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Technical Note 112

AUTOMATIC CHARACTER RECOGNITION

A STATE-OF-THE-ART REPORT

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS
Technical Note

112

MAY 1961

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Mary Elizabeth Stevens

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AUTOMATIC CHARACTER RECOGNITION:
A STATE-OF-THE-ART REPORT

M. E. Stevens

ABSTRACT

A state-of-the-art report on current progress in automatic character recognition is presented. Areas of applicability and possibilities for controlled solutions to automatic character reading problems are discussed. Some commonly used methods for character recognition, the steps involved in a generalized recognition process, and comparative characteristics of certain representative character recognition systems are considered. Prospects for further progress, including potentially related research in pattern recognition, are reported.

1. INTRODUCTION

Current progress in research looking toward large-scale information selection and retrieval systems or toward mechanized translation, has been accompanied by increased attention to problems of input, file preparation, and file maintenance. These two are important areas for the potential application of automatic information processing techniques. In both there is an increasingly well-recognized need to prepare large files or a large volume of input messages in machine-usable language. In addition, the availability of natural language textual material in machine-usable form is becoming increasingly important for further progress in research in linguistics, which should pace further promising developments in both information selection and mechanized translation.

This report of the Research Information Center and Advisory Service on Information Processing is one of a series intended as contributions to the improvement of cooperation in the fields of information selection systems, information retrieval research, and mechanized translation. In these fields, as in others, the use of automatic data processing equipment has both posed new problems and offered new solutions to the handling of large masses of information. From a systems standpoint, a particularly critical problem is the need to copy, to transcribe and in some cases to transliterate large volumes of data for further processing by machine. The background of the present study, certain general observations, and a brief discussion of the presentation to be followed are given first.

1. 1 Background

The development of automatic techniques for transcribing data from typed or printed form to a form directly usable by machines holds considerable promise for eventual application in a wide variety of data processing operations. Such automatic techniques consist, in general, of devices or machine systems that are capable of performing the following operations:

(1) Feeding paper or other carrier material that bears typed or printed alphanumeric information to a sensing station;

(2) Controlling the position of each line and each symbol for scanning;

(3) Scanning and processing the two-dimensional visual image presented;

(4) Comparing an input image as a pattern against a set of reference patterns representing the vocabulary of symbols to be recognized;

(5) Identifying the input pattern as the product of the scanning-recognition process;

(6) Providing an output symbol representing the particular input symbol that has been recognized.

Such techniques promise major advantages in a wide variety of data processing and data handling situations, specifically including those of mechanized information selection systems and mechanized translation. These potential advantages include reductions in manpower requirements as well as reductions of errors and inaccuracies found in manual data transcription operations.

This report incorporates the results of a fact-finding survey of automatic character reading techniques which was conducted by the National Bureau of Standards for the Rome Air Development Center in the period 1956-1957. The earlier survey has been extended and supplemented by study of the available literature, by continuing inspections of character reader devices, and by periodic discussions with research and development personnel interested in automatic character recognition techniques. The purpose of this report is therefore to review current developments in the field of character recognition, with emphasis upon actual devices designed to identify printed or typed information.

"That the blind may read," 1/ is the earliest recorded objective for research attempts to develop devices capable of reproducing and transcribing printed, typed, or handwritten characters. From the Optophone of Fournier d'Albe as demonstrated in 1912 2/ to the latest contractor's progress reports to the Prosthetic and Sensory Aids Service of the Veterans Administration, 3/ this objective has been approached in two distinct ways. The first avenue is that of reproduction, such as pantographic copying in a different size or at a distance. This direct translation approach includes many different means for transducing the black and white character to some other form. Examples include the conversion of a distinctive two-dimensional visual pattern to a distinctive pattern of sounds 4/ and the projection of the character pattern to a pattern of raised pins on the head-surface of a hand-held probe. 5/ We note that: "Such reading machines have no 'brains' whatever built into them. They require on the part of the user the mastery of a code which bears no relation to anything he may have learned before." 6/

The second avenue, conversely, is that of the development of techniques capable of reading and recognition in the sense of identifying a given character image as a specific one of a number of images in a reference vocabulary. That is, the character is 'recognized' and not merely copied or transformed. We thus define 'recognition' as a process requiring a decision as to which specific one of a plurality of possible input patterns was in fact 'sensed' by a suitable scanning-detection mechanism. Such a decision is used to select a particular one of a plurality of possible output patterns, whether it is a phonetic sound, associated with an alphabetic character or the appropriate code-sequence for direct computer processing. Ultimately we may hope for the machine-recognizer to do more: in effect, to override as necessary the formal implications of a received input pattern. There is, for example, no acceptable word in English with the character sequence "a, c, o, u, i, ..." so that "q" should be substituted for the "o" by applying context-dependency rules. It is this second approach, involving recognition decision, that we shall refer to by such terms as "automatic reading techniques" and "automatic character recognition".

Various distinctions have been made in the literature between 'character recognition' and 'pattern recognition'. For example, it has been noted that: " 'Pattern' ... means much more than 'character pattern' and generically connotes an arrangement or inter-orientation with no necessary semantic value". 7/ On the other hand, it has been observed that: "The distinction between a 'character' and a 'pattern' is important because both a Gothic and an Arabic A may be considered to be the same 'character', but are entirely different patterns". 8/ In this report we shall be concerned with the recognition of character patterns, that is, with appropriate subsets of the set of two-dimensional visual patterns which display substantial color-contrast between figure and ground and which are equated for various practical purposes with the letters of the alphabet, the digits of a numbering system, and punctuation marks. We shall also consider certain aspects of the more general field of pattern detection, pattern recognition, and pattern formulation from the point of view of indicating fruitful areas for further progress.

1/ Kerwood uses exactly this wording as title for a brief survey of reading aids, " ... That the blind may read," Ref. 253. (Note: The notation "Ref xxx" refers to the correspondingly numbered item in the bibliography, pp. 137-168.

2/ Fournier d'Albe, E. E. "A reading optophone", Ref. 145. See also Refs. 2, 144, 146, 149, 386, 549.

3/ Freiberger and Murphy (Ref. 149) provide a recent review as of March 1961. Representative progress reports include Refs. 1, 3, 4, 120, 121, 300.

4/ See, for example, Refs. 38, 149, 507, 508, 509, 541, 544, 545, 547, 548, 549.

5/ That is, a "tactile replica" device. See Surber, "Reading and writing device for the blind", Ref. 465. See also Refs. 149, 412, 434, 487, 507 (pp 9-10), 508 (p. 6).

6/ Ritter, C. G. "Technical research and blindness", Ref. 386, p. 17.

7/ Young, D. A. "Automatic character recognition", Ref. 539, p. 2.

8/ Grimsdale, R. L., F. H. Sumner, C. J. Tunis and T. Kilburn. "A system for the automatic recognition of patterns", Ref. 185, p. 210.

1.2 General Observations

The present state of the art in automatic character recognition, as we have defined it, ranges from magnetic ink character recognition devices to continuing activity in research on character and pattern recognition techniques. It covers both optical readers now in actual field use for applications involving limited character vocabularies or specialized fonts, and operational prototypes of devices capable of reading a typed or printed page. In the 1957 survey, the following evaluation of the then state of the art was made:

> "In summary, then, the current state of the art of automatic character recognition provides reasonably good prospects for reading limited vocabularies of good quality material where carrier-item handling and positioning difficulties can be closely controlled. For large-vocabulary multiple-type carrier-item applications, considerable development effort will still be required. This is especially true in the areas of full-page text reading, in the reading of average quality typewritten material at normal spacing, and in the reading of foreign language materials. The possibilities of developing a standardized type-face for general use in both printed and typed material should materially reduce the logical requirements in automatic readers as well as produce other benefits to management. Paper handling and positioning problems will require extensive engineering for improvements necessary to deal with a variety of materials in varied formats from a variety of sources over which there is no administrative control." 1/

In a later survey of the field, Minot 2/ made the following evaluation:

> "Commercially profitable devices for pattern recognition, as of 1 April 1959, include devices for (1) reading capital letters and numbers of a selected type face or faces, and (2) counting objects of certain sizes and shapes. The extent of research, development, and interest in this field and allied fields suggests strongly that within two to five years much more complicated tasks of 'visual' recognition will be performed automatically."

The American Bankers Association recommended adoption of magnetic ink for automatic character recognition in 1956, 3/ There is now widespread commitment to and use of this "MICR" system in various banking operations. The Farrington Company, through its subsidiary, the former Intelligent Machines Research Company, can claim the pioneering application of optical reading techniques in actual production situations, with an installation at Reader's Digest in 1955. 4/ Farrington - IMR today has more than 40 machines installed for various customers, including the Rome Air Development Center 5/ which has a page-reader in operation. A typed-page reader for double-space, upper case, 12-point standard elite type, has also been demonstrated for the U.S. Army Signal Research and Development Laboratory, by Control Instruments Company, a subsidiary of the Burroughs Corporation. 6/ Other organizations currently engaged in development of full-page character readers, some of which are designed for Cyrillic alphabets, include Baird-Atomic, Philco, RCA, and Rabinow Engineering. In a survey for the journal Management and Business Automation, for September 1960, Keller, after citing Farrington-IMR automatic reader applications, made the following statements:

1/ Ref. 462, p. 67.

2/ Minot, O.N. "Automatic devices for recognition of two-dimensional visual patterns: a survey of the field", Ref. 310, p. 23.

3/ The report, "Magnetic ink character recognition: the common language for check handling", prepared by the Technical Subcommittee on Mechanization of Check Handling of the Bank Management Commission, American Bankers Association, was published in the journal Banking in August 1956. See Ref. 289, also Refs. 8, 9, 10, 11, 12, 13, 14.

4/ Keller, A.E. "Optical scanning - an unlimited horizon", Ref. 249, p. 25.

5/ "Electronic machine reads typewritten material", Ref. 115; see also Ref. 333.

6/ Deckert, W.W. "The recognition of typed characters", Ref. 87.

"IBM, GE, RCA, and NCR are among those expected to announce their entry into the optical scanning field at any moment. The National Data Processing Company, Dallas, has announced plans to install the first optical scanning system to handle retail accounts receivable." 1/

The IBM 1418 Optical Character Reader has already been announced, with deliveries promised for early 1962. 2/ The equipment will be capable of reading IBM 407 type font, 10 characters to the inch, or the 407-E font, 7 characters to the inch, as imprinted by plastic charge plates. 3/

Many other companies, both in the United States and abroad, have developed either magnetic ink recognition devices, or optical reading equipment, or both. Demonstrations of additional full-page readers for printed and typed material are scheduled for the early months of 1961. In most of these cases, there are limited, specially designed vocabularies of characters to be recognized. Engineering considerations have generally been more significant in these development programs than questions of research in recognition logic have been.

In the United States, a list of companies and organizations interested in the field of either magnetic or optical scanning would be out-dated almost as soon as such a list could be alphabetized. Most of the major U.S. concerns engaged in data processing, manufacture of office equipment, and development of communication systems, are actively interested in possibilities for automatic character recognition. For example, among the organizations not yet committed to a specific product development line, the Remington Rand Division of the Sperry Rand Corporation reports that it is actively investigating the developmental and marketing possibilities for optical as well as magnetic ink scanning and recognition. New entries in the field are to be noted almost daily. Thus, in the March 1961 issue of Datamation, 4/ an advertisement reveals that a long-range program in pattern and character recognition has been initiated at the General Motors Research Laboratories, Warren, Michigan.

Elsewhere than in the United States, optical character recognition techniques are being investigated, for example, in a number of institutions in the Soviet Union: at IBM Deutschland, at the Technische Hochschule, Karlsruhe, and at Standard Elektrik Lorentz, in West Germany; at universities at the National Physical Laboratories, and by commercial organizations in the United Kingdom. Perotto of Olivetti, Milan, and Gamba, of the University of Genoa, represent interests in the field in Italy. 5/ Research and development activities in automatic reading techniques are in progress at the Eleccrotechnical Institute, Japan, and a prototype reading machine developed by Sakai of the University of Kyoto was demonstrated in February of 1961. 6/

In the three and a half years that have elapsed since our previous report on this subject, therefore, we note that there has indeed been progress. However, there has been rather less progress, with certain notable exceptions, than might have been expected considering that the domain of potential applicability is so widespread. Within this wide area, certain problems can perhaps be solved no other way. Thus the state of the art remains characterized by both paradox and promise. There are paradoxical aspects because that which can be regarded as "everybody's problem" tends to remain "nobody's problem". Minot in his 1959 study 7/ specifically states that such advances as recognition of many styles of printed characters, handwriting, landmarks, silhouettes, reading of diagrams, and the like, must await "mostly the necessary economic push".

There also appears, paradoxically, to be some tendency to wait for solutions to the most sophisticated problems in the field rather than to test the already available aids to mechanized information processing. The feasibility of applying automatic reading techniques for good quality

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1/ Keller, A.E. "Optical scanning ... ", Ref. 249, p. 24. See also Ref. 90, p. 39.

2/ See Refs. 222, 223, 224, 234, 349.

3/ "IBM general information manual. 1401 Data Processing System. 1418 Optical Character Reader," Ref. 232.

4/ Datamation, 7:3 (March 1961) p. 59.

5/ See Ref. 154.

6/ See Ref. 332.

7/ Minot, O.N. "Automatic devices for recognition of visible two-dimensional patterns: a survey of the field." Ref. 310.

printed, typed, or tabulator-listed copy does not necessarily depend upon the achievement of high accuracy in letter-by-letter recognition of cursive handwriting. On the other hand, in fact, handwritten numerals have already been recognized with accuracies of 80% or better.

There also seems to be some insistence on gaining a number of major new advantages concurrently. That is, some proposed performance specifications call for markedly increasing the speed of transcription while reducing costs and also simultaneously improving upon present standards of reliability. A suggested performance standard for an automatic character reader, for example, 1/ includes the following statements:

> "A fundamental requirement is reliability. All characters within its scope should be read correctly in spite of bad printing, dirt and smudges, impurities in paper, misalignment, and other unavoidable imperfections ..... on no account should it misread one character for another."

Such requirements are both impractical and unrealistic in the face of the fact that manual errors are now lived with, even in carefully controlled accounting operations. As many as 2 in 10,000 keypunched characters may be erroneous, even after verification. Without verification, the keypunching error rate may be as high as 1 in 500 characters. In addition, as much as 4% or more of the original data may be in error by virtue of human mistakes in copying, say, a stock or catalog number.

We note that there is promise, however, both in the area of development of automatic character recognition devices and in the area of potentially related research. The use of optical character recognition techniques for special-purpose alphabets has been independently adjudged economic in at least one nationwide industry in the United States.2/ Several different page-readers for a reasonable variety of Cyrillic typeface styles are approaching the stage of demonstration. A proposed reader for microfilmed pages of Russian text, intended for input to a mechanized translation program, was described by Baird-Atomic representatives at hearings of the Committee on Space and Astronautics, U.S. House of Representatives, in the Spring of 1960. 3/ At least one organization engaged in development of automatic reading techniques, the Rabinow Engineering Company, is considering a character recognition system for a 10,000-character Chinese font.

Tests recently conducted by the Bureau of Supplies and Accounts, Department of the Navy, for typewritten material prepared in the field show surprisingly good results considering the lack of control of the quality of input. Figure 1 shows samples of the material, prepared on typewriters with a slightly modified typeface, which was successfully read by a Farrington-IMR reader (Figure 1a) or rejected by the machine as too light (Figure 1b), or too dark (Figure 1c). Other samples were rejected as being improperly prepared (Figure 1d). It should be noted that those who were to type the material for the tests were specifically instructed not to make strikeovers. Even on preliminary tests, after sorting out improperly prepared documents, 80% or more of the samples were read. Under these conditions, the preliminary observed error rate of 3.03%, for documents, but of only 0.33% in terms of characters, appears promising. 4/

We note also that the "too light" category of Figure 1 is to be interpreted in terms of the conditions of the test. Specifically, these included card characteristics such as the use of format and field boundary lines and preprinted fixed information. Although the carrier background was deliberately imprinted in light blue ink, the typed impression in some cases gave approximately the same intensity-contrast values as did that background. The same characters on clear white bond paper would often have been readable by the same machine.

An important distinction for purposes of evaluating current progress and promise in the field is to be made between "rejects" and "errors". The term "reject" refers to nonrecognition, or failure to identify, while "error" refers to a misrecognition, or false identification such as a mistaking of an "A" for an "R". 5/ If, in the operational requirements of a particular proposed application of

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1/ Broido, D. "Recent work on reading machines for data processing," Ref. 61.

2/ Keller, A.E. "Major breakthrough in paper processing", Ref. 248.

3/ Baird, W.S., W. C. Driscoll, and J. A. Fitzmaurice. "Statement." In: <u>Research on mechanical translation. Hearings before the Special Investigating Subcommittee of the Committee on Science and Astronautics,</u> Ref. 33.

4/ Data through the courtesy of B. Radack, Systems Research Division, Bureau of Supplies and Accounts, Department of the Navy.

5/ Compare, for example, the definition of Marill and Green: "Each physical sample will be considered as 'actually belonging to' one of ... n categories. Whenever a pattern recognizer assigns to category j a physical sample actually belonging to a category other than j, we say that the pattern recognizer has made an error." (Ref. 294, p. 472.)

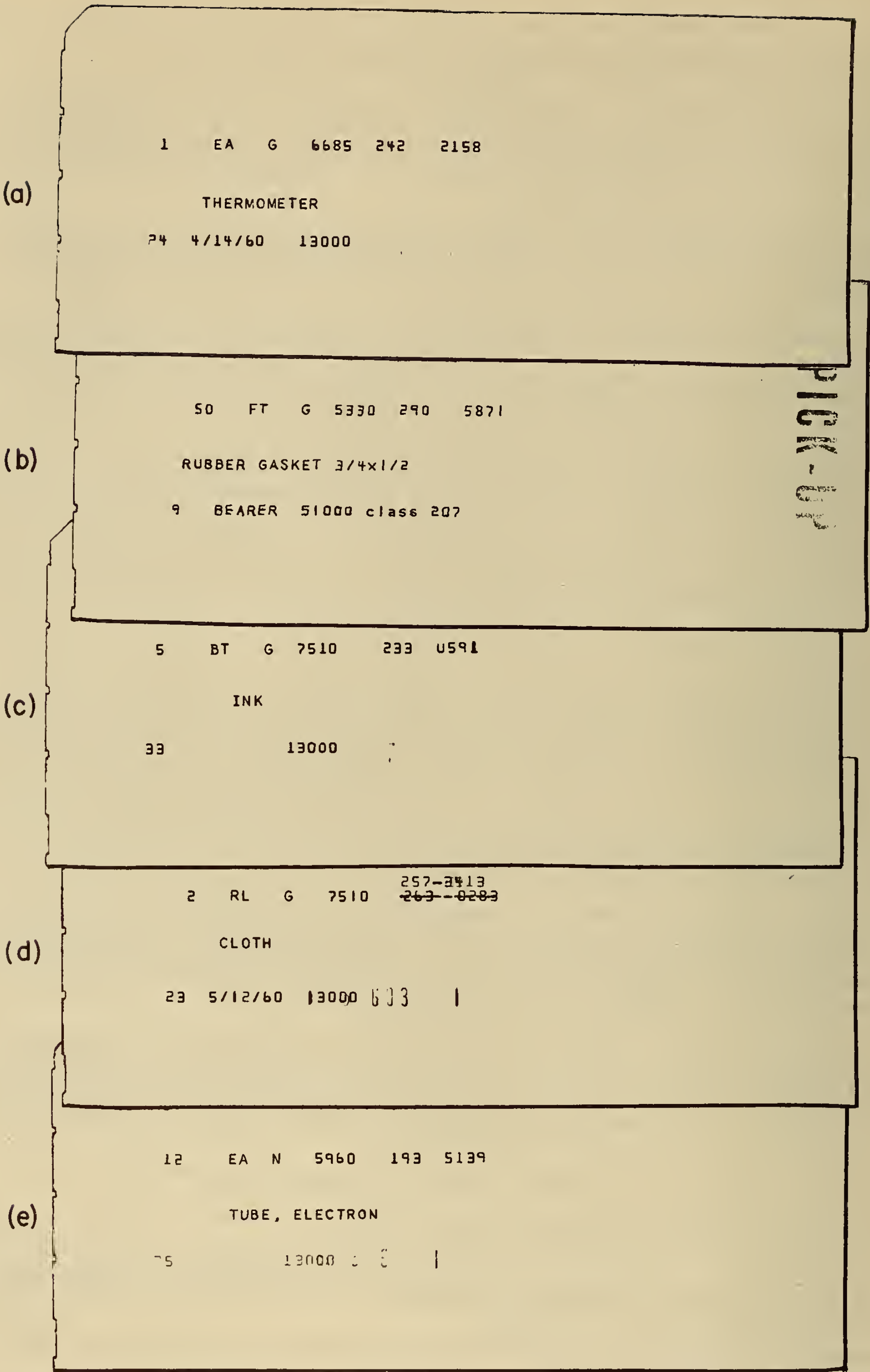

Figure 1. Samples of Typed Material for Test of Automatic Character Recognition

automatic reading techniques, the minimization of true errors is a critical factor, the system can often be designed so that the threshold for rejects is low enough to avoid all but a very small percentage of errors, say, 1 in 100,000, but at the price of manual processing of reject material. It is, as we have noted, one of the paradoxes of the difference between promise and performance in practical use of character recognition systems to date that potential customers insist on minimum-error-rate specifications for a machine of 1 in 100,000, or even more stringent requirements, whereas 1 or more errors in 1,000 characters punched, or 1 in 500 characters typed, is not unusual for manual operations.

Let us suppose, however, that we are concerned with the transcription of natural language texts into machine-usable form. There is to be 100% verification (complete duplicate re-punching, with locked controls for any difference with prior-punched material). Under such conditions, organizations engaged in the machine processing of natural language material report an average cost for input keypunching with verification ranging between 1.5 and 5 cents per word. 1/ Let us further suppose conservatively, that the equivalent cost for machine character recognition systems is not more than a tenth of a cent per word. 2/ Then, we would still have a comparative cost of $2,500 per 100,000 words for the manual system vs. less than half this cost with even a 40% reject rate. 3/

An important indication of future promise, therefore, lies in the realistic appraisal of acceptable reject rates, adjusted so as to minimize the possibility of true errors. We shall discuss the question of the relationship between economic break-even points and possible reject rates in more detail in a later section of this report.

Finally, in the area of promise, we note that research efforts are moving forward in potentially related techniques for the large and open-ended vocabularies of possible character configurations needed for the future. For example, in related research areas, computer simulations of several different methods for recognition of handprinted or handwritten material have been demonstrated. 4/ It has been reported that Solartron will produce a prototype machine for reading handwritten numerals in 1961; 5/ a device for this purpose is being demonstrated at Rabinow Engineering laboratories, and an experimental constrained handwritten character recognizer was displayed by IBM at the 1961 Western Joint Computer Conference. Special devices and computer simulation techniques have also been used in pattern recognition experiments to identify abstract geometric shapes. 6/ Thus we find a spectrum ranging from special-purpose pattern detection devices, where the "patterns" allowed are limited to the specially designed, highly stylized, quality controlled characters in a very limited vocabulary (whether magnetically or optically sensed) to pattern recognition techniques which seek to equate any character that is recognizable by human beings as "A" with any of the other possible printed, typed, block-printed or handwritten versions of "A".

From the standpoint of current development of operational devices and the application of automatic readers in productive data processing situations, however, the following major factors affect the feasibility or the cost of automatic character recognition, in a descending order of importance:

(1) Quality of input;
(2) Size and nature of the vocabulary of characters to be recognized;
(3) Carrier handling requirements;
(4) Reliability requirements;
(5) Flexibility in making adjustments to meet changing requirements.

Of far less significance, as we see the present progress in this field, are such questions as: Particular scanning techniques--for example, whether optical or electronic; particular recognition

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1/ Data presented at the Third Institute on Information Storage and Retrieval, The American University, Washington, D.C., February 1961.

2/ Or less, and we should note that this consideration includes equipment amortization, which is not possible for that part of manual operations involving personnel time and costs.

3/ That is, 100,000 words at $0.001 per word; 40,000 words at a manual rate (for rejects) at $0.025 per word.

4/ See for example Bledsoe, W.W. and I. Browning. "Pattern recognition and reading by machine", Ref. 51. Doyle, W. "Recognition of sloppy, hand-printed characters," Ref. 104, and Estavan, D. "Pattern recognition, machine learning, and automated teaching." Ref. 125.

5/ Young, D.A. "Automatic character recognition", Ref. 539, p. 3.

6/ See for example Clark, W.A. and B.G. Farley. "Generalization of pattern recognition in a self-organizing system," Ref. 76; Harmon, L.D. "A line-drawing pattern recognizer," Ref. 194; Hodes, L. "Recognition of outline figures," Ref. 216; Uhr, L. and Vossler, C. "A pattern recognition program," Ref. 497, and Unger, S.H. "Pattern detection and recognition," Ref. 501.

logics--however simple or however sophisticated; rate-of-recognition, or reject rates. With respect to recognition rate, or reading speeds, for example, we find a range of several seconds per character for computer analysis and decision in the case of handwritten characters, several hundred characters per second for limited vocabulary character readers already in field use, and one or more thousand characters per second in readers designed for alphanumeric page reading. We note especially that the speed at which characters can be identified may exceed the speed at which blocks of such characters can be moved into position for scanning or the speed at which the desired output patterns (such as holes punched into cards or paper tape) can be produced. 1/ For machines with reading rates of better than 1,000 characters per second, direct output to magnetic tape is almost mandatory if the character recognition system is not to 'hurry up and wait' during a large part of the reading cycle.

Closely similar conclusions with respect to the predominance of the factor of quality of input have been stated by the founder of Intelligent Machines Research, (now Farrington Electronics) as follows:

> "However, by far the most significant aspect of most practical character sensing applications is the necessity to cope with imperfections in printing, imprinting, writing of the characters themselves, which imperfections can confound any rule, and in the extreme will confound the human also. When printing is very good very little improvement can perform wonders. When very poor, the most sophisticated logic runs into trouble. Most practical applications lie in between." 2/

1.3 Presentation

For these reasons, then, the present survey of current progress in the field of automatic character recognition will be concerned with the general areas of applicability of character recognition devices, with operational requirements in representative applications, and with possibilities for controlled solutions to character recognition problems, as well as with descriptions of selected techniques and systems and discussion of the prospects for further progress.

The presentation of this report on current progress in automatic character recognition is intended to accommodate various depths of interest, in either scope or coverage of technical detail, on the part of readers having different outlooks with respect either to areas of applicability or to questions of instrumentation. We have therefore: (1) considered information retrieval or mechanized translation applications as only a special case of general data-processing applications of automatic character reading techniques, (2) discussed certain commonly employed methods for character recognition in simplified or general terms, (3) chosen selected examples to illustrate important concepts and current progress, 3/ and (4) considered the broader field of automatic pattern recognition as providing research results clearly indicative of potential applicability to improvements in practical character recognition devices.

2. AREAS OF APPLICABILITY OF AUTOMATIC READING TECHNIQUES

In the broad sense, the ultimate areas of applicability of automatic character recognition techniques include:

(1) All documentation activities where data originally recorded in handwritten, typed, stencilled, or printed form must be copied, re-recorded, or transcribed to the same or to another form and onto the same or onto different types of recording media;

(2) All activities where handwritten, typed, stencilled, or printed data may be verified, counted, sorted or selected without the need for human intervention in these operations;

(3) All activities where other material bearing handwritten, typed, stencilled, or printed information may be sorted, counted, selected, or routed on the basis of the data so recorded, again without human intervention in the data identification processes.

1/ Compare, for example, the following: "NCR's reader has an instantaneous reading rate of approximately 11,000 characters per second. In actual practice, rates are slower than this because of the difficulty of moving paper documents at speeds permitting such fast reading." (Ref. 346, p. 28.)

2/ Shepard, D.H., private communication, February 25, 1958. Compare also the following: "Control of the source and quality of printing is ultra-important'. Once this is achieved, the equipment will take over and do an effective job." (Ref. 90, p. 39.)

3/ In the choice of illustrative examples, however, there has been some deliberate emphasis on early references, precedents in the patent literature, and foreign developments, since these are likely to be less well-known than other sources to readers who have a general familiarity with progress in the field of automatic character recognition systems.

In this sense of character recognition, we are first concerned with the transcription of humanly legible alphabetic and numeric information to some other form, as in an aural character-code for the blind, or as required for some communication-transmission system. Next, we note the applicability of character reading devices as an alternate to the punching and subsequent interpretation of punched-hole patterns on cards or tape for use in such data-processing operations as selecting, counting, sorting, and deriving various statistical tabulations and analyses. With respect to the documentation and utilization of scientific information, there are many possible applications in the preparation of bibliographies, listings of references and acquisitions, catalog cards and index entries; in copying of abstracts; in re-editions of handbooks, catalogs and manuals with minor revisions of text, and in automatic proofreading, especially where the latter task is tedious, painstaking, and requires careful concentration because of the absence of meaningful context.

In the field of mechanized information selection and retrieval systems, potential needs for automatic character reading range from the creation of machine-usable files of documents, messages, and records of subject content analyses, through the use of machines as aids to the analysis (e.g., by various 'automatic extraction' techniques 1/ in the derivation of indexing and selection entries), to the automatic dissemination of selected abstracts or texts to the users via communication channels. The applicability of automatic character recognition techniques in mechanized selection and retrieval systems is, in turn, complemented by the applicability of information selection and retrieval techniques in the general field of pattern recognition, including the special field of character recognition. Thus, as Minot has remarked, 2/ "Recognition beyond mere reception of a stimulus may be considered a matter of information storage and then retrieval in accordance with stimulus cues."

This complementarity is less surprising if we consider that increased use of machine processes for information selection and retrieval will be concerned with basic problems in the recognition of patterns--patterns in information, the data itself, and its surrogates, including linguistic and graphic representations. That is, improved solutions to selection and retrieval problems may well depend on answers to such questions as how a machine can be designed or programmed to recognize a structure embedded within another structure. Other questions relate to machine processing potentialities for recognizing synonymity--of word with word, of drawing with word, of equation or formula with text or with drawing, and of described function with given structure, as in the search to correlate particular configurations in chemical structures with therapeutic effects. In terms of practical applicability in the immediate future, however, the areas of application in information selection and retrieval operations will be primarily those in which information is to be transcribed for machine processing or for transmission via communication links, where manual transcription is too slow, too costly, or unable to cope with the volume.

Early patents pertinent to the art of automatic character recognition include devices for transcribing copy for use in communication systems and for statistical counting or tabulation. A patent for a statistical machine, issued to Goldberg, in 1928, 3/ provides for such a statistical device. Handel similarly disclosed a statistical counting invention employing symbol and character recognition in a patent issued in 1933. 4/ It is interesting to note that while the Handel device must discriminate between symbols in order to tabulate items in each symbol category, the use of this device as a reader is nowhere claimed in the patent. Tauschek, however, in his application for patent filed in 1929, 5/ specifically claimed to effect "the reading of such characters or indications and thus replace reading by a person." Moreover, he foresaw the possible use of reading machines for such purposes as "controlling any desired machine, however, it will be found very useful in connection with office machines, ... testing and counting security bank notes and so forth and for controlling automations and the like." Two patents issued in 1931, 6/ to Parker and Weaver,

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1/ See Luhn, H.P. "Auto-encoding of documents for information retrieval systems." Ref. 281; Luhn, H.P. "The automatic creation of literature abstracts (auto-abstracts)", Ref. 282; Swanson, D.R. "Searching natural language text by computer", Ref. 467; and System Development Corporation. "Research Directorate quarterly report." Ref. 469.

2/ Minot, O.N. "Automatic devices for recognition of visible two-dimensional patterns; a survey of the field." Ref. 310.

3/ Goldberg, E. "Statistical machine," U.S. Patent 1,838,389; Ref. 169.

4/ Handel, P.W. "Statistical machine," U.S. Patent 1,915,993; Ref. 191.

5/ Tauschek, G. "Reading machine," U.S. Patent 2,026,329; Ref. 477.

6/ Parker, R.D. "Telegraph reading machine," U.S. Patent 1,815,986, Ref. 352.
Weaver, A. "Telegraph reading machine," U.S. Patent 1,815,996, Ref. 527.

respectively, provided somewhat similar recognition devices whereby text could be automatically transcribed for telegraphic transmission.

As we have previously noted, one of the first of the potential applications to be actively explored was the proposed development of mechanical devices for transcribing information from the printed page to signals for the use of the blind, thus eliminating the need for human transcription from printing to some other recording medium such as Braille. Such devices would also minimize the need for multiple copies of material in Braille form by providing multiple transcription machines to be used by the blind reader when and where required. Reading aids for the blind which are of the transducer (direct translation) type, involving no identification or recognition properly speaking, include the Naumburg Visagraph as well as the original Optophone, 1/ the RCA A-2 or 'flying pencil' reader, 2/ and several Batelle devices. 3/

On the other hand, the recognition-type devices have usually been found to be less susceptible to practical and economic implementation as aids to the blind. Thus Zworykin, Flory, and Pike, reviewing the state of the art in 1948, observed that:

> "In the case of the letter-recognition system, little is known of any early work although many proposals have been made. Quite generally they have suggested an optical matching system which would look at the letters to be identified and run through a set of letters, for instance on a drum, until the optical match of the unknown letter was found at which time a signal would be given to activate the indicator corresponding to the letter." 4/

In these relatively early years it could be concluded that the recognition-type system proposals would result in devices that would be both costly and cumbersome.

A decade later, at the Fifth Technical Session on Reading Machines for the Blind, held in 1958, it was still necessary to emphasize that the more complex recognition-type machines would be expensive, large in size, and therefore best used "in a library or other central facility." 5/ Intermediate machines, giving a reasonable correlation between a character configuration on the typed or printed page and a distinctive sound, where the printed pattern is analyzed in terms of zones which distinguish letters with ascenders or descenders from those without, have of course, been under development for some years. 6/ It is still true, however, even with the more recent progress in automatic reading techniques, that character recognition systems do not yet meet the requirements of either low cost or portability necessary for the blind. In fact, the commercially available character reader, as of May 1961, may have a capital investment cost of $120,000 to $200,000 or more, 7/ may have a power consumption rate of 6 kilowatts, 8/ and may displace approximately the same cubic space as a small digital computer.

The first published report of the RCA devices for the blind appeared in 1946, 9/ the same year in which the computer ENIAC first went into productive operation. The age of Tauschek's "automations"

1/ Fournier d'Albe, E. E. Refs. 144, 145, 146. See also Refs. 61, 149, 199, 243, 386, 507, 508, 509.

2/ Donahue, W. "Research with A-2 Reader. Final report." Ref. 102. See also Refs. 370, 371, 372.

3/ Refs. 1, 2, 3, 4, 149. Various intermediary or partial-recognition devices are mentioned in Refs. 149 and 243, and those described therein or in the various summary reports of the Technical Sessions on Reading Aids for the Blind (Refs. 507, 508, 509) include devices of Argyle, Blum, Brown, Schutkowski, and Thomas, among others.

4/ See Ref. 549, p. 484.

5/ See "Summary, Fifth Technical Session," Ref. 509, p. 1. Compare also the following: "It seems doubtful that the recognition machine can be made simply and cheaply enough to be a personal reading machine; rather it seems likely to find its place in libraries and institutions." (Ref. 199, p. 24.)

6/ See, for example, Mauch, H. A. "The development of a reading machine for the blind," Ref. 300, also Refs. 149, 301, 509.

7/ See, for example, Refs. 224 and 330, for cited prices of $133,800 and $190,000 respectively.

8/ For example, the Solartron ERA for Boots Pure Drug Company, See Ref. 117, p. 970.

9/ Refs. 370, 548.

was at hand. This initial use of a high-speed electronic digital computer led rapidly to the development and utilization of a number of large-scale digital data processing machines for many applications, with almost revolutionary impact on traditional data processing operations. Today, there are literally thousands of computers large and small in use in many different parts of the world. Computers are widely used for scientific and engineering computations; for statistical analyses and tabulations; for accounting, recording-keeping and paperwork processing in business, industry, and government; as tools for research in universities and elsewhere. More recently, the use of computers for mechanized literature search and information retrieval and for mechanized translation has received increasing attention.

The emergence of automatic data processing techniques has emphasized the need for automatic reading devices and has generated new areas of applicability for such machines. The high speed of the automatic data processing system calls for rapid input of information in order to keep the central processor busy. Automatic data processing equipment can produce enormous outputs at high speed, such as tables of numerical values, which may require extensive checking or proofreading. Computers and related processing equipment demand machine-usable files and machine-usable output, including re-usable output, such as "turn-around" documents. 1/ In addition, it has been suggested that a future use of automatic reading techniques will be for mechanized input to the computer of handwritten programs. 2/

Even more significant than the input demands of automatic data processing equipment, however, is the fact that the effective utilization of the new equipment demands the re-engineering of the entire information cycle from data origination to data usage in order to provide an integrated processing system. We can safely predict that this will be as true for the mechanized library of the future as it is today for many large-scale business operations. The whole concept of integrated data processing stresses the importance of recording information at its point of origin (or point of first recording) in a mechanically re-usable form. This is necessary in order to speed subsequent processing and to avoid the errors that are inevitable at each stage of transcription or re-recording. Investigations of complete machine processing of hand-written data sheets, which may be the original form of recording of experimental data later to be incorporated in the technical literature, are also in process. 3/

One of the results of the new emphasis on the speed and the accuracy with which input data can be fed into automatic data processors has thus been to provide for mechanization of information at the point of origin. A common method is the use of by-product data generation or of "dual language", e.g., the generation of a punched paper tape with the necessary data about a transaction produced automatically in the proper code by the device that records the transaction. The information is thus recorded simultaneously in two forms, one of which is immediately legible to human eyes and the other of which is directly "legible" to processing equipment.

In many cases, however, the number and geographical dispersion of the points from which necessary information originates preclude the use of such relatively expensive devices as Flexowriters, or accounting machines with punched paper output, in favor of the ordinary typewriter. At present, such typed information must usually be converted to machine-usable form (i.e., as holes in punched paper tape or punched cards, or as magnetized spots on magnetic tape) by a separate keyboard operation. Considerable advantage may be gained by the development of devices which translate or convert information that is recorded in a typed or printed form to some other form. Preferably, this other form will provide direct input of the code patterns resulting from character identification to an automatic data processing system.

