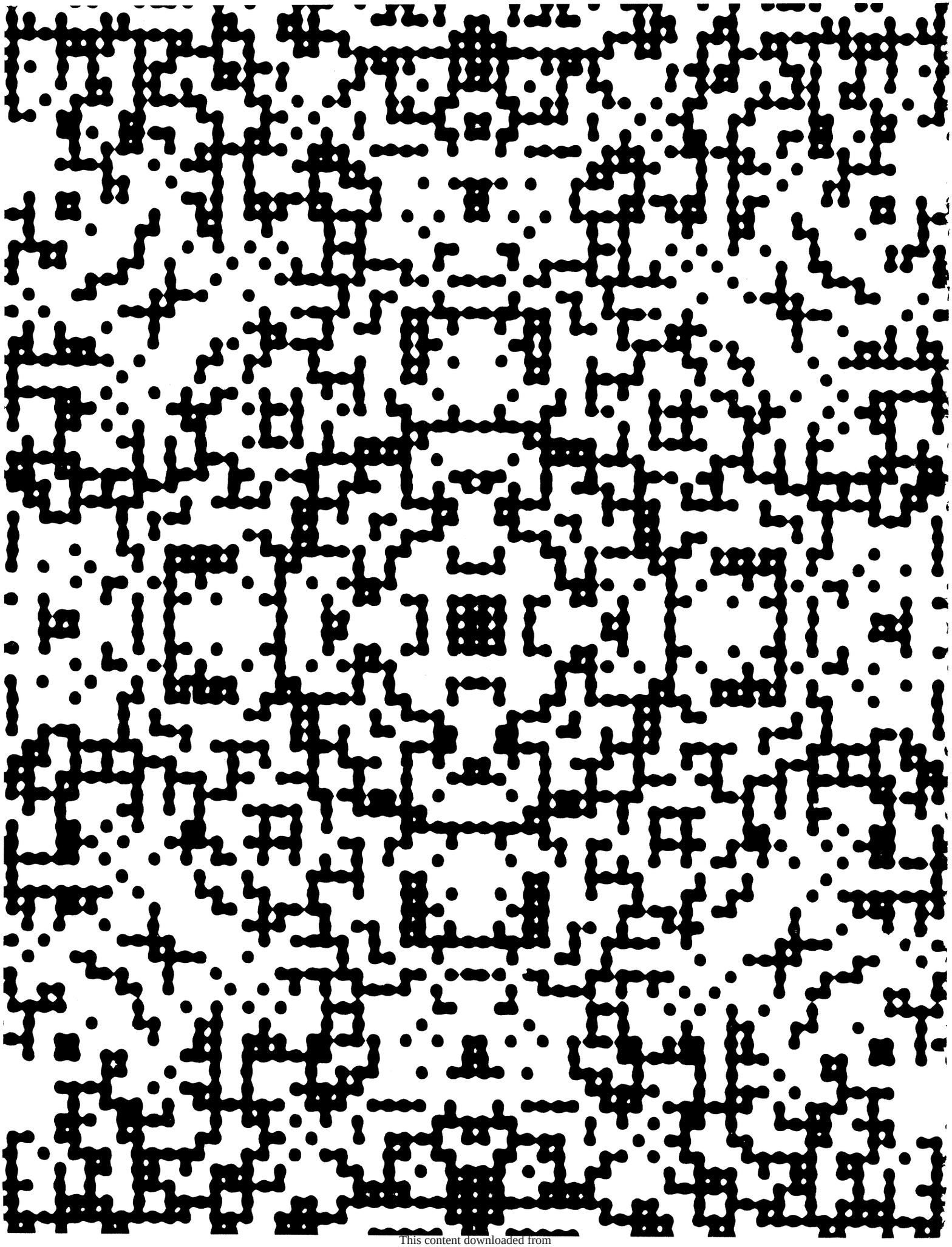


Dr. Kenneth C. Knowlton works in Computer Programming Research at the Bell Telephone Laboratories at Murray Hill, New Jersey. He is interested in experimental "computer languages," and one of the "languages" he has created is capable of generating designs, diagrams and animated motion pictures. One problem which is difficult to solve in motion picture languages for computers is the production of different shades of gray. This problem has been solved by Dr. Knowlton in his BEFLIX language. Making animated movies by a computer programmed with BEFLIX has proven to be reasonable and feasible from a financial point of view. Moreover, BEFLIX can generate very complex patterns of considerable aesthetic merit which would be difficult and very time consuming to produce manually. The patterns sometimes come close to the products of oriental rug makers and thus provide the viewer with the impression that there may be a "human touch" to a machine-generated picture.

