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Experiments in Processing Pictorial Information with a Digital Computer

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I. Introduction

In almost all digital data processing machine applications, the input data made available to the machine are the result of some prior processing. This processing is done manually in many applications. Thus, such inputs as punched cards, magnetic tape, and punched paper tape often are the result of a manual processing operation in which a human being is required to inspect visually an array of printed characters and to describe these data in a form capable of being processed by machine. In recognition of the importance of automating such operations, many investigations have been undertaken to devise automatic character sensing equipment. Suppose, however, that we attempt to view such efforts in proper perspective. We find a more fundamental problem that has, heretofore, failed to receive the attention that it warrants. The problem is one of making directly available to a computer pictorial information which would ordinarily be visually processed by human beings before being fed to a data processing system. This pictorial information may range from such highly stylized forms as printed characters, diagrams, schematic drawings, emblems, and designs through less stylized forms in cartoons and handwritten characters to such highly amorphous forms as photographs of real objects, *e.g.,* people, aerial views, and microscopic and telescopic images.

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In recognition of the importance of pictorial sources of data for a data processing system, experiments were undertaken at the National Bureau of Standards to determine whether automatic processing techniques might be applied to pictorial information in order to reduce the amount of human intervention required during the input process. In considering this problem, new areas of the application of automatic data processing techniques for processing pictorial information have appeared. It had not been suspected that automatic data processing techniques were applicable in some of these areas, even if human intervention were allowed. The type of information with which these investigations are concerned ranges from the stylized to the amorphous forms previously mentioned. In the NBS experiments described in this paper, the equipment used consists of the general-purpose digital computer SEAC, to which are attached an input scanner for sensing pictures and copying them into the computer memory, and a cathode-ray-tube output display for reproducing processed pictorial information from the computer memory.

II. Description of the Experimental Equipment

A. SEAC

The experiments described here were performed on SEAC during a period when the capability of the computer for performing logical data processing operations was being enhanced by the addition of several new features. The state of SEAC at the time of most of the experiments described here was that of a 1500-word memory computer with an average time of 250 microseconds for performing a three-address instruction. Although faster computers exist, SEAC was found to have one decided advantage over these machines, namely, its availability for experimental use and modification on some frankly exploratory ventures. The restriction of having to account for every minute of use on a more powerful machine would have been a serious deterrent to the production of the experimental results described here.

B. The Scanner

In order to feed pictorial information into SEAC, it was considered adequate to construct a simple mechanical drum scanner which could digitalize the information in a picture and feed it into SEAC in a few seconds. The scanner is shown in Fig. 1. The photograph to be scanned is mounted on a drum about two thirds of an inch in diameter. As the drum rotates, a photomultiplier and a source of illumination mounted on a lead screw progresses along and scans the whole picture with a helical scan. The pitch of the lead screw is such that the photomultiplier assembly progresses 0.25 mm along the picture for each revolution of the drum. Between the drum and the photomultiplier, and in the image plane of the optical system, there is an opaque mask with a square optical hole of such a size that a square area, 0.25 mm on a side of the picture, illuminates the photomultiplier at each instant. A strobe disk mounted on the same shaft as the drum produces optical pulses each 0.25 mm of drum rotation. These optical pulses are arranged in the format of SEAC input words, *i.e.*, multiples of 44 binary digits. The time for the scanner to scan one photograph is 25 seconds.

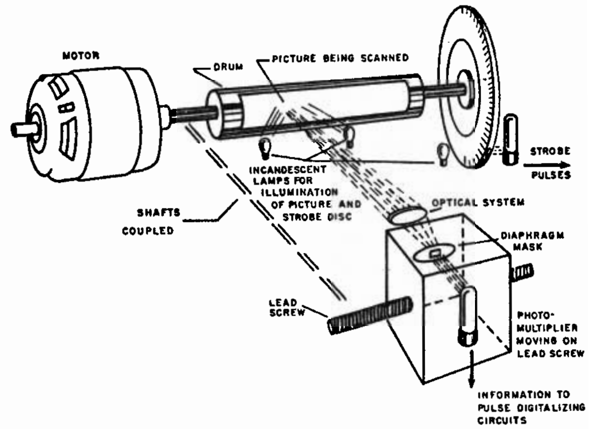


Fig. 1—The scanner.

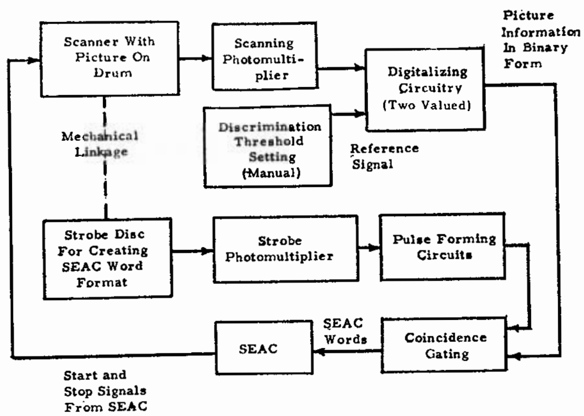


Fig. 2—The scanner connections to SEAC.