Cash register tally roll accounting, especially in retail chain store operations or in large department stores, is a further example of situations where records from many individual locations are subsequently to be processed in a centralized operation. This is an area of applicability that is being actively investigated both in the United States and abroad. Figure 2, for example, shows a portion of a tally roll record which was read by a Solartron prototype reader in demonstrations at the British Computer Exposition held at Olympia in December 1958.

Another important area, considering data processing operations generally, is that of applications where the turn-around document is an integral part of the information flow. That is, as we have

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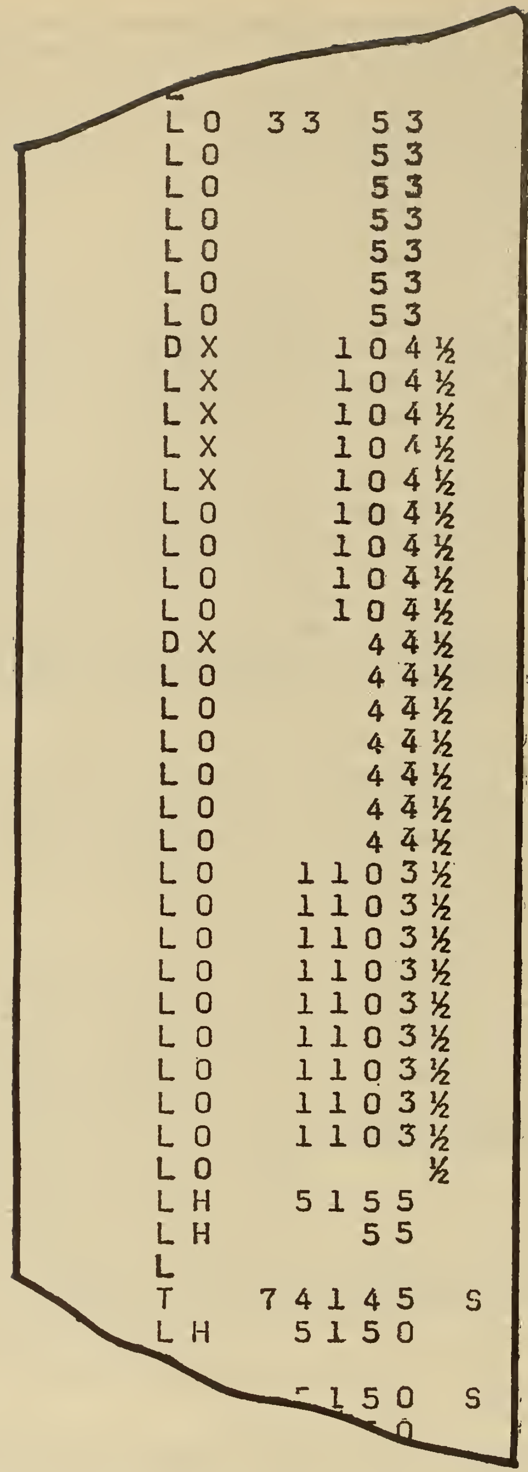
1/ This term refers to documents that are prepared, sent to customers or other users, and then returned for further processing and automatic re-entry to, say, an accounting system or a record file. It also includes source documents that are imprinted at remote locations. (See Keller, A.E. Ref. 249, p. 23.)

2/ Young, D.A. "Automatic character recognition," Ref. 539, p. 4.

3/ See the report of character recognition research being conducted by Hansche and Steck at Sandia Corporation in Ref. 506, p. 101.



L O 3 3 5 3
L O 5 3
L O 5 3
L O 5 3
L O 5 3
L O 5 3
L O 5 3
D X 1 0 4 ½
L X 1 0 4 ½
L X 1 0 4 ½
L X 1 0 4 ½
L X 1 0 4 ½
L O 1 0 4 ½
L O 1 0 4 ½
L O 1 0 4 ½
L O 1 0 4 ½
D X 4 4 ½
L O 4 4 ½
L O 4 4 ½
L O 4 4 ½
L O 4 4 ½
L O 4 4 ½
L O 4 4 ½
L O 1 1 0 3 ½
L O 1 1 0 3 ½
L O 1 1 0 3 ½
L O 1 1 0 3 ½
L O 1 1 0 3 ½
L O 1 1 0 3 ½
L O 1 1 0 3 ½
L O 1 1 0 3 ½
L O 1 1 0 3 ½
L O ½
L H 5 1 5 5
L H 5 5
L
T 7 4 1 4 5 S
L H 5 1 5 0
1 5 0 S
0

Figure 2. Sample of Tally Roll Record Read by Machine

noted, the turn-around or re-entry document ~~is one~~ which, having been processed in whole or in part by machine, is distributed to customers or users and is later returned for further processing. Examples include utility bills, subscription records, traveller's checks, and premium payment notices. In a variety of potential applications in the U.S. Government, which have been investigated by a task group of the X3-1 Subcommittee of the American Standards Association, a large part of the workload involves forms and documents to be filled in by multiple sources, including the general public.

The turn-around document area thus specifically raises the problem not only of multiple sources of data origination, but also of multiple methods of data inscription. These methods commonly involve combinations of pre-printed, addressograph-plate inscribed, typewritten, business machine prepared, and, to a lesser extent, handwritten data entries. For example, of 46 different Government applications studied by the X3-1 Task Group, 83% of the carrier items considered had combined addressograph, business machine listing, and typed information. These specific potential applications in Government amount, in the aggregate, to over 2,000,000 separate forms which must be processed daily. 1/

In addition to voluminous input of source data, such as current transactions, many large-scale data processing operations also require the input of previous records, prior summaries, and detailed data maintained in reference files. Where such files have previously been maintained manually, an enormous data conversion problem is often involved in key punching the data so that it can be transcribed to storage media acceptable to the machine, such as magnetic tape. Where these files are collections of the literature, or even of library catalog cards, the problem is even more severe.

The use of computers for mechanized translation also emphasizes this need for automatic character reading. For example, Shiner predicts in part that:

> "The ideal system for performing automatic language translation could have a printed character recognizer which would automatically scan the Russian text, recognize the printed characters...and transform into a suitable code...at speeds capable of keeping pace.. 10,000 characters per second." 2/

Russian scientists are also aware of the need for automatic character reading as input to mechanized translation programs. Work in character recognition has been reported at the Institute for Precise Mechanics and Computing Techniques, the Steklov Institute, the Kiev Computing Center, and elsewhere in the Soviet Union. 3/

Potential applications of automatic data processing systems for mechanized translation may in fact depend on the development of automatic reading techniques for the re-recording of dictionaries and for the input of documents to be translated, if the conversion to automatic processing is to be practical at all. For example, Wall 4/ points out that the development of an automatic reader to transcribe from the printed text of the source material to the machine language used is crucial if the process itself is to be economical. 5/ This is because human transcribers who do not know the

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1/ Data from an informal memorandum by J.H. Cummins, April 4, 1961, to the Task Force Chairman, Sub-Committee X3-1, A.S.A.

2/ Shiner, G. "The USAF automatic language translator, Mark I," Ref. 424, p. 301. Compare also Reitwiesner and Weik, "Survey of the field of mechanical translation...", Ref. 380, as follows: "Problem areas requiring attention include...character sensing of printed pages of source language text at the rate of the order of thousands of characters per second...," p. 40.

3/ See Ware, W.H., et al. "Soviet computer technology, 1959," Ref. 524. See also Refs. 21, 156, 380.

4/ Wall, R.E. "Some of the engineering aspects of the machine translation of language," Ref. 523.

5/ Pahl, in a later study of needs for character recognition for the mechanized translation program is even more specific: "At present, the transformation from alphabetic to binary code is done by a machine operator who reads the text letter-by-letter and depresses corresponding keys on the keyboard or a card or a tape punching device. The process is relatively slow and thus is responsible for roughly 60% of the per word cost of machine translation." Ref. 350, p. 4-5.

source language will copy slowly and will make many errors. Again, the volume is enormous. In a large-scale mechanized translation project being conducted by Georgetown University for the United States Government, over 500,000 words of text in the field of economics and a similar 500,000 words from the literature of organic chemistry have already been transcribed by manual operations. It is estimated that an additional 3,000,000 words of text will have to be keypunched during the first year of production-type operations of this MT system.[1/]

The need for automatic character recognition devices to provide the basic input to files of information about items to be selected and retrieved in mechanized document retrieval systems has also been widely recognized. In special situations such as that of the Patent Office collections, the volume of information to be recorded, transcribed, and stored for subsequent search may be more than the full text of the patents themselves. Koller, Marden, and Pfeffer point to this need for reducing the file-input-processing bottleneck, as follows:

> "One of the most voluminous and demanding tasks in setting up a large searching system will be the preparation of the search file (the library file). An enormous expenditure of man-power will be required to analyze and encode the documents and to transcribe the codes onto a permanent storage medium. Since the effectiveness of the system will depend largely upon the accuracy and completeness with which the file is prepared, the importance of this task cannot be overemphasized. This job will ultimately have to be performed by machines if our long-range objectives are to be achieved." [2/]

In the preparation of scientific information for publication, we also find needs, not only for recognition of typed characters, but also for the development of techniques that will enable the recognition of handprinted or handwritten characters and symbols. At present, the repetitious typing, copying, re-typing and transcription of a series of drafts and revisions contribute significantly to the costs of physical preparation of papers for publication. In this connection, we note that Russian scientists are reported to be considering the use of character recognition devices for automatic typesetting. [3/]

In other potential applications, incoming textual material may be scanned for the occurrence of certain key words or phrases which are then used for mechanized indexing or for preliminary routing or classification. This latter example is analogous to preliminary sorting of incoming mail, where a preliminary subject-matter or field-of-interest segregation is made by mailroom personnel. In some operations, machine detection of certain marks or symbols, other than the text, can be used in selective retranscription or re-use of data, such as the reading and retranscription of those portions of teletype messages that have been bracketed by a human editor.

Similarly, recognition of special symbols may be made to result in self-adjustments of the reading process such that the detection of underlining by the machine may be used to cause the machine to skip the reading of symbols that are underlined. [4/] Conversely, the reader-system may be designed so that it reads only underlined material, as for example, the specific words in a patent text indicated by an analyst as those to be converted to appropriate code symbols for subsequent mechanized search.

1/ As reported by P. P. Toma, "Brief description of the experiments conducted in machine translation at Georgetown University, Washington, D. C., with special view on lexicography and lexical information theory." Distributed at Kolloquium uber Maschinelle Methoden der Literarischen Analyse und der Lexikographie in Tubinger, 24-26 November 1960. [Symposium on Machine Methods of Literary Analysis and Lexicography.]

2/ Koller, H., E. Marden, and H. Pfeffer. "The HAYSTAQ system: past, present, and future," Ref. 260, p. 334.

3/ Reitwiesner, G. W. and M. H. Weik. "Survey of the field of mechanical translation of languages," Ref. 380, p. 33.

4/ "It will be noted that a certain amount of automatic editing may be expected of a machine according to my invention. For example, the machine may command that any character which is underlined be omitted in transmission to the output mechanism. This is accomplished by simply assigning a shape and memory unit to recognition of an underline. When this shape is recognized, the output pulse is blocked by a relay or tube. Also, the insertion of special symbols may be used to tell the machine to perform such functions as to go up a line to read a word inserted in the space between double-spaced lines of text, to go immediately to the next line of text, or to stop the machine." --Shepard, D. H., Ref. 415.

An important area of application of the read-and-sort possibilities is concerned with the recognition of addresses on mail, so that the envelopes may be sorted to appropriate destination-routing bins. The Canadian, U.S., Dutch, and German Post Office Departments, among others, have all been active in the support of such developments. Continuing support is exemplified by the following announcement:

> "An all-electronic alphanumeric recognition device for identifying typed or printed envelope addresses is being developed by Philco Corporation's Research Division...for the U.S. Post Office Department. The machine will be integrated with letter-sorting machines developed by the Post Office Department to further the automation of mail-handling in post offices. Electronic-scanning techniques will be used to locate and sort as many as 50 different addresses at the rate of 1,000 alphanumeric characters per second." 1/

Additional areas of applicability of automatic character recognition techniques include the checking, verification, and proof-reading of machine output, such as tables of numerical values, ballistic tables, code-book data, printed indexes, and bibliographical lists. The use of high-speed on-line or off-line printing of the results produced by computer generation and processing of such data emphasizes the need for high speed verification processes to keep pace with output.

As a further example of potential applicability, we note that transliteration (whether from the geometric configuration of an alphabetic character to the punched hole pattern representing that character or from, say, a Cyrillic script character to its English language equivalent) can frequently be achieved as a by-product of the recognition process. In effect, the symbol that is read is decoded. The identification of the characteristics of the input symbol as a specific one of a number of reference symbols in the vocabulary is used for re-encoding. Multiple transliterations can be made as desired from the single identification decision. Thus, a reading device with added processing logic should enable elaborate decoding and unscrambling of security-coded material. In this connection, as well as in that of mechanized translation, it has been noted that: "One of the major bottlenecks in the field of Intelligence Data Processing is the translation of printed matter to machine language." 2/

In general, then, there are many situations where automatic character recognition devices are and will be needed. These include a variety of business data processing operations in which punched cards are widely used today. For these operations, we can be, as Spiegelthal has said, "hopeful that keypunch machine operators will sooner or later be superseded by character reading devices." 3/ Even more optimistically, the president of the National Data Processing Corporation, which is active in both magnetic ink and optical reader developments, has predicted:

> "Now the technological barrier has been broken. Machines are in being that can 'read' and process information on documents of original entry and sort these documents into any desired arrangement. Investment is more than justified by the elimination of the costly inefficiencies inherent in the use of punched cards. Availability of these machines will enable the automation of business operations to move forward at an even more rapid pace than heretofore and the obsolescence of the punched card is at hand." 4/

In many of the areas of potential applicability, however, greater flexibility is needed than is provided in currently available readers which have a limited vocabulary, often of specially stylized design. In many of these areas the quality of the input cannot be controlled and a wide variety of sizes and styles of type will occur. In most of the proposed mechanized translation programs, natural language text, as printed on the page, is the necessary input. Thus, as Pahl has emphasized:

> "For machine translation and related applications, the need is for a reader with maximum flexibility. That is, the reader must be able to recognize a large group of characters and resolve a multitude of problems relating to variations in the printed material." 5/

A printed page may also contain subscripts and superscripts, special symbols, and graphic material such as mathematical equations, chemical structure diagrams, charts, drawings, and photographs. In such cases, a temporary solution may be to provide certain manual pre-processing steps such as the sorting of material by font or the masking out of graphic material and footnotes appearing in small type.

1/ "An all-electronic alphanumeric recognition device for identifying typed or printed envelope addresses...," Ref. 5, p. 72.

2/ Stone, W.P. "Alphanumeric character reader," Ref. 464, p. 1.

3/ Spiegelthal, E.S. "Computing educated guesses," Ref. 438, p. 70.

4/ Philipson, H.L., Jr. "A prediction...", Ref. 356, p. 26.

5/ Pahl, P.M. "Automatic character recognition." Ref. 350, p. 53.

Techniques being developed for automatic character recognition, however, should also eventually be applicable to the recognition of simple geometric shapes and schematic stylized graphic material such as is found in line drawings and electrical circuit or chemical structure diagrams. The potentialities for automatic recognition of graphic information, specifically including the problems of machine encoding of chemical structures, have been considered both in the HAYSTAQ system and in other projects of a cooperative program between the National Bureau of Standards and the Patent Office. 1/ The Perkin-Elmer Corporation, which has been active in pattern recognition developments for blood-cell identification, has also explored the problems of machine recognition of chemical structure diagrams. 2/

The first approaches to machine recognition of simple shapes in line drawings have already been demonstrated, for example, by Shepard, Harmon, Hodes, and Singer 3/ among others. At the Western Joint Computer Conference held in Los Angeles in May 1961, Uhr reported additional results from a pattern recognition program, 4/ including recognition of outline drawings of shoes, chairs, and comic strip cartoon faces. Fain, a Russian scientist working in the field, has been reported as investigating possibilities for recognition of three-dimensional objects by a technique involving possible projections in terms of a grid mask. 5/

Research in pattern recognition, while not typically oriented to the development of operational devices, even more noticeably points to additional possibilities. Areas of future applicability which are being explored in pattern recognition research include:

(1) Identification of cursive handwriting; 6/
(2) Speech recognition; 7/
(3) Recognition of Morse Code messages; 8/

1/ See, for example, Kirsch, et al, writing in 1956, as follows: "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, widths 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." (Kirsch, R.A., L. Cahn, L.C. Ray and G.H. Urban, "Experiments in processing pictorial information with a digital computer," Ref. 257, p. 226.)

2/ Private communication, E.W. Schlieben, April 19, 1961.

3/ Harmon, L.D. "A line-drawing pattern recognizer," Ref. 194. Shepard, R.N. "Application of IPL-V to the simulation of perceptual learning," Ref. 420. Hodes, L. "Machine processing of line drawings," Ref. 216. Singer, J.R. "Electro-mechanical model of the human visual system," Ref. 426. Also, "Model for a size invariant pattern recognition system," Ref. 429, and "A self-organizing recognition system," Ref. 430.

4/ Uhr, L. and C. Vossler. "A pattern recognition program that generates, evaluates, and adjusts its own operators," Ref. 497.

5/ Garmash, V.A. "Seminar on reading machines," Ref. 156, p. 12.

6/ Frishkopf, L.S. and L.D. Harmon. "Machine reading of handwriting," Ref. 151. See also Refs. 98, 99, 192, 277.

7/ See, for example, Fry, D.B. and P. Denes. "Experiments in mechanical speech recognition," Ref. 153, also Ref. 152.

8/ Especially the Maude program at MIT. See Gold, B. "Machine recognition of hand-sent Morse Code," Ref. 168, also Refs. 107, 295.

(4) Target detection in aerial photographs; 1/
(5) Detection of patterns in electro-cardiograph or electro-encephalograph recordings; 2/
(6) Automatic correction of misspelled words and other misprints; 3/
(7) Fingerprint identification; 4/
(8) Recognition of specific features in star plates or bubble chamber data; 5/
(9) Recognition of features in microphotographs of sections of tissue, metal structure, and the like. 6/

It has been suggested that the development of machines capable of translating back and forth automatically between printed and spoken language would simplify the telephone system, replace stenographers, and effect great economies in communication channel capacity, as well as giving the blind a way to read and the deaf a means to hear. 7/ It has also been suggested that mechanized pattern recognition will be important in space exploration so that a probe can alter its trajectory 8/ on recognizing where it is.

Ultimately, then, we should look to the development not only of versatile readers capable of handling multiple fonts, special symbols, and other schematic information such as that contained in structural or electrical circuit diagrams, but also of pattern recognition techniques capable of processing pictorial as well as textual material.

3. CONTROLLED SOLUTIONS TO CHARACTER RECOGNITION PROBLEMS

In view of the very broad extent of the areas of potential applicability, it is not surprising that many different solutions have been suggested for problems involving the possibility of automatic character recognition. When specific areas of applicability of automatic reading techniques have been identified and the objectives to be served have been defined, it is sometimes quite feasible to limit the problem of developing and using automatic character reader systems by adopting controlled solutions. Such controlled solutions include specifically: (1) the preprinting of the input material that is to be read, (2) the establishment and maintenance of quality controls on the input material, (3) the adoption of special stylizations, such as use of a standardized font, and (4) the limitation of the nature and size of the vocabulary to be recognized. It is actually for situations where such special conditions have been imposed that most of the progress made to date in the productive use of reader devices has occurred. 9/ Controlled solutions of these four types are discussed below.

1/ See Uhr, L. "Intelligence in computers; the psychology of perception in people and machines," Ref. 494, p. 179; see also, for example, Murray, A. E. "Perceptron applicability to photo-interpretation," Ref. 320.

2/ See Bauer, W. F., D. L. Gerlough, and J. S. Granholm. "Advanced computer applications," Ref. 41; Farley, B. G., L. S. Frishkopf, W. A. Clark and J. T. Gilmore. "Computer techniques for the study of patterns in the electroencephalogram," Ref. 130; Taback, L., E. Marden, H. L. Mason and H. V. Pipberger. "Digital recording of electrocardiographic data for analysis by a digital computer," Ref. 471.

3/ See Blair, C. R. "A program for correcting spelling errors," Ref. 48. Reitweisner and Weik report that D. G. Ellison of Indiana University has worked on a computer to read printed characters and to correct misprints. (Ref. 380, p. 20.)

4/ "Scanner spots fingerprints," Ref. 401; see also Sherman, H., "A quasi-topological method for machine recognition of line patterns," Ref. 421.

5/ See Innes, D. J. "FILTER -- a topological pattern-separation computer program," Ref. 227; Metzelaar, P., "Mechanical realization of pattern recognition," Ref. 305; and Uhr, L., Ref. 494.

6/ Tolles, W. E. and R. C. Bostrom. "Automatic screening of cytological smears for cancer; the instrumentation," Ref. 488.

7/ Miller, G. A. "Speech and communication," Ref. 308; p. 397; see also Young, D. A. "Automatic character recognition," Ref. 539, p. 4.

8/ Metzelaar, P. "Mechanical realization of pattern recognition," Ref. 305, p. 2, (preprint).

9/ Compare, for example, De Paris, J. R. "Optical character recognition equipment," as follows: "The secret of optical scanning lies in control of printing. Virtually any situation in which you control the printing of documents at the source is susceptible to optical scanning. If you can control the physical dimensions of the document, the positioning of the data on the face of the document, and the actual printing of data - be it by typewriter, plate imprinter, line printer, or whatever-you have satisfied the primary requirement for effective use of optical scanning." (Ref. 90, p. 38.)

3.1 Preprinting of Input Material

Preprinting of the input material that is to be read covers two general cases. First is the case of simultaneous recording of data in machine-usable form as well as in typed or printed form. Second is the case of controlled preprinting using special inks, special fonts, and characters stylized in such a way as to provide maximum legibility for the machine in distinguishing one character from another.

Included in the first case are various systems capable of by-product data generation. Sometimes this solution involves a second, simultaneously produced record on its own carrier medium, such as the production of a punched paper tape concurrently with the production of typed, hard copy originals. Sometimes it involves the imprinting, on one and the same document or carrier, of both humanly legible characters and of the same information in encoded form, such as the use of a bar or dot code. Special inks, ribbon or carbon paper may be used to provide the encoded, 'dual language' version of information that is also simultaneously recorded in conventional form.

For potential applications in information selection and retrieval systems and in mechanized translation, an interesting variant of this first case is the preparation of special punched paper tape as an intermediate step in setting text for Monotype printing. Another example is the use of a tape-controlled typewriter in the initial preparation of texts of abstracts, producing a punched paper tape version as a direct by-product. The use of tape-typewriters has, for example, been proposed as a method for cooperative sharing of abstract and catalog card information between libraries and information centers. 1/

Monotype or Teletypesetter punched paper tapes are or could be made available for certain printed books, certain published abstracts, and certain periodicals. Both the preprints for, and the Proceedings of the International Conference on Scientific Information, held in Washington in November of 1958, were deliberately processed so that the Monotype tapes would later be available to researchers interested in automatic indexing experiments or in machine processing of natural language texts. 2/ Unfortunately, there is not at present commercially available equipment capable of converting from the 30-channel Monotype tape, with special format and special symbols to control the subsequent type-setting process to either punched card code or to conventional computer input media. Prototype equipment for conversion either to punched cards 3/ or to punched paper tape 4/ has been developed, however.

An interesting proposal has recently been made by the Air Force Office of Scientific Research to compile abstracts of basic research supported by that office for issuance both in book form and in the form of magnetic tape derived from the by-product paper tape produced on initial typing. Loan copies of such tapes are to be made available to workers who wish to experiment with the recorded material, on condition that they report back the results of their experiments. 5/

The second case of the typical preprinting solutions to automatic reading problems is that of controlled preprinting using special inks, special fonts, and a limited vocabulary of characters stylized so as to provide greater machine legibility. This second case includes a variety of operations exemplified by checkhandling operations in banks, where the serial number, account number, and other information may be preprinted in special ink (magnetic, fluorescent, phosphorescent, etc.) and in either a standard or a specially designed font. In 1956, the Bank Management Commission of the American Bankers Association approved the adoption of magnetic ink character recognition as the basis for a common machine language most suitable for check handling. This action was based upon the report of the Technical Subcommittee on Mechanization of Check Handling which had conducted a survey of the then available character recognition techniques. 6/

1/ Mooers, C.N. "The 'Tape typewriter plan', a method for cooperation in documentation," Ref. 315.

2/ This deliberate decision included a specified requirement that periods ending sentences be followed by a double space in order to distinguish these punctuation marks when used in this way from the periods used to indicate decimal points or abbreviations. The requirement was met in spite of the printer's objections on grounds of typographical aesthetics. (Refs. 237, 238.)

3/ A prototype equipment was used, in part, for an experiment at IBM on automatic indexing of a small portion of the text of the Preprints, International Conference on Scientific Information, Ref. 237.

4/ At the University of Cambridge. Private communications, R. Wisbey and E. Mutch, Feb. 1961.

5/ Wooster, H. "Possible availability of interdisciplinary abstracts on magnetic tape," Ref. 538.

6/ See Refs. 8, 9, 10, 11, 12, 13, 14.

The ABA recommendations for magnetic ink character recognition stressed the value of normally appearing Arabic characters, the ability of large and small printing concerns to use the inscription medium, the ability to imprint by a variety of printing means, including typewriters, and the reading accuracy demonstrable with then existing reader devices. The choice of magnetic vs. optical reading techniques, however, was largely because of the weight placed on the evaluation factor of relative insensitivity to over-marking. Mutilations and obliterations occur in check handling both by the public and by banking personnel. It was considered that the reading equipment must be capable of recognizing the basic information even when obscured by overprinting (teller's stamp), pencil or ink marking, adhesive tapes used to mend torn checks, and other "noise" superimposed by oil, grease, and the like, in order that the rate of machine rejections be held to an acceptable minimum.

Both in America and abroad, the magnetic ink character recognition systems are gaining acceptance in banking and accounting operations. At least five organizations or groups are actively preparing machine installations for test by the Federal Reserve System. 1/ One of the Federal Reserve Banks has determined that better than 12% of the banks which it serves are already using MICR. 2/ Representative of European developments is the Compagnie des Machines BULL 3/ magnetic ink reader demonstrated for the Conference of European Bankers held in Paris in October, 1959 and presently undergoing trial operation in a Credit Lyonnais installation. This machine reads preprinted numeric information in a specially designed font where each figure consists of a series of seven vertical lines spaced either 0.2 or 0.4 mm apart. Interpretation and recognition are achieved on the basis of the combination of widths for the six spaces of each character, in effect, a multiple-cut font. Advantages claimed for this technique include the normal appearance of this font in terms of legibility to the human eye, and the tolerance in printing, since the amount of ink in each line is not itself the basis for identification.

The FRED (Figure Reading Electronic Device) System developed by Electrical and Musical Industries (E. M. I.) in England is claimed to be capable of either magnetic ink or optical character recognition. This system utilizes a specially designed typeface style. In the FRED System, the shape of each character conforms to a fixed distribution of variable width black strokes with respect to the central five or seven vertical columns or zones. 4/ A German prototype reader for the American E 13 B font is reported to be under development by Telefunken in Germany. 5/

In the United States, use of the MICR system in situations where preprinting occurs is proceeding so rapidly that a number of test and evaluation centers are being established to control the quality of the magnetic ink imprinting. 6/ An address on testing devices for MICR printing was presented at the 1959 annual convention of the Lithographers and Printers National Association. 7/ This address reported on experiments conducted by the Office Equipment Manufacturers Institute with the cooperation of a number of printers, demonstrating that for a given press and ink there is a good correlation between the 'color' or blackness of the printed image and the required magnetic level.

With regard to possibilities for optical rather than magnetic preprinting, similar considerations of possible standardization and a specially designed stylized type-font are being explored. Since

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1/ National Cash Register, Burroughs, Ferranti-Packard and Pitney-Bowes, IBM, the National Data Processing Corporation.

2/ Emma, Thomas. "Federal Reserve to test five systems," Ref. 122, p. 35.

3/ "Direct reading for data processing," Ref. 101.

4/ See Figure 5(a), p. 25.

5/ See Auerbach, I. "European electronic data processing...," Ref. 21. Auerbach also reports work at Siemens. Note, however, that a distinction should be made between MICR reader developmen ts in Europe, and other European work in optical character recognition, discussed elsewhere in this report.

6/ A trade publication report, "A magnetic ink character evaluation center," indicates that the General Electric Center at Phoenix will in fact use a 'production character-reader sorter' for evaluation of printing quality; (Ref. 288).

7/ Miller, G. M. "Testing devices for magnetic ink imprinting," Ref. 309, pp. 4-5.

1959, there has been increasing interest in cooperative effort to study these problems and to provide generally acceptable recommendations. A special committee on "Optical Scanning Standards" was formed by the Retail Research Institute of the National Retail Merchants Association in August 1959.

This Optical Scanning Standards Committee has recommended optical rather than magnetic character recognition systems for application in the retail merchandizing industry for the following reasons:

1. Field imprinting should be possible with less expensive and more reliable imprinting devices;

2. Re-entry processing should be possible with at most a change of typeface on existing printers;

3. Use of plastic plates (e.g., for customer charge recording) could continue;

4. Existing equipment, such as adding machines, cash registers, and printers, could continue to be utilized with relatively minor modifications.[1/]

This NRMA Committee has maintained liaison with other industry groups studying similar problems, e.g., the Air Transport Association and the Life Insurance Automation Committee.

More recently, with the establishment of the X-3 Committee on Automatic Data Processing of the American Standards Association in March 1960, an even broader interest in possibilities for controlled solutions to automatic character recognition problems has developed. Subcommittee X3-1 is specifically concerned with character recognition and will consider problems of fonts and formats, printing requirements, and applications requirements both in industry and in government.[2/]

It is to be noted that while the magnetic ink recognition systems are largely limited to operations where preprinting is feasible, the optical recognition methods are applicable not only to preprinting solutions but also to situations where the adoption of stylized standard fonts provides a more general solution. Ultimately, optical recognition techniques will be applied to operations involving processing of large volumes of data typed or printed without prior restriction. Thus the X3-1 Task Groups exploring applications may be expected to investigate not only business data processing requirements but also those requirements which involve the further processing of enormous quantities of previously printed material, such as is found in the ever-growing body of scientific and technical literature.

We note, however, that preprinting of input material enables extensive control of document format, carrier characteristics, characteristics of the inscription, placement and spacing of information, an arbitrarily limited vocabulary, choice of type styles including those of special design, and other critical factors affecting production and performance of character reading systems for business and industry.

3.2 Quality Control of Input Material

Preprinting of input material as a controlled solution to problems of automatic reading and re-transcription can be applied only in those limited situations where there is administrative control over the data-originating processes as well as control over the information itself. Generally, however, the data to be read is a direct product of transactions whose timing, occurrence, volume, format, and specific information content cannot readily be predicted. In such situations, only a limited amount of the data can be preprinted, at best. However, if the organization that is concerned with subsequent reading and use of the data is also administratively responsible for the data-originating operations, administrative requirements and specifications can be established which will have the effect of controlling to some extent the quality of material that will become input to an automatic reading process.

Quality control requirements include, first, advance prescription of the information carrier characteristics such as the size, shape, rag content, color, and other characteristics of the paper to be used in printing or typing messages or data. The characteristics to be specified would of course be selected so as to minimize paper handling problems and to maximize ink-to-paper contrast and definition of character edges. Secondly, specifications as to the inscription procedures to be used might include requirements for daily or hourly cleaning of typewriter keys, replacement of typewriter ribbons after a specified number of uses, requirements to double- or triple-space all material to provide substantial leading, and the like. Where preprinting of the information is not feasible, it may nevertheless be practical to preprint guide lines, such as boxes, within which

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1/ Sherwood, H. F. "An interim report on optical character recognition," Ref. 422.

2/ See Ref. 349.

information must be placed, even if it is to be inscribed by the general public, as in tax returns. Requirements for ample but precise margins and other format specifications can be established. These controls would minimize problems in positioning of information for subsequent scanning. Controls on the size of the total symbol vocabulary to be permitted in the system can extend to the prescribed use of a single typestyle, a limited number of characters, or to the requirement of the use of a stylized font especially designed for mechanized reading.

Quality control by means of constraints on placement and shape of input characters has also been considered in the case of handwritten block capital letters prepared to fit (i.e., touch the appropriate edges of) a prescribed guide-box frame as in the case of handwritten numerals inscribed by telephone operators. If the operator writes down the digits with care to center them about two preprinted dots, a surprising variability in the actual shape of handwritten numerics can be accommodated in a character recognition system. 1/ In a proposed variation of the FOSDIC System, in which mark-sense data pattern recognition is used for direct input to processing equipment, 2/ handwritten numerals so drawn that distinctive "tails" project from the top, bottom, or sides of a preprinted box would provide a basis for subsequent identification. 3/

Where controls over the data originating operations are impractical or too costly, some degree of quality control over input material may nevertheless be achieved through operations at the stations where data to be read are received. This would include such operations as culling of poor quality materials or sorting of incoming material as to size and style of font for routing to different readers each of which reads a different type style. Finally, in applications where for other reasons (such as compression of records for archival storage), photographic reproductions are used as the carriers in the character reading process, certain controls can be applied to improve quality. For example, operations are available to provide enhanced contrast between figure and ground or to normalize the size of different lines of text.

3.3 Stylization and Standardization

The extent of dissimilarity between different characters in the same symbol vocabulary is a major factor in the elimination of ambiguity in a recognition process. Therefore, the possibilities for development of a special type style and for the adoption of such a type style as the basis for a standardized font hold considerable promise for controlled solutions to automatic reading problems. In addition, standardization of type styles and fonts would have many advantages in design of equipment such as new high-speed printers, in procurement of typewriters and printers, and in usage of printing and typing equipment.

The design of specific type styles in the past has been largely influenced by traditional and aesthetic considerations in the general art of typography. The use of special type styles in proposed reader devices, however, has been directed primarily to the production of characters that differ significantly one from another in relatively simple aspects. The special styles developed have included superimposed ornamentation or exaggeration of character configurations where the location of the superimposed indicia is a direct clue to the identification of the characters. Other examples are 'cut fonts' where breaks in normal strokes of characters provide identity clues by location or by width of cut, and fonts designed to cover certain distinct areas.

Among the bases for character differentiation in especially designed fonts that have been proposed are the following: variations in the total width of the character, the height of the character, the total inked area, 4/ the width of individual character strokes, the number and position of strokes between different characters, the opaqueness or pattern of the body of character strokes or character elements, 5/ and the geometry of the character such that there are unique patterns of coincidence of black areas (character stroke elements) with the intersections of a superimposed grid.

1/ See Dimond, Johnson, Refs. 98, 240, respectively, and Figure 16, p. 49.

2/ See Ref. 143.

3/ Greenough, M. L., private communication, November 15, 1960.

4/ The patent awarded to Davis and Hinton (U.S. Patent 2,500,630, Ref. 86) discloses a proposed reading aid for the blind in which variations in total area, transformed as relative intensity of reflected light to a photocell, are claimed to result in unique displacements of a D'Arsonval mirror so as to select to an appropriate sound track and provide an audible output representative of the character scanned. It is to be noted, however, that gross area variation provides an inadequate basis for discriminating more than a few characters if they are shaped in anything like normal configurations.

5/ See, for example, the de France patent, Ref. 88.

Figures 3 through 7 illustrate some of the special stylized fonts that have been designed to facilitate automatic reading by machine. The examples include: special fonts for use with magnetic ink character readers, Figure 3; special fonts from the patent literature, Figure 4; special area-covering fonts, Figure 5, 'cut fonts', figure 6; and special fonts for optical reading equipment, Figure 7. In Figure 3, examples (a) and (b) illustrate magnetic ink fonts developed by Stanford Research Institute for the Bank of America, while example (c) shows the E 13 B special font currently used in the MICR systems that have been adopted by many American banks.

Figure 4 shows two examples from the patent literature of uniquely embellished characters or fonts having, in Broido's classification, 1/ "external code marks." The upper one, that of Heidinger, 2/ is actually more of a 'dual language' technique, with discrimination to be based on the varied sizes and locations of the added dots. Example (b) shows specially stylized characters with discriminating embellishments as disclosed by Dickinson, et al, in 1937. 3/

The converse technique to that of external marking and embellishment is that of "internal positional codes" or critical-area-covering designs, wherein: "Recognition can be achieved by designing each character so that it possesses unique and readily recognizable features... portions of each character may be arranged to cover a predetermined number of code positions." 4/

A vertical-zone area-covering design is used in the E. M. I. "FRED" system, example (a) of Figure 5. Figure 5 (b) shows the critical area-covering font of Maul's U. S. Patent 2, 294, 679, in which he describes the technique as follows:

> "... The graphical characters, such as for instance the numerals, are so selected in their configuration that in accordance with an index-point system... a different combination of black and light analyzing points is obtained for each character, whereby ... a differential control of the machine is made possible." 5/

Figure 6 represents two examples of the so-called 'cut fonts.' In cut font stylization there are deliberately placed breaks or gaps in the strokes that make up a character pattern. Recognition is based not on the character pattern itself but rather on the detected pattern of these gaps in the normally black stroke construction. Detection of the gaps, either by number encountered or by location with respect to specified subareas of the image field, thus serves as a code upon which identification can be based. In other words, the portions of the character that are missing tell what the character is.

The BULL magnetic ink reader font, example (a) of Figure 6, is a special case of a multiple-cut font, in which the patterns of relative widths of the vertical gaps cut through the entire character from top to bottom serve as the basis for recognition. Cuts may be so placed that they provide direct binary encoding--a single cut in the lowest level zone, "1"; a single cut in the next lowest level, "2"; cuts in both the lowest and next lowest levels, "3", and so on. A cut font design of Rabinow Engineering Company is illustrated in example (b) of Figure 6.

Examples of special fonts used for optical reading equipment are shown in Figure 7. Example (a), the Farrington-IMR Scandex "Selfchek" font, was developed originally for charga-plate use in the oil industry. This is a "matchstick" type of construction, a "built-in bar code," 6/ in which the different stroke combinations are used to provide a minimum of two stroke differences between any two numerics in this type face. For certain applications the account number also contains a redundant digit, so that, for a single error, the missing digit may be automatically calculated. 7/

Example (b) of Figure 7 is that of the National Cash Register Company font, which also provides self-checking features. The characters are constructed by considering the space the figures are to

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1/ Broido, D. "Recent work on reading machines for data processing. Part 1: Masking, scanning, and external coding techniques." Ref. 61.

