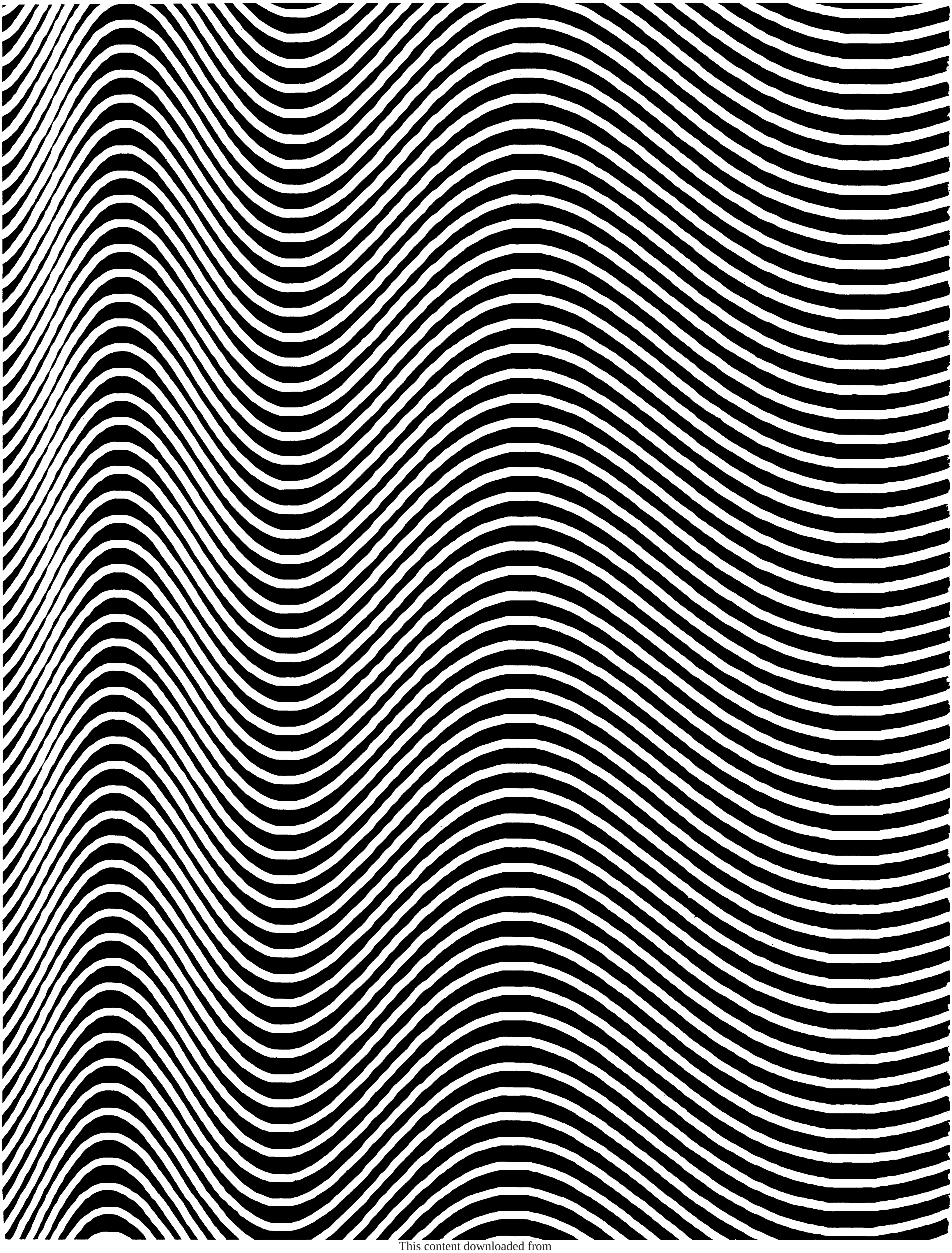


A. Michael Noll is on the research staff of the Bell Telephone Laboratories in Murray Hill, New Jersey. He has worked in the field of two- and three-dimensional films and moving pictures generated by computer to display scientific information, and is interested in the computer as a creative medium in the arts. His computer-generated pictures have been exhibited at the Howard Wise Gallery, New York. As a logical extension of Mr. Noll's computer technique for generating two-dimensional pictures, it became possible to use computer-generated stereoscopic drawings to achieve a three-dimensional effect if viewed with polaroid glasses. From the three-dimensional still picture, the next logical step was to animate the picture and then to produce moving, three-dimensional objects or kinetic sculptures.

The use of computers in communication research has uncovered techniques which can be applied to other areas of the visual and performing arts. For example, the same technique may be used to simulate or record choreography for dance. New computer languages are being developed which will make it very easy for the artist to communicate instructions to the machine. Computers with display equipment will also become more readily accessible with the net result that many more artists and designers will become computer oriented.