BEFLIX will be of great interest to the film maker who produces educational and other animated movies. The development of such languages together with the increased use of graphic output devices will make the computer very useful for the draftsman, artist and film maker.

COMPUTER-GENERATED MOVIES, DESIGNS AND DIAGRAMS

by Kenneth C. Knowlton

Opposite page: Enlarged segment of computer-produced design.

An automatic microfilm recorder, composed of a camera and a cathode ray display tube which faces the camera, is now being used for the production of movies, designs and diagrams. Controlled by a computer, this recorder works at electronic speeds and can plot points and draw lines many times faster than a human draftsman.

One component of the automatic microfilm recorder, the cathode ray display tube, resembles a television tube except that it is controlled not by signals from a broadcasting station, but rather by signals from the electronic computer or a computer-written magnetic tape.

The microfilm recorder "understands" various kinds of commands. It "understands" the instruction to advance the film in the camera to the next frame. It responds when commanded to display a spot of a certain brightness at specified coordinates of a 1024-by-1024 grid on the tube face. It also draws a straight line segment from one such point to another. Some display units, such as the one produced by Stromberg-Carlson in San Diego, California,[2] in addition to producing graphic output, can generate typographic output by selecting, at high speed, characters from a given alphabet. This is achieved by deflecting an electron beam through the appropriate letter locations of an alphabet template in the tube. By passing through the template, the beam takes on the form of the letter and is subsequently deflected into a precise position on the display face of the tube. In some other display units, characters may be "drawn" by automatically plotting appropriate patterns of spots or line segments on the face of the tube with the electron beam.

Despite the simple principle of this machine's elementary operations, the machine can compose complicated pictures or series of pictures from a sufficiently large number of appropriately placed points, lines and characters. It can draw and film these elements fast enough to produce in a reasonable time a very complicated picture or series of such pictures. Current speeds of microfilm recorders lie in the range of 10,000 to 100,000 points, lines, or characters per second. This is fast enough to compose, in a matter of seconds, a television-quality image consisting of a fine mosaic of closely-spaced spots, or fast enough to produce several simple line drawings per second.

THE QUESTION OF EFFICIENCY

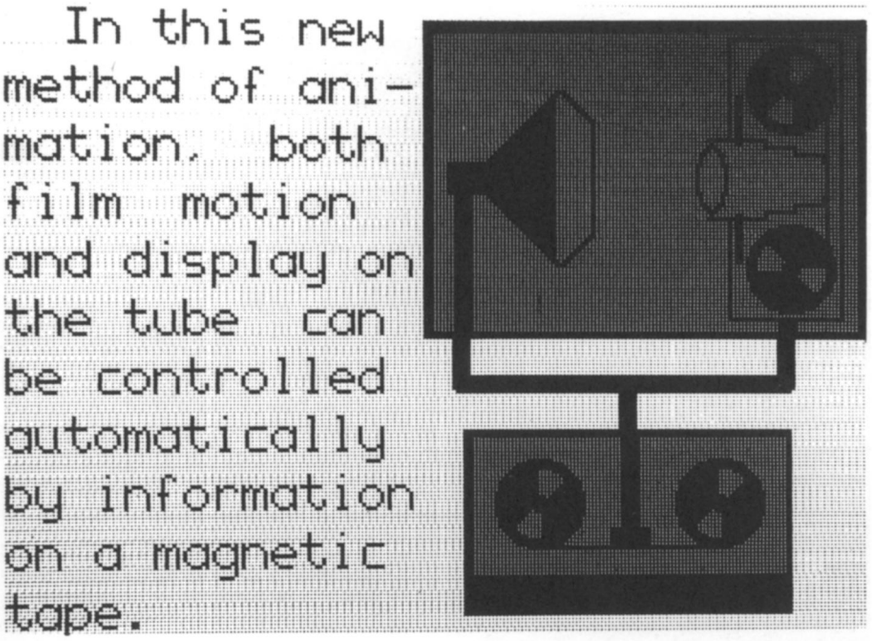
It should be understood at this point that the basic question in this research area is not whether a computer equipped with a microfilm recorder can produce complicated or interesting pictures. Indeed, almost any picture imaginable can in principle be composed as a particular configuration of points and lines. The basic question is whether this is an efficient and feasible way to produce useful pictures.