2/ Heidinger, W., U.S. Patent 2, 362, 004, Ref. 207.

3/ Dickinson, A.H. and J.N. Wheeler, U.S. Patent 2, 261, 542, Ref. 94.

4/ Broido, D. "Recent work on reading machines for data processing," Pt. II, Ref. 61, p.224.

5/ Maul, M., Ref. 303.

6/ Wentworth, V. "Farrington has optical scanning lead," Ref. 530.

7/ See Refs. 202, 249, 419, 483.

(a)

(b)

(c)

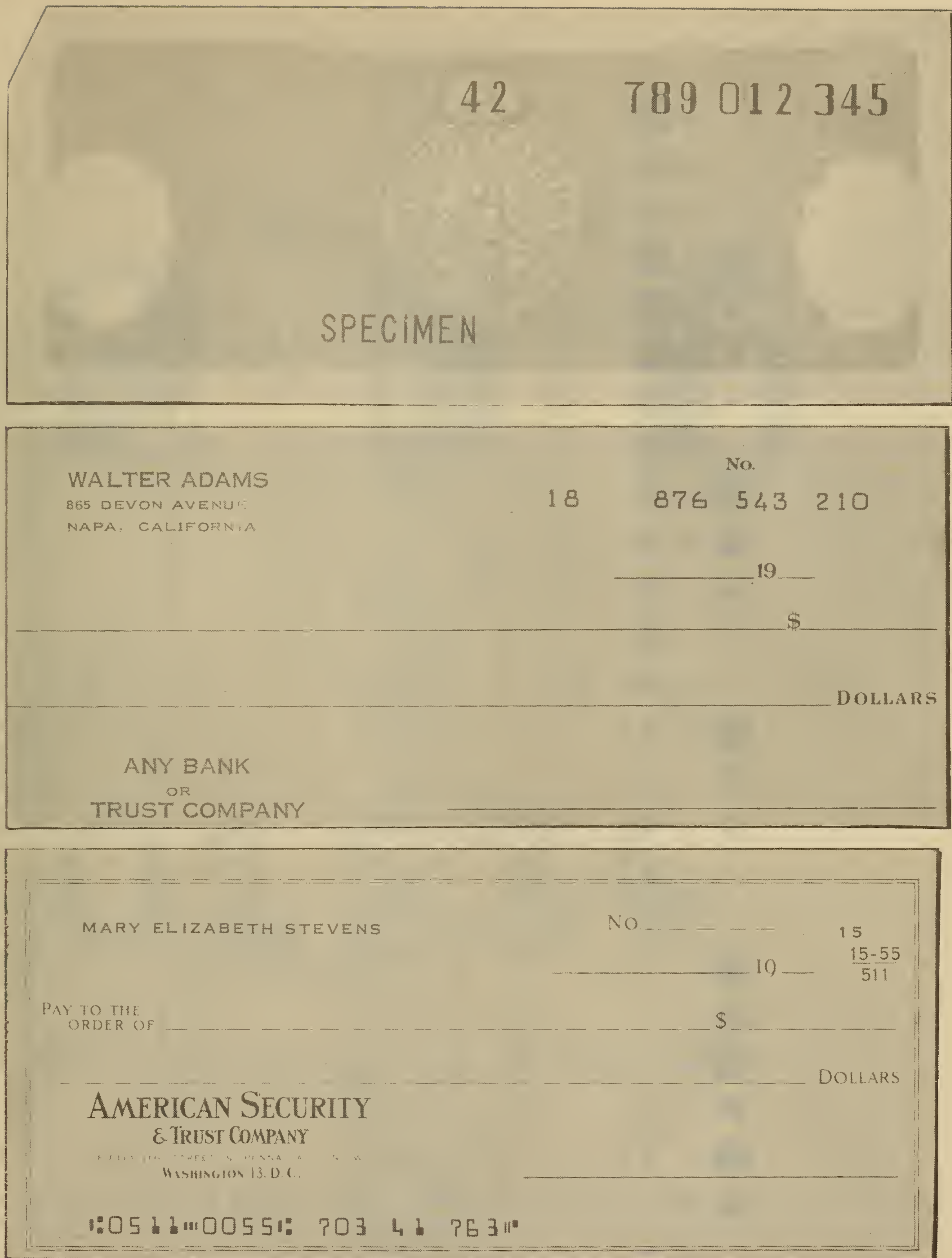
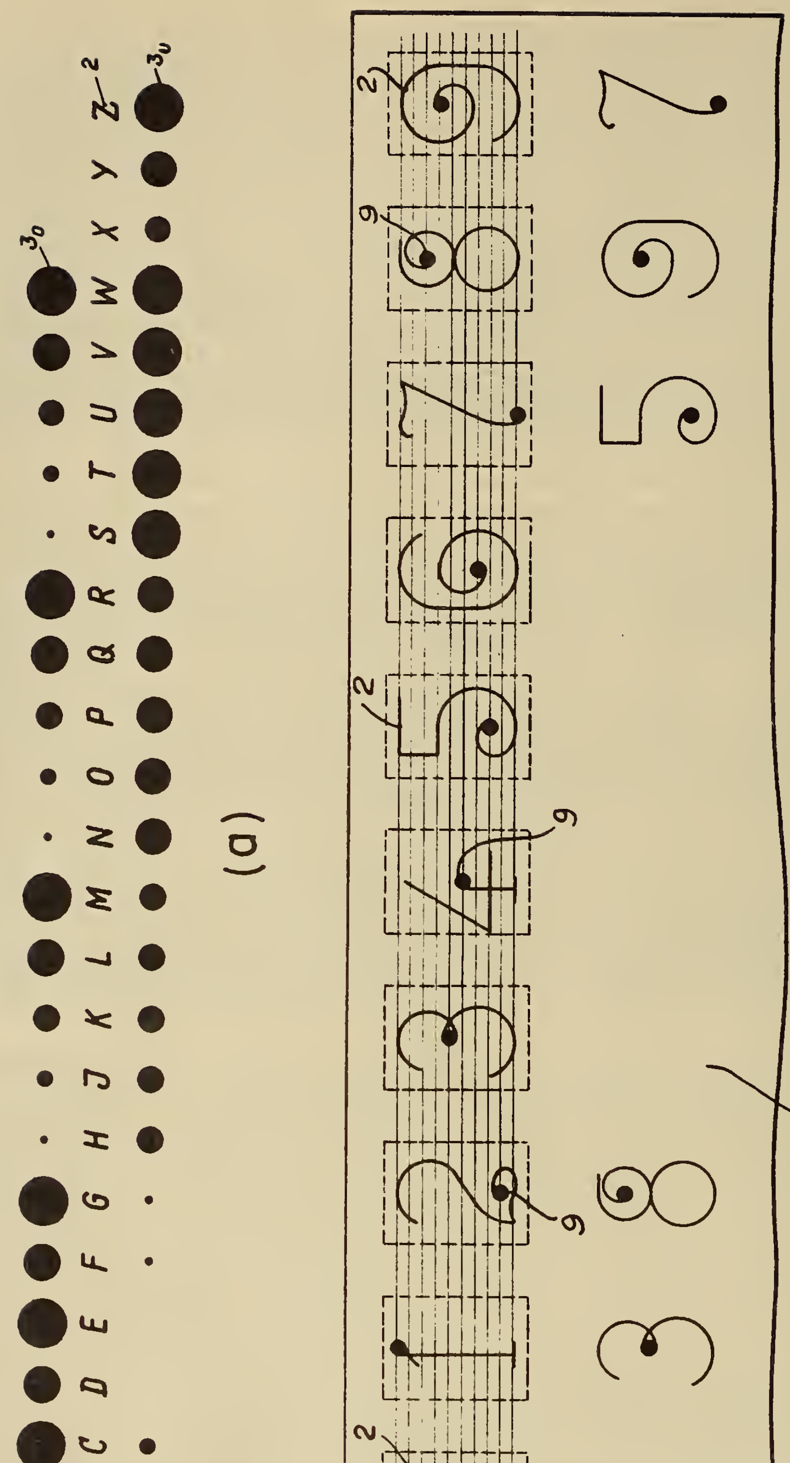


Figure 3. Examples of Special Fonts for Use with Magnetic Ink Character Readers


A B C D E F G H J K L M N O P Q R S T U V W X Y Z
(a)
(b)

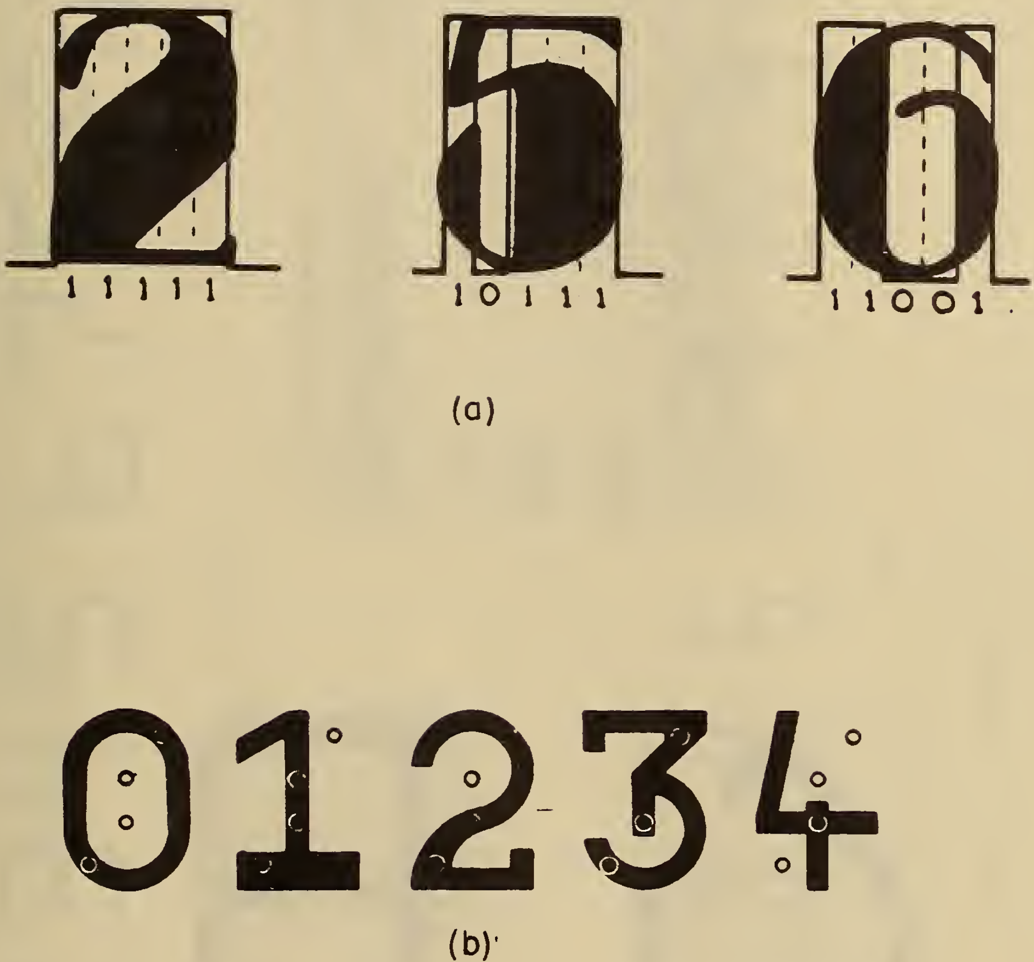
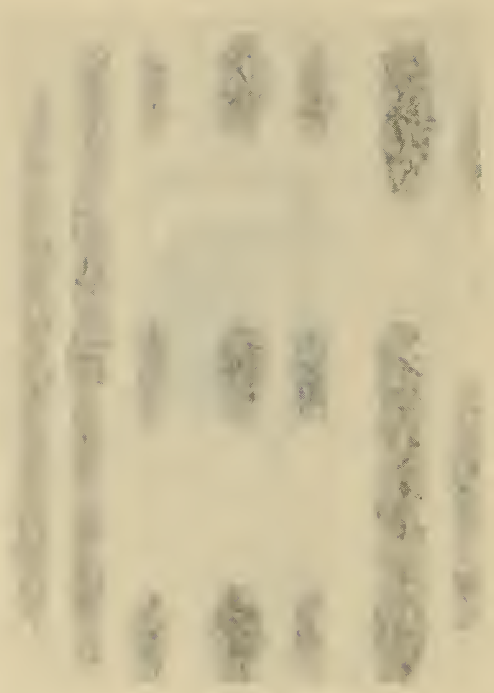
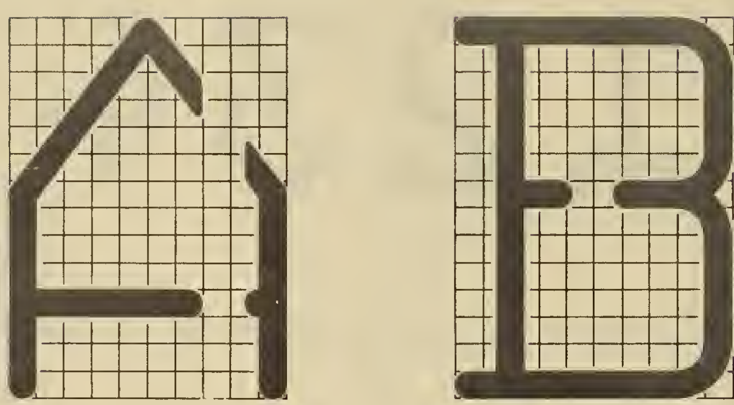


Figure 5. Examples of Internally Coded, Area-Covering Fonts



(a)



(b)

Figure 6. Examples of 'Cut' Fonts

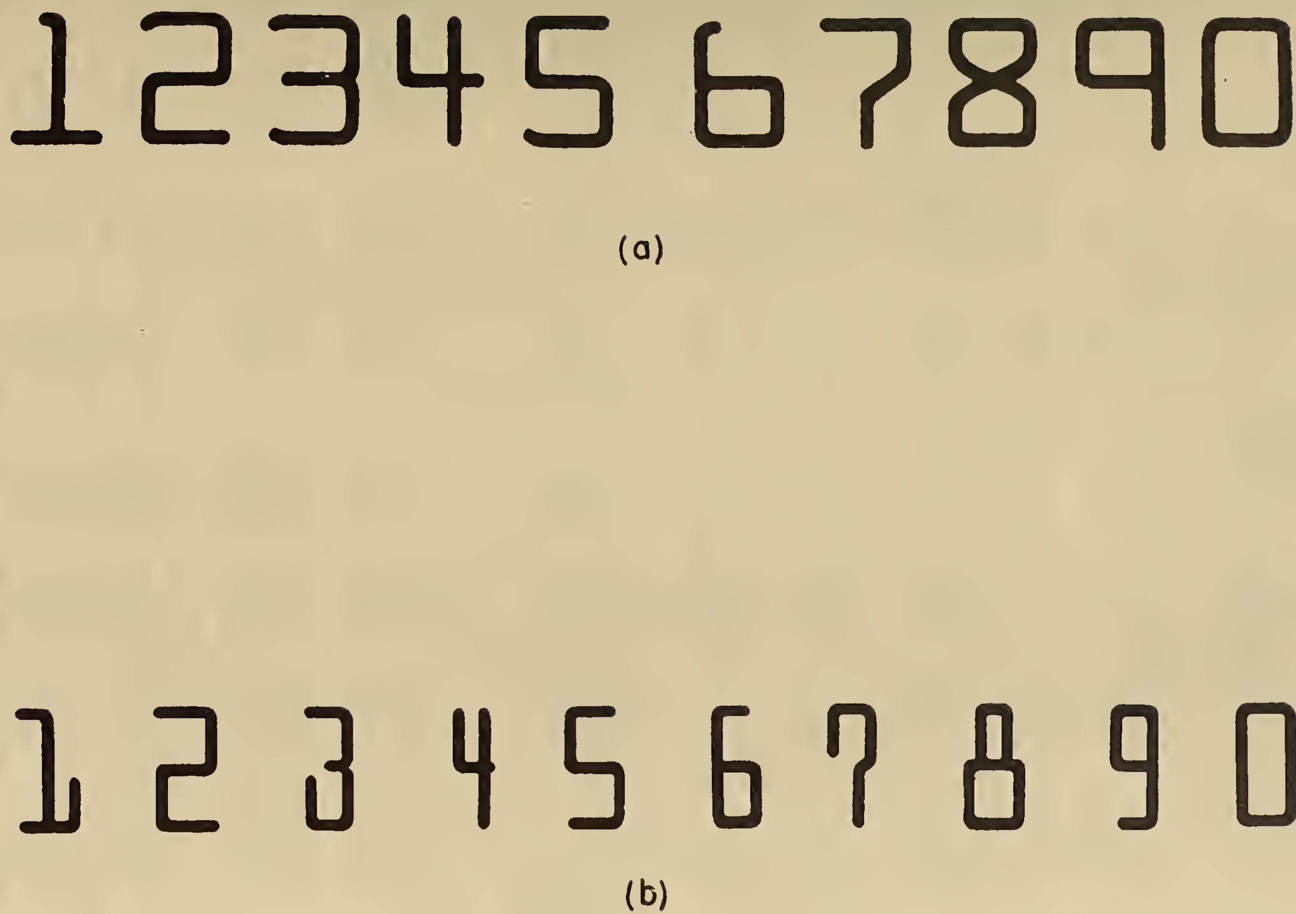


Figure 7. Examples of Special Fonts for Optical Reading Equipment

occupy as divided into an upper and lower half, each of which may contain one or two vertical strokes in any of five stroke positions. Thus, in effect, the automatic reader will view each character as being composed of two five-bit numbers. For machine purposes, this design is actually one which requires only the vertical strokes, the horizontal ones being added merely for the convenience of human readers. 1/

Many of these bases for character differentiation in specially designed type styles have definite limitations. Those which have to do with the gross style of the character, such as the width, height, or total area of the character, either presuppose a relatively limited vocabulary (10-20 characters) or require high resolution in the scanning-recognition system to detect small differences. In addition, for typed material, considerable variation in actual area of a character often occurs even on the same page, and character-image area variations may occur not only as effects of paper quality or ink density, but also as effects of temperature and humidity. Variations in specific style may result in character forms that are clumsy in appearance and therefore may be difficult for the human viewer to read easily. Variations in opaqueness of character strokes (such as the use of differentially spaced fine lines to fill in the body of a character element) 2/ may have limitations similar to those involved in variations of gross style.

A particular embodiment of the Weaver character reader invention for telegraphic transmission utilized only five selected sub-areas of an image field for character discrimination. 3/ A font of 32 characters especially designed for unique black-white patterns for the five positions would be required. Weaver illustrated such a font which, for particular characters, resulted in character shapes quite different from their forms in a normal font. One of the more promising bases for stylized characters for use in a standardized font was studied at the Diamond Ordnance Fuze Laboratories in close collaboration with the National Bureau of Standards. 4/ This is based on a 5x7 character element grid that is particularly well adapted to both mechanized reading and the design of high-speed printing devices. Many of these devices already employ elemental printing mechanisms (capable of very high speed imprinting) by pressing any desired combinations of pins or wires from a cluster of 35, each of which corresponds to an element square of the character grid, against an inked ribbon which transfers the impression to a suitable carrier medium. These character configurations can also be produced by conventional methods of printing and typing. Figure 8 shows a method for construction of characters in a 5x7 grid. Individual characters are designed by inscribing circles in any of the 35 squares of the grid and by drawing tangent lines to the other character elements, as illustrated in Figure 8. Characters of such shapes can be readily produced in the elemental printing devices.

A recommended font for business machine use, including typewriters, is illustrated in Figure 9, and Figure 10 indicates some of the alternate character shapes that are possible in this font. Very large total symbol vocabularies can be achieved. This font has been used by RCA in certain systems for optical character recognition now under development, especially for large-scale business data processing operations. Similar 5x7 fonts are being used by Eastman Kodak, Addressograph-Multigraph, IBM, and others. In addition, several typewriter manufacturers have indicated the feasibility of supplying a type-face incorporating this particular style.

The Subcommittee on Character Recognition Standards (X3-1) of the American Standards Association has reviewed the various proposed stylized fonts. The 5x7 grid has been considered, but with modifications both to make the style more pleasing to the eye and to accommodate scanning features of several different readers. As of February 1961, the preliminary recommendations were reported to be for 5x9 grid characters of uniform width, with strong right edges, and with minimum serifs. 5/

A stylized font based on either the 5x7 or the 5x9 grid lends itself readily to various automatic scanning recognition techniques. These include reader designs which use a sequential scan and also those which make a simultaneous analysis of the entire image field. Since the character shape is preunitized, by reference to the element squares of the theoretically superimposed grid, the resolution of scan may be arbitrarily improved at the points of critical analysis by application of the same detent principle that is involved in locating gross scan reference marks. An advantage of the 5x7 or 5x9 style for both automatic reading and for photocopying or microfilming of the printed or typed

1/ "This code 'within the character' achieves the goal of combining two languages in one. The machine reads only a code while the human reads conventional printed characters slightly stylized." (Ref. 346, p. 28.)

2/ See de France, H. "Numbers reading device," Ref. 88.

3/ Weaver, A. "Telegraph reading machine," Ref. 527.

4/ Rabinow, J. "Standardization of the 5x7 font," Ref. 368.

5/ See "Optical recognition--the breakthrough is here," Ref. 349, p. 22.

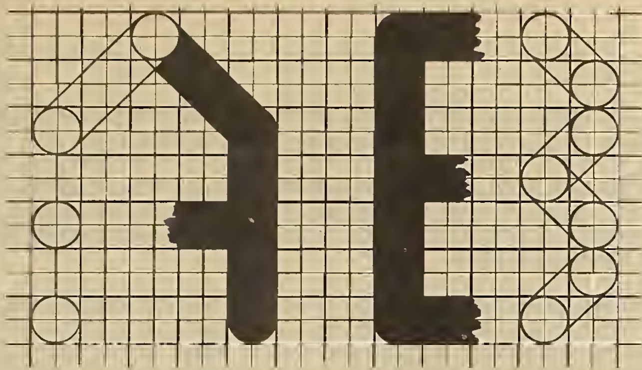


Figure 8. Construction of Characters in the 5 x 7 Grid

Figure 9. The Recommended 5 x 7 Font

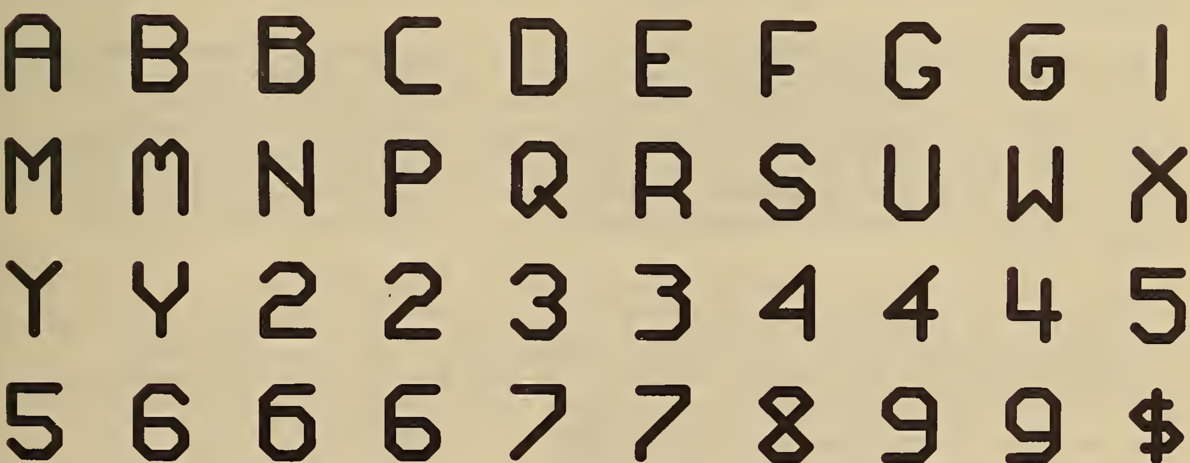


Figure 10. Some of the Alternate Characters Possible in the 5 x 7 Font

material is the fact that the thickness of the character lines bears a fixed relation to the size of the character and that the width of the lines is constant for a particular font.

Figure 11 shows a preliminary design for a possible standardized font that presents a compromise which adequately meets the requirements of both those reading techniques that are based on stroke analysis and those that require area-correlations. It follows the 5x9 matrix recommendations under consideration by the X3-1 subcommittee.

General adoption of a standardized type style, would obviously require the cooperation and agreement of manufacturers of printing devices, type-setting equipment, and the like. It should be based upon a design well-adapted to automatic reading as well as being easily reproducible, well-adapted to both conventional and high speed printing devices, and clearly legible to the human eye. Even more significantly, however, typefaces of arbitrarily specialized design can now be obtained and installed in at least some makes of ordinary typewriters. Further standardization will require widespread management appreciation of the advantages to be gained not only for automatic reading but for other administrative purposes as well.

Alternatives to the adoption of and possible standardization on one or a few type styles designed for automatic reading have included proposals to arbitrarily increase the size of characters to be read (by preprinting, by specification of equipment to be used, or by modifications of existing equipment), or to increase the space around characters, both inter-line and inter-character. It should be noted that increasing the space between characters involves more extensive and more costly alteration of existing typewriters and business machines than does the replacement of type bars with others bearing characters in a specially stylized font. In addition, increasing the space results in a considerable decrease in the storage density of carrier documents.

In most cases, the use of a stylized type-font such as those shown in Figures 9, 10, and 11 would provide the advantages of both preprinting and quality control of material to be read by automatic recognition techniques. Moreover, these advantages might be gained with less administrative complexity and at a cost less than that typically involved in installing equipment that simultaneously produces copy in both normal printed and in machine-usable form.

3.4 Limitation of Vocabulary

Second only to maintenance of consistent high quality of input, limitations on the size and nature of the vocabulary of characters to be recognized affect the feasibility and cost of development of specific character recognition systems. If only 16 to 20 numerics and special symbols used on an accounting tally roll, or only the upper-case characters of standard teletype font are to be read, practical character readers can and have been designed. Examples are the Solartron ERA (Electronic Reading Automaton) system and one of the early Farrington-IMR machines, respectively. Automatic reading techniques for a small vocabulary situation have been demonstrated where the "characters" in the limited vocabulary are the typed names or abbreviations of a selected list of cities and states. Examples again include an early Farrington-IMR machine and, more recently, machines under development by both Farrington and the Philco Corporation for the U.S. Post Office Department.

For the small vocabulary situations, relatively simple recognition logics are normally sufficient. Techniques for parallel matching of input characters with all the reference characters (i.e., 20 to 50 in the vocabulary) are also quite readily available, as in multiple-character template arrays or decoding matrices for sampled waveforms. In this connection we note that "... a successful character recognition machine may be developed without the necessity of being concerned with fundamental pattern recognition problems," 1/ and that the hardware may be relatively inexpensive to build and easy to maintain. Unfortunately, however, many of these techniques are not capable of being extended to significantly larger vocabularies (i.e., more than several hundred individual character forms).

The truly large-vocabulary situations are exemplified by requirements for reading pages of text from many sources and perhaps in many languages. Here we must deal with complete alphabets in different fonts, with different sizes and with italic variations for each font. In addition to font and size variations, special characters such as mathematical symbols and interspersed graphic material may appear on any given page. In just a few of these situations, controlled solutions may be adopted by rigorous limitation of the particular fonts and sizes within a font to be accepted by the

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1/ Kirsch, R.A. in Ref. 49, p. 234.

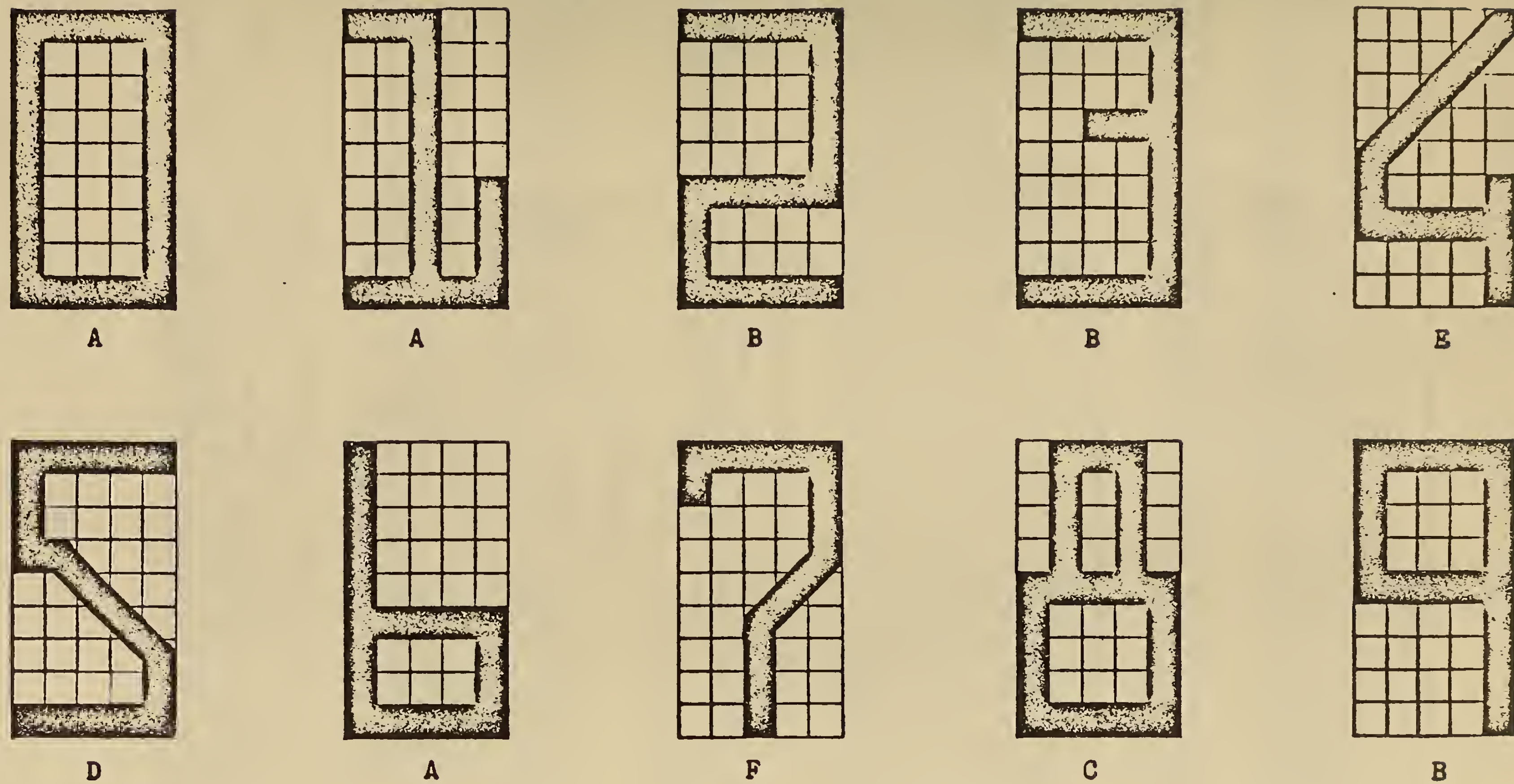

Figure 11. A Possible 5x9 Standardized Font

character recognition system. A compromise solution of this type would require adequate provision for blocking out or ignoring the unacceptable material if such material occurs on the same carrier unit as that which is accepted.

Some representative limitations of acceptable vocabulary in character recognition systems that have been tested are indicated in Table 1.

A variety of scanning and sensing methods and a variety of different principles of recognition logic have been applied in the limited vocabulary reading systems listed in the table. In many cases, the particular scanning technique and recognition logic adopted has a direct effect upon the size and nature of the vocabulary that can be accommodated. On the other hand, as we have previously noted, such factors as consistent high quality of input usually outweigh differences in scanning and logic in considering the use of automatic character recognition techniques in a particular operational situation.

Before discussing characteristics of representative systems, therefore, we shall indicate some of the variety of combinations of scanning and logic that can handle high-quality input and we shall then review various operational requirements typically encountered. We shall consider first the general process of character recognition.

4. THE CHARACTER RECOGNITION PROCESS

Typically, the process of recognizing an object consists first of sensing or scanning the characteristic properties of that object. These properties occur as patterns (e.g., of color, sound, or geometric configuration) in some spatial or temporal order, in some appropriate sensing field, as the visual or auditory field in the human. Upon input of such a source pattern, various operations to isolate, reinforce, or improve the source pattern may occur, transforming it into an input pattern which is equivalent to the source pattern. This pattern may then be systematically compared with previously stored reference patterns in order to determine the identity of the input pattern or to classify it as being a member of a class of patterns that have been previously sensed. Figure 12 represents a schematic diagram of these and subsequent operations that may be involved in a generalized recognition process. Before considering these process steps as applied specifically to automatic character recognition, however, let us first consider some commonly used methods for character recognition in various reader devices.

4.1 Some Common Methods for Character Recognition

Figure 13 illustrates in simplified form some of the commonly used methods for character recognition employed in automatic reader devices which are already in use or which have been demonstrated under laboratory conditions. These common methods will be described, with simplified examples, in the following discussion. They illustrate various possible combinations and implementations of the processes shown in Figure 12.

4.1.1 Template Matching

Example (a) in Figure 13 is that of one of the earliest methods considered -- matching the input pattern with a stencil, mask, or template -- which means, in effect, that the reference patterns are photographic-negative images of the possible source patterns that are allowed in this type of automatic reading system. The character may also be matched with respect to the white areas that should surround it or be included in it. Glover gives the following definition:

> "Template matching ... is defined as a process that compares a group of templates, each representing a specific character, to a sample character for identification based on the degree of matching between each template and the sample. The templates are identical copies of the characters themselves, including the white area both in and around the black portion of the characters within a square that is large enough to enclose the largest character." 1/

This method is also known as a 'map-matching' or 'mask-sensing' technique. 2/

1/ Glover, E.B. "Simulation of a character recognition system utilizing a general purpose digital computer," Ref. 167, p. 1 (preprint).

2/ See Broido, D. "Recent work on reading machines for data processing," Ref. 61, who cites as examples the Tauschek, British Thomson-Houston, Handel, Goldberg, and Bryce patents. (Refs. 475, 476, 477, 60, 191, 169, 65.)