C. Method of Input

The scanner was first connected to SEAC in November, 1956. As far as SEAC is concerned, the scanner is just another input device, and it may be selected by the computer interchangeably with such other input and output devices as a printer, magnetic tapes, etc. This is shown in Fig. 2. At any time during the operation of a program if the input of photographic information is called for, SEAC starts the drum rotating. The analog signal from the scanning photomultiplier is compared with a dc reference signal that has been manually determined with a potentiometer setting. If the light reflected from the 0.25-mm square being scanned is less than that needed to produce a signal equal to the reference signal, then when a strobe pulse occurs, a binary 1 is fed to SEAC. If a sufficiently white spot is being scanned, a binary 0 is fed to SEAC.

The result of this operation is that in 25 seconds (or less) SEAC can, upon demand, call for all (or any part of) a picture to be fed into its memory. The whole picture is 44 mm by 44 mm and is thus digitalized into 176 by 176 or 30,976 binary digits, each binary digit representing the blackness of a unit square 0.25 mm by 0.25 mm in the picture. The elementary squares cover the whole picture and are nonoverlapping. The entire picture with one binary digit per square occupies 704 words of SEAC memory. One way of recognizing several different levels of grayness is to use several scans of the picture made with different manual settings of the discriminator threshold. The mechanical precision of the equipment is such that on successive scans of the same picture the scanner reproduces its scan with a maximum discrepancy of less than 0.25 mm at any point in the picture.

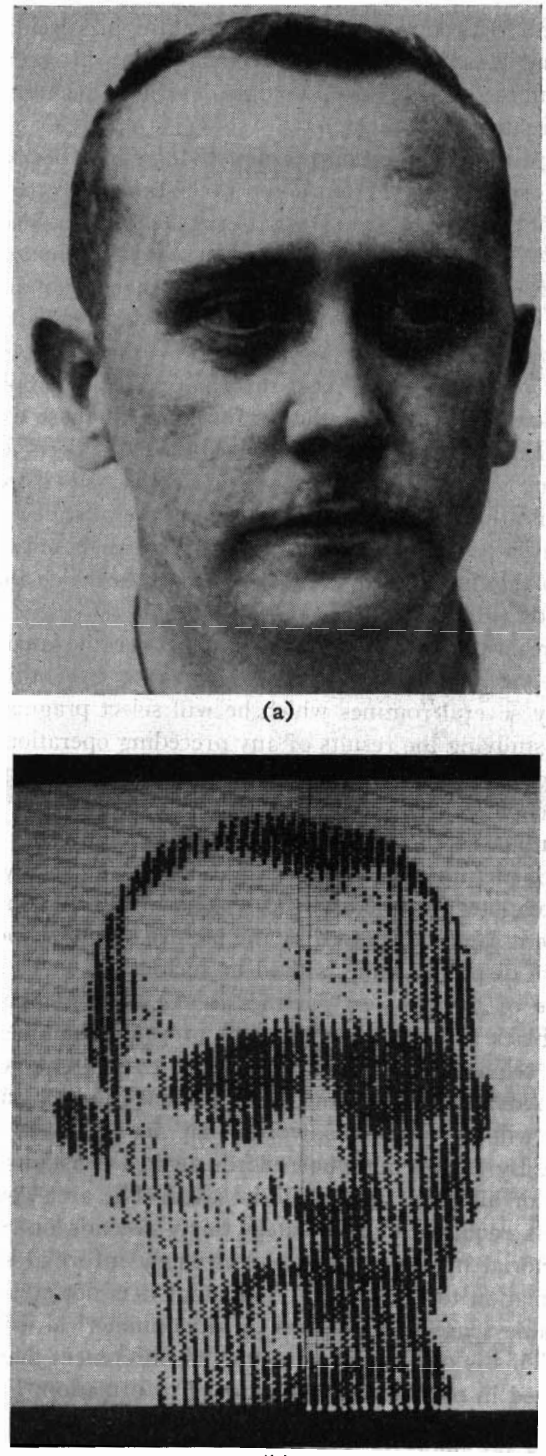
D. Method of Output

As soon as the first picture was fed into SEAC, an uncomfortable fact became apparent. SEAC could store pictorial information in its memory, but the machine users could not "see" the picture in the SEAC memory except by the very time-consuming procedure of printing the contents of the computer memory on a typewriter and attempting to interpret the numerical information. Fortunately, however, there was conveniently available a piece of equipment well suited to the task of producing pictorial output from the SEAC memory. This equipment was capable of decoding two ten-bit fields in a SEAC memory word and producing two analog voltages corresponding to the two sections of the word. There could be up to 96 such words decoded. The rate of presentation of the output signals was 23 kc.