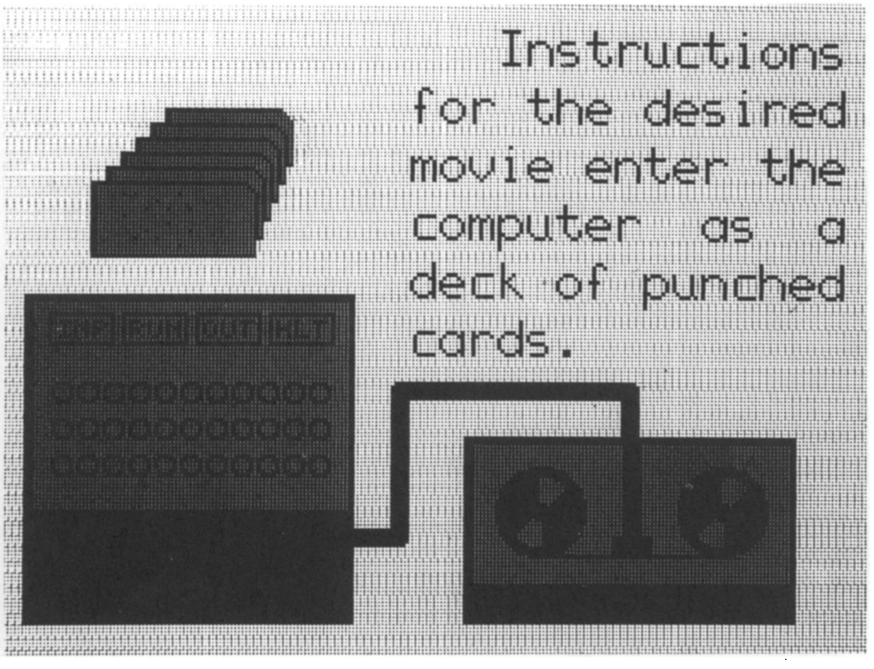
What the picture or movie producer would like to do, instead of specifying his pictures in terms of their elementary components such as spots and lines, is to talk in a more powerful language to the machine — the way he is used to talking to his human "assistants," or even more effectively. He would, for example, like to say: "Type such-and-such a title, center each line, give the letters shadows, then shoot 150 frames." The job of the computer, equipped with a program for understanding this kind of talk, would be to deduce, from a few statements in this powerful language, the very large number of corresponding instructions for the microfilm recorder, and thus to produce the pictures automatically.

The interesting research questions are, first: "Is it possible to provide a sufficiently complete language so that most things which an animator or diagrammer wants to do can be expressed easily?" and secondly: "Will the computer's subsequent calculations be reasonably fast and hence economical?" From my experience with a particular "movie language," the answers are definitely "Yes" — at least for a broad category of pictures which I will herein describe.

THE BEFLIX MOVIE LANGUAGE

The work in this area has involved the mosaic type of picture, consisting of tens of thousands of spots or tiny characters, as contrasted with the line drawings of A. M. Noll and F. W. Sinden, also working at the Bell Telephone Laboratories, where a single picture is composed of hundreds of line segments. In particular, my contribution was the development of a special





Above: Frames from computer-produced film, "A Computer Technique for the Production of Animated Movies," produced by programming in the BEFLIX language. Each frame is a 252 by 184 array of spots (actually alphanumeric characters). Shown here is the microfilm printer, consisting essentially of cathode ray tube and camera, both controlled by information on magnetic tape.

The job of the computer is to accept instructions for the movie on punched cards and to compute and write spot-by-spot descriptions of pictures on this tape.