TABLE I

REPRESENTATIVE LIMITATIONS OF VOCABULARY

SYSTEM	NATURE OF VOCABULARY	SIZE OF VOCABULARY	CARRIER UNIT	SPECIAL PROVISIONS
SRI, Bank of America	Specifically designed numerics	10	Checks	Magnetic ink
ERMA-MICR	Specially designed font, ABA	10-16	Checks	Magnetic ink
IBM-EVEY	IBM font	10-16		Magnetic ink
BULL	7-element cut font	10-16		Magnetic ink
FRED	Modified, striated Broadway	16		Magnetic or optical
Farrington-IMR-Scandex	Stroke-design, charga-plate	10-16	Tab-card Invoice	"Selfcheck" stylized font
NCR	Special design of 2-5 bit vertical bars	10-16	Paper	Self-checking stylized font
Rabinow	Numerics	10-11	1-line item	
Solartron	Numerics, plus special characters	16-21	Paper roll 20" - 48'	
Farrington-IMR-P. O.	Standard elite typewritten	25 city and state names	Envelope	
IMR-Teletype	Standard teletype font	Upper or lower case alphabet	Page	
IMR-Typewriter	Typed alphanumeric slightly modified pica elite	Full keyboard	Page	
Rabinow	Alphanumerics	51	Page	5x7 font design
Baird-Atomic	Alphanumerics	250-1,000	Page	Microfilmed
RCA	Alphanumerics	250-1,000	Page	Microfilmed

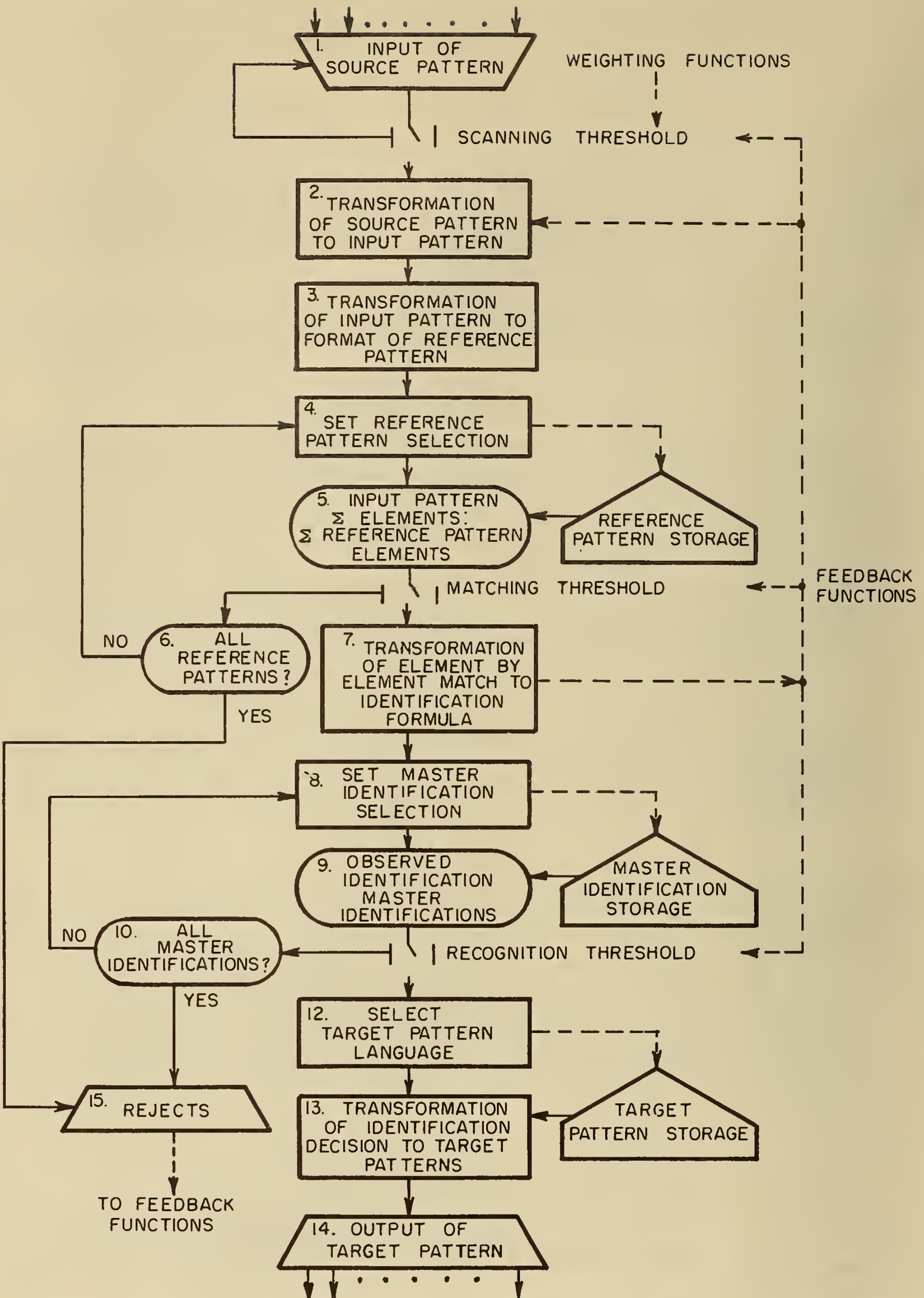

Figure 12. A Generalized Recognition Process

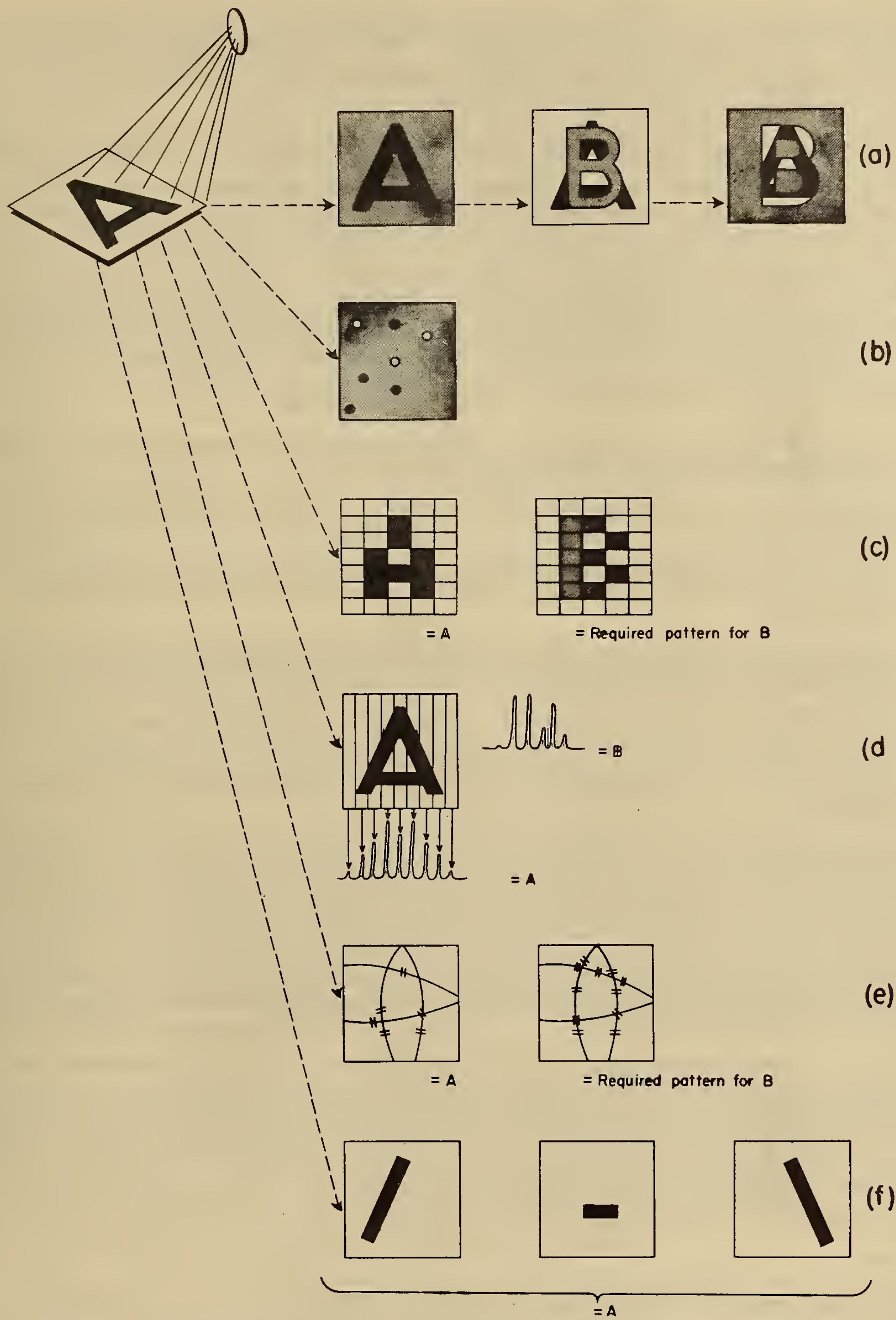

Figure 13. Some Common Methods of Character Recognition

Goldberg, in his 1931 U.S. Patent, 1/ disclosed this principle as applied to statistical operations such as selecting and counting particular records identified by some specified combination of indicia, for example, various alphabetic and numeric symbols. In a suggested embodiment he visualized the records as being stored on a positive photographic transparency and a 'search plate' with the negative images of the selection criteria processed as follows:

> "If the transparency containing the various statistical indications is now run through the machine in such a manner that the negative coincides with the transparency a complete coincidence impenetrable to any light or heat radiation will only be possible in one defined case; this will only occur when the negative bears exactly the same characters, marks, figures, etc., as the transparency in question, the only difference being that in the negative these records are light on dark ground, while in the transparency they are dark on light ground. A certain combination has thus been picked out of a large number of others with extraordinary speed and reliability hitherto not obtainable. In order to obtain the coincidence of the negative with the transparency they can be either brought into contact (direct superposition) or be projected one upon the other (optical superposition); the latter method being more advantageous as the mechanical features of the machine are simplified."

Thus we have the nucleus for a character recognition system in which:

(1) The input of the source pattern requires the positioning and illumination of the carrier (such as paper) on which the character is imprinted;

(2) The source pattern is transformed into the input pattern by a suitable means of optical projection;

(3) The projected pattern is optically superimposed against the reference patterns which are the photographic negative images of the characters permitted in the vocabulary of the system;

(4) When the input pattern exactly coincides with some one reference pattern, light is extinguished to a photocell located behind the reference pattern mask; and

(5) The extinction of light to the photocell, in combination with suitable means for identifying the particular reference pattern for which the exact coincidence occurred, is used to effect the output of a target pattern, such as punching the appropriate combination of holes in punched card or paper tape that is the code for the character identified.

The statistical machine proposed by Handel in 1931 2/ similarly provides that successive comparisons be made between a source pattern character image on a carrier item, such as a card with printed numerical information, and each of a series of character stencils. The reference pattern stencils are arranged on a rotating disk, with photoelectric apparatus employed to respond to extinction-type coincidence. When coincidence is detected, the position of the disk triggers a tallying operation for the proper symbol or character category. In still another example, in this case directed to reading aids for the blind, Sharples 3/ discloses the use of a drum with photoelectric cells and a "system so focussed as to project an image of the proper size to coincide with one of an alphabet series of transparent stencils."

This basic system continues to provide, with many improvements and refinements in the various process steps, a common method for automatic character recognition. Early work at the Diamond Ordnance Fuze Laboratories was based upon the improvement of optical matching techniques used in the selection system of the Bush Microfilm Rapid Selector (which also utilizes a Goldberg-type principle). Improvements were desired that would minimize the limitations of a direct comparison

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1/ Goldberg, Emanuel. "Statistical machine." Ref. 169.

2/ Ref. 191.

3/ Sharples, A.R. "Audible reading apparatus," Ref. 414.

scheme in which the entire field of the input image was matched against a mask containing the complement of the pattern to be selected, with the extinction of light to photocells occurring only when exact match occurred. Rabinow, then in charge of the DOFL project, recognized that the problems of differentiating between mismatches and light leakage, or variations in the relative contrast between dark portions of the input pattern and its lighter background, might be solved by examining the input field in small sub-areas one at a time. The change in electrical output for a true mismatch in any portion of the image is significantly greater than those usually occurring from light leakage, background noise, or imperfections in the blackness of the input character in each small sub-area.

The DOFL First Reader [1/] utilizes this principle of scanned comparison. A prototype model, built in 1954 merely to demonstrate feasibility, recognized typewritten characters of a single type-style at a rate of one character per minute. In this model, the source pattern is derived from the unknown typed character symbol and is transformed into the input pattern by optical projection of the image field. This input pattern is scanned by a modified Nipkow disk and is then compared sequentially with a mask containing as reference patterns the photographic negative images of each of the characters in the vocabulary. As each scanned comparison is tried sequentially, the photocell output connected to a modified peak detector produces charges in a set of capacitors that is proportional to the quality of match between the unknown input pattern and the reference pattern (mask character) against which it is projected.

Recognition elements are connected to the capacitors in such a way that when the comparison cycle has been completed the "best fit match" is directly identified. It will be noted that the recognition logic is simply that of best match of the complete input pattern as a single input pattern element with the images representing the vocabulary. Minor additions of logic circuit interlocks to distinguish between an "I" covered by a "T" or an "F" covered by an "E" are provided. The transformation of the results of the matching process to the observed identification formula is thus an identity transformation, and the matching-recognition thresholds of Figure 12 would therefore coincide for this system.

Various techniques for increasing the recognition rate of this type of template reader, e.g., by the substitution of electronic for disk scanning and by simultaneous rather than sequential comparisons against the array of vocabulary masks, were proposed by Rabinow before he left Government to establish his own engineering concern. Some of these suggestions have been subsequently explored at NBS, as described below.

A demonstration model of a reader for typewritten characters, using an "adequate fit" or threshold setting scanned comparison method, was designed and built by Greenough and Gordon of the Electronic Instrumentation Section. [2/] As in the DOFL Reader, the unknown source pattern is projected optically against one of a series of reference patterns that are photographic negative images of the characters to be identified. The resultant light pattern is scanned to determine the exact degree of match between the input pattern mask and the reference pattern. Masks representing the vocabulary of reference patterns for a particular type font are changed automatically until a match is obtained. Electrical indication is then provided for the particular mask that is being tried when recognition occurs. This apparatus differed from the earlier DOFL mechanical model chiefly in employing electronic scanning and modified recognition techniques. As a result, an operating speed at the rate of one character recognized every two seconds was achieved in an experimental model. This model equipment was able to recognize all of the letters of the alphabet (upper case) and all numbers under normal spacing conditions.

In this demonstrator model of a "typereader", the masks used are individual frames on 16 mm motion picture film with 26 letters, 9 numbers, and a blank space on an endless belt run through a modified movie projector. The light passing through the mask opening is projected upon an image dissector television pickup tube. Electronic scanning then provides the input pattern in the form of optical signals upon which recognition can be based. The signal is first passed through a clipper, emerging as either "black" or "white" signals, depending upon whether ink or paper is seen through the mask. Those areas where white paper is visible through the transparent portions of a particular mask are summed in an integrator. When the integrated total mismatch is below a certain recognition threshold value, this mask is recognized as the correct one.

In the reading process, a telephone type selector switch moves a deflector vane that is used to provide a small horizontal shift of the unknown character with respect to each mask. This allows a certain amount of correction for horizontal displacement. Six horizontal scans occur while the deflector vane moves slowly from left to right, so that there are "tries" at a match for six different horizontal positions of the unknown character with respect to each mask. The first reference pattern

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1/ Rabinow, J. "Report on the DOFL First Reader," Ref. 367.

2/ Greenough, M.L. and C.C. Gordon. "Technical details of print reader demonstrator," Ref. 182.

in the vocabulary for which recognition occurs directly determines the identification of the source pattern character. The last mask in the series is entirely opaque so that "recognition" must occur, thus providing an indication of nonrecognition of any of the standard characters. Since the masks are tried sequentially in this model, the sequence of matching has been arranged to eliminate possible ambiguities, e.g., the letter "Q" mask occurs before the "O" mask in order to screen out erroneous recognition of an actual Q as an apparent O.

Apparently a threshold of mismatch exists that will permit discrimination between all of the letters and numbers provided that the quality of the typing is fairly good. This threshold appears in practice to be somewhat less than that of the cross-member which distinguishes upper-case "G" from "C". However, further study would be required in order to determine the permissible range of limits for this threshold.

Following the trial of the breadboard typereader, an improved design was proposed in which comparisons would be made against all stored characters in parallel in order to achieve practical reading speed. 1/ The proposed reading process is entirely electronic except for the paper-moving mechanisms to bring each line and each character in each line successively into the field of view. The field of view is illuminated by a light source providing about 20,000 foot-candles that would be seen by an optical system consisting of a lens and an image dissector tube. Transformation of source pattern (the image field in view) to the input pattern is accomplished by converting the optical image into electrical signals in accordance with an applied scan pattern. The time-varying signal derived from scanning the image in a raster which covers the field in a linear grid pattern would then be compared with similar signals generated by similar scanning of the masks of the characters stored in the vocabulary. An integrator for each mask would add up the integrated mismatch each time the field is scanned for a comparison, so that the integrator giving a value of mismatch less than a selected threshold value will be that which designates the character being read.

Various portions of this proposed reading system were then tried experimentally. A complete scanning system was operated in conjunction with a mask scanner for a single character in order to develop comparison circuits. As a result of these experiments, a circuit was developed that automatically adjusts the threshold bias used for recognition to a value midway between the values of signal corresponding respectively to the ink density and to the paper surface. Other system improvements that have been developed include a means for deriving two images from each mask scanner, one for recognition and one for register control, and a method for sensing both the vertical and horizontal directions of misregister. The latter results then activate the positioning controls of the scanning tubes to move the images into proper register.

This experimental work at DOFL and NBS was carried to the point of constructing a prototype device and of demonstrating the probability that a successful reader could be constructed on these principles. Several commercial organizations active in the field of automatic character reading have continued to exploit similar techniques. Rabinow has been awarded a patent disclosing the use of a multisided prism with many flat faces, each of which reflects the illuminated area to different positions in the reference pattern storage array as a means of parallel simultaneous processing. 2/ Blum has reported that Schutkowski, in Germany, invented a similar technique described as follows:

> "A lens, cut with facets, simultaneously projects the letter to all matrices of the alphabet. To accomplish this, all the matrices are assembled on one plate. Behind each single matrix there is a photocell. The photocell acts when there is exact conformity between picture and matrix. The letter is thereby identified. The photocell controls the Braille or sound output of the reproduction part." 3/

4.1.2 Peephole Template Matching

The second method of character recognition shown in Figure 13 (p. 35) also employs, in effect, a template or mask, but one in which only a relatively small number of selected sub-areas of the image field are used as apertures for matching. That is, it serves as a "definitive grid," 4/ or weighted-area mask. This method, like that of the overall character image template matching, is also a very early development in the field, dating back at least to the early 1930's.

1/ Cook, H. D. "A study of print reading systems leading to a proposed reader for typewritten material," Ref. 80.

2/ Rabinow, J. "Reading machine," Ref. 366.

3/ Blum, W. "Current efforts to design reading machines," as cited in a survey of reading machines, Ref. 373, p. 26. See also Refs. 243, 404.

4/ See Kharkevich, A.A. "The principles of the construction of reading machines," Ref. 255.

As we have previously noted, early work on readers for machine encoding for telegraphic transmission led to two closely similar patents issued on July 28, 1931 to Parker and Weaver respectively. Parker proposed to scan character images sequentially through a mosaic mask of 100 apertures. 1/ The Weaver patent 2/ covers a modification in which the source pattern image field is scanned through a plurality of selected subareas of the image field, a "peephole" template or mask. In one suggested embodiment of this patent there is provision for the use of only five sub-areas in a grid superimposed on the unknown character. These are so chosen that, for a font especially designed to cover or not cover these critical areas, which are areas of optimum discrimination, there will be unique combinations of black-white patterns for 32 characters or symbols. Appropriate identification formulas for derived black-white pulse combinations would lead, when matched with the input pattern for an unknown character, to the triggering of means to perforate paper tape with the transmission code symbol corresponding to the character thus identified.

A similar principle, using a larger number of selected sub-areas, so that the input pattern is composed of a particular combination of a number of black or white input pattern elements, is utilized in the Burroughs-Control Instrument Typed-Page Reader (AN/FST-6) developed for the U.S. Army Signal Corps. 3/ Optical scanning is used and character recognition is accomplished by a process whereby the character is, in effect, examined through an array of apertures which is automatically registered with respect to the detected location of the character. In this case, a specially designed font is not required. The critical 'apertures' or test points have instead been selected by careful intercomparison of the upper case characters of standard elite typewriter font to determine optimum match and mismatch areas that differentiate one character from another. This method may be further illustrated by reference to Figure 14, which shows an aperture mask or peephole template that would discriminate between the six Cyrillic characters shown.

Implementation of the method in the case of the AN/FST-6 Reader involves:

(1) Input of source pattern by directing the beam of a flying-spot scanner onto the page, pickup of the scan information by a photocell, and use of a servo system to center the scan at the bottom edge of each character,

(2) Transformation of source pattern to input pattern including both 'cleanup' operations and quantization, that is, conversion of the video signals to either black or white,

(3) Transformation of the input pattern to the reference pattern format by presenting the signals to a 'black' and a 'white' matrix, each having 96 cores which serve as 'look' or analytical points,

(4) Matching of input pattern elements to reference pattern elements by the generation of mismatch signals when a 'black'video signal is on a 'white' core, and vice versa, where differential wiring of the cores provides a wired-in standard for each of the characters in the vocabulary and where the minimum mismatch voltage for a particular wired-in reference pattern serves to identify the unknown input.

In an interesting variation of the peephole template technique, Stone of the Rome Air Development Center Laboratories 4/ developed a prototype alphanumeric character reader in which the peephole mask is a single master reference pattern composed of 13 areas of different shape and size. When viewed against this master pattern, which Stone refers to as a "space matrix", each unknown input pattern is scored for the incidence of black or white in each area. A decoding table or matrix then provides an identification formula consisting of the specification of which areas must and which areas must not be black for each of the vocabulary characters. A given character identification formula need not specify the requirements for all areas, and, on average, only half of the areas are required for recognition of any particular character.

In still another variation, the single master peephole template is replaced by several specially designed templates. Baumann, for example, has suggested a "weighted area scanning" technique which would use several such reference patterns, each designed for a particular subset of the characters in the vocabulary. 5/ We shall discuss the more general case of weighted area templates after considering some of the other recognition methods.

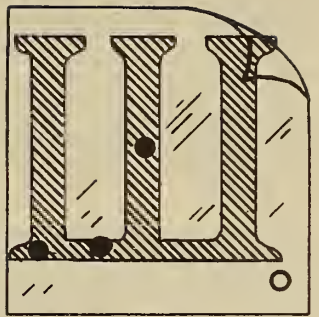
1/ Parker, R.D. "Telegraph reading machine," Ref. 352.

2/ Weaver, A. "Telegraph reading machine," Ref. 527.

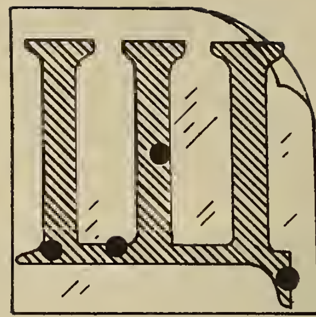
3/ See Deckert, W.W. "The recognition of typed characters," Ref. 87, and patents issued to Relis, et al, Refs. 381, 382, 383.

4/ Stone, W.P. "Alpha-numeric-character reader," Ref. 464.

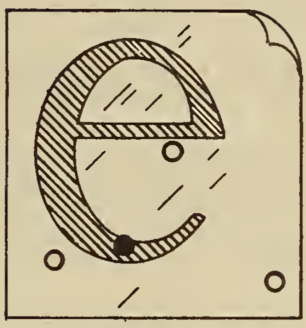
5/ Baumann, D.M., F.T. Brown, et al. "Character recognition and photomemory storage devices feasibility study," Ref. 43; also Ref. 44.



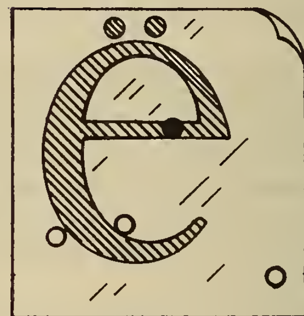
"Shah"



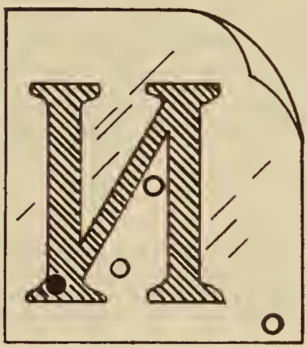
"Shchah"



"Yeh"



"Yio"



"Ee"

"Short Ee"

Figure 14. Peephole Template For Cyrillic Characters

4.1.3 Coordinate Description Matching

Just as was the case for the two template methods discussed above, we find that the method of coordinate description matching (Figure 13c) was also a very early suggestion in the field. Parker, whose patent we have noted was issued on the same date in 1931 as was that of Weaver 1/, described his own invention as follows:

> "It is assumed that one letter at a time is passed before a scanning or analyzing device... Each letter is illuminated... by a source of light and a perforated disk whereby the area covered by the letter is scanned in parallel lines; that is, parallel rows of small sub-areas are examined in sequence. Since each letter of the alphabet and each of the other commonly employed characters is of a distinctive shape, a different arrangement of pulses will be produced in the output circuit of a photo-electric cell associated with the illuminating and scanning device. The output of the photo-electric cell is then amplified by suitable means and is passed to the arm of a distributor having a series of segments--one hundred, for instance. Each letter or other character may be represented by a certain combination of these distributor segments and when that combination is recorded the proper selecting magnet or magnets of the perforator or printer will be operated."

Thus we would have, in effect, the superimposition of a rectilinear grid, mosaic, or small-mesh aperture array upon the image field in which the source pattern character appears. The identification formulas for given characters would then consist in the description, by their co-ordinates, of those cells or sub-areas that are black or that are white when that particular character is sensed through the grid. This coordinate description method differs from the two previously discussed template methods in that it considers the entire image field and tests each area of that field for source patterns that may be located in various positions in the field.

Scanning means for the sensing of a vertical segment of the image field are typically combined with means for keeping track of relative position within each such segment. This combination, together with timing control accounting as scans are repeated for successive vertical segments, provides an effective equivalent to the actual superimposition of a rectilinear grid on the image field as a whole and the subsequent inspection of each cell of that grid. Successive segments may be obtained by moving the scanning means from one edge of the image field to the other. Alternatively, and much more commonly, segment readings may be obtained by moving the image field in discrete steps past the scanning station, e.g., by movement of the carrier on which the source pattern appears. Subdivisions along a segment or slice of the image field may be achieved by time-interval count control or by a quasi-geographic factor such as which specific one or ones of a column of photocells are affected by the portions of character encountered in each scan segment. 2/ If the column of photocells has more photocell members than a normalized range of heights of characters in the vocabulary would require, then suitable adjustments for vertical misalignments of source patterns can be accommodated in the system.

The use of similar techniques in Russian investigations of character recognition has been described, for example, by Kharkevich, as follows:

> "The scanning process consists of sequential inspection of the image by a traveling beam. The trajectory of motion for the beam shall be called the scanning line. The scanning line is specified analytically in a certain coordinate system which is relative to the field of the image. The simplest forms of scanning are directly related to definite coordinate systems, so that the scanning line reproduces a coordinate grid." 3/

Significantly, the coordinate description recognition method involves in most cases an encoded template as a reference pattern. Often, in fact, the encoding results in a string or sequence of binary symbols, where each bit position represents a particular cell of the grid. Thus, for example, in an 8x9 array, "some advantages in richness of detailed information and, possibly, hardware may attend the procedure of expressing the morphological structure of characters by means of 72-place numbers of the binary system, with each 0 or 1 of the expression corresponding respectively to a non-intersection or an intersection of character and sensing line in the coordinates of the sensing system." 4/

1/ Parker, R. D. "Telegraph reading machine," Ref. 352.

2/ For example, a Rabinow Engineering reader uses this technique, see Ref. 369.

3/ Kharkevich, A. A. "On the principles of designing reading machines", Ref. 255, p. 19.

4/ Boni, C. "Russian type study", Ref. 55, p. 6-8.

Whether the encoding is direct or indirect, however, the encoded input pattern is typically matched to the correspondingly encoded reference patterns. That is, the matching decisions with respect to the input-pattern elements are: Is this cell, with coordinates i, j, black where the reference pattern cell with the same coordinates is black, or white where it is white? Even in the sell-publicized Perceptron 1/ systems, despite the emphasis upon 'learning' and upon the randomness of the connections between S-units (i.e., sensory-receptive cells of a retinal mosaic) and A-units (association cells, between which and the sensory units random connections have been established), the identification formula for recognition of a given character or geometric shape will depend on some particular coordinate-description in the A-unit space which has been 'reinforced' for 'correct response', however dissimilar in shape this may be to the original source pattern. In the Perceptron systems, of course, as in many reader systems, the actual identification formula for any recognizable symbol may be that of a highly idealized or skeletonized character.

We should note here, however, that in considering these first three common methods of character recognition, all of which include 'templates' in one form or another, we have made certain simplifying assumptions. In particular, we have tended to assume that the source pattern (that is the unknown character to be recognized) has been accurately positioned so that the image field for the input pattern coincides with the area defined by the boundaries of any character to be recognized in the system.

Such an assumption is not, in general, supported by realistic operational requirements. Even if the recognition vocabulary is limited to, say, 16 numeric and special symbol characters of an adding machine or of a cash register tally machine, or to the characters of a standard typewriter font, there is still the problem that lines of typed or tally-roll characters are subject to misregistration, misalignment, and skew of the individual characters. Thus, as Horwitz and Shelton observe:

> "One of the outstanding engineering problems encountered in the construction of character recognition devices has been the accommodation of character misregistration." 2/

Frequently encountered anomalies of registration must be accounted for if automatic character readers are to become truly productive tools for data processing. Even for conventionally printed characters, there are significant character-to-character variations in width and in height, notably including lower-case use of ascenders and descenders. There are also, for page-reading and other multi-line reading operations, significant differences in size, even within the same type-style, that must often be accommodated. Moreover, within the same font, relative height-width proportions for character strokes may vary with varying size. (See Figure 15 for some of the features and terms that are commonly used in identifying differential type style characteristics.) There are, in principle, two classes of solution to these and related problems.

The first such solution is to provide for an image field large enough to accommodate not only the tallest and widest characters that will occur in the permitted vocabulary, but also some pre-established allowable range for vertical and horizontal displacements. Unfortunately, for image fields (i.e., input pattern possibilities) larger than actual source patterns, the number of possible coordinate descriptions soon becomes astronomical if we allow for variations in size, rectilinear translation, and rotation. Fain 3/ has calculated the total number of coordinate descriptions possible for any geometric shape in a given image field that is divided by a superimposed grid to lie between $1/6\ \pi k^2$ and πk^2 where k is the area of the retinal grid in terms of the number of cells in the grid. He has used this estimate as a major criticism against character (and geometric shape) recognition schemes such as those of the Perceptron, Taylor, 4/and others, which depend upon direct or derived coordinate descriptions as recognition-identification formulas.

1/ See Rosenblatt, F. "The Perceptron: a perceiving and recognizing automation (Project Para)," Ref. 393. See also Refs. 52, 66, 83, 241, 242, 321, 392, 394, 396, 397, 398.

2/ Horwitz, L. P., and Shelton, G. L., Jr. "Pattern recognition using autocorrelation," Ref. 220, p. 175.

3/ Fain, V.S. "On the quantity of coordinate descriptions of the image in systems designed for recognition of visible objects," Ref. 128.

4/ Fain, V.S. "On the principles of designing a machine for recognizing images", Ref. 127. For Taylor's work, see Refs. 132, 338, 478, 479, 480, 481, 482. We should note, of course, that both Rosenblatt's experiments with Perceptrons and Taylor's work in pattern recognition are directed primarily to the investigation of self-organizing systems and to possibilities for machine simulation of learning-type processes, rather than to the development of practical character reading equipment.

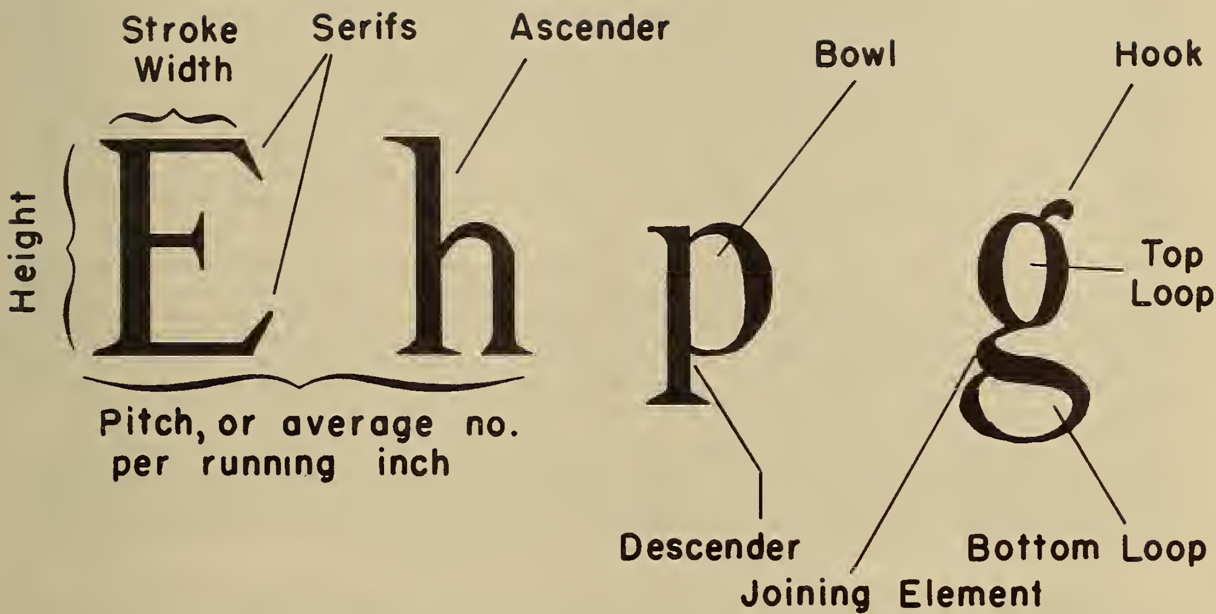


Figure 15. Terms Used in Identifying Type Style Characteristics

Similarly, Young, in commenting on Taylor's recognition system, concludes that:

> "An inordinate amount of logic would be required to analyze the summations of all possibly semantically equivalent combinations of sensory data, derived from a sensory matrix sufficiently large to permit of the necessary discriminations." 1/

Metzelaar has put the same general problem in the form of an analogy in which he compares the degree of mesh necessary to pick out the smallest level of detail necessary for discrimination (e.g., the diacritics shown in Figure 14 to grains of sand, and concludes that:

> "...today's average recognition machine would attempt to recognize a mountain by examining each and every grain of sand in relation to its neighbors to build up the pattern." 2/

A second class of solutions to the problem of registration of the image within the coordinate description field is directed primarily to the problem of rectilinear displacement or translation rather than to those of rotation or expansion. In this class of solution we find the successive horizontally-displaced 'tries' for a match in the DOFL-NBS optical template readers. We also note as belonging to this class of solution the 'finding' of a boundary edge (bottom, top, etc.) to serve as a reference mark against which to superimpose a peephole-template. This operation tends to limit the image field to the outermost expected limits of the widest and tallest characters, as in the Burroughs-Control Instrument Page Reader. 3/ Other techniques are used both in optical and in magnetic ink character scanning in order to physically center the source pattern as it is transformed to an input pattern, either in the actual center of a field corresponding to the reference pattern image field, or by, in effect, moving the input pattern until it touches one or more designated edges of such a field.

Several systems use various types of processing of input patterns through a suitably designed shift register, either to allow for various possible coordinate descriptions of the same input pattern under rectilinear translation or to provide a position-normalizing feature such as centering before the matching operations are attempted. The principles involved are exemplified in a prototype reader developed at Standard Elektrik Lorenz, and demonstrated at Hamburg, Germany, in 1959. 4/ In this machine, a shift register technique is used for systematically moving the input pattern through various possible coordinate description-positions. 5/ This is done until the input pattern is sufficiently 'centered' for match with the reference characters, say, until a cell or cells in the upper lefthand corner (column 1 and row 1 of the grid) show black. If no recognition occurs, the process is repeated, shifting by pulses (as derived from the input black-white quantized scan) to the left and to the top, for another try. Since this machine is designed for the reading of typewritten numerals, the shifting technique is intended not only to control the displacement problem but also to alleviate recognition problems caused by badly smudged characters.

Related possibilities obviously include shifting a given input pattern through all positions until a match with a reference pattern occurs. These focussing-down or shifting-through solutions, however, are not necessarily adaptable to problems of size variation or of tilt or skew. The Rabinow Engineering Company has proposed a method that might rather ingeniously accommodate a limited number of variable coordinate descriptions as well as certain different styles of some specific character (i.e., a Roman "A", an italic "A", a Greek "A", etc.). This proposal is based on an adaptation of the "Peek-a-Boo" technique that has become familiar in some nonconventional information retrieval systems. 6/ More specifically, the proposed reader involves, first, a fixed matrix of photocells onto which the source patterns are projected. The associated reference pattern

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1/ Young, D.A. "Automatic character recognition", Ref. 539, p. 4.

2/ Metzelaar, P. "Mechanical realization of pattern recognition," Ref. 305, p. 13, (preprint).

3/ See Refs. 57, 79, 87, 381, 382, 383.

4/ See Dietrich, W. "The automatic recognition of typewritten numbers", Ref. 96; also Refs. 97, 443, 444.

5/ Similarly, in the IBM 1210 Sorter/Reader for E13B magnetic ink characters, the input pattern, which is stored in a 10x7 matrix, is 'rolled' up through each of the 10 rows. See Ref. 126.

6/ See Refs. 535, 536. Note also that Bledsoe and Browning, Ref. 51, also apply a modified "Peek-a-Boo" or term-entry type system, by dedicating bit positions of stored computer words to the presence or absence of a bit, for a given n-tuple matching test for a previously seen input pattern, to the category to which the previously seen pattern belongs.

storage is comprised of a stock of movable cards or plates which represent the modified "Peek-a-Boo" system.

Each photocell of the reading matrix activates the motion of one card into one of two positions, slightly displaced, depending upon whether the light from the photocell exceeds a specified threshold value. In the stack of cards there is another matrix having one or more fields or hole areas for each character to be recognized. Light is impressed at one end of the stack, as the input pattern activating the reading process has been processed, and there is a second matrix of photocells at the other end of the stack. These latter photocells comprise a recognition matrix, with either one photocell for each character to be identified, or better, n cells can be used to identify 2^n characters.

If there are n reading (sensing) photocells, there are n cards, and 2^n card position combinations. If there are ℓ characters to be recognized, then there are n recognition photocells where $2^n = \ell$. For any printed character, there may be (within economic limits) arbitrarily many combinations of card positions which give recognition, corresponding to different fonts, upper or lower case, skewed characters, or character images displaced in either horizontal or vertical direction. As a character source pattern is moved across the scanning field (or, conversely, as the scan-read mechanism is moved across the character image field), recognition could be arranged to occur at many points, and the actual identification could be effected on a probability basis in order to allow a limited number of false recognitions to occur without necessarily spoiling the overall accuracy of such a recognition system.

Fitch has proposed still a different attack on the problem of the many different coordinate description templates necessary to accommodate variable configuration and registration of the same character. 1/ He considers first a binary encoding of those coordinate positions which are black for a given source pattern presentation. The coded input pattern is then fed to a cross-grid network analyzing circuit which effects a decision-tree type of recognition decision. The paths through the network constituting the reference pattern for each vocabulary character are set up by the use of wire contact relays having pluggable jumper wires. In each reference pattern network, 100 or more paths representing permissible variations in coordinate descriptions of the same character may be established. The pluggable jumper wire technique permits the establishment or subsequent modification of particular paths based upon empirical observations of sample characters.

Other interesting variations on the coordinate description method include the disregarding of selected 'grey' cells or sub-areas (those which, for a particular vocabulary, do not serve to distinguish one character from another), 2/ or the differential weighting of results from different sub-areas, 3/ to form what Kharkevich terms a "definitive grid." 4/ Thus, for example, in the Taylor proposals, it is claimed that:

> "To make use of the fact that the detail important for recognition is located in regions where the signal amplitude changes appreciably, it is necessary to attach greater weight to signals derived from such regions. This weighting process will be called 'detail filtering', and the detail-filter networks for performing this operation are believed to be similar to the neural networks that produce a similar effect in the nervous system." 5/

These methods are similar to the critical or significant area techniques in certain of the peephole-template methods. Still another method, that of Bledsoe and Browning, utilizes a number of arbitrarily chosen n-tuples of grid cells (exclusive pairs, triples, etc., randomly located in the field) to derive black-white 'scores' for an input pattern, which are then compared against the previously derived scores for reference patterns. 6/

1/ Fitch, C. J. "Character sensing and analyzing system", Ref. 135.

2/ See Refs. 225, 226, 521.

3/ See Refs. 478, 479, 482.

4/ Kharkevich, A.A. "The principles of the construction of reading machines," Ref. 255.

5/ Taylor, W.K. "Pattern recognition by means of automatic analogue apparatus," Ref. 482, p. 204. For similarity to phenomena in living organisms, see Lettvin, J. L., et al. "What the frog's eye tells the frog's brain", Ref. 269.

6/ See Bledsoe, W.W. and I. Browning. "Pattern recognition and reading by machine", Ref. 51.

Multiple reference patterns are necessary (and allowed) in the Bledsoe and Browning system for the simple reason that, with rotation and translation and size variance (expansion and contraction), the type of n-tuples suggested would saturate and discriminability would be lost. 1/ Bomba, 2/ however, suggests that n-tuples based upon relatively invariant feature assumptions can be used to preserve or increase discrimination, and with obviously greater economy in storage of reference patterns or reference pattern elements.