COMPUTERS AND THE VISUAL ARTS

by A. Michael Noll

The techniques and concepts which have been developed during the past few years for using computers to generate visual displays of scientific data can be applied with very little effort to the production of artistic visual displays. Previous experience has indicated that emotional feelings and prejudices often against the concept of computer art exist on the part of both artists and scientists. Actually, what artists may learn in using these new computer techniques could be valuable to scientists and engineers. Conversely, artists may discover that computers are very advantageous in many artistic endeavors. Thus, computers may play an important role in linking art and science, with the artist and scientist mutually assisting each other. But before all this can happen, the artist and scientist must become familiar enough with the other's field so that each can recognize the advantages of mutual cooperation.

Art has always depended upon science and technology to supply both the medium in which the work is done and the tools for doing it. The techniques are common whether the computer is used to generate visual displays of scientific data (e.g., shapes and motions of mechanical systems, mathematical rotations of n-dimensional objects, motions of atoms in a fluid) or shapes and motions which may be important in design or as an artistic medium.

COMPUTERS AND PICTURES

All digital computers are similar in that they manipulate binary numbers under the control of a stored set of instructions called a program. The actual manipulation is performed by electronic circuits and devices. 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.

As an example, the stored program might first instruct the machine to read the numbers punched on a card into a portion of the memory allocated for data storage. The arithmetic processor might then fetch these numbers from the memory and add them all together. The final sum might be returned to memory and from there printed out by a typewriter. Each operation is controlled in sequence by the stored program.

Computers are only capable of performing operations for which they have been programmed and instructed to perform. However, these machines are incomprehensibly fast in doing their tasks and are also capable of analyzing many factors to make different decisions. This extreme speed coupled with the inherent accuracy of digital calculation explains the desirability of computers.

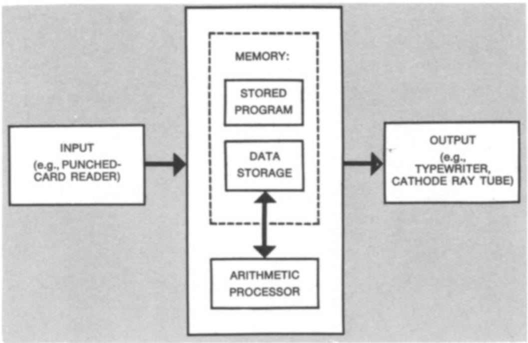
Recently, progress has been made in obtaining new output devices which allow the computer to produce visual output. One such device is the microfilm plotter.

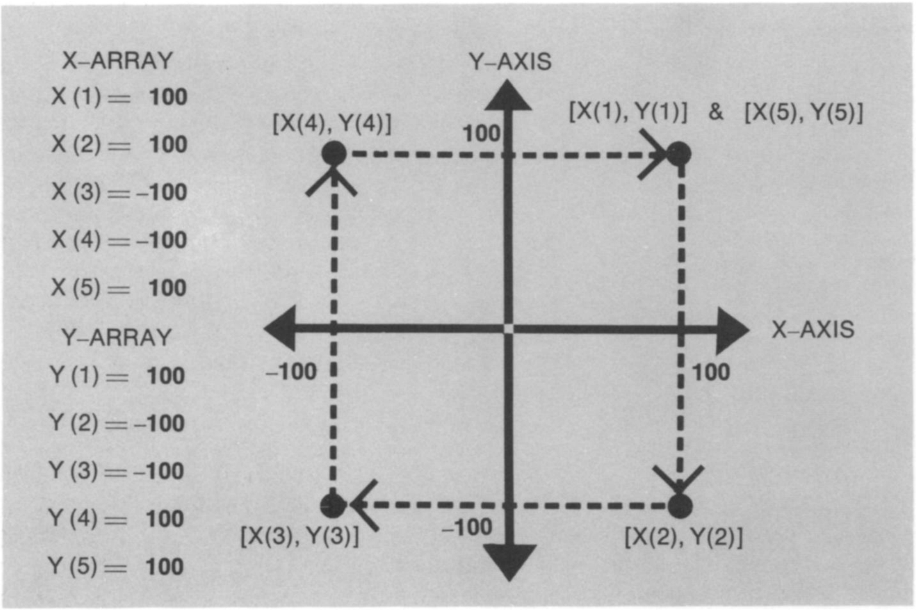
The microfilm plotter consists of an interconnected cathode ray tube (conceptually similar to the picture tube in a television set), a camera, and some electronic control equipment. The cathode ray tube produces pictures on a phosphorescent screen with an electron beam which is electrically deflected 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. In this way, pictures are generated on the microfilm plotter by instructions comprising a part of a program in the main computer.

As an example, suppose a square is to be generated on the microfilm plotter. The required program would first make two arrays of numbers whose elements are the X and Y coordinates of the corners of a square; i.e., $X(1) = 100$, $Y(1) = 100$, $X(2) = 100$, $Y(2) = -100$, $X(3) = -100$, $Y(3) = -100$, $X(4) = -100$, $Y(4) = 100$, $X(5) = 100$, $Y(5) = 100$. (The fifth point is required to close the square.) The program would, secondly, contain an instruction to advance the film to an un-

Opposite page: Enlarged segment of computer-produced picture.