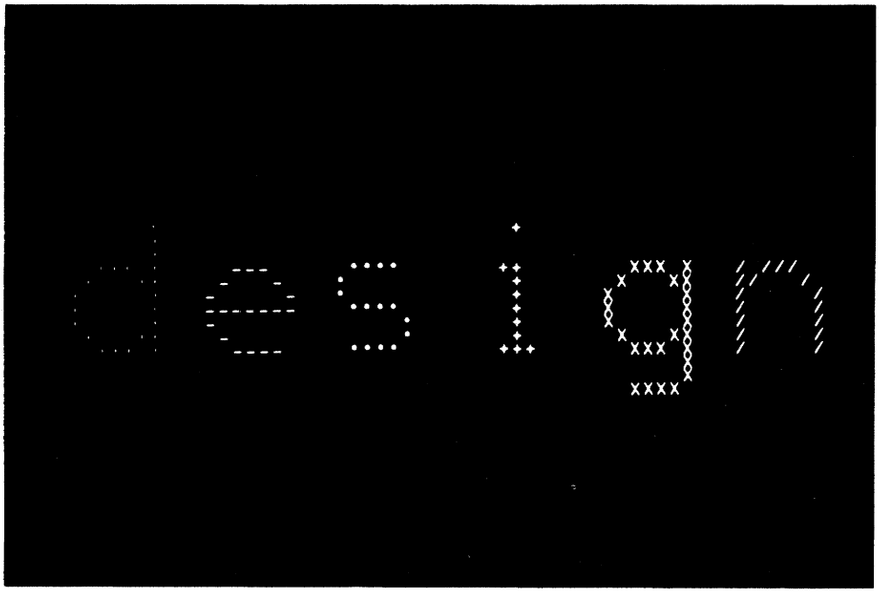
programming language. A programming language is used to prepare computer programs and, as such, it is a language that interprets human language to the machine. This programming language was geared for producing animated movies and, necessarily, a corresponding computer program, which "understands" this language and carries out the designated operations, was written.[3]

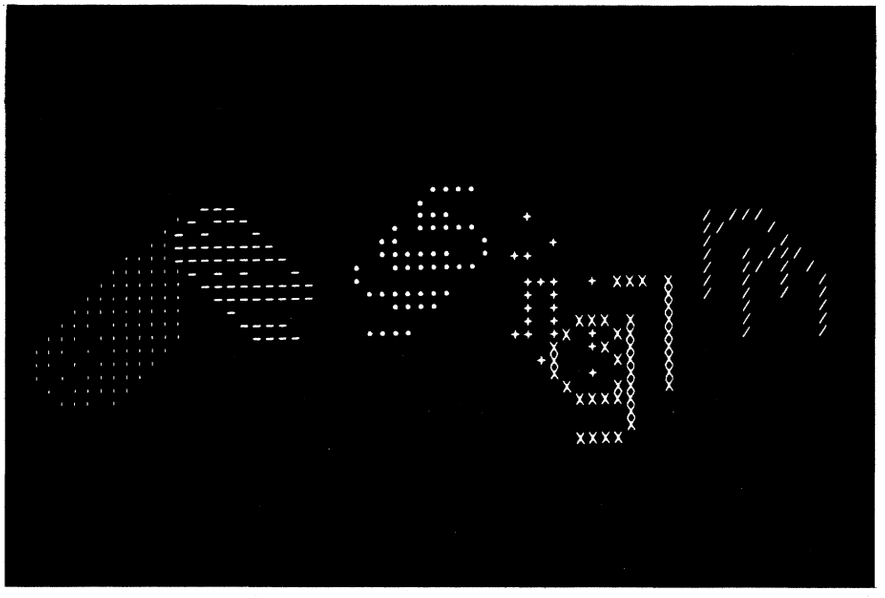
The programming language called BEFLIX (for "Bell Flicks"), deals with pictures as a large rectangular surface made up of 252-by-184 elements. Each of the 46,368 elements is represented within the computer by a number from 0 to 7, indicating the intensity of light at that point (which is equivalent to a "shade of gray"). Pictures are built up and modified within the computer by appropriate manipulation of these numbers. At desired times these numbers are used to direct the microfilm recorder in displaying the entire surface of 252 x 184 = 46,368 spots on the cathode ray tube in order to expose one frame of film. (Actually, these "spots" were generated by typing tiny letters, using the Stromberg-Carlson 4020 "charactron" tube in the "typewriter" mode — different characters being used for different intensities according to their overall gray level.)