4.1.4 Characteristic Waveform Matching

The characteristic waveform matching method (Figure 13d) is perhaps best exemplified by a Stanford Research Institute reader for magnetic ink recognition for use in ERMA, a system which was a prototype for the American Bankers Association promotion of industry-wide adoption of MICR. In this recognition system, 3/ the characters are printed with an ink pigment containing iron oxide, and they are styled so that the various characters in the vocabulary produce dissimilar waveforms when scanned by the machine. Immediately before reading, the characters are magnetized uniformly by a fixed-field magnetic write head. The paper carrier (check) on which the characters appear is then moved past a magnetic read head. This read head is similar to conventional magnetic tape reading heads, but the gap length is several times the height of the character, allowing the reader to tolerate a degree of displacement with respect to registration and a minor amount of skew. As the source pattern moves past the reading head, the head senses the area of magnetic ink under it at a given time interval, and produces an input pattern which is an instantaneous output voltage proportional to the rate of change of the magnetic flux. A characteristic voltage waveform is thus developed as a function of time. The waveform is next fed into a lumped-constant delay line which is of sufficient length to permit storage of the entire character waveform derivative.

Comparison of the waveform to other possible waveform patterns is made from a number of tap points on the delay line holding the total input pattern. These go to each of fourteen different correlation networks, one for each of the fourteen numerals and symbols in the vocabulary of this system. The delay line and the correlation networks (which consist of a number of resistance matrices) form, in effect, a family of matched filters which uses the full analog information in the waveform for decoding, so that minor deviations from the expected shape are permitted when making the identification decision. A timing circuit supplies a readout gate when the waveform is completely stored in the delay line. Fourteen differential amplifiers compare the outputs of the various correlation networks at the instant of readout, so that recognition is based on the correct channel having a greater output than any of the other channels. The decision is thus made on a 'best fit' basis. Upon identification, the output signals are coded into a form that can be used by a computer, sorter, or other equipment for output of the appropriate target pattern.

Closely similar methods may be employed in optical scanning, also, with suitable means for determining the relative black, rather than the relative magnetization, in successive vertical sub-areas which segment or 'slice' the character. In both magnetic and optical uses of the characteristic waveform method, however, the number of discrete characters that can be discriminated is usually quite limited, and closely similar characters found in many conventional fonts often cannot be distinguished one from another.

We note that the transformation of the input pattern (derived time-varying signal or continuous waveform) to the reference pattern format (Operation 3 of Figure 12, p. 34), usually consists, in the characteristic waveform matching method, in the sampling of the input pattern at discrete intervals. This is not at all necessarily a series of 'critical' choices, however, as in most instances of peep-hole-template matching. Moreover, the number of sampling points that are technically or economically easy to use in such a system may markedly affect the total size of the vocabulary that can be handled. This is particularly the case where a waveform derived from single-slit scanning is used as the input pattern. Thus Dickinson states:

> "The single-slit scan system can be used for a limited number of characters provided a special font of characters is used. The extension of this system to reliably read alpha-numeric characters of normal size that are humanly readable does not appear feasible." 4/

1/ See discussion by Kirsch, Ref. 49.

2/ Bomba, J.S. "Alpha-numeric character recognition using local operations," Ref. 54.

3/ Eldredge, K.N., et al. "Automatic input for business data processing systems," Ref. 109. See also Refs. 110, 111, 112, 124, 247.

4/ Dickinson, W.E. "A character-recognition study," Ref. 95.

Further developments in the use of characteristic waveform methods therefore have included exploration of possibilities for combining the results of slit scanning in several different directions. In particular, work at the University of Birmingham, England, under a U.S. Army contract, has included experimentation with a 3-way system providing a horizontal scan and two 45° scans, together with means for correlation detection, in order to differentiate the characters of a standard commercial font. 1/

4.1.5 Vector Crossings

In each of the four previously considered, commonly used methods of automatic character recognition (template matching, peephole-template matching, coordinate description matching, and characteristic waveform matching), we have been dealing with situations in which it is tacitly assumed that all the possible source patterns which can be 'recognized' in a particular system, have, at least as prototypes, been 'seen' before. Recognizable patterns can be found, by suitable area-preserving and shape-preserving transformations, to be equivalent to previously seen, classified, and identifiable, reference patterns.

This assumption, of course, implies that all recognizable variations-of-a-single-character for a given system have previously been analyzed as to significant, recurrent characteristics or properties in the process of establishing the reference patterns and the identification formulas. In some systems, provisions have been made for variable identification thresholds, such that, for example, an abnormally thick or an abnormally thin "I" would still be recognized as "I". In an operational system such as the Solartron ERA machine for tally-roll accounting data input for chain-store accounts data processing applications, some latitude in possible vertical displacement is provided. 2/ But such gains are typically achieved at the price of duplicating the recognition logic circuitry, of multiplying the reference pattern storage requirements, 3/ or both.

Methods which try to develop areas of optimum discrimination for recognition-identification (especially in the case of peephole- templates, or in weighted coordinate description methods using 'gray' or 'don't-care' conditions) also assume that the range of allowable variations in vocabulary-character configuration is known in advance. That is, alternate placements and minor details of shape of character-variants to be recognized as a single character in the output of the recognition system have been specified. The peephole-template technique, for example, if properly designed, will tend to ignore serifs and other minor typographic-stylistic embellishments as well as certain additive or reductive noise (i.e., smudging or mutilation of the original character image). Nevertheless, the conditional requirement in this as in other cases, - 'properly designed' -, implies exhaustive advance exploration of the permissible possibilities of source pattern variation.

These first four methods for automatic character recognition are, then, primarily closed-end vocabulary systems. They are, at least in principle, template-matching systems however different the reference patterns as templates may be from the appearance, to the human eye, of the source patterns that are machine-recognizable in the system. Under template matching conditions, of whatever kind, there is implicit a one-to-one correspondence between 'input-pattern-space' and 'reference-pattern-space' that is generally conservative of both area and shape characteristics of the original given image.

Moreover, the subsequent mapping from the specific location in "reference-pattern-space", as indicated by input pattern processing, to "target-pattern-space" is usually such as to provide that a given "A" on the printed, typed, or handwritten page will be consistently correlated with an appropriately equivalent code or symbol output form. This equivalent target pattern will represent the character 'A' if and only if the source pattern significantly coincides with a reference-character version of the physically-similar configuration of "A" as it might be seen by the human eye. In other words, a set of "A" patterns must have been repetitively observed and classified as 'A' in a sense that preserves certain of the area and shape characteristics common to the set, before an "A"-template, leading to an 'A' identification, can be utilized. This will generally follow, notwithstanding the fact that other templates, for sets ("A")'and ("A")", etc., may also be correlated with a suitable target pattern output representing 'A'.

In many cases, however, template-reference-pattern vocabularies are not a feasible solution in some character recognition systems for the simple reason that the possible variations of source pattern corresponding to some specific desired target pattern output are not well enough known in advance. Such is obviously the case with handprinted or handwritten characters. In these situations,

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1/ Birmingham University, "Character recognition", Ref. 47.

2/ See Refs. 25, 30, 84, 116, 117, 118, 405, 435, 436, 437.

3/ To at least the possibilities for constructing the π k 2 requirements for coordinate description variations for a given reference pattern. See Fain, V. S., Ref. 128.

effective, precise templates are either not known, or, even if they were available, would impose prohibitive reference pattern storage requirements. Thus there has been, with respect to possibilities for automatic character recognition in such situations, either the imposition of constraints on possible variations of size or shape or centering, or an attempt to utilize relatively invariant discriminating characteristics, or both.

The method that we have termed "vector crossing matching" (Figure 12e, p. 34) has been used in both types of proposed solution. A dramatic example of the use of this method in close conjunction with suitable constraints on the formation and placement of handwritten numeric digits was demonstrated at the Eastern Joint Computer Conference held in Washington in 1957, 1/ and we should note that a similar technique had previously been disclosed in the patent literature. 2/ Dimond of the Bell Telephone Laboratories reported at this 1957 EJCC Conference on a successful method for the automatic reading-recognition of numeric digits handwritten by telephone toll switchboard operators in the Bell System who produce in the aggregate some two billion toll tickets, with 20 to 30 characters each, per year. This automatic reading may be accomplished by either direct, by-product, machine-language data generation through use of a stylus in combination with a special recording device, or by subsequent machine recognition of characters recorded on paper in accordance with preprinted guides.

The stylus-recording-inscription device is simple in operational principle, easy to use, portable, and presumably inexpensive--all very desirable features in terms of the proposed application. This device has been tentatively termed a "Stylator", and its basic principles are as follows:

> "A writing surface is provided on which there are two guide dots surrounded by a set of criterial areas consisting of seven conductors embedded in a plastic plate. As a numeral is written with a stylus connected to a source of potential, the stylus energizes, one at a time, the conductors in the criterial areas involved in the numeral. The combination of areas energized causes certain flip-flops in a translator to operate and drive the rest of the translator to indicate the correct numeral." 3/

In other words, the conductors marking the significant areas serve as vectors which, if crossed by the stylus as the numeric digit is written, will, in accordance with specific vector-crossing patterns, serve to identify the digit that was written. In the Bell Stylator device, the sequence in which the stylus crosses various vectors as the characters are produced is important for recognition purposes.

An independent invention was disclosed in the Johnson patent, assigned to IBM, which provides for the use of two centering dots and of radial areas extending from these dots for the sensing of conduction of the marks or crossings constituting the numeral written. 4/ Figure 16 is a reproduction of two cards processed in an experimental reader, based on this principle, demonstrated at the Western Joint Computer Conference of 1961. Figure 16(a) represents source patterns correctly read and recognized. In Figure 16 (b) however, there is a nonrecognition of the fourth handwritten digit, because that digit, "6", was not properly formed in accordance with the system constraints. Provided that the required vector crossing pattern is not violated, however, considerable variation in the exact shape of the handdrawn digits can be tolerated.

Similarly, supposing that in effect suitable chosen vectors are superimposed on the image field in which a previously written, typed, or printed character appears, the detection of the intersections by a black portion of the character with any of these vectors provides an input pattern which can then be matched to reference patterns, leading to a discriminating identification formula. Such a method for character recognition shows certain similarities to the peephole (critical-discriminant-area) template method, but it is much more tolerant of stylistic idiosyncracies, size variations, and skew, except where the peephole-template can be readily expanded, contracted, and rotated in accordance with preliminary scan-detection of character-edge boundary limits.

It will be noted that in both the IBM and Dimond examples the vectors are designed in a manner intended to optimize discriminations between the members of a relatively small character vocabulary, where the possible shapes and sizes of actual character-images recognizable as a particular member

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1/ Dimond, T. L. "Devices for reading handwritten characters," Ref. 98.

2/ Johnson, R. B. "Indicia-controlled record perforating machine," Ref. 240.

3/ Dimond, T. L. "Devices for reading handwritten characters," Ref. 98, p. 236.

4/ Johnson, R. B., "Indicia-controlled record perforating machine," Ref. 240.

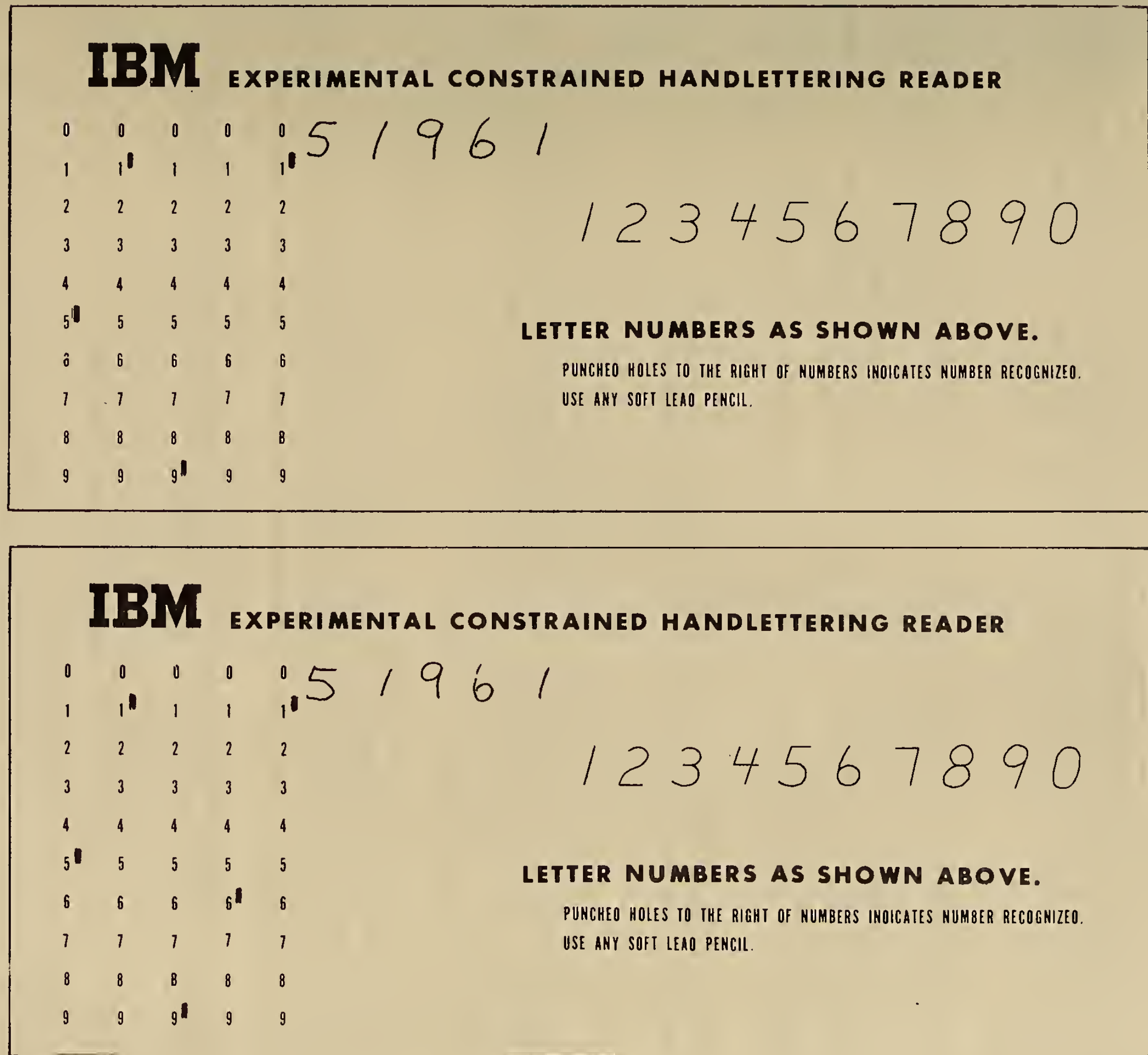

Figure 16. Hand Written Numerals, Vector Crossings Technique

of the vocabulary vary within certain constraints, such as the requirement that the handwritten numeral be centered about two preprinted dots. Other work at Bell Laboratories related to the Dimond technique has included the use of stylus movement, vector crossing, principles for the identification of handwritten names of the decimal digits, 'four', 'nine', etc. 1/

In some cases, a few vertical and a few horizontal scan lines, in a 'cross-hatched' scan, will identify individual characters by detection of crossings or intersections. In the case of a specially stylized font, such as Rabinow's 'cutless' cut font, 2/ only horizontal or only vertical crossings may be employed. It has been reported that at the Steklov Institute for Mathematics, in Moscow, "Dubinsky is working on the idea of drawing a series of parallel lines through a line of print and then attempting to identify the characters by examining the intersections of the series of parallel lines with the letters." 3/

Marill and Green 4/ have used a variation of the vector crossing scheme to illustrate a proposed model of pattern recognition as applied to handwritten characters. In this scheme, involving in effect a polar scan, 5/ where the vectors dissect the image field at 45° intervals, they measure the distance along each radial vector from the edge of the field until the first character portion crossing is detected. Kelly and Singer 6/ also report means for obtaining characteristics of curves, for character recognition purposes, by measuring distances from the center of gravity with respect to radial vectors.

Vectors of different angles with respect to the source pattern field are assumed in an invention of Oliver. 7/ He discloses the use of a carrier for the reference pattern elements such as a disc, drum, or belt that operates cyclically in one direction. This carrier contains slits or apertures that are arranged at various angles to the carrier's direction of travel, so that each of the slits will coincide with just those character strokes that are parallel to a given slit. Thus the source pattern as it is projected is scanned along several different axes of the image field.

In other character recognition systems that have been proposed, the vector crossing method is applied with respect to a larger number of vectors than the previously discussed systems require. Moreover, in some of the latter systems, the vectors are regularly oriented and displaced with respect to one another, with provision that the relative displacement be proportional to the size of the character, that is, by the provision of means for automatically varying the size of the scanning pattern in accordance with the size of the source pattern to be identified. 8/

Such a system is exemplified in the "Rotating Raster Character Recognition System," described by Weeks with respect to work at the IBM San Jose Laboratories, in August 1960. In these experiments, both machine printed and handwritten numeric characters served as source patterns which were scanned: "In television fashion with a raster consisting of six lines uniformly distributed over the digit at six different angles uniformly spaced 30 degrees apart." 9/ The vectors in this case are the 36 scan lines, which are proportionally spaced by preliminary scanning. There is then

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1/ See, for example, Refs. 192, 193, 277, 539.

2/ I. e. , a font in which, by deliberate design, only a few characters of the vocabulary are sufficiently ambiguous in the system to require cuts for discrimination.

3/ Ware, W.H., ed. "Soviet computer technology, 1959," Ref. 524, p. 100.

4/ Marill, T. and D. M. Green. "Statistical recognition functions and the design of pattern recognizers," Ref. 294.

5/ See Bomba, J.S. "Alpha-numeric character recognition using local operations," Ref. 54, for a distinction between the polar scan vector crossings technique and a feature extraction process also utilizing coincidence with a radial pattern, but requiring that all or nearly all the input pattern cells along the radii coincide with those of the reference pattern.

6/ Kelly, P.M., and J. R. Singer. "Bio-computer design," Ref. 251.

7/ Oliver, W.C. "Scanning device," Ref. 344.

8/ Rohland, W.S. "Character reader," Ref. 390, and "Character sensing system," Ref. 391.

9/ Weeks, R.W. "Rotating raster character recognition system," Ref. 528, p. 2 (preprint).

processing which determines the first scan line crossing and the last and then divides the intervening area into 7 equal groups to obtain 6 equally spaced areas across the character image. The number of vector crossings or intersections per scan line are now counted, since different portions of the character image may be crossed by the same scan line. The counts are compared with probability tables, which are based on statistics gathered from previously scanned and processed characters and thereby provide the identification formulas.

4. 1. 6 Criterial Feature Analysis

(We should note first, before describing what we have termed the "Criterial Feature Analysis" approach to problems of automatic character recognition, that the word "criterial" may pose certain difficulties for the reader. It is not strictly a coined, but, rather, a shorthand, term. As a word, it does not appear in Webster's (unabridged). International Dictionary. Instead, the word "criterional" appears, with precisely the denotation and connotation we intend to convey by our shorter term--namely, that that which is 'criterial' is that which is: "Of, or pertaining to ... a standard of judging; a rule or test, by which facts, principles, opinions, and conduct are tried in forming a correct judgment respecting them." [1/] In other words, the criterial features matching approach attempts to isolate those characteristics and properties of a source pattern that are essential for recognition.)

The criterial features approach is intended to determine and apply the "machine-idea of an 'E'" [2/] in the identification of a given source pattern as indeed an "E", or as not an "E", and so on for the other characters of the vocabulary. Similarly, in early work in automatic pattern recognition, Selfridge and Dinneen emphasized that the recognition problem is one of classifying possible configurations of input data into equivalence classes such that many different configurations belong to the same class. Selfridge in particular defines the basic problem of pattern recognition as "the extraction of the significant features from a background of irrelevant detail." [3/] In simulations of machine recognition of handdrawn characters on the Lincoln Laboratory Memory Test Computer, they recognized the embarrassingly large number of reference patterns necessary for the template approach to variable configurations of the same character. They therefore specifically suggested various types of filtering of the source pattern in order to extract significant features, such as edges and corners.

Character stroke analysis is an obvious example of the criterial feature method, where an "E" might be identified on the basis of an input pattern consisting of the record of detection of "a long vertical stroke followed by three horizontal strokes" regardless of how large the source pattern was, where it was in the image field, whether there were serifs, and the like.

Metzelaar discusses character stroke analysis, in part, as follows:

> "Several researchers have found that as far as printed letters are concerned, one of the simplest methods of avoiding the complications due to variations of location, size, and density, is to recognize letters by their 'character strokes.' In this technique, letters are scanned, for instance, by a scanner and photomultiplier... The scanner has a beam much narrower than the width of a letter... The number of intercepts of the light beam, the length of each intercept, and the relative location of intercepts are used as three basic inputs to the recognition logic." [4/]

In addition to stroke analysis, per se, the criterial features analysis may involve detecting the occurrence of specific connections between strokes, a specified sequence of strokes and connections, or of specially chosen shape segments. Shepard's Patent No. 2, 663, 758, on "Apparatus for Reading" was granted under date of December 22, 1953. [5/] This patent discloses a basic design which employs a mechanical rotating scanning disk having radial slits and a stationary slit, arranged to move a spot

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1/ Webster's New International Dictionary of the English Language, 2nd ed., unabridged, p. 627. We note, moreover, that the term "criterial areas" is specifically used by Dimond (Ref. 98) in this sense.

2/ A paper presented at the 15th National Conference of the Association for Computing Machinery, August 1960, by D. S. Himmelman and J. T. Chu of RCA, (Ref. 213), reported on studies both of human recognition of systematically deteriorated character patterns and of a computer simulation program to explore optimum discriminant areas and other criterial features of a topological nature. They reported that, for their program, the machine idea of the 'E' could be further simplified to the formula: "A black stroke followed by three dots to the left, and any multiples thereof."

3/ Selfridge, O. G. "Pattern recognition and modern computers," Ref. 410; Dineen, G. P. "Programming pattern recognition," Ref. 100.

4/ Metzelaar, P. "Mechanical realization of pattern recognition," Ref. 305, p. 7.

5/ Shepard, D. H. "Apparatus for reading," Ref. 415.

of light across the printed characters from top to bottom as the print moves from right to left. A photocell examines the reflected light and generates the input pattern.

In a particular embodiment, which was built and demonstrated by IMR, the input pattern is a series of pattern elements detected by means of a specially designed scanning disk. This latter disk comprises a rotatable mask, divided into sectors, each of which sectors has a fixed arrangement of specially shaped openings through which light may or may not be sensed, depending upon the shape of the source pattern being scanned. Thus when any one sector of the mask is superimposed on the image field, an input pattern element is registered for that sector if any portions of the image being scanned coincide with the sector openings so as to reduce light to the photocell. All sectors of the mask are passed sequentially over the image field a certain number of times as the unknown symbol to be read is moved laterally across the scanning field. The input pattern thus consists of the series of hit-no-hit indications for each sector as a sub-set of input pattern elements and of the series of hit indications per sector per rotation cycle comprising the complete input pattern element set.

The scanning disk with specially placed and specially shaped apertures in different sectors is in effect a plurality of mask arrays, which select criterial segments of character shape such as those shown in Figure 13, example f., p. 35. Such a disk thus serves as a master reference pattern. The element-by-element match of the input pattern with the total vocabulary of reference patterns coincides with the transformation of the source pattern to an input pattern and its transformation to the format of the reference pattern. The latter transformation also effects a considerable reduction in the total information available in the original source pattern, by selecting for matching only those portions of the total symbol image which will serve to differentiate it from other symbols in the vocabulary.

Transformation of the results of the element-by-element match (hit indications from the various apertures), which in this case are identical with the input pattern, consists in the determination of which sectors have had hits and in what order, as the observed identification formula. This is then compared with each of the set of master identification formulas to achieve recognition.

The system described above is thus illustrative of early reduction to practice of criterial features matching methods, as was, for stroke analysis, a Laboratory for Electronics reader. 1/ In the last few years, a great variety of criterial features have been proposed and tested for use in automatic character recognition. This is true for character and pattern recognition research and development efforts both in the United States and abroad. For example, Grimsdale, et al, 2/ at the University of Manchester in England have explored the use of criterial features with respect both to areas and to shape characteristics such as slope of a character line. Recent Russian work in character recognition has also included this approach, as in a system proposed by A.G. Vitushkin which determines characteristic feature combinations such as 'long vertical line to the right,' 'three short vertical lines to the left', and the like. 3/

Somewhat similar effects may also be achieved in a variation of the coordinate description method to provide a special form of criterial analysis in which certain cells (coordinate positions) of the superimposed grid must be black and certain cells white, but the majority, for any given character pattern, may be 'grey' - that is, in an indeterminate or 'don't-care' status. In statistical studies made by Baran and Estrin, for example, the a priori probability distribution for each cell being black, white, or grey is determined with the assistance of a computer. As a result, they report, "The offspring stencil used is not of the outline of the character being recognized, but is distorted to emphasize those subareas which are significant in differentiating one character from all others." 4/

In this sense, a weighted area scanning, or weighted matrix correlation technique, may be considered to be the more general principle subsuming both holistic templates and reductive templates such as the peephole-templates previously described. That is, the weight for the area exactly covered by a given photographic negative pattern or stencil in holistic systems is one, and for all other areas zero, whereas in peephole-templates the weighted areas are precisely the test points where either black or white is seen.

1/ "Interim report of the check reader," Ref. 264, see also Glauberman, M.H., Refs. 163, 164, 165.

2/ Grimsdale, R.L., F.H. Sumner, C.J. Tunis, and T. Kilburn. "A system for the automatic recognition of patterns," Ref. 185.

3/ Garmash, V.A. "Seminar on reading machines," Ref. 156, p. 11.

4/ Baran, P., and G. Estrin. "An adaptive character reader," Ref. 34, p. 33.

Reductive templates of the peephole type have been derived, for the most part, by manual trial-and-error methods or on an intuitive basis. [1] In fact, it was not until programs of computer simulation were developed that the weighted, and therefore criterial, coordinate description methods began to receive widespread attention. In the Japanese Electrotechnical Laboratory system, for example, the criterial black-white coordinate positions were arrived at after extensive computer analysis of character samples. [2] In general, however, we will distinguish between template systems, whether holistic or reductive, and systems that seek criterial features in the sense of properties that are relatively invariant under transformations of exact area or position or of size.

Since criterial feature extraction may be considered as a case of property filtering, related basic research simulating perception by living organisms is also of potential interest. Loebner, for example, has developed a recognition device, combining optical and electronic techniques, specifically designed to simulate the property filtering that occurs in the eye of the frog. [3] We shall consider criterial feature extraction and analysis in more detail in discussing certain characteristics of representative recognition systems in a later section of this report.

4.1.7 Curve-following Recognition Techniques

In addition to the various commonly used methods for character recognition shown in Figure 13, one additional technique that has frequently been suggested should be discussed. This is the technique of curve-following or contour-direction-change tracing. A curve-tracing device, consisting of a spot of light travelling in a circle, can be made to follow the direction of a black-white boundary and to generate x and y deflection voltages which are a function of the shape of the continuous outline of a character. The waveforms can subsequently be analyzed in terms of the equivalent reference patterns for the vocabulary characters. Advantages of this technique would include tolerance for considerable variation in size or exact shape of symbols scanned. Disadvantages, however, include relative intolerance of broken strokes and of fill-in, such that the gap between different strokes might be insufficient for tracing reentrant sections of the character edges.

The curve-following method may be applied in conjunction with either a template principle (the exact shape of the contour) or to a criterial feature principle (the number and kind of changes of line direction along the contour). In fact, Kamentsky specifically includes "edge tracing" in the "Searching for Features" category of his classification of various recognition methods. [4] Sequences of contour change similarly provide the "edge sequence" criteria for certain recognition sets as proposed by Unger. Unger, however, notes that for the more general case of two-dimensional graphic patterns, including badly malformed characters as well as abstract geometric shapes, the edge-tracing sequences are often insufficient for discrimination in a particular vocabulary set. He suggests that considerations of relative edge position are often necessary, and that, as in an example given of a badly distorted "H", questions of relative proportion may also be involved. He further suggests that: "An arbitrary set of standards may be chosen for each target set, such as the requirement: 'The width of the wider leg must not exceed twice the width of the narrower leg.'" [5] Such an approach obviously combines curve-following feature extraction with other types of criterial feature analysis.

The method of curve following or edge tracing strongly suggests analogy with certain findings in the area of human perception, namely, that critical points for human recognition of shape seem to be concentrated along contours or boundaries of sharp color contrast. [6] Hartline, moreover, has reported an experimental confirmation using the horseshoe crab, as follows:

1/ Compare Gill, A. "Pattern recognition," Ref. 159, p. 676.

2/ See Iijima, T. "Basic theory of pattern recognition," Ref. 225, and Wada, H. et al. "An electronic reading machine," Ref. 521.

3/ Loebner, E. E. "Image processing and functional retina synthesis," Ref. 276. See also "Neuron information theory may be used in computers," Ref. 329, p. 4.

4/ Kamentsky, L. A. "Pattern and character recognition systems; picture processing by nets of neuron-like elements," Ref. 244.

5/ Unger, S.H. "Pattern detection and recognition," Ref. 501, p. 1741.

6/ See, for example, Attneave, F. and M. D. Arnoult. "The quantitative study of shape and pattern perception," Ref. 18. Attneave, F. "The relative importance of parts of a contour," Ref. 19, and "Some informational aspects of visual perception," Ref. 20; Anderson, Nancy S. and E. T. Klemmer. "A review of stimulus variables of patterns," Ref. 16.

"Inhibitory interaction in the retina results in the enhancement of brightness contrast. Since the inhibition is greatest between elements that are close together, contrast is greatest at borders and edges in the retinal image, where steep gradients of intensity exist. Direct experimental evidence for this has been obtained from the eye of Limulus." 1/

The technique of curve-following as a means for automatic character recognition was proposed at least as early as 1953, 2/ and several organizations active in the field have continued to explore possibilities. For example, the Perkin-Elmer Corporation in the U.S. and the Levy Associates Company in Canada have been investigating reductive transformations of curve-tracing data as a means for recognition of specific character and symbol shapes. Russian experiments have been reported combining a scanning mechanism with a computer program to follow the source pattern outline, record shifts in direction, and, by computer analysis of the sequence of values for observed directions and comparison with previously analyzed reference patterns, accomplish recognition. 3/ However, it does not appear that operational results are as yet available nor that a practical reader using this method is as yet in operation. 4/

Variations on curve-following techniques have been or are being used, however. In discussions of a paper by Sprick and Ganzhorn at the International Conference on Information Processing, (to be discussed below), several techniques were described. Elkind has obtained 85% accuracy in experimental recognition of handprinted block capitals by determining slopes of character lines, dividing the slopes into three categories, and determining the number of incidences for each category per character. 5/ Preliminary work at the Dahlgren Proving Ground was also reported 6/ in which curve following is employed, but the input pattern elements consist of indications of horizontal and vertical motion and of transfers from one mode to another. A variation of curve-following that is non-reentrant is used in a prototype reader for handwritten numerics at Rabinow Engineering.

Contour-tracing in a sense begins as a direct translation or pantographic copying process, but the copy-reproduction motions are then subjected, as both Minot 7/ and Fairthorne 8/ have suggested, to an operational analysis which in effect constitutes the input pattern. Where this operational analysis effects the elimination of redundancy in continuous-direction line traces we have, as previously noted, a criterial features input pattern. We might also expect to find possibilities for combination with either criterial area or vector crossing principles. Thus if the pantographic copying (whether mechanical or derived from electronic scanning) can be suitably deflected into a given fixed reference

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1/ Hartline, H.K. "Receptor activity and neural interaction in the eye." (Abstract) Ref. 198.

2/ Loeb, J. "Communication theory of transmission of simple drawings," Ref. 275, and Beurle, R.L. "Letter-tracing device," Ref. 46.

3/ See Garmash, V.A. "Seminar on reading machines," Ref. 156, p. 11, referring to work of V.A. Kovaleskiy.

4/ Haller, who conducted a master's thesis study on line tracing as simulated on a computer, made the following evaluation: "The basic conclusion of this paper is that character recognition by line tracing is feasible and limited only by the complexity of the recognition tree ... Attempts to recognize typewritten characters, which are exceedingly rich in frills leads to an impossibly complex tree." Ref. 190, p. 4.

5/ Ref. 439, Discussion by J.C.R. Licklider, p. 244.

6/ Ref. 439, Discussion by M.S. Maxwell, p. 244.

7/ Thus Minot suggests that one may operationally define the generation of all figures of a given class, such as, for circles, a complete tracing with return to the starting point, plus constant curvature. Suitable detecting and classifying procedures would then be applied to unknown input characters to provide a basis for matching with the previously stored class definitions. "This sort of process may be called operational identification." (Ref. 310, p. 13.)

8/ Private discussions between R.A. Fairthorne, H. Pfeffer, and M.E. Stevens on possibilities for recognition of chemical structure diagrams, September 1959.

area, crossings of these vectors by the copy motion might be used for recognition purposes. Suitable adjustments for size and tilt normalization might also be employed.

A variant on the curve-tracing, contour-following method has been developed by Sprick and Ganzhorn, 1/ in which contour data for the two opposite sides of the character given by the source pattern are obtained. Related techniques disclosed by Sprick 2/ include:

(1) A prescanning operation, which effectively locates the center of a character;

(2) The generation of successive angularly displaced radial scan sweeps from that effective center which produce signals when a portion of the character is encountered;

(3) Means to process these signals such that their magnitude is a function of the distance from the center to the intercepted character portion in each of the radial zones, and

(4) Means to produce a waveform that approximates the outline of the character scanned. 3/

In the two-side contour version of this variant method, the waveforms are differentiated and passed through a criteria detecting circuit and further logic for comparison with reference patterns. Young, in evaluating this Sprick-Ganzhorn technique, notes that in experiments where only seven criteria combinations were used a number of different shapes were successfully recognized, but that:

> "Considerable difficulties have, however, been caused by poor quality print, smudges, and specks, and these are particularly important to solve when using a fast contour-following technique." 4/

Thus we again find that such factors as quality of input, limitations of vocabulary, and the like, are of more significance than specific differences of technique in some of the commonly used or proposed methods of automatic character recognition.

4.2 Process Steps in Character Recognition

The common methods for character recognition discussed above have illustrated various different combinations of means to carry out process steps such as are shown in the generalized diagram of Figure 12, p. 34. Let us now consider the steps of a generalized recognition process in more detail. We note, first, however, that many of the transformations shown in Figure 12 can be, for a specific case, identity transformations or null operations. In the case that operation 7 of Figure 12 is an identity transformation, for example, operations 8, 9, and 10 would coincide with operations 4, 5, and 6, respectively. In the case that operations 4 or 8, or both, are instrumented in a particular system by the simultaneous selection of all reference patterns, operations 6 and 10 would not be activated and operations 5 and 6 would represent multiple comparisons being made in parallel.

4.2.1 Input and Transformations of a Source Pattern

Operation 1 in Figure 12, the input of a source pattern, represents the impingement of the data of the source pattern upon suitable receptor organs. It may be more simply referred to as "pick-up". This operation is typically under the control of the scanning threshold, which is subject to such weighting functions as scanner resolution, adjustments of scanner sensitivity to contrast, and the like. For example, in an application of an automatic optical reader for the processing of traveller's checks, 5/ the scanning mechanism includes a means for 'gloss-sensing' so that the source pattern pick-up of the serial number digits which have high gloss characteristics can be accomplished despite interference and noise from over-stamping.

This source pattern input operation may include positioning and repositioning of the source material for effective pick-up, including movements of the source pattern carrier, the scanning

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1/ Sprick, W. and K. Ganzhorn. "An analogous method for pattern recognition by following the boundary." Ref. 439.

2/ Sprick, W. "Character reader," Ref. 441.

3/ As previously noted, a scheme proposed by Marill and Green, although more properly a vector crossings method, provides the converse of Sprick's method, by measuring the distance from the boundaries of the image field until first character encounter for each scan-line, without requiring that the source pattern first be centered. See Ref. 294.

4/ Young, D.A. "Automatic character recognition," Ref. 539.

5/ Installation of a Farrington-IMR reader at the First National City Bank, New York, see Keller, A.E., Ref. 249, p. 25.

mechanism, or both. In some automatic character recognition systems, when only white areas are sensed at a given input time, operation 1 is automatically repeated. Both gross positioning and micropositioning operations are carried out as required in the source pattern input step.

In some systems, there may be a gross (low resolution) prior scan to locate fiduciary marks ("begin read" signals), or any black area first encountered on a page (or in the expected image field), or the first black encountered coming up from the bottom edge of an envelope. [1] Other line-finding and line-following operations to adjust for tilt of a line of characters which will become, successively, a sequence of source patterns, may also be involved. Examples include, for gross positioning, an experimental Farrington-IMR machine for post office mail-sorting applications, and for micro-positioning, techniques such as those disclosed by Bozeman. [2]

In an early Post Office address-reader designed by Farrington-IMR, the input process consists first of finding the lowest line of the typed address on an envelope, with scan of each successive one of four areas 1 1/2 inches wide to determine where this last line is located, and with subsequent scanning such as to follow the apparent lowest line. The shadow cast by the window of a window envelope has, for example, caused difficulties in adjustment for this lowest line position. It is noteworthy that at least one organization active in the development of automatic character reading techniques has estimated that a large percentage of the cost of a reader-system is in precisely such housekeeping operations as line finding and servoing the scanning means to follow a skewed or tilted line.

In the Bozeman patent, assigned to Burroughs, the technique for micropositioning (i. e., of the individual source pattern) is described as follows:

> "One of the features of the invention is ths utilization of one or more cathode ray tubes each having sweep circuits that are so synchronized with the scanning of the character that each vertical sweep of the cathode ray tube starts substantially at the instant when the scanning spot encounteres the starting edge of the character in the corresponding vertical scan, and each horizontal sweep of the cathode ray tube starts concurrently with the beginning of the first vertical sweep (that is, with the detection of the starting point). This causes the cathode ray tube to project upon its screen a transformed image of the character wherein the edge of said character that corresponds to the starting edge of the original character is brought into coincidence with a fixed reference line on said screen, and the point on said image corresponding to the starting point of the original character is located at one extremity of said reference line." [3]

The actual input of a source pattern is usually either followed or accompanied by operations 2 and 3 of Figure 12. [4] Operation 2 typically involves the transformation of the source pattern that has been picked up to an appropriate input pattern suitable for further processing in a particular recognition system. For example, the interruption of reflected light to a photocell as a scan line crosses black areas in the image field is translated into a continuous waveform or into pulse patterns. An example of an identity transformation in this operation is the optical reflection of the source pattern image from the original image field.