The obvious course was to connect these two analog voltage outputs to the horizontal and vertical inputs on an oscilloscope and thus to plot points on the face of the scope corresponding to the information presented by a computer program for purposes of display. As it turned out, the display equipment was more than adequately fast for SEAC, since no program could generate useful display information that would change at a 23-kc rate.

To display a picture that had been fed into the computer from the scanner, it was then necessary to write a program which derived a pair of coordinate numbers for each binary 1 in the picture in the SEAC memory in such a way that these coordinates corresponded to those of the point in the picture from which the binary 1 was generated. The program then displayed a spot on the output scope corresponding to the spot on the original picture.

As an example of the use of the output display routine, Fig. 3(a) shows a picture fed into the scanner and Fig. 3(b) shows the same picture reproduced from the output display. To produce this picture, an artifice was used which allows the visual effect of a continuous gray scale to be produced on a single scan. As seen in Fig. 2, there is a manual discrimination threshold setting. Ordinarily, this setting determines the level at which black is distinguished from white. To scan the picture of Fig. 3 this discrimination threshold was varied with a sawtooth waveform at a frequency approximately one half that of the strobing frequency. The result was to produce the familiar "halftone" effect in which the density of uniformly black spots is proportional to the blackness of the original picture. The picture display routine produced the output photograph.



(a)

(b)

Fig. 3—(a) Grey-scale photograph. (b) Computer halftone reproduction of (a).

III. Experimental Investigations

With the equipment that has been described, a series of experiments were initiated with the goal in mind to program SEAC to recognize patterns of the type recognizable by human observers. As a first step toward this goal, it was decided to produce a library of picture processing subroutines which an investigator could use in programming pattern recognition. This section describes the library of routines that were written.

In pattern recognition the aim is to reduce the amount of information to the minimum necessary for recognizing one pattern from a group of patterns. In these experiments the approach was to develop a library of computational processes for simplifying patterns in order to obtain their most significant features. Preliminary experiments were concerned with determining those manipulations which would prove to be the most informative. The compilation of discrete routines for the performance of these elementary manipulations would provide the basis of a flexible system for simulating many widely diversified pattern identification logics. After determining the intended course of his pattern analysis, the programmer needs only to refer to this file and to select those routines which in combination will best serve his purpose.

Furthermore, it should be possible for the analyst to sit at the computer console and to draw from this tape library several routines which he will select pragmatically after studying the results of any preceding operations, and thus guide the computer step by step toward recognition of the pattern being studied. We distinguish two forms of output in these routines—numerical data and transformed pictures. Numerical data can be read directly from the computer but pictorial information must be converted before it can be displayed by the picture output scope. The picture display routine is used in such cases.

One of the simplest routines in the library counts the total black area in a pattern. This program examines each bit in sequence and tallies when the bit represents a black area. Advantage is taken of the fact that in many patterns there will be numerous words that are all black or all white. By comparing whole words against constants of all zeros or all ones, much time is saved. The area counting process requires approximately thirty seconds on SEAC.

Pictorial information is an extremely informal sort of information to feed into a computer; it is not stylized in the same sense as numerical or alpha-numerical information. This is one of the fundamental differences that must be faced in operating upon pictorial information. For one thing, pictorial information often contains a good deal of redundancy. The pictures obtained from the SEAC picture input equipment require about 30,000 bits of computer storage. However, the total number of bits of information in the pragmatic sense of the term is probably somewhat less than 100. In view of this fact, a routine was written to provide the data necessary for efficient encoding of pictures. The routine analyzes pictures and tabulates the number of runs of each length of continuous black or white points as they appear in the picture. On the basis of these run lengths it is hoped that we will be able to determine an efficient method of statistical encoding for these pictures.

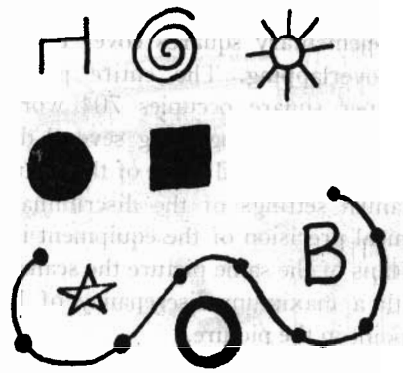


Fig. 4—"Blobs" counted by SEAC.

Object	No.	Area (0.25 mm squares)
	1	56
	2	163
	3	142
	4	187
	5	206
	6	82
	7	404
	8	142
B	9	80

Fig. 5—Areas for each of the objects in Fig. 4.

One possibility is the use of the so-called Shannon-Fano codes [5]-[8] which assign symbols of varying lengths to the different run lengths to minimize the total code length required for any given picture. Preliminary investigation shows that code compressions of the order of at least from 6 to 10 times are possible.