Diagram showing the basic concept for using the computer to produce typewritten or visual output.





Example of drawing a square with the microfilm plotter: Four points are located, each with a value of 100, in a quadrant of the X-Y coordinate system. An instruction to the microfilm plotter to connect these points would thus produce a square.

exposed frame. The next instruction would tell the microfilm plotter to draw a line between the five points whose coordinates 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. The last instruction would once again advance the film.

The arrays are blocks of sequential locations in the computer's memory that have been specified by the programmer as being associated with some name. For instance, in the above case the X and Y arrays each contain five storage locations where X(1) refers to the first location which contains the number 100.

In the preceding example of a square, the coordinates are all known and are therefore put into the X and Y arrays as constants. For more complicated pictures, the program might include instructions for mathematically calculating these coordinates. The essence of all this is that a picture can be specified numerically as a set of points which can be obtained as results of numeric calculations in a computer program. For complicated pictures, the only additional requirements would be more points and smaller line segments.

RANDOMNESS

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 coordinates of points in a computer-generated picture. However, a practical picture cannot be infinite in size, and therefore some limit or range must be placed upon the set of permissible random numbers. For example, only random numbers between −67 and +240 might be allowed. Within a permissible set, certain numbers might occur more often than others, or alternatively the occurrence of all the numbers might be equally probable.

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.

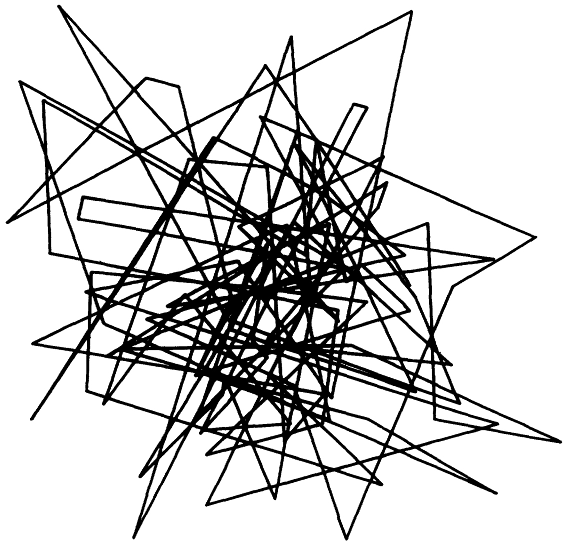
Aside from the uniform probability density there is another density of considerable importance. It is called the normal or Gaussian density (after the mathematician Gauss who first formulated it mathematically). For a Gaussian sequence of random numbers, the numbers tend to cluster about an average. 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 percent of the numbers fall within plus or minus one standard deviation of the average, 95.5 percent within two standard deviations, and 99.7 percent within three standard deviations.

Numerical techniques developed for scientific and engineering use are available for generating a sequence of random numbers with either a uniform or Gaussian density. These techniques have been incorporated into special computer programs called subroutines which calculate the specified random sequence.

