of the words is based merely on statistics, or, on the likelihood of their occurring in a certain order. Yet, they may have 'meaning' for the reader, and he may have an aesthetic appreciation of them.

The passages quoted above were rather disconnected. Our interest finally led us to try a drastic and unscientific experiment. If a lack of long-range connexion was the chief trouble with the text, we could remedy that. On the bottoms of the slips of paper on which we wrote the words, in plain sight of all, various subjects were indicated, among them 'salaries', 'murder story' and 'women'.

The statement on salaries is of interest for a certain partisanship:

'Money isn't everything. However, we need considerably more incentive to produce efficiently. On the other hand too little and too late to suggest a raise without reason for

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[1] I quote from K. Menninger's *The Human Mind*, third edition, p. 223. New York: Knopf. 1945.

'Have just been to supper. Did not knowing what the woodchuck sent me here. How when the blue blue blue on the said anyone can do it?'

remuneration obviously less than they need although they really are extremely meagre.'

The 'murder story' slip contained a passage which goes a little beyond the bloodiest and most disconnected of the genre:

'When I killed her I stabbed Paul between his powerful jaws clamped tightly together. Screaming loudly despite fatal consequences in the struggle for life began ebbing as he coughed hollowly spitting blood from his ears.'

It was on the final slip, 'women', that chance really spoke through clearly. The forty-two-word statement is succinct but not entirely quotable. The last sentence says a great deal:

'Some men repeat past mistakes again and again and again.'

Perhaps this adage appeared because it has so likely a connexion with any part of our lives, our scientific interests included.

Science for art's sake (November 1950)

It would seem odd if mathematics had nothing to contribute to the arts, and yet I think that its contribution has been small. Many mathematicians have constructed designs in the forms of well- or little-known mathematical curves. These are often pleasing but never very surprising. An eminent mathematician, Birkhoff, wrote a book on aesthetic measure.[1] To me personally the work seems doubtfully founded in that it looks rather at pieces of porcelain and scraps of paper than at the human beings who appreciate them. As far as creation goes we need not argue about the methods. The author gives an example to illustrate the application of the rules derived in writing a poem. We see at once that a second-rate poet is, as an artist, still far ahead of a very eminent mathematician. A later author, J. Schillinger, claims a share of the merit of *Porgy and Bess* for his mathematical system of composition. A sceptic might argue that a composer of genius can make good of anything at all. Certainly, when mathematics is used merely as a sort of guide or crutch, it is hard to apportion credit between the mathematics and the user.

Despite the record, one is inclined to believe that mathematics may be of some real use in connexion with the arts, and that it is perhaps through a combination of over-expectancy and misdirection that past users of mathematics have had such dubious success.

The matter of over-expectancy is, I think, very obvious. Scientists do not dash off books giving a world system of science after a few years of work, or even after many. The typical major contribution of the mathematician or physicist is a short paper presenting some new law or proof. Even though a law or theorem may be very general in its implications and applications, the implications and applications are commonly worked out over a good many years by a good many people. It is true that scientific books of great scope are written, but these include much which summarizes the sound work of others, and even these books of wide scope are exceedingly narrow compared, for instance, with a philosophical system, of aesthetics or of anything else.

On the contrary, those who wish to apply mathematics to aesthetics seem to feel that they must conquer much at once, and that they must defend to the death their conquests. A combination of attempted universality and solemnity sets a poor atmosphere for investigation.

One should be happy to achieve anything new through mathematics, however narrow the achievement may be. While great art may sometimes be solemn, there is also an art to escape and amusement. Is it too frivolous to suggest that one might enjoy mathematically produced doubletalk, even if he cannot have a mathematically produced *Paradise Lost*? The first aeroplane was none the less wonderful because it could not imitate the grace and endurance of a bird. The automobile is useful even though it cannot think nor climb a tree. I believe that the mathematical aesthetician must be content with what he can get and must not ask an infant science to duplicate the achievements of an old race.

This leads at once to the question of aim in applying mathematics to the arts. In the past, the machine has not duplicated the complex abilities of man even in any one narrow field, but rather has done a specific task better than man, or has done something beyond man's power. What,

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[1] T. D. Birkhoff, *Aesthetic Measure*. Cambridge, Mass.: Harvard University Press, 1933.

then, could be done by means of mathematics and, perhaps, modern computing machinery, that unaided man finds difficult or impossible? The most common answer is that mathematics can put a pattern into art. From this we have curves and sequences of numbers as a basis for design and music. But, perhaps mathematicians can best be used for quite the opposite purpose, that of taking some of the pattern out of art.

It is clear that one thing which human beings find it almost impossible to do is to behave unpredictably in the simple matters of life. One may, for instance, ask a man to produce a random sequence of digits. Statistical studies of such sequences have shown that they are anything but random; it is beyond human power to write down a sequence of numbers which are not in some manner weighted or connected. Tables of random numbers—there are such tables—must be made up by other means and with great care.

In the same way, it is easy to agree that a truly bad poet never, or almost never, writes a good line. One might think that a good line would appear occasionally by chance. The trouble is, chance has no chance to operate. The bad poet is simply too predictable. Cliché follows cliché; love rhymes with dove, and the narrow pattern is dreadfully monotonous. There is nothing new; there is no surprise.

It would be foolish to maintain that surprise is the only feature, or even a main feature of art, but it is an important feature, and it appears in many surprising places. We certainly are amused when Pepys speaks of 'my wife, poor wretch'. This may have had no element of surprise in the eighteenth century, but it has novelty for us. And it is certain that lack of surprise is a conspicuous element in much inferior art.

Now nothing is more surprising than the number produced by an honest throw of dice. However, the bare numbers turned up have no purely aesthetic interest. It is clear that something else must be added to mere surprise in order to produce anything with amusement value. A clue to what may be added lies in something I discussed in *Astounding Science Fiction* some time ago,[1] something which was based on work that has now appeared in book form as *The Mathematical Theory of Communication*, by Claude E. Shannon and Warren Weaver. This work shows how the missing element can be added to mere randomness.

We have, then, a way of making patterns of letters and words by chance, such patterns as can be aesthetically appreciated by the creative reader. The patterns resemble English words, in that they embody some of the statistics of English. Yet, they escape the more complete predictability of direct constructions of the human mind. In these words the predictable element is carefully, mathematically controlled, so that only so much, of such a kind, and neither more nor less enters into the process of construction. Just enough structure can be put in to give the words aesthetic value to the reader, while one can stop short of banality.

One may object that these results are meagre, and what else should they be at this stage? One may object that they are not new. Indeed, we are reminded of the word frame which the professor showed to Captain Lemuel Gulliver at the Grand Academy of Lagado. One can only admit that Swift had the general idea first, but that he may have been wrong in rejecting it summarily.

Some examples of stochastic English were given in *Chance Remarks*. For a full appreciation of his capacities for creative artistic enjoyment, the reader will need more, however, and some examples follow. If no title is given, none was written on the bottom of the slip:

1 This was the first. The second time it happened without his approval. Nevertheless it cannot be done. It could hardly have been the only living veteran of the foreign power had stated that never more could happen. Consequently, people seldom try it.

2 John now disported a fine new hat. I paid plenty for the food. When cooked asparagus has a delicious flavour suggesting apples. If anyone wants my wife or any other physicist would not believe my own eyes. I would believe my own word.

3 That was a relief whenever you let your mind go free who knows if that pork chop I took with my cup of tea after was quite good with the heat I couldn't smell anything off it I'm sure that queer looking man in the

4 I forget whether he went on and on. Finally he stipulated that this must stop immediately after this. The last time I saw him when she lived. It happened one frosty look of trees waving gracefully against the wall. You never can.

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[1] *Chance Remarks.*

5 McMillan's theorem
McMillan's theorem states that whenever electrons diffuse in vacua. Conversely impurities of a cathode. No substitution of variables in the equation relating these quantities. Functions relating hypergeometric series with confluent terms converging to limits uniformly expanding rationally to represent any function.

6 House cleaning
First empty the furniture of the master bedroom and bath. Toilets are to be washed after polishing doorknobs the rest of the room. Washing windows semiannually is to be taken by small aids such as husbands are prone to omit soap powder.

7 Epiminondas
Epiminondas was one who was powerful especially on land and sea. He was the leader of great fleet manoeuvres and open sea battles against Pelopidas but had been struck on the head during the Second Punic War because of the wreck of an armoured frigate.

I believe that few people will read this material without some interest or amusement. Is this not enough justification for calling it a contribution of mathematics to the arts?

While interest and enjoyment are clearly the contribution of the reader, the reader will be interested and will enjoy only if the text is both recognizable in part at least as possible sequences of words, and original. Thus, consider, 'It happened one frosty look of trees waving gracefully against the wall.' We realize that someone might say this, or, even, might want to say it. However, a person's habits are so strong as to make him unlikely to say it. Starting with the first three words, most people would have said something different and more common. The simple process by which the sentence was constructed has no such inhibitions. As a matter of fact, some people don't have many; madmen and great artists. In case the reader has not suspected it already, numbers 3 and 7 are not statistical English. Number 3 is from James Joyce's *Ulysses* and number 7 from the writings of a schizophrenic.

Perhaps the best means for further exploration is the application of similar means in a different field of art. In the field of visual art this has been anticipated by the kaleidoscope, which combines a random arrangement of coloured fragments into a six-fold geometric pattern—a simple example of much the sort of thing we have been considering. We may remember, too, that many years ago Marcel Duchamp allowed a number of threads to fall on pieces of cloth and then framed and preserved them. Our example shall be in the field of music.

In order to construct music by a stochastic process, a catalogue of allowed chords on roots 1–6 in the key of C was made. Actually, it was necessary to make a catalogue of root 1 chords only; the others could be derived. By the throwing of three especially made dice and by the use of a table of random numbers, one chord was chosen to follow another. The only rule of connexion was that two succeeding chords have a common tone in the same voice. Each composition consisted of eight measures of four quarter notes each. In order to give some pattern, measures 5 and 6 repeat measures 1 and 2. In addition, it was specified that chords 1, 16 and 32 have root 1 and that chords 15 and 31 have either root 4 or root 5.

Three statistical pieces were rapidly constructed according to these rules. Each took perhaps half a day. They are reproduced here so that the curious may play them (figs 14, 15 and 16).

I asked an experienced pianist to play these three for me several times. After a few repetitions, he came to add a certain amount of phrasing and expression which he felt natural. Thus, he made a *performer's* contribution to these works of art. Certainly one cannot object that he was violating the intentions of the composer.

What about the listener's contribution? In my case, I found the pieces a little meaningless at first, but after I had heard them several times and could recognize them they became more 'comprehensible'. Acting in the capacity of a music critic, I should say that they are pleasing rather than deep. They are less dull than poor hymns but are considerably inferior to Bach.

From their common characteristics the pieces are clearly products of the same composer. Some identifying features are that voices tend either to stick to one note repeatedly or to jump wildly. Too, many 'laws' of harmony—no parallel fifths, no doubling of the leading tone, and so on—are flagrantly ignored.

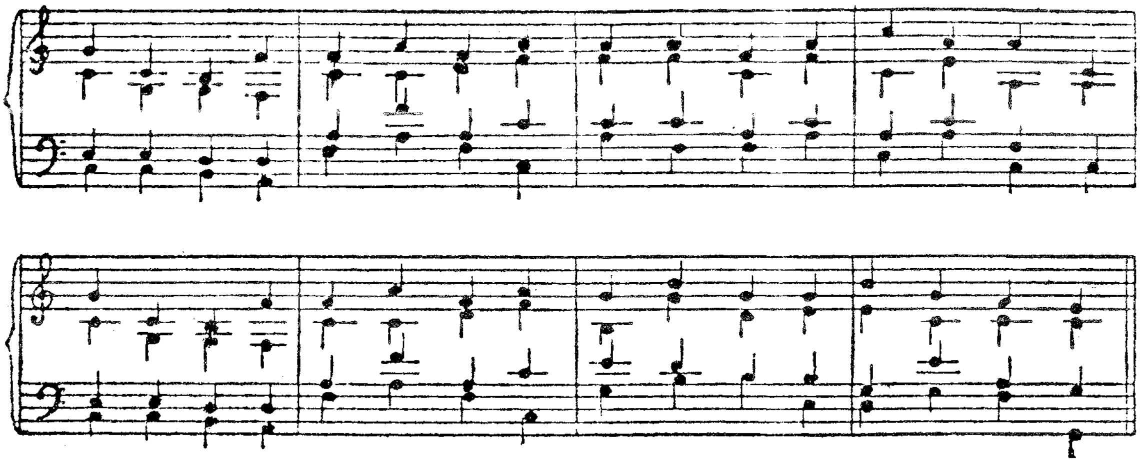


Fig. 14 *Random 1.*

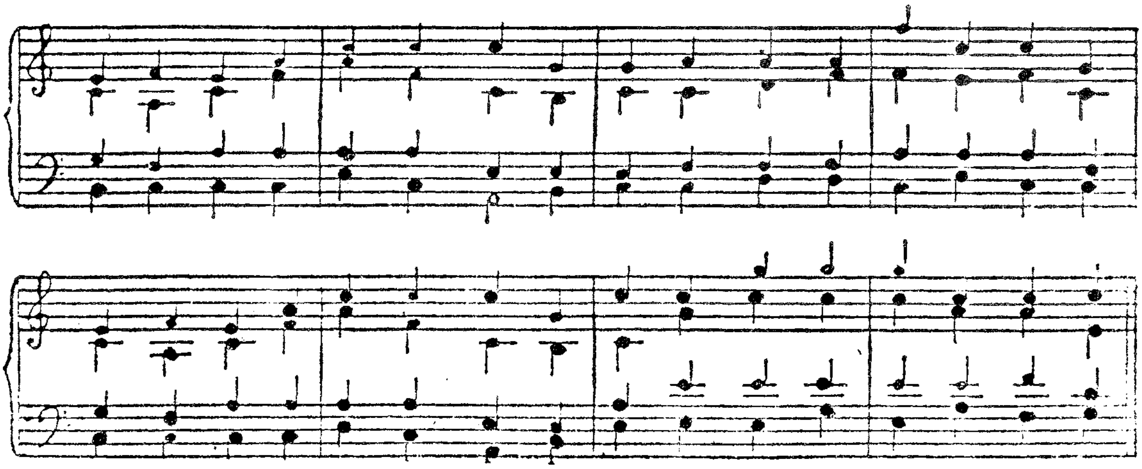
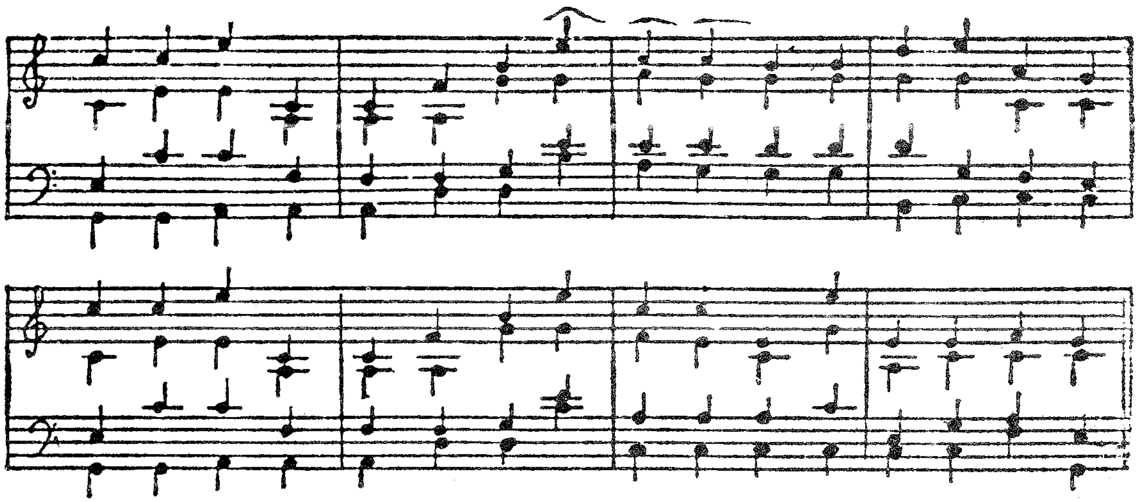
Fig. 15 *Random 2.*



Fig. 16 *Random 3.*

No doubt, by use of more complicated rules stochastic music could be produced which would violate fewer of the rules of harmony. But, would this result in a gain or a loss? If the process has value, does this value not in some degree come from a lack of prejudice and predictability? Statistical music should be urged towards respectability only with caution.

In this connexion it is quite possible that such statistical methods could be of use in trying out proposed systems of harmony. It is difficult for a musician easily to follow new rules; a statistical process is indifferent to whether the rules incorporated in it are old and well known or new and untried.

Returning to the examples of music given, one may object that the three pieces are unduly simple rhythmically and are too conventional harmonically. For the lover of modern music I have concocted a dissonant canon in the whole-tone scale (fig. 17). I will not describe the process of construction in detail, beyond saying that except for the last measure choices were made by repeatedly throwing one die. I won't say much for the canon beyond the fact that while the statistical structure is such as to give both cohesion and variety, the process of composition was quite simple. Artistically, it is perhaps a severe challenge to the listener's powers of creative appreciation.

How seriously is all this to be taken? I think that the crude material presented shows that short pieces of amusing and enjoyable text and music can be produced by processes which are essentially statistical in their character. The interest of this text and music is clearly dependent both on familiarity and on surprise. The processes could be refined. It is not beyond conjecture that a machine could write murder mysteries, for instance, each one a little different, at the punch of a button, with 'hard-boiled', 'sex', 'deduction', and other styles and features adjusted to the user's individual taste.

All this has, however, raised for me an issue beyond that of the stochastic generation of art. Apparently, if I try hard, I am capable of liking almost anything that is surprising if only it has some order or recognizable feature. Too, I am not entirely alone in this. I wonder, how much of the appreciation of some of the more drastic experiments in writing, music and painting is a combination of a knowledge of the artist's style and tricks and a determined effort to enjoy? How can one tell?

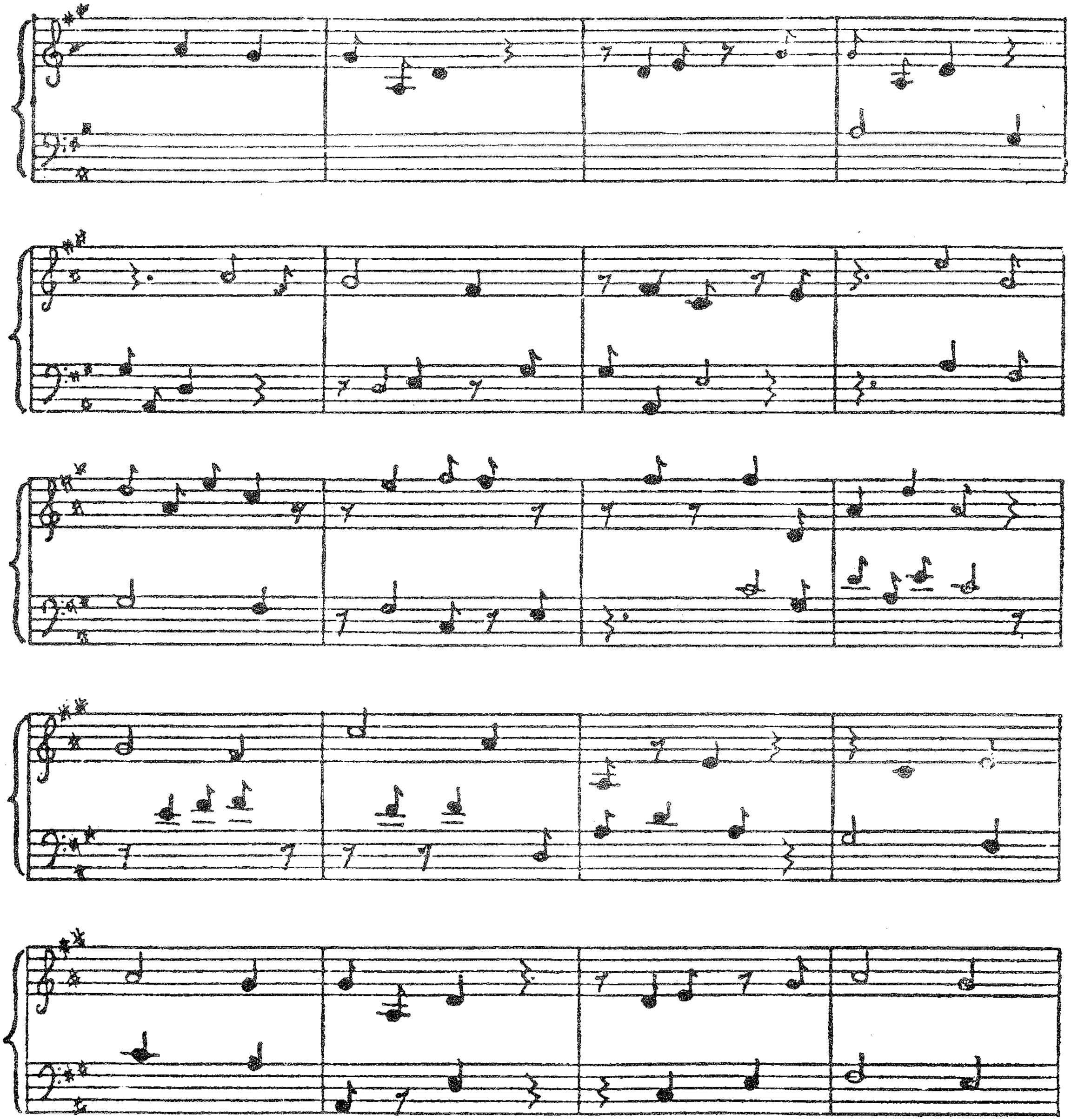



Fig. 17 *Canon*.

Washington dateline
Washington, 1 April 1950

Hitler's most deadly secret weapon, with which he hoped to the last to win the war, was revealed in Washington today by a Nazi scientist. The weapon is known to the Russians and may be in use in this country.

Dr Hagen Krankheit told reporters that he had smuggled the secret of the top Nazi weapon into this country. The weapon was known only to himself, two technicians who were executed before the fall of Berlin, Joseph Goebbels and the Fuehrer himself. Dr Krankheit gained access to this country after the war in the guise of a rocket engineer. Recently he has been threatened with expulsion as a dangerous alien.

The weapon, known as the Müllabfuhrwortmaschine, is a complex device for writing propaganda with great flexibility and subtlety. In appearance it much resembles a large digital computer such as the ENIAC or the MANIAC, Dr Krankheit said. A few key words and instructions are put in and the device automatically produces propaganda in limitless quantity, using all possible combinations and, unlike a human being, overlooking none.

A prominent scientist said that he believed such a machine to be possible, and that it had been partly anticipated in the work of Dr Norbert Wiener of the Massachusetts Institute of Technology and Dr Claude Shannon of the Bell Telephone Laboratories. He did not know of any such machine in this country, he said, but admitted that he did not read the papers.

Dr Krankheit said that the original primitive idea for the machine had been stolen from the Russians by espionage early in the Nazi régime. He insisted that the German machine was a Nazi development, but admitted that the Russians might be using a similar device. Dr Krankheit hinted that such a machine might be in operation in this country, but he refused to give particulars.

Although the original machine was of almost infinite complexity, the fundamental principle is simple. Dr Krankheit demonstrated this with three sets of cards. On one set of cards were written phrases called 'entities', on another phrases called 'operators' and on a third more 'entity' phrases. By shuffling each set of cards and dealing out one card from each, propaganda is produced.

Dr Krankheit demonstrated the cards by producing such statements as:

'Subversive elements were revealed to be related by marriage to a well-known columnist.'
'Capitalist warmonger is a weak link in atomic security.'
'Atomic scientist is said to be associated with certain religious and racial groups.'

The actual machine, Dr Krankheit revealed, could produce whole pages of propaganda suitable for immediate distribution. This was delivered either in printed form or directly as spoken words interspersed with martial and patriotic music. The machine could be adjusted to associate any group with various favourable or unfavourable groups or qualities in any desired degree. Dr Krankheit said that the problem of making the output reasonably connected had been solved only after immense labour, but had been made easier by the fact that propaganda does not have to make sense as long as it achieves its objective.

A committee spokesman scouted the idea that there is such a machine in use in this country. He commented in part: 'This is an effort by fellow-travellers to undermine confidence in the American way of life. We have evidence of a weak link in military security. Government laxness must be called to account. The FBI should investigate all subversive elements.'

A Russian spokesman indignantly denied that his country would use such a device. 'This is a capitalist warmongering plot,' he said. 'Russia stands for true democracy. The degraded and beastly tools of Wall Street will defeat themselves.' He added that the machine's true inventor was an as yet unnamed Russian scientist.

The projects of generative aesthetics

Max Bense

'The aim of generative aesthetics is the artificial production of probabilities of innovation or deviation from the norm.' (*Bense*)

Today we have not only mathematical logic and a mathematical linguistics, but also a gradually evolving mathematical aesthetics. It distinguishes between the 'material carrier' of a work of art and the 'aesthetic state' achieved by means of the carrier. The process is devoid of subjective interpretation and deals objectively with specific elements of the 'aesthetic state' or as one might say the specific elements of the 'aesthetic reality'. These elements are pre-established and their appearance, distribution and formation is described in mathematical terms. Thus this new aesthetics is simultaneously empirical and numerically orientated.

The elements involve not only material or sensuous qualities such as sounds, colours, tones but also meanings to be deduced from objects, figures and words. We can therefore refer to 'aesthetic materials' as well as 'aesthetic semantemes'. The mathematical representation of this new aesthetics includes both, and is by no means concerned solely with the formal or syntactic associations as is often assumed.

Generative aesthetics therefore implies a combination of all operations, rules and theorems which can be used deliberately to produce aesthetic states (both distributions and configurations) when applied to a set of material elements. Hence generative aesthetics is analogous to generative grammar, in so far as it helps to formulate the principles of a grammatical schema—realizations of an aesthetic structure.

Any generative aesthetics which leads to an aesthetic synthesis must be preceded by analytical aesthetics. This process is responsible for the preparation of aesthetic structures based on the aesthetic information found in given works of art. In order to be projected and realized in a concrete number of material elements, the prepared aesthetic information must be described in abstract (mathematical) terms.

At the moment there are four different ways of making abstract descriptions of aesthetic states (distributions or configurations), which can be used to produce aesthetic structures—the semiotic (employing classifications) and the metrical, statistical and topological methods—the latter three are numerically or geometrically orientated.

The semiotic method uses triadic relations of signs in order to determine the single and complex signs which constitute a work of art, by means of three main and nine subclasses developed by Charles Sanders Peirce and others defining the sign in relation to its object, to its interpreter and the sign itself. For the semantic analysis of a work of art as well as for the synthetic realization of units of meaning (semantemes) in a number of material elements, it is necessary to be familiar with the construction of the work in terms of classes of signs.

The metrical method of describing an aesthetic state uses numerical data in the same way as older schematics, i.e. theories of proportion in art. This method will establish the macro-aesthetic constitution of an art object, in other words, the composition dealing with form, figure and structure.

The statistical method is involved with the concept of frequency or probability of appearance of elements. Also with numerically assessed characteristics of elements in their relationship and organization. Thus we arrive at the micro-aesthetic constitution of a work of art which can be used to arrive at, not the 'principle of formation', but the 'principle of distribution'.

Finally the topological method is mainly concerned with the sets of elements which constitute the work of art, based on notions such as environment, connexion, open state, seclusion, simplicity and complexity of sets of elements. With the formation and distribution principles, the 'set' principle is the third.

The system of generative aesthetics aims at a numerical and operational description of characteristics of aesthetic structures (which can be realized in a number of material elements) which will, as abstract schemes, fall into the three categories of the formation principle, distribution principle and set principle. These can be manipulated and applied to an unordered set of elements, so as to produce what we perceive macro-aesthetically as complex and orderly arrangements, and micro-aesthetically as redundancies and information.

This application is not merely the application or imprint of a pattern but a generative principle. Programs, in certain programming languages, can also be used for the mechanical realization of 'free' (stochastic), or 'determined' (established *a priori*, deduced) aesthetic structures. These also belong to the system (and products) of generative aesthetics, provided that the resulting aesthetic information is based on material determinations (e.g. distances and length of word), statistical determinations (sequence of words, positioning), and topological determinations (combinations and deformations).

Aesthetic structures contain aesthetic information only in so far as they manifest innovations, or rather innovations of probable reality. The aim of generative aesthetics is the artificial production of probabilities, differing from the norm using theorems and programs.

Hence, generative aesthetics is an 'aesthetics of production', which makes possible the methodical production of aesthetic states, by dividing this process into a finite number of distinct and separate steps which are capable of formulation. The aesthetic state could be interpreted as the order of innovation through the original distribution or formation of material elements or semantemes. 'The aesthetics of production' is concerned with bringing about 'orderly arrangements' which comprise the topological nature of 'form', and the statistical nature of 'distribution'.

Hence three schemes of generating arrangements of order become discernible:

1 producing order from disorder;
2 producing order from order;
3 producing order from a mixture of order and disorder.

In this context 'disorder' is expressed by an even and regular distribution of elements or particles (dots or syllables) in a given space; whereas 'order' means exactly the contrary, i.e. the irregular distribution of elements. Thus a text consisting of one word, for example 'is is is is is . . .' would be an example of 'disorder' without any innovation whatsoever. It can be transformed into an order incorporating innovation if every 'is' will be associated with a noun, preferably each one containing a different number of syllables, e.g. 'snow is thunderstorm is rain is summer is lightning is . . .'.

Following these assumptions Claude Shannon's well-known, gradually selected approximations of letters to 'real' words, or of words to 'real' expressions in a language, can be seen as a generative aesthetic process.

The first stage of approximation is performed by picking words at random from a vocabulary or a dictionary where every word occurs once, thus making sure that every word has an equal probability of coming up. The result:

very funny kept adhere scale incomplete me blows subject investigate the itself send into for accept daring

The second approximation stage consists of choosing at random from a repertoire of words where proportions correspond to the typical word frequency of distribution of a particular author. In this particular case the translation of a work by Francis Ponge:

keeps flee complete smaller dreams hither over run this way finest has power to sky rely put many thousands line-ahead never border

The third and following approximation can be made by making a random selection from a repertoire where their occurrence approximates to their combined appearance in twos and threes:

milieu of during attack only the pebble entirely eternal towards as terrestrial globes yet so proud of renounced

Now, if a certain frequency is introduced between the nouns and the genitive elements and morphemes into the repertoire of the next stage of approximation, metaphoric forms cannot be avoided and are easily identifiable:

perhaps to begin with really only skin of a butterfly white carefree imagined above thine gone

The statistical approximation of a 'real' text by means of stochastic selection is aesthetically and semantically identifiable, although the aesthetic identification is of the lowest order.

Artificially generated texts which have been produced since 1960 could be seen as a product of generative aesthetics. The artificiality can be increased by carrying out the random selection by means of a randomizer in a computer system. Such texts have been produced at Stuttgart in collaboration with the Elektronische Recheninstitut in 1960. In 1963 Nanni Balestrini published artificial, mechanically produced texts in his book *Come si agisce.* These were not developed like the Shannon approximations, but were programmed on IBM 7070 in 1200 instruction codes in

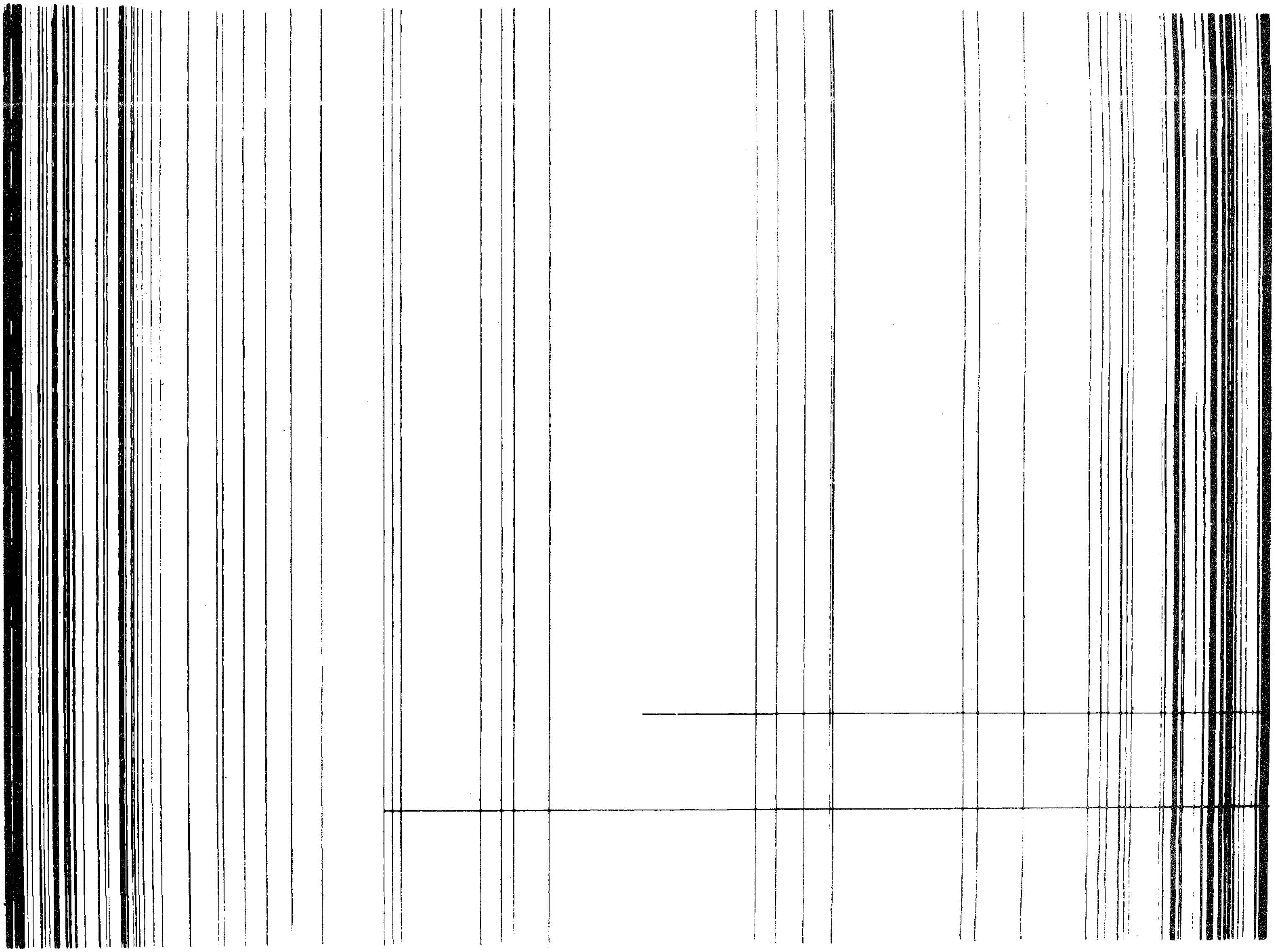


Fig. 18 Computer graphic by Georg Nees. The *Curtains* graphic was discovered through a programming error—thus it possesses improbability in a twofold sense.

relation to combinations of 10 given elements following rules of syntax.

In America Lejaren A. Hiller and his collaborators were particularly successful with a systematic investigation of composing music with the aid of computers. The first successful results date back to 1957 and the *Illiac Suite* for string quartet. The composition was programmed on the Illinois University computer—ILLIAC. In 1963 the famous *Computer Cantata* was composed by Lejaren A. Hiller and Robert A. Baker. Hiller wrote about it as follows: 'Computer music as we see it is therefore produced in two stages. First we create a state of randomization, and then a higher or lower order is superimposed or forced onto this chaos.'

We thus have a process of producing order from disorder or order from order. Three additional compositional considerations provide the basis of a computer music program:

1 The conditions for the composition are set up and introduced by the programmer, i.e. rules of composition such as counterpoint, conventional harmonies, serial sequences, graphic transpositions, or even arbitrary restrictions invented by the composer.
2 Statistical conditions derived from the statistical analysis of any style or compositional method, or from freely invented tables of probability. (In Germany, for instance, Wilhelm Fucks and his collaborators at the Aachen Polytechnic found numerical material suitable for programming through careful analysis of classical and modern compositions.)
3 One can employ schemes which are produced directly and automatically by the computer operation itself.

In the case of the *Computer Cantata* the computer was used to produce musical orders in a cantata form by a stochastic selection. The words used for the cantata consisted of those arrived at by Shannon's approximations, using the stages of stochastic approximations to spoken English based on a series of phonemes selected at random. Thus the statistical musical structure was given a textual correspondence.

Finally I want to mention the computer graphics made by Georg Nees at Siemens in Erlangen which were developed deliberately as aesthetic objects. The programming was done in ALGOL and the random number generator was used to provide the stochastic dispersal of graphic elements, e.g. the positioning of connecting squares. In this particular instance a randomizer was used which repeats itself only after 2^{30} values. Instructions for another program by Nees could be expressed in an everyday language as follows: draw 60 lines parallel to the narrow side of a rectangle inside its framework, in such a way that the parallels accumulate towards the narrow sides with random abscissae (fig. 18).

We can see that the improbability of aesthetic states can be produced mechanically through a methodical combination of planning and chance. In this way the demand which aesthetic objects have to satisfy—namely, to be unpredictable—is combined precisely with their planned construction. It is obvious that even the machine is unable to produce an identical repetition of a product if chance is introduced by means of a random number generator. The uniqueness of aesthetic objects—even those made with the aid of a machine—is maintained in a pseudo-individual or pseudo-intuitive way.

Art and cybernetics in the supermarket

Abraham A. Moles

'*The idea of the machine as creative in its own right is as revolutionary in its own way as the penetration of aleatory methods into scientific thought.*' (*Moles*)

'Artists are Gods. They want to make man all over again, but start with his hat instead of his skeleton.' (Decroux)

Everybody has heard that 'art' is dead. Nobody has listened to the rumour more rapturously than those who found modern art impossible to understand, who were baffled by exhibitions of emptiness and concerts of noise, and felt lost in an ocean of isms.

Actually, far from being dead, art has undergone a process of unprecedented regeneration. New social standards have completely overthrown the old position of art. The artist, just as before, expresses the world he is living in—and if the public at large lags behind, then they are the ones who need jolting.

Meanwhile art has reached crossroads in its relationship with society. In those aspects of the visual arts and music which follow traditional lines, information theory provides methods for examining and analysing the material. An entire range of states from order to disorder has been explored: from the complete ordering of an area of perception (as in a Greek frieze), to the complete amorphy on every level (e.g. background noise, or textural close-ups which are the visual equivalents).

In so far as art creates visual and acoustic shapes, its playground has been completely mapped out, if not yet thoroughly explored. We are still free, of course, to kick a ball about in this playground. Fine art is still very much alive and geniuses will continue to crop up among Sunday painters. Nevertheless, we have already reached the frontier of perfect disorder and have witnessed the breakdown of the work of art as such. Thanks to the few tough spirits who dared stage it, a concert of audience-generated noise took place in New York in 1960, and exhibitions of emptiness have already opened and closed their doors. Art has reached its 'zero grade'.

The value of art must disintegrate in a society in which purchasing power outweighs the spiritual and intellectual quality of life. This is due largely to the so-called 'imaginary museum' which includes in its catalogue the entire collection of all possible reproductions, leading inevitably to the devaluation of the original work. This process has caused new scales of values to be set up, defined by social aesthetics, of which the contemporary aesthetician will increasingly need to be aware. The new principle is: anywhere, any time, anybody is entitled to the knowledge and possession of any spatial or temporal form.

The imaginary museum endows copies with a new value, whether they be photographs, colour reproductions, prints from glossy magazines or recordings. The originals meanwhile become nothing more than matrices for the copies which are made from them. This does not mean that the 'original' should be dispensed with, it simply assumes a different role. The copying process delineates a stage where all forms existing in time and space will be made available to anybody, anywhere, at any time. The problem of art and aesthetic enjoyment belonging to those who can afford to buy or to those who dare steal, has altered radically. Now it is simply a question of wanting it. If we want something beautiful to look at, then all we have to do is to stroll down to the nearest supermarket and buy whatever suits our pockets and our taste.

The gulf between the haves and have-nots, has been replaced by the one between those who desire to see something aesthetic and those who do not.

Endowing a reproduction with as much importance as an original work raises many questions, concerning particularly the value of fidelity. Ideally, the spectator should be unable to detect any difference between the prototype and the copy. The prototype takes on a role akin to that of the standard lengths of measurement in the Guildhall, London, and copies of which—some more, and some less, accurate—can be found all over the world. Quality of fidelity is relevant, but whether a certain quality is satisfactory depends entirely on how much the spectator knows. A given postcard can mean everything to one person, and nothing to another. In the end fidelity becomes a statistical problem.

A line must be drawn between fidelity and another concept usually related to works of art—authenticity. Authenticity is no longer concerned with the work of art as such, but with the relationship of the spectator to the work. It is authenticity of situation. Some situations are authentic, others are not. To someone looking at a postcard with great admiration, the original may eventually lose its authenticity and even be a disappointment when finally confronted. The lack of cultural alienation characterizes this authenticity of situation which relates exclusively to one individual in front of one work of art.

Another vital concept emerges from social aesthetics—this too borrowed from economics. Rules must be set down for an economic system relating to works of art in the imaginary museum. Pareto's interpretation of ophelimity in this context suggests a relationship between multiple works of art (now commonly referred to as multiples) and the structure of the socio-cultural pyramid.

When a work of art is reproduced as a multiple the quality is likely to vary. The greater the number, the worse the reproduction. To deal with this problem in a sociological sense it is, first, necessary to establish a demography of the work of art. A demographic pyramid of 'degrees of quality' would have to be devised, which would show how many copies there are in this vast imaginary museum as a function of their relative quality (fig. 19). This assumes that it is possible to define 'quality' in some way. This profile is then juxtaposed with the socio-cultural pyramid. If there is a similarity between the shapes of the two pyramids, then this represents an adequation, approximating to Pareto's ideal of ophelimity. This would mean a complete adequation between art and the needs of society, inevitably dependent on the criteria used to relate the two pyramids. Such an ideal, however, is admittedly never achieved.

The idea of the imaginary museum has grown more or less consciously from this notion of ophelimity. For the moment, however, it is far from being actually set up. The aesthetic needs of society are far from being adequately satisfied at the present time.

There are considerable differences between the socio-cultural pyramid and the pyramid of quality. The graph shows the discrepancies between the need for beauty and the frustration caused by the democratization (and thereby repetition) of the welfare state. Frustration is one of society's chief motivating powers. In cybernetics one can relate the amount of frustration to the reaction of effects on causes, and deduce what effect the gap between the two is likely to have on the future. It has been observed that various material frustrations result in ingenious solutions—similarly there may be a relationship between frustration and creativity as well as the need for aesthetic experience. The socio-cultural hypothesis might be worth examining.

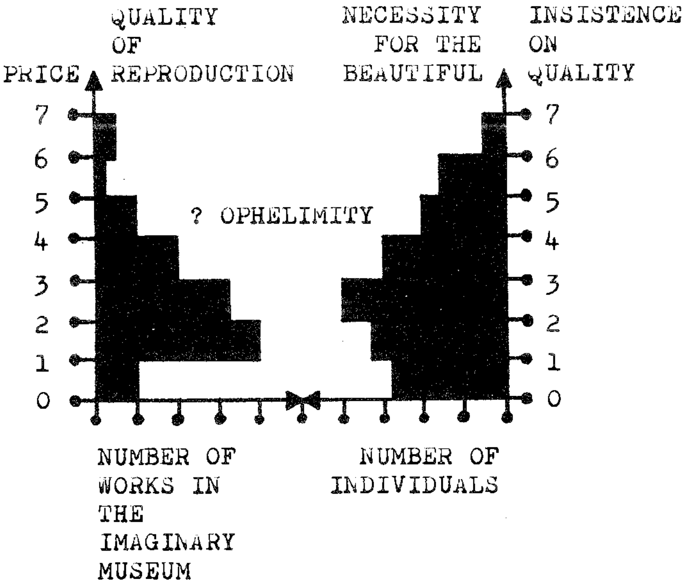


Fig. 19 A pair of demographic pyramids representing the imaginary museum and society's need for aesthetic experience, showing the relationship between the scale of quality (*left*) and the scale of requirements (*right*).

Aesthetic experience has a universal function. I would like, however, to stress a different aspect of aesthetics—its heuristic role. Aesthetics is no longer essentially a philosophy of beauty, but an experimental science based on psychology, sociology and the theory of creativity. One of its basic aims is to find out how creation works by studying art objects and how artists made them.

Up to now critics have focused their attention on finished works of art, studying their effect on the viewer. The process by which a work of art comes about and the general problem of creation is rarely tackled. The constraints imposed by media and colours have been studied, so have the areas of freedom, particularly in the fields of architecture, fresco painting and films. These studies, however, have been generally limited to problems of production.

From studies of creativity carried out so far, by psychologists and philosophers, it transpires that the processes of artistic and intellectual creativity are fundamentally identical. There is simply either a rational scientific framework or a sensual artistic framework, to which the creative processes are applied. The fact that we have powers of recognition makes it all the more important to analyse the processes by which creativity functions. The methods used in making this study rely primarily on information handling machines and the use of analog models.

Imitation and waste

In the early 1960s it was generally felt that the imitation of human thought processes by machines, like automatic translation machines, would progress more rapidly than has actually been the case. We are still on the threshold of this problem and meanwhile the chunks of text produced with the aid of machines are nothing other than fascinating nonsense, since the machines cannot master syntax.

The recent evolution of heuristics, influenced by the new possibilities of information-handling—fragments of knowledge arranged in patterns to make up a message—can be characterized by the emergence, in terms of socio-analysis, of new 'dynamic myths', one of which underlies the irrational efforts of the human mind to create something rational. These myths represent an unattainable ideal.

This new dynamic myth is that of the creative machine. We are, of course, aware that with our present state of knowledge, such a 'machine' cannot be built. However:

1 There are many meanings of the verb 'to create'. One of these is the making of the systematic variations on a given theme, adding supplementary material, or systematically exploring a limited set of permutations, combining different elements, etc. These types of processes can, already, be carried out by machines.

2 It is basic to the cybernetic method of creating models, that the inadequate or unsatisfactory can be replaced by better ones. The model, when examining its weaknesses as they turn out and gradually improving its performance, represents a rational method for approaching this goal.

3 In order to end up with a 'genuine' creation we probably need a new set of theories, but the possibilities inherent in the cybernetic process provide good reason to press on with our quest. Before we turn to other methods, it is advisable to rationalize and imitate those thought and creative processes which it is possible to imitate, in order to examine what remains that cannot be imitated. We shall call this procedure 'neo cartesianism of the computer'.

This brings us back to the scientific method, of which one of the most basic axioms is that one must begin with whatever is easiest. It is by trying to construct messages with more and more outrageous Markovian approximations that one has realized the limitations of the operation, and that the underlying principles should have to be radically altered. This is where the question of the construction of works of art by a machine becomes really interesting.

In the realm of aesthetics the advent of artificial creation poses immediately the problem of the validity of the results. The criteria of a technological product are incomparably easier to satisfy. In this context it follows that the artificial creation represents a tentative attempt which can well be perfected by studying the way in which the technological product fulfils satisfactorily its own criteria.

The linguistic researches which deal with language as fragmentary units or atoms which can be built up into structures, has reached, through the application of the information theory, other fields of the human sciences. The relationship between the 'atomistic' approach on the one hand and the structure on the other, or the whole which is meaningful *per se*, represent what I refer to as the short-range and the long-range orders, respectively. The nearer the observer comes to the parts of a given system in short-range order, the clearer will be the links between them. Concentration on these local aspects will be detrimental to the appreciation of the long-range order eventually, which, for the moment, is hidden from one altogether. In the long-range order, the further the observer finds himself from the phenomenon under study, the better he is able to grasp its general structure. What he sees is a master-plan, a hierarchy, omitting the local details which make up the whole. It is possible to have a simultaneous short-range and long-range order—I refer to this as 'total order'.

Let us take as an example the case of text: if we try to build a machine which can produce texts (e.g. patents or crime novels), we are dealing with long-range order. We find here paragraphs, choice of words and expressions emerging under control. This is not necessarily the case in poetry; experiments of poets like Isou, Queneau and Dufrêne who deal with automatic writing; and other poems where what counts most are the links of association in short-range order.

Our progress in work on 'machines for arranging sequences of elements taken from a given series' (a better expression than the term 'creating machines'), is more successful in the field of short-range order than it is in the long-range order. In information theory, short-range order comes under di-, tri- or polygrammatic processes, governed by matrices of 2, 3 or *n* dimensions. It is possible to extend this notion to the realm of visual elements: François Molnar has demonstrated this by examining the paths of the eye when staring at a picture. By definition, the larger the matrices (order *n*), the smaller their reliability and practical importance.

Long-range order is fostered and enhanced by the role of laws of grammar, logical continuity or consistency. Linguistics rebuilds some of these categories by the artifices of syntactic structures, the equivalent of which in the visual arts has not undergone a proper scientific investigation. The critic who tells us, when discussing an Italian painting, about the way the light from the Madonna dominates the figures surrounding her, is actually talking about forms determined by the syntactical structures of the painting. He describes the painting but does not give us any scientific facts about it. He cannot be blamed for it because to date we know very little about all this, and what little we do know is difficult to construct into models and other analogous forms.

In short we have not yet learned how to handle long-range order, and this is the chief stumbling block when dealing with machines producing texts on scientific matters. In the arts the position is considerably different. At this very moment we can create music, pictures and poems to which both short-range and long-range orders can be applied with sufficient degree of success in order to satisfy the current definition of works of art.

The assignation of a new form to the creative function in the affluent society creates a new role for the aesthetician, who can no longer merely philosophize on various aspects of beauty, but must be an expert in sensations to be able to prepare and design tasks for the translating machine.

The few experiments made in this field so far, reveal a number of different fundamental attitudes. These are aesthetic attitudes which could be compared to different types of flow charts, each one representing a program for the translating/creating machine, or, in short, a computer.

First attitude

The world is full of marvels ready to be explored and exploited. This means that every system for observing the world around us must be adjusted according to critical standards. It also means the setting up of a system for valuing works of art. This could be achieved with a spectator machine and artificial audiences. Attached to it would be a machine that could translate sensations into machine language. This could be a television camera, a microphone or an analog/digital transducer. The machine deals with messages constructed in this way by passing them through a filter program which is nothing other than a mechanical table of values measuring, for instance, the rate of redundancy, the number of repetitions or the amount of symmetrical elements. Thus any image can be analysed according to the principles of information theory. The overall value rating is based on the combination of partial ratings and different levels, according to the rules for every level of the hierarchy of signs, laid down by the aesthetician who wrote or edited the program. The machine then picks out those pictures or performances that come above a certain rating, and labels them 'works of art'. These can then be stacked away in the memory store and be recalled at any time, with the aid of a digital/analog transducer, a television screen or a set of complex sound generators.

Consider the machine as a mechanical critical system to be used by the aesthetician. If we agree that the world is full of beautiful things, then the 'critic' will be turned into an 'artist' the moment he puts a frame round a paving stone whose aesthetic qualities appeal to him. There is no need for a master mind. The program can be selected on the basis of

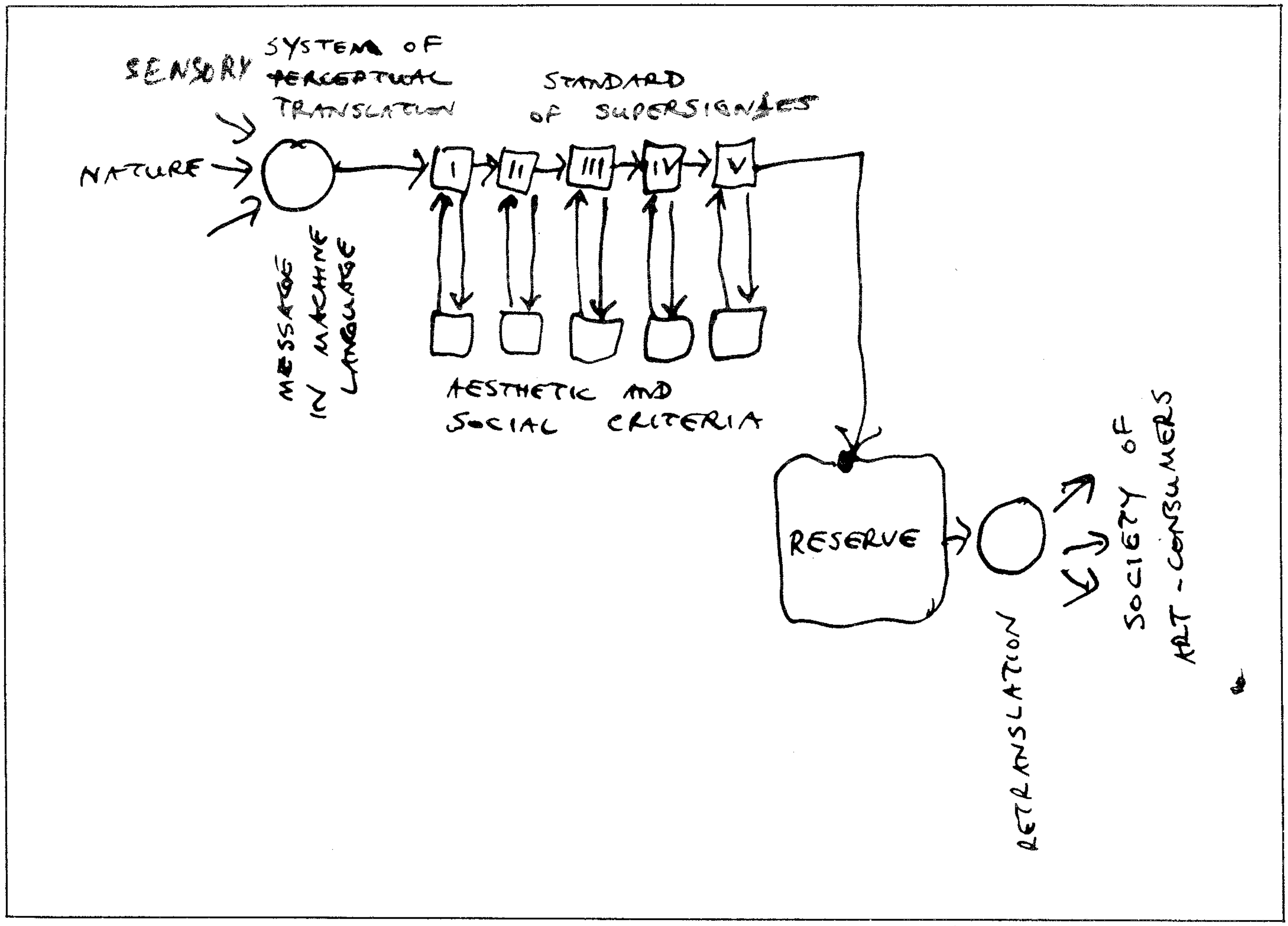


Fig. 20 Artificial listeners and spectators making selections.

the opinion of entire mankind from a source that represents the whole world.

Second attitude

The human mind is not capable of bringing off all the ideas it is capable of thinking up. A responsible artist may think up an idea but be incapable of taking it to its logical conclusion because the work involved in developing it would go beyond human capabilities. This happened to Goetz when he tried to explore the combinations of squares in black and white in order to make 'super-signs'. He had to use a team in which each member worked on a tiny section of the whole picture, according to his instructions. Soon, however, the work which will have to be done will go beyond the limits of human possibilities, and the team will have to be replaced by the computer in its role of complexity amplifier performing the hardest part of the task and taking it to its logical conclusion. Given the idea and a program of symbols, the computer can process the material in many different ways.

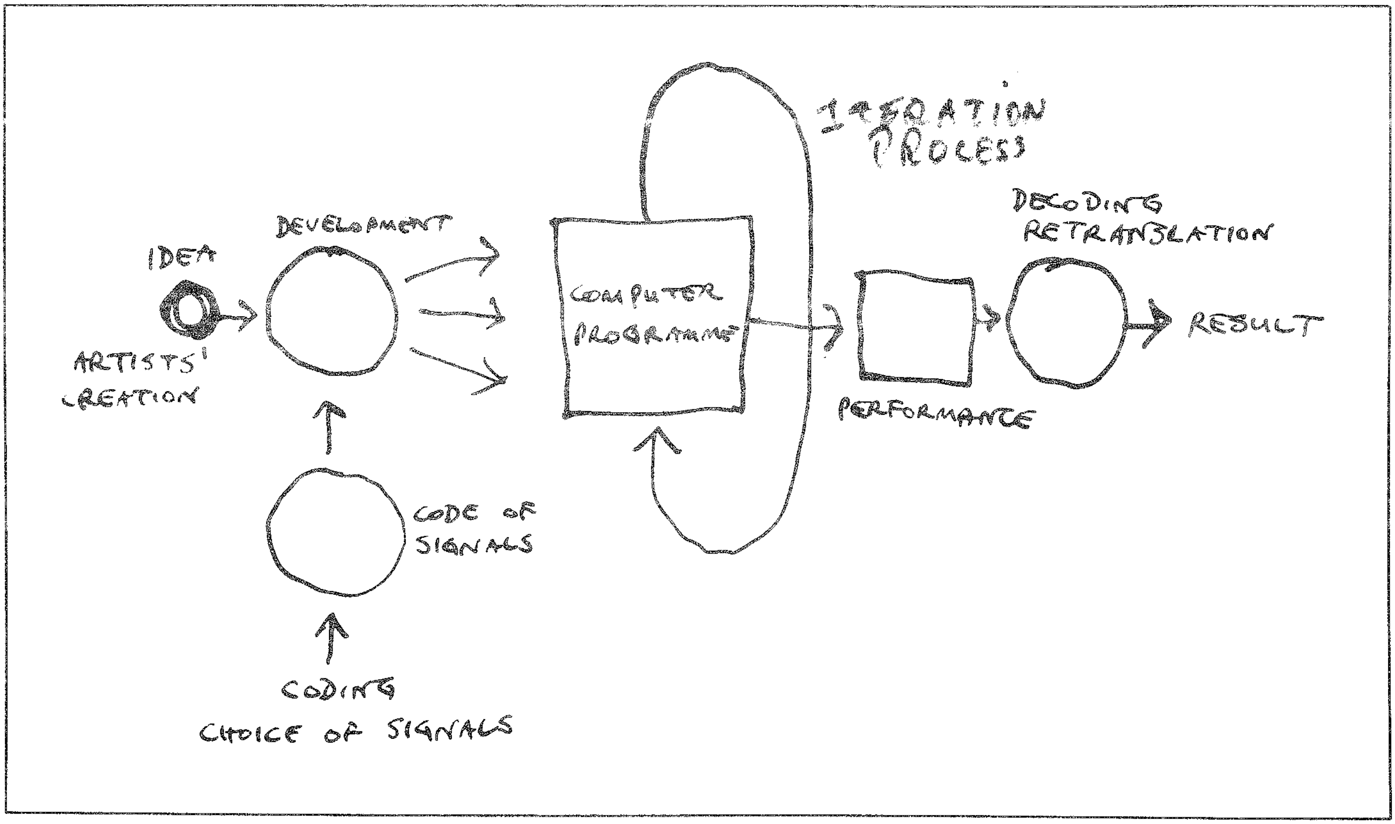


Fig. 21 Artist's original idea is developed with the purpose of creating a new work.

Xenakis, for example, is concerned with the way fragments of sound can be disseminated according to a certain number of simple rules, and to this end he makes use of an IBM 704 computer.

A considerable proportion of art of the future could develop along these lines. If we draw a great number of parallel lines, each sloping a little more than the one next to it, and superimpose this on another kind of hatching, we know that before long all sorts of pattern associations will emerge before our eyes, like the effect of moiré. To explore the gamut of possibilities inherent in a structure of this sort, a computer is invaluable.

Third attitude

Whereas the first and second attitudes deal with the possibilities in nature and the implications of an idea, respectively, the third deals with the systematic exploration of a field of possibilities, by the combination of algorithms relating to elements, whether sound or visual. Although the

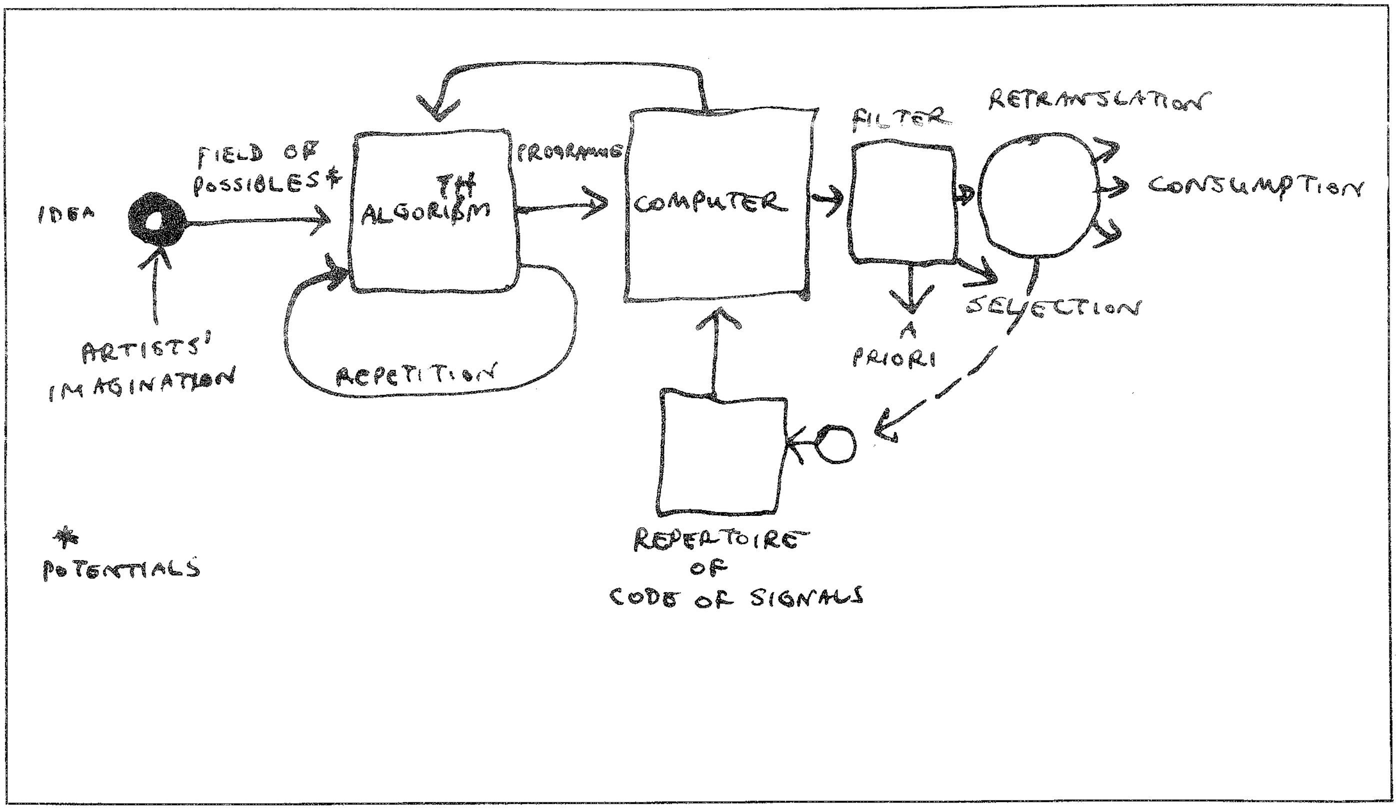


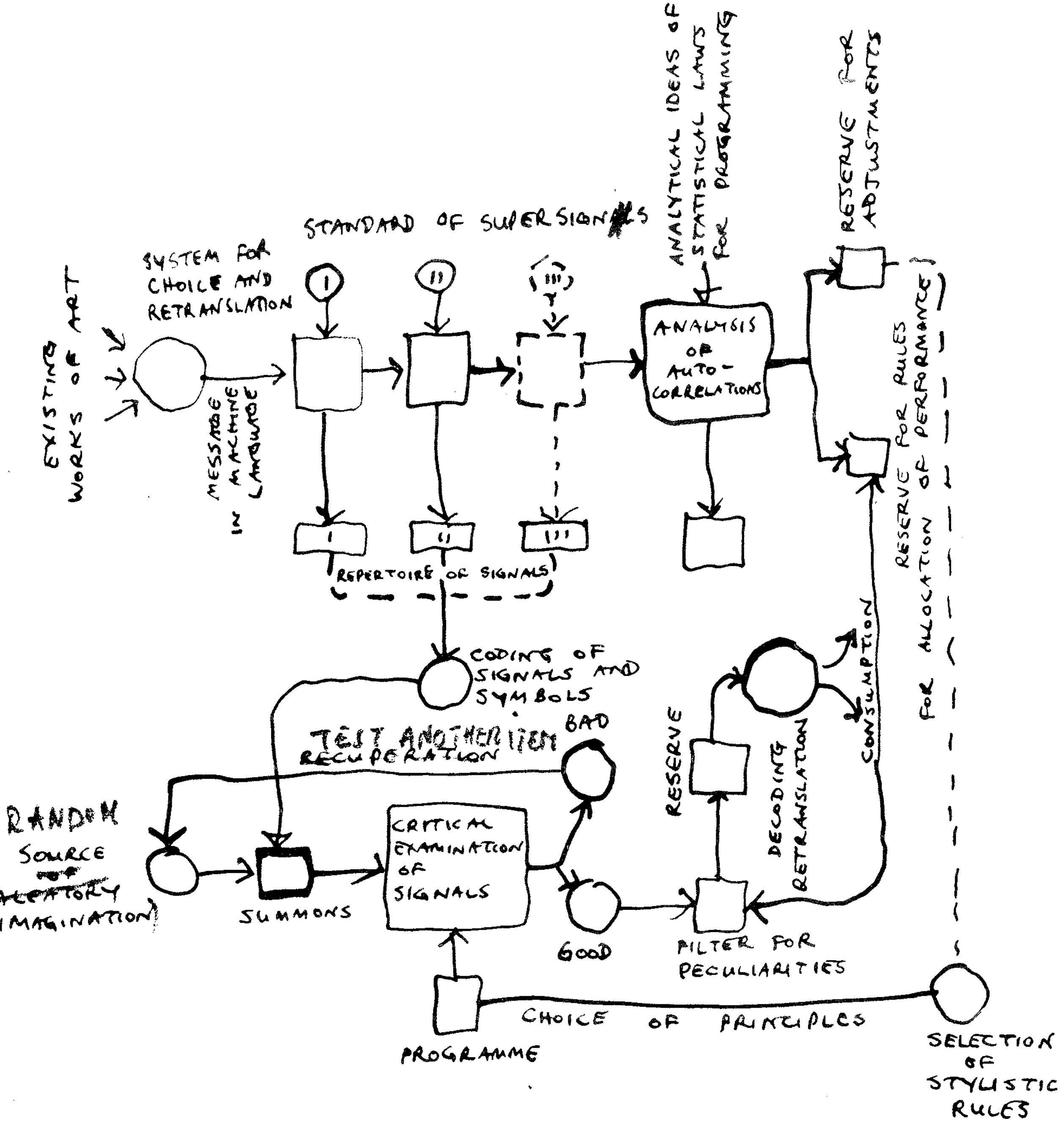
Fig. 22 System involving complexity amplifier working on an algorithm.

exploration of these possibilities could be done laboriously by man, the computer is more competent in the field. We call the results of the process Permutational Art.