Another routine counts the number of separate noncontiguous black objects (blobs) and measures their separate areas [9]. Due to the restricted memory capacity of SEAC, the routine cannot analyze a full-size input image. Therefore, the image is compressed in the horizontal direction by a factor of four. The routine is devised to scan sequentially through the image until a black point is found, then to move systematically through the blob, counting its points and erasing them until the blob is completely removed from the image. Because the compression in one dimension is not linear, the computed areas are only approximately proportional to the original areas. The blobs are traced so that objects with re-entrant profiles and non-simply connected objects will be recognized as single objects. The time required for SEAC to count blobs in an

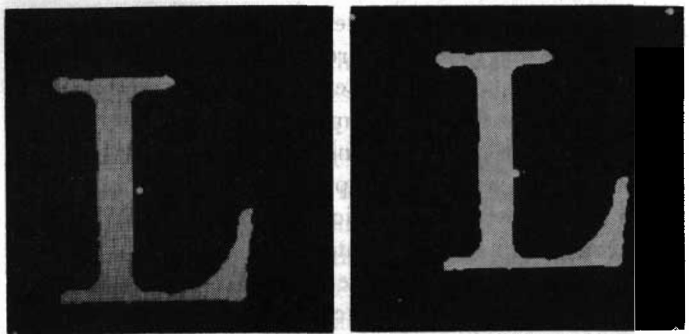


Fig. 6—(a) Letter L with center of gravity. (b) Letter L translated.

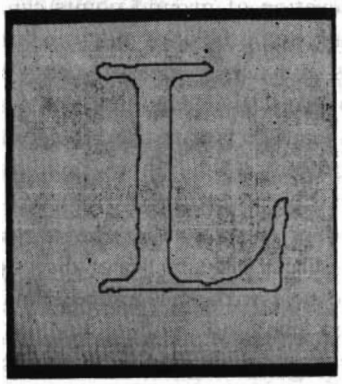


Fig. 7—Boundary of letter L.

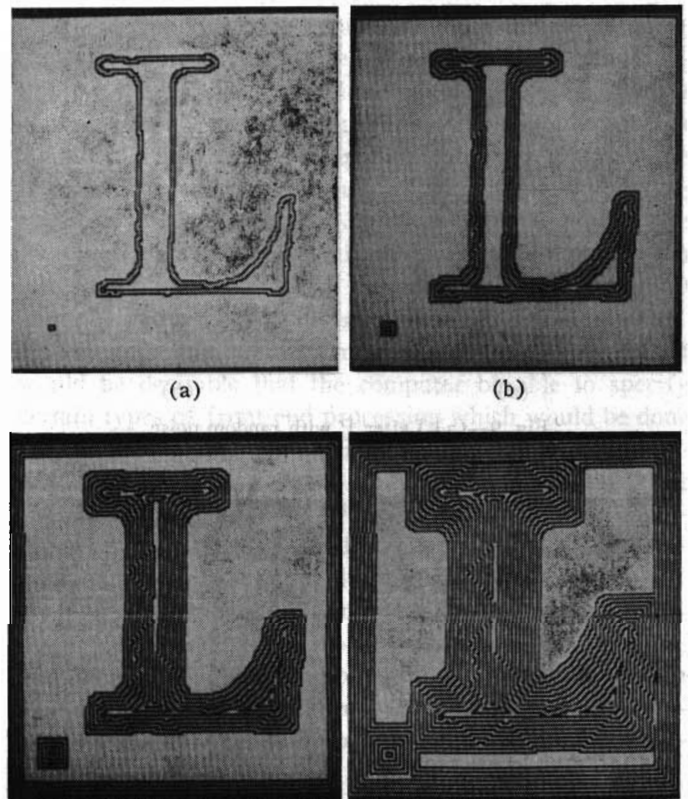


Fig. 8—(a) Letter L custered and complemented two times. (b) Letter L custered and complemented four times. (c) Letter L custered and complemented eight times. (d) Letter L custered and complemented sixteen times.

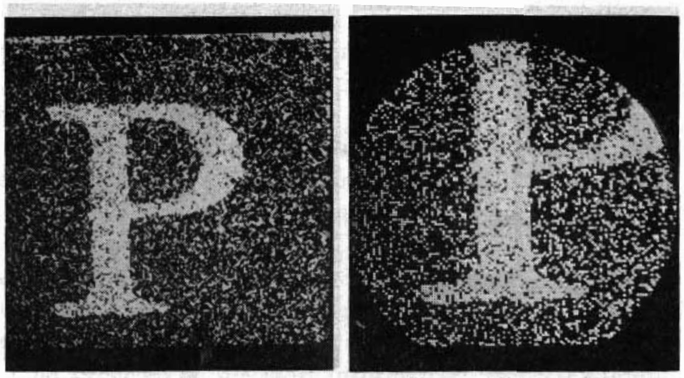
image depends upon the number of blobs and their total areas. An example of the use of the blob counter on the picture of Fig. 4 is shown in Fig. 5, on the preceding page. The area of each blob has not been corrected for the factor of 4 compression.

A second blob counter, which operates with full precision but does not give the areas of the individual blobs, has been planned, but not yet written. This routine examines each bit and its immediate neighbors, generating a tally of each new occurrence of a blob and adjusting when parts of blobs merge or diverge. Nonsimply connected blobs require special checking. There is no limit to the size of the image that can be handled by this routine. The time required on SEAC to process any single pattern from the scanner would be one minute.