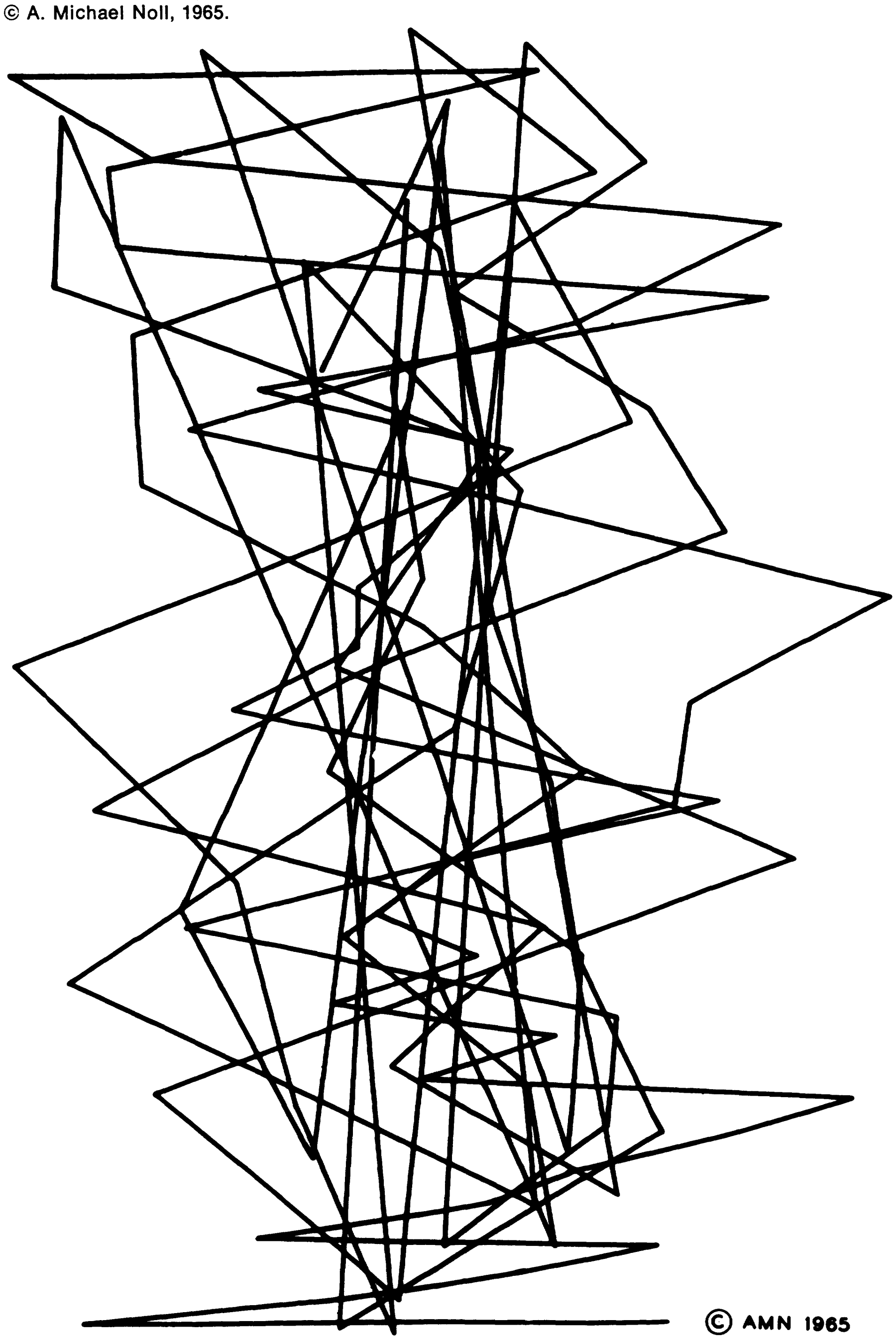
TWO-DIMENSIONAL PICTURES

A computer program can be written instructing the machine to compute coordinates of points which, when connected together with straight lines, produce a picture.

Some interesting pictures can be generated with the computer by programming different random elements into the picture. In the first attempts along these lines, the random number subroutines for uniform and Gaussian densities



Picture with points determined by a random process and then connected by the microfilm plotter.



"Gaussian-Quadratic," © A. Michael Noll, 1965.

were used to generate arrays of numbers which became the coordinates of points. These points were then sequentially connected together with straight lines. The lines in the Gaussian picture cluster about the center since the average of the random coordinates was chosen to be the center of the picture. If desired, the computer could generate series of pictures in which the number of lines or the standard deviation was varied. The best picture could then be chosen from the series.

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 coordinates but introduced a specified and non-random mathematical function for generating the Y-axis coordinates. A particularly good example of this mixing approach is shown in the picture, "Gaussian Quadratic". 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 $1^2 + 5x1$, the second point $2^2 + 5x2$, the third point $3^2 + 5x3$, 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 ($30^2 + 5x30 = 1050$). 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.

The exact proportions of "Gaussian Quadratic" were arrived at in a process of trial and error. The computer very rapidly produced series of pictures in which the different factors were uniformly changed. In this manner it became possible to bring an intuitive feeling for the pictorial effects of these factors into play.

"Vertical-Horizontal" pictures were generated by a scheme in which only one of the two coordinates was changed (alternatingly) from one point to the next. The coordinates were otherwise random with a uniform probability density. "Vertical-Horizontal No. 1" consists of 50 lines with equal ranges in both directions; the number of lines in "Vertical-Horizontal No. 2" was increased to 300. "Vertical-Horizontal No. 3" 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.

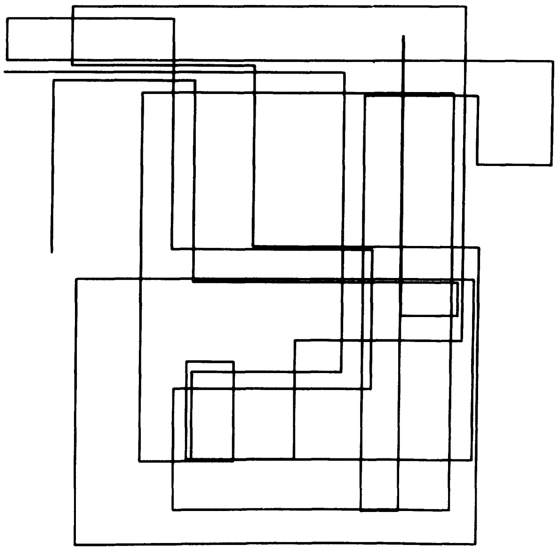
The preceding examples indicate that the computer in association with some method for obtaining visual output can be used to generate