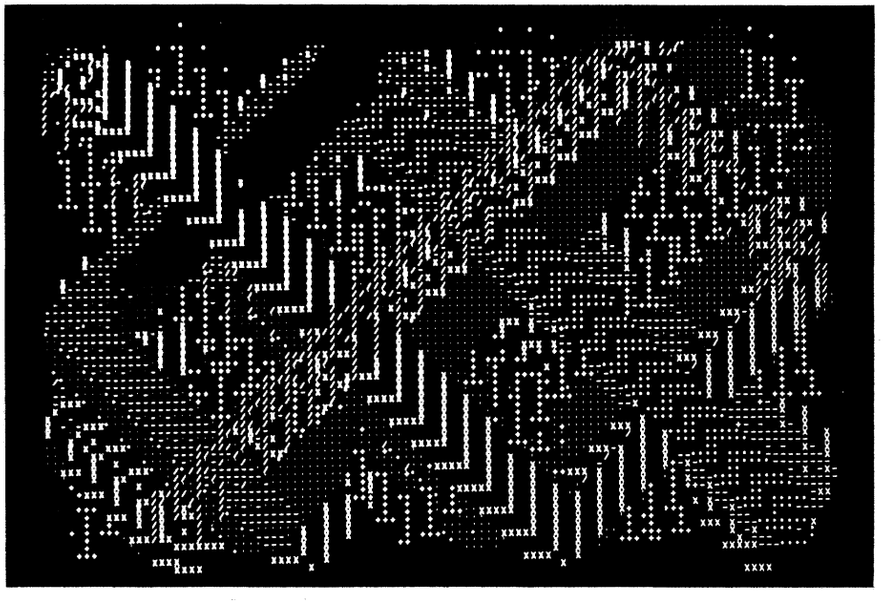
By programming this language, I made a movie about the very process by which the film was made.[4] Many of the scenes, incidently, depict schematically the physical equipment involved. All scenes were produced by BEFLIX instructions such as those for drawing straight lines (which must, of course, conform to the underlying pattern and thus may involve minute steps), drawing arcs and other curves, "painting" an area with a solid shade of gray, copying contents of one area onto another, or shifting the contents of an area up, down, right, or left a specified number of positions. There are also operations for automatically filling an area that has been outlined by a specific shade of gray, for enlarging all or part of a picture, and for gradually dissolving one picture into another which has been drawn on an auxiliary "drawing board" within the computer.

In all, the language contains about twenty-five kinds of instructions, each of which is punched on an IBM card with appropriate parameters specifying just where and how the operation is to be performed and how many movie frames are to be produced at intermediate stages of the operation. For example, the instruction for drawing a straight line requires the programmer to specify beginning and end points, width of line in units, shade of gray, and the speed at which the line is to be drawn, expressed as the number of units the line should advance between successive frames of the movie.

The BEFLIX language actually does not do much which cannot be done by normal methods.







Three frames showing the development of a complicated design produced by giving the computer rather simple rules. BEFLIX was used in the "coarse" mode, where one picture contains only 92 lines of 126 characters each.

Top left: The computer begins by typing the word "design" using different characters as shown.

Center left: Letters follow trajectories, each writing its pattern in its own particular sequence.

Bottom left: After bouncing about inside an imaginary box, complex composite patterns form.

In many cases, however, drawings can be made with far less human effort than when drawn manually, especially drawings which exhibit symmetries or periodical repetitions of equal elements. In one scene of the film, for example, a computer console with thirty-three lights in three rows, is shown. These lights were produced by giving the computer instructions for drawing only one of them and the positions on the picture surface at which a light was to be located. In fact, it was not even necessary to give an explicit list of positions to the computer; only the rules for enumerating these positions were required.