Another simple code computes the center of gravity of a pattern and translates the pattern rectilinearly so that the center of gravity is at the midpoint of the image. Fig. 6(a) shows a pattern before translation and Fig. 6(b) shows it after translation. The boundary of the square and the center of gravity are shown as bright spots in the pictures. The translating routine can use any given set of coordinates to determine the shift.

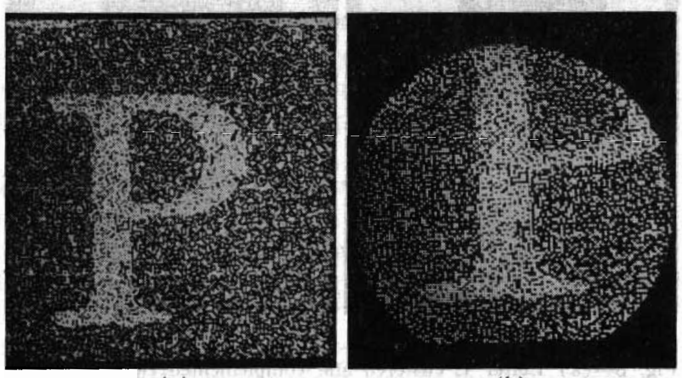
Fig. 7 illustrates the result of a routine which computes what might be called a "first derivative" of the pattern. Each 3-bit square is examined; if all nine bits are black the center bit is replaced by a white bit. The computer operates on three rows at a time, forming logical products of all combinations of each bit with its adjacent bits. These products are, in turn, logically multiplied to produce the final result in which black bits remain only when one or more neighboring bits are white. The effect of this so-called "custer" operation is to preserve the boundaries of a pattern and to erase all the internal areas [10]. Fig. 7 shows the result of computing the boundaries of the letter in Fig. 6. Notice that the boundaries contain most of the significant information of the original picture but require fewer bits. The time required for one "custering" operation is seven seconds.

It was suggested that a thin line representation of certain patterns could be obtained by computing the boundary, reversing the image (*i.e.*, forming the binary complement), recomputing the boundary, etc. Upon consideration it became obvious that this treatment would not produce the proposed result, but the idea aroused considerable curiosity as to what it would produce. As a result of performing this process, it was found, in fact, that the image became more complex and difficult to analyze. In Fig. 8 there are four pictures of the "custered" letter L of Fig. 7 after it was "custered" and complemented a varying number of times. It is interesting to note that the small dust



(a) (b)

Fig. 9—(a) Letter P with random noise.
(b) Expanded section of (a).



(a) (b)

Fig. 10—(a) Fig. 9(a) custered and complemented.
(b) Expanded section of Fig. 10(a).

speck in the lower left-hand corner of Fig. 7 grows much larger in successive pictures, and merges with the L in Fig. 8(d). The next set of figures shows a very surprising result of the custer and complement operation. A program was first written which superimposes controlled random noise on a photograph of a letter P to produce Fig. 9. This noisy letter was then custered 50 times to produce Fig. 10. The "noisy" letter in Fig. 9 is still clearly recognizable in Fig. 10 even after being operated on 50 times. Thus, the "custer and complement" is a process which seemingly preserves the information in a "noisy" picture but degrades the information in a "clean" picture.

In addition to these routines, some other simple routines have been written. These include routines to superimpose pictures, to smear pictures by translating and superimposing them, to magnify pictures so as to make their fine detail visible, to record pictures in permanent form on tapes and wire, and a routine to analyze a set of pictures to determine the number of spots that are always black or always white in the set of pictures.

These routines perform elementary operations, although in some cases, such as "custer and complement," the results of the operation have far from trivial explanations.

Some applied investigations have been undertaken to utilize the potential of this new equipment. Such problems as character recognition, aerial mapping [11], and automatic encoding of the chemical information in chemical-structure diagrams [12] are included.

Much interest has been developed in simulating character recognition logics by some of the preliminary experiments such as those of Greanias, *et al.*, of IBM [2]. The present picture scanning equipment adds to the practicality of simulating recognition logics with computers by providing a convenient source of data input. We plan to simulate some of the logics that have been proposed such as the "peek-a-boo" system, in which characters are recognized by locating the key points in a picture that characterize letters uniquely.

An attempt is being made to program the computer to generate elevation contour lines from aerial photographs. The relative elevation of ground points can be determined from two aerial photographs of the same area taken from different points in space by measurements of the apparent displacement of the elevated points. Some simplifying restrictions were made to reduce the problem to a convenient size for a first attempt. The photographs to be used were assumed to have been restituted to correct for tilt of the focal plane and oriented so that the overlap or shift of ground points occurs only in the x direction. It is much less involved to deal with one-dimensional shifts than the two-dimensional ones.