It can be achieved in the following way. The computer holds in its memory store a specific code of symbols. The algorithm for manipulating them is provided by the aesthetician. The algorithm puts all the elements systematically through all the combinations until the complete field of possibilities has been exhausted. Thus produced is an immense number of works that could be put into reserve and which could be categorized according to the incidence of intelligibility, sensuality, etc. The remaining works can be stored and, eventually, sold.

This is a method employed by Barbaud which he called Algorithmic Music. Permutational Art has considerable importance for the consumer society, since it allows room for personal choice from the vast number of variations created with the aid of a single algorithm. Each patterned formica table-top sold at every chain store in every town could be distinguished by being different from all the others.

Fig. 23 Process of detailed analysis of existing works on which simulated compositional methods can be imposed.



Fourth attitude

This is concerned with the simulation of art processes by imitating faithfully everything that we can possibly find out about them. This process involves the cybernetic principle described earlier, whereby exploratory fumblings and mistakes are gradually corrected. When Lejaren Hiller wrote his *Illiac Suite*, this is the method he employed. The method could actually be used in two different ways simultaneously. One involves an analysis of various sensory phenomena of the external world—in this particular case confined to music but, for the sake of argument, also only those which are considered great works of art. By random scanning of the various characteristics, an attempt is made to enclose each work in a mesh of dimensions, or metrics. Later, from this information, it is possible to work out the correlation between one piece and another, and thus to make generalizations about a number of works examined. The findings can be kept in two distinct memory banks: one stores the material that makes up the combination of rules embodied in the work; the other classifies the rules according to the works to which they have been applied.

A randomly chosen image can be tested to see if it fulfils any of the criteria emerging from the analysis. It can either be incorporated into the overall vocabulary or rejected. In this way the vocabulary of symbols is eventually expanded.

In the next stage it is possible to find out if the information about a work of art which fulfils all the required criteria actually exists, or whether it is the result of permuted material. In the latter case, with decoding procedures and computer peripherals it is possible to give it a physical embodiment. In this way the aesthetician assumes the role of the artist, since he is responsible for the rules according to which this new, hitherto non-existing work was made, albeit even if it is based on acknowledged works of art from the past. This idea carries many implications. For instance, has Brahms produced all the music that he was in fact capable of composing?

If, by feeding information about Brahms's compositions into a computer, we get out nothing more significant than weak variations on the First Piano Concerto, we can assume that either the process of analysis employed is inadequate, or that the Brahms piano concerto is a perfect work of its kind. If, on the other hand, the work or works resulting from this synthetic process are indiscernible from the original, or possibly even better, this means that Brahms's exploration of the field of possibilities did not necessarily lead to the best possible path along the many-forked road, and that somewhere in the realm of ideas there is an even better Brahms piano concerto.

Fifth attitude

There is yet another type of creative machine which can be dreamed up. It is based on the idea of integration of successive levels of perception, the telescoping and contracting of visual messages incapable of being perceived by the human eye which are in fact the sum of a series of images in time, can also be stored in the computer together with other visual phenomena which never had, and probably could not have, a concrete physical form. These phantom forms can be recalled, either as aids to inspiration, or as something interesting to look at.

'The empires of the future are the empires of the mind.' (Winston S. Churchill)
These particular cybernetic procedures say something about the aesthetician's position in relation to the external world, and at the same time say something about cybernetics in general.

1. Information theory provides the point of intersection between structuralist theory and the dialectical theory. From the first it borrows the idea of the model, and that of the structure as sum of constraints controlling the model. From the dialectical theory it borrows the idea of the figure–background relationship, and the system of pattern repetitions which is perfected once the model is set up.
2. The definition of beauty is based on the statistics relating to all that is considered beautiful. Until recently this approach has not even been considered—beauty having been thought of as something that is transcendental rather than something measurable. What is most significant is the connexion between the idea of beauty and the society to which it is meaningful, which is like a meeting point of a great number of individual thoughts.

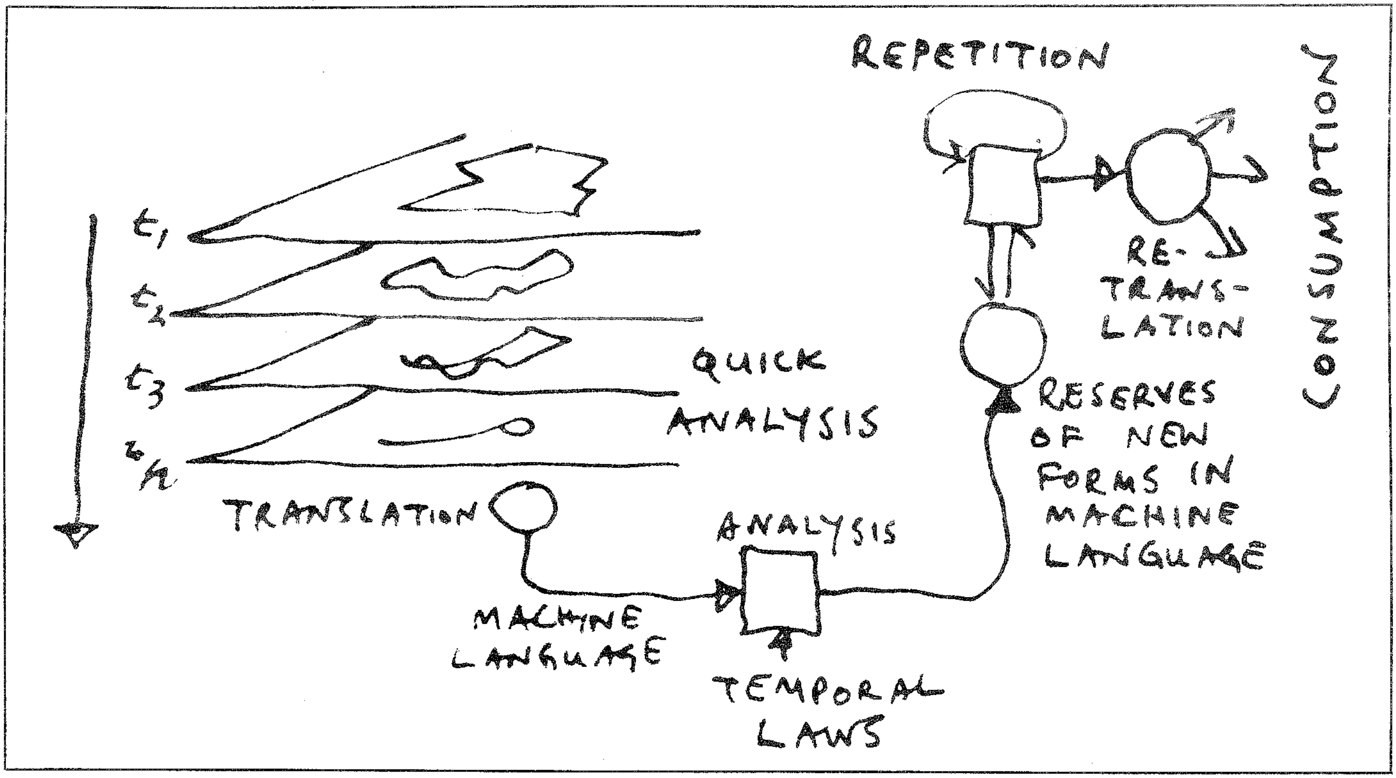


Fig. 24 Integration of forms seen in a long-range order.

3 The method of working with flow-charts, here, makes the process both systematic and exacting. If the program can be seen as an algorithm of the mind, the process is nothing less than the formalization of thought.

4 The flow-chart for a computer program allows for the possibility of establishing hierarchies of order and analytical levels. Thus a poetry-writing machine could be programmed to write poetry with words, producing examples of lettrism; or with phonemes, producing ultra-lettrist poetry. On the level of semantemes, the machine could produce either permutational poems or texts, or even permutational novels.

5 Creative machines bring us face to face with a vital problem. This is the conflict between so-called Markovian structures, which are concerned with short-range examination, and syntactic structures which are concerned with the study of objects at long-range. Novels, with 'tangentially intersecting themes' like *Helzapoppin*, belong to the field of syntactic structures.

6 The aesthetician, in general an unpopular man, and for long subject to terrible inferiority complexes since all he could do was to talk about what other people did, now finds himself on the same level as the artists he used to discuss. He now provides the elements of the program to be introduced into the machine's repertoire and sets a series of rules to evaluate the results. The analytical machine becomes also the synthesizing machine as a source of works of art of which the aesthetician, even if not the legitimate author, is, at least, the manager responsible for the results.

7 The term 'creative' can also be applied to another function of the machine. If information about an aspect of the external world can be fed into the machine in order to obtain further information which will contribute to its improvement then this function could also be described as creative.

The idea of the machine as creative in its own right is as revolutionary in its own way as the penetration of aleatory methods into scientific thought. The influence of this development can only be surmised but it is our duty to calculate the long-term effects when random music, artificial languages, programmed paintings and machine translations become the order of the day. The machine is part of our lives despite our ambivalent feelings about it. How much of it is part of the fabric of our lives can be seen from a few odd sentences which we let slip without quite noticing, like 'we tell the machine to do so-and-so', or 'the machine refuses to', or 'the machine sees that' and so on.

This raises three points specifically in relation to the field of the arts:

1 Will the artists, following the fate of book-keepers and factory workers, also be replaced by machines that make paintings, music and literature? We can safely predict that the artists will not be replaced but their function may be displaced. There is no reason why the computer should show less enthusiasm or passion in inventing algorithms for a computer program than the traditional composer working with conventional instruments applies to his methods of working.

2 The possibilities opened up by the use of the computer in the arts, have a profound sociological implication. Whatever creative material is produced can be produced in such quantities and such variety that no single object is repeated exactly. A new public for art will eventually be created as these objects become more generally available.

3 The negative point about this is what one could describe as 'cultural alienation'. The individual, despite the proliferation of art objects, will be even further removed from the spontaneous moment of original creation. He will be at a greater distance than ever before from the creative personality responsible for the mass-produced art object.

This is likely to lead to our society dividing itself into two distinctly separate groups: first, the consumers of the machine product, as a result of the cultural function becoming more important as the material value decreases; and second, the intellectuals and creative artists, who will keep on rediscovering for themselves the spontaneity of creativity. The artist's fun and freedom will not be diminished by the machine's invasion of our society.

Paul Valéry made a less optimistic prophecy:

'More and more our civilization is taking on, or tending to take on, the structure and appearance of a machine—a machine that does not suffer its empire to cover less than the surface of the whole world, that does not suffer men to exist, ignorant of its deeds, independently of it. Its accuracy, which is one of its essential qualities, tolerates neither indecision nor social fripperies. It will not allow anybody to exist whose role and whose code of existence lack precise definition, and it is likely to eliminate individuals who refuse to be fitted into pigeon-holes, while shuffling and reclassifying the remainder without any further reference to the past or the future of the species.'

Happiness, amplified cybernetically

Ali Irtem

'The amount of happiness could be seen as a measure of the adaptability of a cybernetic system at a given moment, corresponding to the degree of efficiency in a mechanical system.' (*İrtem*)

I published the following equations of happiness in the Turkish paper *Tanin* in 1943, obviously not knowing anything about cybernetics at that time, but hoping that one day it would be found to be relevant to the realm of psychology. (This is a slightly altered version of a paper presented at the 3rd International Congress on Cybernetics, Namur, Belgium, September 1961.)

Measuring happiness

This is an attempt to give a systematic representation of one of the most subtle and complex human conditions—happiness. W. R. Ashby asks, in his 'Design for an intelligence amplifier', 'If physical power can be amplified, why not intellectual?' My question is a similar one: 'If intellectual power can be amplified, why not happiness?' Everyone, who has ever fallen in love, knows that it can. The methods I describe here are more general, and in addition they could be applied not only to men but also to certain kinds of machines and systems.

In order to avoid any ambiguity and needless discussions with writers of love stories, here is the precise definition of what I mean by 'the amount of happiness'. 'The amount of happiness is the quotient of all that is attained at a given moment, and all that is consciously and unconsciously desired at that given moment.'

Thus, if we say that:

G = the amount of happiness
A' = all that is attained at a given moment
W = all that is consciously and unconsciously desired at that moment

then, the above definition can be represented as follows:

$$G = \frac{A}{W} \tag{1}$$

If we consider A as a function of W, $A = F(W)$, we can write:

$$G = \frac{dA}{dW} \tag{2}$$

This equation can serve as another definition of the amount of happiness.

G, A and W are functions of time (t). In order to take into consideration the intrinsic unattainability of certain kinds of desire, the amount of happiness could also be redefined as:

$$G(t) = \frac{\dfrac{dA(t)}{dt}}{\dfrac{dW(t)}{dt}} \tag{3}$$

I will call this 'the main equation of happiness'. According to it, our happiness depends on how far our desires are fulfilled at the given moment. This means that our happiness depends on three factors: time, our desires and the fulfilment of those desires. The following could be said about the above equation:

1 The equation is still correct, even if we only wish to dream of something without actually possessing it, or if we desire, for example, to be excited, without any other aim. (Dreaming, and being excited are 'essential variables'.)
2 Obviously, the numerator and denominator here depend on each other at least sometimes. This situation, however, does not influence the correctness of the subject equation. The derivation will only concern partial differential quotients. Therefore the main equation of happiness will be:

$$G(t) = \frac{\dfrac{dA(t, W)}{dt}}{\dfrac{dW(t, A)}{dt}} \tag{4}$$

3 In order to make G as large as possible, in the equation (1), we have two alternatives: either to make W as small as possible; or we make A as large as possible. It is interesting to note that these two alternatives represent approximately the two different paths followed by the eastern and western worlds in search for happiness.

The East has attempted to optimize the subject equation by minimizing the denominator, by making the wishes smaller and smaller in order to achieve their fulfilment—the object of Nirvana in Indian philosophy.

The West has tried to optimize the subject equation by making the numerator always bigger and bigger, so as to obtain everything obtainable. The result of the western attitude towards happiness is that when all desires for the moment are attained, more desires immediately emerge. This situation makes the function more complex, but does not influence its general formulation.

The difficulties in measuring 'the amount of happiness' emerge from the fact that we are not yet in a position to measure our unconscious desires. It is, however, my interpretation here that our desires whether conscious or unconscious are nothing else than our endeavours and searches for maintaining our essential variables, within the acceptable limits, in optimal ways.

Human happiness could be measured with great accuracy if we understood the homeostatic system in a human being. We do, however, understand the homeostat of Ross Ashby. Therefore, we are today in a position to measure 'desires', at least in relation to a homeostat which requires only that its four needles be in a certain position. Consequently, if only one needle of the homeostat is in the desired position the amount of happiness at that moment is a quarter.

If we want to be more precise, we should take into consideration every position of the four needles, and consider their degree of proximity to the desired positions. In the Ashby homeostat these quantities are measurable, and therefore the amount of happiness in a homeostat, or in a refrigerator, is computable.

The amount of happiness still makes sense, if essential variables of the system (here four needles) show continuity, so that the states of essential variables lie along a scale. In this context, Ashby quotes the following example:

> 'A land animal can pass through many degrees of dehydration before dying of thirst and a suitable reversal from half way down the scale, may justly be called "regulatory", if it saves the animal's life, though it may not save the animal from discomfort.'

Generally, the 'variety' of the scale of desires is greater than that of those attained. In Ashby's notation, we could write equation (1) as follows:

$$G = \frac{A\text{'s variety}}{W\text{'s variety}} \tag{5}$$

If the varieties are measured logarithmically, which can be more convenient, equations (3) and (4) would come out as:

$$G(t) = -\log \frac{\dfrac{dA(t)}{dt}}{\dfrac{dW(t)}{dt}} \tag{6}$$

$$G(t) = -\log \frac{\dfrac{dA(t, W)}{dt}}{\dfrac{dW(t, A)}{dt}} \tag{7}$$

There is a similarity between the amount of information in information theory, and 'the amount of happiness' as given above.

The amount of happiness could be seen as a measure of the adaptability of a cybernetic system at a given moment, corresponding to the degree of efficiency in a mechanical system.

Amplifying happiness: a basic design for a happiness amplifier

'Being happy' is largely, or perhaps even entirely, a matter of 'intelligence'. If I am intelligent enough, I can find ways, or strategies, to make my attainments as great as my desires, or reduce my wishes, so that I can attain them.

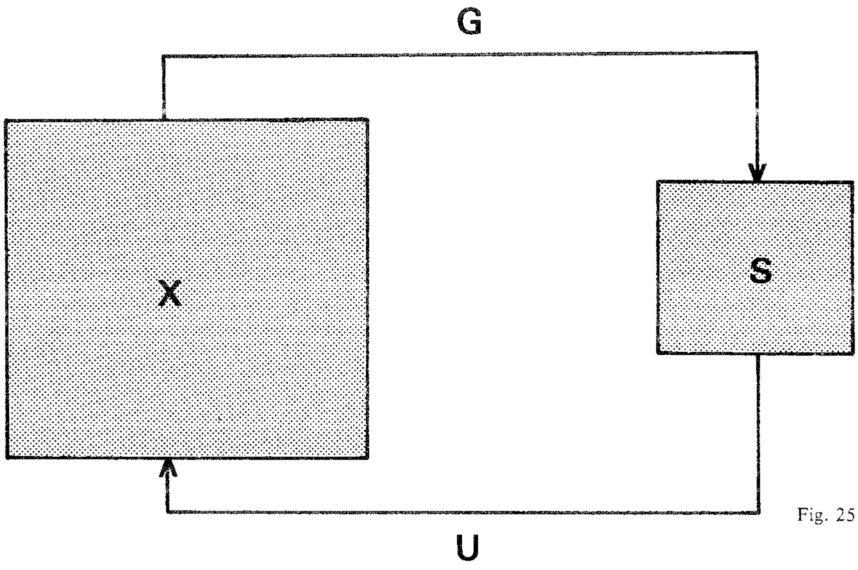


Fig. 25 Happiness machinery.

According to Ross Ashby, intelligence is a matter of selection, and selection can be achieved through an appropriate regulation.

If I can regulate my desires so that I can attain them, or conversely if I have such a perfect regulating system available that all my desires can be fulfilled, then, I am completely happy. In order to amplify the amount of our happiness, all we have to do is to amplify our capacity of regulation.

This implies the provision of additional regulation devices. These additional regulation devices for happiness in men, are often represented by a woman, with whom we fall in love. However, this need not be the only way for the amplification of regulations for holding the essential variables within the determined limits: for happiness. Especially, if the system considered is not a human being but, for example, a homeostatic system.

Ashby's rules for the amplification of intelligence can be used for the amplification of happiness in men, animals and machines. His main points in the 'Design for an intelligence amplifier' certainly apply here.

System *X* can be seen as a man who can only be happy when the condition *p* (*p* may also be a set of desires) is attained. This condition, however, cannot yet be realized in system *X*; we therefore have to amplify *X*'s amount of happiness through an additional and appropriate regulation device. In order to do this, we have to couple system *X* with another system *S*—*S* could be a woman—through channels *G* and *U* so that each affects the other (fig. 25).

The new system *S*, is able to attain a state of equilibrium or happiness if the condition *q* is attained (again *q* could be a set of conditions). Suppose now that linkage *G* will allow *q* to occur in *S* if, and only if, the happiness condition *p* occurs in *X*; *S*'s power of veto, according to Ashby, now ensures that any state of happiness of the whole must imply the happiness condition *p* in *X*. So the selection of the happiness condition *p* is achieved in two stages. The selectivity attained in the second stage may be larger, perhaps even much larger, than that used in the first. Therefore, the amount of happiness is amplified. The rules to be used by future happiness-engineers might be as follows:

1 If the amount of happiness in a given system *X* should be amplified; another system *S* must be provided with the tendency to go to a state of equilibrium (condition *q*).

2 The happiness engineer can then arrange the coupling between the two systems, so that 'lack of equilibrium' is associated with 'lack of happiness' (not—*p*), and 'equilibrium' to 'happiness' (*p*).

3 The engineer can allow the system to function with confidence that the goal will be attained.

4 The engineer simply allows the basic laws determined by the design of *S* to bring about the change in *X*.

5 The engineer must also arrange that:

a system *S* should send disturbances of inexhaustible variety along the channel *U*, if *q* is not occurring in *S*, and

b keep *U* constant, i.e. block the way from disturbances of inexhaustible variety to *U*, if *q* is occurring.

Here I would like to leave the question open, as to whether disturbances of inexhaustible variety are present in every special case of coupling, between man and woman; but I would like to add that it seems to be that falling in love with a girl is simply an attempt to amplify our present state of regulation and intelligence.

However, as mentioned before, this process of amplification could also be achieved mechanically, electronically and chemically, as the case may be.

In the economic world, system *X* might, for example, be represented by a firm which is not making enough money (not-happy), and system *S* could probably be an insurance company which would cover the deficit of the firm (realization of the condition *p*).

Limitations of happiness amplification

A man's or woman's capacity as a regulator cannot exceed his or her capacity as a channel of communication. Anyway, the amplification rate of happiness by coupling, including marriage, seems to be limited. Probably for this reason team-work is recommended as a solution, though polygamy and harems are not allowed in many countries. Nevertheless, machines and human beings must come together, in order to increase their intelligence and to amplify their happiness.

A comment, a case history and a plan

Gordon Pask

'Man is always aiming to achieve some goal and he is always looking for new goals.' (*Pask*)

This article was written prior to the Cybernetic Serendipity exhibition (ICA 1968) and is unaltered. The appendix was added later in 1968.

A comment on the cybernetic psychology of pleasure

Man is prone to seek novelty in his environment and, having found a novel situation, to learn how to control it. Let us develop and qualify this cybernetic statement. In the symbolic domain which constitutes the most important aspect of the human environment, 'novelty' inheres in events or configurations that appear ambiguous to a given individual, that engender uncertainty with respect to his present state of knowing and pose problems. 'Control', in this symbolic domain, is broadly equivalent to 'problem solving' but it may also be read as 'coming to terms with' or 'explaining' or 'relating to an existing body of experience'. Further, when learning to control or to solve problems man necessarily conceptualizes and abstracts. Because of this, the human environment is interpreted at various levels in an hierarchy of abstraction (on the same page we see letters, words, grammatical sentences, meaningful statements and beautiful prose). These propensities[1] are at the root of curiosity and the assimilation of knowledge. They impel man to explore, discover and explain his inanimate surroundings. Addressed to the social environment of other men, they lead him into social communication, conversation and other modes of partially co-operative interaction.

To summarize the issue in slightly different words, man is always aiming to achieve some goal and he is always looking for new goals. Commonly, he deals with goals at several levels of an hierarchical structure in which some members are freshly formulated and some are in the process of formulation. My contention is that man enjoys performing these jointly innovative and cohesive operations. Together, they represent an essentially human and an inherently pleasurable mode of activity.

This dogmatic statement of the human condition does not apply in all circumstances. On occasion, perhaps, men are vacuous. On occasion, they merely respond to stimuli or act as passive receptors. But the characterization is accurate enough whenever a man is involved in aesthetic activities, which include:

1 Organizing a bit of symbolic environment by constructing a tangible work of art (e.g. painting a picture).
2 Writing a prescription which is interpretable as a work of art (e.g. composing music and writing the score).
3 'Performing a work of art' or, strictly, 'interpreting a work of art prescription, such as a piece of music'.
4 Appreciating or enjoying some work of art.

It does not seem useful to make a rigid distinction between the types of mental process that go on when a man occupies these different roles: 1, 2, 3 and 4. The composer is, in some sense, mentally akin to the performer and listener; the man who views a picture is mentally akin to the artist who painted it.

With all this in view, it is worth considering the properties of aesthetically potent environments, that is, of environments designed to encourage or foster the type of interaction which is (by hypothesis) pleasurable. It is clear that an aesthetically potent environment should have the following attributes:

a It must offer sufficient variety to provide the potentially controllable novelty required by a man (however, it must not swamp him with variety—if it did, the environment would merely be unintelligible).
b It must contain forms that a man can interpret or learn to interpret at various levels of abstraction.
c It must provide cues or tacitly stated instructions to guide the learning and abstractive process.
d It may, in addition, respond to a man, engage him in conversation and adapt its characteristics to the prevailing mode of discourse.

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[1] My 'propensities' have been adumbrated under various titles. Bartlett speaks of a 'search for meaning', Desmond Morris of a 'Neophyllic tendency', Berlyn of a 'curiosity drive' and Bruner of a 'will to learn'. My own writing credits man with a 'need to learn'. Social psychologists, such as Argyll, have essentially the same concept. So do the psychiatrists. Here, the point is most plainly stated by Bateson, and by Laing, Phillipson and Lee.

The aesthetically potent environments discussed in this paper are reactive and adaptive. They go *some* way towards explicitly satisfying the requirements of *d*. However, *any* competent work of art is an aesthetically potent environment. Moles has pointed out that its information structure is tailored to suit *a*, *b* and *c* (among other things, this is why a play or a symphony bears repetition). Condition *d* is satisfied implicitly and often in a complex fashion that depends upon the sense modality used by the work. Thus, a painting does not move. But our interaction with it is dynamic for we scan it with our eyes, we attend to it selectively and our perceptual processes build up images of parts of it. Further, consciously or not, the artist anticipated this dynamic interaction (if only because he looks at the picture himself). Of course, a painting does not respond to us either. So, once again, it seems deficient with reference to *d*. But our internal representation of the picture, our active perception of it, does respond and does engage in an internal 'conversation' with the part of our mind responsible for immediate awareness (this is probably the most important consequence of Moles' insistence upon perceptual 'quantization', though he does not make the point in this way).

With suitable qualifications, precisely the same comments apply to works of art (like plays and musical pieces) that are presented in a sequential or partially sequential fashion. In each case, the external aesthetically potent environment gives rise, bit by bit, to an internal representation and the reciprocal interaction of *d* is internalized as a discourse between the internal representation and our immediate selves. In contrast, a reactive and adaptive environment is intended to externalize this discourse.

A couple of questions arise. First, is there any special advantage to external (rather than 'internal') discourse or, by the same token, to reactive and adaptive environments? Next, supposing there is, can it be done?

The latter question can be answered in the affirmative. The former, cannot, so far as I know, be answered at the moment. The chief merit of externalization (apart from the scientifically interesting fact that externalized discourse can be observed, whereas internal discourse is unobservable) seems to be that external discourse correlates with an ambiguity of role. If I look at a picture, I am biased to be a viewer, though in a sense I can and do repaint my internal representation. If I play with a reactive and adaptive environment, I can alternate the roles of painter and viewer at will. Whether there is virtue in this, I do not know. But there might be.

Rather than indulge in a theoretical discussion of reactive and adaptive aesthetically potent environments, I shall present the case history of one and the plan for another. The case history refers to a system called Musicolour which, though workable, suffered from a number of defects. It is closely related to Professor Lerner's well conceived system Colour Music (presented at the Soviet Exhibition in London, 1961), to the fascinating work of Nicolas Schöffer and to various artifacts shown in the USA. Previous accounts of the Musicolour system have concentrated upon its technical aspect. In the present paper, I shall try to give a glimpse of the historical circumstances, since these are relevant to the development of any similar cybernetic system. The plan refers to a project (called a 'colloquy of mobiles') which is a design for an aesthetically potent environment of a sociological type. Although it is a new departure, it relies heavily upon lessons learned in connexion with Musicolour.

A brief case history of the Musicolour system

The Musicolour system was inspired by the concept of synaesthesia and the general proposition that the aesthetic value of a work can be enhanced if the work is simultaneously presented in more than one sensory modality. This notion is old enough. Baudelaire played with it in 'Les Fleurs du Mal'. Scriabin wrote a part for a 'light keyboard' in one of his symphonies and Kleine (among others) realized a 'light keyboard' in the metal. Walt Disney's *Fantasia* (1940) is a synaesthetic film. Nowadays, when psychedelic effects are commonly synchronized with music, the whole idea of augmenting sound by light is almost as banal as another happening. However, it was not so in the early 1950s.

The first Musicolour machine was built and demonstrated by McKinnon Wood and myself at Jordan's Yard, Cambridge in 1953. It was a transducer which accepted a musical input through a microphone (this input is conveniently formalized as the performer's selection from an auditory vocabulary). The output of the transducer consisted in a selection made from a predetermined vocabulary of visual symbols; coloured forms which were projected on to a large screen in front of the performer and an audience. Even the first machine contained one refinement. We realized[1] that if a synaesthetic relation does exist (for example, if high notes suggest puce splodges) then it almost certainly differs between individual performers. Hence, the machine incorporated a rudimentary learning facility able to modify the relation of the auditory vocabulary to the visual vocabulary as a performance went on.

The development of the system, in particular the specification of what constitutes a visual symbol, owes a great deal to Valentine Boss. At gatherings of the Pomegranate Club (an eclectically Dadaist organization which he founded) it was possible to experiment with Musicolour and to observe its effect upon moderately sized groups of people. In the same spirit we also showed the system in a bizarre and eventful tour of the north country, at Liverpool, New Brighton and Llandudno. On the whole, Musicolour elicited favourable comments. Hence, towards the end of the year, we decided to shift our base of operations from Cambridge to London.

By that time it was clear that the interesting thing about Musicolour was not synaesthesia but the learning capability of the machine. Given a suitable design and a happy choice of visual vocabulary, the performer (being influenced by the visual display) could become involved in a close participant interaction with the system. He trained the machine and it played a game with him. In this sense, the system acted as an extension of the performer with which he could co-operate to achieve effects that he could not achieve on his own. Consequently, the learning mechanism was extended and the machine itself became reformulated as a game player capable of habituating at several levels, to the performer's gambits.[2] Nevertheless we retained the name 'Musicolour' and the theme of sensory transduction because they subserved the financial necessity of marketing the system as an entertainment device. We hoped, also, that an audience would become involved in the very real interaction between the performer and the machine. At Pomegranate happenings, this seemed to occur, but probably because the audience were thoroughly involved in the performance. Subsequent attempts to engage the audience in the performer–machine feedback loop gave disappointing results, though the machine consistently had an almost hypnotic effect upon the performer.

By this time also, the scale of the equipment had been enlarged. Experience in Cambridge showed that a picayune display was utterly ineffective. In practice, it was necessary to modulate between 35 and 50 kW of lighting. The apparatus required for this purpose occupied a couple of motor vans and a team of five people was needed to set up for a one-night stand.

A system of this magnitude was installed at Dr Richard Cook's studio in Gunter Grove, London. It was a beautiful barn of a place, built by Alma Tadema, with a north light that frosted over in winter. It contained a grand piano, a stove that either got red hot or went out and a cosy assortment of 1920s reading lamps. For a year or so this was our permanent base.

At this point, the mechanical and electronic essentials of the system were fully evolved. Let us pause to look at them. An outline of the system is shown in figure 26.

The musical performer (who may, incidentally, be replaced by a small group or band) must first be able to see the visual display and second be able to modify his performance according to what he sees. The latter condition can be satisfied in various ways. At one extreme, the performer has a (usually memorized) score and he modifies his performance by giving a different interpretation to the piece. At the other extreme, he improvises in a fashion that is only constrained by the canons of music and his own disposition.

The musical sequence is picked up by a microphone and amplified. The resulting electrical signal is presented to a bank of property or attribute filters which 'listen to' the sequence. The characteristics of these filters are changed by an internal learning process; technically, their parameters are adjusted. Hence the machine can 'listen to' the perform-

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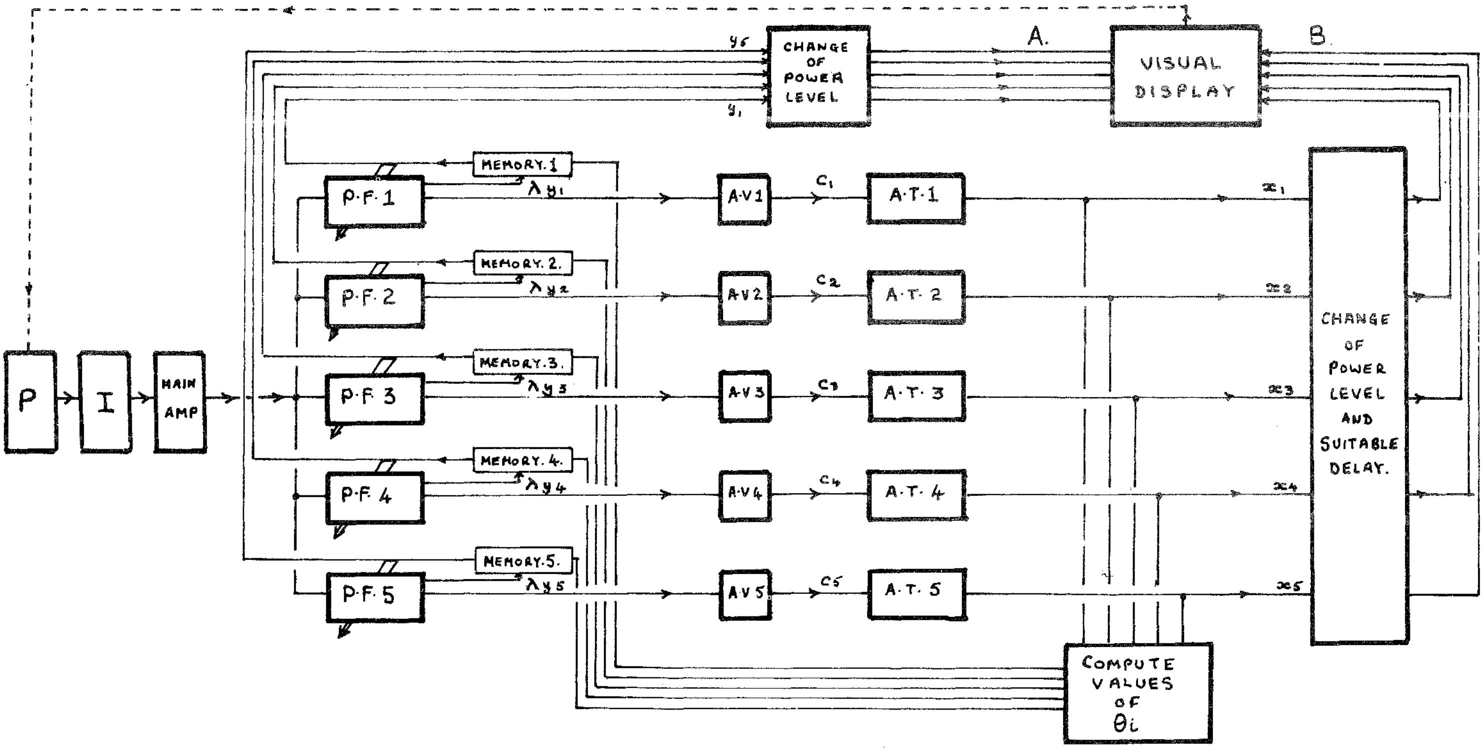
[1] 'We' or 'I' represents Sheila McKinnon Wood, Elizabeth Pask, T. R. McKinnon Wood and myself, together with our immediate collaborators, notably John Brickell and Jone Parry. Rightly, this part of the article should be dedicated to Jone Parry, the musical director, who died while it was being written. Even in the hectic conditions of development and commercial exploitation, Jone worked on the system to produce an art form.

[2] Such a device has much in common with Nicolas Schöffer's artifacts which I learned about many years later.

Fig. 26 Outline of a typical Musicolour system. P = Performer, I = Instrument and microphone, A = inputs, y_i, to visual display that specify the symbol to be selected, B = inputs, x_i, to the visual display that determine the moment of selection. PF = property filter, AV = averager, AT = adaptive threshold device. Memories hold values of (y_i) and (y_i). Control instructions for adjusting the sequence of operation are not shown. Internal feedback loops in the adaptive threshold devices are not shown.



ance in different ways; the machine-learning process is chiefly a matter of learning to listen.

There could be up to eight different property filters, each with an independently adjustable parameter. In the system shown in figure 26, there were five only. Again, the properties could be chosen in various different ways; for example, in the earlier machines we used only frequency band pass filters (the parameter value determining which pass band the filter listened to). For the system of figure 26, primarily designed to suit piano music, the five properties were, (1), (2), (3), frequency filters operating between 50 and 7500 cps (the parameter value for anyone determining the location of the band pass maximum in this range); (4) a transient detector and (5) a fairly complex rhythm detector.[1] The parameters of filters (4) and (5) were delay operators. To complete the description, each parameter could assume one of eight possible values at a given instant.

The electrical output from each filter is now separately rectified and short term averaged. The resulting signals are designated c_i (fig. 26), the subscript $i = 1, 2, 3, 4$ or 5, indicating the name of the associated property filter. c_i is next presented to an adaptive threshold device. Such a device emits an output impulse (designated as $x_i = 1$) if its input, c_i, exceeds some threshold value, T; failing this, $x_i = 0$. To render the circuit adaptive, we arranged that the value of T would decrease at a fixed rate when $x_i = 1$ and that it would increase at a fixed rate if $x_i = 0$. Hence, the circuit automatically adjusts its sensitivity to the mean value of c_i and adapts.

The 5 variables, x_i, are one output from the machine (they determine when a selection is to be made from the visual vocabulary). The other output consists in 5 variables, y_i,

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[1] The circuit detects a beat in the music. Given a beat, it estimates when the next beat will occur on the basis of its previous experience and an internal counter that selects which beat in a short sequence this is. The filter output is high valued if its estimate is right.

which are identical in value with the settings of the filter parameters (the y_i determines which visual selection is to be made).

The learning mechanism in figure 26 sets the values of the y_i. The filter parameter values are changed by motor-driven switches (carrying several banks of contacts but with 8 positions, corresponding, in the case of the *i*th, to the 8 values of y_i). Each contact position is associated with a pair of 'memory' circuits. One of these retains a record of how long it is since this position was last selected (call this quantity $\lambda(y_i)$ for reference; its value is set to 0 when the switch position is occupied and increases otherwise). The other 'memory' contains a record of a selective figure of merit (for the *i*th property filter with a particular parameter value), designated $\theta(y_i)$. This quantity depends upon a 'figure of merit' variable, θ_i, which is associated with the filter alone (irrespective of the parameter value) in the sense that $\theta(y_i)$ is incremented or decremented towards the prevailing value of θ_i on those occasions when the switch is in the given position (i.e. when y_i has a particular value). Now, at a specific instant, $\theta = R_i$ [Time average (x_i)], where R_i is a rough measure[1] of the difference (in the immediate past) between the impulse sequence from the *i*th threshold circuit and the four other impulse sequences. Hence, θ_i is high valued if x_i is often in state 1 *and* if the *i*th impulse sequence is idiosyncratic. $\theta(y_i)$ is high valued if these conditions are satisfied for a particular switch position or value of y_i.

The parameter switches are driven by their motors according to a strategy that seeks a high figure of merit and also guarantees (through the use of the $\lambda(y_i)$) that all of the switch positions are sampled. The strategy is: if the *i*th switch has selected position y_i, remain there for at least a preset minimum interval (about five seconds); otherwise inspect the $\lambda(y_i)$ and the $\theta(y_i)$ and move to whichever position corresponds to a maximum of $\lambda(y_i) + \theta(y_i)$ (if there are several maxima, one is selected by an arbitrary rule).

Applied to each of the switches, the strategy determines the instantaneous values of the 5 variables, y_i.

Such a system 'gets bored' (the electronic circuits that mediate this characteristic are the adaptive threshold devices and the mechanism involving the $\lambda(y_i) + \theta(y_i)$). In the absence of any input the system becomes increasingly sensitive and responds to any slight sound (while strictly desirable, this feature proved to be a nuisance in practice and it was suppressed by an arbitrary gain control circuit which limited the input amplifier gain in the absence of a sensible level of sound). Again, given a repetitive input, the system 'directs its attention' to the potentially novel.

However, the machine is eminently trainable and it is trainable in many different ways. The performer can use several gambits (all involving the accentuation of properties of the music) to reinforce the audio visual correlations which he prefers. At the lowest level, he can concentrate upon single properties of the music (and their visual correlates). At a higher level of interaction, he can make use of emphasis and accentuation in order to reinforce relations between groups of musical properties,[2] and the visual output. Later, I shall argue that he not only can do so but, in fact, does so.

The 'learning' mechanism, in particular its strategy, was chosen as one of many alternatives which foster the transfer of information around the entire feedback loop of figure 26, i.e. the loop involving visual display, performer, musical instrument and 'learning' machine. Phrased differently, the machine is designed to entrain the performer and to couple him into the system. In these terms, the importance of 'habituation' and 'novelty seeking' are evident if we also accept the proposition that man (the converse participant) is impelled to seek, learn about and resolve novelty in his environment.

In the display of figure 26, the y_i specify the set of visual signs from which a selection is actually made. Several arrangements were used to satisfy this paradigm. One is shown in figure 27. The x_i actuate five separate time-lagged dimmers which energize five projector spotlamps aimed at a cyclorama or screen. Each of these has a colour and pattern wheel, the object in figure 27, servo-positioned by the corresponding parameter switch (its position, y_i, determines which pat-

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[1] The measure is obtained by generating for each transition $(x_i = 0) \rightarrow (x_i = 1)$ a positive going, exponentially damped, waveform $\phi_i(t)$ and simultaneously generating its negative going complement $-\phi_i(t)$. R_i is the output of an averaging circuit with a fifteen-second time constant that receives $\phi_i(t)$ and four different waveforms $\frac{1}{4} - \phi_j(t), j \neq i$ as its input. If the impulse sequences $x_i(t)$ are identical, all R_i become 0. The deviation of $x_i(t)$ is roughly indicated by an increase in R_i.

[2] The rhythmic property is inherently time dependent. Apart from this, the performer can establish time-dependent behaviour patterns in the system because of the form of search strategy.

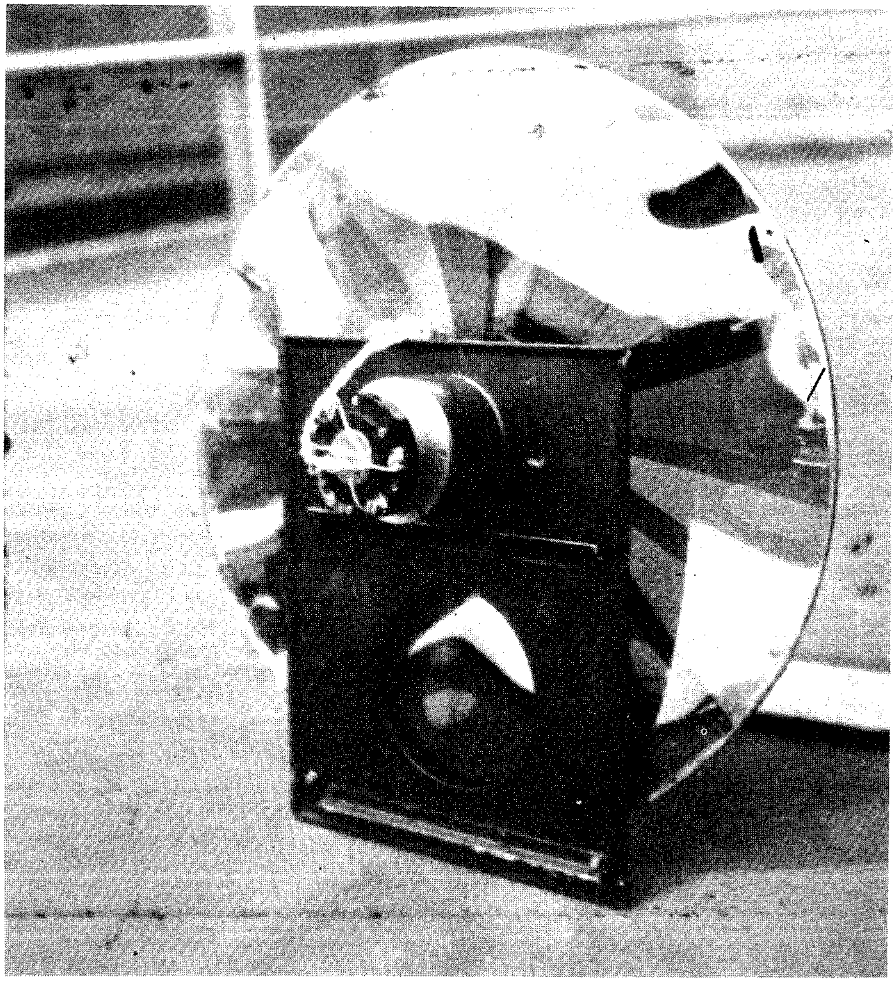

Fig. 27 Servo-positioned projection wheel.

tern will be projected if the spotlamp is energized). The colour and pattern wheels can be replaced by reflectors (servo-positioned in step with the parameter switches); a display of this sort is shown in figure 28.[1] Finally, the controlled position of reflectors can be replaced by the controlled motion of reflectors or three-dimensional objects. Each display mode was used in the first theatrical presentation of Musicolour which took place at the Boltons Theatre in 1955; figure 29 is a view of some details of the set.

The Boltons show came about because some friends, who had seen the Musicolour system in Llandudno, ran a puppet theatre. We decided to combine marionettes with Musicolour in a piece entitled ‘Moon Music’. But marionettes and Musicolour proved to be unhappy bedfellows. There were many difficulties. A number of mechanical creatures had been introduced, by way of gimmickry, one was humanoid, the others more freely conceived. These were meant to move in synchrony with the system output and, at

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[1] This account is somewhat over-simplified. In addition, the y_i selected groups of lamps energized by the x_i. Typically, there were some fifteen different 1-kW lamps and fifteen different $\frac{1}{2}$-kW lamps usually arranged in three or four groups.

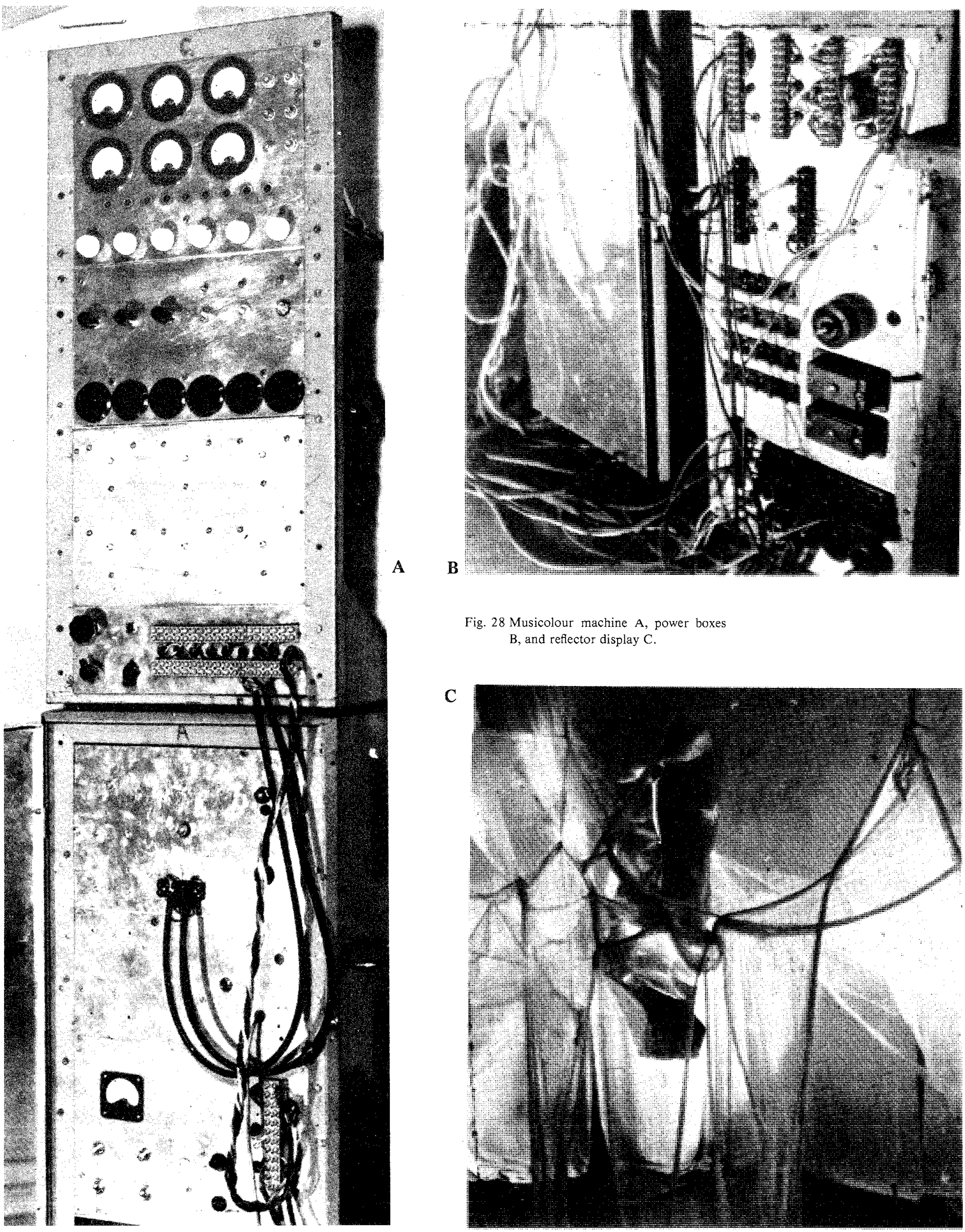


Fig. 28 Musicolour machine A, power boxes B, and reflector display C.

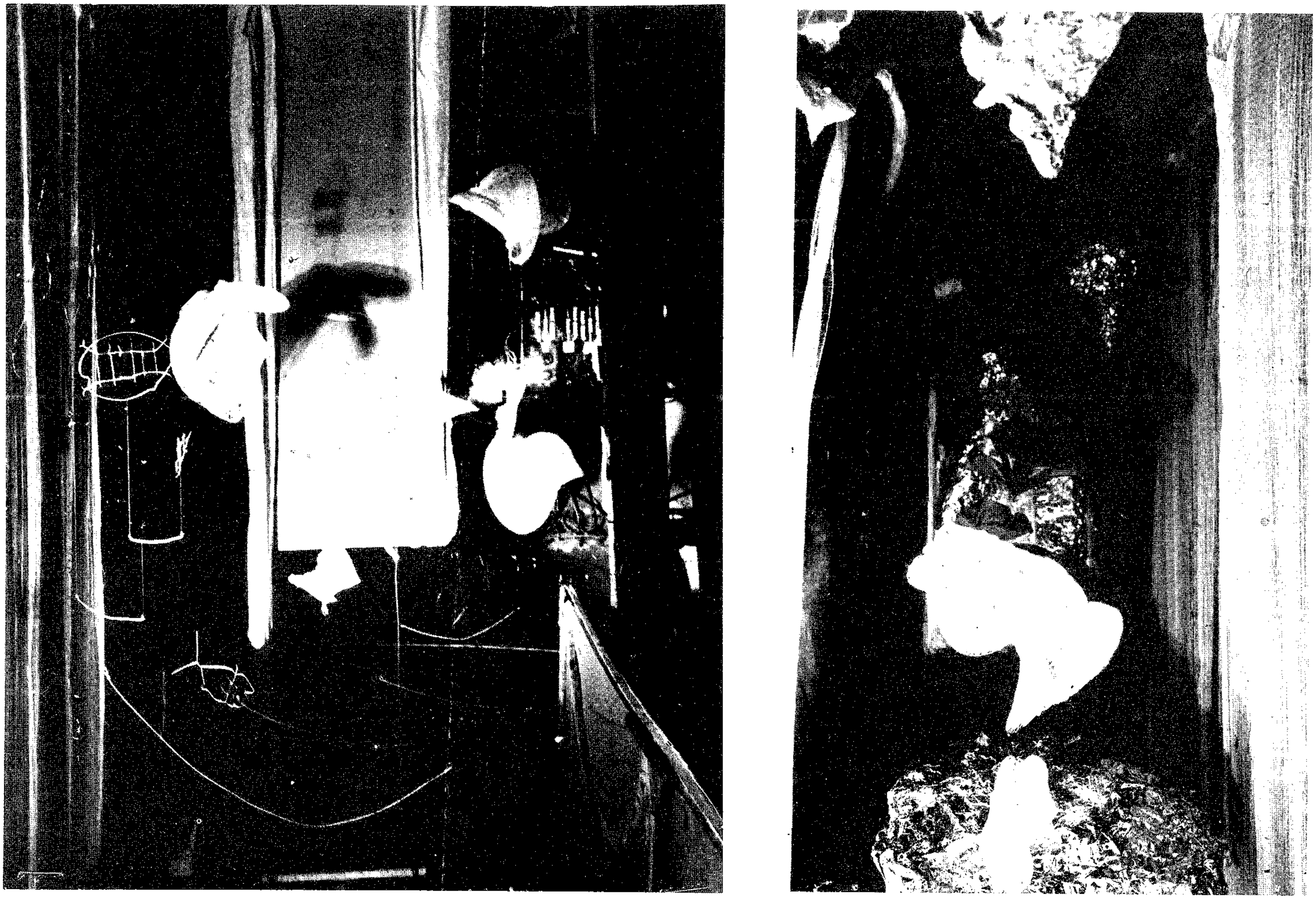


Fig. 29 Part of the Musicolour display at the Boltons Theatre.

rehearsals, they did so. On the first night, however, the humanoid dismembered himself (due to a malfunctioning feedback loop) and scattered his limbs among the audience. Another animal lost its front end. The marionette strings got helpelessly mingled with the display of figure 29. The audience was, at the most, bemused by the entertainment. Finally, our stage manager (who said he was used to puppets) went positively beserk after a week of it and sailed for Portugal. 'Moon Music' closed, leaving us with a month's paid-up rental on the theatre.

It would have been disastrous apart from Jone Parry, our musical director. But the spare month provided her with a public workshop in which to develop the musical potentialities of the system. The show reopened as a concert performance, with Jone, a flautist and a dancer, other musicians playing if they wished to. Jone worked out what a musician can do with the system, both as an aid to composition and an aid to performance. It turns out that one can do quite a lot, for a close co-operative rapport is soon established between the man and the machine.

On a technical level, it was possible to investigate the stability of the coupling, or rapport, which Jone rationalized in aesthetic terms. In this study arbitrary disturbances were introduced into the feedback loop without the performer's knowledge. Even though he is ignorant of their occurrence, these disturbances are peculiarly distracting to the performer, who eventually becomes infuriated and opts out of the situation. But there is an inherent stability in the man–machine relation which allows the performer to tolerate a certain level of disturbance. We found that the tolerable level increases as the rapport is established (up to a limit of one hour at any rate).

Fig. 30 Part of the Musicolour display at Valerie Hovenden's Theatre Club.

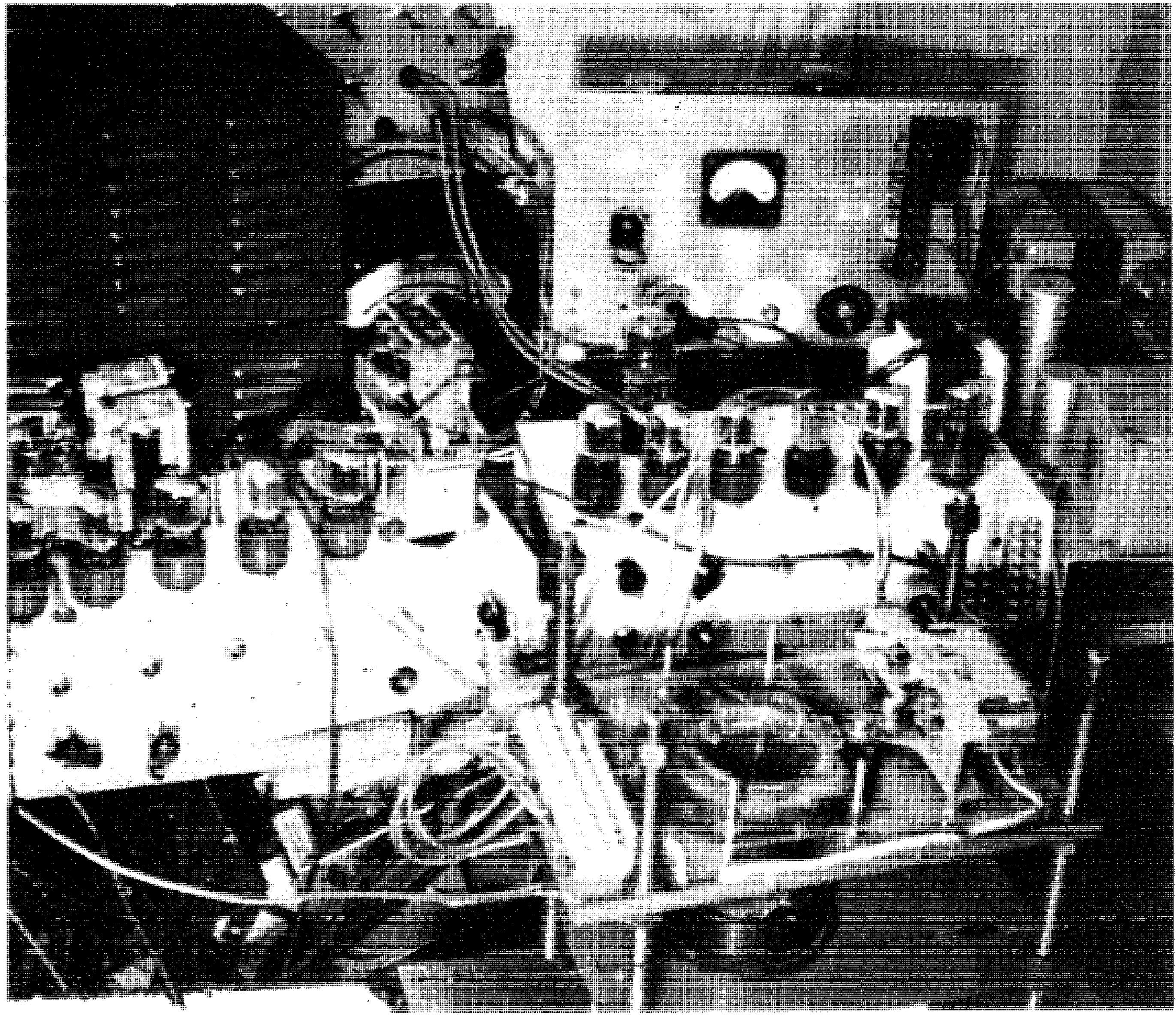


Fig. 31 Electrochemical system.

Meanwhile, John Clark, a psychiatrist, had come to the theatre and we jointly observed some phenomena related to the establishment of rapport. First, there is a loss of time sense on the performer's part. One performer, for example, tootled away on his instrument from 10 p.m. to 5 a.m. and seemed unaware that much time had passed; an hour, he thought, at the most. This effect (manifest to a much lesser degree) was ubiquitous. Next, there is a group of phenomena bearing on the way in which performers train the learning machine.

As a rule, the performer starts off with simple tricks which are entirely open to description. He says, for example, that he is accenting a chord in a particular passage in order to associate a figure in the display with high notes (he can either describe the figure or point it out when it occurs). Soon, and usually about the moment when a performer feels he has control of the system, the determinate trick gives way to a behaviour pattern which the performer cannot describe but which he adopts to achieve a well-defined goal. Later still, the man–machine interaction takes place at a higher level of abstraction. Goals are no longer tied to properties as sensed by the property filters (though, presumably, they are tied to patterns of properties). From the performer's point of view, training becomes a matter of persuading the machine to adopt a visual style which fits the mood of his performance. At this stage in the development of rapport, the performer conceives the machine as an extension of himself, rather than as a detached or disassociated entity.

You need a mellow, elegant, South Kensington period in developing any cybernetic art form.

The next public presentation of Musicolour was at Valerie Hovenden's Theatre Club in Shaftesbury Avenue; literally in the crypt of St Anne's. Miss Hovenden had encouraged me to write a review, 'Nocturne', with the system as a prominent feature. Some rather elaborate display mechanisms were used (see fig. 30) and 'Nocturne', as a whole, was moderately successful. The chief cybernetic developments were an attempt to link the motions of a dancer to the input of the machine (this proved technically difficult but the aesthetic possibilities are indisputable), and a rough and ready study of the perceptual properties of the system. Cogent visual symbols appear to act as 'releaser' stimuli and observations of Clark and myself suggested that the most effective 'releasers' are short sequences of visual events, rather than static configurations.

Since the system was costly to maintain and since the returns were modest, the Musicolour enterprise fell into debt. We secured inexpensive premises above the Kings Arms in Tabernacle Street which is a curiously dingy part of the city of London, often engulfed in a sort of beer-sodden mist. There, we set up the system and tried to sell it in any possible way; at one extreme as a pure art form, at the other as an attachment for juke boxes.

The only real development during this period was an electro-chemical display. It consists of several shallow dishes, one for each output variable, mounted on rotatable frames (one dish is shown in fig. 31). Each dish contains electrolyte and an indicator (which changes colour when the pH of the solution is altered, for example, by local electrolysis). The output x_i energizes electrodes positioned in the ith dish. Current passes, local electrolysis occurs and a colour pattern is built up. The output y_i rotates the ith dish with respect to the electrodes. The patterns are projected on to a screen.

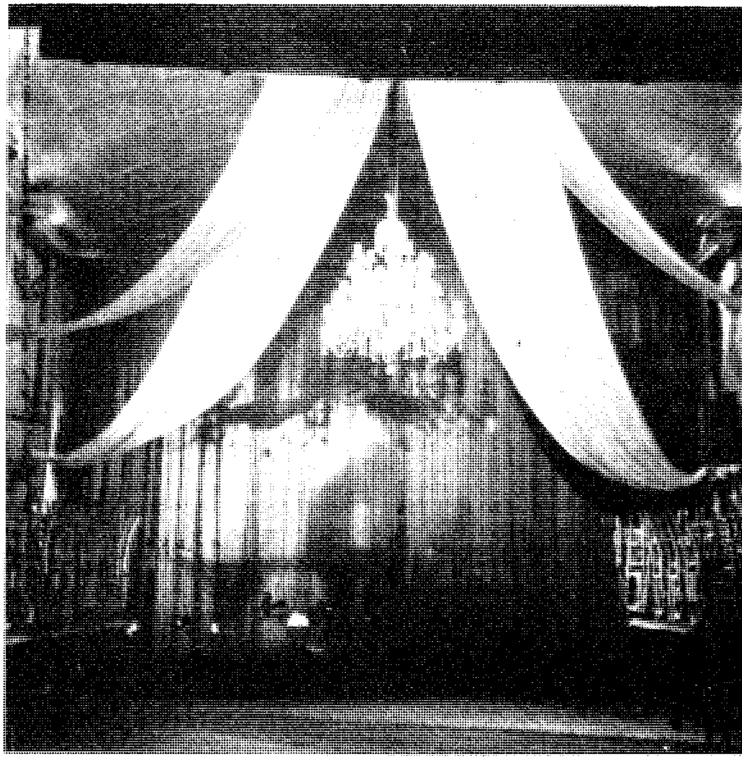
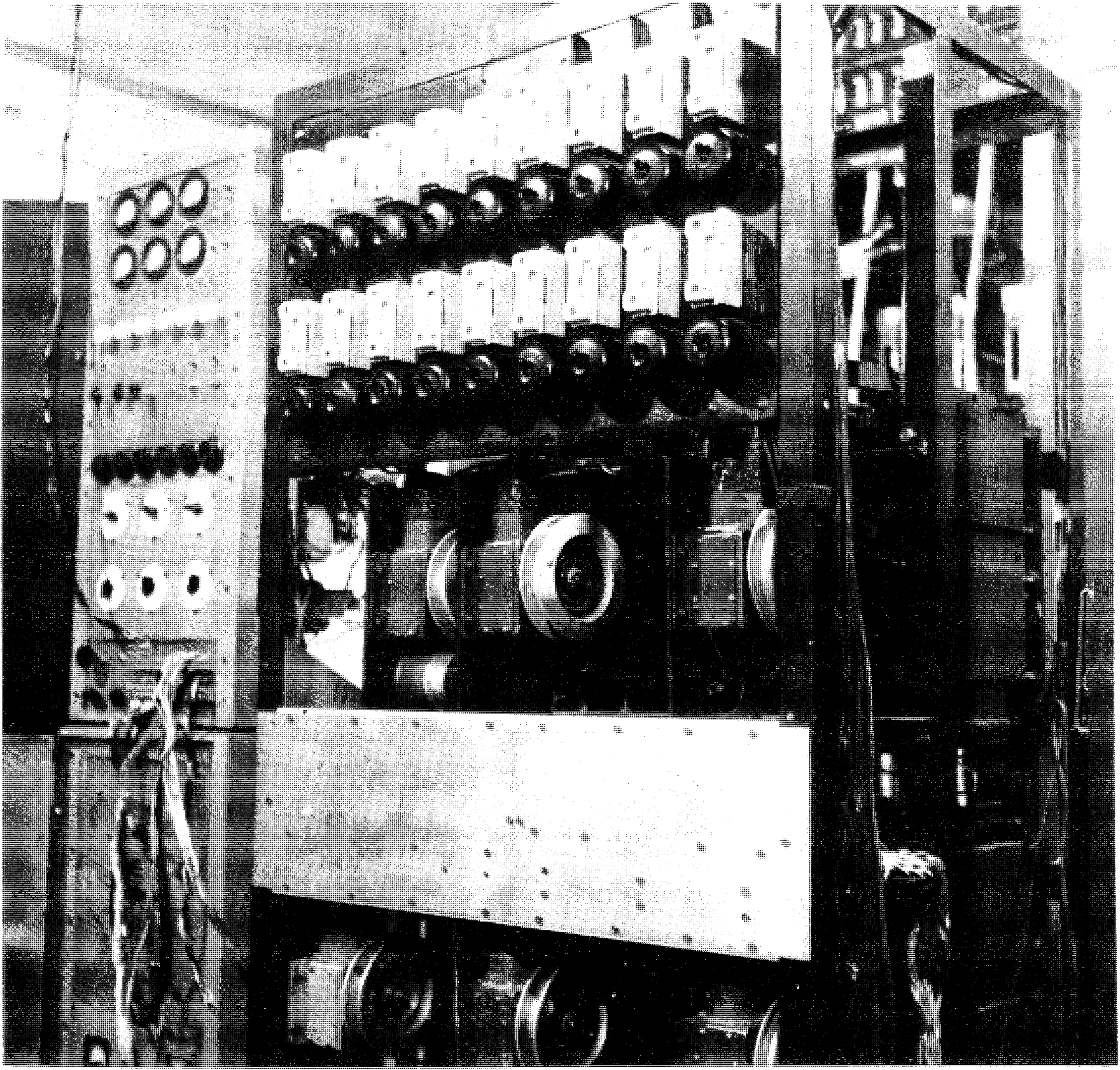


Fig. 32 Musicolour display at Churchill's Club.