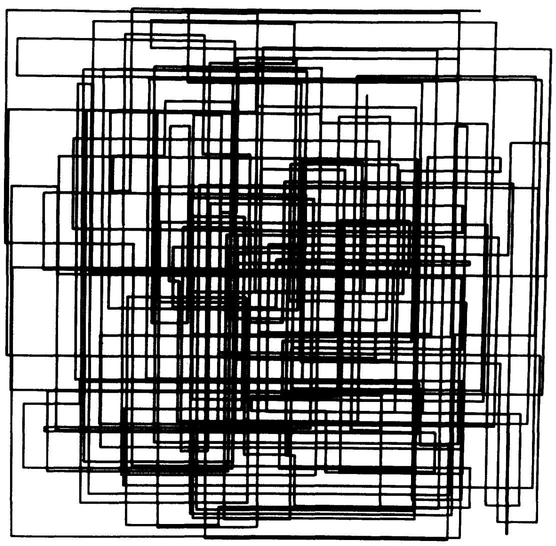
Computer-produced pictures by A. Michael Noll.

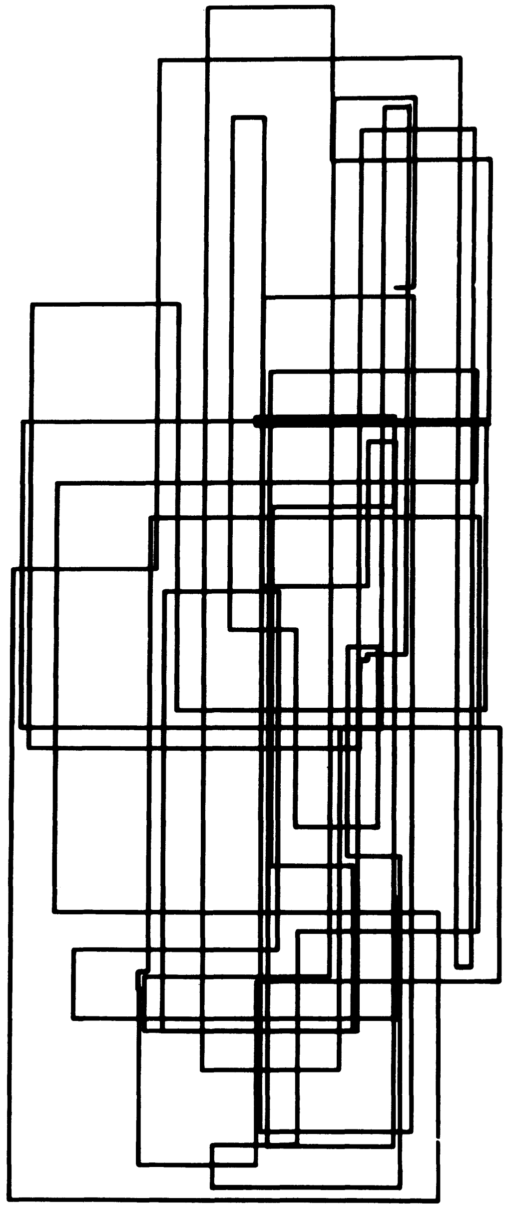
Right: "Vertical-Horizontal No. 1"

Bottom right: "Vertical-Horizontal No. 2"

Far right: "Vertical-Horizontal No. 3" © A. Michael Noll, 1965. In these pictures only one of the two coordinate values (X or Y) was changed from one point to the next along a continuous line. The change alternated between the X and the Y value. Otherwise the positions of the points were chosen at random with a uniform probability density.