The contours are determined in three steps. First, similar areas on the two photographs are identified by checking units of 44 bits for the correspondence of at least 39 of the pairs of bits. Groups of bits that are mostly ones or zeros are not compared. Next, the pictures are shifted with respect to each other to bring them into alignment. Finally, all points with the desired parallax are computed and stored in the contour diagram picture. The first two steps of this program have been completed. The parallax determination and the preparation of output photographs remains to be done.

Another intriguing problem is to find a way that a machine could "look at" a diagram, such as a chemical structure diagram, and characterize it uniquely. The work to date has not been concerned with the more symbolic information that appears on structure diagrams, such as element symbols, double bonds, etc. We have attempted to treat only simple nets composed of vertices and bonds drawn between them. The connection pattern has been treated as a topological net and we are not concerned with such things as size of angles, length of lines, width of lines, and line breaks. The program we have been working on will first locate most of the vertices by counting the number and extent of clumps of "black" spots in each line of a picture in both vertical and horizontal tracings. Where these numbers change between successive lines a vertex is indicated. Then, starting at a vertex the bonding pattern could be traced from vertex to vertex. Thus far, the programming is in a preliminary state. The actual coding and handling of the "housekeeping" procedures remains to be done.

IV. Some Unsolved Problems

Thus far the discussion has been concerned with a report of experimental investigations. To those familiar with the application of data processing techniques to new fields, it should be apparent that such experimental investigations generally lead to the formulation of new problems in the two areas of higher performance equipment design and proper utilization of such equipment. The problems in automatic processing of pictorial information that occur in these two areas will be formulated here. To the knowledge of the authors, no solutions to these problems are available.

A. The Development of a High Performance Picture Scanner for Computer Input

In using a digital computer to process pictorial information, it is unthinkable that any large quantity of pictorial information should be scanned and stored on conventional computer storage media like magnetic tapes unless a tremendous amount of reduction of information has first taken place. The maxim that "one picture is worth ten thousand words" is probably overly optimistic for fairly common sources by about three decimal orders of magnitude, if a "word" means 25 to 50 bits.

This estimate is based on a comparison of the number of binary digits needed to describe highly stylized information in pictorial form and in such a form as to describe only the "meaning" conveyed by the picture. This means that in applications where it is either not possible or not practical to encode (and thereby reduce) information in a photograph, the best way to store a photograph is in its original form.

However, to make such information available to a computer, equipment is needed that will mechanically handle photographic information and that will be able to sense the information for input to a computer. The mechanical handling can probably be solved in many ways. Such devices as a microfilm rapid selector might be appropriate.

For the optical scanning of the photographic information, however, it appears that a device with performance somewhat better than conventional cathode-ray-tube flying spot scanners is required. If we assume an average document size of 8×10 inches then the scanner must be able to resolve a field of the order of $10^3 \times 10^3 = 10^6$ spots. Although it is seldom necessary to scan a whole pictorial source with this resolution, any section of a picture must be capable of being resolved with this precision. The data rate for a computer like SEAC should be 1 megacycle. Thus, if it is necessary to scan a whole field, it should be possible to scan the 10^6 bits in one second.

It is anticipated that with such a scanner, the computer would first direct the scanner to locate information. The most straightforward way to do this would be to have a defocused scan or perhaps several different levels of defocusing. Thus a field of $2^{10} \times 2^{10}$ bits might first be scanned with a raster of 32×32 spots. Since each spot would cover in turn an area of another 32×32 elementary spots, it would be necessary to be able to get something of the order of a 10-binary-digit reading of the light value from any spot. It would be unreasonable to expect an *accuracy* in such a reading, but such *precision* would be required. In other words, upon successive scans of the same large square array of 32×32 elementary spots, the same reading should be obtained within 1 part in 2^{10}, even though the reading itself is not accurate. The inaccuracy can be compensated in the computer programs.

In addition to the performance of the actual scanner, it would be desirable that the computer be able to specify certain types of front-end processing which would be done by suitable fast analog equipment, *e.g.*, time differentiation of the scanning signal and insertion of logarithmic response functions. Certain simple analog operations performed on the scanner signal can save a great deal of complex processing by the digital computer.

With a scanner such as this and with suitable mechanisms for motion of the photographs, it would be possible to get the photographic information into a computer at a rate comparable to the present processing rate of the computer. The next problem would be how to use this information.

B. The Effective Use of a Picture Processing Computer

It was stated at the outset of this paper that an aim of the present investigations is to automate some of the visual processing of information done by human beings. The beginning of the processing operation is, logically, the statement of requirements. Therein lies the rub! We can state our requirements to a human being and expect some intelligent performance but we do not know how to do this with a computer program. There seems to be fairly universal agreement among people as to what constitutes a picture of an automobile, a letter "e," or the President of the United States. This ability to recognize patterns is not learned the way the ability to multiply numbers is learned. Most of the pattern recognition ability of people exists on a nonarticulate level. In order to program a computer to duplicate this pattern recognition ability, it is necessary to make explicit the techniques that people use and then instrument these techniques in computer programs [13].