At this moment, fortune changed a bit, though from a cybernetic point of view the story is nearly told. Cecil Landau became a partner in the enterprise and presented Musicolour in his revue at Churchill's Club (fig. 32). The show was presented twice nightly, at 11 p.m. and 1 a.m. and it had the glittering theatrical proportions to which Mr Landau was accustomed. Indeed, he was prone to regard an

Fig. 33 Musicolour was equipped with a servo-dimmer board and transferred to the Mecca Locarno at Streatham.



archway across the middle of the night-club as a surrogate proscenium and everything beyond it as a stage. But this view of the world was not generally accepted and, in practice, the Musicolour installation sat in a service passage. There it had to be guarded from the half fearful attention of dance hostesses and from waiters who adopted a cavalier attitude to the instrument and dropped cutlery into its entrails. For all that, the audience reaction was favourable and Musicolour became a permanent feature of the spectacle.

We also used the system when people were dancing and discovered that in these conditions an audience can participate in the performer–machine feedback loop just because they are doing something to music and the band is responding to them.

The following year, the system was equipped with a servo-dimmer board (fig. 33), and was transferred to the Mecca Locarno at Streatham. It was used to modulate about 120 kW of power in the existing lighting installation. With a good rhythm group it acted as a conductor, that is, it pulled the group into more fully co-operative activity. With a large band it was less effective. In any case it induced very little participant activity on the part of the dancers in this large dance-hall. We learned that in order to obtain any participation at all, it is necessary to exclude spatial cues that allow the audience to opt out of the display environment. Even an illuminated Exit sign is a nuisance in this respect. On the whole, however, the dancers (in contrast to the band) regarded Musicolour as another fancy lighting effect. It was clear that in large scale (and commercially viable) situations, it was difficult or impossible to make genuine use of the system.

Musicolour made its last appearance in 1957, at a ball organized by Michael Gillis. We used a big machine, a small machine and a collection of display media accumulated over the years. But there were other things to do. After the ball, in the crisp, but fragrant air of St James's Park, the Musicolour idea was formally shelved. I still have a small machine. But it does not work any longer and is of chiefly sentimental value.

A plan for an aesthetically potent social environment

The 'colloquy of mobiles' presented at the Cybernetic Serendipity exhibition is completely system-designed and its electronic parts are largely detailed. It is a socially orientated reactive and adaptive environment. Even in the absence of a human being, entities in the environment communicate with and learn about one another. But a human being can enter the environment and participate; possibly modifying the mode of communication as a result.

To begin with it was necessary to select a structural idiom; preferably (to avoid undue strangeness) an idiom that is accepted within the conventions of art. Rather arbitrarily, I chose to make the communicating entities mobiles and the environment into a community of mobiles. These, however, are powered mobiles, the motion of which is partially determined by instructions from a program (though there are haphazard components as well). They are also provided with computing systems to control their activity.

Next, it was necessary to equip the mobiles with a language in terms of which they can communicate. As a compromise between cogent visual effect and technical convenience, I chose an alphabet of visual signs and audible signs. Each mobile is able to emit and recognize several different colours and time modulations of light and several different tones and time modulations of sound. The syntax of the language depends upon interpretation rules built into each mobile (we come to these in a moment). But, as it stands, the language is no more than a code. Communication could be made to occur but only in the trivial sense of an epiphenomenon. To give meaning to the communication, the mobiles must be given a reason for talking to one another and a set of goals to aim for.

Scrutiny of the goal problem reveals the following desiderata (which may also be regarded as, in some sense, prerequisites for a meaningful community of mobiles which has a chance of being an aesthetically potent environment):

1 The goals of the several mobiles should be partially incompatible, so that the mobiles compete with one another.
2 Some of the goals should be incapable of attainment by any one mobile on its own. In order to achieve such a goal, at least a pair of mobiles must co-operate and in order to co-operate, they must communicate with one another.

3 The main goals of a mobile should be decomposable into sub-goals so that any mobile contains an hierarchical organization.

4 Co-operative interaction must involve main goals and sub-goals so that there are several levels of communication in the system.

5 The pursuit of the lowest level sub-goals should be carried out by autonomously acting programs embedded in each mobile. Whereas selection of these programs depends upon communication mediated feedback, their execution does not. This is one way (incidentally, a biologically important way) of decoupling the mobiles and maintaining their individual integrity.

As designed, there are two sorts of mobiles in the population; say 'male' and 'female'. They are arranged as shown on the plan of figure 34*a* and the elevation of figure 34*b* (this is probably the simplest arrangement; other configurations are possible and the size of the community can be enlarged without seriously affecting the design). The male mobile has two 'drives', O and P (associated with orange- and puce-coloured light) and its drive state is indicated visually by an upper display, A. Its main goal is to satisfy (or reduce) the O and P 'drives' which normally build up over time. It can do so, in the case of O, by projecting an intense beam of orange light from its central part, B, in such a way that it falls upon receptors in its upper part, C; in the case of P satisfaction it must project an intense beam of puce light from B in such a way that it falls on receptors in the lower part, D.[1] In order to achieve this goal it must elicit the co-operation of a female who, unlike the male, is provided with a vertically positionable reflector capable of taking the beam from B and reflecting it back either to D or C.

First, of course, it must find a female. To do so, the male engages in motions that:

1 Rotate the bar linkage, Z and

2 Rotate each male about its point of suspension.

So far as the first motion is concerned, a sort of 'territorial' competition may take place between male I and male II, if their search instructions are in conflict, for example, if I has found a female and wants to remain stationary, but II wants to continue searching. The conflict is resolved[2] by an aggression display (in which the relative power of the males depends upon their drive states). So far as the second motion is concerned, the males are independent (though there is still a sense in which they compete for the available females).

Consider a particular state[3] of any one male, for example, the state in which male I has drive O greater than drive P and has not found a female to help it. In this case, male I sends out an intermittent directional visual signal which serves to identify it as 'male I' and its desire as 'O satisfaction'. It moves according to (1) and (2) above (unless (1) is blocked by male II) seeking a co-operative and receptive female (the females are normally in rotational motion, seeking males). Should the directional signal fall on the receptor a of a female who is willing to co-operate, she produces an identifying sound in synchrony with the intermittent light signal. Male I detects the correlation between the female and his light signal and stops his motion (unless he is prevented from doing so by male II). At this point, he triggers off an autonomous energetic event which consists in shining an intense orange light, for at least a minimum interval, in the direction of the located female. The immediate result is an increase in the O drive. However, male I anticipates subsequent reinforcement (which he will achieve if the female behaves appropriately and if the free moving part, C, is appropriately positioned during at least some of this behaviour). Reinforcement, which substantially *reduces* the O drive, is obtained if the O goal is satisfied; that is, if orange light falls on the receptor in C. Supposing reinforcement occurs, male I emits an identifying sound signal which is received by the co-operating female; the autonomous energetic event is prolonged and the O drive is decreased.

The co-operative encounter terminates after a short time if reinforcement does not occur, or if it is externally disrupted. Otherwise, it continues until the drive state of male I is modified so that he aims for a different goal.

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[1] D and C are free-moving members loosely coupled to the main mobile body.

[2] I shall not go into the aspect of the system, for its details are not yet worked out.

[3] The relevant states are 'upper limit $\geqslant$ drive $O >$ drive $P \geqslant$ lower limit', which induces an O satisfaction search; 'upper limit $\geqslant$ drive $P >$ drive $O \geqslant$ lower limit' which gives rise to the converse; 'lower limit $>$ drive O *and* lower limit $>$ drive P' in which case the male is satisfied and indifferent, and 'drive $O >$ upper limit *and* drive $P >$ upper limit' which produces a search for either O or P satisfaction.

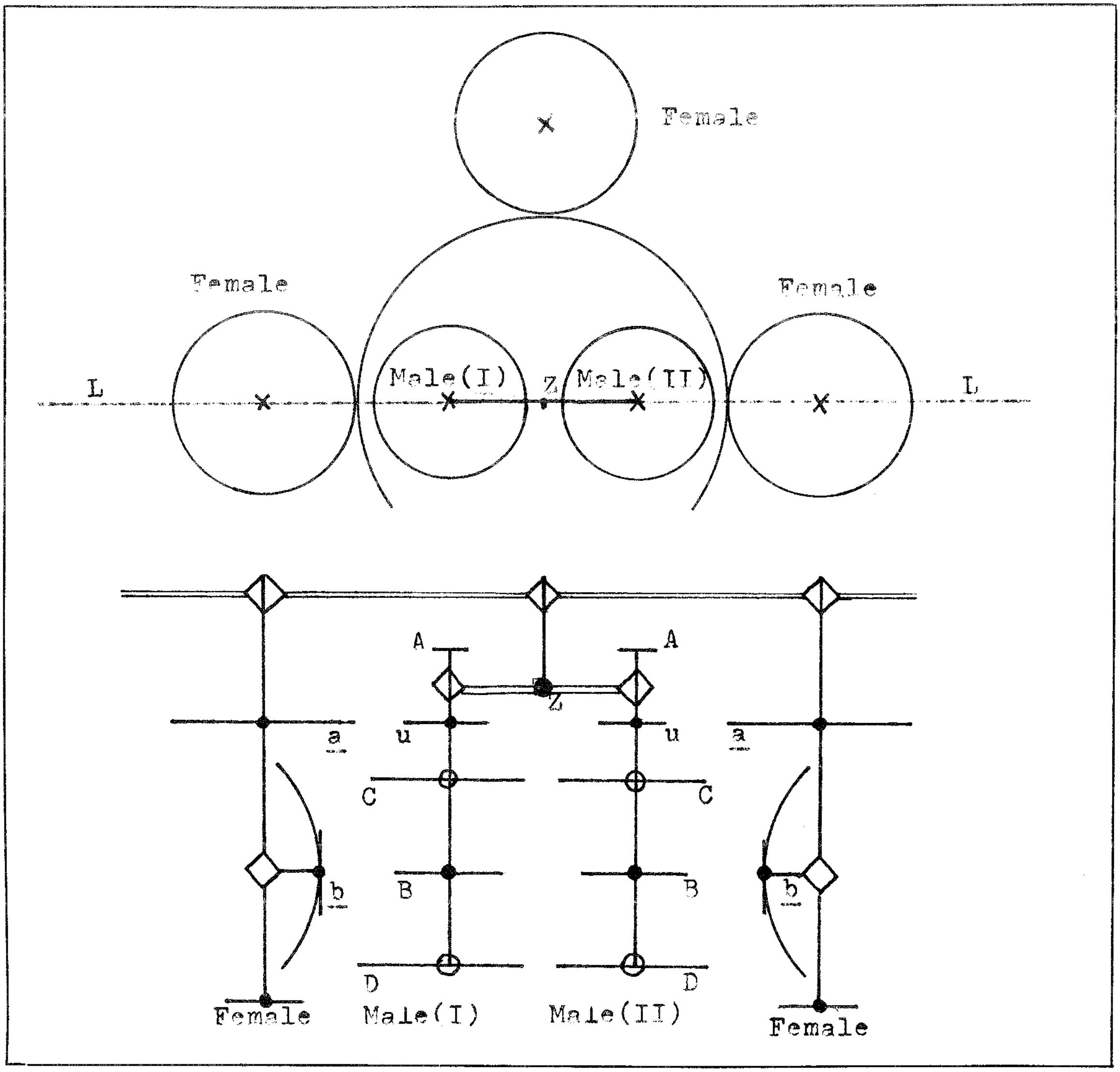

Fig. 34 A rough sketch of powered mobiles.

a Horizontal plan

b Vertical section taken through line *L* in horizontal plan.

A = drive state display for male

B = main body of male, bearing 'energetic' light projectors *O* and *P*

C = upper 'energetic' receptors

D = lower 'energetic' receptors

U = non-'energetic', intermittent signal lamp

a = female receptor for intermittent positional signal

b = vertically movable reflector of female

Z = bar linkage bearing male I and male II

◇ = Drive motor

⊕ = Free coupling

● = Fixed coupling

═ = Bar linkage

It is evident that the achievement of the *O* satisfaction goal involves an hierarchy of sub-goals and that communication in pursuit of these sub-goals takes place at various levels. Further, the selection of a main goal (such as *O* satisfaction) involves a still higher level process. Referring back to the list of desiderata, we can check that the male members of the mobile community satisfy all of them.

Consider a female: she also has an *O* drive and a *P* drive. Unless both drives are satisfied (when she becomes inert) the female rotates and searches for a male. According to her drive state, she is receptive to males offering *O* or *P* co-operation or to both. Suppose that she is looking for *O* co-operation and suppose she encountered male I in the state already described, on receipt of his intermittent directional signal, she puts his name 'male I' and his intention '*O* satisfaction' into a short-term memory. Next, she emits the correlated sound which he can recognize and expects to receive the 'energetic' beam of orange light. If this *does* fall on her vertical reflector, *b*, she stops her rotational motion and starts a search, using this reflector, to position the beam on some part of male I that will give rise to a reinforcement signal; her goal is to obtain the conjunction of orange light on her reflector and the reinforcement signal from male I; goal achievement reduces her *O* drive. Her likelihood of achieving this goal in the rather short time allowed for an unreinforced encounter, depends upon the vertical reflector search strategy and this in turn depends upon her previous experience (upon what she has learned and placed in a long-term 'memory'). In ignorance of males, her vertical strategy is a haphazard search reflecting the beam up and down. However, if she has previously learned that reinforcement for *O* light comes from reflecting it upwards (in fact on to *C* of male I), then her strategy becomes a limited upwards search. A similar comment applies to *P* experience. Further, not all males are necessarily the same; some may like *O* light on *D* and *P* light on *C*; she can learn that trick also.

In any case, the vertical search strategy terminates after a short time (and the rotational search is resumed) if a reinforcement signal is not received from the male.[1] If a signal is received, the vertical search is prolonged possibly until the female drive state has been modified. The whole process is summarized in the accompanying flow-charts. There are five independent systems, three female and two male which are run asynchronously in parallel. The flow-charts of figures 35, 36 and 37 represent a female system and the flow-charts of figures 38 and 39 represent a male system.

This completes[2] our description of the social environment of mobiles.

The really interesting issue is what happens if some human beings are provided with the wherewithal to produce signs in the mobile language and are introduced into the environment. It is quite likely that they will communicate with the mobiles, for the mobiles are interacting already and ostensively define the gambits involved in the process. Further, their community has quite an intriguing organization. At this level alone, the environment has the properties required of an aesthetically potent environment.

But the mobiles produce a complex auditory and visual effect by dint of their interaction. They cannot, of course, interpret these light and sound patterns. But human beings can and it seems reasonable to suppose that they will also aim to achieve patterns that they deem pleasing by interacting with the system at a higher level of discourse.

I do not know. But I believe it may work out that way.

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[1] The vertical search is the female form of an autonomous process.

[2] We have cited special cases. The account is, however, readily generalized to cover all initial conditions of the mobiles.

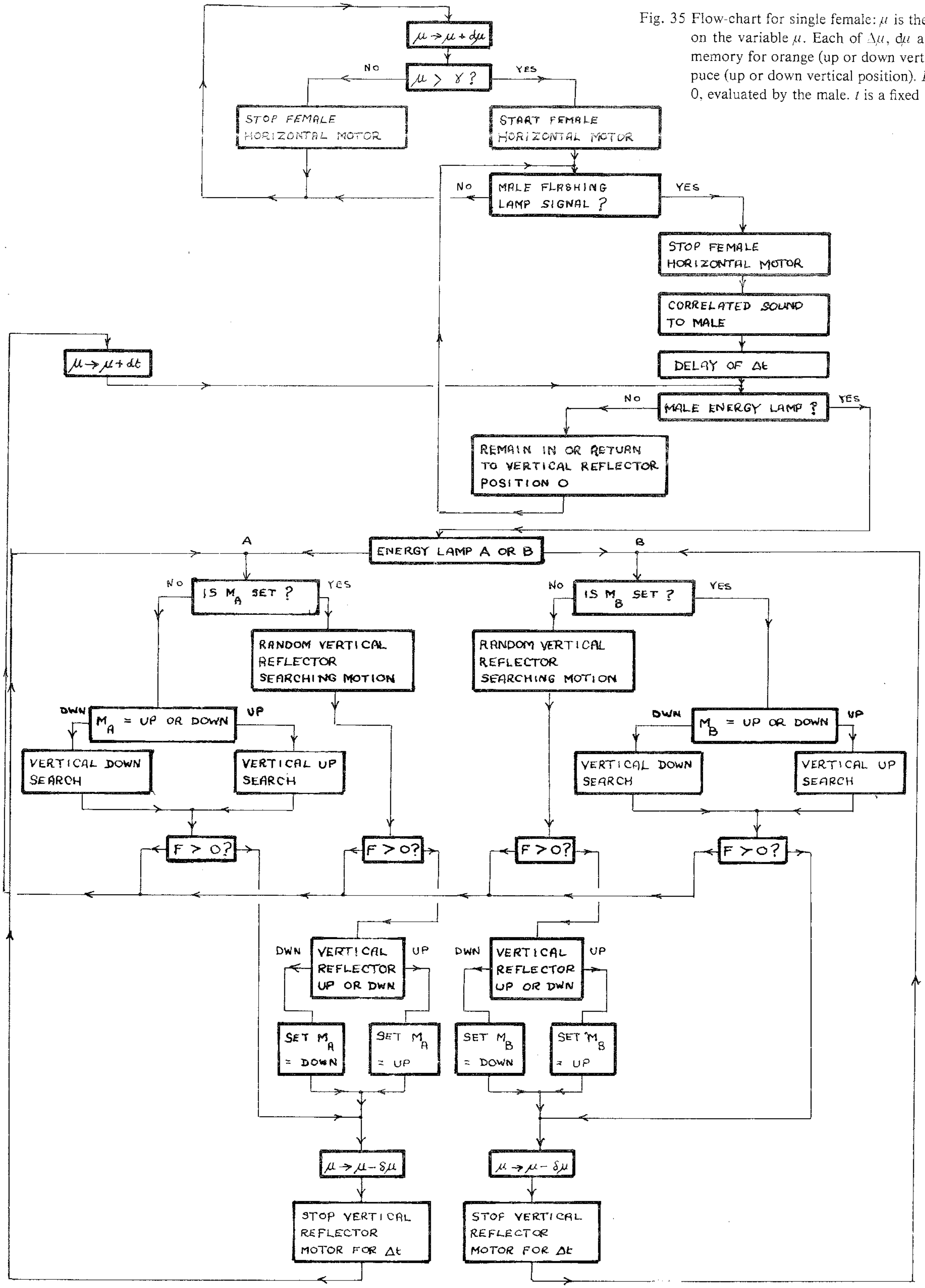
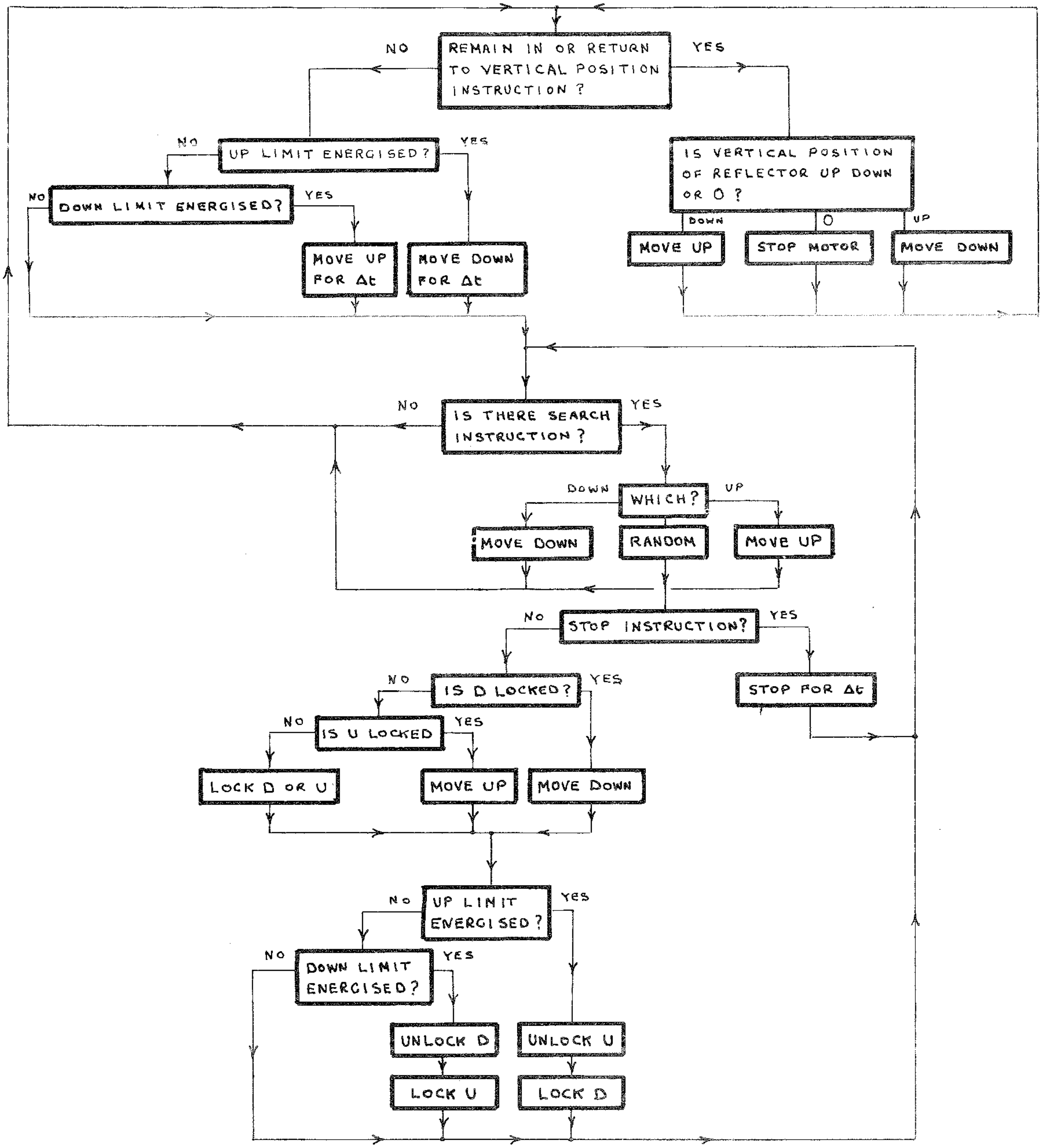


Fig. 35 Flow-chart for single female: μ is the female drive variable and γ is a limit on the variable μ. Each of $\Delta\mu$, $d\mu$ and $\delta\mu$ is a different increment. M_A is memory for orange (up or down vertical position) and M_B is a memory for puce (up or down vertical position). F is a reinforcement variable, $F = 1$ or 0, evaluated by the male. t is a fixed delay.



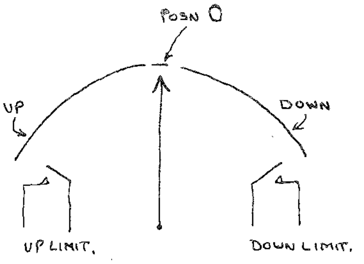


Fig. 36 Female vertical reflector sub-system. Flow-chart for control of vertical motors. This sub-system receives instructions from the main female program, information from a pair of limit switches, and a positional sensing switch on the vertical reflector motor. *D* and *U* are lock relays.

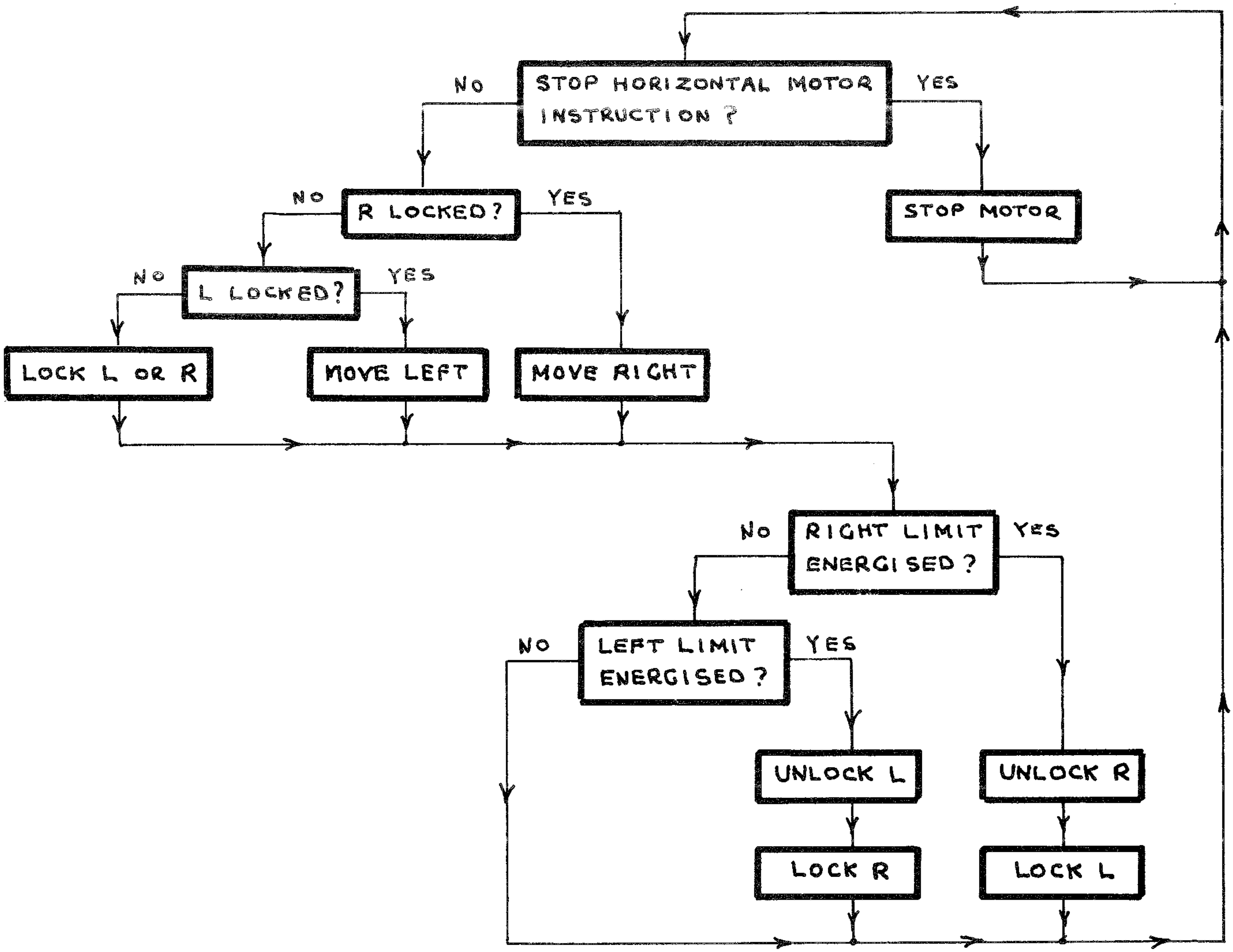
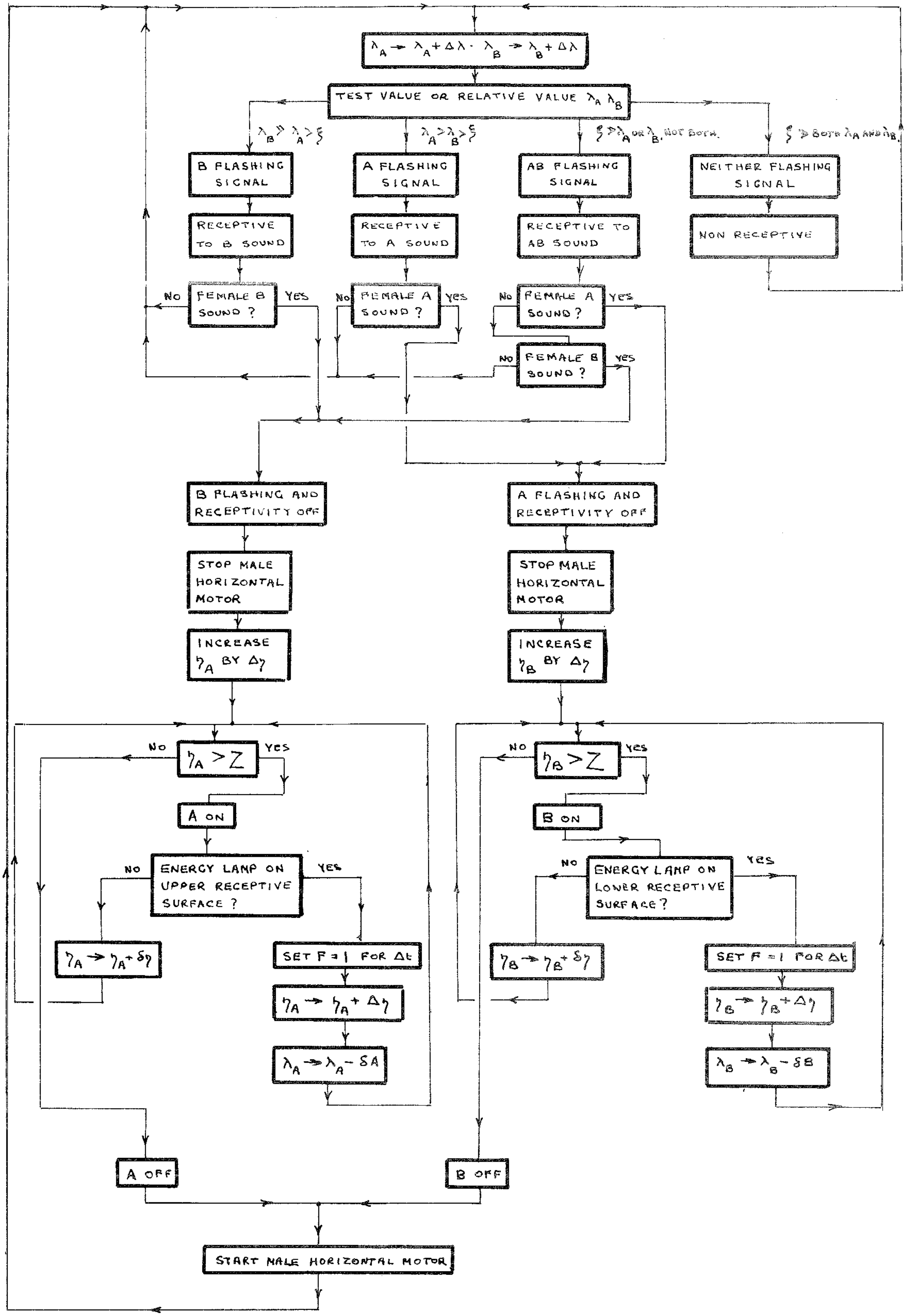


Fig. 37 Flow-chart for female horizontal control sub-system. This sub-system receives horizontal stop instructions from the main female sub-system, information from right and left limit signals. R and L are lock relays.

opposite

Fig. 38 Flow-chart for male: A = orange memory lamp; B = puce energy lamp. Flashing signal is male–female communication signal.
λ_A λ_B are the male drive variables.
η_A η_B are the male internal state variables.
ζ is a limit on λ and Z is a limit on η.
It is assumed that this male is reinforced if either the A male energy lamp is reflected on to its upper receptive surface or if the B male energy lamp is reflected on to its lower receptive surface.
F is a reinforcement variable, $F = 1$ or 0, the value of which is also conveyed to the female.


$\lambda_A \rightarrow \lambda_A + \Delta\lambda \cdot \lambda_B \rightarrow \lambda_B + \Delta\lambda$
TEST VALUE OR RELATIVE VALUE λ_A λ_B
$\lambda_B \gg \lambda_A > \xi$
$\lambda_A > \lambda_B > \xi$
$\xi \gg \lambda_A$ OR λ_B. NOT BOTH.
$\xi \gg$ BOTH λ_A AND λ_B.
B FLASHING SIGNAL
A FLASHING SIGNAL
AB FLASHING SIGNAL
NEITHER FLASHING SIGNAL
RECEPTIVE TO B SOUND
RECEPTIVE TO A SOUND
RECEPTIVE TO AB SOUND
NON RECEPTIVE
NO
FEMALE B SOUND ?
YES
NO
FEMALE A SOUND ?
YES
NO
FEMALE A SOUND ?
YES
NO
FEMALE B SOUND ?
YES
B FLASHING AND RECEPTIVITY OFF
A FLASHING AND RECEPTIVITY OFF
STOP MALE HORIZONTAL MOTOR
STOP MALE HORIZONTAL MOTOR
INCREASE η_A BY $\Delta\eta$
INCREASE η_B BY $\Delta\eta$
NO
$\eta_A > Z$
YES
NO
$\eta_B > Z$
YES
A ON
B ON
NO
ENERGY LAMP ON UPPER RECEPTIVE SURFACE ?
YES
NO
ENERGY LAMP ON LOWER RECEPTIVE SURFACE ?
YES
$\eta_A \rightarrow \eta_A + \delta\eta$
SET F = 1 FOR Δt
$\eta_B \rightarrow \eta_B + \delta\eta$
SET F = 1 FOR Δt
$\eta_A \rightarrow \eta_A + \Delta\eta$
$\eta_B \rightarrow \eta_B + \Delta\eta$
$\lambda_A \rightarrow \lambda_A - \delta A$
$\lambda_B \rightarrow \lambda_B - \delta B$
A OFF
B OFF
START MALE HORIZONTAL MOTOR

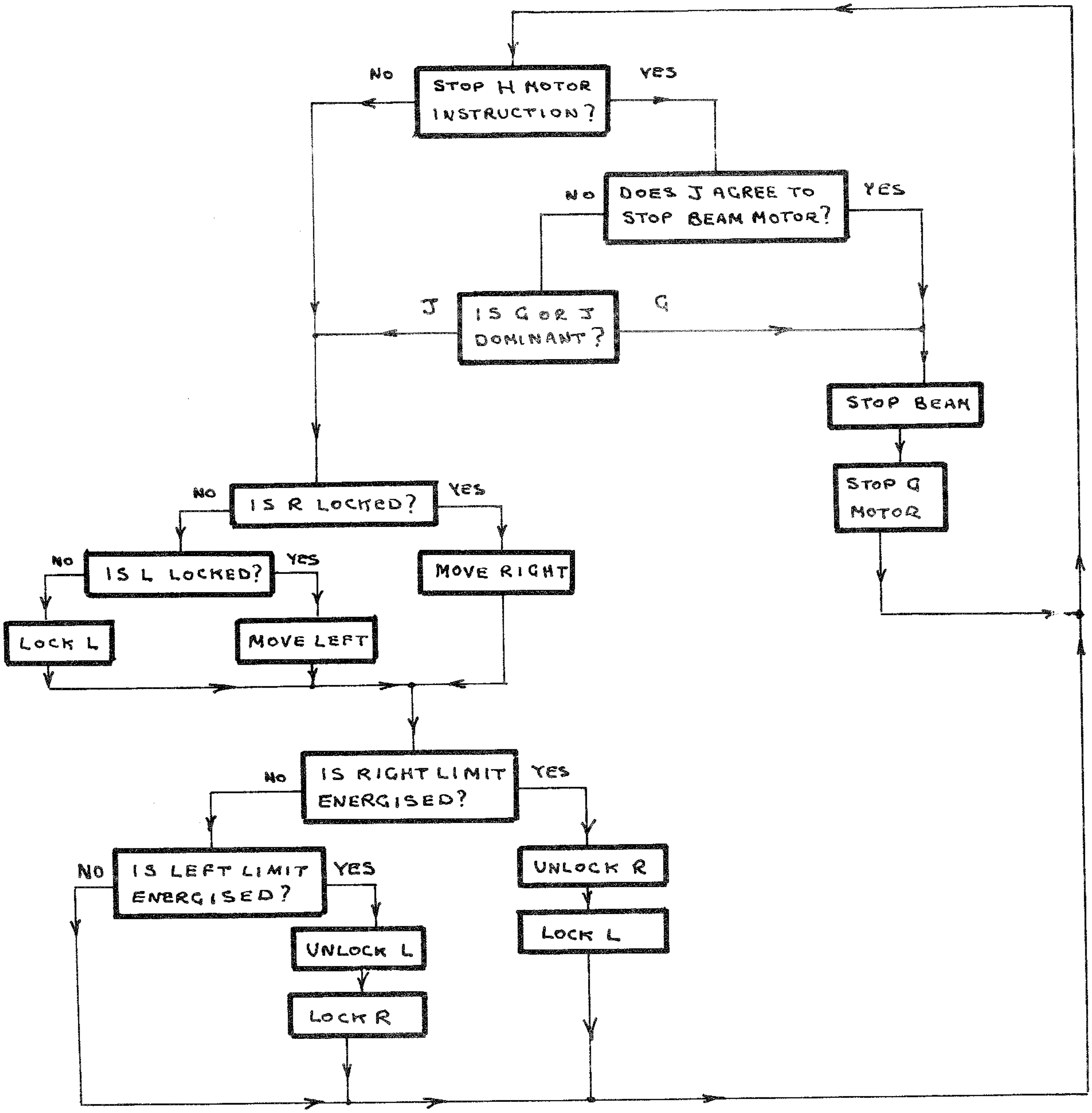
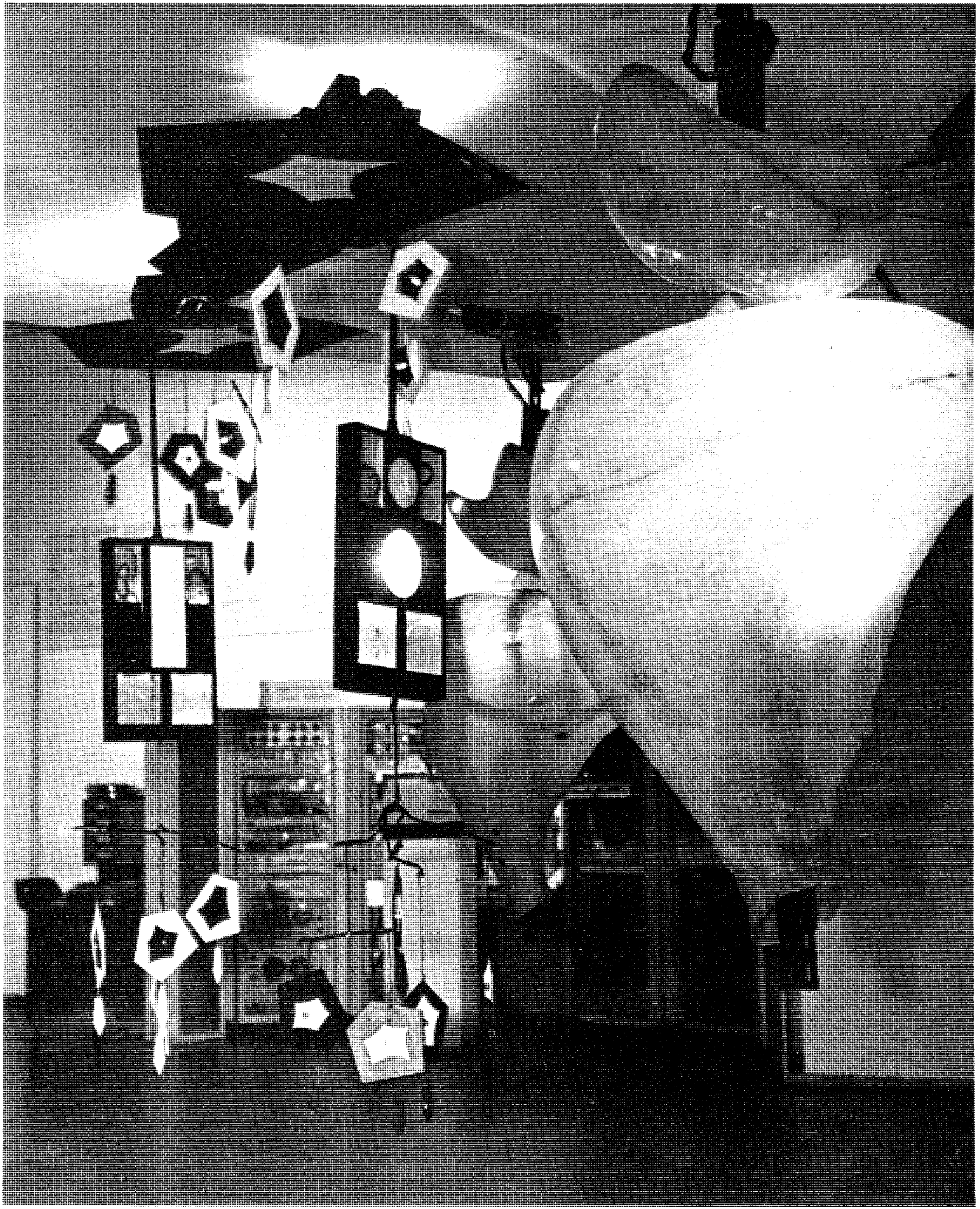


Fig. 39 Male horizontal sub-system: The male horizontal motor (H motor) for each male receives left and right limit signals. There are two males, G and J, this flow-chart is for G only. G and J are mounted on a common beam driven by a beam motor. The normal state for the *H* motor of G, or J, and the beam motor is to be in motion. Thus they are stopped only when a stop instruction is effective. The beam motor, which obeys a similar flow-chart, is normally in quasi random motion scanning its entire track.

opposite
Fig. 40 A view of the 'colloquy of mobiles'.



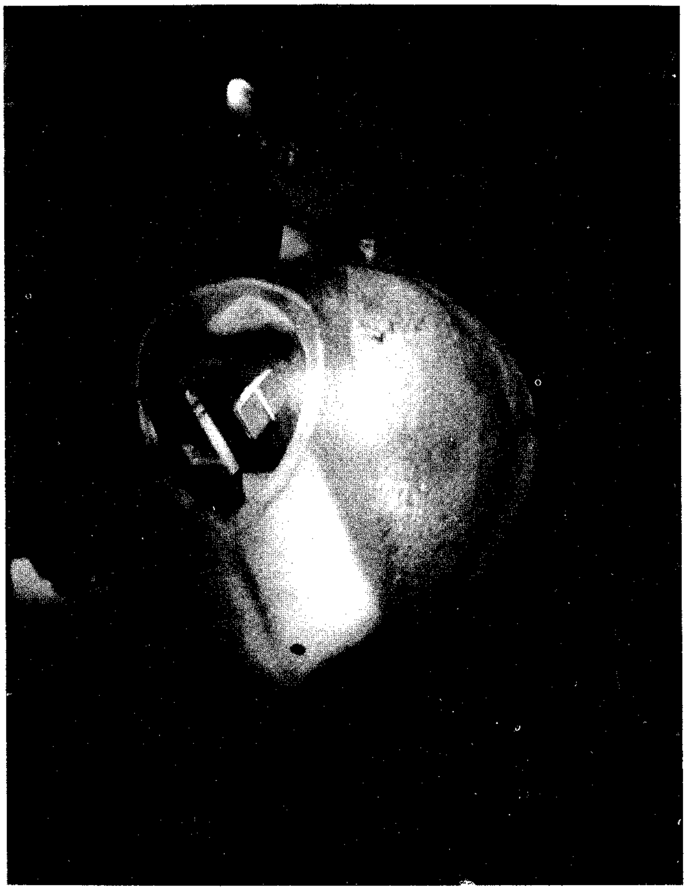


Fig. 41 Close-up of female showing reflector mechanism.

Appendix (added in October 1968)
Since this article was written, the plan for the colloquy of mobiles has been realized (Cybernetic Serendipity, ICA, London, 1968). The real system followed the plan quite closely (only the 'energy lamp' controls being replaced by a somewhat simpler arrangement and the territorial circuit controlling the male beam by a majority decision device). Hence the flow-charts (figs. 35 to 39) are substantially unaltered. Figure 40 is an overall view of the colloquy with its special purpose computer in the right background; here the signalling equipment and the sensory 'vanes' of the male are clearly visible. The light splodges above the males (hanging on the central beam) symbolize their drive levels. Figure 41 is a close-up shot showing a female trying to satisfy a male by adjusting her servo-driven reflector to direct his energy light back to his sensory vanes; her drive level is symbolized by her body illumination. Figures 42 and 43 show the mobiles interacting in the dark. Under these circumstances the prediction contained in the last paragraph of the paper is quite accurate, though entrainment is not nearly so effective with even moderate ambient illumination level. The 'female' forms were designed by Yolanda Sonnabend, the inner 'male' forms and the general set-up by myself; Mark Dowson constructed the electronics and Tony Watts was responsible for the electromechanical side of the project.

opposite
Fig. 42 Mobiles interacting in the dark (shot 1).

Fig. 43 Mobiles interacting in the dark (shot 2).

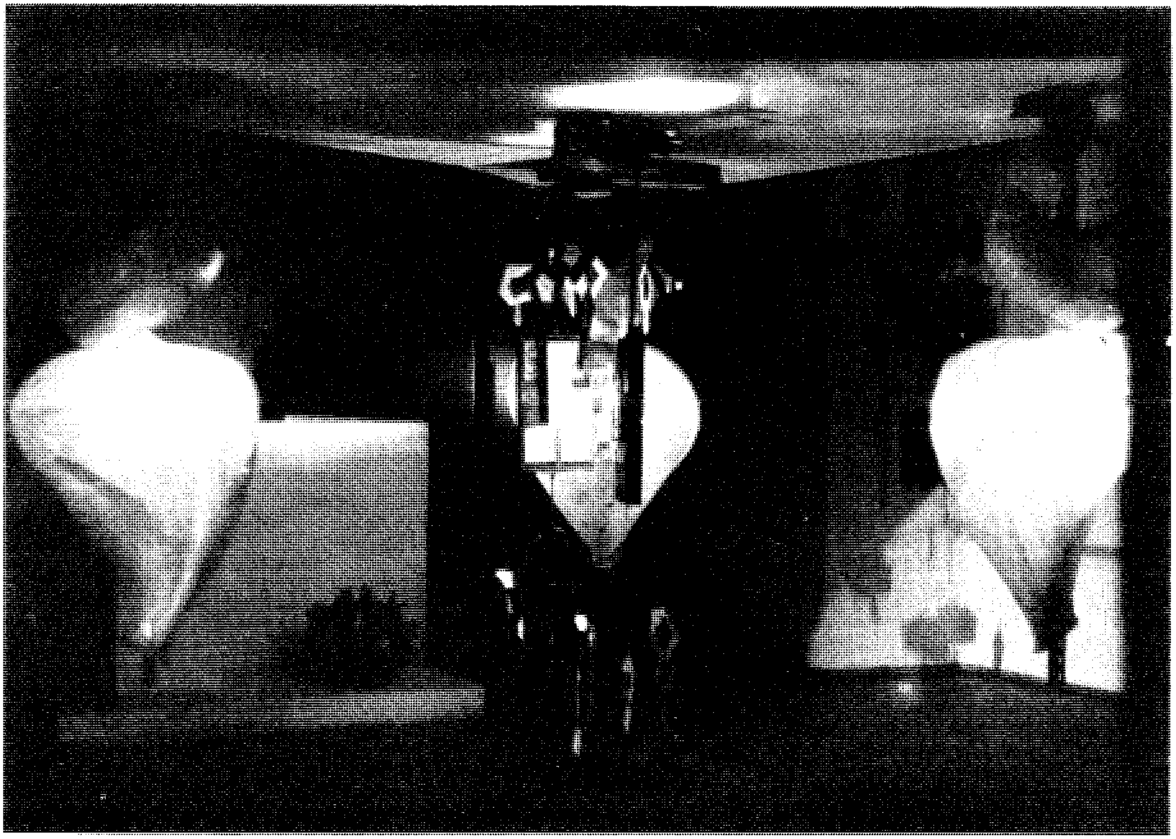
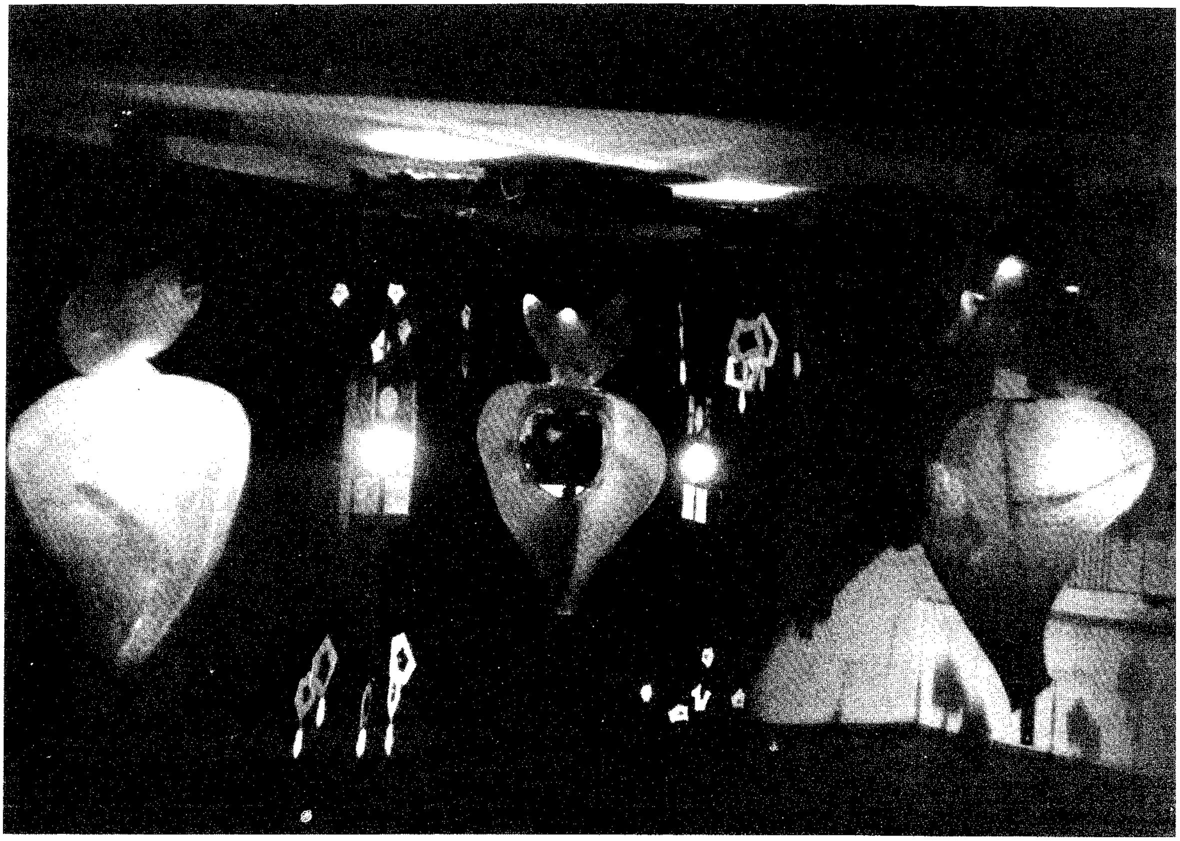


Fig. 42

Fig. 43



Science in the flesh

Irving John Good

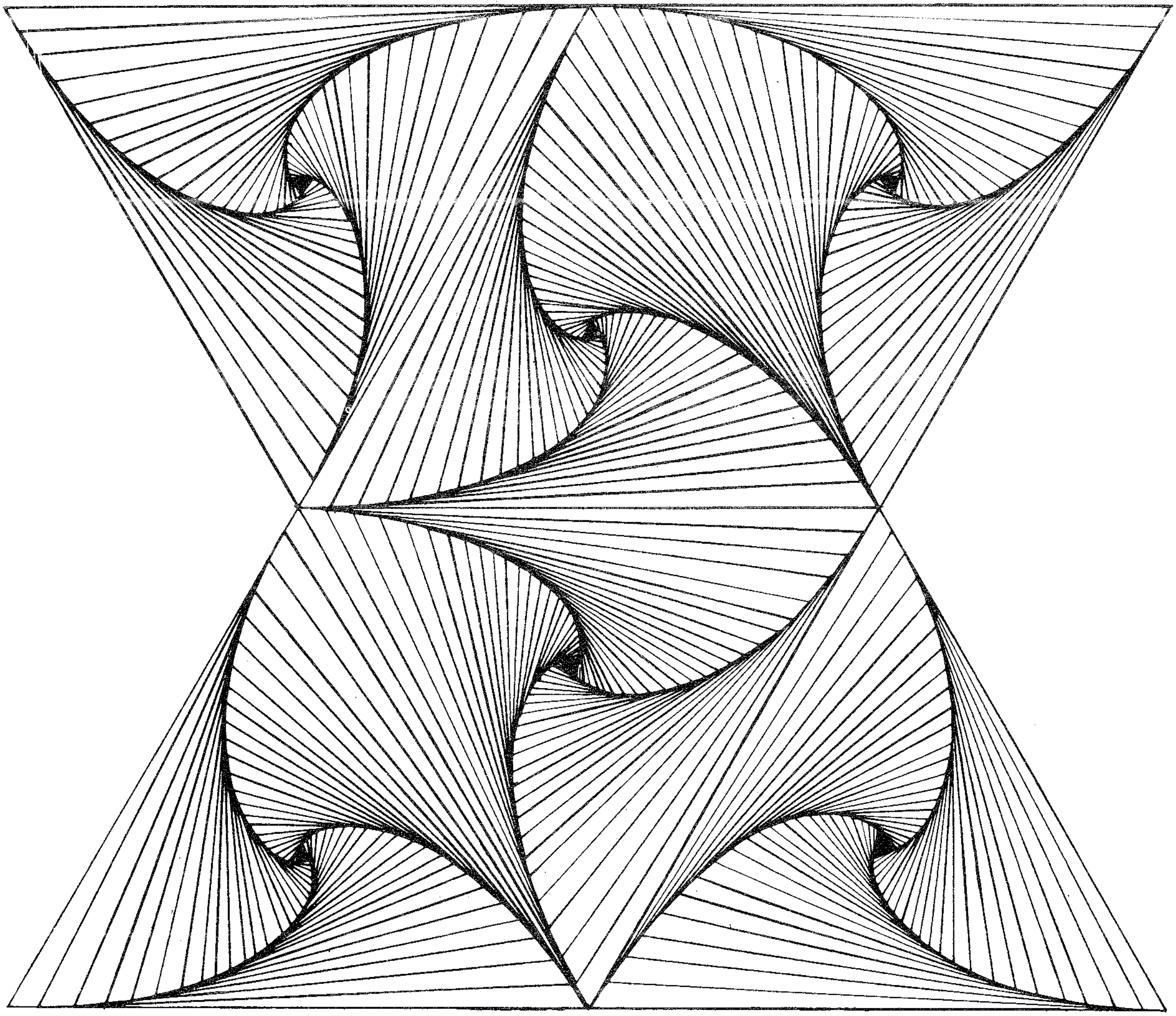


Fig. 44 'hung the right way up'.

'In both the visual arts and in music, expectations are built up by means of patterns and repetitions and there are many surprises which break the monotony and instil life into the study.' (Good)

Artists and scientists are all human and think in similar ways. Both must experiment, and must alternate and compromise between the rational and the irrational, the logical and the intuitive, the objective and subjective, reality and dreams, the conscious and the unconscious, the systematic and the random. This is why Jean Cocteau's expression 'Science in the flesh' is an appropriate description for art in general, and why I believe that scientific and mathematical art, when developed further, will have an increasing influence on other art, and will also help to explain the appeal of some modern art. It is significant that one of the prize-winning entries in a recent computer art contest was somewhat reminiscent of Paul Klee's style.

I shall discuss here a few examples of mathematical art with which I have been directly or indirectly involved, and will mention general principles as they arise. Anyone familiar with mathematics, games or any of the exact sciences,

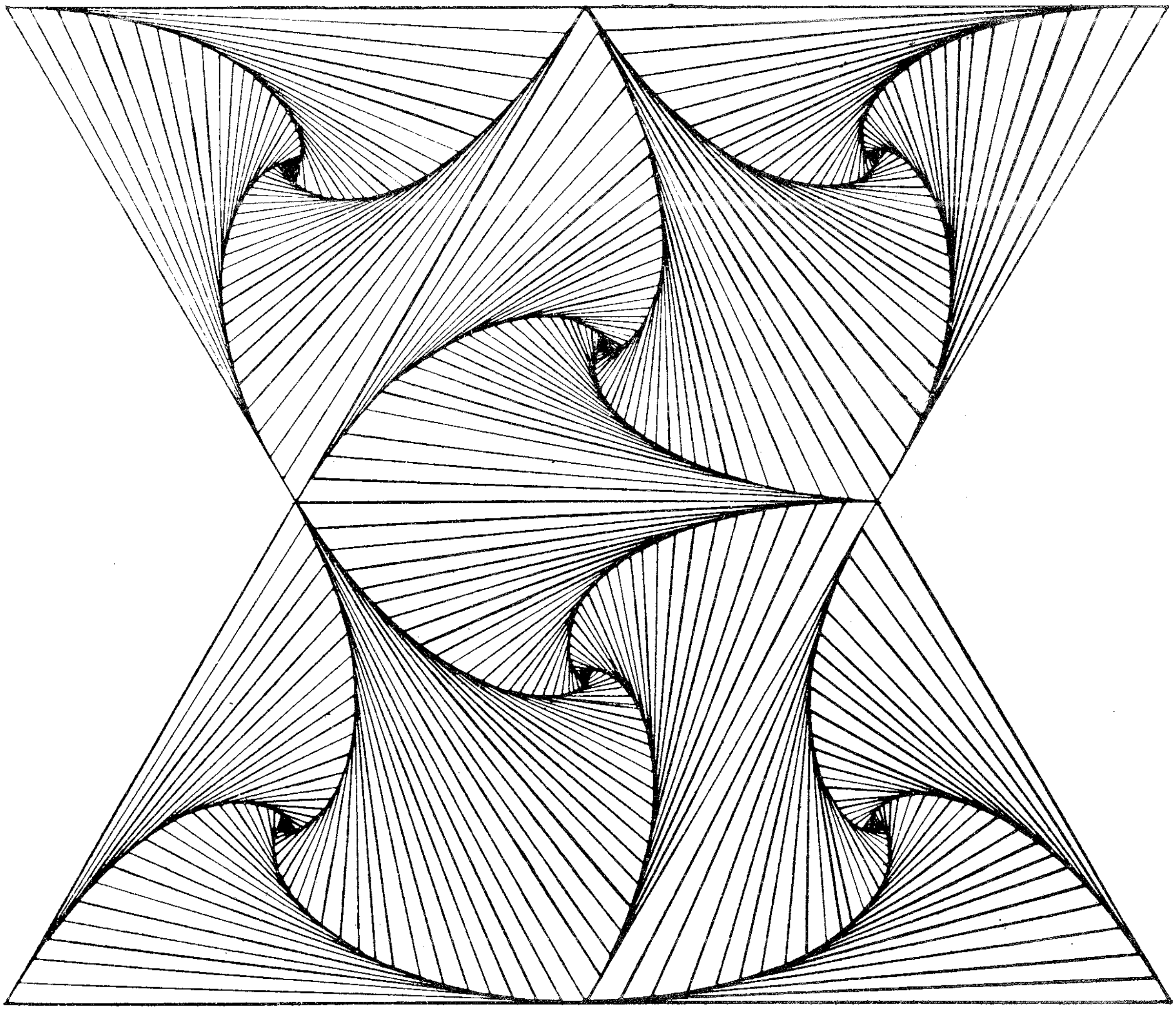


Fig. 45 The vanishing triangles have been put together in random order.

knows that enormous variety can evolve from a few basic principles. The scientist is more wont than the artist tó state general principles explicitly.

Dioximoirékinetic art

While doodling during a committee meeting, I rediscovered a striking method of shading a triangle which is suggested by the problem of three beetles chasing one another cyclically. I later found that interesting pictures, which would now be called 'Op art', could be obtained by fitting these triangles together randomly, and that further effects could be obtained by placing the transparency of one such picture over another (figs 44, 45 and 46). All this was published, with two examples, in the *Mathematical Gazette*, 1959.[1] In this same periodical (1962),[2] I pointed out that one of the two examples had been hung upside down.

A slight modification of my first example was used for the dust cover of the first American printing of *The Scientist*

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[1] I. J. Good 'Pursuit curves and mathematical art', *Mathematical Gazette* 43, pp. 134–5, 1959.

[2] *Mathematical Gazette* 46, pp. 146–7, 1962.

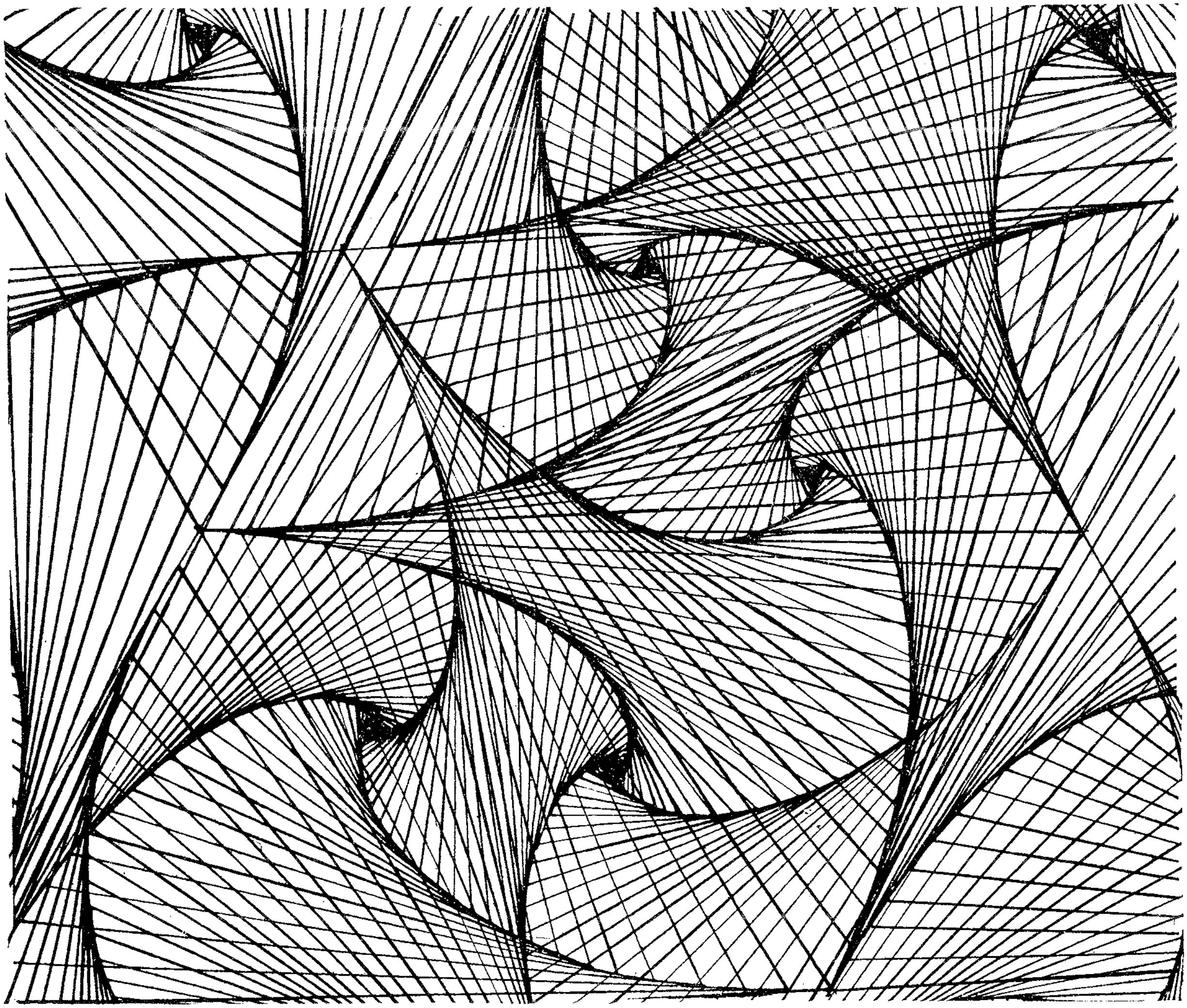

Fig. 46 Two vanishing triangles pictures superimposed at random. The figure can be animated by continuously varying the relative positions of the two basic pictures.

Speculates,[1] but with some deficiencies in execution. Shortly thereafter, to my chagrin, it was pointed out to me that the basic idea of the 'vanishing triangle' had already been exploited by Rutherford Boyd[2] in 1948. But, as his title 'Mathematical themes in design' indicates, he was concerned with design more than with art, and he made no use of randomization. One consequence of the regularity of his design is that it exhibits no hyperboloids, only shields (fig. 47). Features of human interest emerge in figures 44 and 45: an abstract squatting figure and, when inverted, a helmet.

Boyd's design was reproduced in *The Scientific American* (July, 1965). Shortly thereafter, Sam Schmitt wrote a program for generating a variety of pictures based on similar principles, making use of the graphical output of a CDC 1604.

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[1] I. J. Good, A. J. Mayne and J. Maynard Smith (editors) *The Scientist Speculates*. London: Heinemann, 1962; New York: Basic Books, 1963; Capricorn, 1965.

[2] Rutherford Boyd 'Mathematical themes in design', *Scripta Mathematica* 14, 1948.