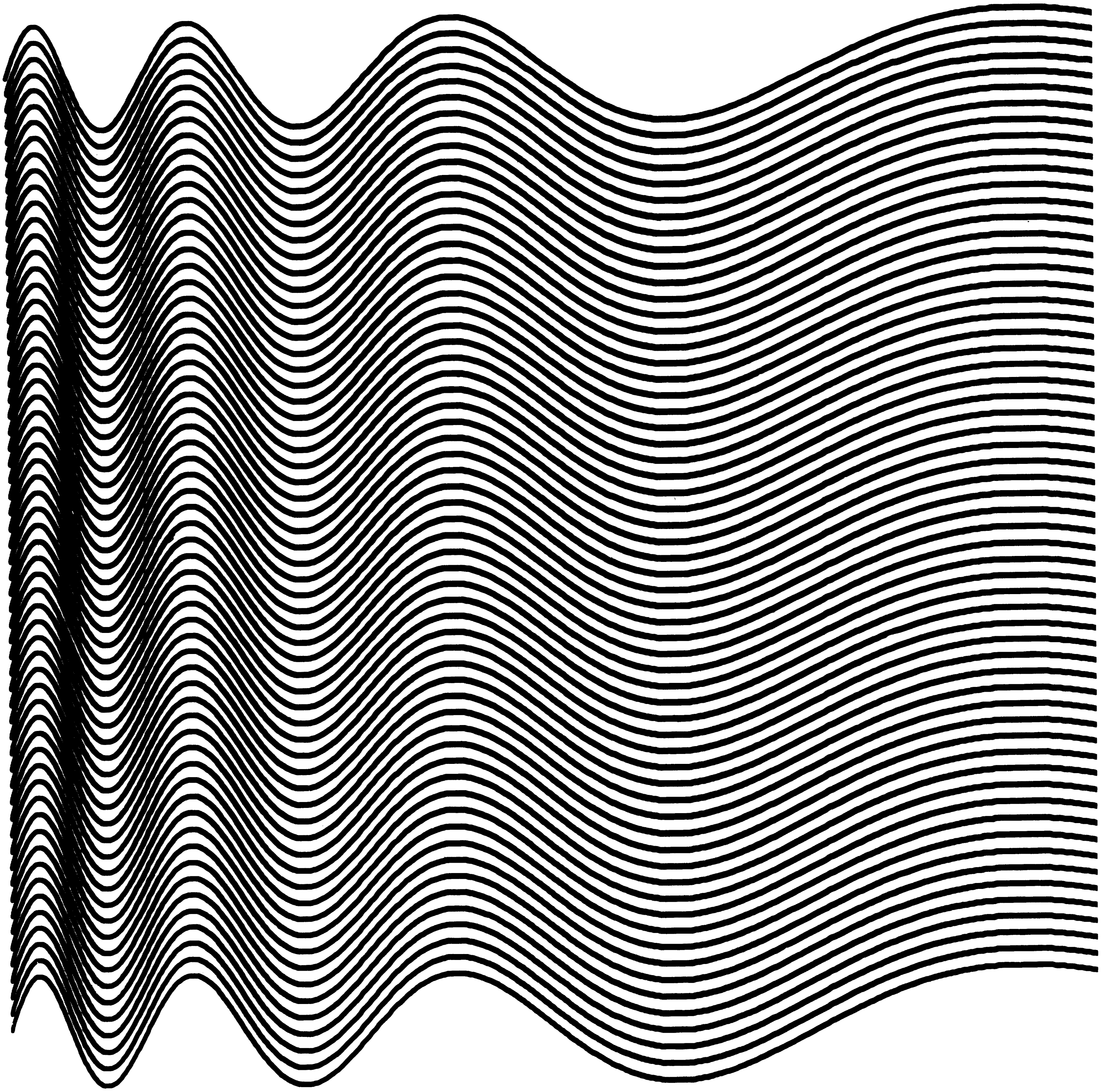
random and quasi-random abstract images. The artistic merit of the image thus generated is a matter of personal opinion, but it should be taken into account that the medium was in this case strongly limited by the exclusive application of black straight lines.

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 enables the computer to calculate an array of points based upon a simple mathematical formula. The microfilm plotter then connects the points to produce the finished result.

The fact that an "op art" picture can be adequately produced by a computer should not detract from the artistic merit of either the artist or the picture resulting from the artist-computer collaboration. The creative process takes place in the mind of the artist; the final painting is only the artist's rendition of his mental image. This is particularly true of "op art" although other types of art do involve the artist's interaction with his materials as part of the creative process.

Since most "op art" is definitely mathematical it is not at all surprising that the computer can duplicate "op" paintings. However, what could the computer do with different forms of abstract paintings?

This problem was approached by trying a quasi-random duplication with the computer of an abstract painting. The painting chosen for this investigation was Piet Mondrian's "Composition With Lines" (1917). This black and white



"Ninety computer-generated sinusoids with linearly increasing period." The top line of this picture was mathematically expressed as a sinusoid curve. The computer was then instructed to repeat the line 90 times. The result approximates closely Bridget Riley's painting "Current."

painting is from Mondrian's earlier period when he was experimenting with representations of the vertical and horizontal motifs of nature. "Composition With Lines" was chosen because it was composed entirely of solid black bars which could be drawn very easily by the microfilm plotter.

A cursory examination of Mondrian's painting reveals that, first, the outline of the painting is nearly circular except for cropping of the sides, top and bottom; second, the bars falling within a region in the upper half of the painting are shortened in length; third, the length and width of the bars otherwise appear random; and fourth, the placement of the bars is not random but seems to follow some scheme so that the entire space is almost uniformly covered.