To accomplish this we require an automatic programming technique in which macroscopic patterns can be defined in terms of more simple ones [14]. This type of technique which would assume the nature of an automatic compiler would eventually enable a programmer to describe familiar objects in terms of other more simple but nevertheless familiar objects. Thus a linguistic formalism would be constructed which would continue to approach closer at successive levels of approximation to the formalism used by people in describing pictorial information.

Experiments are being initiated at NBS on the construction of such a compiler, however, there are no results available yet.

V. Areas of Application of Picture Processing Techniques

Much of the work described in this report was motivated by the promise of application in the solution of important problems. Other areas of application have suggested themselves as the work progressed. We discuss below those classes of applications.

A. Analysis of Pictures

In this class of applications it is desired to subject a picture to an analysis, the result of which is to produce some alphabetical or numerical data. The picture itself has, in principle, no value for retention after the analysis. It is desired to abstract some information from the picture and store this.

The first application in this area occurs in information retrieval of the type practiced in the U.S. Patent Office. Documents containing drawings and schematics are to be stored for purposes of subsequent reference by a computer. If a drawing can be coded so that an equivalent one can be reconstructed from the code, this is sufficient for storage purposes. Obviously, such pictorial considerations as the quality of the lines in a circuit diagram need not be preserved in the code. Thus we are led to the attempt to recognize by machine such configurations as chemical structure diagrams, electronic circuit schematics, and drawings of mechanical configurations. These problems show promise of yielding to the type of investigations described here.

Within the same class of analysis applications fall the problems that involve counting objects in a picture. Here we have such cases as the counting of particles in microphotographs of metallic structures, classification of particles in biological preparations, and analysis of tracks of nuclear particles. In the area of astronomy, knowledge comes mainly from photographs taken through telescopes or other instruments and the analysis of these pictures now requires considerable time in order to generate a rather large body of data. Picture processing techniques might be used for such problems as computing star positions and proper motions, evaluating star brightness or magnitudes, and automatically setting up star catalogs.

B. Transformation of Pictorial Information

In this class of applications, information is to be prepared for visual consumption by human beings. Generally, the information is originally in such a form that it cannot be used by human beings. The question will be left unanswered whether human beings may be replaced by automatic processes as visual consumers of the information produced in the applications in this class.

The first such application occurs in photogrammetry. A stereo pair of aerial photographs is to be processed to produce an elevation contour map. By techniques based on principles described, it is believed possible to use a digital computer to generate elevation contour maps. If investigations in pattern recognition proves successful, it may even be possible to superimpose cultural information upon maps, the whole process occurring automatically.

Another application of these techniques to the transformation of pictures was suggested to the authors by M. L. Minsky of M.I.T. Picture processing techniques could be used to develop a good reliable set of photographs for the planet Mars. We know that one of the main reasons that a good photograph of Mars doesn't exist is that there very rarely are conditions of perfect seeing where the entire disk of the planet is clearly visible and all of the details on it are plainly visible.

There are, however, several million frames of motion picture film that were taken of the planet Mars during its opposition. By an analysis of these photographs, abstracting those bits that represent good clear seeing in any one frame and putting them together to form a composite photograph of the disk of the planet, we may be able to get a good reliable map of the true features of the planet.

C. Simulation of Picture Processing Systems

In this class of applications, the digital data processing system in conjunction with its picture input and output is used to simulate the behavior of a system or the model of a system that processes pictorial information.

The most obvious use of such simulation techniques occurs in applications to character recognition studies. Fairly complex character recognition devices can have their behavior simulated by a data processing system. In this way devices can be "flown on the ground" without the necessity of costly construction of apparatus.

A more unusual application of such simulation techniques occurs in the field of experimental psychology. In attempting to explain human vision, theories have been propounded which are subject to analysis by simulation techniques. Many operations that have neurophysiological counterparts can be programmed on the type of research facility described here [15],[16]. It is to be hoped that the eventual use of general purpose picture processing simulation techniques will aid in encouraging the formulation of more ambitious theories of the functioning of the human visual process.

VI. Conclusions

In this paper a new type of research facility has been described which allows complex investigations to be made into the nature of pictorial information and into ways in which computers may be programmed to process such information with the same comparative ease that characterizes human processing of visual information.

The apparatus described here as well as the experiments performed are strictly of a research nature. Consequently no conclusion should be drawn as to the practicality of such processing as is described here. Before such applications become practical it will be necessary at least to solve the type of problems described here, namely, those of the design of high performance scanning equipment and the development of automatic techniques for the recognition of visual patterns.

The applications of automatic pictorial information processing techniques described here are not meant to represent the most important applications that can be anticipated. They are, rather, meant to illustrate typical classes of processing techniques that can be automated if experiments of the type outlined here lead to successful conclusions.

VII. Acknowledgment

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Bibliography

[1] Glauberman, M. H. "Character Recognition for Business Machines," *Electronics,* Vol. 29 (February, 1956), pp. 132-136.