Feedback functions may affect this operation as in cases where the first input pattern is used to adjust repositioning of the source image, to trigger the beginning of specific recognition steps, to standardize the dimensions of succeeding input pattern elements or to set the frame of reference for more detailed analysis of the input pattern. Feedback functions affecting operation 2 may also arise

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1/ Fiduciary marks are used, for example, in FOSDIC equipment and in a Baird-Atomic page reader. The possibilities with respect to system design will be discussed in more detail in connection with consideration of operational requirements.

2/ Bozeman, J. W. "Character recognition apparatus," Ref. 57.

3/ Bozeman, J. W. "Character recognition apparatus," Ref. 57.

4/ Compare, for example, Kharkevich: "The preparation process may include making the lines finer, smoothing the contours, eliminating small defects in the print, eliminating small spots of extraneous origin, increasing the contrast, etc. The preparation may involve a separate operation which follows inspection using a conventional scanning system; however, it may also be completely or partially included in the inspection process." (Ref. 256, p. 21.)

where any input pattern, or input pattern element, determines the selection of succeeding elements of the source pattern. [1] In reader developments at Philco, several different scan modes and techniques for focussing and defocussing serve to enlarge or reduce the area of pick-up.

In some cases, such as the German reader for typewritten numerals previously noted, operation 2 involves, in effect, transformation of the source pattern into a series of input patterns, systematically displaced by shift register techniques, to accommodate variations in both horizontal and vertical registration, as well as to provide a number of different input images in the coordinate description manner. A major type of operation frequently involved in the scanning pick-up of the source pattern and its translation to an appropriate input pattern, required in the coordinate description methods, and probably found in the human retina itself, is therefore that of "quantization". That is, for a given mesh of theoretically superimposed grid, or for the cells of a retinal mosaic, a decision is to be made as to whether or not a given cell (or coordinate position) "sees" black, white, or some intermediate color value at a given instant of reception of sensory data. Thus we may assume, with Stearns, that:

"1) The pattern to be recognized always may be made to occupy a fixed, finite, rectangular area on a plane.

"2) This area may be divided into n elements.

"3) Each element may be designated either black or white." [2]

Such binary quantization is typically achieved in one of two ways: either by integration over the source pattern sub-area 'sensed' by a particular cell and a comparison of the result with some given threshold value which will govern the decision as to 'black' or 'white', or by a local averaging operation in which a presumed 'black'cell is given an evaluated 'black' or 'white' value in accordance with a criterion based upon the relative 'blackness' or 'whiteness' of its immediately adjacent neighbor cells. It should be noted, of course, that such quantization need not be limited to the binary case. In fact, in a Rabinow Engineering reader design, four levels of quantization--'black', 'medium gray', 'light gray', and 'white' -- are utilized. [3]

Taylor, [4] however, makes considerable point of preserving differential values for relative black or white as actually sensed in each cell of the scanning grid until a later stage in the recognition process, so that in his system the input pattern is claimed to be an accurate 'analog' of the original image pattern. He thus claims, as of 1958, that, "The new apparatus differs fundamentally from any general-purpose pattern-recognition apparatus that has been proposed in the past, since the analogue form of the signals is preserved right up to the output indicating devices." This difference would seem to be one of sequence of processing steps rather than of basic recognition principle since, on the one hand, a distinction between 'long', 'medium', or 'short' black strokes, as in a Laboratory for Electronics reader [5] would also conserve a certain amount of 'analog' data per scan segment, and since, on the other hand, the mesh (e.g., 9x9) with which Taylor has worked is of considerably coarser grain (or resolution) than some coordinate description input patterns to which integration-threshold or local averaging techniques, or both, are applied. Also, of course, criterial area or 'optimum discriminant area' weightings, as noted, among others, by Wada, [6] as disclosed in a recent patent issued to Highleyman [7] and as 'learned' by a reward-punishment procedure in certain of the Perceptron systems, achieve fundamentally the same effect.

1/ The early Laboratory for Electronics reader discussed in Ref. 264, for example, is one in which only those source patterns elements which differ from preceding elements are used as elements of the input pattern.

2/ Stearns, S.D. "A method for the design of pattern recognition logic," Ref. 451, p. 48, see also McLachlan, D., Jr. "Description mechanics," Ref. 286.

3/ Rabinow Engineering Company. "Character recognition machines--principles of operations," Ref. 369.

4/ Taylor, W.K. "Pattern recognition by means of automatic analogue apparatus," Ref. 482.

5/ See Refs. 163, 164, 165, 264.

6/ Wada, H., et al "An electronic reading machine," Ref. 521; for example: "If the black area exceeds k times....(where 0 > k > 1) ... the area in a mesh, it is defined as black mesh, if not, white mesh .... "

7/ Highleyman, W.H. "Character recognition system," Ref. 208.

It should be noted that the identical-copy optical template techniques do not depend upon quantization for derivation of the input pattern. In many of the characteristic waveform matching methods, the effect of quantization is achieved indirectly, by the amplitude differences reflecting the relative density of black (or of magnetization) in a scan segment or sub-area, for example.

We should note, moreover, that even when quantization is not done intentionally, it happens as a result of the finite frequency bandwidth of electrical circuits. Whenever this bandwidth is not several times as great as the highest frequency component required for "perfect facsimile" reproduction of the scanned character, there will be some smoothing or quantizing (i. e., the number of measurably different amplitudes will be limited).

A special case of quantization in connection with a criterial type of line-tracing has apparently been explored in the work of the Russian scientist, Glushkov. The method is reported to involve the scanning of a square sub-area in order to determine its average blackness, and then to proceed as follows:

> "The beam would be programmed to scan adjacent squares in order to determine the direction of maximum darkness and to move in that direction. The associated logical equipment would store this direction and control the motion of the beam accordingly. The direction and curvature of motion would then be computed using first and second order differences. A large change of direction would indicate that such an inflection point should be recorded. If necessary, a coarse measure of length, such as short, average, or long, will also be computed for each line segment. It is hoped that from such a scanning scheme, a set of invariant characteristics can be determined for each character." 1/

Operation 2, for the transformation of the source pattern to the required input pattern, may also include various steps of image improvement, 2/ such as contrast enhancement or integration of the relative black or the relative white for the image sub-area scanned in a given interval of the scan cycle. A variety of "cleanup", "defuzzing", 3/ and skeletonizing or "inlining" operations may be included in the operations of sensing the source pattern and its transformation to the input pattern. These may be applied overall, as in the removal of "salt" (small white spots or holes in areas where the character is generally black) and "pepper" (small black spots in generally white area), 4/ or special "local operations" may be performed on successive small sub-areas. In the Solartron ERA machines, blurred edges are: "Considerably cleaned up by applying pulse-width discrimination to the line scan." 5/

In some cases, the skeletonizing or cartooning operations found in input pattern transformations involve the erasing of all of a character stroke except its outermost edges, as in the edging operations reported by Dinneen in 1955, 6/ and in the 'custering' operation developed at the National Bureau of Standards for picture-processing experiments on SEAC. 7/ Other techniques, however, are directed toward normalizing the character stroke to a predetermined average width or thickness, as in Bomba's system, 8/ or to an otherwise idealized line. Uhr says of his system, for example, that:

> "Figures are sharpened by a single process that does something much like drawing an average or essence-giving line through the figure. This process makes use of a Gestalt-theory concept: a force field toward closure and toward the 'good' figure." 9/

To an extent, as we have previously noted, shift register translation processing in the derivation of the input pattern from the original source image scanned is a cleanup operation for fuzzy edges and

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1/ Ware, W.H., ed. "Soviet computer technology, 1959", Ref. 524.

2/ Such as, for example, those described by Kovasznay and Joseph, Ref. 261.

3/ Rohland, W.S. "Character reader", Ref. 390.

4/ Deckert, W.W. "The recognition of typed characters", Ref. 87.

5/ Bailey, C.E.G. "Character reading is a signal/noise problem," Ref. 30.

6/ Dinneen, G.P. "Programming pattern recognition. ' Ref. 100.

7/ Kirsch, R.A., L. Cahn, L.C. Ray, and G.H. Urban. "Experiments in processing pictorial information with a digital computer," Ref. 257.

8/ Bomba, J.S. "Alpha-numeric character recognition using local operations," Ref. 54.

9/ Uhr, L. "Intelligence in computers: the psychology of perception in people and in machines," Ref. 494.

smudging of characters, at least with respect to the leading edge. However, noise, dirt, and smudging in interior portions of the character and mutilations of the character stroke may also occur. [1] In other cases, therefore, special operations are performed, including the 'local averaging operations' previously mentioned in connection with source-to-input-pattern quantization for coordinate description and other recognition methods.

These local averaging and improvement operations may actually occur directly as the result of variable settings of the scanning threshold controlling operation 1 of Figure 12, (p. 34) but more typically they are carried out in the process of integration and cleanup in the conversion of the source pattern to the input pattern, or in the transformation of that pattern to the required reference pattern format. In a few cases, however, the practical effects of local averaging and improvement operations may be achieved at later stages of the recognition-processing cycle; for example, during the matching process for certain of the photographic template systems, or by the effects of variable weightings directly related to the original intensity of a specific sub-area of the source pattern in the matching of the identification formulas. [2]

We have previously noted the very large number of possible coordinate descriptions of any single character pattern subject to the transformations of size, registration, and rotation. When we take account, in addition, of the problem of handling the randomly superimposed noise, -- dirt, smudging, bleeding and filling of characters, matrix hairline or ribbon fiber impressions, deterioration or mutilation including complete breaks in character strokes, and the like--the number of potential reference patterns is even further multiplied. For this reason, the majority of researchers who have considered this problem are strongly of the opinion that the cleanup operations should be placed as near the beginning of the sensing-recognition cycle as possible. [3]

Still another commonly encountered category of source-to-input-pattern transformations includes various procedures and techniques for the derivation of an input pattern from the source pattern by "optical filtering", "photometric analysis", "autocorrelation techniques", and "field potential analysis". The "lenticular lens" array of a system designed by Briggs Associates, Inc. is another example of a specialized transformation carried out as an operation 2 or an operation 3 process step. The lenticular array is described as consisting of two sets of minute hemispherical ribs positioned at right angles to each other where each lens of the array serves as a minute, independent spherical lens to direct the light from a parallel light source to discrete positions on a viewing plane. The lens array can be tilted to provide various viewing angles. For example, 36 distinct patterns can be discriminated in a 6x6 directional matrix master pattern. [4] We shall defer consideration of some of the other special transformations to a later section discussing some of the design characteristics of selected systems.

Of course, the continuous-time waveform produced by single-slit scanning in certain of the characteristic waveform techniques for character recognition, the binary encoding of coordinate description hits, and the hit-or-no-hit patterns for criterial features analysis or for vector crossings, are also input pattern forms that are derivatives of the original source pattern.

Where operation 3 of Figure 12 is other than an identity transformation on the input pattern, it involves a translation of the input pattern into the repertory of pattern elements used as the basis for identification in the system. It typically consists of such steps as unitizing (or quantizing) of the input pattern, breaking up of a continuous waveform into discrete signals, substituting counts of the number of pulses for the pulses themselves, determining the relative length of pulses or black blobs sensed and substituting symbols representative of these characteristics for the characteristics themselves, and other encoding operations. This operation may also involve the selection from the total input pattern of those elements and only those elements which are significant for identification, as in several of the criterial area aperture techniques.

1/ See, for example, the breaks in the typewritten "L" of Figure 19, p.79 .

2/ For example, in a technique proposed by Hau Wah Lo: "The main scheme is to 'feed' into the program a sufficient number of arbitrarily written figures of each alphabet, record the positions of the points covered by the figure, and them by multiplying by a constant term. Thus, the positions on the screen 'most frequently' crossed by each figure are in storage." Ref. 274, p. 63.

3/ See Refs. 244, 276, 305, 500, 501.

4/ Brown, L.R. "Nonscanning character reader uses coded wafer," Ref. 62.

In a special case of peephole template matching, operation 3 is not a null operation, but rather is used to transform various possible input pattern configurations to a standardized master reference pattern template. This technique is proposed by Mauch for the development of improved reading aids for the blind. In this scheme, the initial input pattern is derived from the source pattern by means of an aperture mask optimally designed for a particular type font. Then, in operation 3, fiber optics are used to transform this pattern into another which is processed by a second aperture array which has a standardized arrangement of apertures, a reference pattern serving as master for more than one type font. 1/

Transformations of the input pattern to the required reference pattern format typically involve such processing steps as obtaining and recording a specific sequence of criterial area coincidences or of zone or vector crossings. Included would be operations to eliminate redundancy, such as ignoring scan segments which give the same results or scores as immediately preceding scans, ignoring line lengths until the line-direction changes, and the like. Two examples are described below.

The first example is that of a check reader designed by the Laboratory for Electronics for the Chase Manhattan Bank. The system consists of the following elements:

(1) A photoelectric scanner where segments of the character to be identified are examined sequentially;

(2) An encoding unit where the scanner output of input pattern elements is manipulated in accordance with built-in logic;

(3) Shift register storage where the encoded data for the input pattern elements is stored until the entire source pattern has been scanned, and

(4) A decoder unit where the coincidence of a specific code pattern for an input pattern with the code pattern for one of the reference patterns in the vocabulary results in positive identification of the unknown character represented by the source pattern.

During scanning the source pattern to be read is moved past a lens which projects a magnified image upon a column of photocells sufficient in number to accommodate the height of the image plus allowance for variations in vertical registry. The outputs of these cells are modulated by black regions caused by the portion of the source pattern in the image field, and are read out sequentially through circuits which at each scan time produce a pulse for every photocell output indicating the detection of a black region and a pulse for every combination of photocell outputs that indicates the detection of a long black region. These pulses are then transmitted to the encoding unit where counts of the total number of pulses per scan and of the number of long black pulses per scan are combined into one of five discrete pulse code patterns. The encoded results of each scan are then transferred to shift register storage subject to the restrictions that the first scan of a character is not used for recognition and that only those scans that differ from the immediately preceding scan are sent to storage.

These restrictions accomplish several purposes. The first scan (operation 1) is used not for recognition but to trigger the recognition process for the succeeding scans: This non-use of the first scan for recognition also minimizes uncertainties in horizontal registry. The non-use of succeeding scans that are identical to an adjacent preceding scan serves to limit the number of input pattern elements necessary to achieve identification. This procedure tends to eliminate the effect of variations in the width of the printed characters, and to permit that document-handling speed need not be exactly synchronized with the scan rate. For example, if the document speed is such that the movement of the source pattern through the image field is slower than the scan rate, the source pattern merely appears wider with respect to the scan rate.

Fitting the input pattern to the reference pattern format provides, as in several other systems, that the encoded results of the scans are systematically shifted through storage until all the encoded results are in known positions in storage. At this time matching identification interrogation is triggered. A diode matrix with appropriate gating provides means for built-in identification formula

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1/ "Our future masks will now consist of two parallel plates, each having a pattern of openings connected by lucite light guides. The openings in the plate facing the photocells have a standard arrangement, while the openings in the plate facing the text are arranged optimally for each type print. The lucite light guides between the plates provide a considerable amount of freedom regarding the mutual arrangement of the openings in the two plates." Ref. 300, p. 5-6.

storage, and the subsequent operations of selection and decision. Thus, if the master identification formula for the numeral "5" requires the occurrence of two pulses and one long pulse on the first scan after the registration scan, the occurrence on the next non-identical scan of three pulses and no long pulse, and the occurrence on a subsequent non-identical scan of two pulses and one long pulse, and the encoded elements of the input pattern derived from the scans of an unknown character (observed identification formula) coincide with this pattern, that output line of the matrix indicating identification of "5" will be energized.

A second example of input pattern to reference pattern transformation is provided in a system proposed by Greig and reported by Boni in a study on Russian printing prepared to define critical factors for automatic character readers for Cyrillic-alphabet source material. 1/ This is an interesting variation on the encoded coordinate description in which the initial input pattern is a black-white quantized pattern with respect to the superimposed grid, but in which the input pattern as transformed to the required reference pattern format consists of encoding the number of black cells in each row and in each column of the array.

In this method, the superimposed grid is called a "shape discriminator sieve". It provides for "articulation of characters by horizontal levels and vertical zones into spatial elements corresponding either to figure elements of characters or background elements of characters and the areas containing characters." 2/ Certain of the horizontal levels comprise a "constant band" which embraces the normal height of characters, exclusive of ascenders and descenders. 3/ This can be utilized as a guide for adjusting to the actual registration of individual characters and character lines.

The transformation of the input pattern to the reference pattern format results in a code string of digits representing 'black' counts for each successive row and each successive column. An additional code for relative character width is an optional feature. Using both row and column codes, it is claimed that each of the 270 characters of a linecasting-machine family of Cyrillic types can be discriminated, provided that the alphabets involved are of the same point-size in Roman, italic, and bold face. As a result of simulation studies, it is further claimed that for a more limited vocabulary the row codes alone should suffice, specifically:

> "The 64 characters of American Linotype type face Russian no. 3 of reference quality (i.e., images derived from pattern-plate impressions), when coded according to their horizontal parameter values...constitute a non-ambiguous set; therefore, ignoring the vertical parameters...has validity for a universe of characters to be recognized in which the character images correspond closely in form to reference-quality images." 4/

Greig and Boni note that such a universe is small, but they suggest the possibilities of deriving from a number of input samples sufficient statistical information to provide alternative reference patterns.

Thus, in general, operations 1, 2, and 3 of Figure 12, serve a variety of purposes, including the sharpening and improving of the character image, the reduction of redundancy, and the elimination of noise and irrelevant details. We should note, however, that any manipulation of the basic input data loses some of it. For example, a scheme for correcting minor breaks or omissions in continuity of the type stroke may cause a "C" to become an "O" if there is a speck between the ends of the "C". Similarly, a scheme for removing specks may open an "O" into a "C" if the "O" is a little thin where the "C" would normally be open. Hence, while such processing improves the effectiveness of scanning devices with respect to good quality material, it can degrade that of poor quality and even for good quality source patterns there is introduced a finite, if small, additional probability of error.

4.2.2 Matching-Recognition-Identification

Once the appropriate input pattern has been derived from the source pattern on the carrier medium, it must be compared with one or more reference patterns. In particular, the elements of the input pattern are to be compared with the elements of the reference pattern or patterns. Operation 4 is preparatory to the matching operations. It involves a setting of the selection of

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1/ Boni, C. "Russian type study," Ref. 55. Section 5 of this study was prepared by J. Greig.

2/ Ref. 55, p. 1-4.

3/ Note that, for Cyrillic characters, even upper case characters may involve ascender and descender levels, as shown in Figure 14.

4/ Ref. 55, p. 6-5.

reference patterns representing the vocabulary so as to compare the input pattern elements in order against the reference pattern elements of each of the available reference patterns in turn. The order in which the reference patterns are selected may be important in devices using recognition techniques such as optical matching where an "E" input pattern may cover an "F" reference pattern and thus result in a false identification. In some recognition systems, operation 4 of Figure 12 (p. 34) is automatically repeated until all reference patterns have been tried, regardless of the degree of match found in the succeeding process step, operation 5.

Repetition of operation 4 for all possible reference patterns, regardless of degree of match, is particularly important in systems which are based on reference patterns that provide probabilistic bases for identification. In some criterial feature analysis systems, for example, each reference pattern is a statistically determined value for certain properties of the expected character, such as the property of having a wholly enclosed white area (the "lakes" vs. "inlets" criterion of Rochester), 1/ or of having a certain hit-score with respect to specific inspection-point n-tuples of the Bledsoe-Browning method. 2/ The "rotating raster" scheme described by Weeks 3/ is another example. Here the number of encountered crossings per scan-line comprise the input pattern elements. Reference patterns are built up by statistical studies of sample characters which may vary both in size and in details of shape, so that the reference pattern elements are the probability scores for a given expected character for each crossing-count and scan-line combination.

For each scan-line in the rotating raster system, a matrix is established that records, in each element, the probability of occurrence of the number of crossings indicated by the column if the system is scanning a pattern proper to the character indicated by the row. Next, as Weeks describes the process:

> "The unknown character is scanned and a particular number, say k, of crossings is encountered. Merely by inspecting the column, k, and selecting the element which has the largest conditional probability, the character most likely to give this particular number of crossings for this particular scan is determined." The process must be repeated for each scan-line to derive the information necessary for identification-decision.

Operation 4 is in some cases either, in effect, 'wired-in', or is a null operation. The reading system may provide for simultaneous comparisons of the input pattern with all the reference patterns of a given vocabulary, by parallel processing. Various techniques for parallel processing are utilized in readers developed by Baird-Atomic, Briggs Associates, Rabinow Engineering, and RCA, for example. Systems involving simultaneous parallel processing typically have a closed vocabulary at any given time. That is, the only character patterns that are recognizable in the system are known in advance. The reference patterns for the Briggs Associates character recognition developments, for example, are determined by photographing samples of the permitted characters through the lenticular lens array. The closed-vocabulary-requirement is found in any of the exact template-matching techniques. In principle, of course, new or improved template reference patterns can be added to these systems, but there is a limit (e.g., 100-200) to the total number that can be used for parallel processing at any one time.

In some cases, operation 4 for selection of reference patterns is in effect replaced or supplemented by operations to repetitively regenerate reference patterns or reference pattern elements. Cook, for example, in a further development of the ideas suggested by the DOFL First Reader 4/ and the electronic version by Greenough and Gordon, 5/ proposed the scanning of both the unknown source pattern and each of the character vocabulary masks concurrently. 6/ Thus the subsequent matching is no longer on the basis of optical fit, although the reference patterns are of the positive optical template type, but rather of the time-varying signals produced as input pattern with the similar signals generated for each of the vocabulary characters simultaneously, the comparisons being made in parallel, and a 'best-fit' decision made in terms of zero or minimum mismatch. An earlier example of this principle is provided in the patent awarded to Ayres in 1935, and assigned to IBM. 7/

1/ Rochester, N., et al. U.S. Patent 2,889,535. Ref. 388.

2/ Bledsoe, W. W., and I. Browning. "Pattern recognition and reading by machine," Ref. 51.

3/ Ref. 528, p. 1; see also p. 68 of this report.

4/ Rabinow, J. "Report on DOFL first reader," Ref. 367.

5/ Greenough, M. L. and C. C. Gordon. "Technical details of print reader demonstrator," Ref. 182.

6/ Cook, H. D. "A study of print reading systems leading to a proposed reader for typewritten material," Ref. 80.

7/ Ayres, W. U.S. Patent 2,131,911, Ref. 26.

In operation 5, the one or more elements of the input pattern are compared either serially or in parallel with the corresponding one or more elements of a selected reference pattern or patterns. In a system where the input pattern is not segmented or quantized the input pattern element is the input pattern as a whole which is compared with the selected reference pattern as a whole. For example, in the DOFL First Reader, the character image as a whole serves as the input pattern which is matched with a reference pattern that is a photographic negative image of one of the vocabulary characters. Systems using encoded input patterns, as the number of black crossovers encountered in one scan across a segment of the character image, compare such pattern elements element-by-element with the cross-overs for the corresponding scan-unit element of the vocabulary reference pattern.

In still other cases, a single master reference pattern is used or implied. It may consist, for example, of a single peephole-mosaic mask which is superimposed on the black and white pattern having a one-to-one correspondence with the inked-not inked areas of the original source pattern. It may also be a simple function table decoder such that for any given input of a pattern consisting of two-valued pattern elements (signals) one and only one output can be energized. For example, in the reader suggested by Stone for the Rome Air Development Center, 1/ the elements of the input pattern are the black-white indications for each of the 13 specially shaped areas, whereas, in effect, the elements of each reference pattern, are the black-or-white requirements, for each of these areas, for each character symbol allowed in the vocabulary of the system.

The output of the matching procedure of operation 5 is controlled by threshold values for the required degree of match, ranging from complete and exact coincidence, to "best fit" comparisons, and to multiple correlation techniques. Where an input pattern is tried in turn against each of a number of different patterns in the reference vocabulary until a specified degree of match occurs, failure to match at operation 5 results in the selection of another reference pattern and repetition of operations 4, 5, and 6 until all reference patterns have been tried. Failure to match any of the available reference patterns results in nonrecognition with appropriate methods for indicating a reject.

There are, however, special cases where the failure to match any of the reference patterns selected in operation 4, or in iterated selections, will serve as a screening device to determine the nature of a particular font that is involved. In the Philco reader for the Post Office, such screening may be used to readjust the height-width ratio for individual character scanning. For such systems as the parallel template matching machines where operation 4 is a null operation in the initial pass of material to be read, this screening may activate a special type of operation 4 selection, namely, the replacement of the initial vocabulary set of reference patterns with another set. Thus, more than the relatively limited number of reference patterns available for parallel processing can be accommodated in reader systems which allow for the substitution of one vocabulary set for another.

Results of the element-by-element matching process are then transformed in operation 7 of Figure 12 to what we have termed an "identification formula". This formula is such that the detected equivalence of input pattern elements with the corresponding elements of one or more specific reference patterns can be checked, as necessary, against required sequences of element "hits" and other requirements, for example, a particular system may require that the element-by-element matches should have occurred in specified combinations. The identification formula is thus a direct representation of the various 'and', 'or', 'and-not', and other operators of a particular recognition logic.

The use of 'and' and 'or' operators at various levels of pattern element matching and identification formula matching is exemplified in the Solartron ERA system. This has been described by Bailey, in part, as follows:

> "The finally cleaned and clipped raster is time-gated into 'features', compared with permanently stored features of recognizable characters, and a definite black-or-white decision made for each of these features by a bistable circuit. The resulting features are stored in a temporary store--a convenient time-translation device to enable parallel operations to be done on the features. The operations are combinations of AND and OR logic in cascade.
>
> "The programming of the logical items, in the form of a block of connections, is quite complex. The principal organization of this process is that in which a number of features have an OR criterion applied to them, so that a black (say) in one will register as black for the group; then groups are connected with an AND criterion to impulse the output corresponding to a given character, when and only when all groups have the appropriate sign. Other more complex arrangements are superimposed with some attention to those in which a final OR combination is used.

1/ Stone, W.P. "Alpha-numeric character reader," Ref. 464.

"The principal characteristic of the store and logic, however, is that the information is condensed to the final minimum required by taking combinations of 'bits' and comparing them by means of an assigned code." 1/

A fairly elaborate example of the use of a number of several different operators in the recognition-identification logic is provided in the "proportional parts" method for character recognition developed by Greanias and others at IBM. 2/ This method, which was simulated and extensively tested on the IBM 650 computer, is designed to use the relative number, position, and size of character elements occurring in a specified sequence as criteria for character identification. The proportional parts method presupposes that the source pattern is derived from the character image by a flying spot scan proceeding from top to bottom and from right to left across the image field. Each vertical scan is subdivided into intervals and the light signals for each interval are quantized as black or as white in accordance with selected thresholds. The resultant binary data for each vertical scan (the input pattern elements) are then encoded to the reference pattern format consisting of three decimal digits which represent the number, position, and size of the black areas in that scan.

The reference pattern is thus a single master covering the allowable range of digit values in each of the three code positions. Examples are, for the first-digit coding, "1" for a single black area, "4" for a medium length black above a short black, "5" for a short black above a medium length black, and the like. The second digit indicates the relative height of the uppermost black area of a given vertical scan as compared to the uppermost black area of the third previous scan, from "0" for no change to "4" from a three unit decrease. Third digit codings from "0" to "7" indicate measures of relative length.

The observed identification formula in this case thus consists of the codes for the input pattern elements derived from successive vertical scans. Matching of the observed identification formula with the master identification formulas involves a logic of 'and', 'or', 'and-not', in sequence and with specified delay (lag) intervals. That is, the sequence of codes selectively derived from the character which has been sensed is checked against a prescribed code sequence for each vocabulary character. This prescribed sequence defines (1) the allowable codes that will satisfy a given stage of the identification decision process, (2) the maximum number of scans that can occur before the next stage of the process must be satisfied, and (3) specific inhibiting conditions or codes that must not occur at or between particular stages of a particular sequence.

Another example of a specialized identification formula is the type of encoded representation of input pattern elements that results from some of the criterial feature analysis techniques. A Russian worker in the field, Blokh, describes this type of formula as follows:

"Whatever characteristics are utilized in recognition, each combination of them, defining a given image, may be written in the form of an n-denominational and m-graded number, in which n is the number of characteristics, and values 0, 1, 2, ..., m-1, represent gradations of these characteristics. In this manner, the technical device accomplishing character recognition realizes a code (with base m), in which each code combination corresponds to one image of a given set." 3/

We have noted previously that most of the criterial feature analytic methods result in what may appropriately be termed values with respect to a property list. Farley, in discussing the broader problems of pattern recognition, pattern perception, and pattern classification, uses this terminology and, moreover, stresses the enormous advantages in storage economy that can result from use of identification formulas rather than template-type reference patterns. For example, Farley states, in part:

"The idea of a percept as an association, class, or 'bundle' of properties probably goes back at least as far as Aristotle and has reappeared in one form or another many

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1/ Bailey, C. E. G. "Character reading is a signal/noise problem," Ref. 30.

2/ Greanias, E. C., C. J. Hoppel, M. Kloomok, and J. S. Osborne. "Design of logic for recognition of printed characters by simulation," Ref. 175.

3/ Blokh, E. L. "The question of minimum description," Ref. 53, Translation by A. K. Smilow, (National Bureau of Standards), of the original Russian publication, is quoted here.

times since then. . . However, the idea does not seem to have been put forward in a form definite enough to indicate how it might eventually evolve into a model of perception. There would seem to be sound reasons from both biological and psychological considerations for attacking perception from this standpoint. . . .

". . . every object, or (more generally) percept, may be defined by a list of the properties it possesses and the observed ranges (or better, the probability distributions) of the values of each property . . . Each different class of properties makes up a percept, . . . c_1, c_2, etc., . . . In order to determine to which percept a given input belongs, it is only necessary to measure its properties and see which class c_i it fits best. . .

"One interesting advantage of this model is the vast number of classes c_i which can be distinguished by means of a few properties. For example, if one hundred measurable properties are available, and if they average ten distinguishable distributions of value each, then the number of distinguishable classes is of the order of 10^{100}. A great deal of the 'storage' for the class recognition is thus accounted for by computation of property measurements which are used over and over again." 1/

The observed identification formula is typically compared against master identification formulas in operation 8, under the control of an appropriate recognition threshold setting. If the observed identification formula matches a specific master identification formula, the decision is made that the unknown source pattern is equivalent to this one of the patterns of the master vocabulary. If it does not match, and if all formula-to-formula comparisons have not been made, a new master formula is selected and operation 9 is repeated. The ultimate results of operation 9 are thus either a positive identification followed by the appropriate steps to transform the identification decision into a target pattern for output, operations 11, 12, and 13, or a rejection of the input pattern as unrecognized, operation 14. The occurrence of a reject may lead to a re-trial of the input pattern at different scanning, matching, or recognition threshold values. 2/ Correlative functions, such as use of indications derived from context, may be used to adjust the recognition threshold.

Particularly interesting examples of character recognition principles which illustrate use of character-feature probabilities and context-dependency adjustments, although not primarily involving design of a practical character reader, are to be found in various programs involving experiments on machine recognition of handprinted alphabetic characters. The work of Doyle at M. I. T. has resulted in computer recognition, correct approximately 87% of the time, of "sloppy" handprinted characters. 3/ Further investigations of the frequency with which a given character was confused with some other showed that many of the incorrect recognitions were for character pairs ('A', 'R') where the source pattern would be almost equally ambiguous for a human reader.

The emphases in the Doyle program are on parallel processing of the observed against the master identification formulas and on derivation of probabilities of occurrence of the results of criterial feature tests by extensive testing with samples of the characters to be recognized. The handprinted characters, whether 'teaching' samples or unknowns to be recognized, were constrained by the frame within which they were printed but otherwise were often badly formed and noisy. The input pattern for each character was quantized in a 32x32 array, with image enhancement processing for each 3x3 sub-area in accordance with fill-and-delete rules suggested by Unger. 4/ Various aspects of this system have been described by Doyle as follows:

"With parallel processing all tests are made before any decision is undertaken. Though the individual tests may be poor a reliable decision can be available provided there are enough tests, each contributing some different fractional bit of information. Such a set of tests may be considered a code with redundancy, an appropriate counter to noise and distortion. . .

1/ Farley, B. G. "Self-organizing models for learned perception." Ref. 131, pp 15-16, passim.

2/ For example, in the more general field of pattern recognition: "Booth (1956) has described a method that makes use of standard scanning to count the number of intersections between the input pattern and the lines described by the scanner. Using what he terms the 'principle of digital feedback', the machine will then apply additional scanning patterns until any near ties are broken." (Uhr, L. Ref. 496, referring to Booth, A. D., Ref. 56.)

3/ Doyle, W. "Recognition of sloppy, hand-printed characters", Ref. 104.

4/ See Unger, S. H. Refs. 500, 501.

"The action to be taken following a particular test should be determined by observing the results of testing real known samples from the population of characters one eventually hopes to be able to recognize rather than by applying preconceived rules...

"The scheme to be described incorporates both these notions--decision reserved until all test results are in, and discrimination based on 'learning' from real data...

"Symbols representing the outcomes of various tests applied to each sample... (are) ... collected in a table ... which contains a tally of the number of occurrences of each test outcome for each pattern ...

"Finally the observed incidences of outcomes are combined with assumed a priori probabilities of occurrence for each character to calculate the inverse probabilities for each character given test and outcome...

"The ... (operation) ... 'Decide' forms weighted averages of the inverse probabilities corresponding to the observed outcomes from the separate tests and indicates which character corresponds to the highest of these averages of a posteriori probabilities." [1/]

The Bledsoe-Browning approach [2/] also uses the establishment of test outcome probability criteria on the basis of experience with 'teaching' examples of the expected character population. In this case the test outcomes are the hit-no-hit patterns for the input character, with respect to each of a number of arbitrary n-tuple groupings of specific cells of a 10x15 photocell mosaic. Reference patterns are built up, then, of the observed hit patterns for each of the n-tuple groupings for the particular character in a particular position. Additional reference patterns are necessary if wide differences in translation, rotation, size, and other variations of the same character are to be accommodated. For an unknown source pattern, the input pattern elements (test outcomes) are derived and a score is developed with respect to each reference pattern, for each coincidence of a particular hit-no-hit outcome with the same outcome in the reference pattern. When such scores have been obtained for all members of the reference vocabulary, the highest score wins.

Bledsoe and Browning first investigated this method using as n-tuples 75 randomly chosen exclusive pairs of cells of the mosaic. Variations included obtaining probability values by averaging scores for several different 'teaching' alphabet sets. Another variation involved consideration of score distributions typical of each character, by use of average scores from additional alphabets as a 'secondary experience'. Still another variation first 'taught' the system the scores for 10 simplified shape configurations, [3/] such as horizontal, vertical, and diagonal bars or strokes. Then several alphabets were compared with the earlier score material in order to obtain score distributions which in turn facilitated distribution-comparison decisions for new characters.

The basic technique was also further modified to provide for identification of alphabetic characters with respect to their word contexts. The length of an unknown word is first established by counting the number of characters encountered between blank spaces. The observed score for each of these characters is then obtained. Next, reference is made to that portion of a special dictionary where words of that length are recorded. The scores per possible character identification that coincide with the characters of a valid word are added in proper order, and the word with the highest total score wins.

4.2.3 Target Pattern Selection and Output

The generalized recognition process is terminated by an appropriate action following identification, usually in the form of the selection and output of a target pattern that is the equivalent of the original source pattern. In general, operations 11, 12, and 13 of Figure 12 encompass a number of well-known techniques for the conversion of a specific signal, indicating the identification of a particular character, to the desired output. The desired output may be the activation of a typewriter key, the punching of a punched card code pattern, the generation of the appropriate symbol code in a particular machine-language for direct input to computer, or, as in the case of reading aids for the blind, appropriate auditory or tactile patterns representing that character in accordance with a predetermined convention. In the case of reading aids for the blind, target pattern selection may also involve holding the results of individual character decisions until an entire word has been completely read and then synthesizing a sound pattern representative of that word as a whole.

1/ Doyle, W. "Recognition of sloppy, hand-printed characters," Ref. 104, p. 133-134.

2/ Bledsoe, W.W. and I. Browning. "Pattern recognition and reading by machine," Ref. 51.

3/ Bledsoe and Browning refer to these as "arbitrary" shapes in the same sense as the random pairing, but they are in fact closely similar to those used for extraction of criterial features in several other systems.

We have already noted the possibility that both transliteration and encrypting or decrypting operations may be included as direct by-products of the recognition-identification process. These steps would of course require additional logic to accomplish consistent application of conventions adopted 1/ for target-pattern selection and output. This transliteration may be at the letter, phoneme, or word level, comprising, for the latter case, in effect a word-for-word translation. In demonstrations for the International Conference on Scientific Information held in Washington in November 1958, for example, audiences were requested to select one of four Russian nouns or proper names for input to a scanning device, SADIE, and to a computer-processing look-up technique programmed for SEAC, one of the pioneer electronic computers developed by and still in use at the National Bureau of Standards. The individual characters of the selected noun were then fed one by one into the machine-processing system. Each was identified by the obviously simple and quite naive method of gross black-area discrimination for a vocabulary limited to 14 Cyrillic upper-case characters.

As each character was recognized it was assigned an appropriate character-identification code. When a blank, white, space indicating the end of a character-string (or word) occurred, the accumulative identified-character-code could be used in conjunction with a computer program for any of the following operations:

(1) The English-word transliteration of the Cyrillic-letter string,

(2) The 'definition' of the word, such that for the proper name of a Russian author, the subject could be identified as: "Author" "Area X", 2/ "Human", etc.;

(3) The extension of the word, e.g., the extension of the received Cyrillic character sequence translatable as the English word 'chairman', in the form of a list of the names of the 'Panel Chairmen' for the ICSI Area discussions, and

(4) Given that the recognized word was the proper name of either a Russian Panel Chairman or of an ICSI author who is Russian, the 'location' of the person referred to by that proper name, as "Russia". 3/

A special variation of the operations to select the target pattern language, to transform the identification decision to the selected target pattern, and to provide output is given in the case where the recognition process controls other operations. This is the case for counting or sorting of objects which have alphanumeric characters as indicia for action. An obvious example is in the sorting of first class mail. Levy 4/ has been a pioneering exponent of the substitution of reading machines in mail-sorting operations for the Canadian Post Office and himself holds a patent for an intermediate step: a first human reading, inscribing of special address-destination marks, machine reading of these marks in order to control routing to bins or pockets of a sorting machine. 5/ The U.S. Post Office Department has supported automatic reading technique developments at Farrington-IMR for this purpose, and has recently placed new contracts both with Farrington and with the Research Division of the Philco Corporation. The latter contract is for a reader to recognize 75 addresses at anticipated rates of 1,500 characters per second. 6/ The target pattern output in these cases is the routing of the envelopes on which these addresses appear to the appropriate sorting bins. The German and Dutch Post Offices have also been among the postal service organizations that have demonstrated interest in these possible applications.