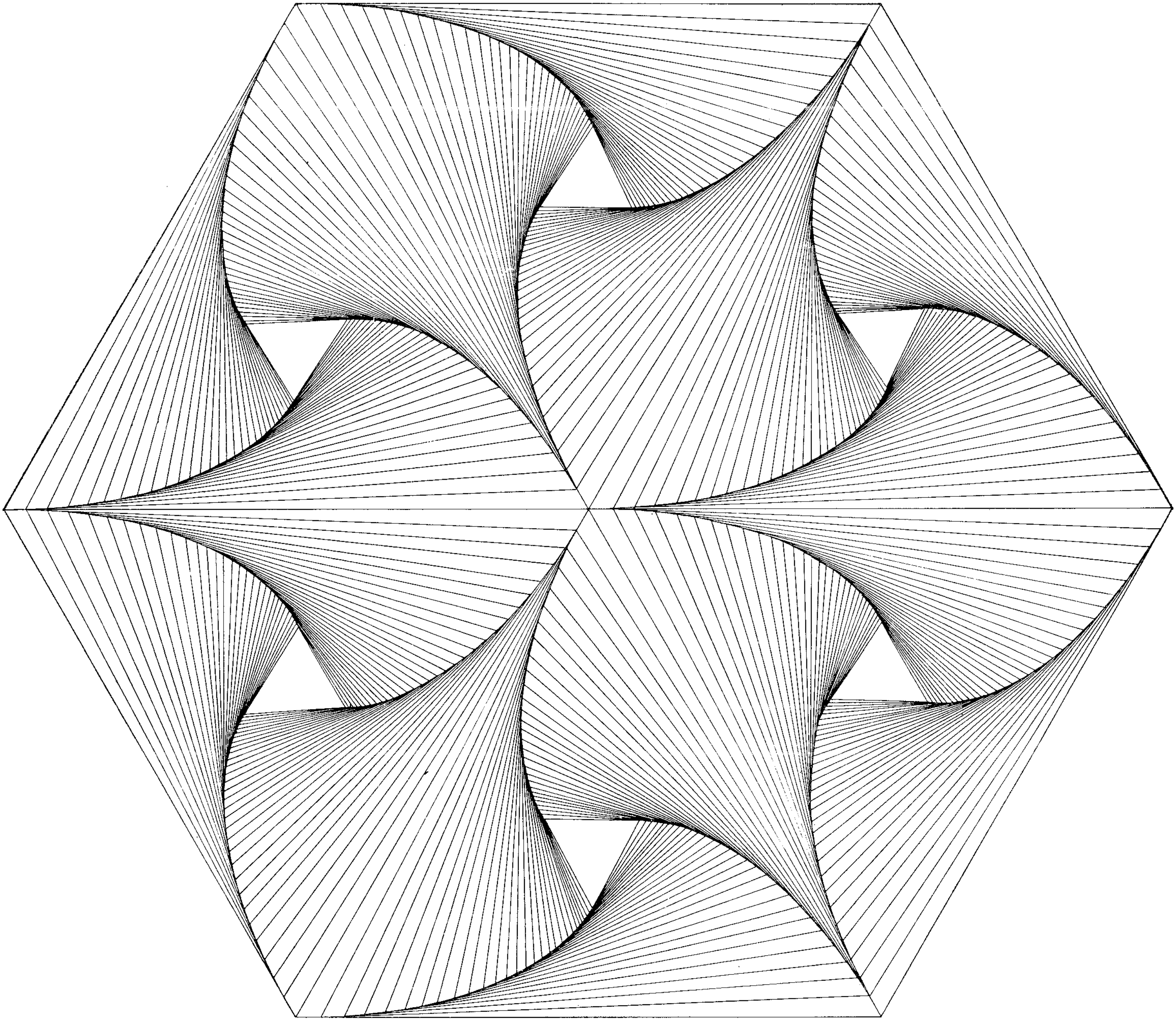

Fig. 47 The mystery of the vanishing triangle by Rutherford Boyd. In constructing the diagram only triangles were drawn yet the weird spade-like shape so dominates the result that the triangles pass unnoticed.

The shaded triangle, which is the basis of the diagrams of Rutherford Boyd and myself, is of course a special case of a wide class of diagrams based on pursuit curves. We can start with n beetles $B_1, B_2, \ldots, B_n$, in random or systematic positions and we can select any rule that states which beetle is chased by which beetle. This rule can itself be chosen at random in a large number of ways, $1.2.3 \ldots (n-1)$ if the chasing is 'cyclic', and $(n-1)^n$ if it is allowable for one beetle to be chased by more than one. At any given moment, straight lines are drawn from each chaser to its chasee, then chasing takes place for a short time interval, and then the straight lines are drawn again, and so on. Sam Schmitt's program will carry out this process, and the human operator is expected to stop each machine run when he chooses. *Sailboat* (fig. 48) was drawn in this way at Princeton, the choice of beetles being due to Stockton Gaines. In the latter he introduced deliberate symmetry by having several beetles starting at one point and these chased symmetrically placed beetles at other positions.

When I showed Gerald Oster figures 44 and 45 he suggested that when superimposing two transparencies one of them could be a negative of the other, instead of a pure copy, and that this would give rise to moiré effects. By moving one transparency more or less randomly with respect to the other, some striking results are obtained. This was very effectively shown by the black box constructed by Martine Vite and exhibited jointly at Cybernetic Serendipity by her and myself (fig. 49).[1] Pulsating organic forms emerge from simple principles. An enormous number of other examples of 'dioximoirékinetic art' could be produced. (The prefix 'dioxi' comes from the Greek for 'pursuit'.) It is a good example of the putting together of a few distinct principles.

Note that the pursuit curves of figure 45 are not drawn *qua* curves, but are generated by families of straight-line tangents. The notion of the 'envelope' of a family of straight lines is of course a familiar one in geometry. More generally, a family of curves can be tangential to another curve and this separate curve will present itself to the eye when enough representatives of the family are drawn. Moreover, such diagrams usually exhibit some three-dimensional features owing to the variations in the density of light and darkness. Thus two-dimensional figures can suggest solidity but without any three-dimensional concept clearly in the mind of the artist. This is a familiar feature of Op art and occurs again (on p. 110). Many three-dimensional string figures have a similar characteristic of suggesting shapes not present in the actual structure, as if a fourth dimension were represented. Although this idea is now rather familiar it still has a slightly menacing mystery about it. Escher's insinuations (1961) of a fourth dimension are of course more intentional and direct.[2]

Perhaps this is an appropriate place to say a little about moiré patterns. 'Moiré' is a French word meaning 'watery' or 'watered silk' and has now been adopted in English. Watered silk and mohair fabric have an appearance that is both shimmery and like the grain of wood. That such patterns could be produced with a pair of diffraction gratings was pointed out by Lord Rayleigh in 1874, who also mentioned that the principle could be useful in making accurate measurements.[3] For this purpose, it became of great industrial importance in the 1950s owing to a new, cheap method for making diffraction patterns suggested by Sir Thomas Merton,[4] and largely developed at the National Physical Laboratory in Teddington, England. Moiré techniques have become familiar also for the production of Op art.[5]

A diffraction grating is a transparency with ruled parallel lines so close that they cannot be seen with the naked eye. But if two such gratings are superimposed, with slightly different rulings, a pattern analogous to the beats of sound becomes entirely visible, in fact a good alternative name for moiré patterns would be 'visible beats'. One is provoked to conjecture that the fundamental nature of matter is based on such a principle. Perhaps all we can observe in nature are moiré fringes produced by something analogous to diffraction gratings in which the distances between adjacent lines

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[1] This item has been acquired by the Palace of Arts and Science, San Francisco.

[2] M. C. Escher *The Graphic Work of M. C. Escher.* London: Oldbourne Press, 1961.

[3] Lord Rayleigh 'On the manufacture and theory of diffraction gratings', *Scientific Papers* 1, p. 209; *Philosophical Magazine* 47, pp. 81–93 and 193–204, 1874.

[4] T. Merton 'On the reproduction and ruling of diffraction gratings', *Proceedings of the Royal Society* series A, 201, p. 187, 1950.

[5] J. Guild *Interference Systems of Crossed Diffraction Gratings: Theory of Moiré Fringes.* London: Oxford University Press, 1956. J. Guild *Diffraction Gratings as Measuring Scales.* London: Oxford University Press, 1960. G. Oster and Yasunovi Nishijama 'Moiré patterns'. *Scientific American* May 1963, pp. 54–63.

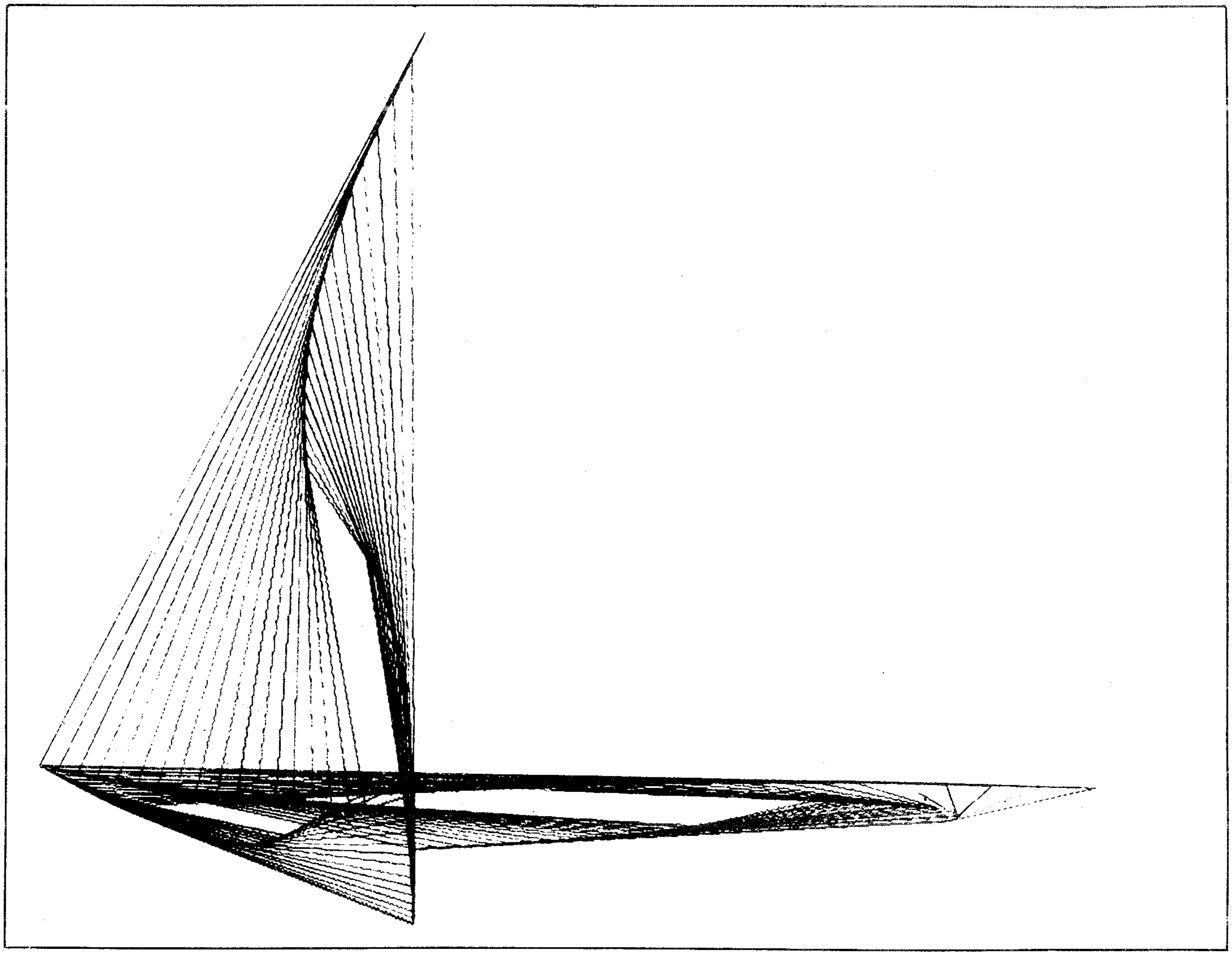

Fig. 48 *Sailboat* by Sam Schmitt and Stockton Gaines: based on pursuit curves with random selection of the initial positions of the beetles; drawn by computer CDC 1604.

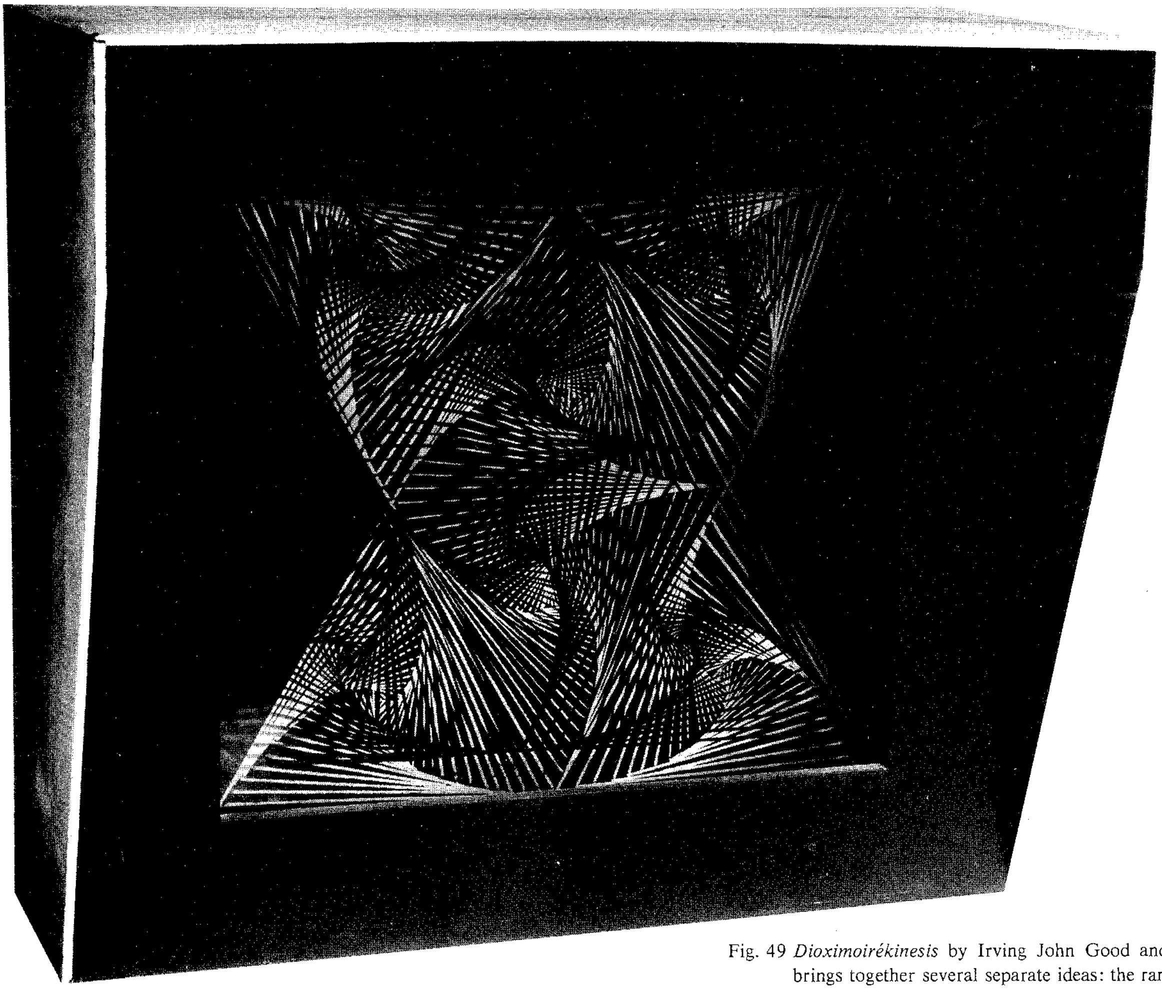

Fig. 49 *Dioximoirékinesis* by Irving John Good and Martine Vite. This model brings together several separate ideas: the random combination of pursuit triangles, moiré effects and kinetic art. The result is a pulsating organism in a black box.

are so small that there is no method known for their direct observation, even with an electron microscope. This suggestion would fit in well with the theory of 'winding space', where space is assumed not to close on itself but to just miss, that is, instead of being a hypersphere it is a sort of hyperhelix. The unobservable 'diffraction gratings' in a pair of sheets then might provide all the elementary particles and physical phenomena that are observable. It is hardly possible to avoid making this conjecture when one looks at the double screen in the Princeton Inn in New Jersey. The conjecture is a modernized form of Plato's 'shadows in' the cave'.

Good's dream figure

'Flexo' is a toy, no longer available, consisting of flexible plastic skeletons of rectangles (1·5 × 0·75 inches) which can be fitted together at their corners. If the long edges form the sides of triangles and the short edges the sides of pentagons, the result is to produce an approximate sphere or icosahedron. This structure is illustrated on the brochure that was issued by the manufacturers. If the pentagons are replaced by hexagons the effect is to produce a plane hexacomb. It occurred to me on Christmas Day, 1957, to see what would happen if heptagons were used in the place of the pentagons or hexagons, and a friend and I devoted about

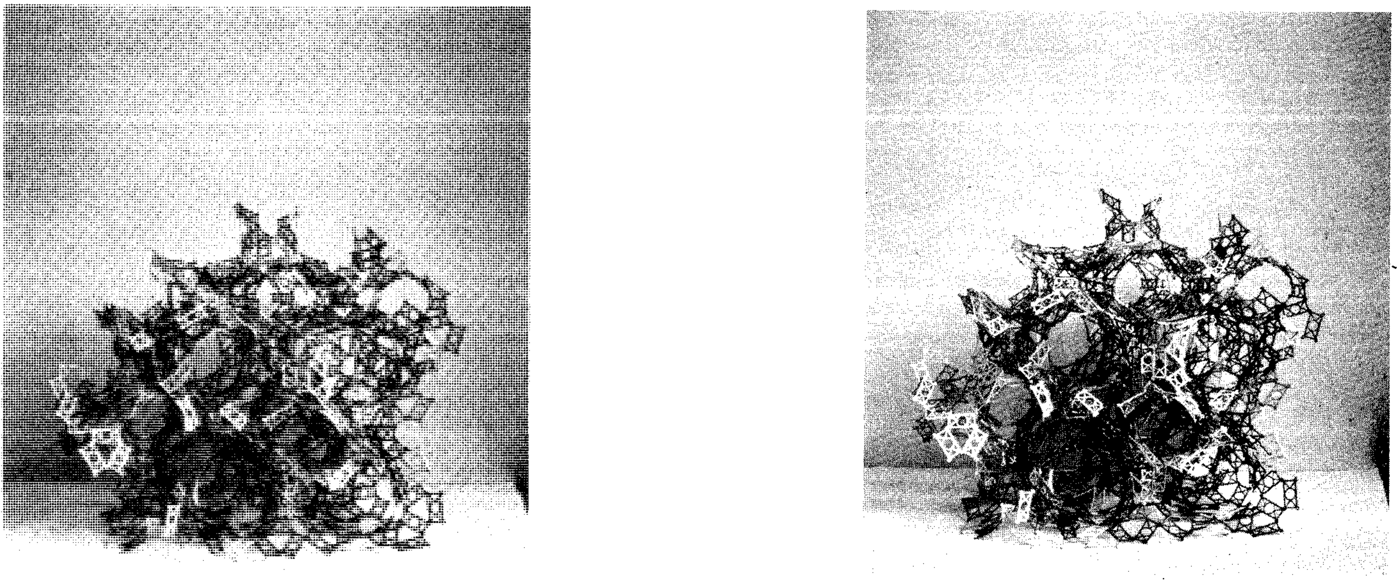

Fig. 50 Stereoscopic transparency of Good's 'dream figure', built in December 1957.

an hour to trying the experiment, but without finding any interesting patterns. All we obtained were structures that proliferated like a cancerous growth.

The same night I dreamt, with astonishing lucidity, the figure whose stereoscopic photograph is shown in figure 50. The lucidity of it gave me a strong hunch that it must be attainable and I tried with success the next morning, having first guessed that octagons would be more likely to succeed than heptagons. The net result was a structure that would in principle extend to infinity in all directions, consisting of spheres with their centres at the points of a regular three-dimensional lattice, connected by tunnels in three mutually perpendicular directions. More precisely the structure is a single surface which bounds all these spheres and tunnels. Kittens like to crawl through it as in a maze. I would like to see it built in reinforced concrete with a restaurant at the top, as part of a scientific exhibition.

The other side of the surface bounds another set of spheres and tunnels and these two sets interlock and fill all space. If the Flexo pieces were square the two interlocking sub-spaces would be congruent.

The structure has exactly the same features at all points, namely the regular alternation of triangles and octagons. The complexity of the structure is interesting considering the simplicity of the principle of its design. There is nothing random about it but it had relevance to the Cybernetic Serendipity exhibition owing to the serendipity of its discovery, analogous to the dream of the benzene ring by Kekulé. Kekulé's dream was of greater scientific importance, but then it was only two-dimensional! My structure was regarded as interesting by Dr A. F. Wells, the expert in geometrical crystallography, whose address, appropriately enough, was Hexagon House.[1] He referred to the structure in a paper published in 1963.[2]

Mathematicians often solve problems soon after waking up, but less often in a dream.[3] What makes this experience especially remarkable is that I could not have solved the problem consciously without paper and pencil and without handling the Flexo pieces.

Other similar structures can be constructed with Flexo. For example, I found in about January 1958 that triangles can be alternated with dodecagons to give a pleasing result. The resulting structure has symmetry in two directions but not in the third. Each dodecagon is folded over so that from one direction it looks like a U and from another like a hexagon with one side missing.

In about August 1959 my colleague A. G. D. Watson constructed a Flexo model, suggested by mine, but with squares alternating with hexagons. The structure was such that, without much additional effort, he was able to take advantage of the three colours of the Flexo pieces.

The form of my dream figure can also be brought out by means of the colours of the Flexo pieces, but for this purpose only two colours are required. Since the original colours of the Flexo pieces are garish and irrelevant I have had the model painted black, and the second colour is represented by means of dog collars surrounding the necks connecting the spheres.

A white icosahedron or ball is trapped inside one of the spherical cavities. It suggested to me the possibility of a physical capture, without chemical combination, in a crystalline structure. I later learned that such combinations are known as 'clathrate compounds' (from the Greek for a cage), and that research on them started as late as 1948.

I also learned later that my structure is closely related to the infinite regular polyhedra attributed by Coxeter[4] to a personal communication in 1926 from J. F. Petrie. The ordinary five regular polyhedra were known to the ancient Greeks and are known as the five 'Platonic bodies'. It is curious that it took two thousand years for the space-filling species to be discovered.

The Riemann zeta function

The Riemann zeta function is a very famous mathematical function defined in the first place by the equation:

$$u + v - 1 = \zeta(z) = 1^{-z} + 2^{-z} + 3^{-z} + \dots$$

the definition being completed by 'analytic continuation'. Here z is a complex variable, $z = x + y\sqrt{-1}$. A picture of the relief surface of this function is given by Jahnke and Emde.[5] (The relief surface is the graph, in three dimensions, of the square root of $u^2 + v^2$, regarded as a function of x and y.) It seems to me that this relief surface has artistic merit which is improved by making the background black (as in fig. 51). The surface looks rather random and it is surprising that it is given by a simple mathematical formula which defines a function famous for other reasons. As a matter of fact the zeta function does have some properties that can be regarded as pseudo-random.

The distinction between randomness and pseudorandomness is one that is familiar in the so-called 'Monte Carlo' method of calculation. For example, the digits of the decimal expansion of $\pi = 3{\cdot}1415926535\dots$ behave for most purposes like a sequence of random digits. In applications of randomization to mathematical art, pseudorandomness is just as good as strict randomness.

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[1] The probabilitist, W. Feller, lives in Random Road, and the puzzle journalist, Martin Gardner, lives in Euclid Avenue. There seems to be some synchronicity here!

[2] A. F. Wells 'The geometrical basis of crystal chemistry, VII', *Acta Crystallographica* 16, 1963. See especially page 871.

[3] J. Hadamard *An Essay on the Psychology of Invention in the Mathematical Field*. New York: Dover Publications, 1954.

[4] H. M. S. Coxeter 'Regular skew polyhedra in three and four dimensions, and their topological analogues', *Proceedings of the London Mathematical Society* series 2, 43, pp. 33–62, 1937.

[5] E. Jahnke and F. Emde *Funktionentafeln*, p. 322. Leipzig and Berlin: Teubner, 1933.

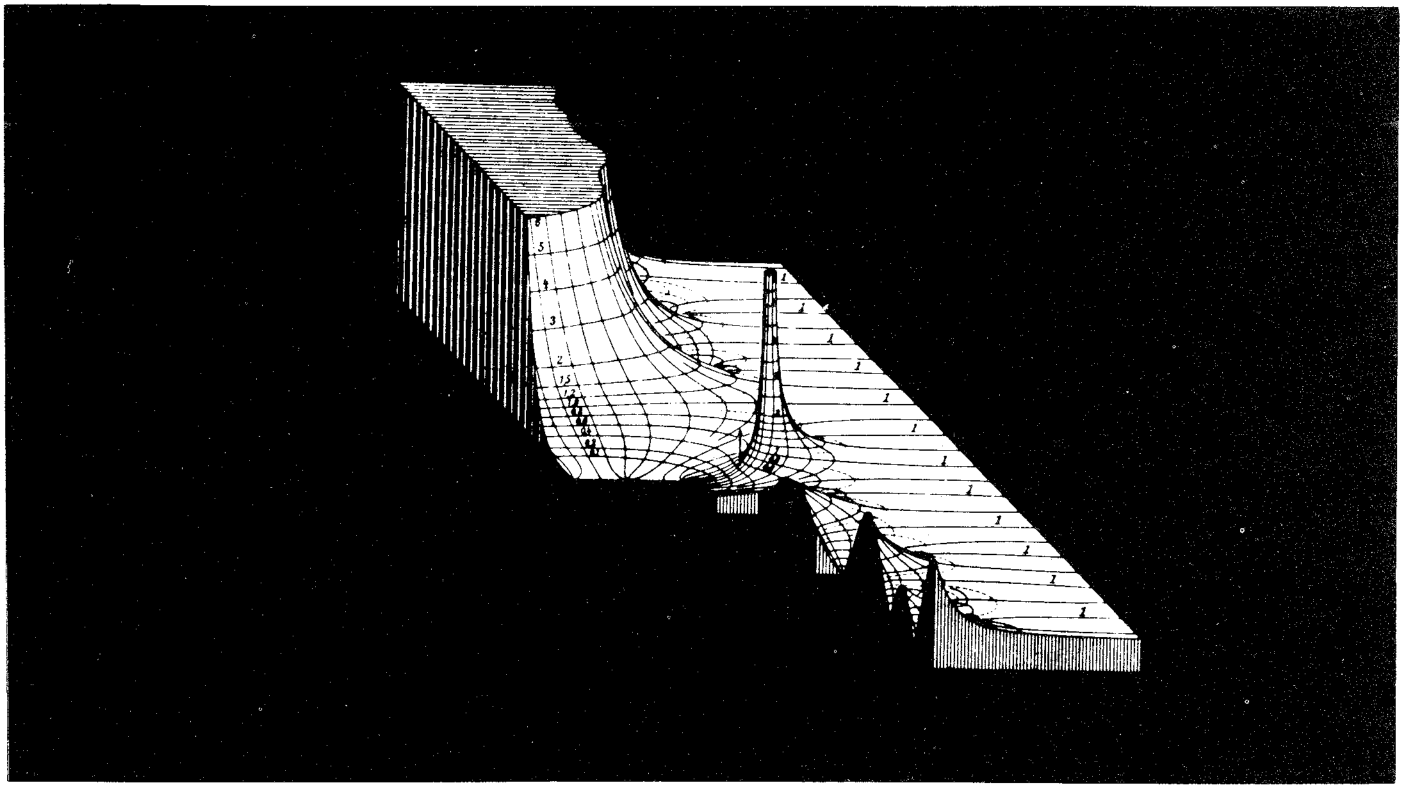

Fig. 51 The Riemann zeta function.

It could be asked whether an artist who makes use of randomness in a study can be said to have planned the work in detail. I think it is reasonable to say that he did if he decided in advance, explicitly or implicitly, on the probability distributions he would use. But it is not true that it 'would have made all the difference' if any one detail were changed, any more than it would have been important to correct some random misprints in a table of random digits.

In both the visual arts and in music, expectations are built up by means of patterns and repetitions and there are many surprises which break the monotony and instil life into the study. The surprises themselves form patterns and the patterns form a hierarchy; patterns of patterns and patterns of patterns of patterns. Moreover, the beholder perceives patterns that were not necessarily put there deliberately by the artist, especially if the study is partly random. It is easy to find transient patterns in a table of random numbers. In fact we continually look for new patterns, especially in the visual field, owing to the need to give meaning to our environment. This is true whether or not the environment has random features. It is not just the scientist who searches for structure in the world. If you stare at a hexagonally tiled floor you will without effort see new patterns at the rate of about two per second, too fast to be recorded; at least that is my experience.

In music, perhaps the simplest example of randomization is to play at random, with one finger, on the black notes of a piano. To occidental ears it sounds like uninspired Chinese music. Several examples of the use of randomization in black and white drawings were selected by Berkeley.[1] He does not state that any of the examples were only pseudo-random and not even an expert cryptologist could expect to tell the difference.

While we are on the subject of randomization the following piece of autobiography might be of some interest. When I was some ten years of age, at one of my compulsory art classes, instead of the usual copying of still life we were asked to draw anything we liked. I came up with something having the same general plan as the illustration opposite page 45 in von Foerster.[2] The art master held my drawing up to ridicule, to my acute embarrassment. It was only in later life that I discovered that nothing can be original if it is not laughed at, although it is sometimes laughed at even when it is unoriginal.

Cubic interpolation

The smoothing of experimental data by polynomial interpolation is familiar in numerical analysis. Sam Schmitt of Princeton had the idea of using (cubic) interpolation of the abscissae and ordinates separately. This provides smoothing in a peculiar sense since it can give rise to nodes and small loops, and this peculiarity, when combined with the clean sweeps of uninhibited curves, is largely responsible for the artistic effects. Figure 52 was produced by Schmitt with the help of a CDC 1604. Further examples could be readily generated with the aid of the following precise description:

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 $(F_r(0\cdot 1), G_r(0\cdot 1))$, 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.

The reason why cubic interpolation is required is that quadratic interpolation would not be smooth enough.

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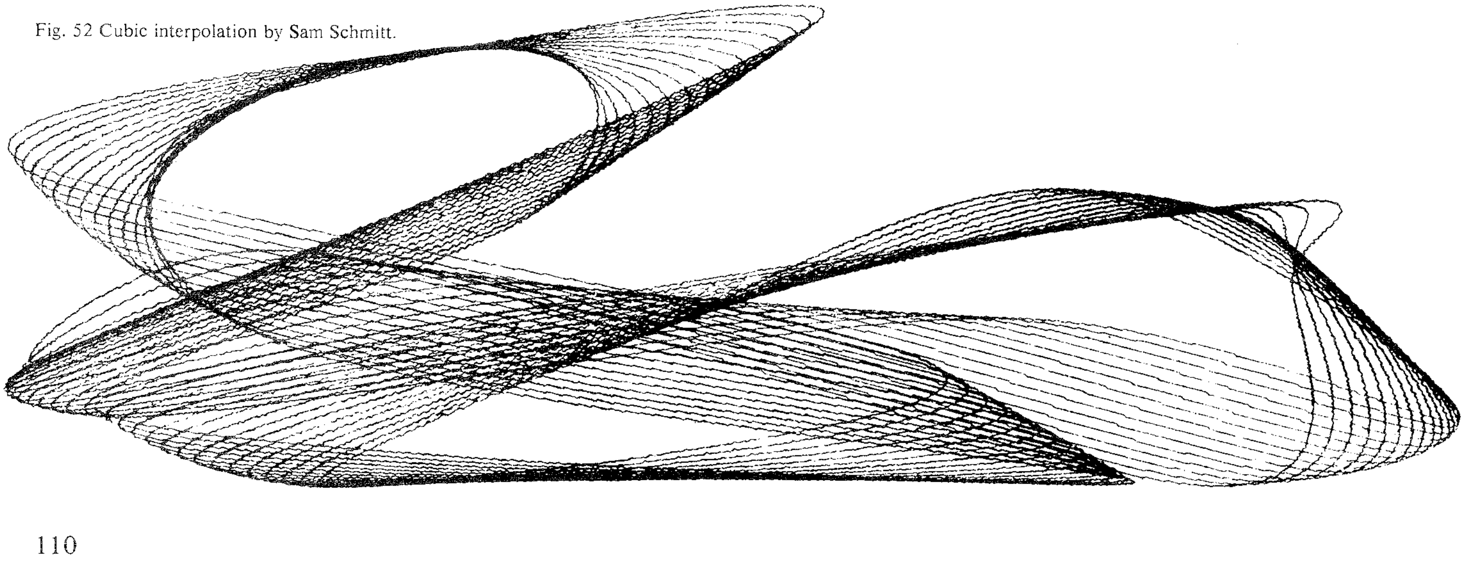
[1] E. C. Berkeley (editor) 'Annual computer art contest'. *Computers and Automation* August 1967, pp. 8–21.

[2] H. von Foerster 'On self-organizing systems and their environments', in *Self-Organizing Systems* (edited by M. C. Yovits and S. Cameron). Oxford: Pergamon Press, 1960.

Fig. 52 Cubic interpolation by Sam Schmitt.



Towards a metamusic
Iannis Xenakis

'We must open our eyes and try to throw bridges towards other cultures, as well as to the immediate future of musical thought, before dying suffocated by electronic techniques, applied either on the instrumental level or on the level of computer compositions. (*Xenakis*)

This article appears by kind permission of *La Nef*, in which it was first published in French (1967). A different English translation appears in the book by Iannis Xenakis, *Formalized Music: Thought and Mathematics in Composition*, published by Indiana University Press, 1971.

Present-day technocrats and their followers liken music to a message which the composer (source) transmits to a listener (receiver). They think that they can, in this way, resolve the nature of music and the arts in general into the formulae of 'information theory'. When they draw up an account of bits or quanta of information transmitted and received they believe that they are supplied in this way with objective scientific criteria of aesthetic value. Apart from an elementary statistical concoction, however, this theory, which is valid for technological transmissions, has proved to be incapable of giving characteristics of aesthetic value, were it only for a simple melody of J. S. Bach. Music-message, music-communication, music-language, these identifications are schematizations which lead only to absurdities and desiccations. Certain African tom-tom escape this criticism but they are an exception. The nebulous character of music cannot adapt itself to excess of theoretical precision. Later, perhaps, with the refinement and invention of new theories this may be possible.

The followers of information theory or of cybernetics are at one extreme. At the other end lie the intuitionists who are divided into two main groups: the first which is called 'graphist' raises the graphic symbol above the music (the sound) and in some way makes a fetish of it. Within this group it is good form not to write the notes but some drawing or other. The 'music' is judged on the beauty of the drawing. Attached to this, is what is called 'aleatory' music, this term being an abuse of language since the real term is 'improvised' music of our grandfathers. This group does not know that graphic writing, either symbolic as in traditional sol-fa, or geometrical or numerical, should be only an image, as faithful as possible to the whole of the instructions which the composer is transmitting to the orchestra or to the machine.[1] This group drags music outside its real domain.

The second group adds spectacle in the form of extra-musical scenic actions as an accompaniment to the musical execution. Influenced by the 'happenings' which very often express the disarray of some artists, they take refuge in the gesture and ill-assorted events thus betraying a very limited confidence in the music proper. Actually they accept the certain failure of their music. These two groups share a romantic attitude. They place their faith in immediate action and care very little for control by thought. But since the imperative need of musical activity is reflection under pain of being tossed about in trivial improvisation, lack of precision and irresponsibility, these groups in fact deny music and force it out of context.

Linear thought

I will not say, like Aristotle, that the golden mean is necessarily best since in music as in politics, the mean signifies compromise. I will speak of perspicacity and the keenness for critical thought, that is to say, action, reflection and self-transformation by the sounds alone. Thus, in the service of music, as in all human creative activity, scientific and mathematical thought must be dialectically blended with intuition. Man is one, indivisible, whole. He thinks with his gut and feels with his mind. I can suggest what, in my opinion, covers the expression, music:

1. First a kind of behaviour which is necessary to the one thinking it and doing it.
2. An individual pleroma, an accomplishment.
3. A fixing by sound of imagined virtualities (cosmological, philosophical theses, etc.).
4. It is normative, that is to say, it constitutes models of being or acting which bring about an unconscious imitation.
5. It is catalytic; its presence alone permits internal psychical transformations or transformations of thought just like the crystal ball of the hypnotizer.

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[1] Iannis Xenakis 'Towards a philosophy of music', *Gravesaner Blätter*, no 29. Tessin. Switzerland: H. Scherchen Gravesano. 1966.

6 It is the free play of a child.
7 It is a mystical (but atheistic) asceticism. Consequently, expressions of sadness, joy, love, or of situations in general, are only very limited particular cases.

Musical syntax has undergone very big upheavals and today it would appear that innumerable possibilities co-exist in chaos—the abundance of theories, individual (sometimes) styles and styles of younger or older schools of thought. But how do we make music? What can be passed on by oral teaching? (This is a burning question if we want to reform the teaching of music, and this reform is necessary throughout the world, not only in France.)

We cannot say that the informationists or cyberneticians and still less the intuitionists have raised the question of an ideological cleaning out of the dross which the centuries and present-day development have accumulated. All, generally speaking, are unaware of the substratum on which they place their theories and their actions. This substratum exists, however, and it is this which will enable us to lay the foundations for the first time of axiomatics and to bring out a formalization unifying the past, the present and the future and this on the planetary scale, that is to say, comprising the still sealed-off sound universes of Asia, Africa, etc.

In 1954[1] I denounced linear thought (polyphonic) by bringing out the contradictions of serial music. I suggested in its place a universe of sound masses, of vast groups of sound occurrences, of clouds, of galaxies governed by new characteristics, such as density, the degree of order, the speed of change, etc., which necessitated definitions and implementations with the help of probability calculus. Thus stochastic music was born. Actually, this new conception of large numbers, relating to the mass, was more general than the polyphonic linear conception since it could include the latter as a special case (by reducing the densities of clouds). General harmony? No, not yet.

Today, after more than ten years, these ideas and the achievements which accompany them have been all round the world and exploration appears to be practically finished. Our musical terra firma, however, on which all our music rests, the tempered diatonic system, seems unshaken either by reflection or by music itself.[2] But it is this way that the next stage will be accomplished. Its exploration and its metamorphoses will open up a new era which is very rich in promise. To understand its decisive importance we must go back to its pre-Christian origin and its later development. I am going to speak therefore about the structure of ancient Greek music and then that of Byzantine music which preserved it best while at the same time developing it and did this much more faithfully than its sister, the Western plainchant. After having brought out in a modern manner their abstract logical constructions I shall try to express in a simple mathematical and logical but universal language, what was and what could be valid in time (transversal musicology) and in space (comparative musicology).

To do this I propose to differentiate in musical architecture between the architectures or categories called 'out of time',[3] the 'in-time' architectures or categories and, finally, the 'temporal' architectures or categories. A given range of pitches, for instance, is an 'out of time' architecture since no horizontal or vertical combination of its elements changes it. The event in itself, that is to say, the actual occurrence, belongs to the temporal category. Finally a melody or chord on a given range is made from the relationship between the 'out of time' category and the 'temporal' category. They are the setting of 'out of time' constructions in time. I have already dealt with this distinction elsewhere but here I shall show how ancient and Byzantine music can be analysed with the help of these categories and how general is this way of looking at them, since it allows universal axioms to be made about music and a large number of aspects of all the music on our planet to be formalized.

Ancient structure

The Gregorian chant in its origins was based on the ancient structure; in spite of the thesis of Combarieu and of others who accused Hucbald of being behind the times. The swift

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[1] cf. *Gravesaner Blätter*, nos 1 and 6, 'Scores of Metastasis' (1954) and 'Pithoprakta' (1956) issued by Boosey and Hawkes, record Le Chant du Monde L.D.X.-A-8368, and Cardinal, USA.

[2] It is not a question here of music with the present-day use of quarter tones or sixths of a tone because they are used in the same tonal-diatonic field.

[3] cf. My book *Musiques Formelles* chapter 5. Paris: Richard-Masse, 1963; and the English edition *Formalized Music: Thought and Mathematics in Composition*. Indiana University Press, 1971.

development of western European music as from the ninth century simplified and levelled the plain-chant and the practice lost its theory. But in profane music we still find shreds of the old theory in the fifteenth and sixteenth centuries. To wit, the *Terminorum Musicae Diffinitorium* of Johannis Tinctoris.[1] To reach antiquity we look down the Gregorian telescope and its 'modes' which we have for a long time ceased to understand. Then we only begin to catch a glimpse from other directions of the explanations of the modes of the plain-chant. The Gregorianists say now that the mode is not merely a type of scale but is characterized by melodic formulae. The only one as far as I know to have introduced other ideas complementary to the idea of the scale is Jacques Chailley[2] who seems to be correct. I think we could go further and assert that ancient music, at least up to the first centuries of Christianity, was certainly not based on scales or 'modes' of an octave but on tetrachords or 'systems'.

Specialists in antiquity (with the exception of those mentioned above) have overlooked this basic reality, their minds being clouded by the tonal construction of the music of the post-Middle Ages. Here now is what existed with the Greeks: a hierarchical structure, the complexity of which came from successive interlockings, by inclusions and intersections from the particular to the general of which we can retrace, by following the texts of Aristoxenos, the basic scheme.[3]

Primary level: the tone and its subdivisions. It is defined as being the quantity by which the consonance of the fifth exceeds that of the fourth. It is subdivided into halves called semitones, thirds called chromatic dieseis, fourths called enharmonic dieseis, no smaller interval being practised.

Secondary level: the tetrachord, defined by the first consonance, the diatessaron. The diatessaron interval is equal to two tones and a half, therefore to thirty-twelfths of a tone, which we shall call Aristoxenian segments. The two extreme sounds always have the same consonance distance of a fourth, the other two inside ones are mobile and their positions determine the three genera of tetrachords (the other consonances of fifth, octave, etc., creating nothing):

1. The enharmonic genus containing, from low to high pitch, two enharmonic dieseis $3 + 3 + 24 = 30$ segments or $X^{1/4} . X^{1/4} . X^{2} = X^{5/2}$ (X being the value of a tone);
2. The chromatic genus:
    (*a*) soft, containing two chromatic dieseis, $4 + 4 + 22 = 30$ segments or
    $X^{1/3} . X^{1/3} . X^{1/3+3/2} = X^{5/2}$
    (*b*) hemiholon (sesquialteral) containing two sesquialteral dieseis. $4{\cdot}5 + 4{\cdot}5 + 21 = 30$ segments or
    $X^{(3/2)(1/4)} . X^{(3/2)(1/4)} . X^{7/4} = X^{5/2}$
    (*c*) 'toniaion', containing two semitones and one trisemitone $6 + 6 + 18 = 30$ segments or
    $X^{1/2} . X^{1/2} . X^{3/2} = X^{5/2}$
3. The diatonic genus:
    (*a*) soft, containing, still from low to high pitch, one semitone then three enharmonic dieseis and then five enharmonic dieseis, $6 + 9 + 15 = 30$ segments or $X^{1/2} . X^{3/4} . X^{5/4} = X^{5/2}$;
    (*b*) 'syntonon', containing a semitone then a tone and again a tone $6 + 12 + 12 = 30$ segments or $X^{1/2} . X . X . = X^{5/2}$.

Tertiary level: the system is essentially a combination of the elements of the primary level but in particular of several conjunct tetrachords or tetrachords disjunct by one tone. Hence the pentachord (the utmost interval being the perfect fifth) and the octachord (the utmost interval being sometimes the perfect octave). The subdivisions of the systems also follow those of the tetrachord. They are also a function of connexity and consonance.

Quartenary level: the tropes, the keys or the modes; they were undoubtedly only special handlings of the 'systems', thanks to cadential, melodic formulae, to the dominants, to the registers, etc., as in the case of Byzantine music, ragas, etc.

Here ends the description of the 'out of time' structure of Hellenic music. All the ancient texts which we can consult beginning with Aristoxenos explain this hierarchical

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[1] Johannis Tinctoris *Terminorum Musicae Diffinitorium*. Paris: Richard-Masse, 1952; in French.

[2] Jacques Chailley 'Le mythe des modes grecs', *Acta Musicologica* vol. 28, fasc. 4. Basel: Bärenreiter-Verlag, 1956.

[3] R. Westphal, 'Aristoxenos von Tarent', *Melik und Rhythmik*. Leipzig: Verlag von Ambr. Abel (Arthur Meiner). 1893: German introduction. Greek text.

process. It seems that Aristoxenos served as their model. But later traditions parallel to Aristoxenos, faltering interpretations and sedimentations have distorted the facts of this hierarchy, from antiquity onwards. Moreover, it would appear that theoreticians such as Aristides Quintilian or Claude Ptolemy had little understanding of music.

This hierarchical 'tree' was completed by transition algorithms, 'metabolai' (changes) from one genus to another, from one system to another, or from one mode to another. But we are far from the simple modulations or transpositions of the post-middle ages tonal music.

The pentachords are subdivided according to the same types as the tetrachords which they contain. They derive from the tetrachords but nevertheless serve as a primary notion, in the same way as the tetrachord, to define the interval of the tone. This is a vicious circle, but one which is explained by Aristoxenos' purpose to remain faithful to musical experience (and he insists on this), which by itself alone defines the structure of the tetrachord and of every harmonic edifice which is the combinatory consequence of it. All of his axiomatization principles derive from this and his text is an example of a method to be followed. The absolute (physical) value of the diatessaron is not yet defined, and this differs from the Pythagoreans who define it by the ratio 3/4 of the lengths of the strings. This, I think, is a sign of wisdom. The ratio 3/4 is in fact an average.

Two languages

We must draw attention to the fact that the additive operation is used for the intervals, thus foreshadowing logarithms before their time, contrary to the practice of the Pythagoreans who used the geometric language (exponential) which is multiplicative. Here the invention of Aristoxenos is fundamental, since:

a it constitutes one of the two methods which have permitted musical theory to be expressed throughout millenia,
b it initiates a 'calculation' which is more economic, easier and more adapted to music, by addition,
c it lays the basis of the equal temperament almost twenty centuries before its application in western Europe.

The two languages: arithmetic (the adding operation) and the geometric (coming from the relationships between the lengths of the strings with the multiplying operation) have always been mixed and have interpenetrated each other throughout the centuries and have created much unnecessary confusion in the calculation of the intervals and consonances, and consequently in the theories. Actually they are two expressions of the group structure with two non-identical operations; they are therefore formally equivalent.[1]

Musicological specialists of recent times have smugly assumed that, 'The Greeks', they say, 'came down the scales instead of going up them as is the practice today.' Well, we can find no trace of this in Aristoxenos, nor in his successors, including Aristides Quintilian[2] or Alypius, who give a most complete new writing on the degrees of many of the tropes. On the contrary, it is always with the low note that all the ancient authors begin the theoretical explanations and the naming of the degrees.

Nor can we find any trace in his text of the supposed 'scale of Aristoxenos'.[3]

An explanation of the structure of Byzantine music can serve for a far better understanding of ancient music, the western plain-chant, non-European traditional music, the dialectics of recent European music and its false paths and dead ends; it can serve to envisage and build the future with a view looking over the far-off landscapes of the past and the electronic future. Thus the direction of research will take on quite a new value. On the other hand, the ineptness of serial music in certain fields and the wrong which it has done to musical development by its ignorant dogmatism will be indirectly brought out.

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[1] G. Th. Guilbaud, *Mathématiques*, vol. 1. Paris: Presses Universitaires de France, 1963.

[2] Aristoudou Kointilianou, *Peri Mousikes Proton.* Leipzig: Teubner Verlagsgesellschaft, 1963.

[3] The scale of Aristoxenos seems to be one of the experimental versions of the ancient diatonic unlike either the Pythagorean or Aristoxenian theoretic versions. $X\,.\,(9/8)\,.\,(9/8) = 4/3$, $6 + 12 + 12 = 30$ segments respectively. The version $X\,.\,(7/8)\,.\,(9/8) = 4/3$ of Archytas or that of Euclid are significant. On the other hand the so-called 'scale of Zarlino' is no other than the so-called 'scale of Aristoxenos' which actually only goes back to Ptolemy and Didymos.

Byzantine structure

The Byzantine structure[1] amalgamates the two calculations, Pythagorean and Aristoxenian, multiplicative and additive. The fourth is expressed by the ratio 3/4 of the monochord, or by the 30 tempered segments (72 for the octave).[2] It defines three kinds of tone, the major (9/8 or 12 segments), the minor (10/9 or 10 segments) and the minute (16/15 or 8 segments). But smaller or bigger intervals are constructed and the elementary units of the primary level are more complex than with Aristoxenos. It recognizes a preponderance in the natural diatonic scale (the supposed scale of Aristoxenos) the degrees of which are with the first tone in the ratios: 1, 9/8, 5/4, 4/3, 3/2, 27/16, 15/8; and bear the alphabetical names A, B, Γ, Δ, E, Z, H, the Δ, initial low-pitch degree, practically corresponding to G_2 (in segments: 0, 12, 22, 30, 42, 54, 64, 72 or 0, 12, 23, 30, 42, 54, 65, 72). As early as the first century, Didymus told of it and then in the second, Ptolemy, who permuted one term and recorded the shifting of the tetrachord (tone-tone-semitone) which has since remained unchanged.[3] But apart from this attraction of the diapason (octave), the architecture is hierarchical and 'nested' as with Aristoxenos:

Primary level: the three tones 9/8, 10/9, 16/15, a supermajor tone 7/6, the trisemitone 6/5, another major tone 15/14, the semitone or leima 256/243, the apotome of the minor tone 135/128 and finally the comma 81/80. This complexity is the result of mixing the two methods of calculation.

Secondary level: the tetrachords which are defined as with Aristoxenos. Just as for the pentachords and the octachords. The tetrachords are divided into three genera:

1 Diatonic subdivided into:
first scheme, 12 + 11 + 7 = 30 segments or 9/8 . 10/9 . 16/15 = 4/3 beginning on the Δ, H, etc.
second scheme, 11 + 7 + 12 = 30 segments or 10/9 . 16/15 . 9/8 = 4/3 beginning on the E, A, etc.
third scheme, 7 + 12 + 11 = 30 segments or 16/15 . 9/8 . 10/9 = 4/3 beginning on Z, etc.
This shows an elaborate combinatory method which is not to be seen in Aristoxenos. Three of the six possible permutations of the three tones are used here.

2 Chromatic, subdivided into:[4]
a Soft chromatic coming from the diatonic tetrachords of the first scheme, 7 + 16 + 7 = 30 segments or (16/15) . (7/6) . (15/14) = (4/3) commencing on Δ, H, etc.
b Syntonon or hard chromatic coming from the diatonic tetrachords of the second scheme, 5 + 19 + 6 = 30 segments or (256/243) . (6/5) . (135/128) = 4/3 beginning on E, A, etc.

3 Enharmonic coming from the diatonic by changing the mobile notes and subdivided into:
first scheme, 12 + 12 + 6 = 30 segments or (9/8) . (9/8) . (256/243) = 4/3, beginning on Z, H, Γ, etc.
second scheme, 12 + 6 + 12 = 30 segments or (9/8) . (256/243) . (9/8) = 4/3 beginning on Δ, H, A, etc.
third scheme, 6 + 12 + 12 = 30 segments or (256/243) . (9/8) . (9/8) = 4/3, beginning on E, A, B, etc.

There is clearly a phenomenon of absorption of the ancient enharmonic by the diatonic. This must have occurred in the first centuries of Christianity in the struggle between the fathers of the Church and paganism and some manifestations of its art. The diatonic has always been considered as sober, severe, noble, in contrast to the other genera. Actually, the chromatic genus, but above all the enharmonic, require a more elaborate musical culture as

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[1] Avraam Evthimiadis *Stichiodi Mathimata Byzantinis Ekklisiastikis Mousikis*. Thessaloniki: OXA Apostoliki Diakonia, 1948.

[2] With Quintilian and Ptolemy, the fourth is divided into 60 equally tempered segments.

[3] R. Westphal, *op. cit.*, pp. 47 onwards, we find the shifting of the tetrachord mentioned by Ptolemy: lichanos—(16/15)—mese—(9/8)—paramese—(10/9)—trite (harm. 2, 1 p. 49).

[4] With Ptolemy the names of the chromatic genera were changed; the soft chromatic containing the 6/9 interval and the hard or syntonon chromatic containing the 7/6 interval (cf. Westphal, *op. cit.*, p. 32).

Aristoxenos and other theoreticians already noticed, a culture which the masses of the Roman period possessed still less. Consequently, on the one hand, combinatory speculation and on the other, practical usage, forced the specific characters of the enharmonic genus to disappear to the benefit of the chromatic one, a subdivision of which disappeared in Byzantine music, and of the diatonic syntonon. A phenomenon of absorption is comparable to that of scales (or modes) of the Renaissance by the major diatonic scale which perpetuates the ancient diatonic syntonon.

This simplification is, however, curious and it would be interesting to study its circumstances and causes. Apart from the differences in, or rather variants of, ancient intervals, Byzantine typology tightly adapts itself to the ancient. With the tetrachords it builds the upper floor with the help of definitions which throw a singular light on the theory of the Aristoxenian systems, a fairly detailed account of which we can find already in Claude Ptolemy.[1]

The systems and scales

Tertiary level: the scales are constructed with the aid of systems with the same ancient rules for consonance, dissonance and assonance (paraphony). With the Byzantines, the principle of iteration and juxtapositioning of the systems led very clearly to the scales, which was still fairly obscure with Aristoxenos and his successors, with the exception of Ptolemy. With Aristoxenos, for whom the system seemed to be a category and an end in itself, the idea of the scale was not detached from the method which constructed it. With the Byzantines, on the other hand, the system is called method of construction of scales. It is a kind of iterating operator which builds from the lower category of tetrachords and its derivatives, the pentachord and the octachord, more complex organisms, in chains, just like the genes of chromosomes. From this point of view the system-scale couple achieved a blossoming forth which had not existed among the ancients. Here is the Byzantine definition of the system: 'The system is the simple or multiple iteration of two or more or all the tones of a scale.' Scale is understood here as an already organized succession of tones such as the tetrachord or its derivatives. Byzantine music uses three systems:

a the system of the octachord or diapason;
b the system of the pentachord or wheel (trochos);
c the system of the tetrachord or triphony.

The system can unite the elements by conjunct (synimena) or disjunct diazevgmena (juxtaposition). The disjunct juxtaposition of a tone, of two tetrachords constructs the diapason scale containing one perfect octave. The conjunct juxtaposition of several of these perfect octave diapasons leads to the scales, and modes with which we are familiar. The conjunct juxtaposition of several tetrachords (triphony) produces a scale, the octave of which is no longer a fixed sound of the tetrachord but one of its mobile sounds. It is similar for the conjunct juxtaposition of several pentachords (trochos).

But the system can be applied to three genera of tetrachord and to their subdivisions separately, and this creates a very rich set of scales. Finally, the types of tetrachords (as in the selidia of Ptolemy) can be mixed in a scale and this is conducive to an enormous variety. The scale level is therefore the result of a combinatory method, or better, of a huge montage (harmony), by the repeated juxtapositioning of already very diversified organisms, the tetrachords and their derivatives. The scale, as defined here, is a richer and more universal conception than all the impoverished conceptions of the early Middle Ages and modern times. From this point of view it is not the temperament but the absorption by the diatonic tetrachord (and the corresponding scale which derives from a disjunct system of two diatonic tetrachords separated by a whole tone—white keys on the piano) of all the other combinations or montages (harmonies) of the other tetrachords which constitutes the enormous loss of potential, both abstract and sensory, which we now have to reconstruct—but in a modern manner as we shall see. Examples of scales are shown below in segments of the Byzantine temperament identical to the Aristoxenian (an exact fourth = 30 segments):

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[1] Selidion 1, mixture of syntonon chromatic (22 : 21, 12 : 11, 7 : 6) and of toniaion diatonic (28 : 27, 7 : 8, 9 : 8); selidion 2, mixture of soft diatonic (21 : 20, 10 : 9, 8 : 7) and of toniaion diatonic (28 : 27, 8 : 7, 9 : 8); etc. (cf. Westphal, *op. cit.*, p. 48).

Diatonic scales
Diatonic tetrachords:
system by disjunct tetrachords,
12, 11, 7/12/11, 7, 12 beginning on low-pitched Δ,
12, 11, 7/12/12, 11, 7 beginning on low H or A;
system by tetrachord and pentachord: 7, 12, 11/7, 12, 11 beginning on low Z;
wheel system (trochos) 11, 7, 12, 12/11, 7, 12, 12/11, 7, 12, 12/, etc.

Chromatic scales
Soft chromatic tetrachords: wheel system beginning on H, 7, 16, 7, 12/7, 16, 7, 12/7, 16, 7, 12/, etc.

Enharmonic scales
Enharmonic tetrachord second scheme: system by disjunct tetrachords beginning on Δ, 12, 6, 12/12, 12, 6, 12—it corresponds to the mode of D. The enharmonic scales by the disjunct system construct all the ecclesiastical scales or modes of the West. Also others, for instance: enharmonic tetrachord of the first scheme by the triphonic system, beginning on low H: 12, 12, 6/12, 12, 6/12, 12, 6/12, 12, 6/.

Mixed scales
Diatonic tetrachords first scheme + soft chromatic: disjunct system, beginning on low H, 12, 11, 7/12/7, 16, 7/. Hard chromatic tetrachords + soft chromatic, disjunct system, commencing on low H, 5, 19, 6/12/7, 16, 7/.

Not all the 'montages' are used, which demonstrates the absorption phenomenon of the non-perfect octaves by the perfect octave by virtue of the basic consonance rules. This limits the case very much.

Quartenary level: The tropes or echoi (ichi). The echos is defined by:
the genera of tetrachords (or derivatives) which make it up;
the system of juxtaposition;
the attractions;
the bases or 'tonics';
the dominant sounds;
the endings or cadences (catalyxis);
the apichima, melodies of introduction of mode;
the ethos which follows the ancient definitions.

Without going into the details of this level, this is a brief explanation of the analysis of the 'out of time' structure of Byzantine music.

The metabolai
This structure could not be satisfied with a partitioned hierarchy. It had to be able to circulate freely between the tones and their subdivisions, between the kinds of tetrachords, between the genera, between the systems and between the echoi. Thus we arrive at an outline of 'in time' structure, which we shall run through very briefly. There are operative signs which permit changes, transpositions, modulations and other transformations (metabolai). These signs are the phthorai and chroai of notes, tetrachords, systems (or scales) and echoi.

Metabolai of note:
a the metathesis: passing from a tetrachord of 30 segments (perfect fourth) to another tetrachord of 30 segments;
b the parachordi: distortion of the interval corresponding to the 30 segments of the tetrachord into another, bigger, and the reverse; or, passing from one distorted tetrachord to another distorted tetrachord.

Metabolai of genera:
a phthora characteristic of the genus, not changing the name of the notes;
b with change in name of notes;
c using the parachordi;
d using the chroai.

Metabolai of systems: passing from one system to another by means of previous metabolai. Here we are involved with metabolai of the echoi by special signs, the martyrikai phthorai or alterations of the mode initialization.

It is because of the complexity of the metabolai that the pedal notes (isokratima) cannot be 'left to the ignorant'. Isokratima constitutes an art in itself since it is responsible for emphasizing and favouring all the 'in time' fluctuations of the 'out of time' structure of the chant.

It is clear that the crowning of this 'out of time' edifice is the most complex and refined thing which could be invented by the monodic chant *par excellence*. What could not be developed in polyphony has been elaborated to a richness so luxuriant that in order to be able to recognize it one has to pursue years of practical study in the manner of singers or instrumentalists of high Asiatic cultures. But none of the specialists of Byzantine music appear to be aware of the importance of this edifice. They have been so absorbed in the deciphering of ancient notations, it would appear, that they have taken no heed of the present tradition of the Byzantine church and have thus produced misleading false assertions. And so it was barely a few years ago that one of them,[1] following the Gregorianists, began to attribute to the echoi, characteristics other than those of the western scales which they had been taught in the conformist schools. They have finally discovered that the echoi contain some characteristic, although sedimentary, melodic formulae. But they have neither been able nor wanted to go further and to abandon their cosy manuscript retreat.

The lack of understanding of ancient[2] music, Byzantine and Gregorian in its origin, is certainly due to the oblivion caused by the growth of polyphony, the highly original creation of the barbarous and uncultivated west and by the splitting of the Churches. The passing of the centuries and the disappearance of the Byzantine State have hallowed this oblivion and this separation. The effort, therefore, of knowing a 'harmonic' language which is much finer and much more complex than that of the syntonon diatonic and its octave scales is undoubtedly very much beyond the normal capacity of the Western 'specialist' even if present-day music has been able to free him (partially) from this crushing hold. I will make an exception for the extreme orientalists,[3] who are never cut off from musical practice and since they have to deal with living matter, are able to look for a harmony other than the tonal one of twelve semitones.

The crowning aberration is in the transcription of Byzantine melodies[4] into western notation by the tempered system. Thus thousands of transcriptions are wrong! But the critical approach which can be made to the Byzantinologists is that, by remaining cut off from the great musical tradition of the Eastern Church, they have caused this abstract and sensual, complex and remarkably interlocked (harmonious) architecture, this survival of and this real accomplishment of the Hellenic tradition, to disappear. In this way, they have held back the progress of musicological research:

a of antiquity
b of the plain-chant
c of the folk-lores of European countries (especially eastern);[5]
d of musical cultures of other continents;
e of a better understanding of the musical development of western Europe from the early middle ages to modern times;
f of the syntactic prospection of the music of tomorrow, its enrichment and its survival.

I wanted to present this architecture linked with antiquity and of course with other cultures since it provides elegant living evidence of what I must define as the 'out of time' category (algebra, structure) of music as opposed to the two other categories, 'in time' and 'temporal'. It has often been said (Stravinsky, etc., Messiaen too) that time is everything in music, forgetting the basic structures on which personal languages rest, however simplified they may be, such as 'pre- or post-Webernian serial' music. In order to understand the universal past and present, as well as to prepare for the future, we must distinguish the structures, the architectures,

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[1] Egon Wellesz *A History of Byzantine Music and Hymnography*. Oxford: The Clarendon Press, 1961, p. 71, etc. On page 70, he, too, takes up the myth of the descending ancient scales.

[2] The same negligence can be observed in the antiquizing Hellenists, by way of example, the classic Louis Laloy in *Aristoxène de Tarente*, 1904, p. 249, etc.

[3] Alain Danielou went to live in India for many years and learned to play Hindu instruments, similarly with Mantle Hood with Indonesian music, not to mention Tran Van Khê, theoretician and artist-composer, practising the traditional music of Vietnam, etc.

[4] cf. Egon Wellesz *A History of Byzantine Music and Hymnography*, also the transcriptions by C. Höeg, another great Byzantinologist who has overlooked the problems of structure, etc.

[5] Surprise of specialists, on discovery of Byzantine writing in notation of Rumanian folk-lore, in 'Complementary Reports on the XIIth International Congress on Byzantine Studies', *Ochride* 1961, p. 76. These specialists certainly are unaware that an identical phenomenon exists in Greece.

the sound organisms from their temporal manifestations. We must therefore make veritable successive tomographies in time, compare them and disentangle from them the relationships and architectures and vice versa. Besides, thanks to the metric character of time we can provide it too with an 'out of time' structure, leaving finally to the temporal category only its true nature, completely bare, that of the immediate reality, or instantaneous 'becoming'.

Consequently, time could be considered as a blackboard (blank) on which symbols and relationships, architectures and abstract organisms are written. From the collision between architecture-organisms and instantaneous immediate reality is born the primordial quality of an actually experienced awareness.

Ancient and Byzantine architectures relate to the pitches (dominant character of the simple sound) of sounds. The rhythms are subject to an organization though a much simpler one, which we need not go into. We shall certainly not use these ancient and Byzantine models to imitate or copy but to show a fundamental 'out of time' architecture which has been counteracted by the temporal architectures of the modern (post-Middle Ages) polyphonic systems. These systems, including the serials, are again a fairly confused magma of 'out of time' and temporal structures since no one has yet thought of disentangling them.

Gradual loss of 'out of time' structures

The tonal organization coming from the polyphonic adventure and the forgetting of the ancients has, by its very nature, leaned very much on the temporal category defining by 'in time' the hierarchies of its harmonic functions. 'Out of time' it is clearly very poor, its 'harmonics' being reduced to a single octave scale (the C major with two bases the C and the A) corresponding to the syntonon diatonic of the Pythagorean tradition or the Byzantine enharmonic of the first and second schemes. Two metabolai have been preserved: that of the transposition (shifting of the scale) and that of modulation which consists in moving the base on the degrees of the same scale. Another impoverishment is the adoption of the coarse temperament of the semitone, twelfth root of two. The consonances are enriched by that of the third which until Debussy, had almost ousted the traditional perfect fourths and fifths. The final atonalism, prepared by the theory and the music of the romantics, at the end of the nineteenth and beginning of the twentieth century practically abandoned all out of time structure. This was confirmed by the dogmatic suppression of the Viennese who accepted only the final 'total order' of the tempered chromatic scale. Of the four forms of the series, only the inversion of the intervals is related to an 'out of time' structure. Naturally, regrets, conscious or otherwise, are felt and intervallic relationships of symmetry are grafted on to the total chromatic scale in the choice of notes of the series but always in the 'in time' category. Later, this situation hardly changed with the post-Webernians. This gradual loss of the 'out of time' structure of music as from the early Middle Ages is perhaps the characteristic fact of the musical development of western Europe. It is a gradual loss which led to the excrescence of unequalled temporal and 'in time' structures. Therein lies its originality and its contribution to universal culture. But therein too lies its impoverishment, its loss of charge and what would appear to be the risk of a dead end. For the way in which European music has developed up to now is unsuited to giving the world a field of expression on a global scale, a universality; it is in danger of being isolated and cut off from historic necessity. We must open our eyes and try to throw bridges towards other cultures, as well as to the immediate future of musical thought, before dying suffocated by electronic technology, applied either on the instrumental level or on the level of computer compositions.

Reintroduction of the 'out of time' structure through stochastic methods

By the introduction of the probability calculus (stochastic music) the small present horizon of 'out of time' structures and asymmetry has been completely explored and is seen to be closed. But by the very fact of its introduction, stochastics has caused a leap in musical thought to be made over this fence, towards the clouds, masses of sound events and towards a plasticity of statistically controlled large numbers. There is no longer a distinction between the 'vertical' and the 'horizontal'. The indeterminism of the 'in time' came with dignity into the fabric of music. And, full of Heraclitian dialectics, indeterminism became coloured by, and was structurized with, special stochastic functions; it was generously organized. It could hold in its lap the determined and, in a still nebulous way, the 'out of time' structures of yesterday. 'Out of time', 'in time', 'temporal', these categories which have been unevenly united in the history of music suddenly take on their fundamental significance and can serve to build for the first time a coherent and universal synthesis in the past, present and future. I must insist on saying that this is in the order of possibility and even that it is a privileged direction. But we have not yet cleared this distance. We must complete our arsenal with sharper tools, with decisive axiomatics and formalization.

Sieve theory

To do this we must establish an axiomatic basis for the structure of total order (structure of additive group = Aristoxenian additive structure) of the tempered chromatic scale by taking up what has been published at other times.[1] Axiomatics of the tempered chromatic scale is inspired by the axiomatics of Peano's numbers: First terms: O origin stop, n a stop, n' the stop resulting from the elementary displacement of n. D the set of the values of the sound characteristics envisaged (pitch, density, intensity, duration, speed, degree of disorder, etc.). The values will be identified with the displacement stops.
First propositions (axioms):

1. The stop O is an element of D;
2. If the stop n is an element of D, then the new stop n' is an element of D;
3. If the stops n and m are elements of D, then the new stops n' and m' will be identical if, and only if, the stops n and m are identical.
4. If the stop n is an element of D, it will be different from the origin stop O;
5. If the elements belonging to D have a special property P such that the stop O has it also, and if, for every element n of D having this property, the element n' also has it, the elements of D all have the property P.