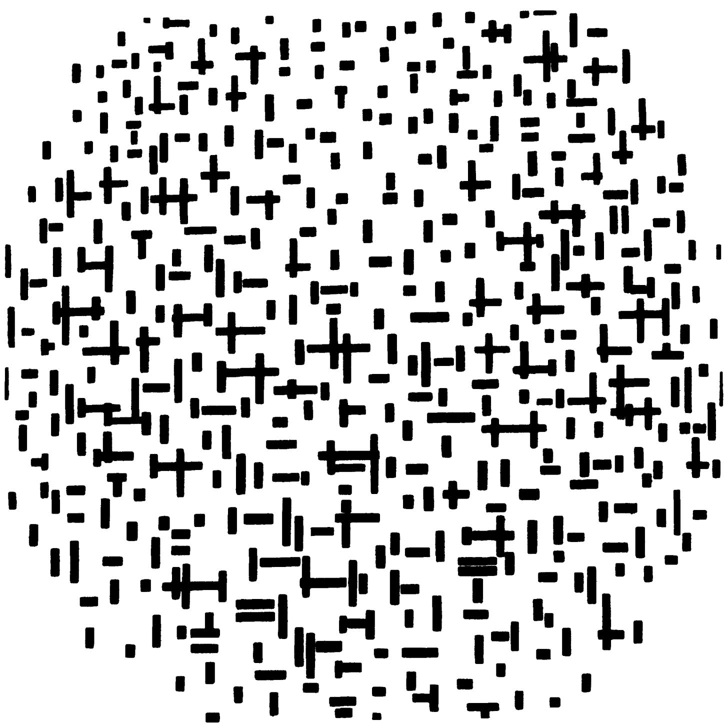
A computer program was written utilizing the first three of the observations about Mondrian's painting. The placement of the bars was random with a uniform density. The vertical and horizontal bars were approximated as a series of closely spaced, and therefore overlapping, parallel line segments. These bars were placed randomly within a circle of radius 450 units. The choice of vertical or horizontal bars was equally likely. The width of the bars was equally probable between 7 and 10 units while the length of the bars was equally probable between 10 and 60 units. If the center of the bar fell inside a certain parabolic region with its origin at the center of the circle, the length of the bar was reduced by a factor proportional to the distance of the bar from the edge of the parabola. A trial-and-error approach ensured that the final picture was reasonably similar to the Mondrian painting.

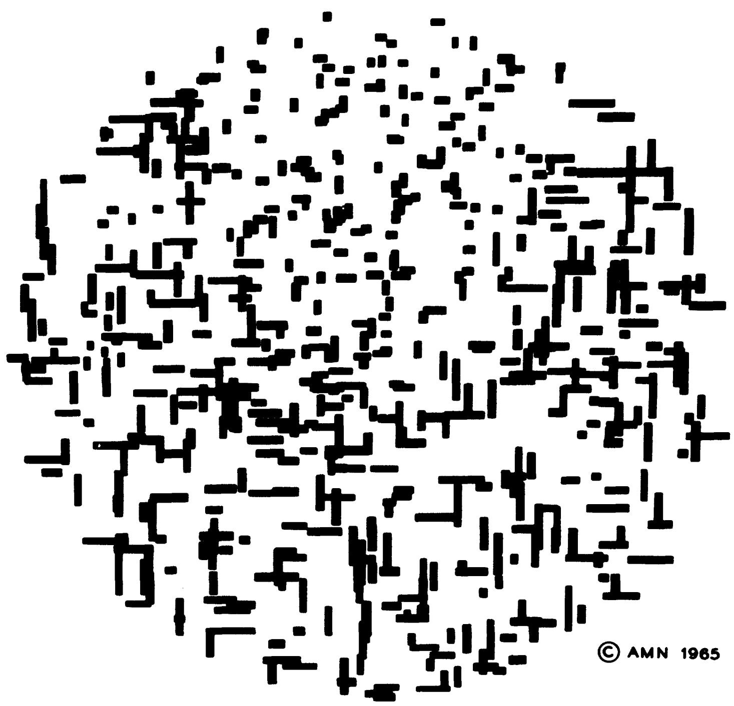
In a psychological experiment, a sample of one hundred artistically naive subjects were given reproductions of the Mondrian and of the computer picture.[1] These people were instructed to indicate which of the pictures they preferred and to identify the computer picture. In this particular group, 59% of the subjects preferred the computer picture and 28% identified correctly the computer pictures, i.e. 72% thought the Mondrian picture was done by computer. The sample group was composed of technical and clerical personnel who probably had no bias against computers. As indicated by questionary comments of these subjects, there was a trend among the non-technical people to associate randomness with creativity. Therefore, the results of this experiment neither discredit Mondrian nor imply that the computer is a greater artist than Mondrian, but raise the question to what extent randomness has aesthetical and emotional appeal. To answer this question, more experiments with controlled groups of subjects would be required.