[2] Greanias, E. C., Hoppel, C. J., Kloomok, M., and Osborn, J. S. "Design of Logic for Recognition of Printed Characters by Stimulation," *IBM Journal of Research and Development,* Vol. 1 (January, 1957), pp. 8-18.

[3] Rabinow, J. "Report on DOFL First Reader," Diamond Ordnance Fuze Laboratories, Washington, D.C., Report TR-128, November 26, 1954.

[4] Stone, W. P. "The Alphanumeric Character Reader—RADC, ARDC, USAF," RADC-TN-56-194, AD 103-237.

[5] Fano, R. M. "The Transmission of Information," Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Mass., Technical Report No. 65, 1949.

[6] Huffman, D. A. "A Method for the Construction of Minimum-Redundancy Codes," Proceedings of the IRE, Vol. 40 (September, 1952), pp. 1098-1101.

[7] Michel, W. S. "Statistical Encoding for Text and Picture Communication," AIEE Conference Paper CP 57-723, May 1, 1957.

[8] Shannon, C. E. "A Mathematical Theory of Communication," *Bell System Technical Journal,* Vol. 27 (July, 1948), pp. 379-473 (October, 1948), pp. 623-656.

[9] Dell, H. A. "Stages in the Development of an Arrested Scan Type Microscope Particle Counter," *British Journal of Applied Physics,* Supplement, No. 3 (1954), p. 156.

[10] Kovasznay, L. S. G., and Joseph, H. M. "Image Processing," Proceedings of the IRE, Vol. 43 (May, 1955), pp. 560-670.

[11] Strand, O. N. "Mathematical Methods Used to Determine the Position and Attitude of an Aerial Camera," U.S. Ordnance Test Station, 1585, NAVORD Report 5333, March, 1956.

[12] Ray, L. C. and Kirsch, R. A. "Finding Chemical Records by Digital Computers," *Science,* Vol. 126 (October 25, 1957), pp. 814-819.

[13] Selfridge, O. G. "Pattern Recognition and Modern Computers," *Proceedings of the Western Joint Computor Conference* (March, 1955), pp. 91-93.

[14] Dinneen, G. P. "Programming Pattern Recognition," *Proceedings of the Western Joint Computer Conference* (March, 1955), pp. 94-100.

[15] Clark, W. A., and Farley, B. G. "Generalization of Pattern Recognition in a Self-Organizing System," *Proceedings of the Western Joint Computer Conference* (March, 1955), pp. 86-91.

[16] Farley, G., and Clark, W. A. "Simulation of Self-Organizing Systems by Digital Computer," IRE Transactions on Information Theory, No. P61T-4 (September, 1954), pp. 76-85.

Discussion

V. M. Wolantis (Bell Telephone Labs.): Do you find it satisfactory to distinguish only between black and white rather than a number of shades of gray?

Mr. Kirsch: No, that is often not adequate. For purposes of looking at schematic diagrams or printed characters, two values of light intensity are adequate. However, for looking at the most interesting types of pictorial information, people's faces and so on, we should like to distinguish several shades of gray. What I showed you was a poor compromise between having full gray scale rendition and having only the black and white rendition. In the photograph of the person's face, what we were doing was sacrificing some of our resolution in order to get some gray scale information, but certainly ideally we would like to have considerably more gray scale information.

Mr. Wolantis: To what extent would a TV camera help solve the problem you mentioned near the end of your talk?

Mr. Kirsch: A TV camera would help. We would like to scan a million-bit picture in a second, but we also want to be able to deflect to any spot or zone on the picture with an access time of a few microseconds.

For the purposes of using the picture as a computer memory, which is after all what we were proposing that the high performance scanner do, we would want considerable reproducibility of scan. We would want the scanning device to go back and look at the same picture any number of times over the course of a machine computation, and be able to copy the same information; I don't know whether a standard TV camera type of scan is capable of that type of performance.

Mr. Rellis: Can you state time required to execute some of the programs cited?

Mr. Kirsch: Yes. The custer and complement for one cycle takes seven seconds and thirty seconds to take the area of a whole picture. To generate the coordinates of the output point from the information in the memory for a whole picture of 30,000 bits takes about one minute.

The most time consuming of the routines is the blob counter, which is a function of the complexity of the image being blob counted, and here that routine will take anywhere from about a minute to perhaps three minutes, or even more. However, these numbers are a reflection not of the intrinsic complexity of the processes, but rather of SEAC computation time, and an indication of that speed is that the SEAC add time is about a quarter of a milli-second. So you can see that a faster machine certainly would be able to do the processing more rapidly. It turns out, however, that by way of impedance matching the operator's thinking time with the computer, this is not really too slow. The machine can test out an idea at about the rate a person can generate it.

Mr. Rellis: Has any consideration been given to the similarity between multiply-custered black objects on white, and fingerprints?

Mr. Kirsch: Yes, many people have suggested this, and although we haven't done any serious investigation, some people have also suggested that perhaps by doing inverse custering on a fingerprint, one might get a picture of the criminal's face.