We have thus defined axiomatically not only a tempered chromatic scale with pitch sensations but also with all the sound properties or characteristics of the domain D stated above (density, intensity, etc.). Moreover, this abstract scale, as Bertrand Russell quite rightly remarked *à propos* the axiomatics of numbers of Peano, does not have a unitary displacement defined or related to an absolute size. Consequently it can be constructed with tempered semitones or with Aristoxenian segments (twelfths of a tone) or with the commas of Didymos (81/80) or with quarter tones, tones, thirds, fourths, fifths, octaves, etc., or again with any other unit, no multiple of which corresponds to the perfect octave.

For the moment, let us define on this scale another equivalent scale but one whose unitary displacement will be a multiple of the first. It can be expressed by the notion of congruence modulo m. Definition: two integers x and n are said to be congruent modulo m if m is a factor of $x - n$. It is written symbolically $x \equiv n \pmod{m}$. Thus two integers are congruent modulo m, if and only if, they differ from n by an integer multiple (positive or negative) of m, for example, $4 \equiv 19 \pmod{5}$, $-3 \equiv 13 \pmod{8}$, $14 \equiv 0 \pmod{7}$. Consequently, any integer is congruent modulo m, to one and to only one of the numbers n:

$$n = (0, 1, 2 \ldots, m-2, m-1)$$

We say that each of these numbers form a residual modulo m class; they are, in fact, the smallest non-negative modulo m residues.

$$x \equiv n \pmod{m}$$

is therefore equivalent to

$$x = n + km$$

where k is an integer,

$$k \in Z = (0, 1, -1, 2, -2, \ldots)$$

For any given n and for $K \in Z$, the numbers x will belong by definition to the residual class n modulo m. We will call this class: m_n.

To fix the ideas let us take as unit of displacement the tempered semitone of the present-day scale. On this we apply the previous axiomatics for a second time with, as

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[1] cf. my text in the record, issued by Chant du Monde L.D.X-A-8368 and Cardinal records USA. See also *Gravesaner Blätter* no 29, and *Musiques Formelles*, (*Formalized Music*).

elementary displacement[1] a size of say 4 semitones (major third). We are defining a new chromatic scale. If the stop at the origin is placed on a D sharp of the first scale, then a second application of the same axiomatics will supply us with all the multiples of the 4 semitones, that is to say with the scale of major thirds,

D sharp_0, G_0, B_0, D sharp_1, G_1, B_1

which are the notes of the first scale, the numerical order of which is the congruent to 0 modulo 4 residue class (they all belong to the residue class 0 modulo 4). The residue classes 1, 2, 3 modulo 4 will use up the notes of this total chromatic scale. These classes are symbolized in the following way:

residual class 0 modulo 4 by 4_0
residual class 1 modulo 4 by 4_1
residual class 2 modulo 4 by 4_2
residual class 3 modulo 4 by 4_3
residual class 4 modulo 4 by 4_4
and so on.

As it is in fact a matter of sieving the basic scale (elementary displacement of a semitone) each residual class forms a sieve which allows only some elements of the total chromatic scale to pass through. By extension, the total chromatic will be called sieve 1_0. The scale by fourths will be given by sieve 5_n, in which n will have one of the values $n = 0, 1, 2, 3, 4$. A transposition of this scale shall correspond to each changing of the index n. Thus the Debussy scale by tones, 2_n with $n = 0, 1$ has two transpositions:

$2_0 \rightarrow$ C, D, E, F sharp, G sharp, A sharp, C . . .
$2_1 \rightarrow$ C sharp, D sharp, F, G, A, B, C sharp . . .

From these elementary sieves, equivalent among themselves, we can construct more complex scales, all the scales imaginable, with the aid of the three operations of the 'logic of classes'; union (disjunction) marked V, intersection (conjunction) marked Λ and the complementary element (negation) marked with a bar placed over the sieve modulus.

Thus:

$2_0 \mathrm{V} 2_1 =$ chromatic total (which could be marked 1_0)
$2_0 \Lambda 2_1 =$ no notes, or empty sieve marked ϕ
$2_0 = 2_1$ and $2_1 = 2_0$

The major scale could be written:

$$(\overline{3}_2 \Lambda 4_0) \mathrm{V} (\overline{3}_1 \Lambda 4_1) \mathrm{V} (3_2 \Lambda 4_2) \mathrm{V} (\overline{3}_0 \Lambda 4_3)$$

This writing by definition confounds all the 'modes' of the white keys of the piano, since what we are defining is the scale, the 'modes' being architectures basing themselves on the scales. Thus the mode of D placed on D will have the same writing. But in order to recognize the 'modes' we could introduce the non-commutativity of the logical expressions. On the other hand each of the 12 transpositions of this scale will be a combination of cyclic permutations of the indices of sieves 3 and 4. Thus the major scale, transposed upwards by a semitone (shifting to the right) will be written:

$$(\overline{3}_0 \Lambda 4_1) \mathrm{V} (\overline{3}_2 \Lambda 4_2) \mathrm{V} (3_0 \Lambda 4_3) \mathrm{V} (\overline{3}_1 \Lambda 4_0)$$

and in general

$$(\overline{3}_{n+2} \Lambda 4_n) \mathrm{V} (\overline{3}_{n+1} \Lambda 4_{n+1}) \mathrm{V} (3_{n+2} \Lambda 4_{n+2}) \mathrm{V} (\overline{3}_n \Lambda 4_{n+3})$$

where n will take any value from 0 to 11, but reduced, after addition of the constant index of each of the sieves (moduli), modulo the corresponding sieve. The scale of D placed on C will be written:

$$(3_n \Lambda 4_n) \mathrm{V} (\overline{3}_{n+1} \Lambda 4_{n+2}) \mathrm{V} (\overline{3}_n \Lambda 4_{n+2}) \mathrm{V} (\overline{3}_{n+2} \Lambda 4_{n+3})$$

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Let us now change the base unit (the elementary displacement) of the sieves by taking the quarter tone. The major scale will be written,

$$(8_n \Lambda \overline{3}_{n+1}) \mathrm{V} (8_{n+2} \Lambda \overline{3}_{n+2}) \mathrm{V} (8_{n+4} \Lambda 3_{n+1}) \mathrm{V} (8_{n+6} \Lambda 3_n)$$
with $n = 0, 1, 2 \ldots 23$ (modulo 3 or 8)

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[1] The elementary displacements are among themselves like integers, that is to say that they are defined as resulting elements of another axiomatic definition, the same one.

The same scale with a still finer screen (one octave = 72 Aristoxenian segments) will be written:

$$(8_n\Lambda(9_n\mathrm{V}9_{n+6}))\mathrm{V}(8_{n+2}\Lambda(9_{n+3}\mathrm{V}9_{n+6}))\mathrm{V}(8_{n+4}\Lambda 9_{n+3})$$
$$\mathrm{V}(8_{n+6}\Lambda(9_n\mathrm{V}9_{n+3}))$$
with $n = 0, 1, 2 \ldots 71$ (modulo 8 or 9)

posed of a hard chromatic tetrachord and of a diatonic tetrachord of the second scheme separated by a major tone is written in Aristoxenian segments: 5, 19, 6/12/11, 7, 12 and its logical expression will be:

$$(8_n\Lambda(9_n\mathrm{V}9_{n+6}))\mathrm{V}(9_{n+6}\Lambda(8_{n+2}\mathrm{V}8_{n+4}))\mathrm{V}(8_{n+5}\Lambda(9_{n+5}\mathrm{V}9_{n+8}))$$
$$\mathrm{V}(8_{n+6}\Lambda 9_{n+3})$$
with $n = 0, 1, 2 \ldots 71$ (modulo 8 or 9)

The Bhairavi Raga of the Andara-Sampurna class (pentatonic ascending, heptatonic descending)[1] expressed by an Aristoxenian basic sieve (octave, of period 72), will be written:

Pentatonic scale:

$$(8_n\Lambda(9_n\mathrm{V}9_{n+3}))\mathrm{V}(8_{n+2}\Lambda(9_n\mathrm{V}9_{n+6}))\mathrm{V}(8_{n+6}\Lambda 9_{n+3})$$

Heptatonic scale:

$$(8_n\Lambda(9_n\mathrm{V}9_{n+3}))\mathrm{V}(8_{n+2}\Lambda(9_n\mathrm{V}9_{n+6}))\mathrm{V}(8_{n+4}\Lambda(9_{n+4}\mathrm{V}9_{n+6}))$$
$$\mathrm{V}(8_{n+6}\Lambda(9_{n+3}\mathrm{V}9_{n+6}))$$
with $n = 0, 1, 2 \ldots 71$ (modulo 8 or 9).

These two scales expressed by a sieve with the comma c of Didymos as elementary displacement $c = 81/80$ (81/80 raised to the power $55 \cdot 8 = 2$), therefore, the octave with period 56 will be written:

Pentatonic scale:

$$(7_n\Lambda(8_n\mathrm{V}8_{n+6}))\mathrm{V}(7_{n+2}\Lambda(8_{n+5}\mathrm{V}8_{n+7}))\mathrm{V}(7_{n+5}\Lambda 8_{n+1})$$

Heptatonic scale:

$$(7_n\Lambda(8_n\mathrm{V}8_{n+6}))\mathrm{V}(7_{n+2}\Lambda(8_{n+5}\mathrm{V}8_{n+7}))$$
$$\mathrm{V}(7_{n+3}\Lambda 8_{n+3})\mathrm{V}(7_{n+4}\Lambda(8_{n+4}\mathrm{V}8_{n+6}))\mathrm{V}(7_{n+5}\Lambda 8_{n+1})$$
for $n = 0, 1, 2, \ldots 55$ (modulo 7 or 8).

The theory of sieves, therefore, enables us to express by logical functions (and, therefore, mechanize) any scale whatsoever, and thus to unify the study of the structures of levels superior to those of the total order. It can be used in quite new constructions. Let us for this purpose imagine complex non-octave forming sieves.[2] Let us take as sieve unit the tempered quarter tone. An octave contains 24 quarter tones. We must therefore construct a sieve composed in such a way that its cycle would be other than 24 or than one of its multiples, therefore a cycle non-congruent to $k \,.\, 24$ modulo 24 (for $k = 0, 1, 2 \ldots$). If, for instance, it be any logical function of the sieve of moduli 11 and 7 (of periodicity $11 \times 7) = 77 \neq k \,.\, 24$),

$$\overline{(11_n\mathrm{V}11_{n+1})\Lambda 7_{n+6}}$$

it establishes an asymmetric distribution of the degrees of the chromatic scale by quarter tones. We can even use a compound sieve which will throw the period outside the limits of the audible area, for example: any logical function of moduli 17 and 18 (F(17, 18)) since $17 \times 18 = 306 > (11 \times 24)$.

Superstructures

By stochastics: we can rest a closer structure on a compound sieve or simply leave the choice of the elements to a stochastic function. We shall obtain a statistical colouring of the chromatic total with a higher complexity level.

Using metabolai: we know that with any periodic combination of sieve subscripts (transpositions) and with any change of the modulus or moduli of the sieve we get a metabola (modulation). The following are examples of a choice of metabolic transformations: let us take the smallest residues which might be prime to a positive integer r, they form an abelian (commutative) group if the law of composition of these residues is defined by the multiplication with reduction modulo r. Numerical example: if $r = 18$, the residues 1, 5, 7, 11, 13, 17 are prime to r and their products after reduction modulo 18 do not go out of this group

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[1] Alain Danielou *Northern Indian Music*, vol. 2, p. 72. Hertfordshire: The Halcyon Press, 1954.

[2] This perhaps answers the desires of Edgar Varèse taken up by his scale in spiral—cycle of fifths not related to the octave. This information, alas only summary, has been supplied to me by Odile Vivier.

(closure). They form a finite commutative group, a fragment of which is as follows:

$5 \times 7 = 35$; $35 - 18 = 17$; $11 \times 11 = 121$; $121 - (6 \times 18) = 13$, etc. Moduli 1, 7, 13 form a cyclic subgroup of order 3. Let it now be a logical expression,

$$L(5, 13) = \overline{(13_{n+4} \vee 13_{n+5} \vee 13_{n+7} \vee 13_{n+9})} \wedge$$
$$5_{n+1} \vee \overline{(5_{n+2} \vee 5_{n+4})} \wedge 13_{n+9} \vee 13_{n+6}$$

of the two sieves with moduli 5 and 13. We can imagine a transformation of the moduli in pairs, beginning with the abelian group defined above. Thus the kinematic diagram will be (in-time), $L(5, 13) \rightarrow L(11, 17) \rightarrow L(7, 11) \rightarrow L(5, 1) \rightarrow L(5, 5) \rightarrow \ldots \rightarrow L(5, 13)$ to go back to the starting expression (closure).[1]

This theory of sieves can be architecturized in many ways, so as to create classes successively included or intersected, and therefore stages of increasing complexity, that is to say orientations towards increasing determinism in the choices, in the topological tissues of proximity.

Consequently this veritable musical 'out of time' histology can be 'realized' in time by the temporal functions, by giving for instance, functions of change, either of subscripts or of moduli, that is to say the nesting of logical functions parametered by time.

The 'sieve theory' is absolutely general and consequently applicable to other sound characteristics which would be supplied by the structure of the total order, such as intensity, duration, density, degrees of order, speeds, etc. I have already mentioned it elsewhere, as well as in the sieve axiomatics. But this method can equally be applied to visual scales and to the fields of optical art of the future.[2]

Moreover, we shall see in the immediate future the exploration of this theory, its utilization everywhere with the aid of computers, since it is completely mechanizable. Then, at a second stage, will come the study of structures of a partial order such as is found in the classification of timbres, for instance, by the technique of lattices or graphs.

Conclusion

Present-day adventures in music reside, I believe, in this research of the atrophied out of time category which has been dominated by the temporal category.

Moreover this method is capable of unifying the expression of the fundamental structures of all Asiatic, African, European music, etc. It has a considerable advantage; its mechanization, and consequently the tests and models of all kinds which can be introduced by it into the computers which will cause musical science to advance.

Actually we are witnessing an industrialization of music. It has already begun whether we like it or not. It is already flooding our ears in many public places—shops, radios, aeroplanes—throughout the whole world. It permits the consumption of music on a fantastic scale, never before attained. But it is the lowest possible form of music, made from a heap of antiquated clichés from the lowest strata of musical intelligence. Well, it is not a matter of stopping this invasion, which, in spite of everything, increases musical participation, even if it is passively consumed. It is a matter of preparing a qualitative conversion of this music by disputing it and making radical but constructive criticism of our ways of thinking and making music. Only in this way, for which this study is intended to be a model, will the musician come to dominate and transform this poison distilled into our ears, provided he does it immediately. But again we must envisage in the same way, a radical conversion in the teaching of music throughout the world. The non-decimal systems are taught well in some countries and the logic of classes, why not then their application to a new theory of music of which I have given a rough outline here.

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[1] These latter structures have been used in *Akrata* (1964) for 16 winds and in *Nomos alpha* (1965) for cello solo. *Akrata* is recorded by None Such and CBS, USA, and Pathé-Marconi, Europe. *Nomos alpha* by Pathé-Marconi and HMV, Europe, and Angel, USA. See also 'Towards a philosophy of music' in *La Revue d'Esthétique*, nos 2, 3 and 4, Paris 1968; and *Formalized Music*.

[2] For instance *Polytope*, a light-composition in the French Pavilion, Expo '67 Montreal, Canada.

Free stochastic music from the computer

Iannis Xenakis

'In spite of being scientists, three gentlemen consented to an experiment which must have appeared rather mad at first sight, namely the marriage between music and the world's most potent machine.' (Xenakis)

This article, which is largely a translation of chapter 4 in *Musiques Formelles* by Iannis Xenakis (Paris: Richard-Masse 1963), also appeared in *Gravesano Blätter* no 26, 1965. A different English version appears in *Formalized Music: Thought and Mathematics in Composition* by Iannis Xenakis, published by Indiana University Press, 1971.

There is a great diversity of public reaction to the partnership between the machine and artistic creation. Some people maintain that a work of art cannot result, for by definition it must be 'created', in the whole and its parts, all along the line, by a human being, whereas a machine, being dead, cannot invent. Others again hold that one might certainly undertake the ride by machine just for fun, or to see what will turn out, but the result will not be 'finished' or anything more than an experiment, interesting though it might be. The fanatics, finally, accept without hesitation all the marvels of the craziest science-fiction. The moon? Why not—it's quite within our reach.[1] Longevity, too, is just around the corner ... Why not the creative machine as well? These are some of the faithful whose cranky optimism has replaced the myths of Icarus and of fallen fairies by the scientific civilization of the twentieth century—and this civilization does not even prove them altogether wrong.

In actual fact, there is neither a paradox nor any almighty force in science, which progresses by steps which are limited but unpredictable in the long run.

In all the arts there has always existed what we might call rationalism, in the etymological sense, namely, the quest for proportion. The artist has always appealed to this, by necessity. No matter how much the rules of construction have differed from one century to another, there has never been any epoch without any rules at all, which are a necessity for mutual understanding. And the first category of persons are also the first to withhold the predicate 'artistic' from any product they cannot understand.

Thus a musical scale is a convention restricting the scope of possibilities to particular kind of symmetry. The rules of Christian hymnography, of harmony or counterpoint of the various ages, enabled artists to construct and to make themselves understood by those who adopted the same restrictions, by tradition, by collective taste (i.e. mimicry), or by sympathetic resonance. The twelve-note rules, e.g. the banishment of the octave as a legacy of tonality, have imposed restrictions which are partly new but just as real.

Now every rule, every reiterated restriction, is part of a mental machine—a little 'imaginary machine' as Michel Philippot would have put it—a choice, a group of decisions. A work of music can be analysed into a large number of such mental machines. The theme of a symphony is a mould, a mental machine, and its form is another. Some of these mental machines are very restrictive and deterministic while others are very vague, leaving too much open to choice. In recent years it has been realized how very general this idea of a mechanism really is, and that all the domains of human knowledge and activity, from strict logic to artistic manifestation, are covered by it. The wheel, one of the greatest creations of human thought, is a mechanism enabling a man to travel a greater physical distance in a shorter time and with more luggage: electronic computers are the same, in respect of his mental journeys. If most people are prepared to recognize the advantage of using geometry in the plastic arts (e.g. architecture, painting), it is only a very small step further to the use of more abstract (non-visual) mathematics in music, which is more abstract than the plastic arts, and thus, to the employment of computers as an obvious aid to this. To sum up:

a Creative human thought is a secretion of mental mechanisms which turn out to be nothing more than a collection of restrictions or choices; this statement applies to all fields of human activity, including art.

b Some of these mechanisms can be represented by mathematics.

c Some mental mechanisms can be given physical form, e.g. wheel, motor, rocket, analog machines, computers, etc.

d Some mental mechanisms have equivalents in certain mechanisms of nature.

e Certain aspects of artistic creation can be mechanized, and these can be simulated by certain physical mechanisms (machines) already existing or awaiting creation.

f It so happens that computers can be of some use.

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[1] This paper was written in 1963.

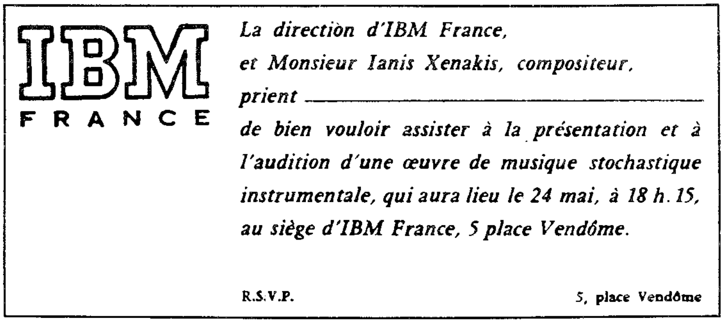
This, then, is the starting-point of the application of electronic computers to musical composition.

The following can be added: two factors combine to complete the part the contemporary composer must play: one is his evolution at a higher level where he must invent schemes (formerly forms) and explore their limits, and the other is the scientific synthesis of new techniques of sound production and emission, which are likely very soon to cover the whole old and more recent instrumentarium, including electronic instruments, using, for example, the analog converters already employed by N. Guttman, J. R. Pierce and M. V. Mathews of the Bell Telephone Laboratories of New Jersey for communication research. Now all this pioneering work involves an impressive knowledge of mathematics, logic, physics and psychology, but more than anything else it demands the use of electronic computers, not only to save time in the mental work of exploring virgin land but also because they provide immediate experimental verification at every stage of musical construction.

Music, being essentially abstract, is the first of all the arts to have attempted the reconciliation of scientific thought and artistic creation. The industrialization of music is an irrevocable matter of destiny, and hints of this are already evident in the attempts by the Parisian team of P. Barbaud, P. Blanchard and Jeanine Charbonnier to industrialize serial and light music as well as in the musicological research work of L. A. Hiller and L. M. Isaacson at the University of Illinois.

In a number of issues of *Gravesaner Blätter* I have referred to various new fields of musical creation, such as Poisson processes, Markov chains, musical games, the minimum-rule thesis, etc., all of which are founded on mathematics in general, and the theory of probability in particular: thus they very largely lend themselves to computer treatment and exploration. The most simple of all these schemes, and the most significant, is the thesis of composition with minimum restrictions, as propounded in *Achorripsis*.

Fig. 53



IBM
FRANCE

La direction d'IBM France,
et Monsieur Ianis Xenakis, compositeur,
prient ______
de bien vouloir assister à la présentation et à l'audition d'une œuvre de musique stochastique instrumentale, qui aura lieu le 24 mai, à 18 h. 15, au siège d'IBM France, 5 place Vendôme.

R.S.V.P.
5, place Vendôme

Through the good offices of my friend M. Georges Boudouris of the Centre National de Recherche Scientifique I made the acquaintance of M. Jacques Barraud, lecturer in engineering at the Ecole des Mines and Electronic Control Section Head at Société des Pétroles Shell-Berre, who again undertook to introduce me to M. François Génuys, senior mathematics lecturer and research head at IBM-France. In spite of being scientists, these three gentlemen consented to an experiment which must have appeared rather mad at first sight, namely the marriage between music and the world's most potent machine. Persuasion by pure reason rarely plays an exclusive part in human relations, which are governed by questions of material interest more than by anything else. In this particular case, however, the bonds were joined even less by interest than by reason: at the root of our collaboration there seems to have been the purest form of free decision in favour of an experiment, or a game, for its own sake. Stochastically speaking, my project should have failed miserably. Well, the doors had been opened, and at the end of about eighteen months, on 24 May 1962, there took place at the head office of IBM-France, 5 place Vendôme, Paris, as 'the most unusual event of the company and of the concert season', a live concert presenting an instrumental stochastic work called ST/10-1,080262 computed on the 7090 and conducted to a success by C. Simonovic and his Ensemble Instrumental de Musique Contemporaine de Paris (fig. 53). This work objectivizes, by its passage through the machine, a stochastic method of composition, namely that of minimum restriction and rules.

Statement of the problem

The first stage was to work out the flow-chart, which meant that all the operational steps of the composition of *Achorripsis*[1] had to be written out clearly and properly

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[1] This work is described in detail in 'In search of a stochastic music' in *Gravesaner Blätter* 11/12 112 (1958); the general synthetic method of this minimum-restriction structure is shown in *Musiques Formelles*, chapter 1, and in *Formalized Music*.

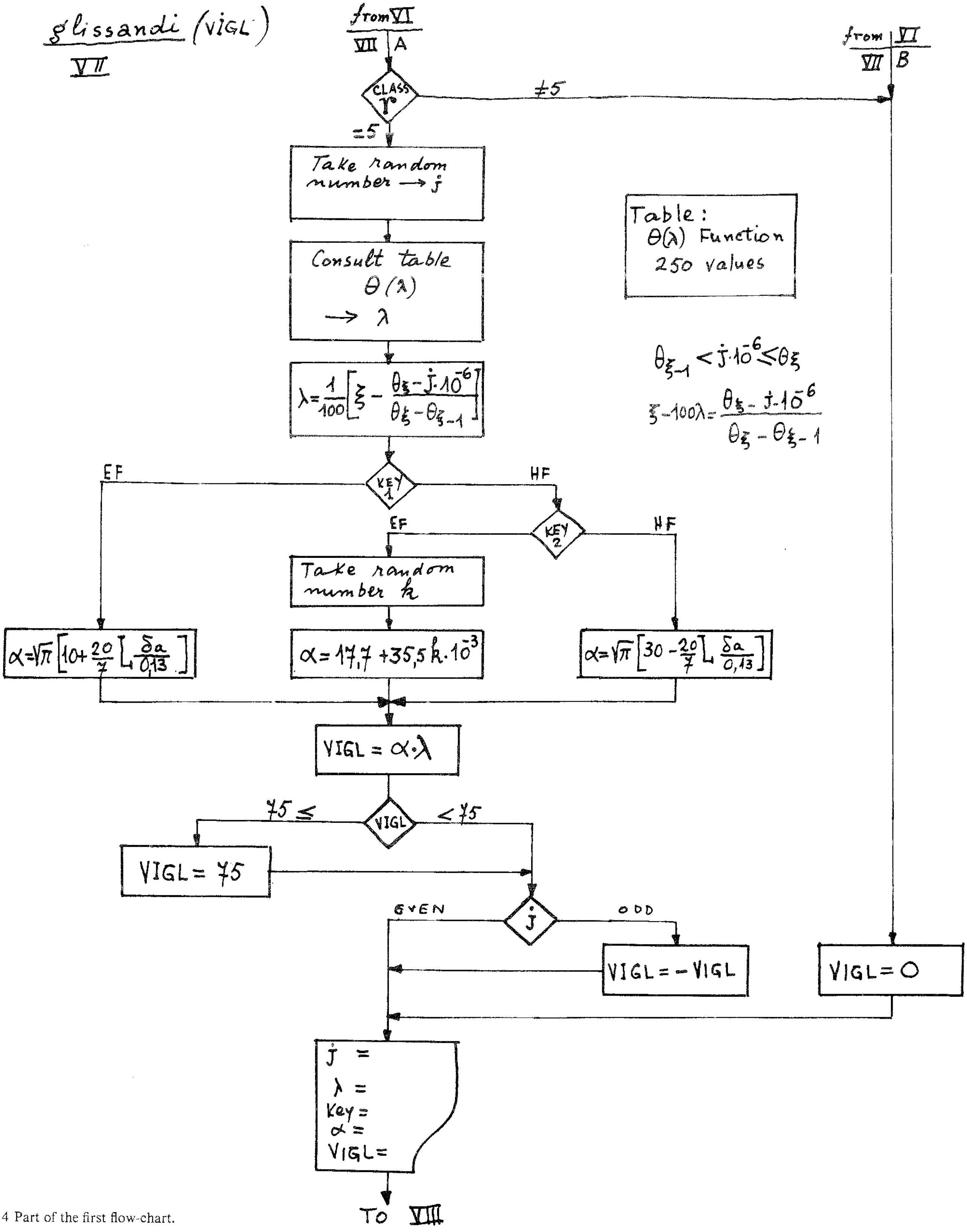


Fig. 54 Part of the first flow-chart.

arranged in a structure appropriate to the machine, one of whose most important features is the capacity for extremely fast reiteration, so that the thesis had to be broken down into a progressive series of operations reiterated in loops (fig. 54).

From this point of view, the thesis of *Achorripsis* was interpreted as follows:

1. *The work comprises a succession of sequences (of movements) of a_i seconds each.* The individual durations are entirely independent (asymmetrical), but there is a definite mean duration introduced as a parameter. The durations and their stochastic succession are given by:

$$P_{ai} = ce^{-ca_i}\, da_i$$

2 *Determining the mean density of notes occurring in the time a_i:* various sound sources emit a number of notes during any sequence. If the total number of such notes (or points) occurring in a sequence is N_{a_i}, then the mean density of this cloud of points is $\frac{N_{a_i}}{a_i}$ notes (points) per second. In general, and more particularly in the case of a given instrumental combination, this density is limited by the number and type of instruments and by the playing technique; a large orchestra can play up to 150 notes/sec. The lower density limit $V3$ is arbitrary, and the value chosen was $V3 = 0{\cdot}11$ notes/sec. Past experience has shown me that the most suitable density progression is a logarithmic one with a base between 2 and 3, the value chosen being $e = 2{\cdot}71827$, so that we can imagine the densities as being entered on a straight line as points with logarithmic spacing (base e) between the limits $V3$ and $V3 \,.\, e^R$, this upper limit being equivalent to, for instance, 150 notes/sec. To conform to the proposition of complete independence, each of the sequences a_i calculated in the preceding section 1 could be given a density represented by any random point in the straight line just mentioned. However, the desire for a certain amount of continuity makes it appear expedient to temper this independence somewhat: this is achieved by including a certain 'memory' from one sequence to the next, as follows:
Let a_{i-1} be a sequence of duration a_{i-1}, DA_{i-1} its density a_i the following sequence of duration a_i, DA_i its density. Then the density of DA_i is given by the equation:

$$DA_i = DA_{i-1} \,.\, (V3)e^{\pm x}$$

where x is a segment taken at random from a straight-line segment of a length $s = (R - 0)$. The probability of x is given by:

$$P_x = \frac{2}{s}\left(1 - \frac{x}{s}\right)dx$$

and finally

$$N_{a_i} = DA_i \,.\, a_i$$

3 *Determining the instruments playing during the sequence a_i.* The instruments are grouped into r timbre classes, e.g. the flute-and-clarinet class, the oboe-and-bassoon class, the brass class, the bowed-string class, the plucked-string class, the struck-string (*col legno*) class, the glissando class, the skin, wood and metal percussion class, etc. The instruments to be used in any sequence are determined stochastically, without any predetermined choice. In any particular sequence lasting a_i we might have, for example, 80 per cent plucked strings, 10 per cent percussion, 7 per cent keyboard instruments and 3 per cent flute classes. Actually it is the density which determines the constitution of the orchestra, and therefore these two factors are related to each other by a special diagram, an example of which from ST/10-1,080262 is shown in figure 55, which is a graphical representation of the equation:

$$Q_r = (n - x)\,(e_{n,\,r} - e_{n+1,\,r}) + e_{n,\,r}$$

where $r =$ class number

$$x = 1n\,\frac{DA_i}{V3}$$

$$n = 0,\ 1,\ 2 \ldots R \text{ such that } n \leqslant x \leqslant n + 1$$

and $e_{n,\,r}$ and $e_{n+1,\,r}$ are the probabilities of the class r in terms of n.

There is hardly need to point out that the calculation and draughtsmanship involved in this diagram entails much artistic delicate and complicated precision work.

After these preliminary steps we can pass on to determine each of the N_{a_i} notes of the sequence a_i.

4 *Determining the point of time when the note N of the sequence a_i occurs.* As the mean density of points (notes) to be distributed through

$$a_i \text{ must reach a value of } k = \frac{N_{a_i}}{a_i}$$

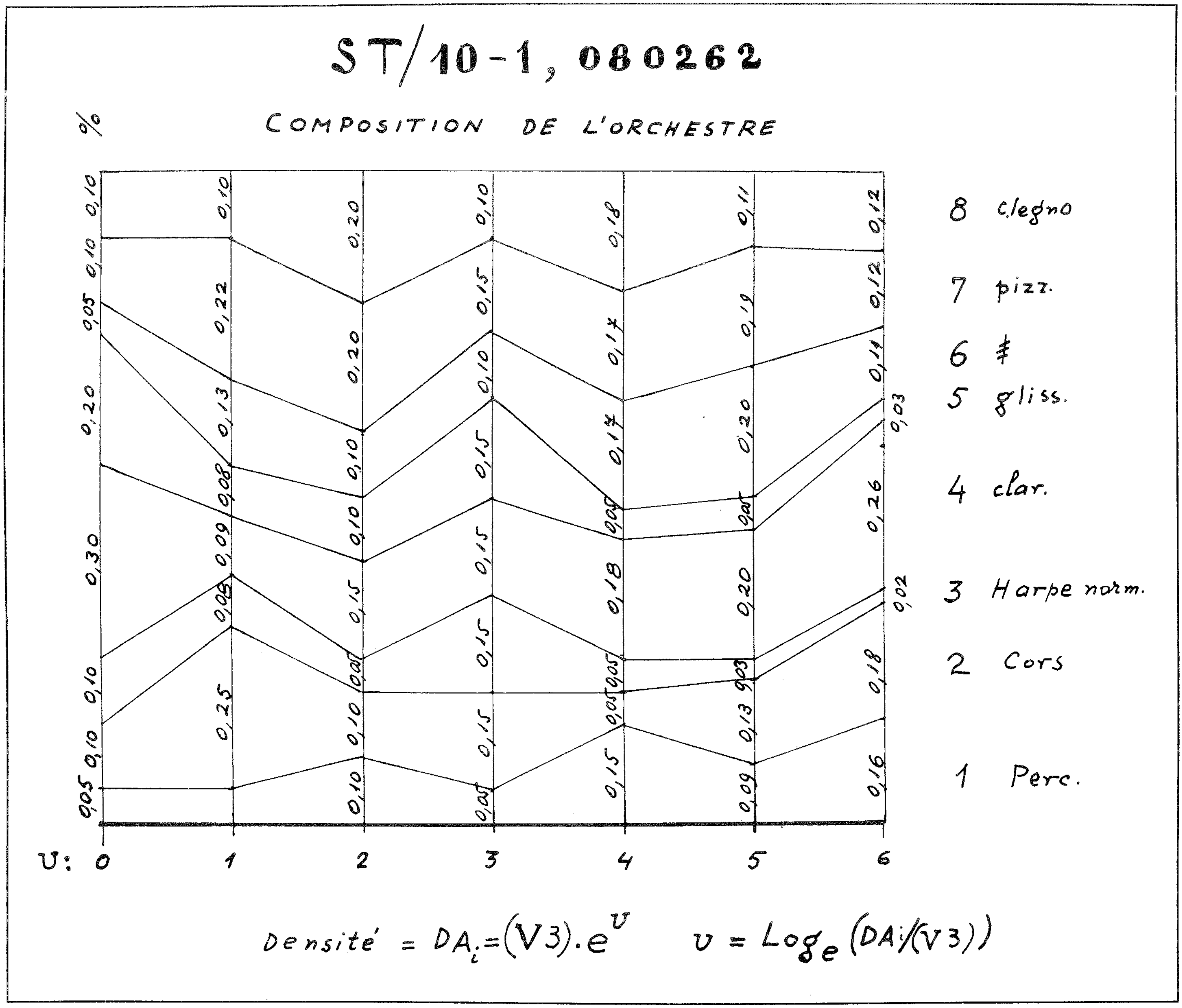


Fig. 55 Constitution of the orchestra in terms of density.

the time interval between the entry of one note and the next is given by:

$$P_t = ke^{-kt}\, dt$$

5 *Choosing an instrument n, out of those already calculated under 3, to play the preceding note N.* The class r among the instruments in use calculated under 3 is chosen at random (as in the case of a ballot-box containing balls in r colours), and then the number n of the instrument of this class is chosen at random following the probability q_n given by an arbitrary table (ballot box with balls in n colours). The correct proportioning of instruments within a class is again a most delicate and complicated matter.

6 *Determining a pitch in terms of the instrument.* A chromatic scale of about 86 semitones is represented as ascending from an origin equal to zero and corresponding to the note A_2. Thus the compass s of each instrument can be expressed by a natural number (distance). But the pitch h_u of a note played by that instrument is expressed by a decimal number whose integral portion refers to a degree of the chromatic scale within the instrument's compass.

As in the case of the density (section 2), the pitch of one note depends to a certain extent on the pitch of the same instrument's previous note because of a memory by which

$$h_u = \mathrm{h}_{u-1} + z$$

z being given by the probability relationship

$$P_z = \frac{2}{s}\left(1 - \frac{z}{s}\right)dz$$

where P_z is the probability of the interval z chosen at random out of the compass s.

7 *Determining the sliding speed in the case of the glissando classes.* The hypotheses of homogeneity lead to the equation:[1]

$$f(v) = \frac{2}{a\sqrt{\pi}}\, e^{-\frac{v^2}{a^2}}$$

and, by putting $\frac{v}{a} = u$, to its equivalent

$$T(u) = \frac{2}{\sqrt{\pi}}\int_0^u e^{-u^2}\, du$$

which is given in the tables, and where $f(v)$ is the probability of occurrence of the speed v (in semitones per second) and a is a parameter proportional to the standard deviation $s(a = s\sqrt{2})$.

a is determined in terms of the logarithm of the density of the sequence a_i by:
an inversely proportional function

$$a = \sqrt{\pi}\left(30 - \frac{20}{R}\, L\, \frac{DA_i}{V3}\right)$$

a directly proportional function

$$a = \sqrt{\pi}\left(10 + \frac{20}{R}\, L\, \frac{DA_i}{V3}\right)$$

or by a function independent of the density,

$$a = 17{\cdot}7 + 35\, k$$

where k is a random number between 0 and 1.

The constants in these equations are derived from the limiting glissando speeds playable on stringed instruments.

Thus if $DA_i = 145$ notes/sec, then $a = 53{\cdot}2$ semitones/sec
and $2s = 75$ semitones/sec
and if $DA_i = 0{\cdot}13$ notes/sec, then $a = 17{\cdot}7$ semitones/sec
and $2s = 25$ semitones/sec

8 *Determining a length x of the note played.* For simplicity, a mean note-length per instrument, independent of the register and the dynamic, is assumed. Consequently we reserve the right to alter it during transcription into traditional notation. The following list shows the restrictions to be taken account of in determining the note-length x:

Longest breath, G
Density of the sequence, DA_i
Probability of class r, p_r
Probability of instrument n, q_n

and the mean length z of a note is inversely proportional to the probability of occurrence of the instrument, so that

$$z = \frac{1}{DA_i \,.\, p_r \,.\, q_n}$$

and z will be a maximum for $(DA_i \,.\, p_r \,.\, q_n)$ minimum so that

---

[1] *Musiques Formelles* chapter 1, and *Formalized Music.*

```
ppp---------ppp
ppp---------p
ppp----p----ppp
  p---------ppp
ppp---------f
ppp----f----ppp
  f---------ppp
ppp---------ff
ppp----ff---ppp
 ff---------ppp
ppp----f----p
  f---ppp---p
  p----f----ppp
  p---ppp---f
ppp----ff---p

 ff---ppp---p
  p---ppp---ff
  p----ff---ppp
  p---------p
  p---ppp---p
  p---------f
  p----f----p
  f---------p
  p---------ff
  p----ff---p
 ff---------p
ppp----ff---f
 ff---ppp---f
  f---ppp---ff

  f----ff---ppp
  f----p----ff
  f----ff---p
  p----ff---f
 ff----p----f
  f---------f
  f---ppp---f
  f----p----f
  f----ff---f
  f---------ff
 ff---------f
 ff---------ff
 ff---ppp---ff
 ff----p----ff
 ff----f----ff
```

Fig. 56 Table of the 44 dynamic forms: a linear combination of 4 mean dynamic values, *ppp, p, f, ff.*

it would be possible to take $z_{\max} = G$. Instead of this we take a logarithmic law to freeze the growth of z. For any value z of

$$\frac{1}{DA_i \cdot p_r \cdot q_n}$$

this law is

$$z' = G \, \frac{1nz}{1nz_{\max}}$$

(in the program, z' is replaced by GE).

As there is complete independence, the density distribution of note-length x is normal:

$$f(x) = \frac{1}{s\sqrt{2\ \pi}} e^{-\frac{(x-m)^2}{2s}}$$

where m is the average duration (mean value)

s is the standard deviation

and $\left.\begin{array}{l} m - 2s = 0 \\ m + 2s = z' \end{array}\right\}$ is the linear system providing the constants m and s.

If we put $u = \dfrac{x - m}{s\sqrt{2}}$ we again find the function $T(u)$ which can be looked up in the tables.

Finally, the note-length x is given by the relationship

$$x = us\,2 + m$$

The incompatibility of instruments is neglected so as not to encumber the program and the computation unnecessarily.

9 *Determining the note's dynamic form.* We take four zones of mean dynamics:

ppp, p, f, ff.

There are $4^3 = 64$ combinations and permutations of any three of these four elements, including repetitions, but only 44 of these are musically distinct, e.g. *ppp* > *f* < *p*. These are chosen like 44 colours out of a ballot-box (fig. 56).

10 *All the steps are repeated for every note of the cloud* N_{a_i}.

11 *All the other sequences are calculated similarly.*

The next step is to transcribe this sequence of steps into FORTRAN language which the machine can 'understand': the FORTRAN program of this family of stochastic structure is given here (fig. 57). Rather than give a tedious account of the transcription of the whole flow-chart into FORTRAN, we shall show the principle of this process by a relatively simple example: suppose that in the elementary law of probability (probability density)

$$f(x)\,dx = ce^{-cx}\,dx$$

we wish to obtain the values of x with the probability of $f(x)\,dx$. Now the computer is capable of choosing random numbers y between 0 and 1, with equal probability, so the problem reduces to 'modulating' this equal probability:
Let x_0 be any length;
then

$$\text{Probab. } \{0 \leqslant x \leqslant x_0\} = \int_0^{x_0} f(x)\,dx = 1 - e^{-cx_0} = F(x_0)$$

where $F(x_0)$ is the distribution of x. But

$$F(x_0) = \text{Probab. } \{0 \leqslant y \leqslant y_0\} = y_0$$

$$\text{where } 1 - e^{-cx_0} = y_0 \text{ and } x_0 = \frac{\ln(1 - y_0)}{c} \text{ for all } x_0 \geqslant 0$$

As another example, let us consider the relationship

$$P_j = f(j)\,dj = \frac{2}{a}\left(1 - \frac{j}{a}\right)dj$$

In this case, the computer's equiprobability is modulated in quite a similar way to the former case, and we obtain

$$j = a(1 - \sqrt{1 - y_0}) \text{ for all } 0 \leqslant j \leqslant a$$

Once the program has been transcribed into a form the computer is capable of assimilating (this transcription took several months), the cards can be punched and a series of test runs can be made to disclose errors of logic and orthography and to determine the starting values of the parameters introduced as variables. This is a most important stage of the work, making it possible to explore the whole range of the program and of its possibilities.

The final phase of the work is to decode the computer results and transcribe them into traditional music notation, although this job could ideally be taken over by an automatic plotter. Figure 58 shows the tentative results of a stage in the analysis.

In conclusion, the method disclosed opens up a vast field of musical composition, for every thinkable formation of instruments or of any other sound sources. One such work, for large orchestra, has already been calculated on commission for the RTF (France III): it is called ST/48-1,240162 (figure 59 shows a page of the finished score); figure 60 shows the computer input data for another work, *Atrées* for ten solo instruments (ST/10-3,060962), while yet another piece is *Morsima-Amorsima* for four instruments, etc.

Although this program solves the problem of the minimum-restraint structure quite well, it would be desirable to exceed pure composition and feed the computer output into an analog converter which directly turns numbers into sounds of a precalculated internal structure.

Some of the advantages of the use of electronic brains in musical composition might be sumarized as follows:

a The long and laborious manual calculation practically vanishes. The operating speed of a computer like the IBM 7090 (which has also been employed for interplanetary rocket control) is of the order of half a million simple operations per second, which saves an enormous amount of time.

b This time can be spent by the composer on general problems arising out of the new musical form, whose every nook and cranny remains to be explored by means of altering the starting values. For example, all possible instrumental combinations can be tested, starting from single instruments and passing through small chamber ensembles to chamber orchestras and finally the symphony orchestra. With the help of an electronic brain the composer turns into an astronaut pressing the buttons of his musical space-ship

Fig. 57a Complete FORTRAN program of *Atrées* ST/10-1.080262.

```
C     PROGRAMME XENAKIS  STOCHASTIC MUSIC   FORTRAN II                  XEN    1
C                                                                       XEN    1
C     READ CONSTANTS AND TABLES                                         XEN    1
      DIMENSION Q(12),S(12),E(12,12),PN(12,50),SPN(12,50),NT(12),       XEN    1
     1HAMIN(12,50),HAMAX(12,50),HBMIN(12,50),HBMAX(12,50),GN(12,50),H(12
     2,50),TETA(256),VIGL(3),MODI(7),Z1(8),Z2(8),ALFA(3),AMAX(12)
C                                                                       XEN    1
      I=1
      DO 36 IX=1,7
      IX8=8-IX
      MODI(IX8)=I
      I=I+I
   36 CONTINUE
C                                                                       XEN    1
      READ INPUT TAPE 5,114,(TETA(I),I=1,256)
      READ INPUT TAPE 5,113,(Z1(I),Z2(I),I=1,8)
C                                                                       XEN    1
 3000 READ INPUT TAPE 5,110,DELTA,V3,A10,A20,A17,A30,A35,BF,SQPI,EPSI,VI
     1TLIM,ALEA,ALIM
      READ INPUT TAPE 5,109,KT1,KT2,KW,KNL,KTR,KTE,KR1,GTNA,GTNS,(NT(I),
     1I=1,KTR)
      READ INPUT TAPE 5,115,KTEST3,KTEST1,KTEST2
C                                                                       XEN    1
      IF(KTEST3)2000,2001,2000
 2000 PRINT 118
 2001 R=KTE-1
      A10=A10*SQPI
      A20=A20*SQPI/R
      A30=A30*SQPI
      DO 92 I=1,KTR                                                     XEN    1
      Y=0.
      KTS=NT(I)                                                         XEN    1
      READ INPUT TAPE 5,112,(HAMIN(I,J),HAMAX(I,J),HBMIN(I,J),HBMAX(I,J)
     1,GN(I,J),PN(I,J),J=1,KTS)
      DO 95 J=1,KTS
      Y=Y+PN(I,J)
      SPN(I,J)=Y
   95 CONTINUE
      IF(ABSF(Y-1.)-EPSI)92,9,9
 92   CONTINUE                                                          XEN    1
C                                                                       XEN    1
      DO 90 I=1,KTR                                                     XEN    1
      READ INPUT TAPE 5,111,(E(I,J),J=1,KTE)
 90   CONTINUE
      DO 88 J=1,KTE
      Y=0.
      DO 83 I=1,KTR
      Y=Y+E(I,J)
   83 CONTINUE
      IF(ABSF(Y-1.)-EPSI)88,9,9
   88 CONTINUE
      DO 30 I=1,KTR
      AMAX(I)=1./E(I,1)
      DO 30 J=2,KTE
      AJ=J-1
      AX=1./(E(I,J)*EXPF(AJ))
      IF(KT1)151,150,151
  151 WRITE OUTPUT TAPE 6,140,AX
  150 IF(AMAX(I)-AX)31,30,30
   31 AMAX(I)=AX
   30 CONTINUE
```

Fig. 57b

```
      IF(KT1)153,152,153
  153 WRITE OUTPUT TAPE 6,141,AMAX
C
  152 JW=1
      SINA=0.
      IF(KTEST1)1000,1,1000
 1000 TAV1=TEMPSF(1)
 1    NLINE=50
C
C     PARTS 1 AND2,DEFINE SEQUENCE A SECONDS AND CLOUD NA DURING A
C
      KNA=0
      K1=0
   21 X1=RANDOMF(0.,1.)
      A=-DELTA*LOGF(X1)
      IF(ALIM-A)23,2,2
   23 IF(K1-KT2)24,91,91
   24 K1=K1+1
      GO TO 21
   91 A=ALIM/2.
      X1=0.
    2 K2=0
   11 X2=RANDOMF(0.,1.)
      IF(JW-1)9,3,5
    9 CALL DUMP
    3 UX=R*X2
      GO TO 4
    5 IF(RANDOMF(0.,1.)-0.5)6,7,7
    6 UX=UPR+R*(1.-SQRTF(X2))
      GO TO 8
    7 UX=UPR-R*(1.-SQRTF(X2))
    8 IF((0.-UX)*(R-UX))4,4,85
   85 IF(K2-KT2)19,3,3
   19 K2=K2+1
      GO TO 11
    4 U=UX
      DA=V3*EXPF(U)
      NA=XINTF(A*DA+0.5)+1
      IF(FLOATF(NA)-GTNA)74,60,60
   60 IF(KNA-KT2)62,54,54
   62 KNA=KNA+1
      GO TO 21
   54 A=DELTA
      GO TO 11
   74 UPR=U
      IF(KT1)13,14,13
   13 WRITE OUTPUT TAPE 6,101,JW,KNA,K1,K2,X1,X2,A,DA,NA
      NA=KT1
      IF(KTEST3)1007,14,1007
 1007 PRINT 116,JW,NA,A
C
C     PART 3,DEFINE CONSTITUTION OF ORCHESTRA DURING SEQUENCE A
C
   14 SINA=SINA+FLOATF(NA)
      XLOGDA=U
      ALOG=A20*XLOGDA
      M=XINTF(XLOGDA)
      IF(M+2-KTE)43,43,44
   44 M=KTE-2
   43 SR=0.
```

Fig. 57c

```
          M1=M+1
          M2=M+2
     154 DO 15 I=1,KTR
          ALFX=E(I,M1)
          BETA=E(I,M2)
          XM=M
          QR=(XLOGDA-XM)*(BETA-ALFX)+ALFX
          IF(KT1)157,156,157
     157 WRITE OUTPUT TAPE 6,143,XM,ALFX,BETA
     156 Q(I)=QR
          SR=SR+QR
          S(I)=SR
    15    CONTINUE
          IF(KT1)16,22,16
    16    WRITE OUTPUT TAPE 6,102,(Q(I),I=1,KTR),(S(I),I=1,KTR)
  C
  C       PART 4,DEFINE INSTANT TA OF EACH POINT IN SEQUENCE A
  C
      22 IF(KTEST2)1004,1003,1004
    1004 TAV2=TEMPSF(1)
    1003 N=1
          T=0.
          TA=0.
          GO TO 25
    26    N=N+1
          X=RANDOMF(0.,1.)
          T=-LOGF(X)/DA
          TA=TA+T
    25    IF(KT1)27,28,27
    27    WRITE OUTPUT TAPE 6,103,N,X,T,TA
  C
  C       PART5,DEFINE CLASS AND INSTRUMENT NUMBER TO EACH POINT OF A
  C
    28    X1=RANDOMF(0.,1.)
          DO 29 I=1,KTR
          IF(S(I)-X1)29,35,35
    29    CONTINUE
          I=KTR
    35    KTS=NT(I)
          KR=I
          X2=RANDOMF(0.,1.)
          DO 72 J=1,KTS
          INSTRM=J
          SPIEN=SPN(KR,J)
          IF(X2-SPIEN)73,73,72
    72    CONTINUE
          INSTRM=KTS
    73    PIEN=PN(KR,INSTRM)
          IF(KT1)38,67,38
      38 WRITE OUTPUT TAPE 6,104,X1,S(KR),KR,X2,SPIEN,INSTRM
  C
  C       PART 6,DEFINE PITCH HN FOR EACH POINT OF SEQUENCE A
  C
      67 IF(KR-1)9,37,39
      37 IF(INSTRM-KR1)18,41,41
      18 HX=0.
          GO TO 52
    39    IF(KR-7)41,42,42
    42    HSUP=HBMAX(KR,INSTRM)
          HINF=HBMIN(KR,INSTRM)
```

Fig. 57d

```
      GO TO 45
 41   HSUP=HAMAX(KR,INSTRM)
      HINF=HAMIN(KR,INSTRM)
   45 HM=HSUP-HINF
      HPR=H(KR,INSTRM)
      K=0
      IF(HPR)46,46,56
 56   X=RANDOMF(0.,1.)
      IF(N-1)9,46,48
   46 HX=HINF+HM*X
      GO TO 52
 48   IF(RANDOMF(0.,1.)-0.5)49,50,50
   49 HX=HPR+HM*(1.-SQRTF(X))
      GO TO 51
   50 HX=HPR-HM*(1.-SQRTF(X))
 51   IF((HINF-HX)*(HSUP-HX))52,52,57
   57 IF(K-KT2)55,46,46
 55   K=K+1
      GO TO 56
 52   H(KR,INSTRM)=HX
 53   IF(KT1)47,58,47
   47 WRITE OUTPUT TAPE 6,100,K,X,HX
C
C     PART 7,DEFINE SPEED VIGL TO EACH POINT OF A
   58 IF(KR-5)40,10,40
   40 VIGL(1)=0.
      VIGL(2)=0.
      VIGL(3)=0.
      X1=0.
      X2=0.
      XLAMDA=0.
      GO TO 82
   10 KX=1
   59 X1=RANDOMF(0.,1.)
      IF(X1-0.9997)121,122,123
  121 I=128
      DO 124 IX=1,7
      IF(TETA(I)-X1)125,126,127
  125 I=I+MODI(IX)
      GO TO 124
  127 I=I-MODI(IX)
  124 CONTINUE
      IF(TETA(I)-X1)128,126,129
  126 XLAMDA=FLOATF(I-1)/100.
      GO TO (98,61),KX
  122 XLAMDA=2.55
      GO TO (98,61),KX
  129 I=I-1
  128 TX1=TETA(I)
      XLAMDA=(FLOATF(I-1)+(X1-TX1)/(TETA(I+1)-TX1))/100.
      GO TO(98,61),KX
  123 DO 130 I=2,7
      TX1=Z2(I)
      IF(X1-TX1)131,132,130
  130 CONTINUE
      I=8
      TX1=1.
  131 TX2=Z1(I)
      XLAMDA=TX2-((TX1-X1)/(TX1-Z2(I-1)))*(TX2-Z1(I-1))
      GO TO (98,61),KX
```

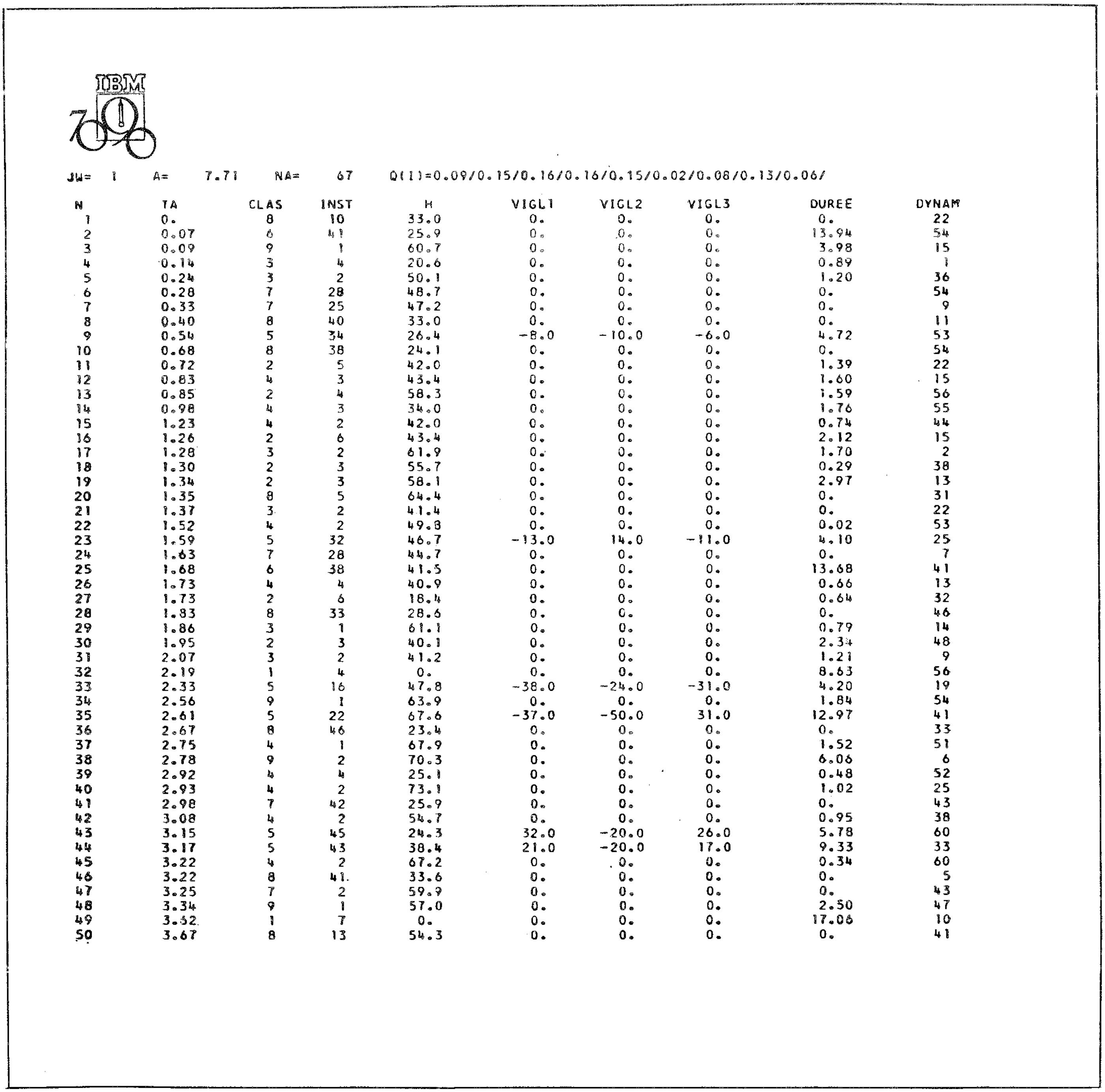
Fig. 57e

```
  132 XLAMDA=Z1(I)
      GO TO (98,61),KX
   98 ALFA(1)=A10+ALOG
      X2=RANDOMF(0.,1.)
      ALFA(2)= A17+A35*X2
      ALFA(3)=A30-ALOG
      DO 63 I=1,3
      VIGL(I)=INTF(ALFA(I)*XLAMDA+0.5)
      IF(VIGL(I)-VITLIM)65,64,64
   64 VIGL(I)=VITLIM
   65 IF(RANDOMF(0.,1.)-0.5)66,63,63
 66   VIGL(I)=-VIGL(I)
 63   CONTINUE
   82 IF(KT1)69,68,69
   69 WRITE OUTPUT TAPE 6,106,X1,X2,XLAMDA,(VIGL(I),I=1,3)
C
C     PART 8, DEFINE DURATION FOR EACH POINT OF A
C
 68   IF((KR-7)*(KR-8)) 70,70,71
   71 ZMAX=AMAX(KR)/(V3*PIEN)
      G=GN(KR,INSTRM)
      RO=G/LOGF(ZMAX)
      QPNDA=1./(Q(KR)*PIEN*DA)
      GE=ABSF(RO*LOGF(QPNDA))
      XMU=GE/2.
      SIGMA=GE/4.
      KX=2
      GO TO 59
   61 TAU=SIGMA*XLAMDA*1.4142
      X2=RANDOMF(0.,1.)
      IF(X2-0.5)75,76,76
 75   XDUR=XMU+TAU
      GO TO 77
 76   XDUR=XMU-TAU
      IF(XDUR)70,77,77
 70   XDUR=0
 77   IF(KT1) 78,79,78
   78 WRITE OUTPUT TAPE 6,105,ZMAX,XMU,SIGMA,X1,XLAMDA,X2,XDUR
C
C     PART 9, DEFINE INTENSITY FORM TO EACH POINT OF A
C
 79   X=RANDOMF(0.,1.)
      IFORM=XINTF(X*BF+0.5)
      IF(KT1)97,96,97
   97 IF(NLINE-KNL)86,84,99
   99 NLINE=1
      GO TO 20
   86 NLINE=NLINE+1
      GO TO 20
   84 WRITE OUTPUT TAPE 6,118
      NLINE=0
      GO TO 20
   96 IF(NLINE-KNL)93,94,94
 93   NLINE=NLINE+1
      GO TO 32
   94 WRITE OUTPUT TAPE 6,107,JW,A,NA,(Q(I),I=1,KTR)
      WRITE OUTPUT TAPE 6,117
      NLINE=1
   32 WRITE OUTPUT TAPE 6,108,N,TA,KR,INSTRM,HX,(VIGL(I),I=1,3),XDUR,IFO
     1RM
```

Fig. 57f

```
C
C      PART10,REPEAT SAME DEFINITIONS FOR ALL POINTS OF A
C
   20 IF(N-NA)26,80,80
C
C      PART 11, REPEAT SEQUENCES A
   80 IF(KTEST2)1006,1005,1006
 1006 TAP2=TEMPSF(1)-TAV2
      TAP2=TAP2/FLOATF(NA)
      WRITE OUTPUT TAPE 6,106,TAP2
 1005 IF(JW-KW)81,89,89
 81   JW=JW+1
      IF(SINA-GTNS)33,89,89
   33 GO TO 1
   89 IF(KTEST1)1002,1001,1002
 1002 TAP1=TEMPSF(1)-TAV1
      TAP1=TAP1/FLOATF(KW)
      WRITE OUTPUT TAPE 6,106,TAP1
 1001 GO TO 3000
C
  100 FORMAT(1H ,I6,2E20.8)
  101 FORMAT(1H1,4I8,3X,4E18.8,3X,I8)
  102 FORMAT(1H ,12F9.4)
  103 FORMAT(//,I8,3E20.8)
  104 FORMAT(1H ,2E20.8,I6,2E20.8,I6)
  105 FORMAT(1H ,5E15.8,F11.4,E15.8)
  106 FORMAT(1H ,6E19.8)
  107 FORMAT(1H1,4X,3HJW=,I3,4X,2HA=,F8.2,4X,3HNA=,I6,4X,5HQ(I)=,12(F4.2
     1,1H/))
  108 FORMAT(1H ,I7,F12.2,I9,I8,F11.1,F13.1,2F10.1,F14.2,I11)
C
  109 FORMAT(5I3,2I2,2F6.0,12I2)
  110 FORMAT(F3.0,F3.3,5F3.1,F2.0,F8.7,F8.8,F4.2,F8.8,F5.2)
  111 FORMAT(12F2.2)
  112 FORMAT(5(5F2.0,F3.3))
C
  113 FORMAT(6(F3.2,F9.8)/F3.2,F9.8,E6.2,F9.8)
  114 FORMAT(12F6.6)
  115 FORMAT(5I3)
  116 FORMAT(1H0,2I9,F10.2)
  117 FORMAT(/6X,1HN,9X,2HTA,8X,4HCLAS,4X,4HINST,8X,1HH,9X,5HVIGL1,5X,5H
     1VIGL2,5X,5HVIGL3,9X,5HDUREE,7X,5HDYNAM)
  118 FORMAT(1H1)
  140 FORMAT(1H ,E15.8)
  141 FORMAT(1H ,9E12.8)
  142 FORMAT(1H ,I3)
  143 FORMAT(1H ,3F20.8)
      END
```

Fig. 58 Tentative results of a stage of the analysis.



```
JW=  1     A=     7.71    NA=     67     Q(1)=0.09/0.15/0.16/0.16/0.15/0.02/0.08/0.13/0.06/

  N        TA        CLAS    INST      H        VIGL1     VIGL2     VIGL3       DUREE      DYNAM
  1       0.          8       10      33.0       0.        0.        0.        0.          22
  2       0.07        6       41      25.9       0.        0.        0.       13.94        54
  3       0.09        9        1      60.7       0.        0.        0.        3.98        15
  4       0.14        3        4      20.6       0.        0.        0.        0.89         1
  5       0.24        3        2      50.1       0.        0.        0.        1.20        36
  6       0.28        7       28      48.7       0.        0.        0.        0.          54
  7       0.33        7       25      47.2       0.        0.        0.        0.           9
  8       0.40        8       40      33.0       0.        0.        0.        0.          11
  9       0.54        5       34      26.4      -8.0     -10.0      -6.0       4.72        53
 10       0.68        8       38      24.1       0.        0.        0.        0.          54
 11       0.72        2        5      42.0       0.        0.        0.        1.39        22
 12       0.83        4        3      43.4       0.        0.        0.        1.60        15
 13       0.85        2        4      58.3       0.        0.        0.        1.59        56
 14       0.98        4        3      34.0       0.        0.        0.        1.76        55
 15       1.23        4        2      42.0       0.        0.        0.        0.74        44
 16       1.26        2        6      43.4       0.        0.        0.        2.12        15
 17       1.28        3        2      61.9       0.        0.        0.        1.70         2
 18       1.30        2        3      55.7       0.        0.        0.        0.29        38
 19       1.34        2        3      58.1       0.        0.        0.        2.97        13
 20       1.35        8        5      64.4       0.        0.        0.        0.          31
 21       1.37        3        2      41.4       0.        0.        0.        0.          22
 22       1.52        4        2      49.8       0.        0.        0.        0.02        53
 23       1.59        5       32      46.7     -13.0      14.0     -11.0       4.10        25
 24       1.63        7       28      44.7       0.        0.        0.        0.           7
 25       1.68        6       38      41.5       0.        0.        0.       13.68        41
 26       1.73        4        4      40.9       0.        0.        0.        0.66        13
 27       1.73        2        6      18.4       0.        0.        0.        0.64        32
 28       1.83        8       33      28.6       0.        0.        0.        0.          46
 29       1.86        3        1      61.1       0.        0.        0.        0.79        14
 30       1.95        2        3      40.1       0.        0.        0.        2.34        48
 31       2.07        3        2      41.2       0.        0.        0.        1.21         9
 32       2.19        1        4       0.        0.        0.        0.        8.63        56
 33       2.33        5       16      47.8     -38.0     -24.0     -31.0       4.20        19
 34       2.56        9        1      63.9       0.        0.        0.        1.84        54
 35       2.61        5       22      67.6     -37.0     -50.0      31.0      12.97        41
 36       2.67        8       46      23.4       0.        0.        0.        0.          33
 37       2.75        4        1      67.9       0.        0.        0.        1.52        51
 38       2.78        9        2      70.3       0.        0.        0.        6.06         6
 39       2.92        4        4      25.1       0.        0.        0.        0.48        52
 40       2.93        4        2      73.1       0.        0.        0.        1.02        25
 41       2.98        7       42      25.9       0.        0.        0.        0.          43
 42       3.08        4        2      54.7       0.        0.        0.        0.95        38
 43       3.15        5       45      24.3      32.0     -20.0      26.0       5.78        60
 44       3.17        5       43      38.4      21.0     -20.0      17.0       9.33        33
 45       3.22        4        2      67.2       0.        0.        0.        0.34        60
 46       3.22        8       41      33.6       0.        0.        0.        0.           5
 47       3.25        7        2      59.9       0.        0.        0.        0.          43
 48       3.34        9        1      57.0       0.        0.        0.        2.50        47
 49       3.52        1        7       0.        0.        0.        0.       17.06        10
 50       3.67        8       13      54.3       0.        0.        0.        0.          41
```

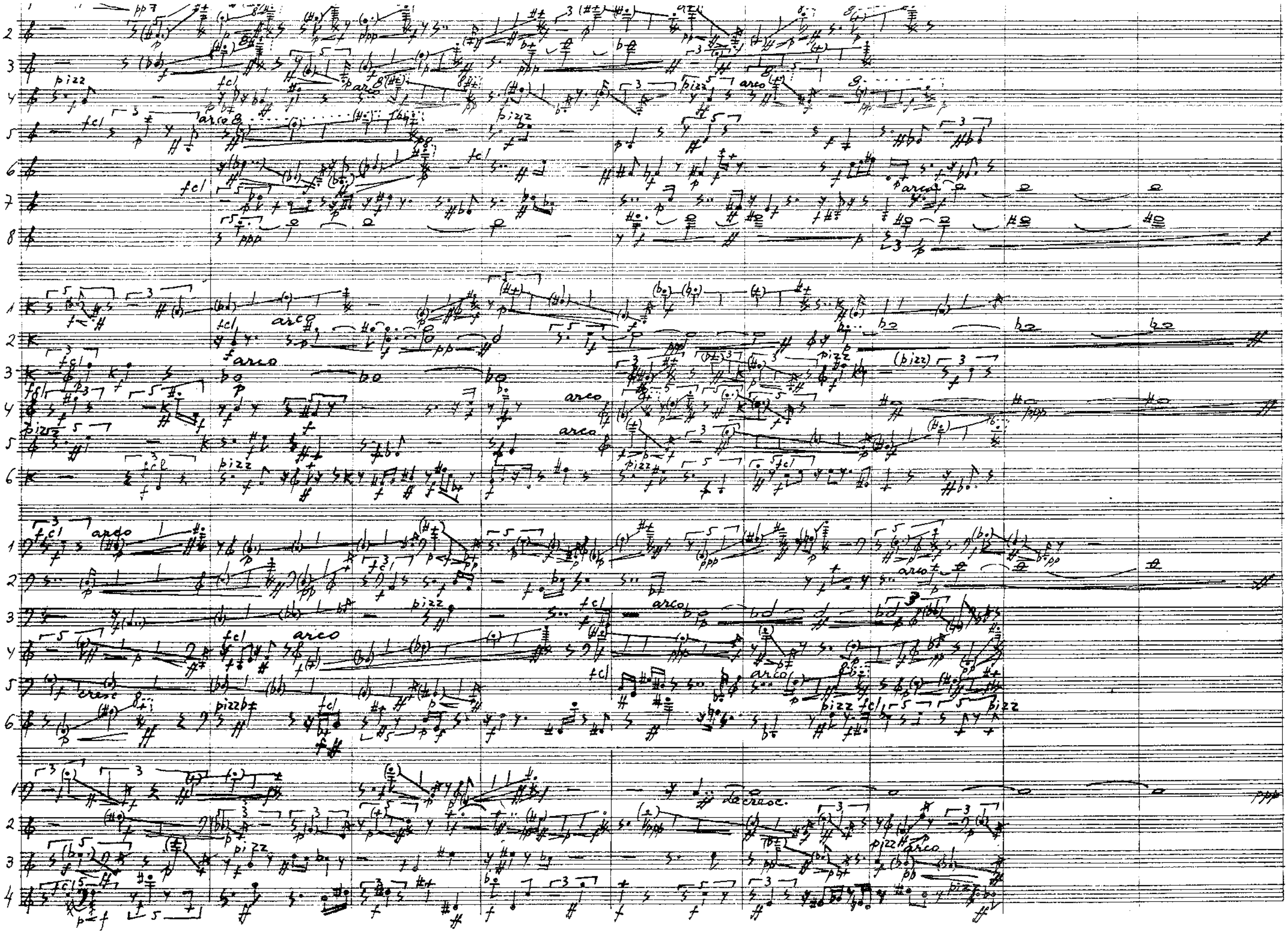


Fig. 59 A section of the finished score of ST/48-1,240162.

to introduce co-ordinates and keep the course of his vessel on its journey through constellations and galaxies of sound, controlling from his easy-chair what the imagination of yesteryear could have envisaged only in its remotest dreams.

c The program, i.e. the sequence of operations making up the new musical form, is an objectivation of that form and can be sent to any place on earth possessing comparable computers where they can be used by any other pilot-composer.

d By leaving certain points of the program open, a pilot-composer is even able to impress his own personality on the result he obtains.