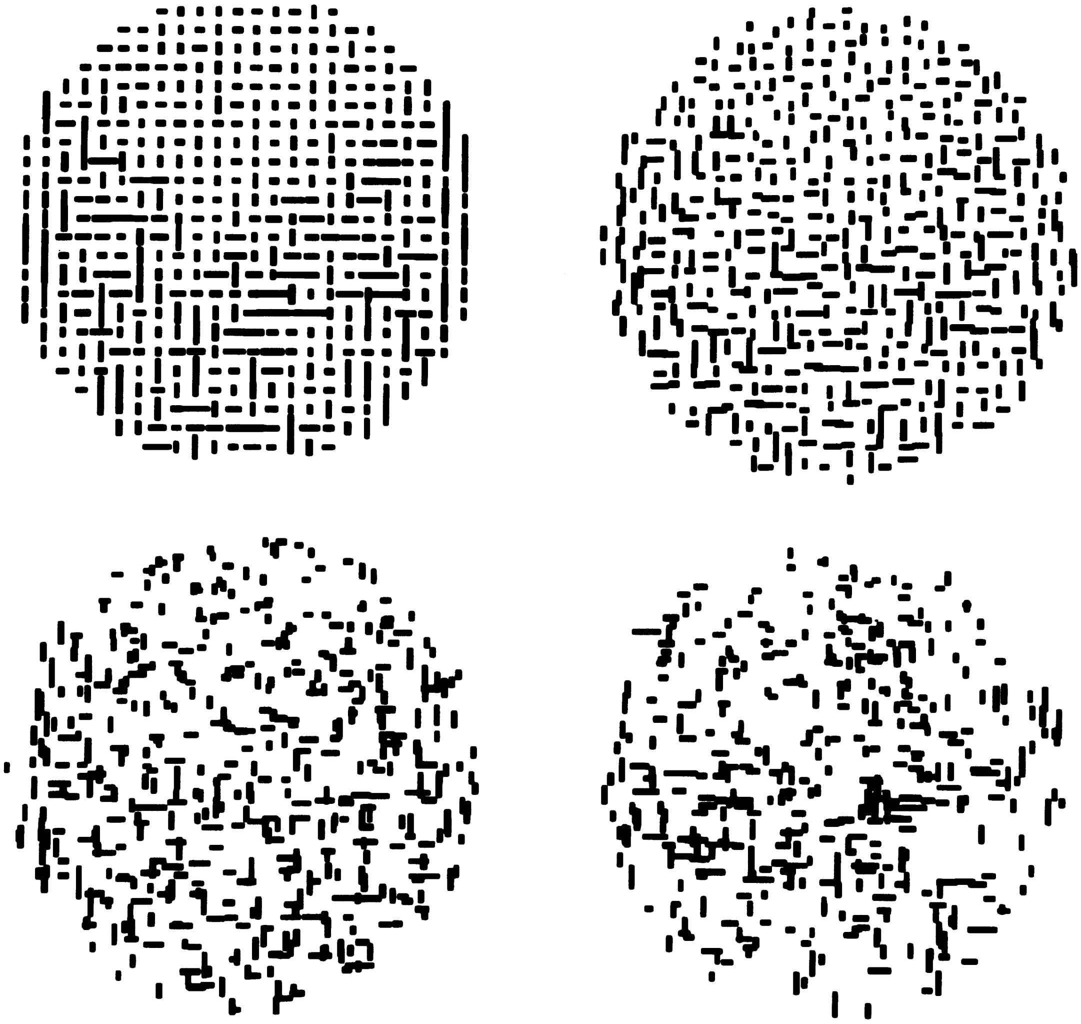
The human-or-machine experiment, testing the preference of the two pictures, one computer-generated, the other by Mondrian, could raise a few more questions. For instance, although only one particular sequence of random numbers was used by the computer in producing this picture, it is not known if other pictures generated by statistically identical random sequences would be preferred over the Mondrian. The computer picture would clearly be more random than the Mondrian painting. However, more elaborate schemes could be used to produce pictures that even more closely resemble the Mondrian.

Bottom left: "Composition with Lines," (1917) by Piet Mondrian, © Rijksmuseum Kroller-Muller.

Bottom right: "Computer Composition With Lines," by A. Michael Noll in association with an IBM 7094 digital computer and General Dynamics SC-4020 microfilm plotter, © A. Michael Noll, 1965. This composition approximates Piet Mondrian's "Composition with Lines" (1917).







Four computer-generated random patterns based on the composition criteria of Mondrian's "Composition with Lines."

As a follow-up, another 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.

The conclusion of these investigations of computer-generated two-dimensional pictures is that the exciting potential of computers in art consists in their capability of producing mixtures of random elements with mathematically specified formulae for order. The experiments reported here involved only black and white pictures, but in the very near future color picture tubes will be controlled by computers, and infinitely variable color mixing will be possible. Presently, any artist desiring to use the computer would require a fairly sophisticated knowledge of computer programming. However, special "programming languages" that closely suit the needs of any particular artist could be developed, and these languages could be as natural to use as the conventional brushes and oils. Until recently the time lag between the running of the computer program and the finished picture has been several hours. Now, however, new display devices which immediately create an image on a large picture tube are being made available. Special lightpens are also available for writing and drawing on the face of the cathode ray tube and in this way it is possible to modify the picture. Such devices allow the computer-artist to sit at the console of the machine and to interact with the machine to produce a picture immediately. In the future it may even be possible for an artist to rent a console with a display device and work with a computer over distances. Many people would share the same mammoth facilities of a central utility computer. As leisure time increases and computer costs decrease, the use of time-shared computers for creative activities may become quite commonplace.

REFERENCE

1. "Human or Machine: A Subjective Comparison of Piet Mondrian's 'Composition With Lines' and a Computer-Generated Picture," *The Psychological Record,* Vol. 16, No. 1, January 1966, pp. 1-10.