1/ That there are difficulties in the establishment and use of such conventions is evidenced by variable transliterations of Russian proper names which occurred in the bibliographical research related to this report. Thus we have found both 'Charkevitch' and 'Kharvevitch', and 'Fain' and 'Fayn' for certain Russian authors who have been cited. This problem of transliteration has been aggravated by the very diversity of schemes that have been used. See, for example, Razran, G. "Transliteration of Russian", Ref. 374.

2/ The ICSI program was divided into 7 specific subject matter 'Areas', and Discussion Panels were selected for each such Area.

3/ For a discussion of the computer programs involved, see Stevens, M.E. "A machine model of recall", Ref. 461.

4/ Levy, M.M. "The electronic aspects of the Canadian sorting of mail system", Ref. 270.

5/ Levy, M.M. U.S. Patent 2,925,586, Ref. 271.

6/ "All-electronic reader", Ref. 6, p. 14.

Thus, many different combinations of scanning techniques, recognition logic, and target pattern output have been proposed for carrying out the process steps of character recognition. These various combinations reflect different possibilities for meeting the requirements of a particular proposed application of automatic reading techniques. The operational requirements in a particular situation are therefore of considerable importance not only in the development of the performance specifications for a system but also in initial appraisal of feasibility and in system design if new equipment is to be developed to meet specific user needs.

5. OPERATIONAL REQUIREMENTS IN AUTOMATIC CHARACTER RECOGNITION

The factors that are critical for the development of performance specifications for any given application of automatic character recognition techniques are directly related to the objectives that are to be served in that intended application. Similarly, the operational requirements for a character recognition device are related to the characteristics of the situation in which it is to be applied and to the standards of reference selected for performance measurement. The evaluation of a given character recognition system is therefore directed as much or more to these factors as to the logical and mechanical characteristics of the system or device itself. For example, in such massive paperwork activities as the keypunching of individual wage earnings data from employer tax returns for social security accounting, a steadily increasing work load may outstrip available manpower. There may be a high rate of turnover among personnel who perform the necessary keyboard operations, and a high training and replacement cost. In such situations the basic management objective in looking toward automatic reading devices is to meet present manual output standards for an increased volume of work. That objective would be of greater significance than increasing the speed or the accuracy or decreasing the cost of the transcription operations, although obtaining these latter advantages would also be desirable.

Another major management objective in appraising the feasibility of automatic character reading techniques might well be that of achieving truly integrated data processing, from data origination to ultimate use of processed output. Thus, as Hattery has noted, "... Automatic character scanning or reading .... promises to give a new dimension to the revolution which is already taking place with the introduction of electronic computers." 1/ We have already remarked on the appetite of automatic data processing systems for large quantities of input, which can then be processed at rates far out of balance with manual methods of data preparation and insertion. An eminently reasonable objective, therefore, in considering the possible applicability of character recognition devices is that of restoring the input-processing balance where automatic data processing equipment is used. Even more significantly, the objective may be to make the use of such equipment profitable. 2/

Some of the critical factors useful in evaluating the feasibility of using automatic character reading techniques are discussed below: first, in terms of overall requirements based upon objectives and characteristics of the processing situation; secondly, in terms of specific requirements such as the characteristics of the initial recording medium and the font or type faces used; and, thirdly, in terms of criteria for performance measurement. Special difficulties with typewritten and foreign language materials will also be discussed.

5.1 Overall Requirements

Overall system requirements that determine what factors will be most significant in evaluating automatic character recognition techniques for a particular application involve the various stages of data origination, transmission, receipt, input to the reading-recognition process, output, storage, and subsequent use. In any specific case, the pertinency and weight to be assigned to the various factors must be determined by thorough fact-finding and analysis of present and desired conditions and procedures. In general, possibilities for maintaining high quality input, limiting the size of the vocabulary, handling carrier items efficiently, and meeting realistic reliability requirements, should outweigh questions of position-dependent as versus shape-dependent recognition logic, permissible reject rates, and speed or rate of recognition. In particular, we should note that the accuracy of the recognition system output cannot be expected to exceed the accuracy of the data or information as it is initially generated and initially recorded.

It is significant of the present state of the automatic character recognition art that all of the reader devices that have actually been built and subjected to extensive tests, whether in the field or in the laboratory, have had relatively limited vocabularies. Vocabulary sizes that have been tested range from 10 to 16 symbols (for Arabic numerals and a few special characters) up to about 100.

1/ Hattery, L.H. "Automatic character reading...", Ref. 200, p. 159.

2/ Compare, for example, the following view: "Conversion from the human to the machine has in many cases so increased the cost of the total system that the resulting processing efficiencies have not been warranted on a dollar-and-cents basis." (Ref. 346, p. 28.)

Some of the criterial analysis techniques that have been tested, such as those which analyze the number, position and relative size of character strokes, are relatively independent of minor variations in several different but similar type styles. Other systems permit reprogramming of identification formulas for a new type face, as by re-wiring of a plugboard control panel, or the insertion of a different set of vocabulary masks, or a different master mask.

Difficulties are apparent with all of the techniques so far proposed in equipment under actual development, in terms of idiosyncracies of poor quality, especially typed, material. Problems in horizontal registry may be overcome to some extent by utilizing the first of a series of scans not to recognize the source pattern but to trigger the recognition process so that the input pattern is not fed in until the leading edge of the source pattern has been detected. This principle is employed, for example, in one of Laboratory for Electronics readers. A positioning mask is used to similar effect in both the Cook Typereader proposal and in a Rabinow reader. However, the use of the first scan for registering purposes, or an alternative technique of 'rolling' through a shift register, is impractical in many cases where there is extensive overlap and running together of characters.

Even more significant than the limitation of presently available reader systems to applications having restricted vocabularies, however, are the restrictions on the size, format, and variety of carrier items so far successfully handled in actual devices. For example discussions with Control Instruments personnel during our 1957 survey brought out the facts that in their investigations such factors are frequently more critical than are details of particular recognition logics. They mentioned such problems as variable opacity of the scanning slit, scanning photocell (white) noise, maintenance of constant speed during carrier item feeding, lack of exact reproducibility of character image even from the same printing device, positioning during scan, tilt, and variations in lighting source for tilted material. It is also noteworthy that present paper feed limitations restrict practical recognition rates (i.e., of several thousand characters per second in several devices that have been tested) to one-sixth to one-tenth of the rates theoretically possible with present scanning rates, if the printed page must be used. Prior microfilming of the input material may result in higher effective rates, but is in some cases not feasible.

Consideration of the factors involved in the operations of data origination includes determination of the answers to such questions as the number of different sources of information. This question is in turn affected by whether or not such sources are under the direct or indirect administrative control of the agency which subsequently processes that information. In the case of material gathered or intercepted for intelligence purposes, there may be a wide variety of sources over which there is no control. On the other hand, in the case of traveler's checks, all the information to be read by machine may be fully controlled by preprinting of material issued only by the organization that will later process the checks when they have been used.

In many Government applications, the turn-around document presents special problems in that the degree of control varies widely for different information that appears on one and the same document. On U.S. Savings Bonds, for example, there is preprinted information completely under control, but there is also information as to the date of issue that is stamped and the name and address of the purchaser that may be typed or even handwritten by the thousands of issuing agents throughout the country. Census questionnaires, tax returns, marketing certificates, and other forms provide additional examples of applications in which, for a single item, there is a mixed degree of prior control and there are mixtures of inscriptions of information, often from various different sources. Questions on the extent of control that is possible in the origination of data will therefore also involve the average volume of messages that are generated per source, the average length of such messages, the different types of messages, uniformity of the subject matter of various messages, and the rates of message production per type per message source.

Factors relating to the methods of inscription at a message generating source typically cover the following:

(1) The inscription equipment and its accuracy;

(2) Rates at which inscription proceeds;

(3) Characteristics such as size, shape, thickness, uniformity, recording density, etc., of the carrier medium or media, and

(4) The quality of the original inscription in such terms as, for example, uniformity of ink density, placement, alignment, and registration.

For example, Heasley has reported typical inscription irregularities in several of the Farrington-IMR installations as follows:

" ... The encoder is found to degrade the symbol shapes by variation in strength of impression and in amount of inking, and by inking noise. On typical business equipment, these factors may result in line-width variations of five to one, missing portions in light impressions, blotted portions of heavy characters, random additional interference on either light or dark characters, and a pronounced ribbon pattern ... The handling process further degrades the symbol by superimposing interference." 1/

The incidence of accidental noise superimposed on the message due to handling should thus also be considered.

Questions of accuracy pertinent to data origination operations include the accuracy of the original data. Accuracy of initial inscription involves both human and mechanical error rates (e.g., human transposition of two or more symbols, on the one hand, and mechanical failure such as failure of a keystroke operation to record the proper impression, on the other).

Closely similar considerations are involved in the various stages of data transmission and data receipt. Error rates may be particularly significant, as for example in teletype transmission, rates running as high as 30%. In addition, factors in data transmission and receipt include consideration of the number of transmission channels available, and the traffic capacity per channel. Other possible factors are the tolerance for missing or erroneous information, the readiness with which the receipt of garbled messages can be detected, the possibilities for repeat transmissions, and the tolerance for delays in receipt or for delays in processing after receipt, i.e., a "stack up" tolerance.

Factors involved in the operations of actual input to a character recognition device involve both system requirements and specific requirements inherent in particular problems. The former include such considerations as the kind and extent of preparatory operations such as culling of illegible material. In particular, possibilities for sorting the input material by document size, by quality of carrier medium (e.g., bond paper as against newsprint paper), by font or type-face or size of type, and the like, should be carefully considered. Pre-editing operations such as handmarking of the beginning and end of passages to be read or the masking out of interpersed graphic material would also be included. Related system requirements at the initial input stage include the time and costs of manpower involved in handling and preparatory operations, the percentage of material culled because of illegibility and the costs of obtaining correct re-transcriptions of such material, and the requirements and costs of manually processing the material that is insufficiently legible to be read by machine.

Output, storage, and subsequent usage considerations with respect to material to be read similarly involve questions of the quantity, rate, and quality of output, with specific attention to acceptable reject (non-recognition) and error (misrecognition) rates. Also involved at the output stage are questions of the characteristics of the output language or languages. Whether the output feeds other processing equipment as an on-line process, and if so at what required rates, are also questions that must be considered. Format and other characteristics of the output and storage recording media are pertinent. Additional storage and usage factors include considerations of desired quality of output such as legibility for human inspection, considerations of economic storage density, and requirements for subsequent retrieval and re-use of material that has been read.

The interaction of the overall objectives and the specific operating conditions in a particular proposed application forms the basis, first, for feasibility evaluation and, secondly, for determination of performance specifications. Thus such factors may determine the minimum acceptable reading rate necessary to keep up with a given flow of input information and a desired output rate, whereas the specific requirements, to be discussed below, determine design specifications such as the tolerances for space between lines or the rate of scan necessary to achieve recognition of a specified vocabulary at the desired reading rate.

Patterns of critical performance factors derived from analysis of overall requirements may be exemplified by the hypothetical application of character recognition techniques to the automatic dictionary problem as follows:

It is assumed that an extensive set of words or symbols in some one language or code format, together with a set of alternate meanings or equivalent code representations for each word, in the same or in another language, are to be established. The processing problem is to take incoming words in a source language and to match them to the corresponding stored words in the dictionary. Upon matching, we wish to receive as output the equivalent word, meaning, or code representation in the target language. Automatic character recognition techniques might be applicable in initial establishment of the reference or dictionary file, in the preparation of source words for input to the mechanized look-up process and, as in the case where the dictionary is used for preparation of encoded messages, in automatic proofreading of the output results.

1/ Heasley, C. C., Jr. "Some communication aspects of character sensing systems", Ref. 205, p. 176.

Initial establishment of the reference file would be a one-time task concerned with only one or a few sources of data origination; e.g., an existing bilingual dictionary to be transcribed to machine-usable form or the preparation of a master word list of selected terms in the source language, together with one or more target language equivalents of these selected terms. In the case of transcribing an existing printed or typed dictionary, control of the size and style of type can be exercised only to the extent of selection from the available texts. However, limitation to a single font or type style can be controlled by this selection. Questions of rate of generation of information, volume of messages per originating source, etc., are irrelevant.

The vocabulary of character symbols to be used includes at least the number of characters in the alphabet of the source language plus the number of different character symbols that occur in the target language. For example, for a Russian-English dictionary printed entirely in upper case, 32 plus 15 characters would be required, 11 characters in the English alphabet having identical character forms in the Russian. For the same dictionary using both upper and lower case, the symbol vocabulary would be at least 64 plus 32 characters forms since "veh" (B) and "en" (H) have different lower case forms in the two alphabets. The accuracy of the original data should be high, and in most cases it would be very important to maintain this original accuracy in the transcription process. The rate by which reading-transcription operations proceed for a one-time application would presumably not be a significant factor.

The choice between manual and automatic methods for a one-time reading transcription process would thus largely depend upon the following:

(1) The relative economics of manual-keyboard-transcription operations as against investment in a reader device with a vocabulary that would be larger (e.g., the 96 upper and lower case characters for the second Russian-English example above in at least several different sizes) 1/ than any available in devices as yet in production operation,

(2) the possibilities for subsequent utilization of either the reader equipment or the keyboard operators after the one-time task has been completed,

(3) the relative accuracy of the final transcriptions where in the one case the automatic rejection of marginal recognitions might be quite closely controlled, whereas in the other case human error rates would presumably increase in proportion to lack of familiarity with the foreign language characters, and

(4) the relative availability of keyboard operator personnel or of equipment capable of recognizing the total symbol vocabulary with a degree of accuracy at least equivalent to that obtainable by keyboard plus verification operations.

If, however, the initial reference file were to be based upon the selection and assembly of the word list from a variety of sources, some form of manual transcription would be required in preparing the master list in almost all cases. The relative cost factor would therefore need also to include the comparative costs of keyboard operation where data are simultaneously produced in machine-usable form as on punched cards, punched paper tape, or magnetic tape.

Subsequent use of automatic character recognition techniques for input of material to be looked up in the dictionary or proofreading of output would improve the possibilities for economical use and amortization of capital investment in the automatic reading equipment. On the other hand, subsequent usage planning would require additional consideration of rate, volume, and time factors to keep up with rate of receipt of such input material. For an example of probable minimum input rates, some organizations engaged in manual translations have had an input volume of approximately 20,000 Russian journal pages each year. In the case of input preparation, use of automatic techniques might further aggravate the problem of size of vocabulary available since the input materials might originate from a variety of sources in a variety of formats and type styles.

The critical questions that are raised from the interplay of overall requirements with overall system performance specifications, whether in the above simple situation or in situations where hundreds of manual operators deal daily with tens of thousands of items from varied sources and in varied forms, can be reduced to the following major points:

(1) What is the economic break-even point for the use of an automatic character reader, of given performance capabilities, for all or for a selected part of the work load, in the light of the basic system objectives?

1/ We note, further, that in many type styles, differences in size are accompanied by changes in proportionality of character strokes and in differences other than those of one-for-one reduction.

(2) What are the possibilities, for one or more different reading-transcription techniques (human or machine, or both), for meeting the operational requirements of flexibility with respect to either present or future demands?

(3) What can be done, in the total system, in the light of basic objectives, towards standardization of forms, formatting, standardized or specialized fonts, administrative control of quality of input, to facilitate the use of available character readers at a practical and economically-profitable level?

To take up these points in reverse order, we note first that where management decides on a self-checking specially-designed font, as in charge-a-plate usage in the oil industry, an apparently efficient solution has already been found. The second major question relates, in the first place, to the need for precise operational analysis with respect to real requirements in a particular situation. It relates, in the second place, to the possibility of accepting machine-recognition-processing for a designated part of the total workload. It is thus itself, as a major question, related to the first major point, the question of economic break-even point for some designated part (all or a selected percentage) of the total workload. However, it also relates to the question of using several different techniques (different readers, at different costs and with different performance capabilities) in combination (including the combination of people and machines) to achieve the total system goal.

It is the first question, that of economic break-through, which is of crucial importance with respect to the presently-practical use of presently-available automatic reading techniques. If, after careful consideration of objectives and after detailed appraisal of operational requirements, it is possible to isolate a segment of workload, amenable to strict control over original data preparation and perhaps susceptible to use of a specialized, limited-vocabulary font, then character readers of a type already in use may provide both considerable cost-reductions and considerable savings in speed of overall processing.

With due regard, however, to the previously mentioned factors of (1) maintenance of high quality input, (2) vocabulary, (3) carrier handling, (4) reliability requirements, and (5) flexibility in adjustments for changing requirements, the overall question of feasibility is generally one that depends upon balancing the comparative speed of machine as against human target pattern output, at an acceptable reject rate, with an appropriate safety factor, in terms of comparative costs. We shall consider this point in more detail in terms of criteria for performance measurement, after considering examples of more specific operational requirements and of difficulties with special classes of materials, below.

5.2 Specific Requirements

In addition to overall requirements as related to automatic reading techniques, there are a number of specific requirements. These set the appropriate factors for comparative evaluation which arise from the difficulties inherent in the scanning-recognition process. The carrier medium, such as the paper document on which the data to be read is printed or typed, must first of all be conveyed to a scanning station. The rate of feeding the carrier items must be at least commensurate with the rate at which the average number of characters that can be recorded on such items can be recognized. Otherwise, the reading rate that can be realized will be limited to the carrier-feeding rate. Feeding can be accomplished either by manual insertion, which is comparatively slow, or by automatic paper handling equipment which may be both expensive and difficult to maintain in proper operating order. Quite complicated machinery may be required to maintain regularity in paper feeding unless similar automatic feeding techniques have been used in the initial printing, 1/ as for example, in the case of the sprocket holes for continuous form-feed teletype or tabulator output.

Carrier feed requirements will typically involve questions of handling documents of different dimensions and shapes. Adequacy of means to assure one-at-a-time pickups of carrier items from a feed hopper, and adequacy of means to prevent the interference of one carrier item with another as items are conveyed to the scanning station, are to be considered as factors affecting the paper-feed rate. In some cases, as in taking of physical inventory where labels or tags are to be read at the site of storage or as in reading aids for the blind, the scanner-reader device is brought to the material, imposing the requirement that it be portable. In situations where the input material that is to be read is also to be permanently retained, a preliminary process of microfilming may result in simplification of some of the carrier feed problems, but it may also introduce other factors of cost, process control, and the like.

Carrier-handling problems will also include the positioning of the carrier item at the scanning stations so that, for example, it is not tilted and so that all information on the item can be read.

1/ See Cook, H. D. "A study of print reading systems", Ref. 80.

Assuming the carrier item itself (such as the paper check, punched card, or page of printed or typed material) to be accurately positioned, additional positioning, either by movement of the carrier or by movement of the scanning mechanism or both, is required to locate each unit of information that is to be sensed in its entirety in a scan cycle. These micropositioning requirements are related both to the equipment characteristics in positioning and in scanning and to the registration of the information on the carrier medium. It has been estimated, for example, that tolerances from exact register in order for ordinary printed material to be distinguishable by proposed reading machines cannot be greater than one-thirtieth of the overall width of the widest character. 1/

Micropositioning can be greatly facilitated by the use of relatively gross guide marks that can either be preprinted (where the originating sources are under administrative control) or be added by a pre-editing operation. It is significant to note that such positioning controls, having the effect of a detent mechanism that locks the scanning precisely to the area to be scanned, will also enable various scanning systems, particularly flying spot scanners, to be used at maximum acuity. Thus, arbitrarily improved resolution can be obtained. Without such pre-positioning controls, micropositioning factors to be determined will include the placement of the body of the information with relation to the edges of the carrier medium, and the amount and consistency of leading or space between lines.

Factors involving both system requirements and micropositioning in the sense of carrier handling and reader scanning relate to formatting considerations on the carrier, such as the use of designated fields for certain types of information. For example, on an inventory control document, alphanumeric information may appear in a field reserved for stock identification, but only numeric data should appear in fields used for quantity issued, unit cost, and similar data. Several fields may occur on the same line, with only one to be read. In many other potential applications, information actually appearing may be required to be omitted from the processing, or unreadable information, such as graphic material, may be interspersed with text. In a prototype page reader for Russian text under development at Baird-Atomic, fiduciary marks consisting of black strips of variable width are used to signal 'begin-read', 'stop-read' and 'begin-read-again-in-the-same-line'. These marks are superimposed on the original page copy as it is microfilmed, the reader itself being designed to scan the pages as they are reproduced on 70 mm film.

Micropositioning factors relative to any single line involve questions of the vertical and horizontal alignment of individual characters in that line. With regard to any single character, critical positioning factors include the limits of rectilinear translation of the actual character within the normal character space and the limits of angular displacement or skew of the image in that character space. Improper or irregular spacing, for example, within a word, is found in some typewritten material and quite commonly in cursive handwriting. The question of overlap between characters raises serious problems in scanning-recognition systems that are based on the utilization of a blank space between characters to trigger a character-scan cycle. Usually, however, overlapping and bleeding between characters occurs only where a fixed character space is used for all characters in the line. In the case of printing, or in those few typewriting devices where proportional spacing is used for characters of different width, overlapping does not normally occur.

Once the carrier medium, line of information, and individual character image-unit to be scanned have been positioned, the actual scanning requirements again involve both equipment characteristics such as scan rate, resolution of scan, and illumination of the area to be scanned on the one hand, and characteristics of the information and its carrier on the other. The resolution obtainable in the scanning system will in turn relate to questions of the total amount of information that can be used as a scanning unit at one time and the degree of magnification of the image field to be scanned that may be achieved through suitable optics.

Carrier characteristics affecting the performance requirements for scanning involve the variety of types of carrier media. The physical qualities of the carrier medium as background are particularly important. These will include the color, opacity, roughness of surface, and reflectivity of the carrier material, especially paper. For example, materials such as wood chips used in the making of paper may cause specks and shadows. In the case of Russian printed materials, the use of poor quality paper may be aggravated by poor quality printing so that crossbars of certain characters may be missing and so that matrix 'hair line' tracings are included in the character space. 2/ For typewritten material, roughness of surface causes uneven distribution of

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1/ Cook, H. D. "A study of print reading systems," Ref. 80.

2/ See Boni, C. "Russian type study," Ref. 55. The report includes tables of observed character defects by type of defect. However, the matrix 'hairlines', the "extraneous vertical lines between characters resulting from the accumulation of unwanted type metal on the sides of the matrices," were apparently too numerous to count.

ink from the ribbon and hence imperfect edges of typed characters. In some studies 1/, definite variations in paper reflectivity from point to point have been found, such that design requirements might well include means for accurate control of the distances between light sources illuminating the scanned area, the paper, and the means for signal pickup. In all cases, consideration of carrier background characteristics should include evaluation of the probabilities of superimposed noise from accidental or deliberate over-marking.

One of the most important factors in establishing performance criteria for the scanning process is the contrast between the inscription and the background provided by the carrier on which the information to be read is inscribed. This contrast is typically the product of the interaction of carrier qualities and the physical characteristics of the actual inscription. The signal-to-noise ratio is comprised of the degree of contrast between the inscription and its background (contrast between black ink and white paper) plus both random and superimposed noise (e.g., from over-marking) in the image field that is scanned. In printing processes, the "weight" (the amount of ink the type puts on paper) and the "color" (the density of ink deposited per page) of a given type face directly influence the expected contrast factor for that type face. 2/ In typewritten material, the qualities of the type-writer ribbon compound the variations available from the paper, the conditions of type-surface cleanliness, and operator touch. For example, the texture of the ribbon may result in a super-imposed pattern of the textile threads both upon characters and in the space between characters. 3/

Closely related to questions of degree of contrast and of variability in contrast are factors of the quality of the line edges of the character image, including the phenomena of bleeding and filling in of characters which aggravate the problems of background noise, and of the extent to which portions of the character are likely to be missing or incomplete. In the previously cited study of Russian printing, Boni reports that only 5 of 341 pages sampled from various books were free of defective character forms. Some of the conclusions reached in this study were as follows:

> " ... printed Russian pages are very uneven in color of image and weight of impression; type images are often blurred and broken; sometimes there is complete breakaway; the type does not make contact with the paper and there is no image at all ... The alignment of characters sometimes is poor; matrix sidewalls appear to break down from time to time, producing deformations in character stems and bowls; and many matrix 'hairlines' .... appear between characters." 4/

A final major consideration, in evaluating the probable effectiveness of the scanning process in an automatic reader system, involves the extent of information content of the character image field that is scanned in a single complete scan cycle, and the degree of quantization or unitization of this field that is developed in the scanning process to produce the input pattern. The information content of the scanned field may vary from that located anywhere in the whole area of the carrier item (e.g., scan of an entire envelope to determine where the stamp is located in automatic facing and cancelling systems) through a single line or a single message sub-unit, such as a word, down to the individual source pattern character symbol or to sub-sets of the source pattern image, and even to points or cells in the image field which may be considerably smaller than character elements such as strokes. The character image field, whatever the extent of its information content, may either be traversed continuously or it may be selectively sampled at particular points. Factors involving the extent to which a source pattern can be broken into a number of sub-patterns of elements in the scanning process are closely related to the particular recognition logic employed. Similar factors involving the extent to which the results of any one scan in the cycle are stored for comparison with subsequent scans also interact with the recognition logic.

As a character image field is being scanned, or after the results of scan have been sensed, a variety of processes can be used to improve the derived image. These include, as we have previously noted, various means for contrast enhancement such as comparing the integrated blackness of a scan area with a prescribed threshold value, and readjusting such thresholds in accordance with integrated values derived from preceding scans in the same cycle. 5/ Similarly, results of early scans in a cycle may be used to re-position the scanner mechanism for more exact register. For example, the Solartron ERA optical reading system has the following source-to-input pattern processing features:

1/ See Carlson, C.O. "Preliminary investigations on direct symbol recognition," Ref. 68.

2/ See Karch, R.R. "How to recognize type faces," Ref. 245.

3/ Cook, H.D. "A study of print reading systems," Ref. 80.

4/ Boni, C. "Russian type study," Ref. 55, pp 2-16, 3-4, 3-5.

5/ See for example, Greanias, E.C., Hoppel, et al. "Design of logic for recognition of printed characters by simulation," Ref. 175.

"Each character is submitted in general to three scans of 'frames' with vertical lines. The first of these records the density of the character, and operates a clamped control to ensure that the two following frames have favorable black/white contrast, differentiating the true character from the smudges or 'halo' which surround it. The character is then provided with a fairly clean black edge for the second frame, which covers the same area and measures the extreme black edge at either side, top and bottom of the character. A clamped control derived from this is applied to centralize the character, which it does to within ± 1/2 element vertically and horizontally during the third frame. The third frame, with nearly correct contrast and registration, is used for reading." 1/

Performance requirements in the area of input pattern improvement will therefore relate to the variability of contrast conditions in input material, expected variations in source pattern sharpness and completeness, expected incidence of source pattern mis-register, and the like.

In evaluation of the effectiveness of the recognition processes, a major operational consideration is the total size of the character vocabulary that can be accommodated. Vocabulary size consideration will include questions of whether varying sets of characters (i. e., upper and lower case, character sets of similar but different type style, character sets of different sizes within the same series of type, character sets of different weights within the same family of type, etc.) can be recognized. The number of fonts to be encountered in input material and the type style of particular fonts determine the similarity of the characters that must be distinguished from each other and thus set requirements as to vocabulary size, precision of recognition, or both. Allowable tolerances for nonrecognition of ambiguous characters or for misrecognition will obviously influence the required complexity of the recognition logic.

Where several different fonts are to be recognized, it may be necessary that the recognition process include determination of which of several sets a given input character belongs so as to adjust the logic appropriately. Figure 15, (p. 43) illustrates some of the terms that are used in identifying different type style characteristics. Human operators can distinguish one given type style from another by such features as the shape of the serifs, width of characters, weight, contrast of heavy and light strokes, design of cross strokes, length of descenders, length of ascenders, and design of the lower case "g". 2/ Machine ability to discriminate between such features may therefore be required in a universal-type character reader. Differences in size in the same or different type styles that must be accommodated will influence machine characteristics in the required resolution of scan, in adequacy of means to standardize characters to a definite size during image improvement, or in the required versatility of the recognition logic. Where it is required that a reader system be capable of handling dissimilar fonts with a large total vocabulary, evaluation will necessarily include consideration of the ease with which the reader can be adjusted to handle each different font, e.g., by insertion of a new plugboard or a new set of vocabulary masks, or by self-adjusting processes.

Allowable tolerances for errors and rejects will determine the extent of the capabilities for re-run and re-setting of both scanning and recognition thresholds that will be required. Finally, the specific requirements for output operations will include the means for subsequent handling of carrier items if they are to be sorted or routed as a product of the recognition operation, the ease with which varied output formats may be obtained, provisions for editing such as spacing and tabular alignment of output, machine output characteristics such as punching or printing rate, and, where required, the provision of means for automatic checking of output accuracy. Such output considerations will in turn influence other factors. For example, if the output requirement is to punch cards, a punching rate of 100 cards per minute would clearly indicate that the character recognition rate need not exceed 8,000 characters per minute, or approximately 130 characters per second.

5.3 Special Difficulties with Typewritten Material

We have already mentioned some of the special difficulties that are encountered in automatic reading of typewritten material, such as the variables introduced by characteristics of the ribbon and by differences in operator touch. However, in many potential applications of automatic reading techniques, a significantly large portion of material to be transcribed to machine-usable form consists of information typed on ordinary typewriters at a variety of originating sources. For this reason, some of the critical factors likely to be involved in successful reading of typed material will be discussed in greater detail.

To explore some of the difficulties inherent in the recognition of typewritten material, sample upper and lower case alphabets were typed on a variety of typewriters that were in use on the same

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1/ Bailey, C.E.G. "Introductory lecture on character recognition," Ref. 31, p. 445.

2/ Karch, R.R. "How to recognize type faces," Ref. 245.

day in several different offices. Ten different models of typewriters of various makes were sampled, and in two cases samples were obtained from two different typewriters of the same make and model. This method of sampling was deliberately chosen to obtain results representative of the output of a Government office, on a typical day, without prior warning or opportunity to clean the machines or to change ribbons. Some of the results are shown in Figures 17 through 21. Figure 17 shows the name of the manufacturer and model as typed on each respective machine, for the 12 typewriters from which samples were taken. Figure 17 also illustrates the effect of proportional spacing and use of carbon paper ribbon in the IBM Executive and the effect of a typist strike-over, in the upper Remington Standard.

In all except two cases, the IBM Executive and the upper Remington Electric (sans serif type face), there was a noticeable degree of overlap between characters, or of bleeding from one character to another. Note, for example, "RM" in Hermes, "IB" in IBM Electromatic, "NT" in L.C. Smith Model Seventeen, "RE" in Remington Standard, and "AN" in Royal Standard, as well as the examples shown in Figures 18 (b), 19, 20 (a), 20 (b), and 21. Figures 18 (a) and 18 (b) illustrate differences between two machines of the same make and model (Royal Standard). This is to be expected, of course, since the idiosyncracies of individual machines have been used to identify the machine on which a particular document has been typed. These variations, however, may also cause serious difficulties in automatic recognition. Note that in Figure 18 (b) the letters "A" and "B" overlap, whereas in Figure 18 (a) they do not. The apex of the "A" in Figure 18 (b) has a noticeable hole, such that this character has two enclosed white areas while the "A" in Figure 18 (a) has only one. There is a small but complete break across the vertical stroke of the "B" in Figure 18 (a) such that a scan centered on this stroke might count one long continuous black blob for "B" in Figure 18 (b) but two blobs in the "B" of 18 (a).

Figure 19 again shows overlap or bleeding in upper case letters from one of the Remington Standard samples, together with broken strokes and missing portions of letters. In Figure 20 (a) and (b), we show two lines typed with the same IBM Electromatic typewriter to demonstrate the effects (Figure 20, example b) of overlap from an upper line where only a half space between lines was used. Particularly noteworthy are the differences in the character impressions resulting from one or more variable factors such as key pressure or from use of a different section of the ribbon or different paper characteristics at a different location on the page. Figure 21 illustrates noisy characters, bleeding, and extensive running overlap between lower case characters from the L.C. Smith Model Seventeen sample.

Variations in operator touch, condition of the type keys, paper, and ribbon all affect character quality. Such variations result in non-uniform character shapes because of uneven distribution of ink, broken strokes and missing portions of characters, bleeding, filling, overlap, and non-uniform positioning and spacing. Wide discrepancies are found for typed characters even when typed on the same page and by the same typewriter. For example, Rabinow found that successive imprints of the same character on the same page varied in reflectivity by as much as 30 per cent. 1/

Characteristics of the paper and the paper backing, such as the use of short or long fibres, affect the amount of indentation that occurs when the type strikes the paper and thus determine the quality of the character edge.

Even when of the same make and grade, typewriter ribbons of cotton, silk, or nylon give variable performance on wear-down tests which measure the relative deterioration of the ink density after repeated typing over the same portion of the ribbon. Federal specifications require that an acceptable ribbon should show no filling in the typed character after 800 typings of lower case "e", but such filling from dirty keys as well as from inferior ribbons or ribbons long in use must be expected in average output of typed material.

5.4 Difficulties with Other Types of Special Material

Two other categories of material which may generate specialized difficulties for automatic reading that are of special interest are the case of printed text in other than Roman script, especially foreign language material, and the case of stencilled information. The special problems of ideographic languages, such as Chinese, where the character itself is often the basic semantic unit of the language, will not be considered here, since such problems are almost as much a matter of mechanized translation as they are of mechanized character reading.

A requirement that a reader system be capable of handling varied foreign language material first of all implies the need for a relatively larger vocabulary since languages such as Russian, Arabic and the like, use alphabets containing character shapes not found in the English (Latin) alphabet. Secondly, in many highly inflected languages extensive use of diacritical marks provides,

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1/ Rabinow, J. "Report on DOFL First Reader", Ref. 367.

HERMES AMBASSADOR

IBM ELECTRIC

IBM ELECTROMATIC

IBM EXECUTIVE

LC SMITH MODEL SEVENTE

LC SMITH SUPER SPEED

REMINGTON ELECTRIC

REMINGTON ELECTRIC

RE[illegible]INGTON STAN[illegible]ARD

REMINGTON STANDARD

ROYAL STANDARD

ROYAL STANDARD

Figure 17. Example of Samples Obtained from Different Typewriters

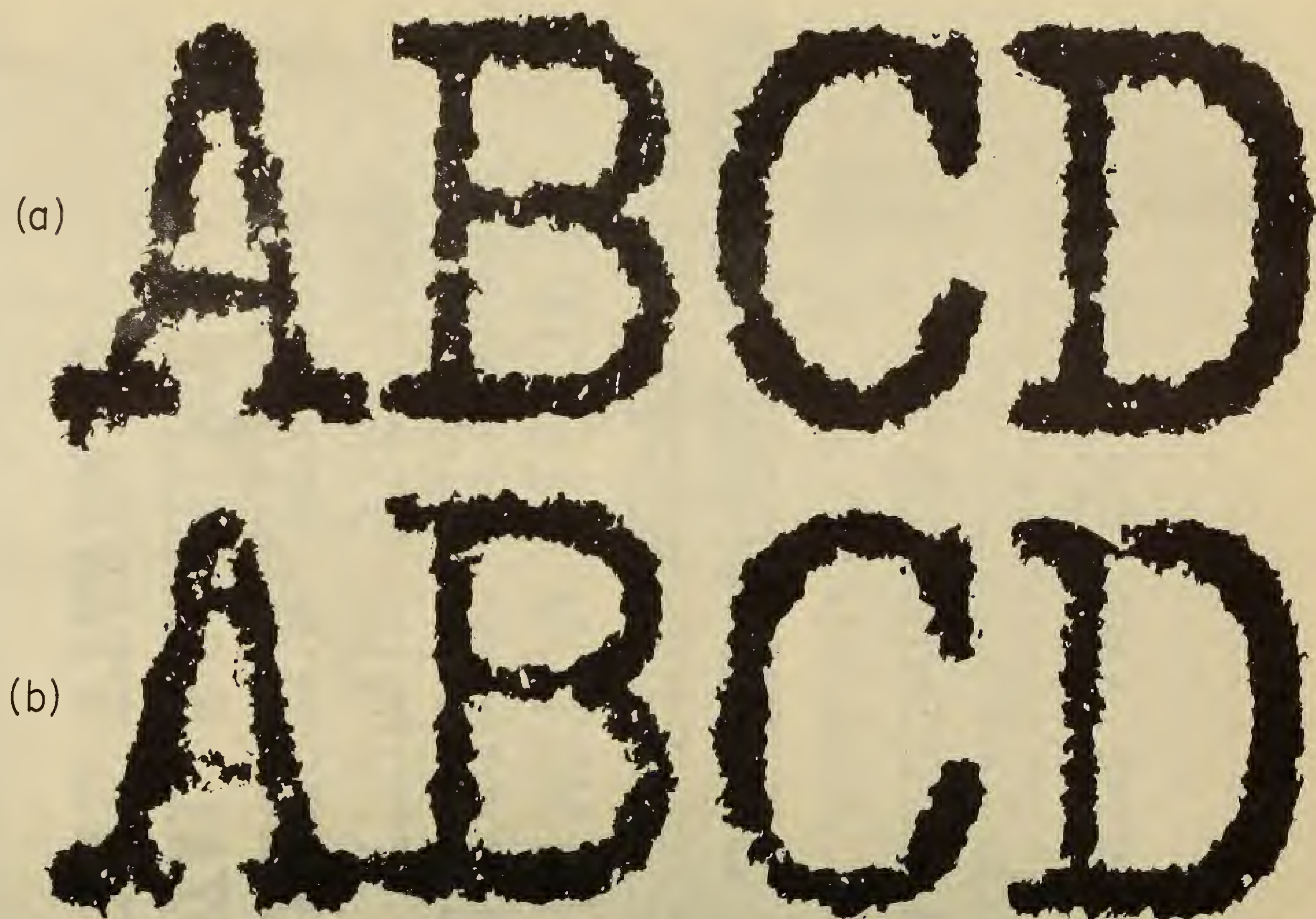

Figure 18. Samples from Two Different Typewriters of the Same Make and Model

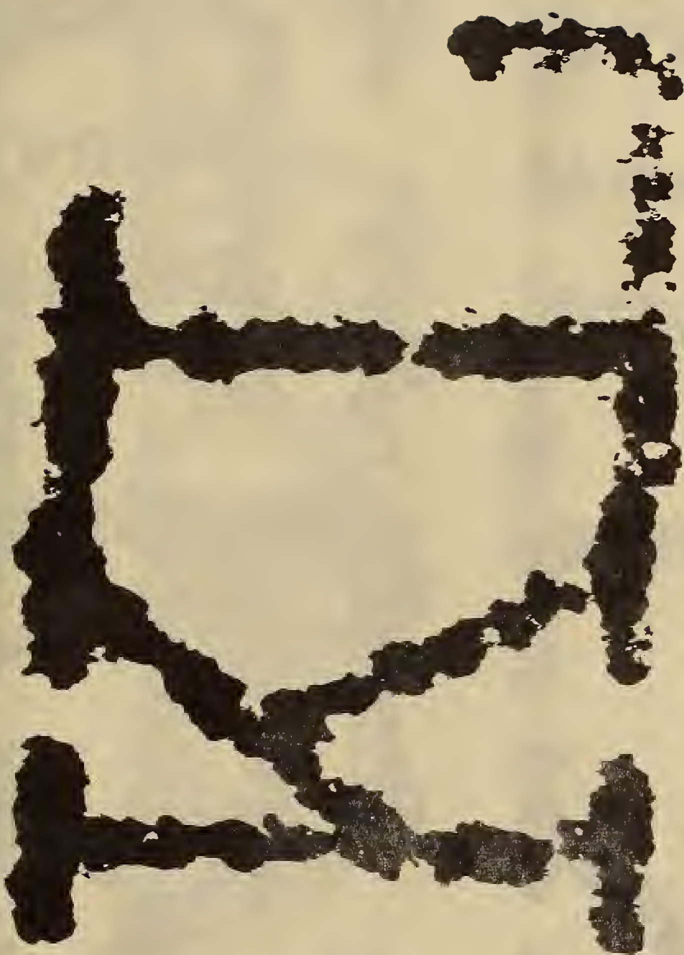

Figure 19. Example of Broken Strokes and Overlap

Figure 20. Two Lines from the Same Typewriter

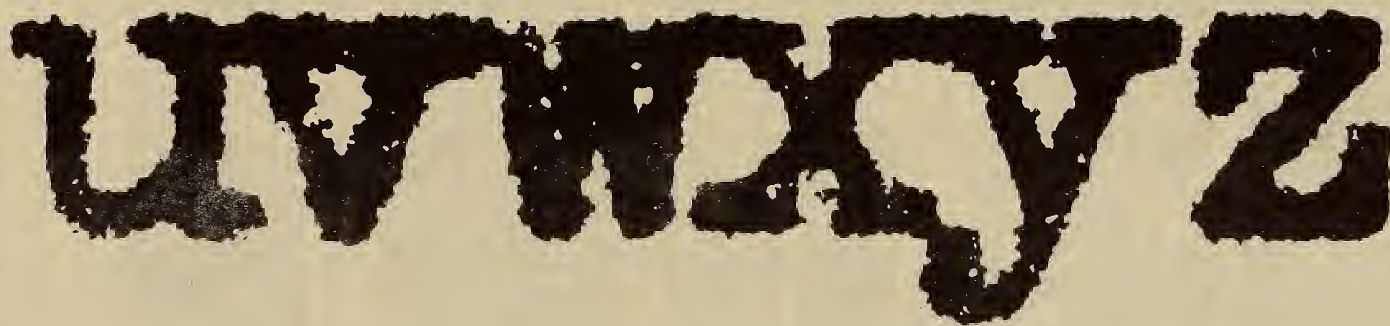

Figure 21. Example of Bleeding and Noisy Characters

in effect, two or more versions of various character shapes. Since such marks may be relatively small they add to the problems of distinguishing one character from another. They add to the problems of discriminating between valid marks of small size on the one hand and general background noise on the other.