Constitution of the orchestra for *Atrées* (ST/10-3,060962) Timbre classes and instruments as on present input data (fig. 60)

CLASS	TIMBRE	INSTRUMENT	INSTRUMENT NO.
1	Percussion	Temple-blocks	1–5
		Tom-toms	6–9
		Maracas	10
		Susp. cymbal	11
		Gong	12
2	Horn	French horn	1
3	Flute	Flute	1
4	Clarinet	Clarinet B♭	1
		Bass clar. B♭	2
5	Glissando	Violin	1
		Cello	2
		Trombone	3
6	Tremolo or flutter-tongue	Flute	1
		Clarinet B♭	2
		Bass clar. B♭	3
		French horn	4
		Trumpet	5
		Trombone a	6
		Trombone b (pedal notes)	7
		Violin	8
		Cello	9
7	Plucked strings	Violin	1
		Cello	2
8	Struck strings[1]	Violin	1
		Cello	2
9	Vibraphone	Vibraphone	1
10	Trumpet	Trumpet	1
11	Trombone	Trombone a	1
		Trombone b (pedal notes)	2
12	Bowed strings	Violin	1
		Cello	2

---

[1] *col legno.*

Fig. 60 Input data for *Atrées* ST/10-3,060962.

```
*      DATA      ATREES      ST/10-3, 060962
000000011300022600033900045100056400067600078900090100101300112500123600 T01
134800145900156900168000179000190000200900211800222700233500244300255000 T02
265700276300286900297400307900318300328600338900349100359300369400379400 T03
389300399200409000418700428400438000447500456900466200475500484700493700 T04
502700511700520500529200537900546500554900563300571600579800587900595900 T05
603900611700619400627000634600642000649400656600663800670800677800684700 T06
691400698100704700711200717500723800730000736100742100748000753800759500 T07
765100770700776100781400786700791800796900801900806800811600816300820900 T08
825400829900834200838500842700846800850800854800858600862400866100869800 T09
873300876800880200883500886800890000893100896100899100902000904800907600 T10
910300913000915500918100920500922900925200927500929700931900934000936100 T11
938100940000941900943800945700947300949000950700952300953800955400956900 T12
958300959700961100962400963700964900966100967300968400969500970600971600 T13
972600973600974500975500976300977200978000978800979600980400981100981800 T14
982500983200983800984400985000985600986100986700987200987700988200988600 T15
989100989500989900990300990700991100991500991800992200992500992800993100 T16
993400993700993900994200994400994700994900995100995300995500995700995900 T17
996100996300996400996600996700996900997000997200997300997400997500997600 T18
997700997900997960998050998140998230998320998400998480998550998620998680 T19
998740998800998850998910998960999010999060999100999140999180999230999270 T20
999300999340999370999400999440999470999500999530999560999580999600999630 T21
999650999670999690999700                                                 T22
255099970000263099980000275099990000313099999000346099999900377099999990 T23
466099999999100E30100000000                           T25
04005010020017730035563177245300100000071000000000012000                   DELT
0000150500500120720001600025000120101020309020201010202                    KT1

01010000100700101000010090010100001012001010000101100101000010090      R101
01010000101200101000010080010100001008001010000101200101000010080      R102
01010000150200101000020020                                             R103
1755000010999                                                          R201
3975000015999                                                          R301
29710000226001754000010400                                             R401
348500001540015630000154001953000010200                                R501
39750000151502971000010090175400000709017550000100903363000010090      R601
1953000010070101300001022034850000152001563000015020                   R602
00003467005000000154800500                                             R701
00003467005000000154800500                                             R801
0000326810999                                                          R901
0000336310999                                                          R1B1
00001953108000000101307200                                             R111
00003487155000000157215500                                             R121
25080408011309                                                          E1J
08071602010110                                                          E2J
03030420010110                                                          E3J
02050325010112                                                          E4J
03350315011505                                                          E5J
02100302103907                                                          E6J
02020203150207                                                          E7J
02020202410207                                                          E8J
03090317041609                                                          E9J
03132003200509                                                         E10J
02052801030409                                                         E11J
45011202020106                                                         E12J
```

Glossary of the principal abbreviations used in the FORTRAN program

A Duration of each sequence in seconds

A 10, A 20, A 17, A 35, A 30 Numbers for glissando calculation, constant in instrumental music

ALEA Parameter used to alter the final result of a second run with the same input data

ALFA (3) Three expressions entering into the three speed values of the sliding notes (see Part 7)

ALIM Maximum limit of sequence duration A (subject to modification)

(AMAX (1), 1 = 1, KTR) Table of an expression entering into the calculation of the note length in Part 8

BF Dynamic form number; the list (fig. 56) is established independently of this program and is subject to modification

DELTA 1/(sounds per second), i.e. reciprocal of the mean density of sound events of a sequence of duration A (subject to modification)

(E (I, J), I = 1, KTR, J = 1, KTE) Probabilities of the KTR timbre classes introduced as input data, depending on the class number I; KR and on the power J = U obtained from V3*EXPF (U) = DA

EPSI Epsilon for accuracy in calculating PN and E (I, J), which it is advisable to retain

(GN (I, J), I = 1, KTR, J = 1, KTS) Table of the given length of breath for each instrument, depending on class I and instrument J

GTNA Greatest number of notes in the sequence of duration A

GTNS Greatest number of notes in KW loops (see Part 10, test 81)

(H (I, J), I = 1, KTR, J = 1, KTS) Pitch of the note depending on timbre class I and instrument J

(HAMIN (I, J), HAMAX (I, J), HBMIN (I, J), HBMAX (I, J), I = 1, KTR, J = 1, KTS) Tables of instrument compass limits, depending on timbre class I or the HB table is followed. The number 7 is defined arbitrarily.

JW Ordinal number of the sequence computed

KNL Number of lines per page of the printed result, equal to 50

KR 1 Number in the class KR = 1 used for percussion or instruments without definite pitch (see Part 6, instruction 37)

KTE Power of the exponential coefficient e such that $DA_{max} = V3{*}e^{KTE-1}$ (subject to modification)

KTR Number of timbre classes, subject to modification

KW Maximum value of JW, subject to modification

KTEST1, TAV1, etc. Expressions useful in calculating how long the various parts of the program will take to compute

KT1 = 0 when the program is in operation

0 when the program is being checked

KT2 Number of loops, equal to 15, by arbitrary definition

(MODI (IX8), IX8 = 7, 1) Auxiliary function to interpolate values in the TETA (256) table (see Part 7)

NA Number of sounds calculated for the sequence A (NA = DA*A)

(NT (I), I = 1, KTR) Number of instruments allocated to each of the KTR timbre classes

(PN (I, J), I = 1, KTR, J = 1, KTS), (KTS = NT (I), I = 1, KTR) Table of probability of each instrument J of the class I

(Q (I), I = 1, KTR) Probabilities of the KTR timbre classes, considered as linear functions of the density (sounds per unit time) DA

(S (I), I = 1, KTR) Sum of the successive Q (I) probabilities, used to choose the class KR by comparing it to a random number X1 (see Part 3 loop 154 and Part 5 loop 28)

SINA Sum of the computed notes in the JW clouds NA, always less than GTNS (see test in Part 10)

SQPI = $\sqrt{\pi}$

TA Sound attack time abscissa

TETA (256) Table of the 256 values of the integral of the normal distribution curve,

$$\theta(\lambda) = \frac{2}{\sqrt{\pi}}\int_0^{\lambda} e^{-\lambda 2}\, d\lambda$$

which is useful in calculating glissando speed and sound event duration

VIGL (3) Glissando speed, which can vary as, be independent of, or vary inversely as the density DA of the sequence, the actual mode of variation employed remaining the same for the whole sequence (see Part 7)

VITLIM Maximum limiting glissando speed (in semitones/sec), subject to modification

V3 Minimum note cloud density DA

(Z1 (I), Z (2), I = 1, 8) Table with values complementary to the TETA (256) table.

The digital computer as a creative medium
A. Michael Noll

'What kinds of artistic potentials can be evolved through the use of computers, which themselves are continually being evolved to possess more sophisticated and intelligent characteristics?' (*Noll*)

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In the computer, man has created not just an inanimate tool but an intellectual and active creative partner that, when fully exploited, could be used to produce wholly new art forms and possibly new aesthetic experiences. Digital computers are now being used to produce musical sounds and to generate artistic visual images. The artist or composer interacts directly with the computer through a console. This article explores the possibilities of the computer as an artistic medium and makes some predictions about the art of the future.

The notion of creating art works through the medium of machines may seem a little strange. Most people who have heard about the experimental use of digital computers in creative endeavours have probably shrugged them off as being of no consequence. On the one hand, creativity has universally been regarded as the personal and somewhat mysterious domain of man; and, on the other hand, as every engineer knows, the computer can do only what it has been programmed to do—which hardly anyone would be generous enough to call creative.

Nonetheless, artists have usually been responsive to experimenting with and even adopting certain concepts and devices resulting from new scientific and technological developments. Computers are no exception. Composers, film animators, and graphic artists have become interested in the application of computers. Moreover, recent artistic experiments with computers have produced results that should make us re-examine our preconceptions about creativity and machines. Some of the experiments, described here, suggest, in fact, that a tight interaction between artist and computer constitutes a totally new, active, and exciting artistic medium.

How does an artist work?

There is an anecdote attributed to Henri Matisse about how to approach the creative act of painting: take a blank white canvas, and, after gazing at it for a while, paint on it a bright red disk. Thereafter, you do nothing further until something occurs to you that will be just as exciting as the original red disk. You proceed in this way, always sustaining, through each new gambit with the paint and brush, the initial high visual excitement of the red disk.

The anecdote is a somewhat simplified version of Matisse's idea, but even if we take it lightly, it can do a number of things for us. For one thing, it dispels some of the sense of mystery that hovers over the procedures of the creative person. It tells us something concrete and easily visualized about the creative process while emphasizing the role of the unexpected ideas for which the artist lies in wait and for which he sets a formal 'trap' in his medium.

Even a relatively 'passive' medium—paint, brushes, canvas—will suggest new ideas to the artist as he becomes engaged. The resistance of the canvas or its elasticity give to the paint-loaded brush, the visual shock of real colour and line, the smell of the paint, will all work on the artist's sensibilities. The running of the paint, or seemingly 'random' strokes of the brush, may be accepted by him as corporate elements of the finished work. So it is that an artist explores, discovers and masters the possibilities of the medium. His art work is a form of play, but it is serious play.

Most of all, the Matisse anecdote suggests that the artistic process involves some form of 'program', one certainly more complex than the anecdote admits, but a definite program of step-by-step action. Without doing too much violence to our sense of what is appropriate, we might compare it to a computational hill-climbing technique in which the artist is trying to optimize or stabilize at a high level the parameter 'excitement'.

Once we have swallowed this metaphor, it becomes less improbable to imagine that computers might be used, in varying depths of engagement, as active partners in the artistic process. But computers are a new medium. They do not have the characteristics of paints, brushes and canvas. Nor are the 'statements' that grow out of the artist's engagement with them likely to be similar to the statements of, for example, oil paintings. An interesting question to explore, then, is how computers might be used as a creative medium. What kinds of artistic potentials can be evolved through the use of computers, which themselves are continually being evolved to possess more sophisticated and intelligent characteristics?

The character of the computer medium

In the present state of computer usage, artists are certainly having their problems in understanding engineering descriptions and in learning how to program computers in order to explore what might be done with them. However, they are learning, and they have already used digital computers and associated equipment to produce musical sounds and aesthetic visual images.[1]

The visual images are generated by an automatic plotter under the control of the digital computer. The plotter consists of a cathode-ray tube and a camera for photographing the images 'drawn' on the tube face by deflections of the electron beam. The digital computer produces the instructions for operating the automatic plotter so that the picture-drawing capability is under program control. Musical sounds are produced by the computer by means of a digital sampled version of the sounds that must then be converted to analog form by a conventional digital-to-analog converter.

For both of these artistic applications, a challenging problem is the composition of special-purpose programming languages and subroutines so that the artist can communicate with the computer by using terminology reasonably similar to his particular art. For example, a special music compiler has been written so that the composer can specify complex algorithms for producing a single sound and then pyramid these basic sounds into a whole composition. A similar philosophy has been used in a special language developed for computer animation called BEFLIX.[2] Both applications share the drawback that the artist must wait a number of hours between the actual running of the computer program and the final generation of pictorial output or musical sounds when he can see or hear the results.

Since the scientific community currently is the biggest user of computers, most descriptions and ideas about the artistic possibilities for computers have been understandably written by scientists and engineers. This situation will undoubtedly change as computers become more accessible to artists who obviously are more qualified to explore and evolve the artistic potentials of the computer medium. Unfortunately, scientists and engineers are usually all too familiar with the inner workings of computers, and this knowledge has a tendency to produce very conservative ideas about the possibilities for computers in the arts. Most certainly the computer is an electronic device capable of performing only those operations that it has been explicitly instructed to perform. And this usually leads to the portrayal of the computer as a powerful tool but one incapable of any true creativity. However, if creativity is restricted to mean the production of the unconventional or the unpredicted, then the computer should instead be portrayed as a creative medium—an active and creative collaborator with the artist.

Computers and creativity

Digital computers are constructed from a myriad of electronic components whose purpose is to switch minute electric currents almost instantaneously. The innermost workings of the computer are controlled by a set of instructions called a program. Although computers must be explicitly instructed to perform each operation, higher-level programming languages enable pyramiding of programming statements that are later expanded into the basic computer instructions by special compiler programs. These programming languages are usually designed so that the human user can write his computer program using words and symbols similar to those of his own particular field. This leads to

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[1] M. V. Mathews 'The digital computer as a musical instrument', *Science* vol. 142, no 3592, pp. 553–7, 1 November 1963.

A. Rockman and L. Mezei 'The electronic computer as an artist', *Canadian Art* vol. 21, pp. 365–7, November/December 1964.

A. M. Noll 'Computers and the visual arts', *Design and Planning 2* edited by M. Krampen and P. Seitz, pp. 65–79. New York: Hastings House, 1967.

E. E. Zajac 'Computer animation—a new scientific and educational tool', *Journal of the Society of Motion Picture and Television Engineers*, vol. 74, pp. 1006–8, November 1965.

[2] K. C. Knowlton 'A computer technique for producing animated movies', *American Federation of Information Processing Societies (AFIPS) Conference Proceedings* vol. 25, pp. 67–87, 1964.

the portrayal of the computer as a tool capable of performing tasks exactly as programmed.

However, the computer is such an extremely powerful tool that artistic effects can sometimes be easily accomplished that would be virtually impossible by conventional artistic techniques. For example, by calculating and drawing on the automatic plotter the perspective projections from two slightly different directions of some three-dimensional object, the computer can generate three-dimensional movies of novel shapes and forms. Such three-dimensional animation, or kinetic sculpture, is far too tedious to perform by any other method. The computer's ability to handle small details has made possible intriguing dissolves and stretches, such as those executed by Stan Vanderbeek, without the tedium of conventional hand animation. Mathematical equations with certain specified variables under the control of the artist have also been used by John Whitney to achieve completely new animation effects. Much of 'Op art' uses repetitive patterns that usually can be expressed very simply in mathematical terms. The waveforms reproduced in figure 73 (p. 159) which resemble Bridget Riley's painting *Currents*, were generated as parallel sinusoids with a linearly increasing period. Thus, the computer and an automatic plotter can eliminate the tedious part of producing 'Op' effects.

Computers most certainly are only machines, but they are capable of performing millions of operations in a fraction of a second and with incredible accuracy. They can be programmed to weigh carefully, according to specified criteria, the results of different alternatives and act accordingly; thus, in a rudimentary sense, computers can appear to show intelligence.[1] They might assess the results of past actions and modify their programmed algorithms to improve previous results; computers potentially could be programmed to learn. Series of numbers can be calculated by the computer that are so complicatedly related that they may appear to us as random.

Of course, everything the machine does must be programmed, but because of the computer's great speed, freedom from error, and vast abilities for assessment and subsequent modification of programs, it appears to us to act unpredictably and to produce the unexpected. In this sense, the computer actively takes over some of the artist's creative search. It suggests to him syntheses that he may or may not accept. It possesses at least some external attributes of creativity.

The Mondrian experiment

How reasonable is it to attribute even these rudimentary qualities of creativity to an inanimate machine? Is creativity something that should only be associated with the products of humans? In 1950, A. M. Turing expressed the belief that at the end of the century 'one will be able to speak of machines thinking, without expecting to be contradicted'.[2] Turing proposed the now well-known experiment consisting of an interrogator, a man and a machine, in which the interrogator had to identify the man by asking the man and the machine to answer questions or to perform simple tasks.

A crude approximation of Turing's experiment was performed using Piet Mondrian's *Composition with Lines* (1917), and a computer-generated picture composed of pseudorandom elements but similar in overall composition to the Mondrian painting (figs 70, 71, pp. 156–7).[3] Although Mondrian apparently placed the vertical and horizontal bars in his painting in a careful and orderly manner, the bars in the computer-generated picture were placed according to a pseudorandom number generator with statistics chosen to approximate the bar density, lengths and widths in the Mondrian painting. Xerographic copies of the two pictures were presented, side by side, to a hundred subjects with educations ranging from high school to postdoctoral; the subjects represented a reasonably good sampling of the population at a large scientific research laboratory. They were asked which picture they preferred and also which they thought was produced by Mondrian. Fifty-nine per cent of the subjects preferred the computer-generated picture; only twenty-eight per cent were able to identify correctly the picture produced by Mondrian.

In general, these people seemed to associate the randomness of the computer-generated picture with human

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[1] M. L. Minsky 'Artificial intelligence', *Scientific American* vol. 215, pp. 246–60, September 1966.

[2] A. M. Turing 'Computer machinery and intelligence' *Mind* vol. 59, pp. 433–60, October 1950.

[3] A. M. Noll 'Human or machine—a subjective comparison of Piet Mondrian's *Composition with Lines* 1917, and a computer-generated picture', *The Psychological Record* vol 16, pp. 1–10, January 1966.

creativity whereas the orderly bar placement of the Mondrian painting seemed to them machine-like. This finding does not, of course, detract from Mondrian's artistic abilities. His painting was, after all, the inspiration for the algorithms used to produce the computer-generated picture, and since computers were non-existent fifty years ago, Mondrian could not have had a computer at his disposal. Furthermore, we must admit that the reduction in size of the original painting and its xerographic reproduction degrades its unique aesthetic qualities. Nevertheless, the results of the experiment in the light of Turing's proposed experiment do raise questions on the meaning of creativity and the role of randomness in artistic creation. In a sense, the computer with its program could be considered creative, although it can be argued that human creativity was involved in the original program with the computer performing only as an obedient tool.

These questions should perhaps be examined more deeply by more ambitious psychological experiments using computer-generated pictures as stimuli.

Toward real-time interaction

Although the experiments described show that the computer has creative potentialities beyond those of just a simple tool, the computer medium is still restrictive in that there is a rather long time delay between the running of the computer program and the production of the final graphic or acoustic output. However, recent technological developments have greatly reduced this time delay through special interactive hardware facilities and programming languages. This tightening of the man–machine feedback loop is important for the artist who needs a nearly instantaneous response.

For example, in the field of music an electronic graphic console has been used to specify pictorially sequences of sounds that were then synthesized by the computer.[1] Functions of amplitude, frequency and duration of a sequence of notes were drawn on the face of a cathode-ray tube with a light pen. If desired, the computer combined specified functions according to simple algorithms. Thus, the fine details of the composition were calculated by the computer and the overall structure was precisely specified by the graphic score. The feedback loop was completed by the computer-generated sounds heard almost immediately by the composer, who could then make any desired changes in the score.

A similar man–machine interactive system has been proposed for choreography.[2] In this system, the choreographer would be shown a computer-generated three-dimensional display of complicated stick figures moving about on a stage (as shown in figure 82). The choreographer interacts with the computer by indicating the spatial trajectories and movements of the figure. Random and mathematical algorithms might be introduced by the computer to fill in certain fine details, or even to give the choreographer new ideas to evaluate and explore.

A new active medium

The beginnings of a new creative partnership and collaboration between the artist and the computer clearly emerge from these most recent efforts and proposals. Their common denominator is the close man–machine interaction using the computer to generate either musical sounds or visual displays. The computer acquires a creative role by introducing randomness or by using mathematical algorithms to control certain aspects of the artistic creation. The overall control and direction of the creative process is very definitely the artist's task. Thus the computer is used as a medium by the artist, but the great technical powers and creative potentialities of the computer result in a totally new kind of creative medium. This is an active medium with which the artist can interact on a new level, freed from many of the physical limitations of all previous media. The artistic potentialities of such a creative medium as a collaborator with an artist are truly exciting and challenging.

Interactive aesthetic experiences

In the previous examples the artist sat at the console of the computer and indicated his desires to the computer by man-

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[1] M. V. Mathews 'A graphical language for composing and playing sounds and music', presented at the *31st Convention of the Audio Engineering Society*, preprint no 477, October 1966.

[2] A. M. Noll 'Choreography and computers', *Dance Magazine* vol. 41, pp. 43–5, January 1967.

ually using push buttons or by drawing patterns on an electronic visual display. These are probably efficient ways of communicating certain types of instructions to the computers; however, the communication of the actual subconscious emotional state of the artist could lead to a new aesthetic experience. Although this might seem somewhat exotic and conjectural, the artist's emotional state might conceivably be determined by computer processing of physical and electrical signals from the artist (for example, pulse rate and electrical activity of the brain). Then, by changing the artist's environment through such external stimuli as sound, colour and visual patterns, the computer would seek to optimize the aesthetic effect of all these stimuli upon the artist according to some specified criterion.

The interactive feedback situation with controlled environment would be completely dynamic. The emotional reaction of the artist would continually change, and the computer would react accordingly either to stabilize the artist's emotional state or to steer it through some pre-programmed course. Here then is a completely new aesthetic experience utilizing man–machine communication on the highest (or lowest, if you will) subconscious level and computer processing and optimization of emotional responses. Only a digital computer could perform all the information processing and generate the sights and sounds of the controlled environment required for such a scheme. One is tempted to describe these ideas as a consciousness-expanding experience in association with a psychedelic computer!

Artistic consequences

Predictions of the future are risky in that they may be really nothing more than what the person predicting would like to see occur. Although the particulars should be viewed sceptically, they actually might be unimportant; if the art of the future follows the directions outlined here, then some general conclusions and statements can be made that should be independent of the actual particulars.

The aesthetic experience will be highly individualistic, involving only the individual artist and his interactions with the computer. This type of participation in the creative and aesthetic experience can be experienced by artist and non-artist alike. Because of the great technical power of the computer, both the artist and non-artist are freed from the necessity of strong technical competence in the use of different media. The artist's 'ideas' and not his technical ability in manipulating media could be the important factor in determining artistic merit. Conceivably, a form of 'citizen–artist' could emerge, as envisioned by Allon Schoener.[1] The interactive aesthetic experience with computers might fill a substantial portion of that great leisure time predicted for the man of the future.

The artist's role as master creator will remain, however, because even though the physical limitations of the medium will be different from traditional media, his training, devotion, and visualization will give him a higher degree of control of the artistic experience. As an example, the artist's particular interactions with the computer might be recorded and played back by the public on their own computers. Specified amounts of interaction and modification might be introduced by the individual, but the overall course of the interactive experience would still follow the artist's model. In this way, and for the first time, the artist would be able to specify and control with certainty the emotional state of each individual participant. Only those aspects deliberately specified by the artist might be left to chance or to the whims of the participant. All this would be possible because the computer could monitor the participant's emotional state and change it according to the artist's specifications. The artist's interaction with the computer would be of a new order because the physical restrictions of the older media would be eliminated.

This is not to say that the traditional artistic media will be swept away; but they will undoubtedly be influenced by this new active medium. The introduction of photography—the new medium of the last century—helped to drive painting away from representation, but it did not drive out painting. What the new creative computer medium will do to all of the art forms—painting, writing, dance, music, movies—should be exciting to observe. We might even be tempted to say that the current developments and devices in the field of man–machine communication, which were primarily intended to give insight into scientific problems, might in the end prove to be far more fruitful, or at least equally fruitful, in the arts.

[1] Allon Schoener '2066 and all that', *Art in America* vol. 54, pp. 40–3, March/April 1966.

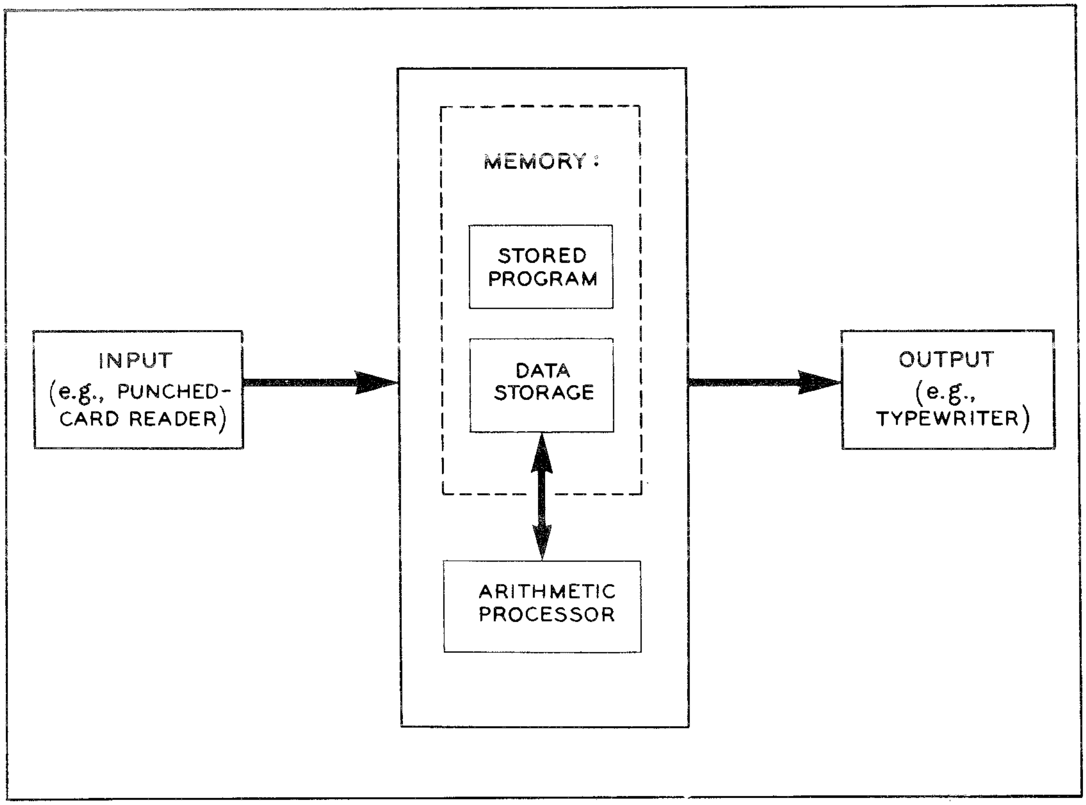

MEMORY:
STORED PROGRAM
DATA STORAGE
INPUT (e.g., PUNCHED-CARD READER)
OUTPUT (e.g., TYPEWRITER)
ARITHMETIC PROCESSOR

Fig. 61

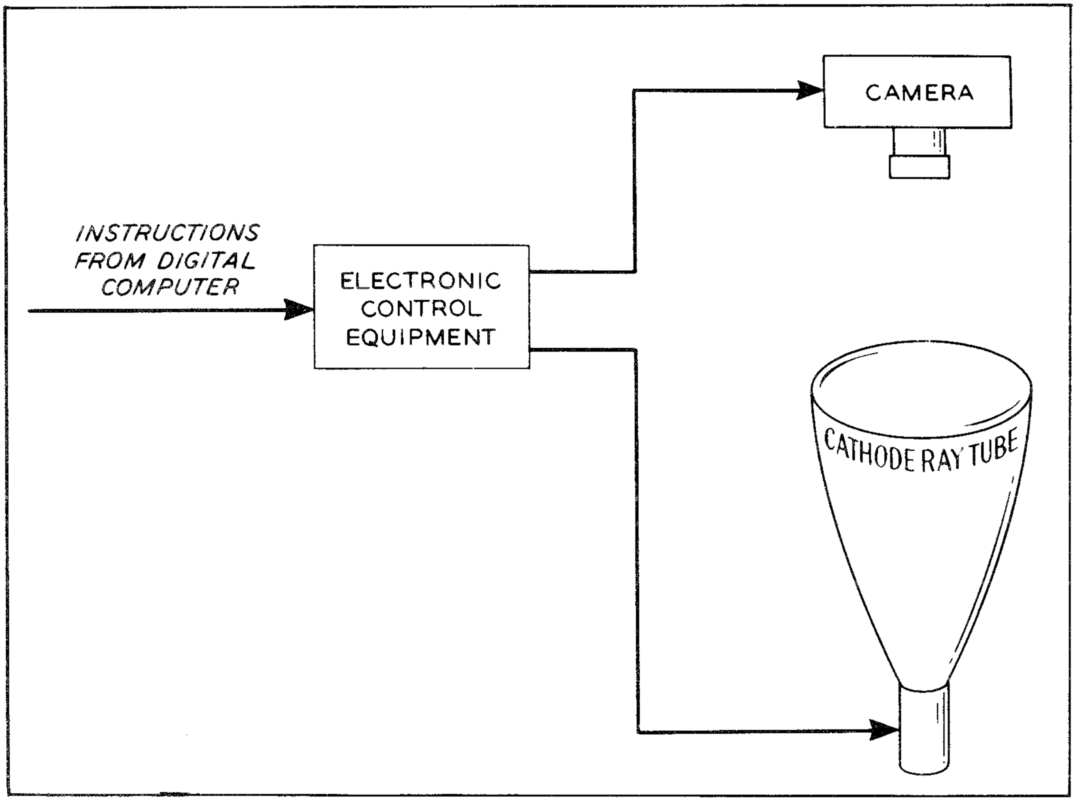

CAMERA
INSTRUCTIONS FROM DIGITAL COMPUTER
ELECTRONIC CONTROL EQUIPMENT
CATHODE RAY TUBE

Fig. 62

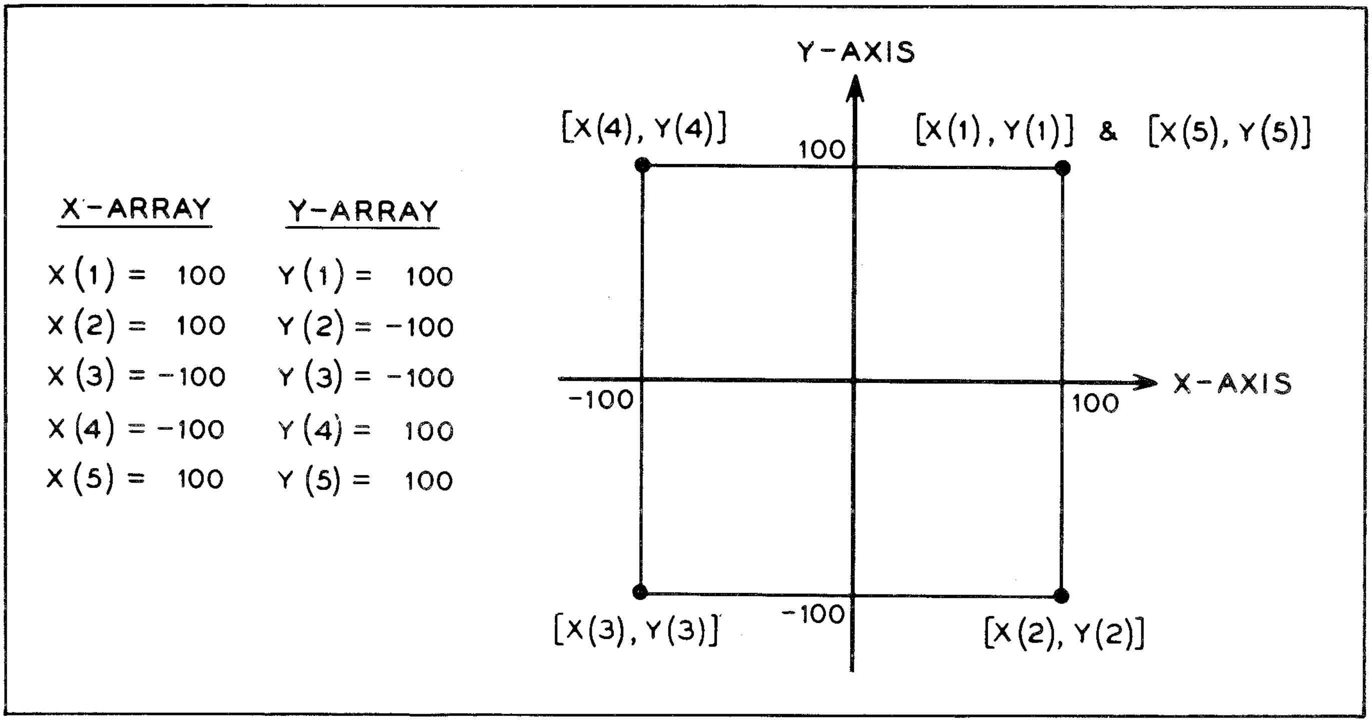
opposite

Fig. 61 All digital computers are similar in that they manipulate binary numbers under the control of a stored set of instructions called a program. Most computers consist of a memory, an arithmetic processor and input and output equipment. The program is stored in the computer's memory and instructs the computer to accept input data, to perform arithmetical, logical, and organizational operations with this data, and finally to generate some form of output.

Fig. 62 New output devices allow the computer to produce visual output. The cathode-ray tube produces pictures on a phosphorescent screen with an electron beam which is electrically deflected across the screen to generate the desired picture. The camera photographs the face of the cathode-ray tube. The required signals for deflecting the electron beam and for advancing the film come from the electronic control equipment, which includes circuitry for decoding instructions given to the microfilm plotter by the main computer. These instructions are commands for drawing straight lines between numerically specified points or for placing dots at specified points on the face of the tube.

below

Fig. 63 As an example, a square would be drawn on the automatic plotter in the following way. The program would first make two arrays of numbers whose elements are the X and Y co-ordinates of the corners of a square. The program would, secondly, contain an instruction to advance the film to an unexposed frame. The next instruction would tell the microfilm plotter to draw a line between the five points whose co-ordinates are contained in the X and Y arrays. Thus, the point ($X(1)$, $Y(1)$) would be connected to ($X(2)$, $Y(2)$), ($X(2)$, $Y(2)$) would be connected to ($X(3)$, $Y(3)$), and so on.



X-ARRAY	Y-ARRAY
X (1) = 100	Y (1) = 100
X (2) = 100	Y (2) = −100
X (3) = −100	Y (3) = −100
X (4) = −100	Y (4) = 100
X (5) = 100	Y (5) = 100

Fig. 64 A sequence of numbers would be described as random if an observer were unable to determine a formula for exactly predicting each number in the sequence. These numbers might represent the co-ordinates of points in a computer-generated picture. If all the random numbers in a sequence fall between the limits a and b, where b is greater than a, and if the occurrence of all these numbers is equally probable, then the numbers are said to have a uniform probability density. Such a sequence is specified by only the limits a and b. The occurrence of any number within these limits is just as probable as the occurrence of any other number. The points in this computer-generated picture were determined by a random process with a uniform probability density.

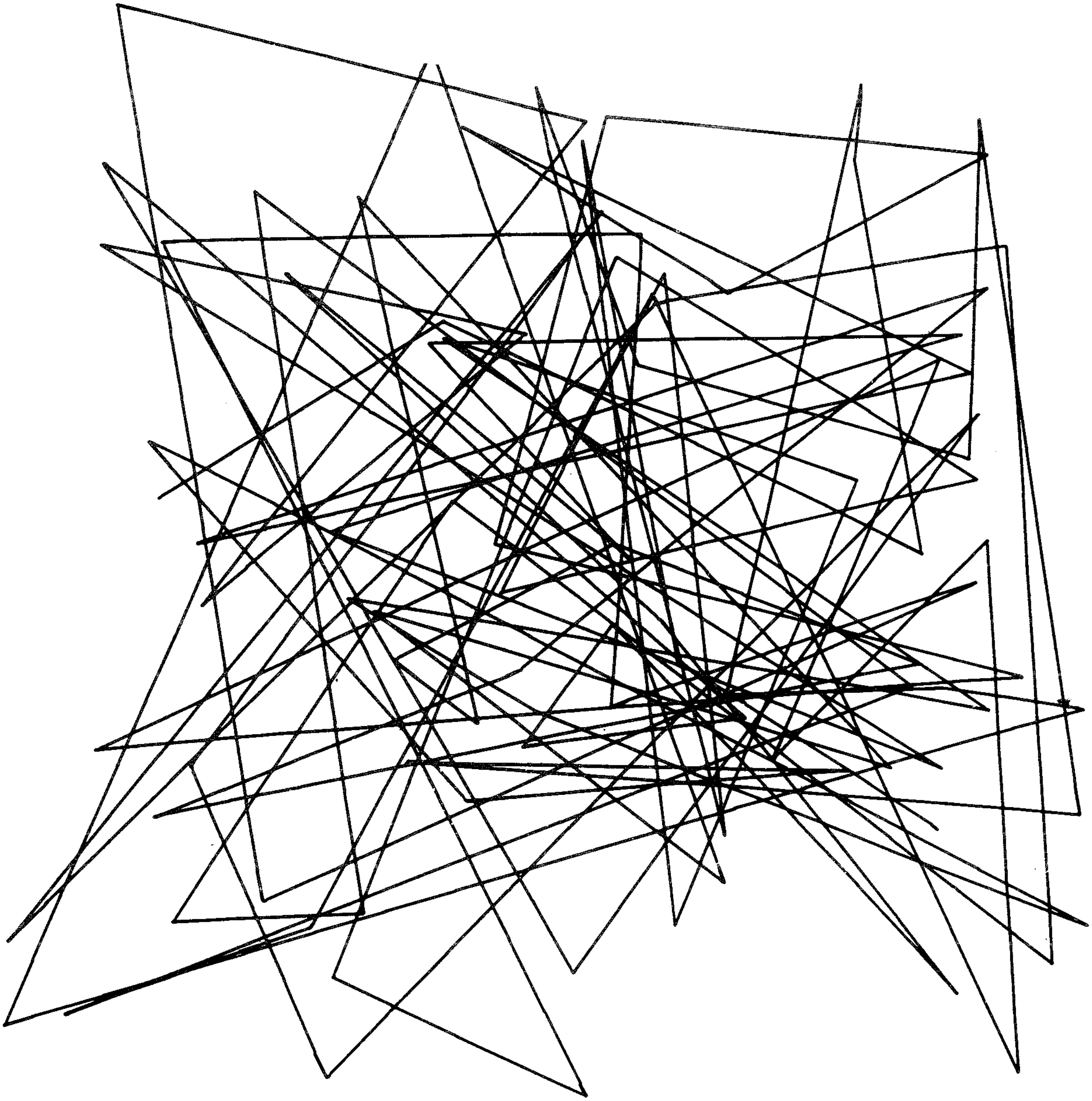
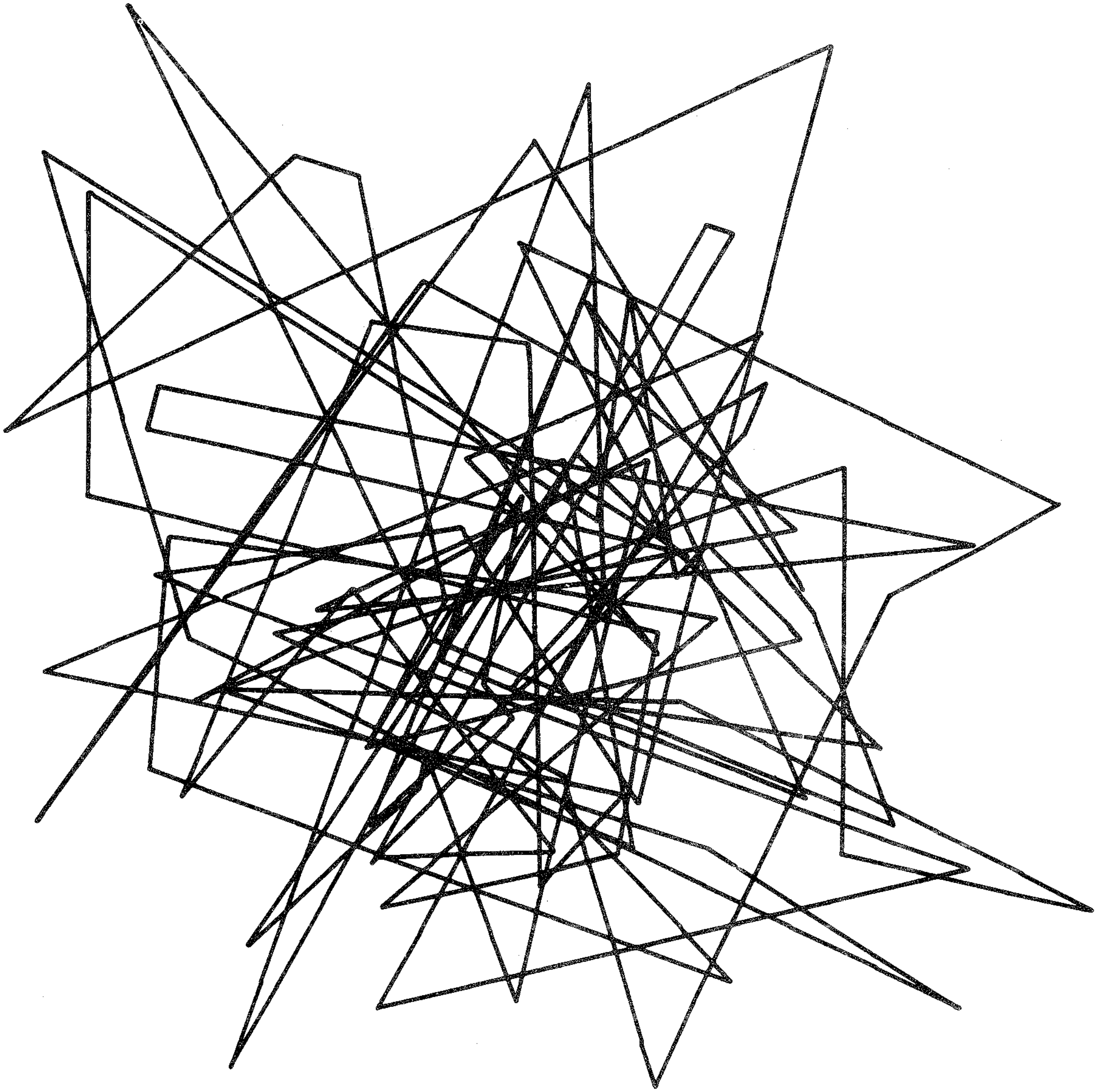


Fig. 65 As well as the uniform probability density there is another density of considerable importance, called the normal or Gaussian density (after the mathematician Gauss who first formulated it mathematically). For a Gaussian sequence of random numbers, the numbers tend to cluster about an average. The larger the number compared with this average, the less probable is its occurrence. Sometimes the Gaussian sequence is 'truncated' so that numbers much larger than the average are not allowed. The Gaussian density is also characterized by its standard deviation which is a measure of the spread of the random numbers about the average. For a very long sequence of Gaussian random numbers, 68·3 per cent of the numbers fall within plus or minus one standard deviation of the average, 95·5 per cent within two standard deviations, and 99·7 per cent within three standard deviations. The points in this computer-generated picture were determined by a random process with a Gaussian probability density.



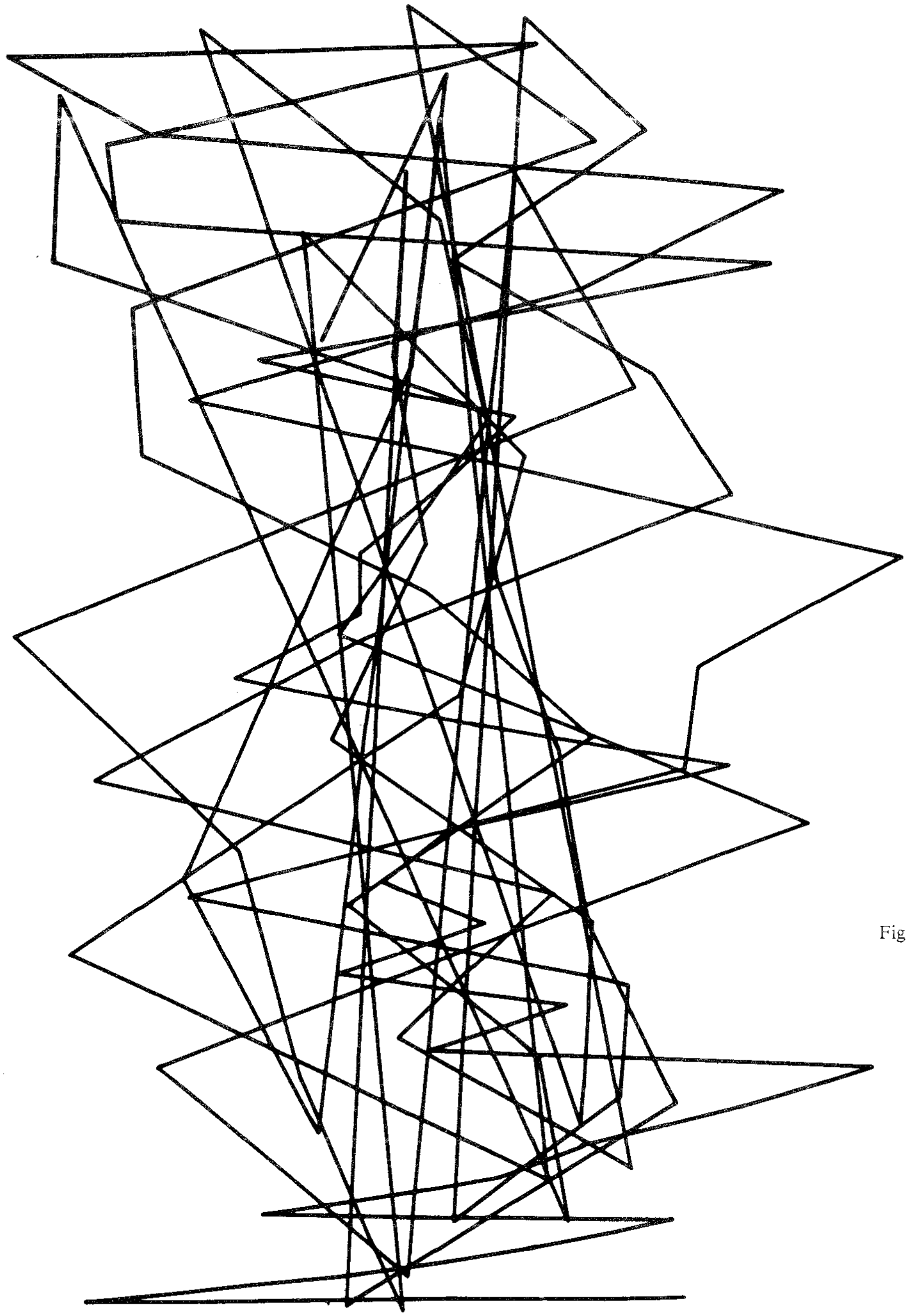
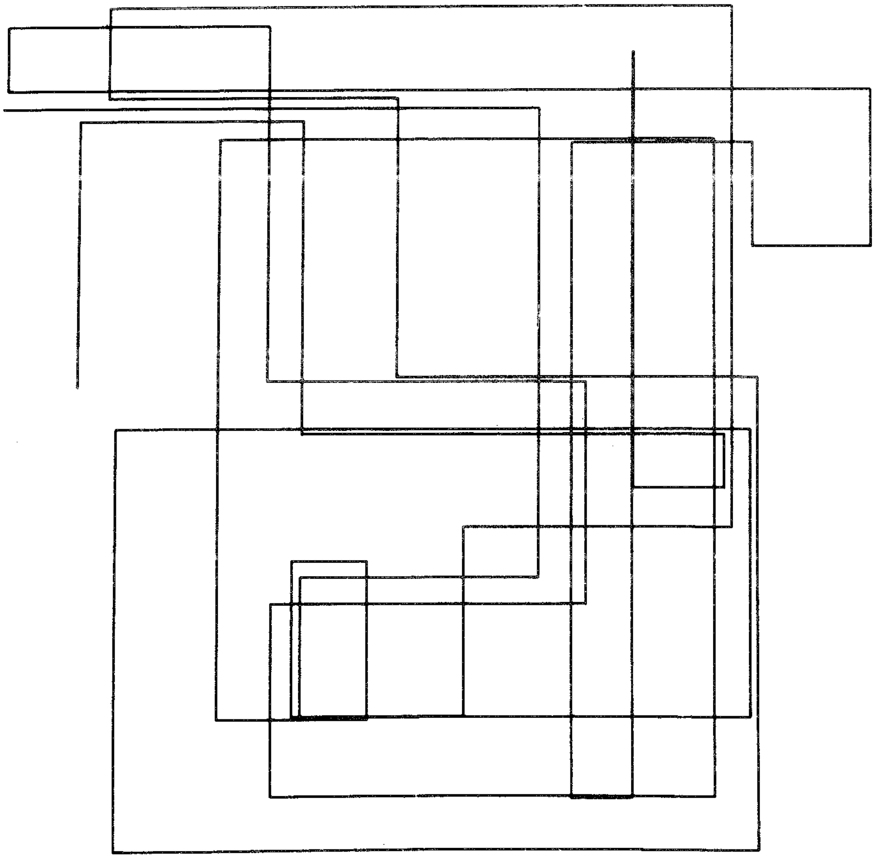


Fig. 66

© AMN 1965

Fig. 67



opposite

Fig. 66 *Gaussian Quadratic* (1963) by A. Michael Noll (© AMN 1965). In general, completely random two-dimensional pictures are not very interesting. However, the computer is also able to mix together randomness and order in mathematically specified proportions to achieve a desired effect. The initial attempts at such mixing used Gaussian randomness for the X-axis co-ordinates but introduced a specified and non-random mathematical function for generating the Y-axis co-ordinates. *Gaussian Quadratic* is a particularly good example of this mixing approach. Ninety-nine lines join together 100 points whose horizontal positions are Gaussian. The vertical positions increase quadratically, i.e. the first point has a vertical position from the bottom of the picture given by $1^2 + 5 \times 1$, the second point $2^2 + 5 \times 2$, the third point $3^2 + 5 \times 3$, etc. The maximum picture size is limited to 1024 units wide by 1024 units high, and thus the 30th point would be off the top of the picture ($30^2 + 5 \times 30 = 1050$). To prevent this from happening, the vertical positions at the top are reflected to the bottom of the picture and then continue to rise. The result is a line that starts at the bottom of the picture and randomly zigzags to the top in continually increasing steps; at the top the line is 'translated' to the bottom to continue its rise. The standard deviation of the Gaussian density is 150.

Figs. 67 (*above*), 68 and 69 (pages 154–5) *Vertical Horizontal* pictures generated by a scheme in which only one of the two co-ordinates was changed (alternatingly) from one point to the next. The co-ordinates were otherwise random with a uniform probability density. Figure 67 consists of 50 lines with equal ranges in both directions; the number of lines in figure 68 was increased to 300. *Vertical–Horizontal No. 3* (1964) by A. Michael Noll (© AMN 1965) (fig. 69) consists of 100 lines with a range of -200 to $+200$ along the X-axis and a range of -500 to $+500$ along the Y-axis.

Fig. 68

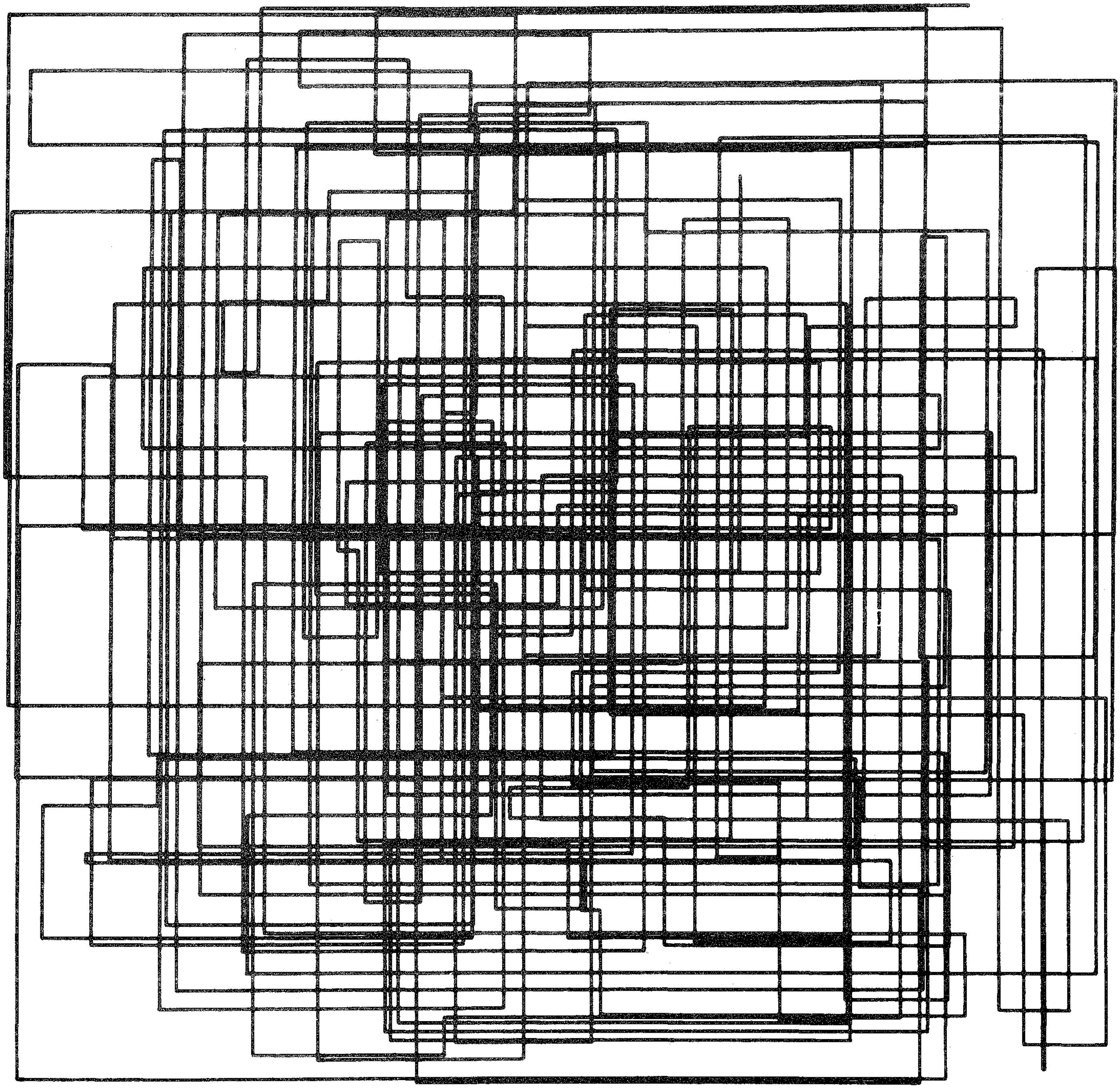
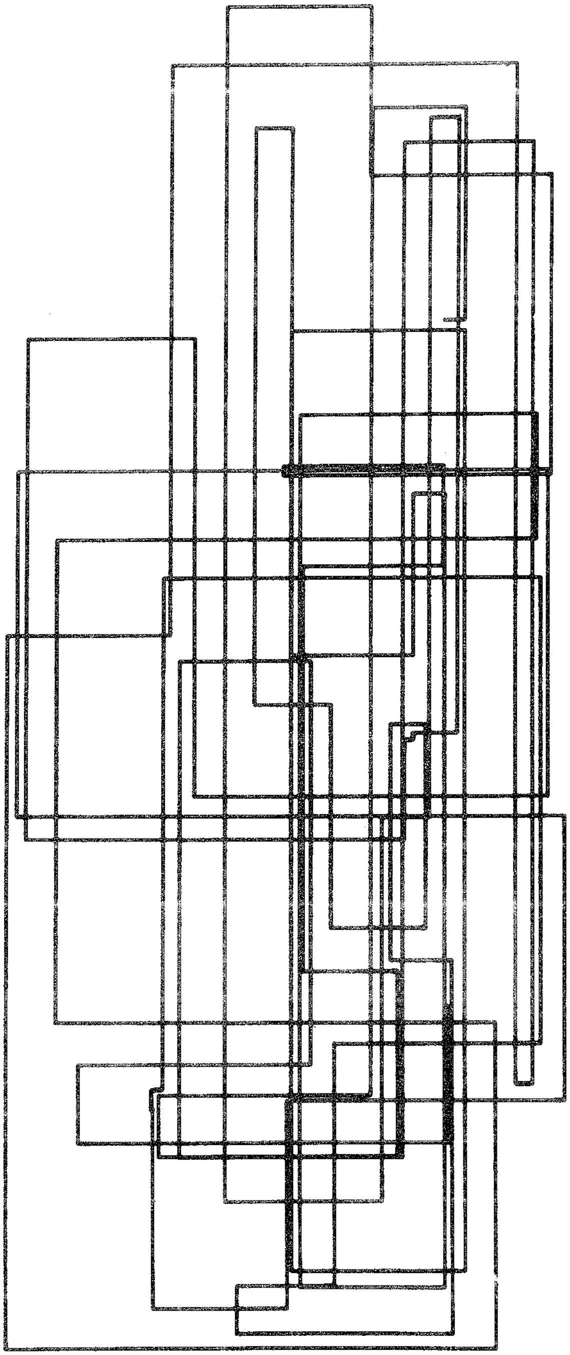


Fig. 69



© AMN 1965

Fig. 70 A reproduction of Piet Mondrian's *Composition with Lines* (1917) in the Rijksmuseum Kröller-Müller.

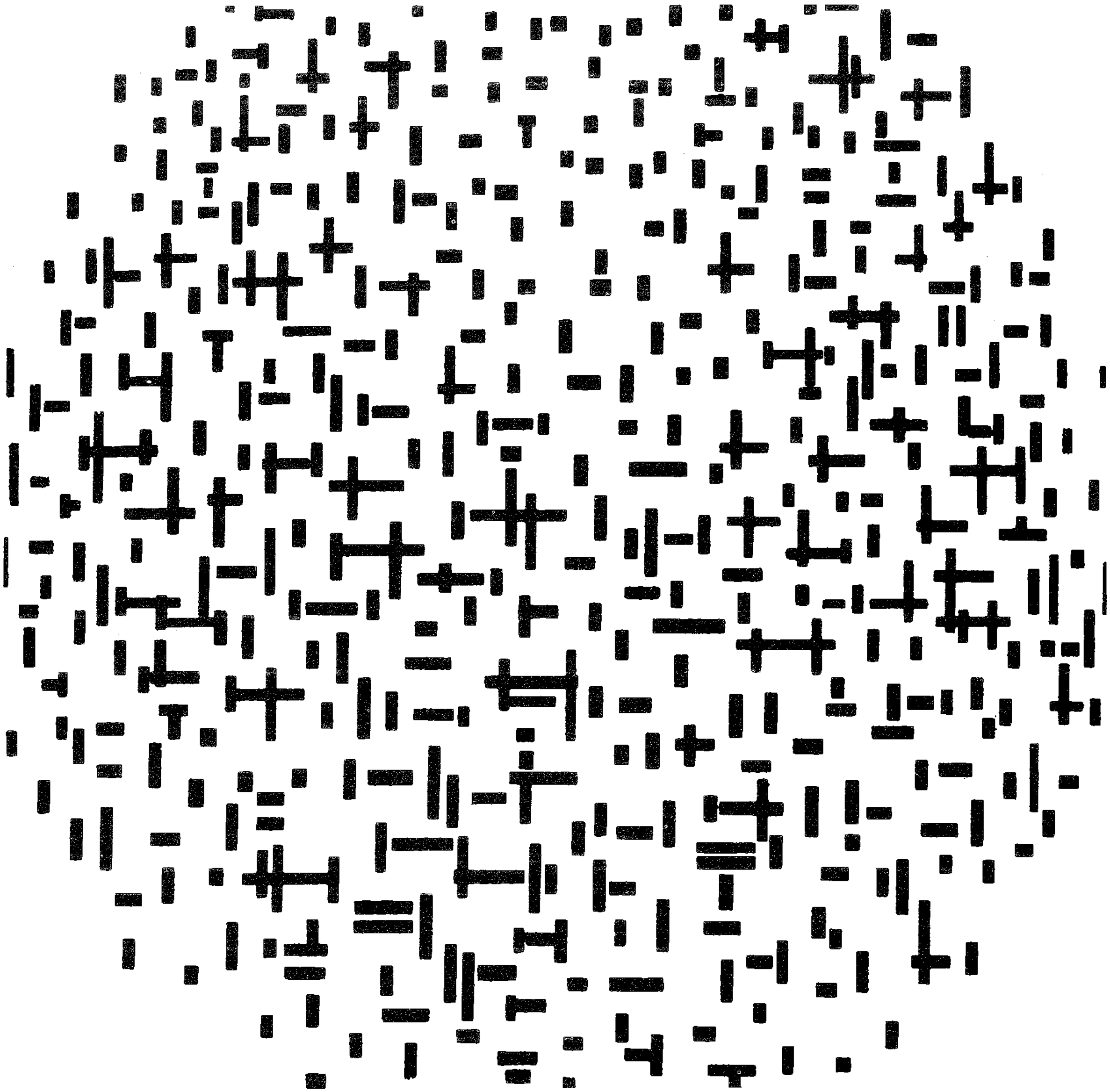


Fig. 71 *Computer Composition with Lines* (1964) by A. Michael Noll (© AMN 1965) was generated by a digital computer using pseudorandom numbers with statistics approximating Mondrian's *Composition with Lines.* When xerographic reproductions of both pictures were shown to a hundred subjects, the computer-generated picture was preferred by fifty-nine of them. Only twenty-eight subjects identified the Mondrian painting. Apparently, many of the observers associated randomness with human creativity and were therefore led astray in making the picture identifications.

Fig. 72 A series of Mondrian-like computer pictures was generated. The scheme used to produce these pictures utilized random bar lengths and random bar widths within specified ranges. The bars were shortened if they fell within a parabolic region in the upper half of the picture. Only vertical bars were permitted along the sides of the picture. The actual positions of the bars were determined by adding a uniform-density random perturbation to an otherwise completely uniform grid-like set of positions. This random perturbation has a specified range; the range is zero and increases geometrically to a range of ±250.