This film, produced entirely by BEFLIX programming, presents a means of judging the economic feasibility of producing movies this way. It is a 17-minute film and thus about 25,000 frames long. However, some of the frames are identical and so there are only 3000 unique pictures. These 3000 pictures were actually produced by approximately 2000 lines (or punched cards) of BEFLIX programming, which took me two months as the sole producer-programmer. The other major expense was four hours of computer time on an IBM 7094 computer (two hours to check out the program and two hours for "production" run).

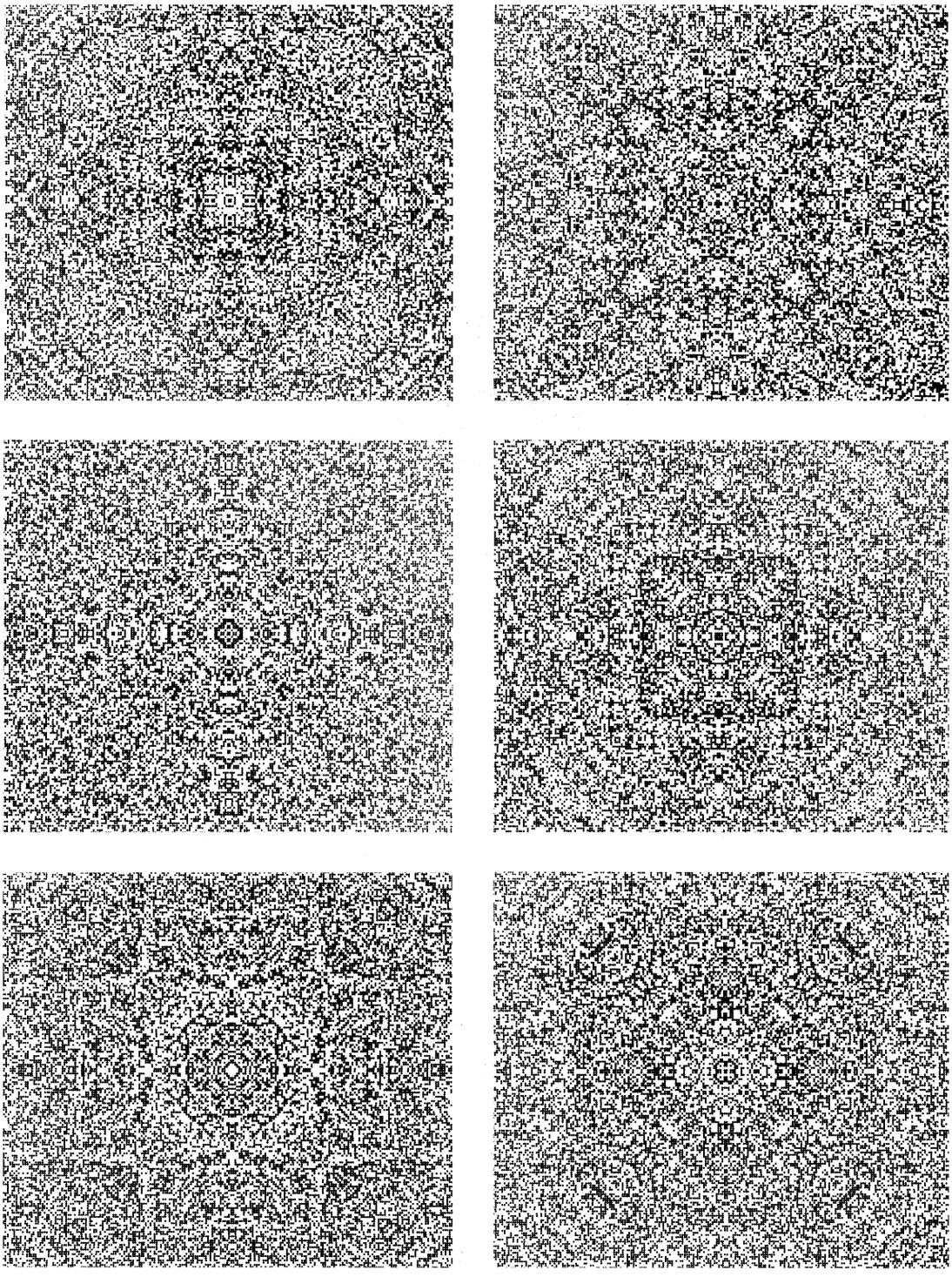
Other incidental costs bring the total cost up to $600 per minute of film which already falls at the lower edge of the range for manual animation of this quality and complexity. Costs of computer animation will undoubtedly go down with increases in size and speed of computers, with development of additional special-purpose equipment better suited to movie-making, and with further development of computer programming languages for the purpose. With efficiency improved only slightly from what is now available, it will also be feasible to improve the resolution of pictures and to do animation in color, both of which will require slightly more computation but only a minor increase, if any, in programming effort.