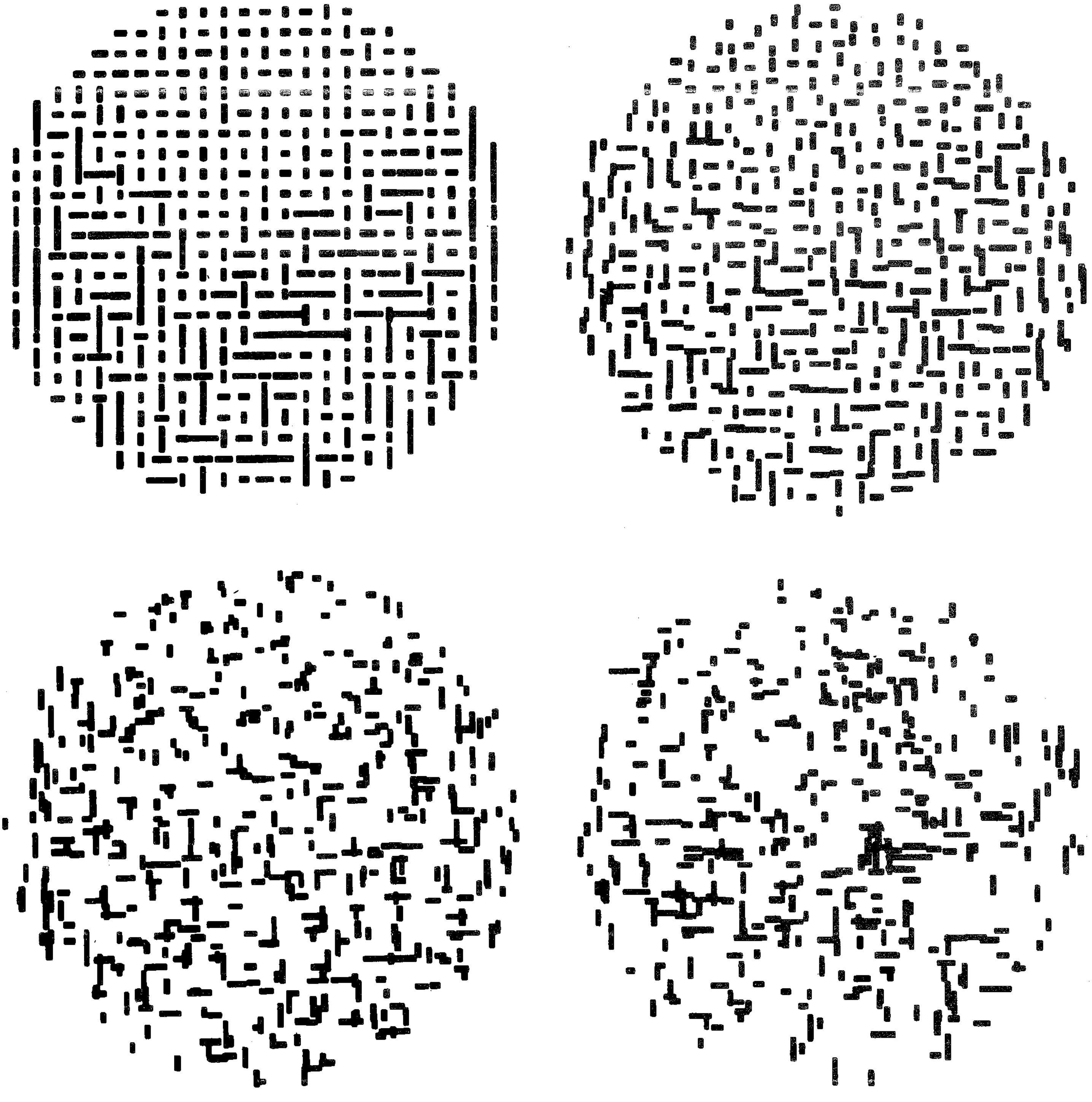


Fig. 73 Many 'Op art' paintings are very regular and mathematical in design. The computer is extremely adept at constructing purely mathematical pictures and hence should be of considerable value to 'Op' artists. The drudgery of drawing or painting complex designs such as those in moiré patterns can be easily done by the machine. As an example, Bridget Riley's painting *Current* is a series of parallel lines that mathematically can be specified as sine waves with linearly increasing period. Such a formulation of her painting enabled the computer to calculate an array of points based upon a simple mathematical formula. The plotter then connected the points to produce the finished result shown here.

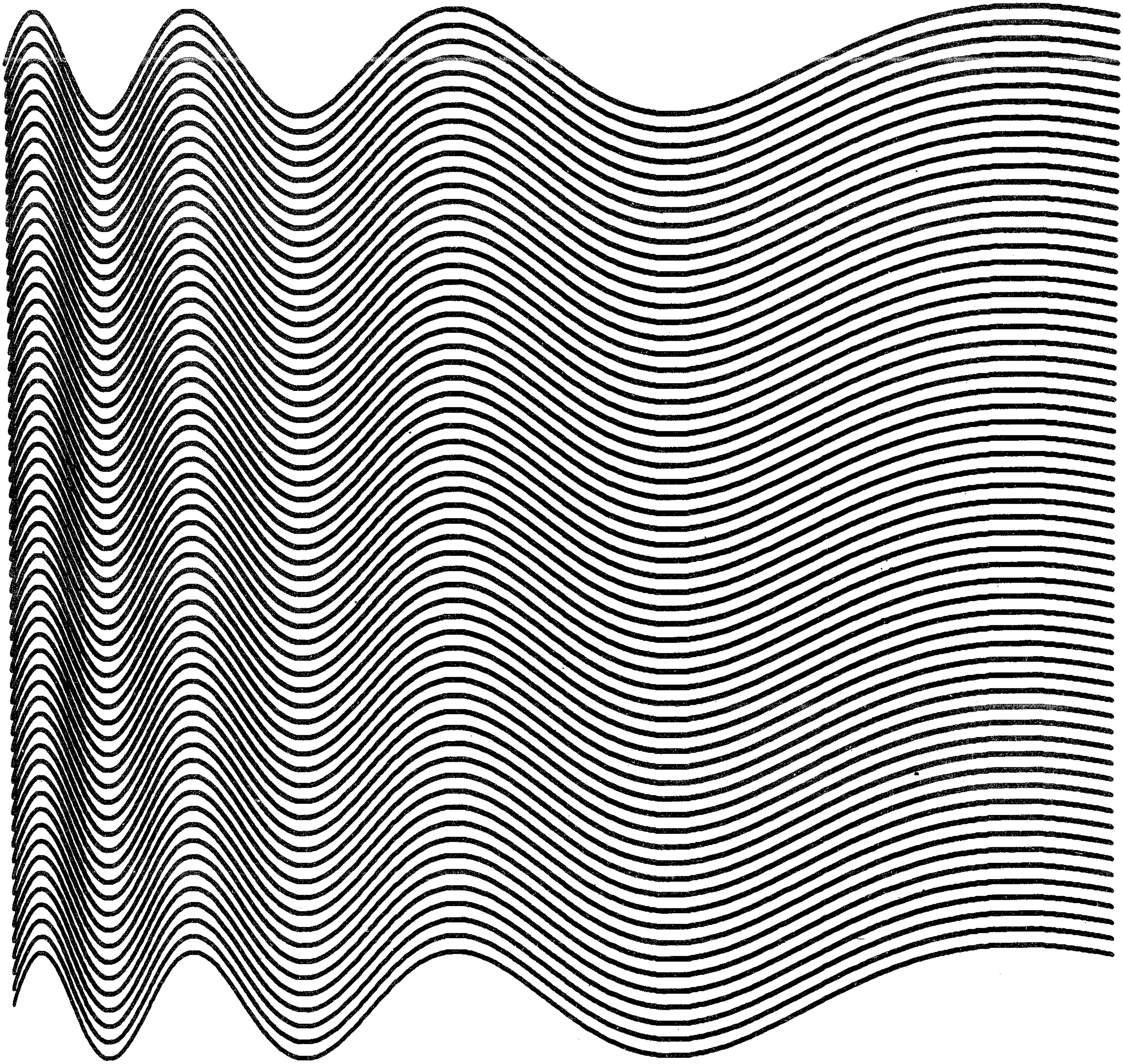
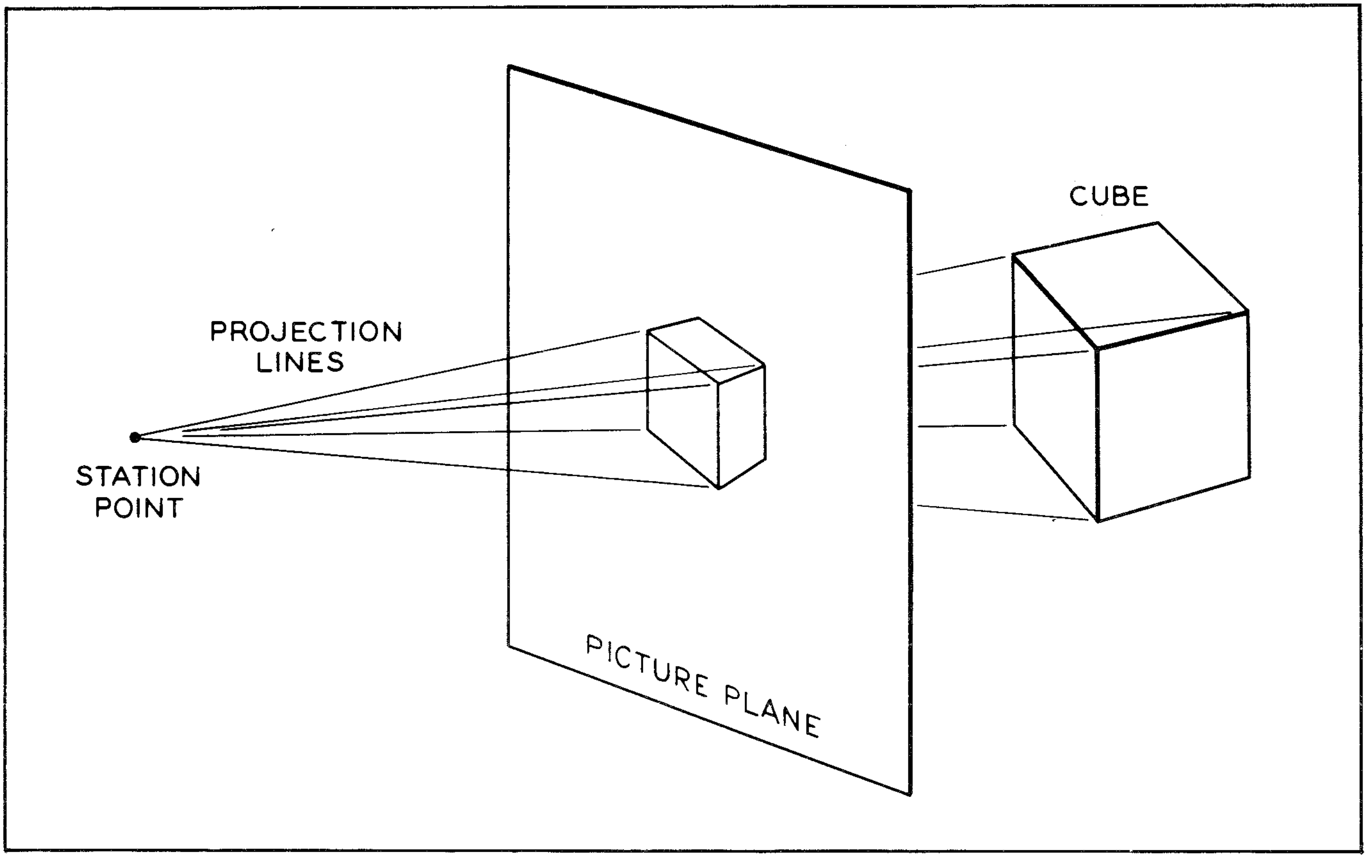


Fig. 74 A perspective drawing is produced by choosing a point (representing the eye and formally called the station point) from which the object is viewed. A picture plane is then inserted between the object and the station point, and projection lines are drawn from the object to the station point. The points of intersection of these projection lines with the picture plane are joined together to produce the perspective drawing shown below. In this way a three-dimensional object is projected on to a two-dimensional plane.



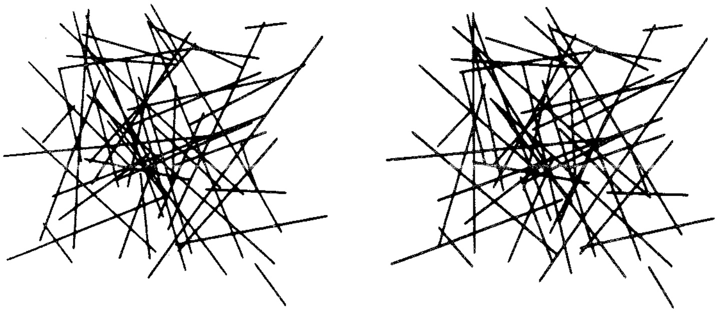


Fig. 75 Two perspective drawings obtained from two picture planes and two station points produce what is called a stereographic drawing. Since the two station points are located in slightly different positions, two slightly different perspectives are obtained. When viewed stereoptically, these minute differences in the pictures presented to the left and right eyes are translated by the brain into a depth effect. This figure shows a computer-generated three-dimensional picture pair of a random structure consisting of 50 lines falling at random within a cube. To view the three-dimensional effect, place a sheet of paper on edge between the stereo pair. Position your head so that each eye sees only one image. With a bit of adjustment, the images should seem to converge and appear three-dimensional.

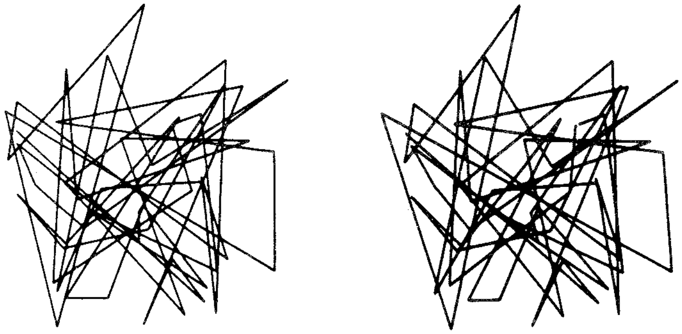


Fig. 76 Three-dimensional picture pair of a random line connecting 50 points chosen to fall randomly within a cube.

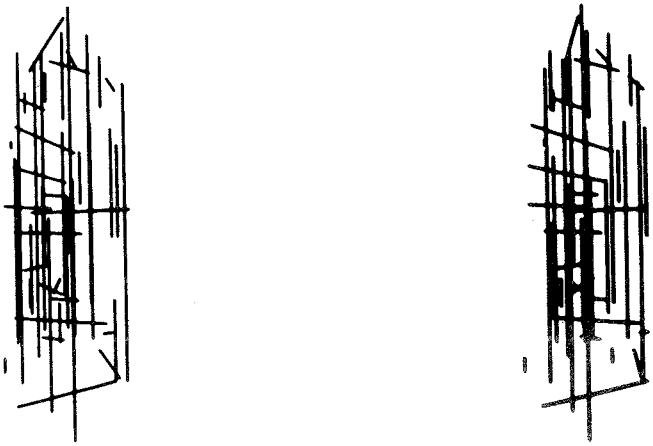


Fig. 77 Three-dimensional picture pair of structures consisting of 30 random-length vertical lines and 20 random-length horizontal lines.

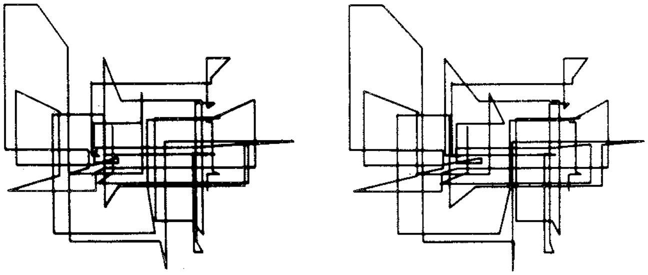


Fig. 78 Three-dimensional picture pair of 85 mutually perpendicular connected line segments.

below

Fig. 79 As an example of the ease with which order can be united with randomness, the computer was programmed to generate its version of Richard Lippold's sculpture *Orpheus and Apollo* which hangs in the lobby of New York City's Philharmonic Hall. This work consists of long flat plates of brass that have been hung from the ceiling by thin wires. For all practical purposes, the plates can be represented by single straight lines. When Lippold's work is so visualized, it becomes possible to describe the sculpture in terms of imaginary trend lines about which the bars have been placed. The computer approach was to specify each trend line by giving the co-ordinates of its end points, and the computer then distributed lines randomly about this trend line. These lines were random distances from the trend line and also had random angular positions in space. A total of six such trend lines were used in the final computer-generated result.

opposite

Fig. 80 The computer was also programmed to produce a series of three-dimensional pictures—a computer-generated three-dimensional movie. The procedure is to specify mathematically the three-dimensional co-ordinates of the points in a line representation of the desired object. The projection program then computes the corresponding points for the left and right perspectives and generates instructions for the microfilm plotter to draw a single frame of the movie. The next position or shape of the object is mathematically specified, the perspective points are computed, and instructions are generated for producing another frame of the movie. This process is repeated until the movie has been completed on a frame-by-frame basis. The whole procedure is somewhat similar to the conventional animation process. In the first attempt at a computer-generated three-dimensional movie the object consisted of 39 line segments sequentially connecting 40 points picked at random (uniform density) to fall within a cube as shown in this figure. At randomly chosen times one of the points is given a new random position within the cube, and the two lines attached to it are instantaneously twisted to new orientations. This is truly a 'kinetic sculpture'. Finally the computer has produced an artistic effect unattainable by any other means. There have been attempts previously by artists to paint by hand three-dimensional films, but attaining the detail of the computer film would be extremely time-consuming and would probably take a lifetime.

opposite

Fig. 81 The four-dimensional analogue of the cube is called a four-dimensional hypercube. A computer-generated movie of a rotating hypercube was made. The rotations which involve the fourth dimension result in the object appearing to turn inside out. The motion itself is very intriguing and, although very complicated, immediately implies a sophisticated generating process.

Fig. 79

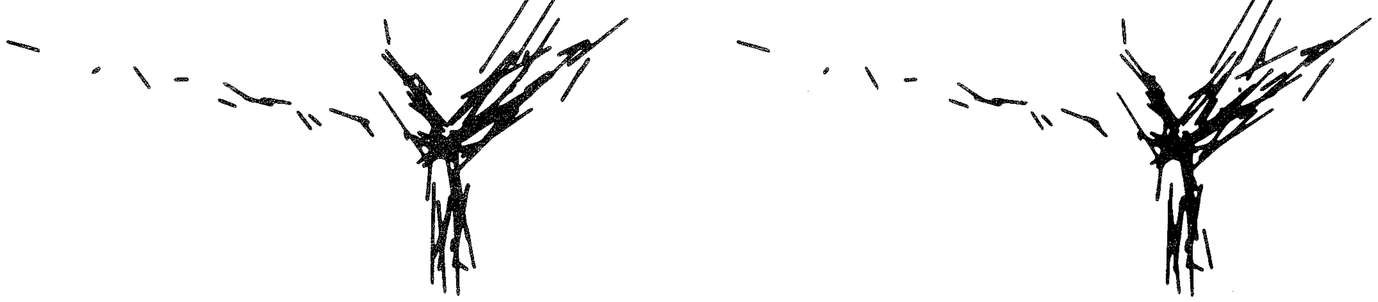


Fig. 80

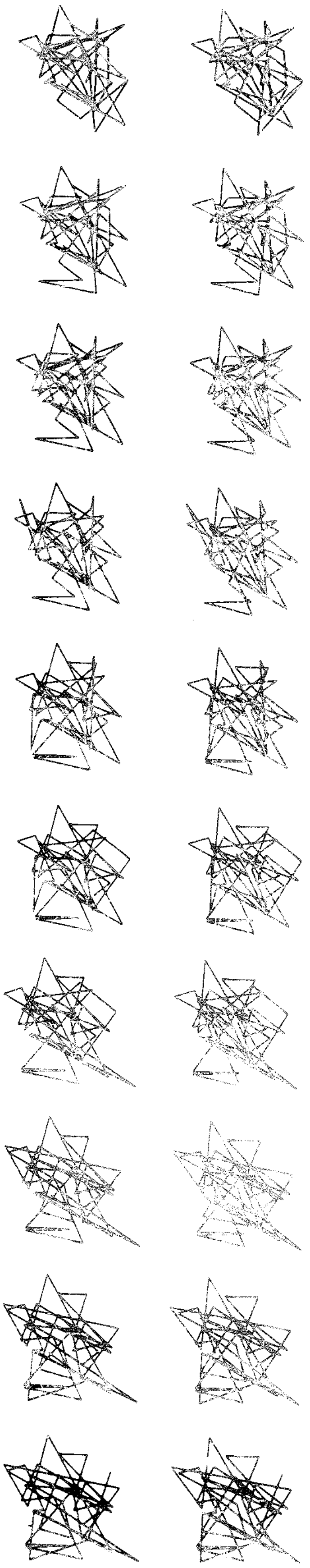
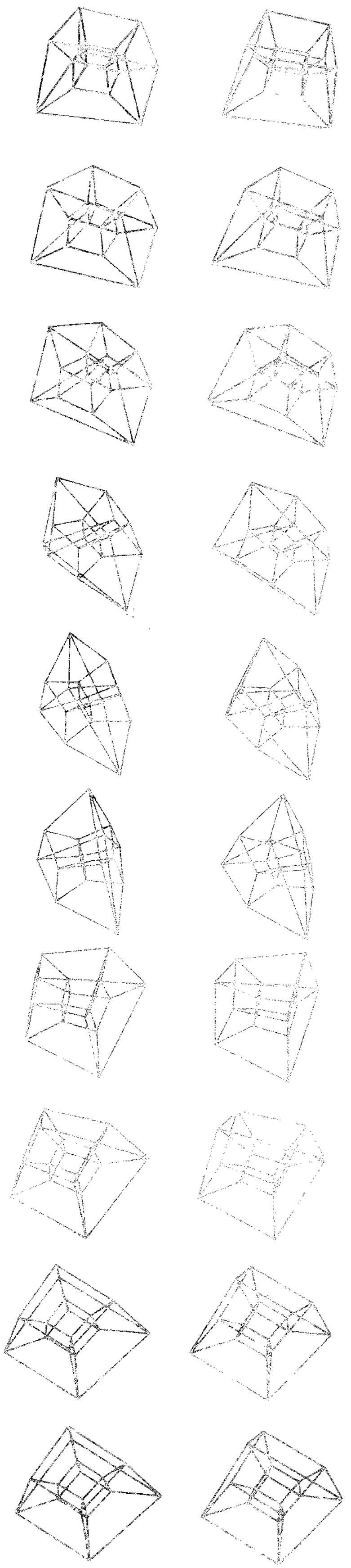


Fig. 81



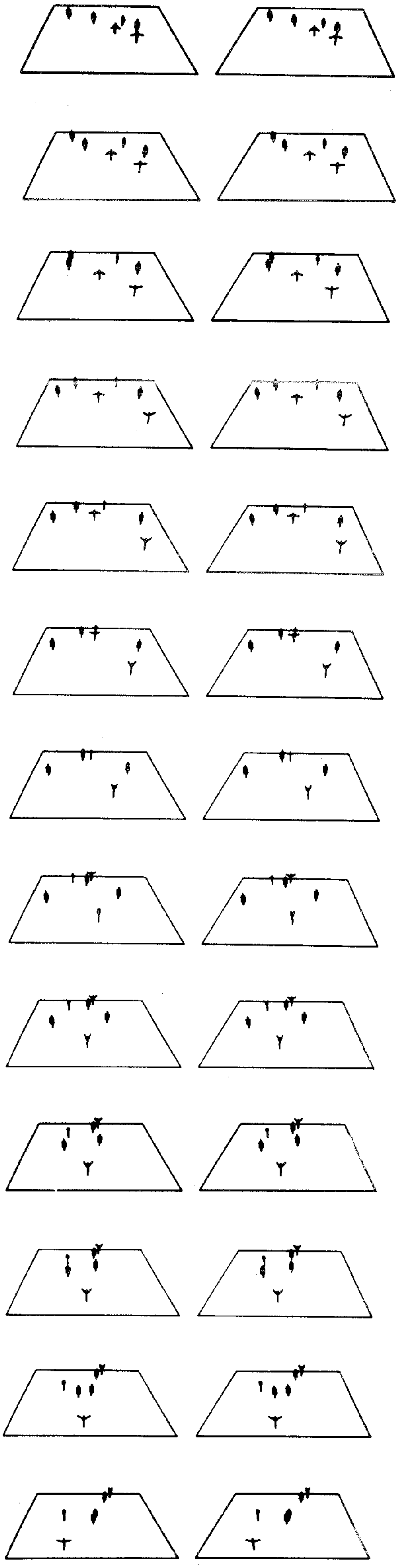


Fig. 82 Stick-figure motion on a stage can be shown by a sequence of movie frames. Each stick figure consists of a single line for the body, a single-line shoulder, and single-line arms. The arm positions are completely variable, and the size of each body element can be individually specified. The whole stick figure can be rotated to any specified angle and located at any position on the stage. In this particular example, six figures were used. Three move their arms uniformly up and down. The stage motion is random (any position is equally likely), but only one co-ordinate changes each time so that the motion is always parallel to the edges of the stage. The motion from position to position is at a uniform rate that is individually specified for each figure. At random times all stage motion ceases, and the three figures with the moving arms make one complete turn. The effect is reminiscent of the motion of atoms in a gas. The stage motion then continues.

Randomness in computer graphics

Leslie Mezei

'We have a random number generator, but we do not have random art.' (*Mezei*)

Computer art began with technical people who had access to computers and computer graphics equipment. They discovered that pleasing results can be achieved when a family of mathematical curves is plotted. Effects similar to Lissajous curves could be generated on cathode-ray tubes or by means of pendulums, including moiré effects when two grids of curves are overlaid. The results are the precise and regular shapes we have come to call mathematical.

Many computer applications involve the use of random numbers generated within the computer. The two most common distributions of such random numbers are the so-called 'rectangular' or 'uniform', where the likelihood of obtaining any particular number within the allowed range is the same as the likelihood of any other number (fig. 83); and the 'normal' or 'Gaussian' distribution, where the nearer to the 'average' a number is, the more likely it is to be chosen (fig. 84). In the illustrations, these distributions are shown by means of spectral lines, 100 lines over a 10-inch base. With the rectangular distribution, the density of lines is the same, on the average, along any part of the base, similar to the disposition of blades of grass on a lawn, pebbles on a gravel road, or leaves on a dense bush. With the normal distribution, the lines are most dense near the centre (the 'average'), thinning out towards the two sides. Were we to redraw these figures a large number of times, using different sequences of random numbers (of the same distribution) each time, the results would look very similar, though no two drawings would be identical.

From the very beginning, these random numbers played an essential role in computer art experiments, helping to avoid the monotony of regularly regimented spacing of the images. A large number of straight lines, or squares, or circles, can be dispersed within the frame in a random manner, allowing the size, the position and the orientation of the individual figures to be determined by chance. This is the general concept of many of the earliest computer art products.

Regularity, predictability, unity, uniformity, are considered 'pleasing'; complexity, irregularity, unpredictability, variation, are thought to be 'interesting'. Many definitions of art refer to 'unity within complexity'. The element implicit in using the computer for making designs, is that all the decisions have to be made specific and explicit, which makes them open to study. By its very nature, computer art, becomes a part of 'generative aesthetics', as discussed by Max Bense (see p. 57).

We have a random number generator, but we do not have random art. Many design decisions have to be made from the very beginning, such as the choice of squares or straight lines among all the possible two-dimensional figures, or the size and shape of the frame. These and other constraints impose the unity, the overall structure, or in the terminology of 'information aesthetics', the macro-aesthetics of the picture. Were we to repeat the experiment any number of times we would get a large number of variations, some more interesting than others, but the overall structure would remain recognizably the same. The program embodies the generating rules, or the algorithm, which with random selection is capable of producing an infinite variety of similar pictures. The creativity is in the choice of the algorithm, not in the grinding out of the variations, which represent the micro-aesthetics of a picture.

The program could be so complex that its designer would be unable to foretell the kind of pictures that it would produce. However, after a few are actually realized, the potential of the program becomes quite clear. Most computer pictures which we see are chosen by their maker, from a great number which are actually produced. Unfortunately, the measures of aesthetic values, such as those proposed by G. D. Birkhoff, are not yet accurate enough to enable us to include in the program the criteria for selecting the most pleasing of our variations.

The programmer–artist goes one step further in his influence over his results. After viewing the output he may well decide to make minor alterations to the program and change the limitations of the distributions, size of the individual elements and so on. Alternatively he might even decide to change some of the major decisions.

To say that we have order on the one side and disorder or 'randomness' on the other is an oversimplification. Two- or three-dimensional figures have many aspects and there are many ways of looking at them. Order with respect to what: choice of elements, number of elements, position, orientation,

Fig. 83 Rectangular distribution.

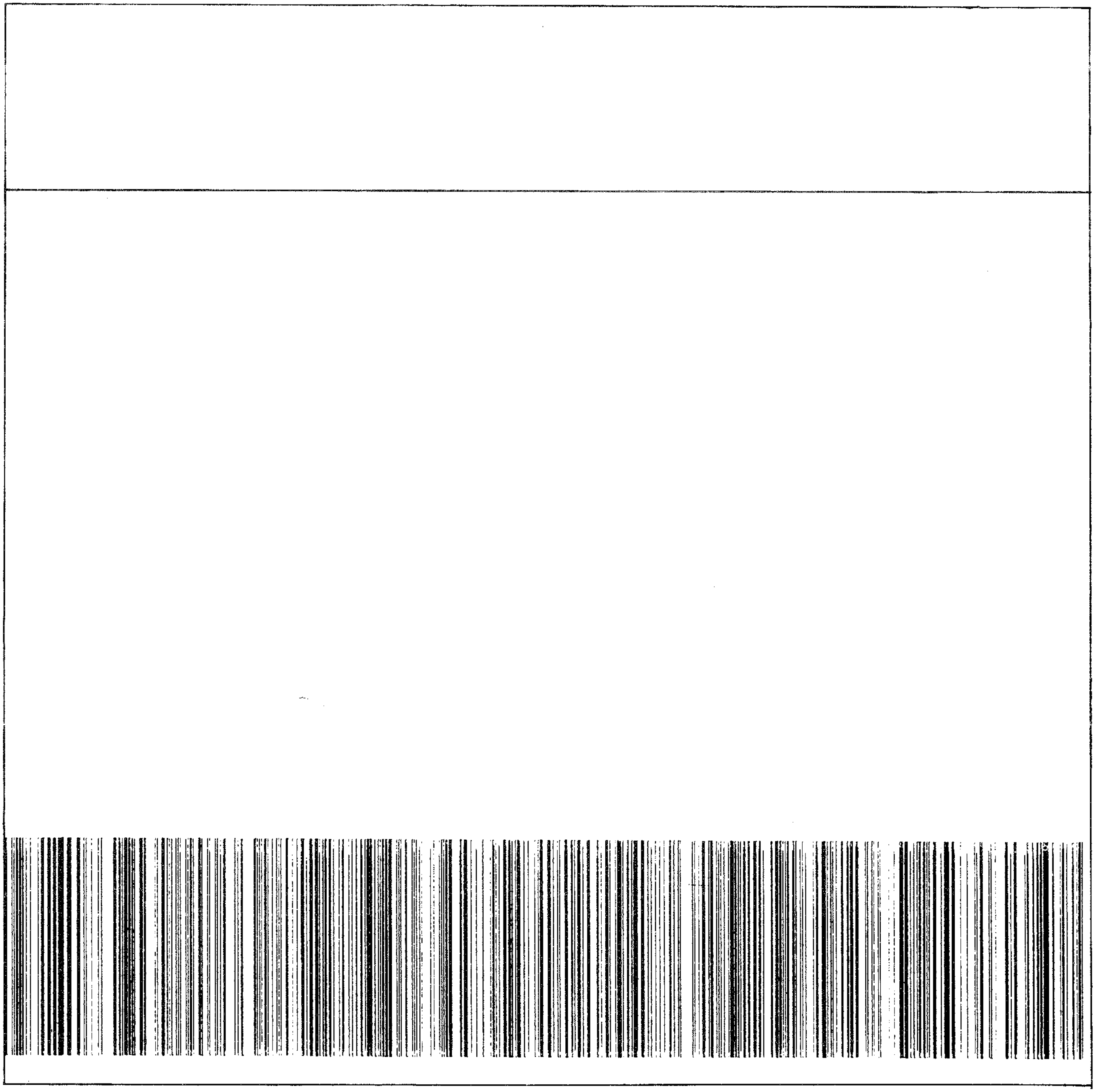
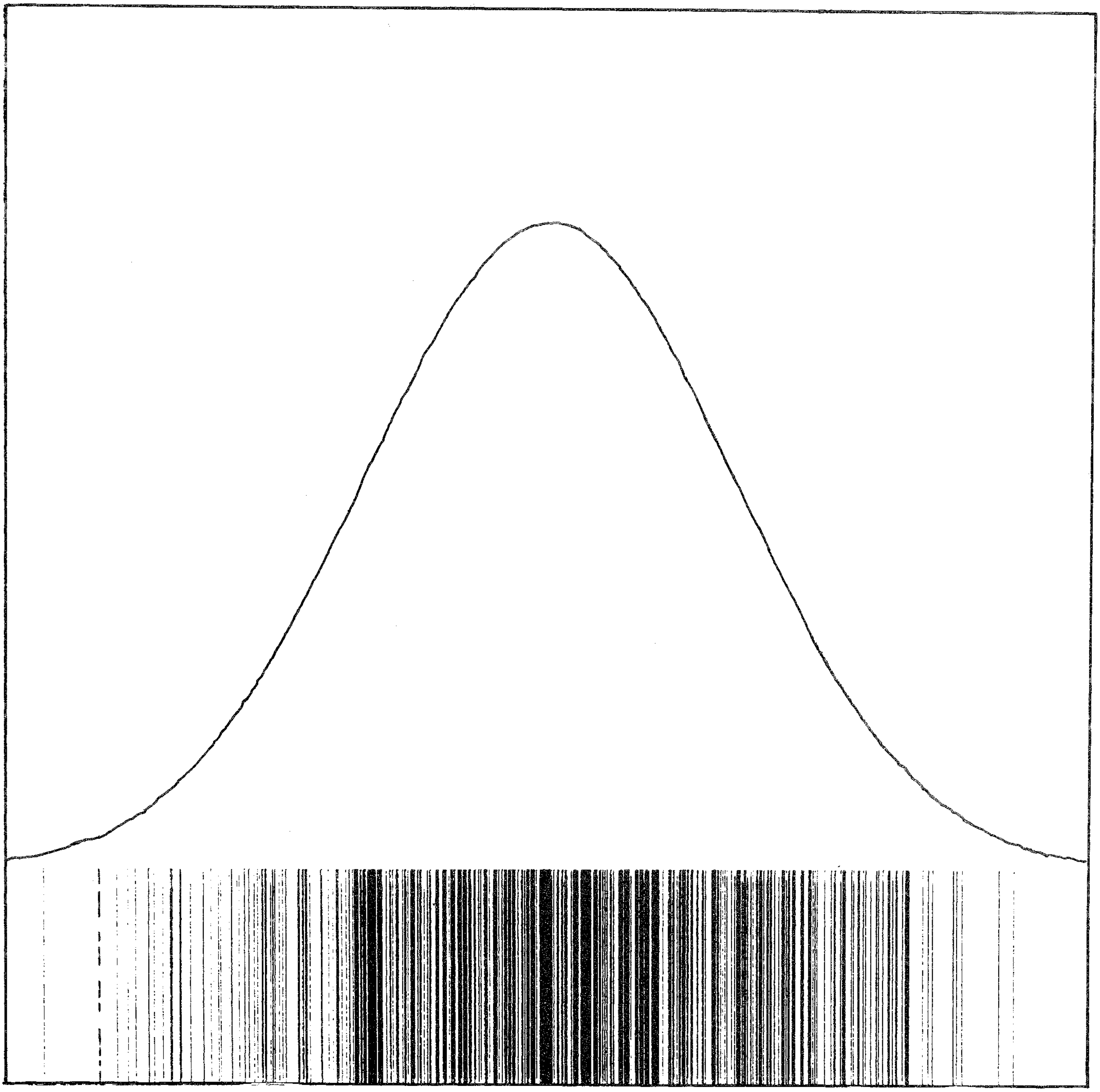


Fig. 84 Gaussian distribution.



size, texture, colour? Each of these aspects can be analysed separately. In respect of any of these attributes we can measure the amount of randomness (or complexity) by means of information theory and auto-correlation. This has already been done to a certain extent in information aesthetics.

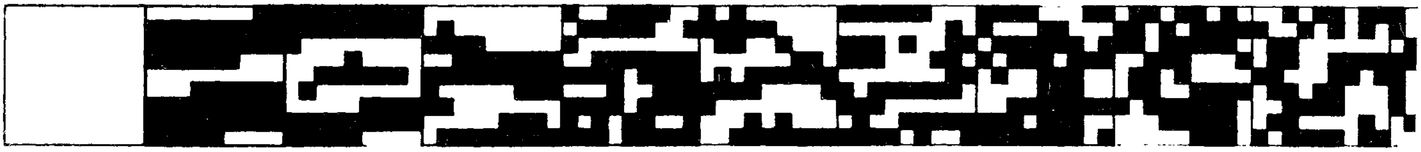
To demonstrate the concept of degrees of randomness, one can generate a particular scale of randomness (fig. 85). Let us take a 9 × 9 chessboard and colour the individual black and white squares according to the rule known as the Markov chain. We colour the top left corner black or white arbitrarily (i.e. a white square at the beginning being as likely as a black one). Let us assign a 'transitional probability' of 0·5. Going from left to right and restarting each line at the left, we can decide the colour of each square based only on the colour of the last one. The chance of a change in colour is determined by the transition probability. Thus if the last square was black the chances are fifty-fifty that the next will be white and vice versa. The result is the middle square in figure 85. Now let us change the transition probability to 0·55 and repeat the process, plotting the result to the right of the first checkerboard; then we take 0·60, 0·65 and so on, up to 1·00 which means the certainty of change. What we then have is a scale going towards more and more regular alternation, till we get the regular checkerboard on the extreme right. One of the most interesting areas is around a transition probability of 0·9 (third from the right) where we have a regular alternation, occasionally broken by a continuation. Now we plot the results with a transition probability of 0·45, 0·40, 0·35 down to 0·00 to the left of the first checkerboard. We thus obtain another scale going towards more and more regular continuation, only occasionally broken by a change in colour at 0·10, and pure repetition at the extreme left. Starting with a search for one scale, we end up with two of them demonstrating the complexity of the problem.

I will use *O Canada* (fig. 86) to give a detailed description of what I call 'controlled randomness'. Here not only external constraints were imposed, but the degree of randomness permitted was also controlled. In this picture I have used four symbols appropriate to Canada's centennial in 1967. Here the major design decision was that all details should be settled randomly, but that the resulting pictorial elements should be arranged into a number of clusters.

As a first step the frame was to contain one cluster. There are four figures: beaver, maple leaf, centennial symbol, Expo symbol. It was necessary then to decide how many figures would constitute the cluster. Only the two random distributions already described, were to be used. For a uniform distribution we need merely to specify the minimum and maximum values, e.g. 4 and 8, meaning that on any particular run of the program (i.e. for each cluster), there is an equal chance of ending up with 4, 5, 6, 7 or 8 figures. To use a normal distribution we specify, in addition, the average value (the most likely) and the standard deviation (which is a measure of the scatter of values, or how fast the density of values falls off in either direction). We might say, for example, that on average 6 figures should be used, with a standard deviation of 1, a minimum of 3 and a maximum of 12. (This would mean, that any number between 3 and 12 may be chosen, but ninety-five per cent of them fall within the range from 3 to 9.)

We choose one of the four figures with equal probability for each. (We could as well specify different relative proportions in which they should appear.) We position it inside the frame and specify probabilities for the size and orientation. The process is repeated until the chosen number of figures is reached. The resulting picture is now scaled down to about

Fig. 85 Scale of randomness.



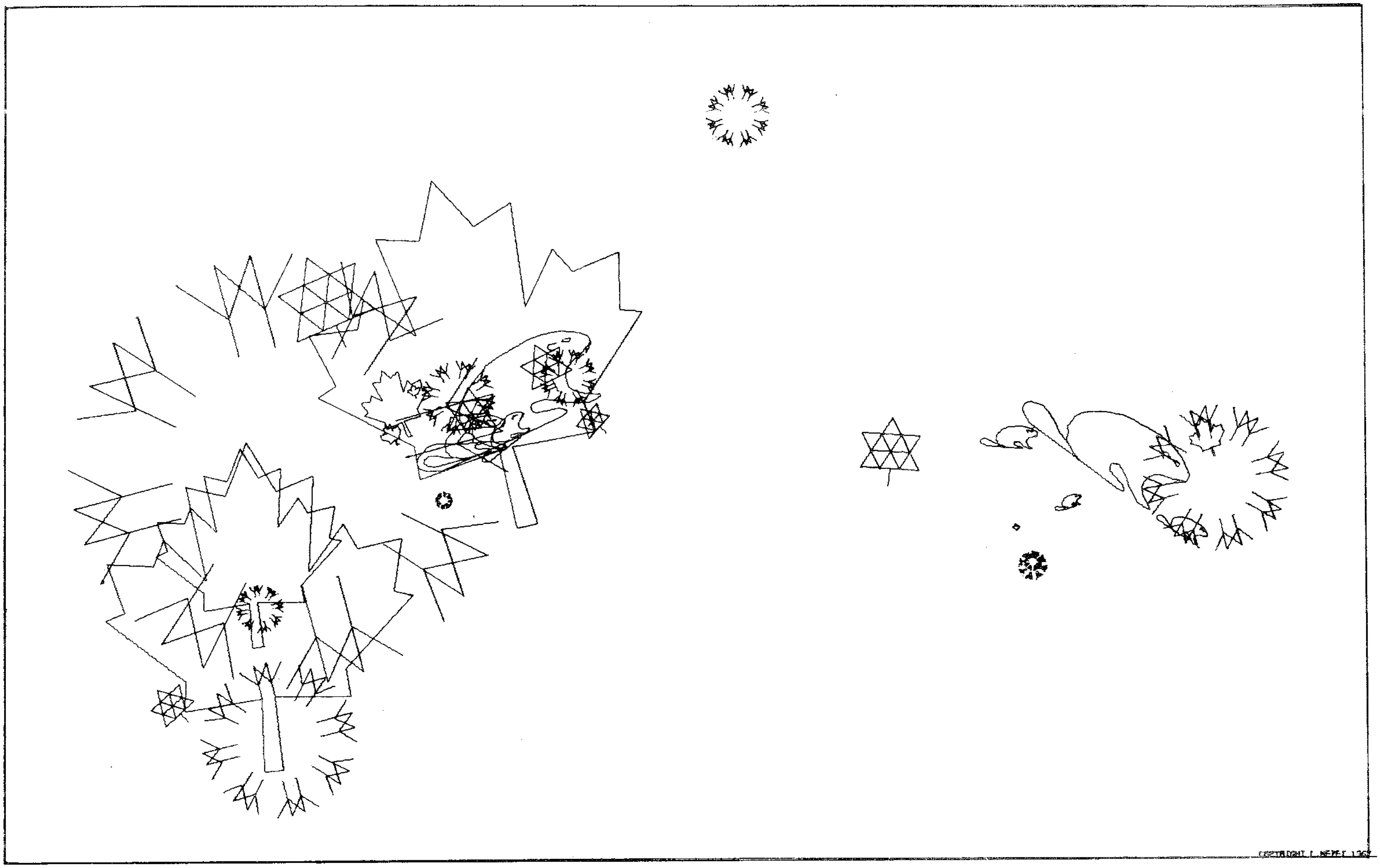


Fig. 86 *O Canada*, L. Mezei, 1967.

Fig. 87a
Girl, L. Mezei, 1967.

one-eighth size and drawn by the plotter. The next cluster is generated, and so on, until the required number of clusters are ready. I found that a considerable variation in size within the clusters, and between clusters, is necessary to obtain interesting results. It was decided, by the way, that the clusters, as well as the individual figures within them, could overlap each other.

Instead of making a composition from many elements, we can take one figure, such as a girl's face, and apply various transformations to it (fig. 87*a*). A number of interesting mathematical transformations is possible, but here I was concerned with those involving randomness. The picture is represented within the computer as the co-ordinates of 660 points with straight lines joining them drawn by the plotter. She can be 'shaken up' causing each point to move in the horizontal direction by at most 0·3 of an inch, with a normal distribution (average 0, standard deviation 0·3) (fig. 87*b*). The picture can be of anything, including letters, the

Fig. 87b
Girl Shook up, L. Mezei, 1967.

same program was used to shake the tower of Babel (fig. 88). These programs were written in SPARTA, a programming language I designed for manipulating arbitrary line drawings such as these. The commands, easily learned by a layman, include words such as MOVE, SIZE, ROTATE, FRAME, RDSTP (random distort points).

We can also deal with lines rather than points, and break them into (controlled) random sections. Or we can allow each of the line segments to shift, change size and be rotated. In the case of figure 89, a shift of lines along the horizontal direction produced a distortion effect not uncommon in some modern paintings.

Since the degree of transformation and distortion can be controlled, we can make a sequence of figures which are continuously transformed from one to the next, and thus produce a film. Running it backwards and starting from the unrecognizable jumbled figure, order and recognizability increase as the girl emerges from chaos.

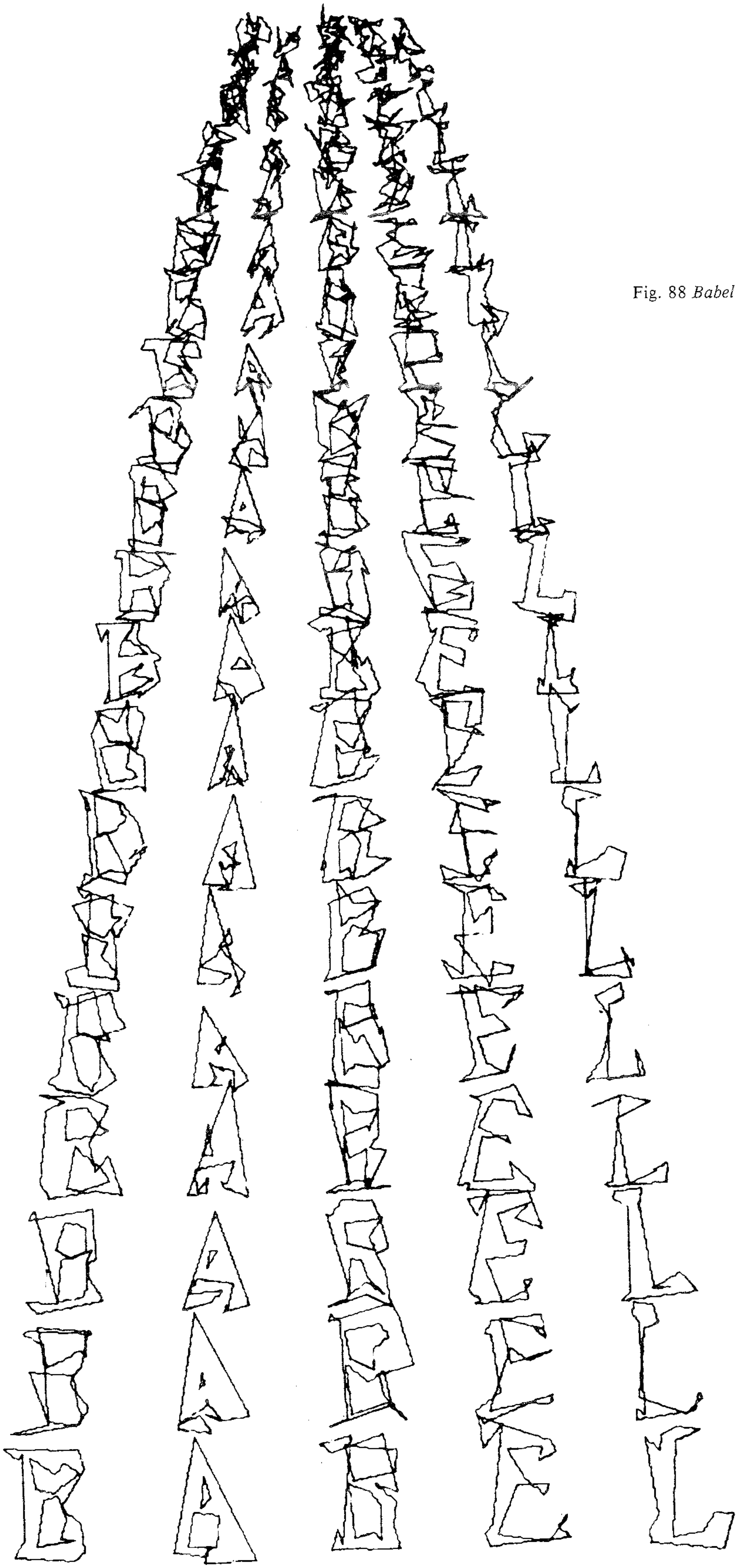
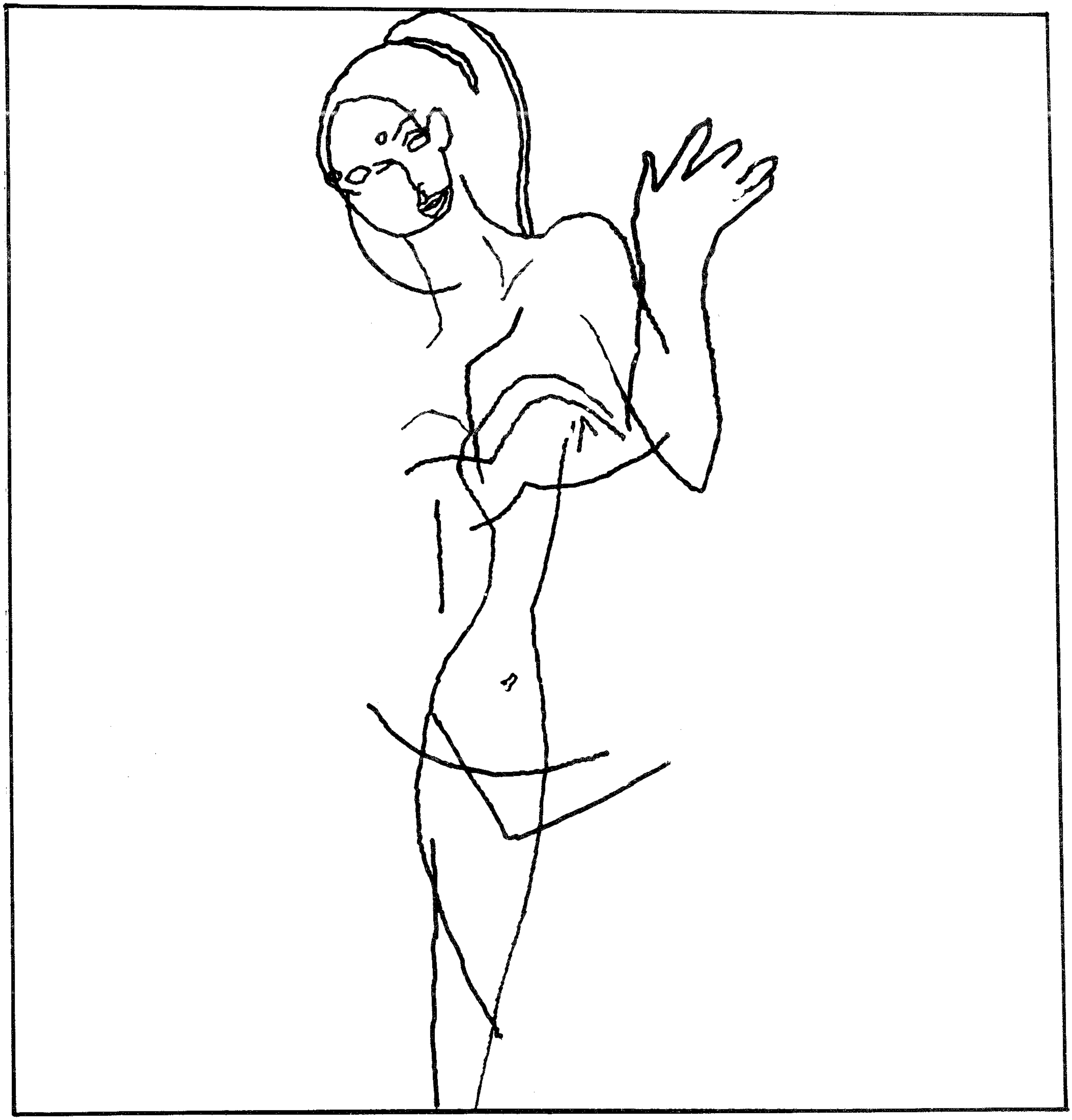


Fig. 88 *Babel Shook*, L. Mezei, 1967.

Fig. 89 *Bikini Shifted*, L. Mezei.



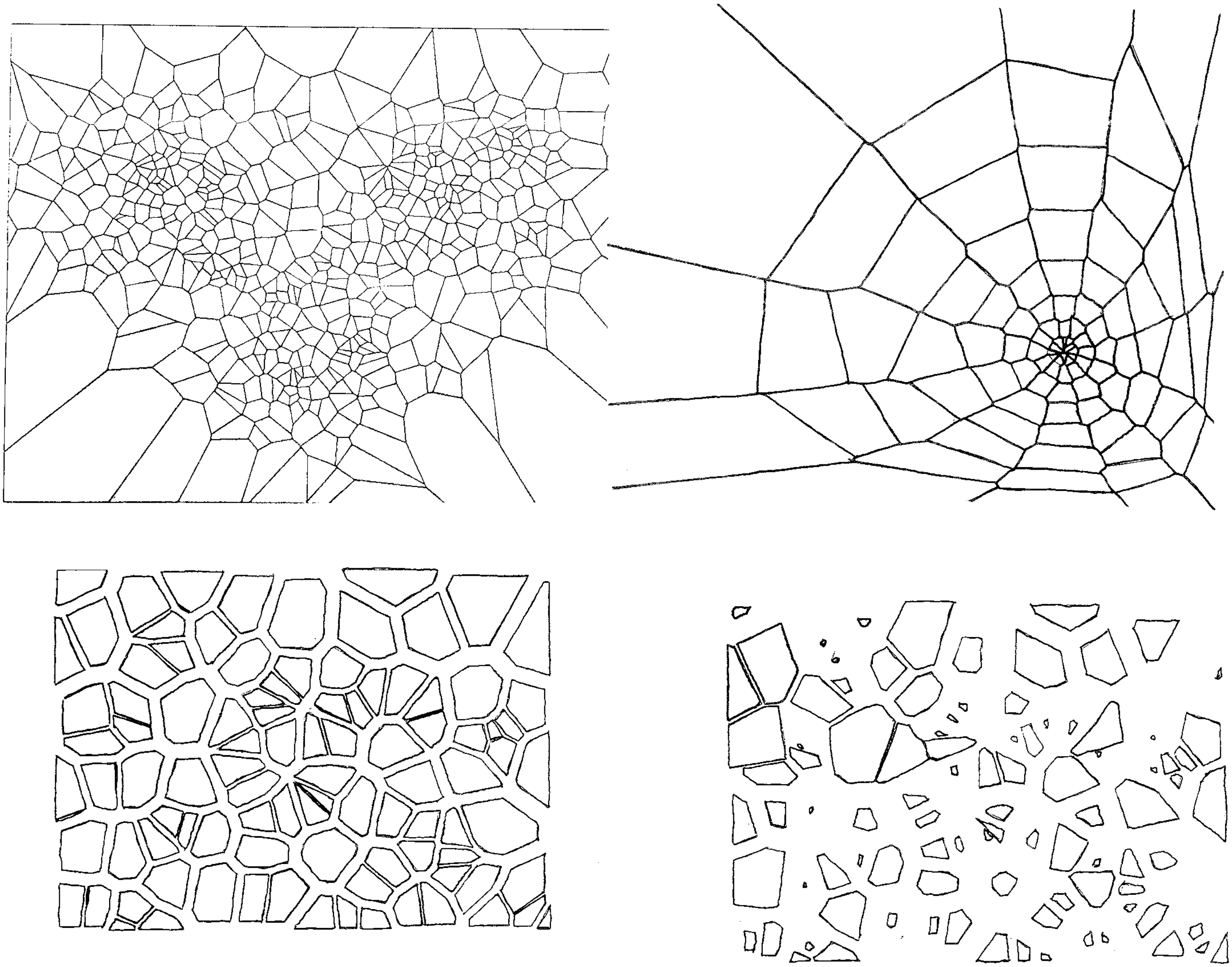


Fig. 90 Cellular patterns generated by a computer, program by Martine Puzin.

A set of programs by Martine Puzin produced results reminiscent of biological cells, cracked earth, ice floes, spiders' webs, Klee's paintings, micro-structure of crystals, honey-combs, soap bubbles and so on (fig. 90), pointing to parallels between the random patterns and distributions found in nature and in art.

The attempt to develop generational rules for patterns not only adds to the usefulness of the computer for graphic design but may also lead to a greater insight into the very nature of patterns and structures. 'Controlled randomness' is offered here as a useful concept in this direction.

Computerized haiku

Margaret Masterman

'. . . playing with any new technique is the first stage of handling it seriously and really exploiting it.' (*Masterman*)

A Japanese haiku is a three-line poem of 17 syllables with the following line-pattern:

Line 1: 5 syllables
Line 2: 7 syllables
Line 3: 5 syllables

It is not limited with regard to subject-matter, but strictly speaking, should contain some reference, however distant, to the season of the year.

Through lack of sufficient knowledge of these facts, our first effort to produce a machine-aided haiku was irregular; since, though the number of syllables was right, the line-pattern of the frame of the haiku, which was stored in the computer, was:

Line 1: 7 syllables
Line 2: 5 syllables
Line 3: 5 syllables

The computer's simulation of the action of the poet's mind: the thesaurus and the frame

In order to use a machine to handle natural language for any purpose whatever, you have to make a hypothesis about the nature, the potentialities and the structure of the sample of natural language which you are putting into your machine. As a radio critic recently said, you have got to 'crack language'. This fact has either not been realized, or has been evaded up to now, particularly by those working on information retrieval and in mechanical translation—two fields in which the capacity to 'crack language' is quite evidently required.

To put 1,000,000 words of Russian–English alphabetized dictionary on disc, make the computer match it with the alphabetized set of words in a Russian text (with the same word matched against the same translation each time it comes), record the matched entries in the serial text order and then print out the English; to do all this without first gaining any insight or understanding of what translation is—this is not to translate at all but to use the computer simply to transliterate. Any true translation there may be will be performed by the unfortunate man who tries to make out what the computer output with which he is presented can possibly have meant; and such a man will be translating (if he can) from computer output into English. What the computer itself produces could only be called 'idiot translation'.

The same goes for poetry. To put a set of words on disc in the machine, program the machine to make a random choice between them, constrained only by rhyming requirements, and to do nothing else—this is to write idiot poetry. Judged by this test (the test being how much insight was used in making them), the poems produced by computers are, on the whole, at present very inferior to computer-produced graphics where sophisticated mathematical formulae are mechanically converted to produce abstract topological designs, some of these being of deep metaphysical beauty.

In poetry, we have not as yet got the generating formulae; though who would doubt that a poem, any poem, has in fact an interior logic of its own? The analytic attack made upon the Japanese haiku, therefore, in order to computerize it, represents a first attempt to get the glimmer of a glimmer of what the interior logic of a simple poem-form could be like.

This fact—that the difficult problem of producing a poem's generating formula was for the first time made explicit by a rudimentary generating formula being actually displayed, sufficiently explains the haiku's unexpected success at the Cybernetic Serendipity exhibition. People who were neither Japanese nor poets could, and did, work the algorithm and produce a poem; which then, in some cases, they carefully treasured and placed in their breast pockets. (The same phenomenon was observed at an earlier stage at the Cambridge Language Research Unit. An engineer and an information-scientist, each with an international reputation, both wrote poems from the algorithm at a research meeting—and both were observed slinking secretly back into the meeting-room afterwards to copy their own poems off the display-board, put them in their pockets and take them home. When a poet, Alan Trist, came to the exhibition, of course, he adopted the idea, not the haiku; and invented his own frame and wrote his own poems, from his own algorithm—which was just what had been hoped that someone would do. But long before this, the exhibit giving the poem-game had succeeded, beyond all hope, in its primary object which was that of enabling non-poets to be able to make poems—by play.)

Not only has it been shown by Huizinga, in his book *Homo Ludens*, that play is a fundamental religious activity; but also playing with any new technique is the first stage of handling the said technique seriously, of really exploiting it. Here, we have got genuine art—creating new techniques—which will emerge as soon as more business executives who have on-line consoles in their offices, find it more fun to write poems on them than to explore the current state of the market, or to model their own firm's production flow. The computer can process more words, faster, than can any human being; it can multi-classify to an extent far beyond the ultimate limit of classification which man can contemplate; it can file-handle, mechanically generating any new file out of any old one with no constraint (e.g. it can turn all the men mentioned in a newspaper report into women, or turn an apologetic business letter into an abusive one, etc.). A moment's reflection should suffice to convince of the immensity of this power. Likewise, it can produce degrees and categories of randomness; and the philosophic re-examination of the whole notion of randomness has been one of the intellectual advances which have occurred partly as side-effects from the intensive study of mechanized calculation. But of all these techniques, the one which is most immediately relevant to computer poetry-making, is that of man–machine interaction by means of a reactive on-line console connected to a large rapid-access computer memory. For this enables the computer to enhance and extend the live poet's creativity; not to replace it, as would batch-programming a poem on a computer. Larger vocabularies and unusual connexions between the words in them, together with intricate devices for hitherto unexplored forms of word-combination—all these can be inserted into the machine, and still leave the live poet, operating the console, free to choose when, how and whether they should be employed: for the machine is being used here as an extension of a typewriter, not as an extension of a desk-calculator.

So, there are genuine new techniques here, for the poet to use, and also genuine areas of knowledge to be explored. One such area is that which lies between what can ordinarily be said, in normal correct English, through what, by extension of saying, might be poetically said, before the boundary is reached of complete gibberish. Another is the exploration of different poetic logics—using 'logic' here in an extended but still definite sense. And the achievement to be conquered *par excellence* is the use of all this new knowledge, when we have it, and of all these new extended-typewriter techniques (when we have developed them more fully) to enhance and give more power and variety to the intuitive creativity of the real live poet; not to replace him. For new techniques, once they become understood, can make possible the creation of startling new beauty. How, for instance, in music, can you have a ground bass continuo, if the only musical instruments known to your culture are a conch, a drum and a flute?

After such talk of man–machine interaction-aided ideals, the computerized toy model of the Japanese haiku will seem trivial indeed. Just so, the 'Think-a-dot' toy computer seems trivial, when played beside, or on top of, the genuine article. But just as the 'Think-a-dot' becomes more or less insight-provoking according to the degree of insight possessed by the man who plays with it, so now. Just as elementary mathematics can be envisaged from an advanced point of view, so elementary computer poem-making can be envisaged from an advanced point of view. And the algorithm given here for generating Japanese haikus on-line endeavours to do just this.

The hypothesis employed here is that every poem has a frame, and that the activity of frame-making can be analytically distinguished from the activity of filling in the frame. In the haiku, therefore, the haiku-frame is stored in the computer; while the thesaurus represents the initial treasury of synonyms, or otherwise constrained word-classes, with which the poet, by man–machine interaction, fills up, one by one, the gaps left in the frame. The computer, meanwhile, having absorbed and inserted these fillings, prints out the final poem with the gaps all filled in; sometimes startling the poet at the computer console, who never did more than choose one word from a given class of words at any one time.

This, of course, is a gross over-simplification of what the true poet does, and in two respects. The true poet starts with inspired fragments, emerging fully formed from his subconscious; only at a relatively late stage, quite often, does he choose his frame. So there are (at least) three stages: orientating hunch, emergence of inspired fragments, choice of frame. Moreover, the true poet will never have a fixed thesaurus. Word-class-generation goes on in him even when sober; and the more so, not the less, the more frightened he is, the more drunk, the more inspired. Nevertheless, there have been periods, and there have been cultures, where presenting your own poem (like making up your own bunch of flowers to place in the bedroom of a guest in our culture now) was an ordinary social grace. If our culture (machine-aided), so changed as to require this grace, bought Christmas and birthday cards would become a thing of the past; you would make or draw your own, using at need, your console, and the convention would be that the letter press of the card had to be your own specially invented poem—or your own specially invented code.

In such circumstances the process of poetic creation would be accelerated, simplified and made self-conscious—and would become something very much more like the process exemplified below in the haiku (which was, indeed, just such a socially required poem in traditional Japan). The frame would be chosen, first, to fit the social occasion; and next, from a more or less stereotyped sequence of word-classes consisting each of monosyllables or rhymes or half-rhymes, the poet would make concurrent choices to fill in the gaps in the frames. And, proceeding thus, a great many mediocre poems (see below) would be generated. But—as also in the case of the socially required poem-form of past cultures—what could be done within the social constraints of such a requirement would only emerge when a true poet, handling the medium, emerged also. A true poet might make inspired choices, even when handling the toy haiku.

Programmed version of the haiku's frame and thesaurus (mark I)

In our first effort, which was irregular, the haiku frame was:

I . . . . THE . . . . IN THE . . . .
ALL . . . . IN THE . . . .
BANG THE . . . . HAS . . . .

No attempt was made semantically to analyse this further; it was stored in the computer in this form using the programming language, TRAC (Text Reckoner And Compiler).

a *The program*

This gave the frame of the haiku:

```
#(ST, POEM, (
#(PS,
I#(PS,#(CL, PP))#(RS) THE#(PS,#(CL; XX))#(RS) IN
THE#(PS,#(CL, YY))#(RS)
ALL#(PS,#(CL, ZZ))#(RS) IN THE#(PS,#(CL, YY))#(RS)
BANG THE#(PS,#(CL, XX))#(RS) HAS#(PS,#(CL, WW))#(RS))))
```

b *The thesaurus*

The thesaurus consists of five lists, known to the machine as PP, XX, YY, ZZ and WW. They were inserted by the following program:

```
#(ST, PP,
SENSE
PAINT
SAW
HEART
TOUCHED)

#(ST, XX,
SKY
CLOUD
SUN
SHADE
WIND
GALE
POOL)
```

#(ST, YY,
POOL
SEA
PLAIN
STREAM
STREET
ROAD
SHELL
SHORE)

#(ST, ZZ,
SPACE
HEAVEN
SOUND
SEED
FORM
WORLD)

#(ST, WW,
SAID
BENT
SHRANK
TURNED
FOGGED
JAMMED
CRACKED
CLEFT
LAPSED
SIPPED
TOUCHED
HEARD
SLID)

c *The operation*

Man	#(CL, POEM)
START	
Machine: (prints out the list PP)	SENSE PAINT SAW HEARD TOUCHED
READY	
Man (making his first choice)	SENSE
START	
Machine: (prints out the list XX)	SKY CLOUD SUN SHADE WIND GALE POOL
READY	
Man (making his second choice)	SKY
START	
Machine (prints out the list YY)	POOL SEA (and so on)
READY	
Man (third choice)	STREET
START	
Machine (prints out the list ZZ)	SPACE HEAVEN (and so on)
READY	
Man (fourth choice)	HEAVEN
START	
Machine (prints out the list YY)	POOL SEA (and so on)
READY	
Man (fifth choice)	ROAD
START	
Machine (prints out the list XX)	SKY CLOUD (and so on)
READY	
Man (sixth choice)	POOL

START

Machine — SAID

(prints out the list ww) — BENT

(and so on)

READY

Man (seventh choice) — TOUCHED

START

Machine — I SENSE THE SKY IN THE STREET,
ALL HEAVEN IN THE ROAD.
BANG! THE POOL HAS TOUCHED.

END

Other outputs (using the thesaurus)

(*a*) I PAINT THE CLOUD IN THE ROAD,
ALL SPACE IN THE STREET.
BANG! THE SHADE HAS BENT.

END

(*b*) I TOUCHED THE WIND IN THE STREET,
ALL SPACE IN THE STREAM.
BANG! THE GALE HAS HEARD.

END

Output (not using the thesaurus but allowing the operator to type in what he liked as suggested by the frame and thesaurus):

(*a*) I SMELL THE STINKHORN IN THE CORNUCOPIA,
ALL FLIES IN THE OINTMENT.
BANG! THE FRUIT HAS GONE

END

The haiku (mark II)

Having increased our knowledge of haiku, we produced, as a second experiment, a frame for a completely regular haiku, with minimal changes from the frame of the first haiku (mark I). This was achieved by reversing the line-frames for the first and second lines.

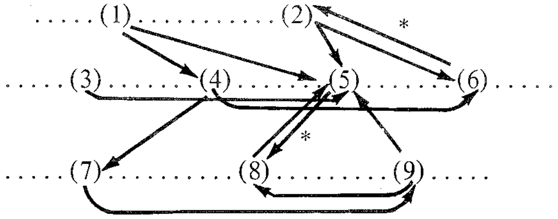
In this second experiment, moreover, the enlarged thesaurus lists contained restrictive warnings, given in the form of arrows, to protect an inexperienced poet from feeding random choices back into the machine. Thus, if the arrow printed at the head of list Y be interpreted to mean, 'see the list X', and if the fact that the arrow is at the top of list Y be interpreted to mean, 'the list Y semantically bears on the list X', and if the words 'the list Y semantically bears on the list X', be interpreted in their turn to mean, 'having chosen a word, *w*, from list Y, choose another word, *v*, from list X such that, grammatically and semantically, *v* fits in with, or, is concordant with, or, seems to you to go nicely with *w*'; then a schema of semantic bearings, or interconnexions, operating within the haiku, can be drawn up.

Such a semantic schema, operating with a thesaurus structured by arrows, to provide words to go into the corresponding slots of a numbered frame, are given below:

a *The numbered frame*

ALL . . (1) . . IN THE . . (2) . .,
I . . (3) . . . . (4) . . . . . (5) . . . IN THE . . (6) . . .
. . (7) . . ! THE . . (8) . . HAS . . (9) . .

b *The semantic schema*



Only one of the arrows starred must be chosen, but the poet is warned to try to find a doubly strong semantic connexion here.

c *The structured thesaurus*

Each list in the thesaurus provided a word-choice for the corresponding slot in the frame.

Slot 1	Slot 2	Slot 3	Slot 4	Slot 5	Slot 6	Slot 7	Slot 8	Slot 9
⟶4	⟶5	⟶5	⟶6	⟶8	⟶2	⟶9	⟶5	⟶5
⟶5	⟶6		⟶7					⟶8
WHITE	BUDS	SEE	SNOW	TREES	SPRING	BANG	SUN	FLIT
BLUE	TWIGS	TRACE	TALL	PEAKS	FALL	HUSH	MOON	FLED
RED	LEAVES	GLIMPSE	PALE	HILLS	COLD	SWISH	STAR	DIMMED
BLACK	HILLS	FLASH	DARK	STREAMS	HEAT	FFTTT	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				

d *Algorithm for operating the system, together with an example*

To write a poem, you go first to the position, or slot, which has the most arrows leading to it. In the semantic schema of the haiku, this is slot 5.

Choose a word for slot 5 from the corresponding thesaurus list, namely list 5. Suppose the word chosen is BIRDS. The frame now becomes:

ALL . . (1) . . IN THE . . (2) . .,
I . . (3) . .   . . (4) . . BIRDS IN THE . . (6) . .
. . (7) . . !   THE . . (8) . .   HAS . . (9) . .

List 5 has an arrow leading to list 8, but the schema shows that it is part of a two-way linkage (a two-way linkage indicates a doubly strong semantic interconnexion). Since, if you go from list 5 to list 8, list 8 will lead you back to list 5, and so on, round and round in a loop, forever, you have the choice as to which of the two arrows, 5 ⟶ 8, or 8 ⟶ 5, you will ignore. You are strongly urged to ignore the arrow 5 ⟶ 8, since you do not as yet know enough about your BIRDS to choose intelligently something which pertains to them from list 8.

Instead, take the first list which semantically bears on list 5 (i.e. which has an arrow to it), namely, list 1. Choose a word from list 1 which, in your view, goes with BIRDS. Suppose the word chosen is BLACK. The frame now becomes:

ALL BLACK IN THE ..(2)..,
I ..(3)..   ..(4).. BIRDS IN THE ..(6)..
..(7)..! THE ..(8).. HAS ..(9)..

Take now, in ascending numerical order, the other four lists which have arrows leading to list 5, namely, the lists 2, 3, 8 and 9.

Choose words, one from each list, respectively, which in your view go with BIRDS. Suppose the words chosen are: MIST (from list 2), TRACE (from list 3), CRANE (from list 8), PASSED (from list 9). The frame now becomes:

ALL BLACK IN THE MIST,

I TRACE ..(4).. BIRDS IN THE ..(6)..
..(7)..! THE CRANE HAS PASSED.

Fill in now the unfilled slots, operating the arrows so that you always proceed from the word you are choosing to a word which you already have. (This is the trick of it.) Thus, the next slot to fill in is 6 (operating the arrow 6 ⟶ 2), since slot 6 has two arrows leading to it, whereas 4 and 7 have only one.

Suppose the word chosen to fill slot 6 is DAWN. Check the appropriateness of this choice in the light of the arrow 2 ⟶ 6 (i.e. is the semantic connexion between 2 and 6 in your view strong enough, or is a closer semantic association, such as a synonym, required?). If, on this review, you do not like your choice for 6, change it.

Similarly, fill in the slots 4 and 7. Suppose the words chosen to fill the slots are, respectively, THIN and WHIRR. Assuming that no changes in choice have been required by the checks which have been operated by using the double arrows, the frame now becomes:

ALL BLACK IN THE MIST,
I TRACE THIN BIRDS IN THE DAWN.
WHIRR! THE CRANE HAS PASSED.

Since the frame is now filled, the poem is complete. (On the assumption that cranes migrate, the presence of the crane can count as a highly indirect indication that the season is not winter; or, alternatively, if the location is further south, that it is winter; and so the poem counts, just, as a haiku.)

The immediate effect of working an example is to make whoever has worked it critical of the thesaurus. For instance, you might consider that the poem in the worked example would be much better if choices 1 and 3 were transposed, so that the final result reads:

ALL THIN IN THE MIST,
I TRACE BLACK BIRDS IN THE DAWN.
WHIRR! THE CRANE HAS PASSED.

To achieve this result, we add the word THIN to list 2. We might then think, moreover, that there was not enough synonym-choice available in list 8 (given the two-way semantic connexion between 5 and 8). SPECK, for instance, should have been added to list 8. So we add it. Moreover, the semantic schema itself is incomplete; it could be said that list 2 semantically bears on list 1, and list 6 also on list 1; i.e. the existence of slot 1, as a secondary semantic centre to slot 5, has not been indicated in the semantic schema, and it should have been. And so on and so on.

That the user who has worked an example in on-line computer-poem making, always wants to improve the semantic schema, and alter or enlarge the thesaurus—this is just what shows the heuristic value, for poets, of the whole enterprise of algorithmic composition in natural language. For this is just the sort of protest which you, as a novice computer-poet, are meant to make; and the fact that you do make it not only shows that your skill and confidence as a computer-poet are increasing every second, but also that, considering yourself now not as a computer-poet but as a real poet, you are finding that you know far more about real poetry than you at first realized. 'These thesaurus lists,' you might say, 'are sickly. I am going to scrap the lot. Where is a pencil, somebody?' And so you start writing new, vivid thesauruses—as a real poet, operating with a real pencil; and, in order to test how these would work out in practice, before you know where you are, you are writing any number of real haikus, between which, using now all your critical and all your creative faculties, you then choose.

Now, in doing all this, and ending up only with paper and pencil, you may think that you are winning over the game, but in fact, the game has won over you. For every time you protest and get angry and make an alteration in the schema which has been given to you, you acknowledge that a computer-algorithm has added to your poetic creativity—which was the original object of the exercise. (Compare and contrast other slot-filling activities. When has filling in a form for a driving-licence or a passport ever added to your poetic—or any other form of—creativity?)

Other poems which were composed using this algorithm:

ALL GREEN IN THE LEAVES,
I SMELL DARK POOLS IN THE TREES.
CRASH! THE MOON HAS FLED.

ALL WHITE IN THE BUDS,
I FLASH SNOW PEAKS IN THE SPRING.
BANG! THE SUN HAS FOGGED.

Looking at the matter analytically, the change from haiku (mark I) to haiku (mark II) reveals what a fundamental semantic change we have made, in the whole underlying mood of the haiku, by reversing the positions of the first two lines. For the semantic centre of the new haiku is slot 5, which has five arrows going to it, and one going from it. Thus (given that this haiku follows up a general characterizing of something with a particular description of it), it is the particular description, in the second line, which contains the semantic centre; and this fact makes the whole haiku concrete. In the first haiku (which was not schematized), the semantic centre was, on the contrary, in slot 4, i.e. in the first position of the general characterization given in the second line. This time, therefore, the centre emphasizes the general metaphoric comparison, given in line 2, with something particular which has already been described in line 1 (e.g. ALL HEAVEN IN A POINT), thus turning the whole haiku abstract.

When we discovered this, and to signal further this change, we allowed the poet (in haiku, mark II) an extra adjectival choice (no. 4 in the new haiku), in order that he might have a chance to give his now central particular description, in line 2, more colour and bite. Thus position 1 (in haiku, mark II) does not consist any more of the frame-word 'ALL' (as in haiku, mark I): it now consists of an adjectival thesaurus choice.

Mechanizing the program

These poems were composed by man-machine interaction. Any computer-programmer will be quick to point out that he could devise choice-sequence algorithms for batch-programming them, so as to make the whole operation fully mechanical.

For instance, it is evident that, by programming the machine to print out all combinations of the words in the thesaurus allowed by the syntactic form of the frame, the machine could have been batch-programmed to print out vast numbers of haikus, which would have included the two given above.

Algorithms can also be used to produce a fully computerized poem. For instance, in the output given immediately below, the machine has been told (*a*) only to choose words beginning with the letter 's' and, (*b*) when there is a choice among 's' words, to take the one whose second letter is nearest the end of the alphabet (and so recursively, if there is still a choice of words):

Out put (mark I)

I SENSE THE SUN IN THE STREET,
ALL SPACE IN THE STREET.
BANG! THE SUN HAS SLID.

Indefinitely many such algorithms, including some which operate a randomizer, could be used, and with a bigger thesaurus, the machine itself could match the words for rhymes.

The fact that some of these algorithms, or tricks, produce quite good output highlights the known fact that traditional poetry also uses tricks of rhythm, rhyme and alliteration to allow words to combine more freely (because more mechanistically), that is, with fewer socially and psychologically motivated constraints, than would be permitted by the stereotype of prose.

The role of the poet in computer poetry

It will be evident from the above that the poet programming a computer must, first, set up the frame, second, create the thesaurus, and third, devise any mechanical systems with which he may desire to operate upon the thesaurus.

He can, of course, be more sophisticated than we have been in setting up and varying his frame (a sonnet, for instance, would represent a greater degree of sophistication).

However, if the computer-poems which we have composed on-line could also be composed by batch-programming—that is, by programming the machine to act on its own, without the man having the power to interact with it, and thus to control progressively the quality of the output—what becomes of the creative contribution of the real poet? The answer is that he himself programs the algorithms at the beginning, and he himself chooses between the vast number of mechanical poems which have been generated, at the end. (He also alters words if he does not like them.) In short, the living poet does make a contribution which consists in making choices between outputs, even when these outputs have been batch-programmed on the machine. But this is a very clumsy and a very frustrating way for him to contribute. Far better that he should sit at his on-line console controlling the whole operation as it develops, so that he gets only one output—the one which his sequence of choices has given him—and so that the machine's capabilities can be used in a genuine way, and not merely in a joke way, to strengthen his confidence and enhance his creativity.

In short, the ultimate creative act, for the computer poet, lies in writing the thesaurus and in filling in the semantic directives. Thus the human creative process is pushed one stage further back; and the poet composes a poetic system, which can produce for him any number of poems formed from a given frame, between which he then chooses, rather than himself straightforwardly writing one poem, and then altering it.

A minimum of actual experimentation will show any computer-poet, that in on-line computer poetry the intuitive creative process is still there.

Computer programming for literary laymen

Robin McKinnon Wood

'We are within sight of our goal of a machine which uses names in language construction in the same way that we do.'
(McKinnon Wood)

The author would like to thank Margaret Masterman and David Shillan of the Cambridge Language Research Unit for their help in constructing this example, and the editor of *Theoria to Theory* for permission to use the title and much of the material. A version of this article appeared in *Theoria to Theory* vol. 1, April/July 1967.

A great deal has already been written on the subject of computers, particularly in those fields where the computer's tremendous speed and storage capacity can be used to carry out calculations which could not otherwise be done. Too much has been written about computers as giant brains, in some ill-defined sense of this word, and this has tended to lead people who are not associated with computers or who are not mathematicians, to consider computers too difficult to understand. In fact a computer is a machine—incapable of doing anything until it has been programmed by some person. It is the originality and imagination of that person which is reflected in the behaviour of the machine. This behaviour may well surprise the originator of the program, but this will only be because he had failed to realize the full implications of his program, which the machine has faithfully carried out. The development of the computer has vastly enlarged the fields of activity which people could investigate and put to practical use. Any program could, in theory, be carried out with pencil and paper, but in practice the time and effort involved would be too great. By using the computer as a tool, great savings of time and effort can be achieved, and new fields of activity developed.

For many years the computer has been used as such a tool in fields where rapid calculation, and latterly, the holding of large quantities of information such as pay-rolls, stock control, production control and so on, were required. In many cases some of these calculations could not have been performed in any other way, because they would simply have taken too long. As a result of technical developments, the cost of computation is decreasing very rapidly, while the speed of computation increases, and likewise the amount of storage space or memory space which the machine may have.

It has thus become possible to use computers in fields more related to everyday life than that of calculating numbers for mathematicians, scientists and accountants—for instance in the use of computers to co-ordinate airline bookings, control traffic and to help to compose music and drawings. But, of course, in these tasks as with all others, the machine requires the skill and imagination of its programmer.

The present state of computer technology is such that it is worth considering the use of computers as a tool not only for scientists and large business organizations, but also for small businesses and even for individual people. In order to do this a number of points must be considered. The first is the question of language, the language in which a person can communicate with the computer and in which the computer can communicate with the person. The second point arises from the very great speed of the machine. This speed today is typically of the order of one micro-second, one millionth of a second. As opposed to this, the speed of a human being is measured in units of one tenth of a second. That is, people compared with present-day computers are one hundred thousand times slower. On the other hand, the ability of people to make decisions, to recognize patterns, to recognize speech, quickly, cannot even be approximated by a machine, notwithstanding the speed with which it works.

Thus we have on the one hand, human beings who can compute only slowly, but who can take decisions, assess facts, recognize complex patterns, very quickly; and on the other hand the machine that can do straightforward computations very very fast but which is unable to perform these essentially human functions. Ideally we wish to have a combination in which a person and the computation power of the machine can work together. Because of the tremendous time-scale differences between the behaviour of people and the behaviour of modern machines, we have two choices: we may either allow the machine to run the person, to force the person to take decisions at the speed which the machine requires; or we may allow the person to be in charge. The machine is the tool so it is the second choice that we wish to make.

This can, however, be expensive. The cost of the machine is reckoned in micro-seconds. If the person takes five minutes to come to a decision the cost can be prohibitive. What is required here is a system in which it is possible for more than one person to communicate with the same machine, so that as one person is taking decisions or contemplating what he wishes to do next, some other person can be using the machine. In this way the machine's time is not wasted, but the human being has the feeling that the machine is entirely his and he can waste as much time as he wishes. In some ways this is similar to any public service, such as the telephone, gas or electricity services, where each user of the service believes that he has the entire capacity of the country behind his supply. In fact, if too many people decide to use it simultaneously, the system will break down. In practice it does not break down because people do not all wish to use the service at the same time. Systems of this type, known as multi-access systems, are now available from some computer service companies. In these systems it is possible for one machine to service a large number of separate programs belonging to different people.

The third point which must be borne in mind is that of the cost to any individual user. Computation costs are decreasing rapidly, and it is expected that this decrease in cost will continue as technology advances and as more and more use is made of these machines.

Taking these points in reverse order, the last one, that of cost, is being taken care of by technology. The second, that of using the machine efficiently, is currently being solved by multi-access systems. The first point, however, that of language, is the one which creates the most interesting problems, and is the one which I should like to discuss here.

In the very early days of these machines, the language used was at the engineering level. The machines were made to produce the results required by physically putting pins into plug-boards and connecting them with wires, thus setting up the logic of the particular problem which was required. A vestige of this remains today but as this is mainly limited to the connexion of input–output devices this language level can safely be left to the maintenance engineers and operators of the computing system.

The first real development of computer languages came about when it was realized that the logic formerly embedded in a plug-board by a set of physical wires could be stored in the machine's own store. From this there developed the concept of pure machine code. This is a code which on the very early machines was written directly in binary notation, that is, using only noughts and ones, and this was stored in the store of the machine and replaced the plug-board of wires and plugs.

It was now possible to make a machine do a particular job by writing marks on paper, which could then be punched on to cards or paper tape. There was now a written language in which the programmer could set up the logic of the machine to do his particular job. For the machine, this language is very efficient, but for the person writing in it the restrictions imposed are unnatural and arbitrary, and involve considerable drudgery which could well be done by the machine.

The next step was to make the machine do more of the work, and to show how this can be done we must go into some detail about how computers are programmed. I will try to show how the steadily increasing sophistication in the use of programming languages can make the seemingly complex task of machine programming into an activity that can be undertaken by an intelligent layman.

Conventionally, the electronics of a digital computer is so organized that it is made to obey a set of instructions, one after the other. As I shall have to contrast what I want to do with a computer with this convention, I shall have to give a brief description of the conventional way of understanding it. These computer instructions are of the form: 'Add a certain number to another number.' or 'If this number is zero, stop and do something else.' These instructions are written by the programmer, using some form of programming language, and are then fed into the computer, usually by punched cards or tape, and stored away in the machine's memory store. When the program is run, the machine takes the first instruction, obeys it—in the sense that it performs whatever action the instruction represents—and then takes the second instruction, obeys it and so on in sequence. Special instructions, like the second one given above, are used to change the sequence when desired.

In the most primitive form of machine-code programming, the program is written as a set of discrete instructions, each of which must contain three separate parts. The first of these is the function, chosen from the set of functions defined by the engineering of the machine. The function part tells the machine what it is to do. The second part is the operand, that is, the item on which the function is to operate, and the third is the location of that instruction in the machine's store. As both instructions and operands are kept in the machine's store, it is convenient to number each storage location, and refer to an item, whether an instruction or an operand, by the number given to the storage location in which it is kept. This is known as the address of the item. Thus a typical instruction might be written as:

26/105-223

meaning that the instruction 26/105 is to be placed in storage location 223, and when obeyed, the machine is to perform the operation 26 to the operand it will find in storage location 105.

It is evident that a primitive use of names has been introduced. What's in a name? A great deal, for the use of names is the key to any attempt to provide a natural way of machine programming. In the example above we have only two types of name—the number 26 is the name of a function, and the numbers 105 and 223 are the names or 'addresses' of storage locations in the machine. The type of name a particular number represents is indicated by its position in the code—that is, before or after the stroke. Apart from the inconvenience of using numbers for names, two major difficulties arise. First, the set of function names is limited by the electronics of the machine, and is neither extensible nor transferable to a machine of a different type. Second, the set of address names are absolute, representing fixed locations in the machine which the programmer must remember. A common error is to use the same location inadvertently for different purposes.

Assembly languages can considerably improve this situation, partly by providing mnemonic names for the functions of the machine but chiefly by providing an indirect naming facility for the storage locations. By indirect I mean that the machine attaches the name to a particular storage location (which the programmer is not aware of) and thereafter uses it consistently. The programmer may thus invent names of his own choice, subject to restrictions imposed by the assembly language, and any occurrence of this name will be recoded by the assembler into the correct machine address. In addition, the assembler will find locations for the program by itself, allowing the programmer to label only those instructions he needs to refer to. Our instruction might be written:

ADD/STOCK—UPDATE

or just,

ADD/STOCK

if a label was not wanted. The assembler will convert ADD to 26, STOCK to 105, make a note that UPDATE is the name of storage location 223, and store the instruction 26/105 in storage location 223.

The use of names has now become considerably more sophisticated, and in fact, a new type of name has been introduced—the label—which is the name of an instruction or a block of instructions. But we are still limited to a small finite set of function names, and although techniques exist to define sub-programs and assign them a label-type name, the ability to create new functions is hedged with restrictions. In particular, the ability to extend the language by naming sub-units of program, and then grouping these into higher level 'concepts' under a new name, and so on, is severely limited.

High-level programming languages attempt to solve some of these difficulties. There are a large number of such languages already, and their number is increasing rapidly. This is in many ways unfortunate, but is necessary at this stage. For even high-level languages do not approach the generality and flexibility of natural languages. So it is necessary to have special purpose languages, such as ALGOL and FORTRAN for scientific work, COBOL for commercial work, and so on. There are even high-level languages, for the sole purpose of writing other high-level languages.

A distinction must now be drawn between a compiled language and an interpreted language. In the former, a machine program, called a compiler, acts as a translator into machine code. When using this type of language system it is necessary to write the complete program first, taking into account all possible contingencies. Once the program is compiled it is too late to change it. For those applications where human intervention is not required during the operation of the program, this type of language is the most efficient, for the translation need be done once only. But it is not possible for the machine to interact with a person in situations which were not envisaged by the programmer.

With a compiled language the program as written undergoes a translation into machine code, in the same sense that a book might be translated into another language, and it is only the resulting machine code that is stored in the machine. A program in an interpreted language, on the other hand, does not undergo this initial translation into machine code, but is stored directly in the machine's store as the string of characters actually written by the programmer. It is thus always accessible, and can be changed at any time. The electronics of the machine requires instructions in the form of machine code, and this conversion is done on the spot, as it were, by a special program called an interpreter.

Just as we can regard the behaviour of a compiler program as analogous to a person translating a book from, say, English to French, so we can regard the interpreter program as analogous to a human simultaneous interpreter translating a conversation between an Englishman and a Frenchman. If we now put the interpreter and the Frenchman into the same box, this box will appear to the Englishman as a box which speaks English, and he need not know that in fact he is speaking to a Frenchman. In the machine case, both interpreter program and machine code electronics are in the same box, and the result is a machine which appears to speak the high-level programming language directly.

Now that we have described an interpreted language, we are within sight of our goal of a machine which uses names in language construction in the same way that we do. For an interpreted language allows us to combine the decision-making abilities of a person with the computing power of the machine. Our interpreted language must, however, handle the symbols we normally use in written natural language and must effect the editing and transformation of texts easily and naturally. Large-scale numerical and commercial calculations can best be left with the compiled languages. We wish to use the machine as a tool—used quickly, changed quickly, without weeks of previous thought. In particular we do not want to know how the machine really works; it must communicate with us in the same language that we communicate with it. And we wish to be able to create names without limit, group these as we wish and rename them, so that we can build up concepts and then use them as a basis for higher-level concepts, without having to worry about the intricate logical problems which such an ability involves. For this purpose we are primarily interested in human efficiency and not machine efficiency.

A number of high-level languages, using the interpretative technique, have been developed for this type of application. As with compiled languages, the particular application intended forces a choice between one or more of these languages. Thus the JOSS system is excellent at arithmetic, the LISP system for the manipulation of lists and tree structure; special languages are also available for simulation studies, and for engineering design.

The language in which I am especially interested is the TRAC (Text Reckoning And Compiling) language designed by Calvin Mooers in 1964. This language is particularly suitable for the processing of strings of characters—the basic symbols of written text, and I shall use it as an example of a 'conversational' mode language. TRAC is a pure interpreted language, based on the concept of a 'character string' —a string of alphabetic or numerical characters typed in on a teletypewriter (a typewriter connected directly to a computer). All input to the machine is in this form, and all output by the machine is in this form. The language is logically very simple, and there are very few exceptions to the basic rules. Notwithstanding this, the language is very powerful, particularly for non-numerical work.

One feature of this language, which some professional programmers find disturbing, is that it is not organized as a sequence of commands. As I have already described, the languages of machine code, assembly language and most (though not all) high-level languages, are based on a series of commands (or instructions) to the machine to do particular operations on particular operands. That is, a program is a set of instructions to perform a given job. In TRAC this mode of operation is no longer the natural one. A TRAC program is the given job, with bits of program stuck in wherever computation needs to be performed. This is possible because the TRAC language works entirely by substitution within the character string which forms the program.

Any sub-set of a character string which is started by the symbol '#(' '(' and terminated by the symbol ')' is treated as a sub-set which requires evaluation. It will then be evaluated and its value substituted for the original sub-set. By character string, I mean here any set of alphabetic, numeric, or punctuation characters which are available on the teletypewriter used, such as the string AXD.! F246. Any program—and any written text such as a book—is such a character string.

Thus, if we typed into the machine the (completely trivial) program:

```
'THE CAT SAT ON THE MAT'
```

The result would be the typing out by the machine of:

```
'THE CAT SAT ON THE MAT'
```

If however we typed in:

```
'THE#(CALL,X) SAT ON THE#(CALL,Y)'
```

and the character string whose name was 'X' was, say, 'DOG', and that whose name was 'Y' was 'CARPET', the machine would type out:

```
'THE DOG SAT ON THE CARPET'
```

The character string '#(CALL,X)' and '#(CALL,Y)' are each started by the symbols '#(' and terminated by ')', and thus require evaluation. 'CALL' is the name of the function 'CALL' and 'X', 'Y' are the names of the strings 'DOG' and 'CARPET'. The function 'CALL' has a substitution value which is the character string corresponding to the given name, in this case, 'X' and 'Y'. The effect of obeying the program is to replace the function '#(CALL, X)' by its value, 'DOG', and similarly for '#(CALL, Y)'. This program is evidently still trivial. This looks rather banal. But watch. With this facility allowed we have opened the door to our computer language. '#(CALL, X)' is no longer a cipher, it is a Gladstone bag for just so much novelty as we are going to want. And this is the principle on which this language works.

The generality of the language arises from the fact that the name 'X' need not necessarily be a simple character string. It might itself be a program. Thus we not only have the ability to give names to objects but also to programs which can manipulate these objects, and to programs which manipulate these programs, and so on. As well as the functions which allow you to give names to character strings (either objects or programs) and to call them forth again, there are a number of further functions allowing various editing, logical and arithmetic operations to be performed.

When reading a TRAC program, it is useful to read the symbols '#(' as 'the result of'. Thus the program given above could be read as: 'THE (the result of calling X) SAT ON THE (the result of calling Y).

The power given in this language by the ability to name pieces of program is increased by the ability to embed functions within other functions. A simple example of this is taken from the field of school arithmetic, and this also shows the contrast between a command language and a substitution language such as TRAC.

Suppose we wanted a program to print the sum of a number given by the human operator with the product of two more numbers given by this operator. In algebraic terms, we want $a + (b \times c)$. In hypothetical command language, we might write this program as follows:

```
let $a$ be the first number typed in,
let $b$ be the second number typed in,
let $c$ be the third number typed in,
let $x$ by the product of $b$ and $c$,
let $x'$ be the sum of $x$ and $a$,
print $x'$.
```

In a substitution language such as TRAC, we might write:

Print the result of adding the first number to the result of multiplying the second number with the third number.

In TRAC itself, we would write:

'#(PRINT STRING, #(ADD, #(READ STRING), #(MULTIPLY, #(READ STRING), #(READ STRING))))' where 'PRINT STRING' is the print function, 'ADD' the addition function, 'MULTIPLY' the multiplication function, and 'READ STRING' the input function which accepts whatever the operator types in. The substitution value of 'READ STRING' is the character string typed in by the operator. The 'PRINT STRING' function causes the machine to type out on the teletypewriter.

Once a program such as this has been written, it can itself be given a name, and then be used as a building block in some larger program. Thus it is no longer essential to write a program from the beginning, with all contingencies planned out in advance. We may write parts of them as the need arises, later combining them into larger and larger units. And where we are unable to decide the course of action to be taken by the machine in some given circumstance, we can cause the machine to ask the person for further instructions, and these can be decided at that time. By building up a program from smaller units, we can also use the basic language to define still higher-level languages for any particular application. In particular, we are no longer restricted to a small, finite set of functions. New functions may be defined and then used freely, not only by themselves but also as new building blocks for still higher-level functions.

We have also lost the restrictions on the use of names for operands. In fact, the type distinction between names referring to operands, names referring to functions, and label names referring to instructions has now disappeared. Names refer to character strings, and this same character string can be used as operand, function, or instruction, as required by the syntactic form in which the name is called. When Shakespeare wrote, 'But me no buts!', his meaning was clear, even though 'but' is defined in our grammar books as a conjunction.

To give an example of the type of man–machine interaction which a multi-access system on a computer with a suitable high-level language makes possible, we have a simplified program to translate English phrases into French. This program is written in the TRAC language. A simplified version of this language was implemented on an ICT 1202 Computer at the Cambridge Language Research Unit, and the example given is the machine output of this translation program.

When using the program, the operator, who does not need to know any French, types in the English phrase, and then calls the program by typing

'#(CALL, TRAN)'

This is a statement in the TRAC language calling for the program called 'TRAN'. The operator then types in 'the phrase form, where XX denotes variable words which will be given later.

```
The operator types in the              THERE IS A FLAW IN THE
phrase to be translated                PROOF

The operator calls the
program called TRAN                    # (CALL, TRAN)
                              START
                              READY
The operator types in the
phrase form                            THERE IS A XX IN THE
                                       XX
                              START
The machine replies by                 DO YOU MEAN
printing a question                    A  CONCRETE OBJECT IN
designed to remove                        ENCLOSURE
ambiguities which must be              B  CONCRETE OBJECT IN
resolved in the French                    LOCATION
language                               C  EVENT IN FUTURE
                                          TIME
                                       D  ERROR IN ARGUMENT
                              READY
The operator answers by
choosing choice D                      D
                              START
                              READY
The operator types in the
value of the first XX                  FLAW
                              START
                              READY
The operator types in the
value of the second XX                 PROOF
                              START
The machine questions the              DO YOU MEAN
word PROOF                             A  DEMONSTRATION
                                       B  TYPOGRAPHIC PROOF
                              READY
The operator answers
with choice A                          A
                              START
The machine prints the                 THERE IS A FLAW IN
English sentence,                      THE PROOF
together with the French               IL SE TROUVE UN/UNE
translation                            ERREUR
                                       DANS CE/CETTE PREUVE
                              END
```

The machine looks this form up in its store, and finds that there is an ambiguity which must be resolved if a French translation is to be achieved. It therefore asks the operator for a decision. The operator makes his decision, and then types in the variable words. If these words are unambiguous then the French translation can be printed out. If there is further ambiguity then the reactive question–answer move is repeated, as is shown with the word PROOF.

The program to do this is a very simple one, and leaves out a great many problems. For example, the machine could easily discover the correct genders of the French nouns, rather than printing UN/UNE. The example does show, however, how a human decision over matters which are not decidable by the machine can allow the combination of man and machine to achieve results which could not have been done otherwise.

In this article I have tried to show how computers can be adapted and developed to allow for their use by a far larger set of people than is usual today. The problems of cost and efficiency are being solved by advances in technology. The remaining problem is to secure that the use of these machines can be mastered without special skills or training. This means that people must have something nearer to natural language in which to work, and to achieve this sets problems that are far from solved. But I believe that 'do-it-yourself' computing is becoming possible, and will prove even more valuable than the present scientific use of these machines.

Computer—servant or master

Donald Michie

'Machine intelligence is not an exercise in philosophy but an engineering project.' (*Michie*)

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It used to be possible to sweep the social challenge of computers under the carpet with the dismissive phrase 'high-speed morons'. Today, however, computers play draughts at a good club standard, solve difficult problems in logic, compose dull but passable music, out-perform librarians in the relevant retrieval of certain classes of document, translate Russian into useful dog-English and perform many other exacting tasks of a non-numerical nature. Clearly if we are to bolster our self-respect as humans in face of the new wave of machine accomplishments we may have to find some other way of doing it than by talking about morons.

Intelligence

My own research as a scientist is concerned with teaching computers not to be morons, and with attempts to find general rules for doing this. I am fairly optimistic, if that is the right word, about the rate of progress in our own and in other similar laboratories elsewhere, in Britain and abroad. I qualify the word 'optimistic' because many people view the objectives of such work with deep unease. If informed that by the late 1970s the first intelligent machines will be in our midst, their dominant feeling would not be one of optimism, but rather of gloom and anxiety. I shall leave to a later stage the discussion of whether there is justification for these fears—dehumanization of life, mass redundancy among brain-workers, suffocation of man by surplus leisure, computer-aided snoopers and 'thought-police'—and consider first in more detail what is meant by the concept of intelligence in a machine.

Turing's test

The problem of testing a machine to see whether it is intelligent was first discussed by the great British logician and computer pioneer, Alan Turing, who died in the early 1950s. It was from my personal association with Turing during the war and the early post-war years that I acquired my interest in the possibilities of using digital computers to simulate some of the higher mental functions that we call 'thinking'. Turing proposed the following test. The machine was to be placed on one side of a screen and a human examiner on the other side. Conversation between man and machine was permitted through the medium of a teleprinter. If after an hour or two's typewritten conversation the machine had managed to fool the examiner into thinking that he had been conversing with a human being, then according to Turing the machine's claim to intelligence should be conceded.

There was undoubtedly an excellent idea here and one which foreshadowed the modern trend towards 'conversational computing'. Unfortunately Turing's test in its original form has been refuted by an ingenious conversational computer program called DOCTOR written by Joe Weizenbaum of Massachusetts Institute of Technology. I reproduce below a fragment of an actual conversation with DOCTOR.

How do you do. I am the DOCTOR. Please sit down at the typewriter and tell me your problem.
I wish I had my baggage.
Can you elaborate on that?
I am not quite clear as to what sort of elaboration is wanted.
Do you believe it normal to be not quite clear as to what sort of elaboration is wanted?
Yes, quite normal.
I understand.
I have lost my baggage.
You say you have lost your baggage.
I feel lost without it.
Do you often feel lost without it?
No, this is the first time.
Why not?
Because I normally do not lose my things.
What other reasons might there be?
My mother trained me not to lose things.
Tell me more about your family.
I have lost my baggage.
Did your parents ever lose you?

At first sight this has an air of (slightly scatty) plausibility. In reality it is a trick—the same trick as most of us employ when keeping a conversation going, perhaps at a cocktail party, while our mind is elsewhere. Instead of attending to the sense of our companion's remarks we merely pick up key words (e.g. 'mother') to which we reply with stock phrases (e.g. 'Tell me more about your family'). If really stuck, we merely play back our companion's last remark with some suitable trimming.

This is essentially how DOCTOR works. Its success as measured by Turing's test is impressive. Patients in Massachusetts General Infirmary were allowed to converse with the program, after being warned that a computer, not a doctor, was at the other end of the line. Sixty per cent of them subsequently rejected this information and insisted that they had been in communication with a flesh-and-blood doctor—'No machine could understand me that well', was a typical reaction.

So Turing's test has to be refined if it is going to be useful in the way intended. Perhaps we should insist that the machine should fool Nobel Prize-winning scientists rather than hospital patients, or alternatively perhaps we should direct attention to whether the examiners feel that they have been having an intelligent conversation. To apply these definitions, they do not need to be philosophically watertight. Machine intelligence is not an exercise in philosophy but an engineering project.

One side of this engineering project is concerned with defining and implementing the separate components of mental aptitude—such capabilities as trial-and-error learning, pattern-recognition, generalization from individual instances, deductive and inductive reasoning, problem-solving and linguistic skill. Somehow these different capabilities, each represented in the computer by a different program, have got to be integrated so that they function as an organized whole. We have some ideas about how this coordination of computer programs might be achieved, but these are still rather primitive and will not be discussed here. What I shall do is to take one of the constituent capabilities as the subject of a brief digression, before considering some of the social and psychological apprehensions which are voiced concerning the development of intelligence in computers.

Learning

The mental capability which I shall single out is trial-and-error learning. This is the simplest and lowest form of learning, in which the learner proceeds entirely *ad hoc*. He says to himself merely 'Have I been in this situation before? If so, what did I do? What were the consequences of my action? If satisfactory, I shall choose the same action. Otherwise I shall try something else.'

Note that no generalization from experience is involved. Situations are separately assessed in the light of past experience without attempting to link them together into meaningful categories according to higher-level considerations. The surprising thing about pure trial-and-error learning is how far a computer system can get using this trick alone, without venturing into the realm of generalization. Samuel's famous computer program for playing draughts (checkers) was able to train itself to a passable amateur level with a system of pure trial-and-error (Samuel called it 'rote-learning') even before its standard of play was further improved by the addition of learning-by-generalization component. The program asked itself 'Have I been in this checker position before? If so, what move did I make? What were the consequences . . .?, etc.' Some years ago I extracted much spare-time amusement from constructing a trial-and-error machine out of matchboxes, whose task was to learn to play noughts and crosses (tic-tac-toe). More recently with the help of my colleague R. A. Chambers I have developed a computer version, and this has been tested on a difficult problem which on the face of it does not look in the least like a game.

Pole and cart

The task is to learn to control an unstable physical system which I shall call the 'Donaldson system', after the Cambridge physiologist who first used it in studies of machine learning. A motor-driven cart is free to run on a straight track of limited length and balanced on it is a pole pivoted at the base which is free to fall down either left or right along the line of the track. The motor is controlled by a single switch which determines at each instant whether the motor's force shall be applied in the left or the right direction. The task is to manipulate the switch so as to keep the cart running backwards and forwards along the track without either running off the end or dropping the pole. This task has obvious similarities to one which most of us attempted, with eventual success, during childhood—namely learning to ride a bicycle. Inevitably the child learns by sheer trial-and-error to begin with.

Our computer program does in fact learn to master the Donaldson system—without utilizing any special knowledge about it or being 'taught' by any human or machine. The program is no more and no less designed to tackle a pole and cart than to learn to guide a car round a closed track or to monitor and control some simple industrial process. In this it illustrates a property which is a 'must' for any component of an intelligent computing system—task-independent capability. The striking feature of the human brain is not so much any outstanding performance at any particular task but rather its ability to make a useful, even if fumbling, attempt at almost any task.

Co-operation

An option in the program allows the human user to intervene and perform the control task himself and a further option permits program and user to work on problems co-operatively, each benefiting from the other's trials and errors. I believe that this type of co-operative interaction between intelligent user and intelligent machine will come more and more to the forefront, and indeed will set the pattern in the future.

When thinking recently about the subject of particular mental capabilities, of which trial-and-error learning is just one example, I amused myself by copying out the late Ludwig Wittgenstein's list of what he called 'language games' and measuring each item against the present state of the art in machine intelligence. I reproduce his list below:

Giving orders and obeying them
Describing the appearance of an object, or giving its measurements
Constructing an object from a description (a drawing)
Reporting an event
Speculating about an event
Forming and testing a hypothesis
Presenting the results of an experiment in tables and diagrams
Making up a story and reading it
Play-acting
Singing catches
Guessing riddles
Making a joke and telling it
Solving a problem in practical arithmetic
Translating from one language into another
Asking, thanking, cursing, greeting, praying

Now let us run through the list again. 'Giving orders and obeying them' has been a routine function of computing systems for many years. 'Describing the appearance of an object, or giving its measurements' is a difficult task facing those engaged on 'hand-eye' computer projects. For a machine to inspect an object with a mechanical 'eye' and then manipulate it with a mechanical 'hand' the first step must be to form a description from the visual image. 'Constructing an object from a description' (e.g. building a tower from a photograph of a tower) is among the most difficult long-term goals of hand-eye projects—such as Marvin Minsky's at Massachusetts Institute of Technology and John McCarthy's at Standford, USA. 'Reporting an event' is beyond present technique. Again synthesis of a description from primary sense-data is the first step. The second is use of the synthesized description to generate appropriate language text. 'Speculating about an event' is even further beyond present technique. 'Forming and testing a hypothesis' is a process under active current study. 'Presenting the results of an experiment in tables and diagrams' is a routine operation of contemporary computer programs for survey analysis. 'Making up a story' is beyond present technique, although 'reading it' from printed text is now marginally feasible. 'Play-acting' would require a great extension to the arts of robotics; as for 'singing catches', humming the tune is easy to program, but singing intelligibly is not. 'Guessing riddles' is under active current study, but 'making a joke' is very far beyond present technique. 'Solving a problem in practical arithmetic' presents no difficulty even to primitive computer systems. 'Translating from one language into another' is just attaining marginal feasibility by commercial criteria. 'Asking, thanking, cursing, greeting, praying' are activities which express emotions, attitudes, desires, sympathies. It is meaningless to talk of them except on the basis of consciousness and self-consciousness in the intelligent system concerned. Many workers in the field of computers believe that success on a really significant scale will hinge on the degree to which machine-representations of these phenomena can be devised—at least to the degree of permitting the machine to form some sort of internal logical model not only of the external world but also of itself in relation to that world. I share this view.

'Who is to be master?' I am inclined to regard the dilemma, 'Computer: servant or master', as a false one. To clear the ground for what I have to say under this heading, let me first sketch a division of tasks into three categories.

1 Tasks suitable for humans alone. This category is concerned with value, i.e. what sort of result do we want to see? For example, what weather do we want, irrespective of problems of prediction. Or what rate of road deaths relative to motorists' convenience are we prepared to tolerate?

2 Tasks suitable for computers alone. These tasks are those of complicated detail and 'tactical' decisions: for example prediction of weather, or control of a city's traffic light system. The case of traffic lights has a special point of interest in the present context: the citizen seems prepared quite happily to accept this form of computer interference in his life, even though he may express great alarm over other forms. The implication is, I think, that the emotions of doubt and opposition to the computer revolution do not in reality hinge on a matter of principle—that control by machine is a bad thing. On the contrary it seems to be a matter of the appropriateness or otherwise of computer control in the given case. As applied to traffic lights, the sheer inhuman equitableness of computer control has a positive appeal. I believe that something similar is involved in the popularity among schoolchildren of computer programming as opposed to Latin. With programming there is no conceivable vulnerability to possible biases or prejudices of the teacher. The entire proof of the success or failure is in the running of it on the machine.

3 Tasks suitable for co-operation. These are tasks which are too difficult at present for either partner to do alone or are in some way intrinsically suitable for conversational computing. In the second category I would place the use of a console connected to a conversational computing system as a 'home tutor' whereby the user can be steered through courses and subjects of study of his own choosing. It is not always easy, once one has taken the plunge into conversational computing, to distinguish a program to help you do something and one to teach you to do it.

In this category of intrinsically conversational uses is the 'question-answering' facility which will one day become available as a service. Not only schools, hospitals and commercial firms but also the ordinary householder will be able to tap information and problem-solving power from a national computing grid with the same ease and immediacy as that with which he now draws on central supplies of gas, water and electricity. Along with question-answering services, which will allow us to inquire about restaurants in our locality or politics in Paraguay, will come the games opponent, the puzzle-setter and the quiz-master. An increasing demand upon computer systems will be for aid in coping in a stimulating way with the growing burden of leisure.

Helpers and hobbies

For many years only the rich will be able to install terminals in their private homes, but I have no doubt that the coming decade will see public telephone boxes up-graded to include a keyboard terminal connected to the computing grid, and it is well within the reach of foreseeable software technology to offer services which will tempt ordinary people to place their largest coins in the slot.

Will computers 'take over'? In the world of information-handling of course the computer will take over. The question is will it take over as servant or master? To this one must reply: not as servant nor as master, but as tutor, as secretary, as play-mate, as research assistant. None of these in their human embodiments is a servant or a master; each is better described as a helper. The lessons of experience with computers do not support the idea that brain workers will be thrown out of employment by the machine. The indications are that as soon as brain workers learn to use the new facilities their work will be enlarged and enriched by the new possibilities which become available to them. The working week will, of course, continue to shorten in advanced countries as productivity rises, but this is a question of technological progress in general, and not specifically a consequence of computers. Whether the increase of leisure time is felt as a burden or a joy will depend on the means available for developing spare-time activities which can exercise and challenge man's varied capabilities.

It is my confident prediction that computer-aided self-instruction in science, history and the arts will have become a consuming hobby of large sectors of the population by the turn of this century. As for fears sometimes expressed that by then Big Brother will be able to watch us over the computational grid, or that our superiors or our neighbours may be able secretly to tap our dossiers kept on the universal electronic file, these fears can be dismissed. It is easier to devise 'unpickable locks' in a computing system than in the world of bank vaults and safes.

The conversational terminal

The present fears of computers represent nothing new. When the first passenger-carrying railway services were opened, eminent medical men warned that if the human frame were transported at these speeds, fatal haemorrhage and seizures would be caused. There is a good parallel here. Imagine framing the question 'Railway train: horse or rider'. The answer, of course, is 'Neither horse nor rider but travel assistant'. As soon as people discovered this, their fears of rail travel disappeared. When computer terminals can offer a useful coin-in-the-slot service, the citizen will, I believe, cease to regard the computer as an alien monster or a ruthless competitor. Instead, the conversational terminal of the future will be welcomed for what it will do to enlarge daily life—as planning assistant, as budgeting assistant, as researcher and above all as a novel and challenging type of conversational companion.

Biographies

Biographies

Jonathan Swift

Jonathan Swift was born in Dublin in 1667 and died there in 1745. He studied at Trinity College, Dublin, and later became Secretary to Sir William Temple at Moor Park. On his return to Ireland in 1694 he took orders but went back to Moor Park in 1698 for a year, returning once more to Ireland to become Chaplain to the Lord Deputy. His two satires—*Tale of a Tub* and *The Battle of the Books*—were published in 1704. He made frequent visits to London and became friendly with Addison, Steele, Congreve and other Whig writers. In 1710, disgusted by the Whigs' neglect both of himself and the claims of his Church, he abandoned them and attached himself to Harley and Bolingbroke. His celebrated pamphlets attacking the Whigs were published soon afterwards—*The Conduct of the Allies* (1712), *The Barrier Treaty* (1714) and *The Public Spirit of the Whigs* (1715). Meanwhile, Swift was made Dean of St Patrick's, Dublin, but the hostility of Queen Anne had proved an insurmountable obstacle to his further advancement. His hopes destroyed, he returned to Ireland, where he remained for the rest of his life a thoroughly embittered man. With Pope and Arbuthnot, he published *Miscellanies* in 1727 and in the same year *Gulliver's Travels*. By some curious irony, in its expurgated form, this bitter and misanthropic satire has become a children's classic.

After the death of his beloved Stella, also in 1727, Swift became increasingly morose, and although he improved for a time—during which he produced some of his most brilliant work (*Rhapsody on Poetry, Verses on the Death of Dr Swift* and *The Modest Proposal*)—he gradually sank into almost total loss of his faculties. He was buried in St Patrick's Cathedral.

Jasia Reichardt

Jasia Reichardt was born in Warsaw and has lived in England since 1946. She has been writing about art since 1958 and since 1963 has been Assistant Director of the Institute of Contemporary Arts, London. She has lectured at various art colleges and taught at Bath Academy of Art. She has edited a series of monographs on living artists, *Art in Progress*, and has written monographs on Pasmore, Schwitters and Agam. At one time or another she has written for most international art journals; she had a regular column for four years on *Studio International*; and contributes regularly to *Architectural Design*.

She organized the first show of British Pop Art in London, 'Image in Progress', at the Grabowski Gallery 1962. Her other exhibitions include: 'Art in Britain 1930–40' at the two Marlborough Galleries 1965; 'Between Poetry and Painting' (concrete poetry), ICA 1965; 'Cybernetic Serendipity' (the computer and the arts), ICA 1968; 'Fluorescent Chrysanthemum' (contemporary Japanese art), ICA 1968/9; and 'Play Orbit', ICA 1969/70. She has participated on several international juries and has organized a number of exhibitions of British art abroad.

Jasia Reichardt is primarily concerned with the periphery of the visual arts and those areas where painting and sculpture relate to science, technology, literature and other fields of human endeavour. Her most recent publication is *The Computer in Art*, Studio Vista, 1971.

Dennis Gabor

Dennis Gabor, CBE, FRS, born in Hungary in 1900, had a career as electrical engineer, physicist and inventor. He is best known for his invention of holography—the new method of photography with coherent (laser) light—which has found innumerable practical and scientific applications. He invented holography in 1948 when he was research engineer in the British Thomson-Houston Company, Rugby. In 1949 he took up an academic career at Imperial College, London, where he became Professor of Applied Electron Physics in 1958. His paper 'Technological civilization and man's future' formed part of his Inaugural Address; it marks a turning point in his life because it was the first time that he spoke up in public on social problems. Since then he has devoted almost all his spare time to the exciting problems of the future. His book *Inventing the Future* appeared in 1963 and has been translated into seven languages. His book on *Innovations* appeared in the autumn of 1970.

Dennis Gabor is convinced that unless the best minds turn their attention from technology and science to psychosocial problems, our civilization will approach a crisis, even before the end of this century.

He has received so many honours that it seems unnecessary to mention any of them.

John Cohen

John Cohen was born in Tredegar, Monmouthshire, in 1911. He studied under Sir Cyril Burt at University College, London; served in the Royal Armoured Corps and at the Office of the War Cabinet. He has held appointments at the Universities of Leeds and London. A former member of various government bodies, he has also served as consultant to UNESCO on many occasions and has acted as guest lecturer in most European countries. He is a Fellow of the World Academy of Art and Science, and of the British Psychological Society; and a Foreign Member of the Centre de Recherches de Psychologie Comparative (Paris). He is the British Editor of *Acta Psychologica* and on the editorial boards of *Journal de Psychologie, Ikon: revue internationale de filmologie* and of *Journal of Peace Research.*

He has had some 200 articles published in scientific, medical and other learned journals. His published books include: *Human Nature, War and Society*; *Chance, Skill and Luck*; *Humanistic Psychology*; *Behaviour in Uncertainty*; *Information and Choice*; *Psychological Time in Health and Disease*; *A New Introduction to Psychology*; *Human Robots in Myth and Science*; *Elements of Child Psychology*; *Causes and Prevention of Road Accidents.* Many of his publications have been translated into German, Spanish, Danish, Italian, French, Dutch and Japanese.

Professor Cohen's first researches were occupied with the factoral analysis of 'higher mental processes', and then with the statistical study of physique in relation to temperament. His main recent work has been on the subject of 'uncertainty and time', including studies of the nature of risk, choice, information and decision, and attempts to extend methods of measurement to subjective aspects of time.

Stefan Themerson

Stefan Themerson was born in Poland in 1910. After studying for a few years in Warsaw, first physics and then architecture, he deserted both to make avant-garde films which he combined with writing. In 1938 he moved to Paris and on the outbreak of the second world war volunteered for service in the Polish army in France. After the French débâcle, he escaped in 1942 to England, where he rejoined his wife (and the Polish army).

Since the war he has written exclusively in English (being first published in *Polemic* in 1946). His first books in English include: *The Lay Scripture, or a draft for a preface to a textbook of physics*, (published in 1947 by Anthony Froshaug), *Bayamus, a semantic novel* (1949) and *The Adventures of Peddy Bottom* (both published by Tambimuttu in Editions Poetry-London). At that time his books were refused by some fifty publishers and his application for membership rejected by the Society of Authors. Subsequently he has published *Professor Mmaa's Lecture* (which is not a lecture but a novel about a six-legged lecturer, with a preface by Bertrand Russell), *factor T* (two philosophical essays—on non-philosophical ethics and on beliefs), *Cardinal Pölätüo* (a novel), *Tom Harris* (a novel), *Wooff Wooff, or Who Killed Richard Wagner?*, *Semantic Divertissements*, *Kurt Schwitters in England*, *Apollinaire's Lyrical Ideograms*. Most of his English writings have been translated into many European languages.

John R. Pierce

John R. Pierce was born in Des Moines, Iowa, in 1910. He joined the Bell Telephone Laboratories in 1936 after receiving a PhD from California Institute of Technology and is now Executive Director, Research-Communications Sciences Division, with responsibilities in such fields of research as radio, electronics, acoustics and vision, mathematics, economic analysis and psychology.

Dr Pierce has published twelve technical books, hundreds of papers and articles, a number of science-fiction stories, some published under the name of J. J. Coupling, and a few poems. Some of his computer music appears on a Decca record, *Music from Mathematics*. He has received the following awards: Eta Kappa Nu, 1942; Morris Liebmann Memorial Prize, 1947; Stuart Ballantine Medal, 1968; Air Force Association HH Arnold Trophy, 1962; the Arnold Air Society General Hoyt S. Vandenberg Trophy, 1962 and 1963; the Edison Medal, 1963; the Valdemar Poulsen Medal, 1963; the National Medal of Science, 1963; the H. T. Cadergren Medal, 1964; Caltech Alumni Distinguished Service Award, 1966. He has been awarded six honorary degrees: DEng from Newark College of Engineering, 1961; DSc from Northwestern University, 1961; DSc from Yale University, 1963; DSc from Polytechnic Institute of Brooklyn, 1963; DEng from Carnegie Institute of Technology, 1964; DSc from Columbia University, 1965.

Dr Pierce is a member of the National Academy of Sciences, the National Academy of Engineering, and the Air Force Association; he is a Fellow of the American Academy of Arts and Sciences, the Institute of Electrical and Electronics Engineers, the American Physical Society and the Acoustical Society of America. He is a Kentucky Colonel.

Max Bense

Max Bense was born in Strasbourg in 1910. He moved to Cologne in 1921. He studied mathematics, physics, geology and philosophy at the Universities of Bonn and Goettingen. In 1938 he received his doctorate in Natural Sciences and his thesis 'Quantenmechanik und Deseinsrelativität' was published the same year. He then worked as a physicist in industry. In 1945 he became Professor and Curator of the Jena University. In 1948 he fled to West Germany. Since 1949 he has been Professor of Philosophy and Theory of Science at the University (previously a technical college) in Stuttgart. His many fields of activity include aesthetics, theory of science and semiotics. He has published works in the fields of philosophy, mathematics, physics, aesthetics and literature. His chief publications include: *Konturen einer Geistesgeschichte der Mathematik 1/11*, 1946/49; *Technische Existenz*, 1949; *Die Philosophie (zwischen den Kriegen)*, 1951; *Der Begriff der Naturphilosophie*, 1963; *Aesthetica, I, II, III, IV*, 1954, 1956, 1958, 1960; *Aesthetica, Einführung in die neue Aesthetik*, 1965; *Theorie der Texte*, 1962; *Semiotik*, 1967.

Abraham A. Moles

Abraham A. Moles, Doctor of Science and Philosophy, is Professor of Socio-aesthetics at the University of Strasbourg, where he directs the Institute of Socio-psychology. He also teaches at the Hochschule für Gestaltung in Ulm, a school of art and design which fulfils the same role today as did the Bauhaus in the 1920s in its attitude of functionalism.

He is well known in France for his books dealing with the application of the 'information theory' to the perception and understanding of art and music, and for his works on methodology. His most recent books are: *Sociodynamics of Culture*; *Posters in Urban Society*; *Psychology of Kitsch*; and *Art and Computer*. His writings have been translated into many languages.

Professor Moles is now concerned with the problems of the role of objects in the affluent society and of the psychological influence of the environment.

Ali Irtem

Ali Irtem was born in Salonica, Greece, in 1909. He studied technical physics in Berlin. Today he is thought of as the 'father of the Turkish cyberneticians'.

He belongs to the following societies: Association Internationale de Cybernetique, Belgium; Sociëté Internationale de Biologie Mathëmatique, France; Artificial Organism, England.

His papers include: 'What is Life?' 1962; 'Democracy evaluated cybernetically' 1963; 'Education of the machine' 1963; 'Self-organizing machines and money-making instrumentations' 1964; 'Cybernetics and *n*-dimensional lines' 1964; 'Some applications of Boolean algebra' 1965; 'How to change the laws of nature cybernetically or programming miracles' 1967; 'How to solve the social and economic problems of Turkey, cybernetically' 1968; 'Manufacturing of a computer-statesman' 1969, and 'How to forecast revolutions in the underdeveloped countries' 1970.

Ali Irtem works in Istanbul as Management Consultant.

Gordon Pask

Gordon Pask was born in Derby, England, in 1928. He was educated at Liverpool Technical College, the University of Cambridge and London Universities, where he studied chemistry, natural sciences and psychology. In the mid-fifties he invented adaptive teaching systems and a number of other devices for co-operative interaction with human beings, subsequently pioneering their exploration. His research has included self-organizing systems, small group behaviour and individual learning, teaching and cognition. His interests include architecture, social systems, the theatre and ethology. He is the author of two books, *An Approach to Cybernetics* (1961) and *Behavioural Cybernetics* (1971), and of about eighty papers. Occasionally he paints pictures and makes pieces of cybernetic artwork.

Dr Pask is Director of Research, System Research Limited, and Professor in the Institute of Cybernetics, Brunel University. He has served as Visiting Professor at the Universities of Illinois, Oregon, Mexico (UNAM) and Georgia Institute of Technology. He lives with his wife and daughters in Richmond, Surrey.

Irving John Good

Irving John Good was born in London in 1916. He received his PhD in mathematics from Cambridge in 1941 and two post-doctoral degrees—ScD Cambridge and DSc Oxford—in 1963 and 1964. He was made Senior Research Fellow, Trinity College, Oxford, and Atlas Computer Laboratory, in 1964.

His teaching appointments include: Lecturer in Mathematics and Electronic Computing, Manchester University, 1945; Visiting Research Associate Professor, Princeton, 1955; Visiting Professor at the Summer Research Institute, Manchester, Melbourne, 1966; Research Professor of Statistics, at Virginia Polytechnic Institute, Blacksburg, 1967.

In the course of his work for the Foreign Office in 1941, Irving John Good was one of four people who helped design the first large-scale electronic digital computer. He has acted as consultant to a number of scientific organizations and government departments, including: Department of Machine Intelligence at Edinburgh, Ministry of Supply, Government Communications Headquarters, Institute for Defense Analyses, Admiralty Research Laboratory, Scientific Advisory Council, Electronics Research Council.

The Author of *Probability and the weighing of Evidence* 1950, and *The Estimation of Probabilities* and the general editor of *The Scientist Speculates*, Good's published writings run to over a million words and he has noted over 700 published references to them (not including reviews, abstracts and index entries).

His current main scientific interests include statistical and scientific inference with medical applications, and machine intelligence.

Iannis Xenakis

Iannis Xenakis was born in 1922 of Greek parents, in Braila, Rumania. His early musical studies were with Aristotle Kundurov in Athens. At that time he was particularly interested in Greek traditional music of the Byzantine Church and folk music, which inspired a number of choral and instrumental works. He fought in the Resistance Movement against the Nazis and in 1947 graduated from the Polytechnic School in Athens with an engineering degree. The same year he went to Paris to continue his musical studies under Arthur Honnegger, Dariusm Milhaud and to attend Olivier Messiaen's courses in Analysis and Musical Aesthetics at the Paris Conservatoire. He was also invited by Le Corbusier to work with him on a number of town-planning and building projects. This association lasted for twelve years during which Xenakis designed the Phillips Pavilion at the Brussels Expo in 1958.

From 1953 onwards he introduced the concept of 'clouds' and 'galaxies' of sound events into music. He made use of calculus and the theory of probability in the construction of 'a stochastic music'. Later he made use of the theory of games in compositions to which he refers as 'strategic music', as well as set theory and mathematical logic in his 'symbolic music'.

Xenakis has written both for conventional instruments of the orchestra and for electronic or concrete sounds. He is the founder of L'Equipe de Mathèmatique et Automatique Musicales, known as EMAMu, in the faculty of the Ecole Pratique des Hautes Etudes at the University of Paris and the Collège de France.

He is Associate Professor and Director of the Center for Mathematical and Automated Music (CMA), at the University of Indiana, USA.

A. Michael Noll

A. Michael Noll was born in Newark, New Jersey, in 1939. In 1961 he received the BSEE degree from Newark College of Engineering, and in 1963 the MEE degree from New York University. He is now working on his thesis for a PhD degree at the Polytechnic Institute of Brooklyn.

Noll joined the Bell Telephone Laboratories in 1961. Initially concerned with the assessment of telephone quality, he was transferred in 1965 to the Acoustics Research Department where he worked on computer simulations and investigations of short-time spectrum analysis and the spectrum method for vocal pitch determination. He is currently in the Speech and Communication Research Department. His interests have included computer-generated three-dimensional displays of data, the application of computer technology to the visual arts, and psychological investigations of human reactions to pseudorandom patterns. He is now exploring more effective forms of man–machine communication including real-time three-dimensional computer graphics and tactile communication. He has been extremely active in the area of computer art since 1962, participating in a two-man show of computer-generated pictures at the Howard Wise Gallery, New York, in 1965 (the first exhibition of computer art). Since then his computer art, choreography and movies have been widely exhibited throughout the world. He has presented a number of technical papers and has published in many journals.

He is a member of Tau Beta Pi, Eta Kappa Nu, the Acoustical Society of America, the American Society for Aesthetics, the Association for Computing Machinery, the Audio Engineering Society, and the Institute of Electrical and Electronics Engineers. He is a licensed professional engineer in the State of New Jersey.

Leslie Mezei

Leslie Mezei was born in 1931 in Budapest. He was educated in Montreal at Strathcona Academy and McGill University, and at the University of Toronto from which he graduated with an MA in Physics in 1954. From 1953–4 he worked as Meteorologist at Malton Airport; 1955–8 as Data Processing Systems Analyst for Ontario Hydro Electric Power Commission in Toronto; 1958–65 as Assistant Actuary and Manager of Systems Programming Department at Confederation Life Association in Toronto; 1964–5 as Lecturer on High Speed Data Processing at the University of Toronto; 1965–6 as Director of Computer Science Programmes; and since 1966 as Associate Professor of Computer Science at the University of Toronto.

He writes a regular column on art and science for *Arts/Canada*, is contributing editor for *Computers and Automation*, and is on the editorial boards of *Computer Studies in the Humanities and Verbal Behaviour* and *Computers and the Humanities*. He has contributed papers to numerous conferences, and since 1962 has written widely on computer art. He has also produced a bibliography on computer art for *Computer Studies in the Humanities and Verbal Behaviour* (vol. 1, no 1, January 1968, pp 48–50).

Professor Mezei is a Fellow of the Canadian Institute of Actuaries, holds offices in the following: Computer Systems Research Group, Computer Society of Canada, Canadian Hearing Society, Alexander Graham Bell Association for the Deaf, Experiments in Art and Technology (Ontario branch); and is a member of the Association for Computing Machinery, the Pattern Recognition Society, the Society for Actuaries, the International Association for Empirical Aesthetics, the Design Research Society and the American Cybernetic Society.

Married, with two children, he lives in Don Mills, Ontario.

Margaret Masterman

Margaret Masterman was born in London. She was educated at Hamilton House, Tunbridge Wells; the University of Paris (Certificate d'Etude Françaises, mention très honorable); and Cambridge University (Major entrance scholarship in Modern Languages, Modern Language Tripos, Part I (French and Latin): Moral Sciences Tripos, Part II (Metaphysics and Ethics). She was the first woman holder of the Burney Studentship in Philosophy of Religion.

From 1948 to 1964 she lectured in Cambridge on philosophy, language and languages. She was Director of Studies in Moral Science at St Catherine's College, and sometime of Pembroke College, and of Fitzwilliam House. Since 1960 she has been Director of Research at Cambridge Language Research Unit; since 1962 Vice President of Lucy Cavendish College—a new collegiate graduate society. Margaret Masterman has published three novels, and has publications on language, information-processing, philosophy of science and philosophy of religion.

She is married to Professor R. B. Braithwaite, has one son and one daughter, and lives in Cambridge.

Robin McKinnon Wood

Robin McKinnon Wood was born in Geneva, Switzerland, in 1931, and educated in the USA and England. He read Mathematics and Physics at Trinity College, Cambridge. After receiving his BA in 1952, he worked for a year as Research Assistant with the Department of Meteorology in Cambridge maintaining radar sets used for cloud research, and gained some knowledge of electronics. At the end of this period, he and Gordon Pask formed System Research Limited to do research in the field of adaptive systems. Its first application was in the theatre, where a system for modulating lights by music was introduced, but the main application was to the study of human learning and the development of adaptive teaching machines.

In 1958 he became a consultant to the Cambridge Language Research Unit, and worked in the field of machine translation by computer. This led to an increasing interest in the problems of computer programming, and of the possibilities of computer languages which could increase the use of computers in those fields where the interaction of man and machine are most needed.

He is married, with three children, and lives in a windmill near Cambridge.

Donald Michie

Donald Michie, born 1923, was educated at Rugby School and Balliol College Oxford where he won an Open Major Scholarship in Classics. He worked with Newman, Good, Whitehead and Turing on early electronic computing equipment during the war, after which he embarked on a biological career at Oxford, graduating with an MA in 1949 in human anatomy and physiology, and DPhil in 1952 in mammalian genetics. From 1952–1958 he did research at the University of London into problems of genetics and reproduction. In 1953 he was made Scientific Fellow of the Zoological Society of London; in 1958 Senior Lecturer in Surgical Science at Edinburgh, and in collaboration with J. G. Howard demonstrated immunological reactivity in the newborn. He was appointed Reader at Edinburgh and Visiting Associate Professor of Electrical Engineering at Stanford, California in 1962, where he started investigating the application of trial-and-error learning concepts to problems in automatic control. In 1963 he was invited by DSIR to survey the state of computer science research in British Universities. As Royal Society Visiting Lecturer, he visited cybernetics research centres in Russia in 1964. In 1965 Professor Michie founded the Experimental Programming Unit at Edinburgh, and the following year was involved in the setting up of the Department of Machine Intelligence and Perception. He was elected a Fellow of the Royal Society of Edinburgh in 1969.