COMPLICATED PATTERNS FROM SIMPLE RULES

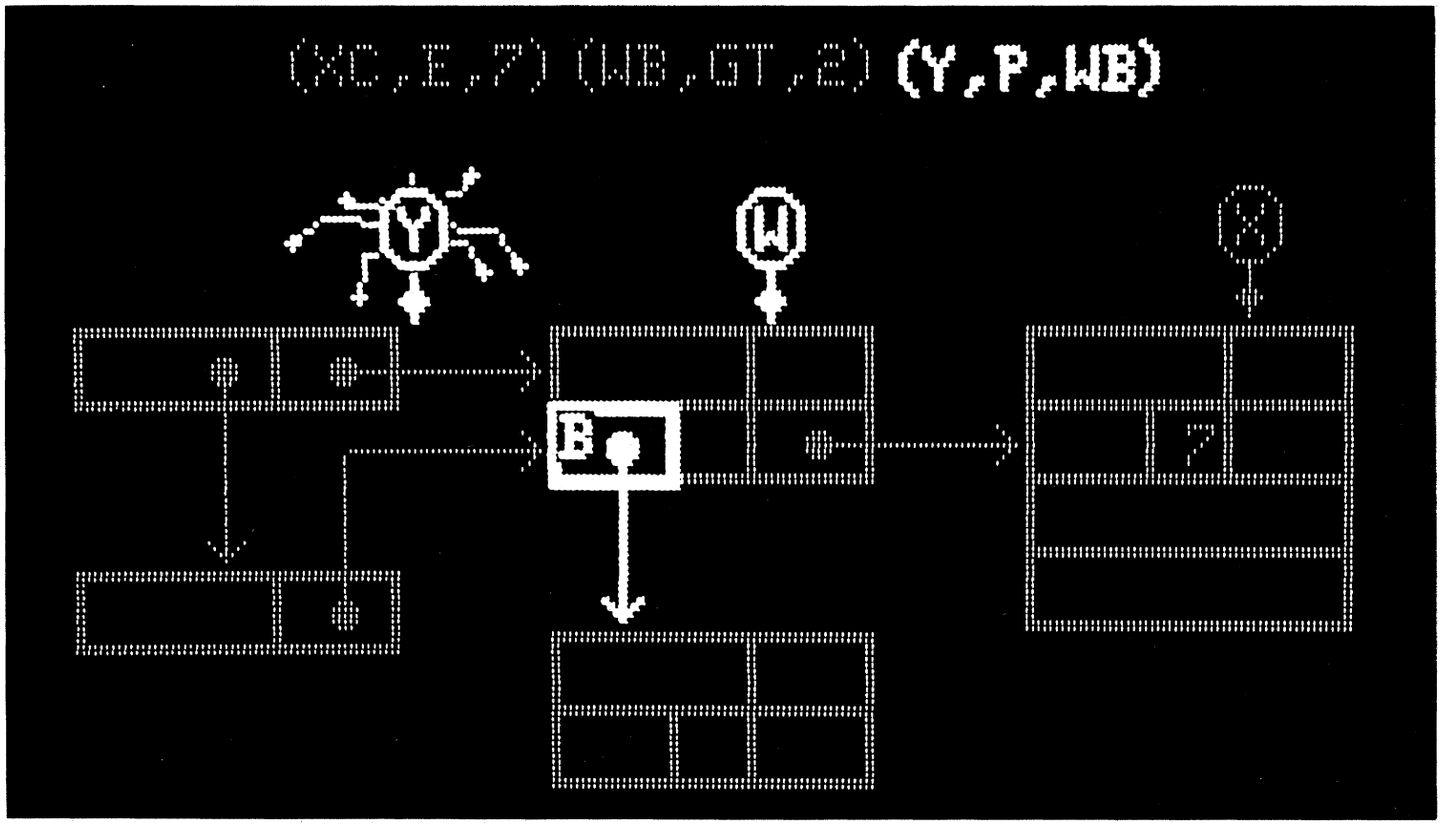
One should not immediately conclude, however, that all drawings and animated movies will soon be done by computer. In fact, it is difficult to imagine at this point how we would formalize for the computer, rules for drawing familiar

cartoon characters. Instead, the computer will be used for the more schematic and geometric form and for those patterns and designs which are logically simple, in the sense that the rules for constructing them are easy to write in a programming language.

An example of such a "logically simple" design may look very intricate. I produced a visually complex picture by instructing the computer first to display the word "design," making up each letter of the word by a different typewriter character. Then the computer was asked to repeat each composite letter along a 45-degree trajectory following its own sequence of writing and/or erasing its pattern. These trajectories were limited by the walls of an imaginary box from which the letters bounded off until a fairly complex visual result was obtained. (For this series of pictures, the "coarse" mode of BEFLIX was used in which pictures are composed in a surface of only 92-by-126 elements.)



Designs exhibiting 8-fold kaleidoscopic symmetry, produced by Drs. Bouche and Julesz (Bell Telephone Laboratories). The computer is programmed to fill an octant at random and copy it seven times through appropriate reflections.



Frame from BEFLIX-produced film "L⁶ — Bell Telephone Laboratories Low-Level Linked List Language." This narrated film explains the workings of a new computer language by means of moving "bugs," block diagrams and letters.

Further examples of complicated pictures produced by simple rules were made by Drs. Carol Bosche and Bela Julesz of Bell Telephone Laboratories, who added a pseudo-random number generator to the BEFLIX system in order to fill one eighth of each frame with black and white spots at random. The operations of BEFLIX were then used to copy this area so as to produce a pattern of eight-fold kaleidoscopic symmetry.

Finally, as another example of the use of BEFLIX for educational purposes, two films about a new computer programming language called L⁶ have been produced.[5] These narrated films, totaling 48 minutes, were produced principally by myself in about four months' time, using ten hours of time on an IBM 7094 computer for a total cost of less than $500 per minute of film.

The L⁶ language should be of great interest to designers who are developing computer-graphics systems for use in their work.[6] It is a programming language especially useful for certain types of non-numeric computation as it may occur in the simulation of circuits or the drawing of flow charts. In many cases it performs ten times faster than languages which have been previously used for these purposes.

CONCLUSION

BEFLIX and L⁶ are cited as two languages which may be used for the computer production of animated movies, designs and diagrams. Further developments in programming languages, aimed either at more general usefulness or at more specific areas, may make the computer still more useful to the draftsman, artist, designer or architect. In addition, future developments in hardware, such as larger and faster computers, and graphics facilities permitting close interaction between designer and computer, should be expected to make the computer an almost indispensable tool in these areas.

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3. Knowlton, Kenneth C., "A Computer Technique for Producing Animated Movies," AFIPS Conference Proceedings 25 (1964 Spring Joint Computer Conference, Washington, D. C.) pp. 67-87. Appendices constitute a programmer's manual for the BEFLIX movie language.
4. "A Computer Technique for the Production of Animated Movies," 17 minute, 16 mm black-and-white silent film about the BEFLIX language and system, and produced by it. Available on loan from the Technical Information Libraries, Bell Telephone Laboratories, Incorporated, Murray Hill, N. J.
5. "L⁶ — Bell Telephone Laboratories Low-Level List Language," 16 minutes, and "L⁶ — Part II: An Example of L⁶ Programming," 32 minutes. Both are 16 mm black-and-white films, with narration, computer-produced by BEFLIX programming. Also available on loan from Bell Telephone Laboratories.
6. Knowlton, Kenneth C., "A Programmer's Description of L⁶," Communications of the ACM 9, No. 8 (August, 1966), pp. 616-625.