Some of these difficulties are illustrated in the case of Cyrillic script where, for example, the Russian letters "shah" and "shchah" (see Figure 13) are distinguishable only by a small difference in total area and shape, and where certain letters can be distinguished from each other only by the diacritical marks. The confusion of these letters with each other might well result in added ambiguity of subsequent interpretation, either in an automatic dictionary or in an automatic translation application. For a simple example, the use of "short ee" rather than "ee" in Russian may distinguish between the single or plural number of certain masculine nouns with soft endings. Similarly, the difference between Russian "yeh" and "yio" may discriminate between the instrumental and prepositional cases of the interrogative pronoun meaning "by what" or "about what".

As has been previously noted, a study of Russian printing quality has been conducted by New York University for the Rome Air Development Center, in connection with a program looking toward mechanized translation. In the report on the results of this study, a number of difficulties are stressed. 1/ These difficulties include variable spacing, both narrow and wide, either to fill out a short line or to provide an effect equivalent to the use of italics, as well as a wide variety of character deformations and the close similarities between several different characters. The effect of operational requirements for applications involving automatic reading of Russian print, therefore, is directly related to system design considerations, as the NYU researchers point out. They conclude that the poor quality "militates against character discrimination through observation of fine or discursive detail"; that methods of discrimination based upon relatively invariant gross characteristics and fundamental structure "offer a greater chance of success", but that a great many 'bits' of information may be required for recognition purposes if frequently mutilated characters are not to be mistaken for their 'homomorphs'. 2/

In the case of stencilled information, the necessary vocabulary is relatively limited in size, since normally only numerals and alphabetic upper case characters are used, but almost all characters have arbitrarily broken strokes such that considerable increase in recognition logic complexity may be required to eliminate ambiguous or erroneous identifications.

5.5 Criteria for Performance Measurement

The critical factors in automatic reading problems include not only the overall and specific performance requirements and the difficulties inherent in the scanning-recognition of printed, typed, stencilled materials, but also the selection and use of appropriate criteria for measuring the performance of equipment to be evaluated.

The obvious standard of reference is of course comparison of reader performance with human performance in scanning and recognition of similar material. Yet the adoption of such a criterion would create great difficulties and would in most cases be misleading. In the first place, human performance is the product of many factors other than visual acuity, specifically including psychological "set" and expectancy based upon prior context. For example, in a series of psychological experiments, the reproduction of ambiguous stimulus figures is definitely influenced by concurrent stimuli, such as a suggestive word, i.e., the "recognition" of a serpentine curve, like a reversed "S", was as "8" in the case where the word, "eight" was concurrently given and as "2" where "two" was given. 3/ Again, such hypotheses as the principles of "closure" and "good continuation" of Gestalt psychology may be the basis for human ability to fill in holes and breaks in a character image of poor quality.

In the second place, human errors result from such causes as inattention, too great a span of perception as in copying from two different lines, and mistaken expectancy as well as from misreadings of poor quality or ambiguous material or material read under inadequate lighting conditions. A variety of human errors may also occur in the transcription part of the process such as inversion of two or more characters, striking of the wrong key, skipping a line, and the like. Thus human errors in a data-copying or transcription process may be highly erratic, difficult to check without 100% verification. The errors to be expected in automatic reading equipment, however, tend to be systematic (an "0" for a "Q", and an "8" for a "B") and can therefore be subjected, if desired, to equally systematic error-detecting and possibly error-correcting processes. Moreover, in

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1/ Boni, C. "Russian type study," Ref. 55.

2/ Ref. 55, pp 1-6, 3-1, 3-2.

3/ Carmichael, L., H. P. Hogan, and A. A. Walter. "An experimental study of the effect of language on the reproducibility of visually perceived form," Ref. 69. See also Stevens, S. S. "Handbook of experimental psychology", Ref. 463.

many cases, reject thresholds can be set sufficiently high as to reject as nonrecognitions all characters ambiguous enough to make misrecognition likely.

The criterion of intercomparison of human and machine performance should therefore be limited to the comparative costs, comparative time figures, and comparative error rates on the same or similar material for manual and for automatic reading-transcription. In our 1957 survey of character recognition we gave as an example an automatic reader device capable of recognizing the upper case vocabulary of machine tabulator output at a rate of only 15 characters per second, with an error rate not greater than one character per thousand, and costing $50,000 as capital investment. Such equipment, with performance specifications considerably below those now obtainable, could provide work-output equivalent to that of 5 GS-3 keypunch operators copying at a steady rate of three characters per second for an eight-hour shift. The cost of these keypunch operators, in direct salaries alone, would be at least $15,000 per year. Assuming that the costs of operating the reader equipment are directly comparable to the recruitment, training, replacement, supervision, leave reserve, and overhead costs, plus rental of keypunch equipment for the manual operators, such a device could be amortized in about seven years. If, under similar circumstances, the reader can recognize 100 characters per second, a machine costing $250,000 could be amortized in five years or less, and its use might well be justified on the basis of economy alone.

Our earlier conclusions have been reaffirmed in an independent study [1/] of the use of optical scanning equipment for the oil industry, conducted in November 1959. In this study, it was determined that the break-even point is where four to six keypunch operators would be involved on a particular application. This later estimate is based upon the assumption that there are 7,000 strokes per hour per operator (a 2 per second average). For a Farrington-IMR installation at the Atlantic City Electric Company it has been reported that the reader does the "work of 8 tape-writer operators in 1/20 the time," with a 2% reject rate, and with no errors as yet discovered. [2/]

Similar conclusions may be reached by considering costs per word read. At a Seminar on Machine Indexing held at American University in February 1961, several speakers agreed that the average cost of keypunching natural language text material is approximately 2.5 cents per word, including verification. At such a rate, the keypunching of just the text of the Harvard Classics, assuming 100 volumes with an average of 100,000 words, would cost more than twice as much as the quoted development costs for page-reader recognition system proposals from several different potential suppliers. When that famous "five-foot shelf" is considered in relation to the collections of printed literature that would be involved in mechanized translation operations, the need for automatic character recognition devices is quite obvious. Criteria for performance specifications and for performance measurement with respect to such potential applications should therefore be appraised realistically in terms of the need and of the comparative costs.

A second criterion for both the initial design of automatic reading equipment and its subsequent performance evaluation is the tolerance allowed in the system for character degradation or deterioration. In studies made at IBM, Greanias and Hill [3/] defined two major factors that might be used in the establishment of a criterion to test various proposed devices. These two factors are:

(1) Permissible character deterioration, determined by measurement and integration of total detectable ink density of an actual symbol over the entire symbol space as against the total density of an ideal image of the same symbol; and

(2) A style factor which is a function of the number of styles, the number of identifications (size of total symbol vocabulary), and the similarity of symbols that do not have the same identification. More precisely, the style factor measures the dissimilarity of different symbols in terms of the total area of a given symbol, that area of that symbol which is not part of a different symbol, and the area of the different symbol that is not common with that of the first.

Character deterioration, as related to maintenance of consistent good quality input, is a key factor in determining the permissible reject rates that must be balanced against needs and comparative costs. These rates can be, in fact, far higher than might be supposed. Table II illustrates some of the relationships between economic break-even points and reject rates, on the basis of the following assumptions:

1/ As reported by Keller, A.E. "Optical scanning - an unlimited horizon", Ref. 249, p. 25.

2/ See Vogler, G.W. "Optical scanning of customer accounts," Ref. 518, p. 26.

3/ Greanias, E.C., and Hill, Y.N. "Considerations in the design of character recognition devices," Ref. 172.

(1) Salaries of keypunch operators are at the rate of $4,000 per annum;

(2) The costs of one or two operators for the reader, power consumption, maintenance, and the like, are assumed to be more than balanced by costs of supervision, overhead, training of operators, not included in potential savings;

(3) The reject rate is assumed to be for documents, not characters; and

(4) The recognition rate of the reader is sufficient to replace the operators shown, assuming that they work steadily at 3 characters per second. 1/

As a safety factor, the reject rates indicated in Table II might well be cut in half, and there would still be good reason to believe that a $300,000 reader with a document reject rate of 35% would produce direct cost savings in situations where the workload requires 50 or more keypunch operators. Similarly, a reader costing only $100,000 as original investment might be applied, with direct savings, in situations requiring only 10 operators, provided that the document reject rate is no more than 20%.

Related to the question of reject rates that can be accepted, questions of performance measurement with respect to a specific proposed character recognition system would also include the ease with which reject reinstatements might be accomplished. For example, in several reader systems under development provision is made for display of characters that have not been recognized, together with provision for manual insertion of the correct character identification. Thus the question of performance measurement with respect to rejects and errors will involve considerations of whether, by accepting relatively high reject rates, the possibilities of true misrecognitions can be held to a negligible level, of the ease with which nonrecognitions can be corrected, and of the possibilities of combining manual and machine techniques in the total operation.

A final area in which the development, selection, and use of appropriate criteria for performance measurement of reader devices is needed is that of standardization of test methods and test materials, including methods of measuring visibility and legibility of printed and typed characters. Some studies have been made 2/ of relative readability of typed and printed materials in various sizes and styles for human readers. However, until quite recently no instruments have been available to obtain quantitative data on such factors as the actual ink density of characters on a page. For example, present Federal specifications for typewriter ribbons use test procedures where subjective judgments must be made by human observers. They determine the deterioration of the intensity of typed characters after repeated typing on the same portion of the ribbon and after controlled exposure to simulated fading conditions to check relative permanence. The use of a color densitometer 3/ has also been developed such that the actual reflectivity from a character space may be measured precisely.

In view of the interdependence of such variables as paper, ribbon, type style, and operator touch in producing discrepancies in character impressions in typed material, it is clear that considerable research would be necessary to prepare reproducible standard material for test of readers designed to read typewriter output.

Development of improved methods of measurement of character quality for both printed and typed characters, for a variety of sizes and styles, a variety of paper stocks, and other variable characteristics of the carrier medium or the inscription would accomplish the following objectives:

1. To provide quantitative data as to the conditions to be encountered for given situations in which reader devices are to be developed or applied;

2. To provide standards for controls on the preparation of input materials, such as the maximum usable life of ribbon, the minimum acceptable quality of paper, and acceptable color of paper; and

3. To provide means for calibration of standard test materials.

Even more directly, such improved methods would facilitate acceptance and quality control of items such as paper, ribbons, typefaces, etc., that should be of considerable interest to large organizations such as the military supply agencies.

1/ That is, for 100 operators, the reader should have a recognition rate of not less than 300 characters per second. This is well within the range of recognition rates that have been demonstrated.

2/ See Greene, E.B. Refs. 176, 177 and Luckiesh, M., and F.K. Moss. Ref. 280.

3/ Sweet, M.H. "An improved photomultiplier tube color densitometer," Ref. 468.

TABLE II. RELATIONSHIPS BETWEEN ECONOMIC BREAK-EVEN POINTS AND REJECT RATES

Original Workload Operators	Savings, Operator Salaries	Operators Retained for Rejects	Costs, 5-Year Amortization Plus Salaries of Operators for Rejects		Reject Rate
			$100,000 Reader	$300,000 Reader	
6	$24,000	1	$24,000	———	10% +
7	$28,000	1	$24,000	———	10% +
7	$28,000	2	$28,000	———	25% +
8	$32,000	2	$28,000	———	25%
8	$32,000	3	$32,000	———	30% +
10	$40,000	2	$28,000	———	20%
10	$40,000	4	$36,000	———	40%
10	$40,000	5	$40,000	———	50%
20	$80,000	4	$36,000	$76,000	20%
20	$80,000	8	$52,000	———	40%
20	$80,000	12	$68,000	———	60%
20	$80,000	15	$80,000	———	75%
50	$200,000	20	$100,000	$140,000	40%
50	$200,000	30	$140,000	$180,000	60%
50	$200,000	35	$160,000	$200,000	70%
50	$200,000	45	$200,000	———	90%
100	$400,000	40	$180,000	$220,000	40%
100	$400,000	60	$260,000	$300,000	60%
100	$400,000	80	$340,000	$380,000	80%
100	$400,000	90	$380,000	———	90%

6. DESIGN CHARACTERISTICS OF SELECTED SYSTEMS

Assuming that overall system objectives and specific operational requirements have been determined and that performance specifications have been established, the potential customer for an automatic character reader would like to make a comparative evaluation of specific systems. In the present state of the art, however, such a customer would be largely limited to design details rather than to operating factors as experienced in practical working situations. By analogy, we might say that a number of American and foreign automotive vehicle prototypes are available, but that very few people have as yet driven them under realistic road conditions.

The examples of reader systems that have been cited in the discussions of the generalized character recognition process clearly show that a variety of techniques can be combined to achieve the objectives of automatic reading of printed, typed, and, in some special cases, handwritten, characters. Consideration of certain comparative characteristics of selected systems that have been proposed should further demonstrate that the automatic character recognition problem has been solved, in principle, and in a variety of different ways, for the closed vocabulary, high quality input, situations. Unfortunately, however, performance data on operational systems is largely lacking. With the exception of Farrington-IMR installations, there is almost no customer experience to report. Deliveries have also been made in recent months by, for example, Solartron and Rabinow Engineering, but there is as yet insufficient information on operations of these systems. Therefore, the inter-comparison even of a relatively small number of systems must be largely limited to system design characteristics. These include mechanisms for scanning and transformation of the source pattern, principles of recognition logic processing that have been adopted, and bases for recognition-identification decisions. We shall consider certain representative systems with respect to each of these categories as well as with respect to a summary or general classification.

6.1 Scanning and Transformations of Source Patterns

An earlier classification of various possibilities for automatic character recognition systems was directed precisely to differences in scanning, sensing, and source-to-input-pattern transformations. Thus, Cook [1/] in an earlier NBS study of print reading systems defined three major categories as follows:

(1) Optical Matching. In such systems the complete input image in two dimensional form is compared directly with two-dimensional reference images stored in the reader, with either direct or "best-fit-correlation" identification.

(2) Scan Line Analysis. In these systems the input image is scanned with a continuously moving spot so as to form a line pattern over the image field and produce a time-varying signal which is then compared with a similar signal stored for each of the vocabulary reference characters.

(3) Image Point Analysis. In such systems, the input image is analyzed point by point over the entire image field in accordance with a specific pattern, and the values obtaining from examining each point are processed digitally to determine the characteristics of the input image.

Frequently, however, variations and combinations of these or other categories occur in proposed devices as, for example, in optical matching of selected image points. Moreover, the use of specialized transformations, for example, by techniques of autocorrelation, provides systems that are difficult to classify in precisely these terms.

Obvious differences between various systems do continue to appear with respect to design characteristics involving holistic, analytic, and criterial feature extraction treatments of the source pattern. In the holistic approaches, the source pattern as a whole is used as the input pattern, the most obvious example being that of optical reflectance through an identical-shape, identical-area mask. In most cases, however, the scan-input operation serves as a transducer: that is, it converts the two-dimensional color-contrast source pattern into some other form. For example, the original black-white contrasts may be converted into contrasts of positive or negative voltage suitable for further processing in an analytic treatment.

Several different transducing steps may also be involved. For example, a first transformation to signals derived from some conventional means of scanning, followed by a procedure for encoding the significant features of these signals. Thus Pahl, considering the possibilities for criterial line-tracing, suggests use of the 'stopped-spot' principle of television scanning, as follows:

1/ Cook, H. D. "A study of print reading systems leading to a proposed reader for typewritten material," Ref. 80.

"In this system the scanning spot passes rapidly over areas of no contrast but halts temporarily at boundaries, the positions of which are coded for transmission. The advantage of the system is that signal redundancy is greatly reduced." 1/

In effect, a holistic representation is preserved in many of the special transformations including those of optical or space filtering and field potential derivatives. 2/ For those holistic systems using optical, or photographic, template reference patterns, we note that the reference pattern vocabulary may be composed of photographic negative images only, as in the DOFL First Reader, or of both positive and negative patterns, as in a proposed RCA reader. A combination of photographic negative masks and block positive masks to determine relative widths and heights are used in a Baird-Atomic prototype page reader. The use of positive and negative masks eliminates the problem of more than one character covering the same mask (upper case "O" and "Q" for example). Several systems embody this principle. For instance, Ress and Greanias, in a patent assigned to IBM, disclose the use of both positive and negative masks. 3/ Both positive and negative masks are also suggested for use in the Briggs Associates lenticular array system 4/ for appropriate "select" and "reject" processing.

In the analytic approaches to various possible methods for scanning, generation, and transformation of an appropriate input pattern, given a source pattern sensed within the image field, we find, first, the operations of segmentation, unitization and quantization of the scanned source pattern field. These may be operations of quantization in terms of a theoretically superimposed grid, or of encoding of relative intensities of black encountered in a given vertical scan segment ('long', 'intermediate', or 'short'black blobs in a single vertical scan for example) or of 'feature extraction' by local operations. 5/

The approaches which involve what we have termed a criterial feature extraction treatment of the scanning and transformation of the source pattern to an input pattern, and its subsequent further transformation into the required format of reference patterns, include, in the simple case, operations of eliminating redundancy by ignoring source pattern 'runs' of the same direction or without significant change in character of successive scan segments. They also include, in the more complex case, derivations such as those in the Bledsoe-Browning method 6/ of 'hit', 'partial-hit', and 'no-hit', coincidences of the input pattern (derived by rectilinear mesh quantization from the source pattern) with arbitrarily chosen n-tuples of particular coordinate description positions.

As we have noted, this latter method involves analysis in terms of coincidence with random features--that is, the arbitrarily chosen n-tuples. A technique that is similar in terms of analysis of random features has been proposed by Novikoff. 7/ He has proposed recognition by observing differences of frequency of crossings encountered with a 'randomly tossed' reference pattern element, such as a line segment or curve. Scores so obtained can serve as master reference patterns which will enable subsequent identification of unknown characters regardless of rotation or translation in the source pattern image field.

In some cases, the analytic and criterial approaches are combined. The method termed "analytic-descriptive" by Rosenblatt may involve either an encoded version of a coordinate description analysis, such as for example a function table entry designation for a particular combination of two-valued variables, or, more commonly, the use of distinctive features as well as analytic processing. Rosenblatt defines his category as follows:

> "The analytic-descriptive method consists of reducing a stimulus pattern, or configuration, to a simple, canonical description which is invariant under the transformation in question. This description (generally given in terms of measurements of lines and angles, ratios of dimensions, etc.) can then be compared with a stored set of master-descriptions to determine which corresponds most closely to the stimulus on hand." 8/

1/ Pahl, P.M. "Automatic character recognition," Ref. 350, p. 15.

2/ See Kazmierczak, H. "The potential field as an aid for character recognition," Ref. 246.

3/ Ress, T.I., et al. U.S. Patent 2,919,425, Ref. 384.

4/ Brown, L.R. "Nonscanning character reader uses coded wafer," Ref. 62.

5/ Bomba, J.S. "Alpha-numeric character recognition using local operations," Ref. 54.

6/ Bledsoe, W.W. and I. Browning. "Pattern recognition and reading by machine," Ref. 51.

7/ Novikoff, A.B.J. "Integral geometry as a tool in pattern perception," Ref. 340. See also Refs. 329, 341, 494.

8/ Rosenblatt, F. "Perceptual generalization over transformation groups," Ref. 397, p. 65.

6. 1. 1 Special Transformations in Source-to-Input-Pattern Processing

With respect to systems involving holistic scanning and sensing of the source pattern, that is, systems that preserve and process the whole of the source pattern image, those systems which utilize special transformations are of particular interest from the standpoint of differences in design characteristics. These include, first, various techniques for optical, or space, filtering. "Space filtering" is defined by Gilmore 1/ as follows:

> " . . . The process of selectively transmitting the spatial frequency components of a pattern . . is similar to the selective transmission of one-dimensional frequency components by an electrical filter. Any image-forming optical system acts as a space filter, since the images it produces of a plane pattern are consistently distorted."

A number of suggestions in the technical literature indicate that optical filtering and Fourier transform techniques of the type used for sharpening and re-focussing of poor quality photographic images might be useful in the field of automatic character recognition. 2/ Elias, Grey, and Robinson, 3/ for example, point out the analogies between multi-dimensional analysis to those of electronic filtering, discuss the use of 2-dimensional filters with space-averaging properties for improvement of degraded images and for discrimination in the presence of noise, and suggest the applicability of these techniques to problems where a particular configuration is to be sought in the image field.

The so-called "field potential" method is another type of transformation. This method is under investigation at the Technische Hochschule, Karlsruhe, Germany. As described by Kazmierczak, 4/ there is a preliminary analytic step of quantization, but it is claimed that the subsequent analysis of the potential field values restores enough of the original exact shape relationship information to provide, in effect, a holistic basis for pattern-matching. In this system, the output of the scanning process provides a quantized voltage distribution in 20x10 shift register storage. This register feeds a network of resistors to establish a potential field. The input pattern is subjected to a shifting process such that it is centered when the currents through left, right, top, and bottom framing leads are equalized. The input and reference pattern elements consist of the values of the potentials and of the derivatives of each of the points in the field. Currents flowing through coupling diodes into the resistor network are also used in terms of relative inflow. From this special transformation of the source pattern into a field potential image, such discriminating determinations can be made as: shapes open to the left, or to the right; a test point is totally enclosed by the character line; a straight line is to the right of the test point; the test point is end of a character line, and the like. A first model of this system, limited to an initial vocabulary of 14 characters, was scheduled for demonstration in April 1961. 5/

A third example of a substantially holistic input pattern which is a specialized derivative of the source pattern is that of the photometric analysis system of Lohninger. 6/ The patent disclosure of certain key features of this photometric system is as follows:

> "Light reflected from the white background area around the particular character is projected . . . to an image splitting device which divides the projected image of the display character along a reference line into a first part and a second part. The total light flux of each part is measured and converted into a potential whose magnitude is proportional to the measured value. The two potentials are compared with each other and the differential obtained.

1/ Gilmore, H.F., Jr. "The use of the Fourier transform in the analysis of visual phenomena," Ref. 161, p. 14.

2/ See for example, Cutrona, L.J., E.N. Leith, C.J. Palermo, and L.J. Porcello. "Optical data processing and filtering systems," Ref. 85, also Kovasznay, L.S.G. and A. Arman. "Optical autocorrelation measurement of two-dimensional random patterns," Ref. 262.

3/ Elias, P., D.S. Grey, and D.Z. Robinson. "Fourier treatment of optical processes," Ref. 119.

4/ Ref. 246; see also Auerbach, Ref. 21, p. 333.

5/ A similar technique is disclosed by Steinbuch in British Patent 825598, assigned to Standard Telephones and Cables, Ltd., covering: "Character recognition by examining predetermined points in a character area, and applying electrical conditions to corresponding points in an electrical arrangement so as to set up a plane field of flow or potential which simulates the character; means responsive to the flow or potential conditions give an identifying output." (Ref. 445, see also Ref. 454.)

6/ Lohninger, W.J. U.S. Patent 2,927,216, Ref. 278.

"The differential signal is fed to a servo system which is coupled to orient the projected image relative to the image splitting device to reposition the projected image relative to the reference line until the total light flux from the first part is equal to the total light flux from the second part. The physical displacement of the projected image relative to the reference line at condition of balanced light flux will vary for different characters and, therefore, this displacement can be utilized to identify the displayed character presented.

"In the identification of a large number of distinctive characters two or more different characters may produce the same displacement at balance. To prevent the generation of spurious results the character can be further divided ... The light flux from each part is then balanced about a separate reference line and ... values representative of the displacement of the projected image relative to the reference lines from all of the initially split parts is obtained ...

"The projected image or each part of the projected image can be displaced angularly or along a straight line relative to a reference line.

" ... The projected image may be divided to present two identical images ...

"One image can be displaced along a straight line while the other image is displaced angularly to obtain two values.

"Thus, by utilizing linear displacement, angular displacements, or a combination of linear and angular displacements, discrete values or photometric centers can be obtained for each character presented for identification."

Here again we find that information with respect to the whole character is preserved in the input pattern transformations.

The various types of special transformations may, however, be applied in techniques utilizing analytic or criterial principles. Horwitz and Shelton, for example, have recently proposed an optical autocorrelation technique in conjunction with a coordinate description method. 1/ That is, they assume, first, that a binary representation of the source pattern is derived by placing a discrete mesh or cell array over the character. They then describe both optical and electronic means for deriving the autocorrelation function, which they explain as follows:

"The geometrical interpretation of the autocorrelation function is that the value of the autocorrelation function at any specified point is proportional to the number of pairs of occupied points having a given displacement and direction. Physically, this is equivalent to taking the same character on two matrices and shifting one with respect to the other through all possible translations and counting the number of coincidences for each relative translation." 2/

This autocorrelation method thus provides a translation-invariant input pattern, regardless of the original position of the source pattern, with the number of pairs of each category of relative separation between 'black' cells of the coordinate description array plotted as a function of each category of relative separation. As such, the method is to be contrasted with cross-correlation methods, in which optical arrangements involving reference pattern apertures produce intensity distributions in the output plane. These distributions are such that, for the case where the input pattern exactly coincides with the reference pattern the effect is the same as in direct matching, but, for misregistered source patterns, a number of anomalies may arise.

Horwitz and Shelton also consider the '180° ambiguity problem', by virtue of which discrimination is not possible for certain characters in certain fonts. For example, a numeric '6' and a numeric '9', or a lower case 'p' and 'd', may be rotational transforms of each other. This 180°-rotation ambiguity problem is attacked by considering an optical arrangement which is a modification of a system proposed earlier by Kovasznay and Arman 3/ to provide autocorrelation in the vertical direction and an autoconvolution operation in the horizontal direction.

1/ Horwitz, L. P. and G. L. Shelton, Jr. "Pattern recognition using autocorrelation," Ref. 220.

2/ Ref. 220, p. 183.

3/ See Ref. 262.

Among the optical schemes discussed for achieving the autocorrelation function is a method involving the Fraunhofer diffraction pattern [1] to provide a 'wave number spectrum' derived from a given source pattern, which is then compared with that from a normalized mask for each of the ideal-character reference patterns. Horwitz and Shelton note, however, that most of the optical transformation procedures have certain disadvantages. Examples are the requirement that the source patterns be available in the form of transparent images (e.g., photographic negatives), the limitation of vocabulary to be handled at one time in a parallel matching operation, [2] and the difficulties in establishing a balance between individual character separability and multiple font recognition possibilities.

Electronic methods for realization of the autocorrelation model of character recognition are discussed, especially generation of the required input pattern by putting the same quantized bit pattern into two shift registers and tallying the coincidences occurring each time one of these registers is shifted with respect to the other. A partial autocorrelation function derived from the counters at the time when input first enters the register serves as an additional input pattern element for purposes of distinguishing a given source pattern from its 180° rotation equivalent.

6.1.2 Characteristics of Selected Coordinate Description Methods

Techniques for automatic character recognition which we have termed 'coordinate description methods' are closely related to Cook's 'image point analysis' category. They may be employed in either an essentially holistic approach, as in Taylor, [3] or in an analytical one, as in Bomba's feature extraction system. [4] Comparative design characteristics that are of particular interest with respect to these techniques are those of degree of mesh, or resolution, and of the thresholds or clipping levels for integration or quantization.

If the source pattern is to be subdivided into discrete sub-areas as a part of the input process, it is obvious that some choice as to the size of these sub-areas must be made. If the sub-area is large with respect, say, to a character stroke (low resolution), then only gross discriminating possibilities will be available. Generally, only a small vocabulary of recognizable patterns can be tolerated. On the other hand, if the sub-areas are small with respect to character strokes (high resolution) then random noise, whether additive or reductive, may seriously interfere with correct identification decisions. Thus Unger emphasizes the following points:

> "Regardless of how fine a grid is used, there are still important transformations which occur when a continuous line is mapped onto a discrete grid ...
>
> "It is important that any system for pattern detection or recognition be relatively insensitive to minor irregularities in the input fields. Interchanging zeroes for ones in a few isolated cells should not cause significant changes in the output of a pattern processing system ... Some smoothing is achieved merely by quantizing the input. This however, is not adequate, and in some cases the quantization itself introduces irregularities." [5]

In addition, there are usually more reference pattern elements to be stored in the high resolution systems. If multiple patterns for the same 'character' subject to translation, rotation, and size variations are to be accommodated, the storage problem increases exponentially. It is for this reason that Fain [6] and others make the significant point that the elimination of the non-criterial information should be accomplished as early in the scanning-input process as possible.

1/ Ref. 220, pp. 179-180.

2/ That is, "The size of the alphabet that can be handled in a parallel optical scheme is limited by the total light energy available from the source; the energy in each channel goes down with the reciprocal of the number of channels." (Ref. 220, p. 175.)

3/ The Taylor system, as we have previously noted, does allow quantization of the original source pattern field, but provides a number of different possible values, representing different percentage coverages of black in a given sub-area, on the grounds that integration to a binary level would seriously impair the kind of flexibility found in human recognition. (Taylor, W.K. "Pattern recognition by means of automatic analogue apparatus," Ref. 482, p. 198.)

4/ Bomba, J.S. "Alpha-numeric character recognition using local operations," Ref. 54.

5/ Unger, S.H., "Pattern detection and recognition," Ref. 501, pp. 1738, 1739.

6/ See Fain, V.S., Refs. 127, 128.

The resolution or fineness of mesh of the coordinate description grid actually used in different systems varies widely. Some examples ranging from low to relatively high resolution, as used in actual systems or in related pattern recognition experiments, are shown in Table III.

It has been widely noted that the scanning-input pattern processing steps of most recognition systems are information-destructive operations. 1/ The extent of information loss in the transformation of the source pattern to the input pattern is, in coordinate description techniques, related both to the resolution of the grid and to the thresholds for integration or quantization. As Ress and Greanias point out, the level at which clipping occurs establishes the threshold or criterion for distinguishing between black and white: "That is, a decision is made as to whether the area being scanned is dark enough to be considered black." 2/

In general, the threshold value usually used is that of 'more than half'. That is, if more than 50% of the area covered by the grid cell is black, the whole cell is treated as though it were black, and conversely for white. Thus, Baumann, among others, considers that: "An elemental area is considered to be one bit of character information if more than 50 per cent of the elemental area is covered by the character." 3/ Wada 4/ and Iijima 5/ provide for a system design where the more general case is considered, that is, where a $\underline{k}$ proportion of the area to be quantized is the threshold value. Iijima in particular considers the case where $\underline{k}$ is about 16% of the elemental area.

Among the various design characteristics that have been suggested for the integration or averaging operation is that of Greanias, in a patent assigned to IBM, which uses a small diameter scanning spot and a data consolidation circuit. "The data gathered by the photomultiplier during a predetermined number of these sweeps is amplified and clipped at upper and lower levels to provide significant data to an accumulator means which can remember what percentage of the time the presence of a portion of a character existed during said predetermined number of scans." 6/ After the last sweep, determination is made as to whether or not that percentage of time-seeing-black is sufficient to match the threshold established for considering the entire sub-area scanned to be black. In a later patent issued to Greanias, Hamburger, and Leimer, 7/ further developments with respect to integration are discussed. These include determinations of the relative location within the sub-area scan cycle of detected black, and a second-level of integration by local context--that is, reference to the results of scan obtained for a neighboring sub-area, such as the previously integrated cell that is immediately adjacent in either a horizontal or vertical direction.

A second level of integration or quantization is thus developed in some analytic systems to achieve input pattern improvement. This is usually accomplished by local averaging operations or spatial transformations of adjacent input pattern elements. This type of process is described by Kamentsky as follows:

> "The signal field is usually resolved into $\underline{n}$ independent elements. During a spatial transformation, the state of each element is examined. The state of this element and other elements whose coordinates are specified with respect to the examined one are functionally related by a specific rule to determine the transformed state of the examined element." 8/

We shall therefore consider such local operations with other image enhancement and input pattern improvement operations, below.

1/ Compare, for example, Kamentsky: "The pattern-recognition machine is thus a device for performing an information-destructive transformation on the signal field ... Internally, the machine may perform a sequence of information-destructive transformations." (Ref. 244, p. 304.)

2/ Ress, T.I., et al. U.S. Patent 2,919,425, Ref. 384.

3/ Baumann, D.M., et al. "Character recognition and photomemory storage devices feasibility study," Ref. 43.

4/ Wada, H., et al. "An electronic reading machine," Ref. 521.

5/ Iijima, T. "Basic theory of pattern recognition," Ref. 225.

6/ Greanias, E.C. U.S. Patent 2,928,073, Ref. 174.

7/ U.S. Patent 2,959,769, Ref. 173.

8/ Kamentsky, L.A. "Pattern and character recognition systems; picture processing by nets of neuron-like elements," Ref. 244, p. 305.

TABLE III. EXAMPLES OF COORDINATE DESCRIPTION RESOLUTION

Horizontal x Vertical	Total	System
3 x 5	15	Early READATRON prototype, National Data Processing Corporation
4 x 5	20	Fitch patent
5 x 7	35	RCA and NBS-DOFL standardized font
5 x 9	45	Suggested standardized font, X3-1
6 x 9	54	GE 69-A font for optical scanning
6 x 10	60	READATRON prototype for Farrington selfchek font
7 x 10	70	IBM 1210 Sorter-Reader (MICR)
8 x 10	80	Howard experiments
5 x 16	80	Burroughs-Control Instrument reader for National City Bank
9 x 9	81	Taylor system
10 x 10	100	Weaver patent
12 x 14	168	Solartron ERA prototype, actual character space
10 x 20	200	Kazmierczak system
12 x 22	264	Philco system
18 x 18	324	Glover experiments
20 x 20	400	Uhr-Vossler experiments
16 x 28	448	Solartron ERA, space in which characters may appear
25 x 25	625	General Motors program
30 x 32	960	Hill studies at IBM; Baran and Estrin program
32 x 32	1,024	Doyle program for hand-printed characters
40 x 64	2,560	Grimsdale, Sumner system
60 x 90	5,400	Bomba experiments
90 x 90	8,100	1955 Selfridge-Dinneen experiments
100 x 100	10,000	Hodes experiments; R.N. Shepard studies
176 x 176	30,976	SEAC-SADIE input for picture processing experiments at NBS

6.1.3 Various Methods of Input Pattern Improvement

Image improvement operations may occur in the source-to-input-pattern sensing and transformation process-steps for any of the input methods, whether holistic, analytic, or criterial. In the DOFL First Reader holistic method, for example, a procedure for integrating over small sub-areas of the source pattern provides for reduction of noise and for image enhancement although it is still the pattern as a whole that is subjected to template matching in the recognition process.

An example of design characteristics used to effect certain combinations of input pattern improvement operations in a system that is in actual operation is found in the Farrington-IMR Scandex reading machines. First, a video channel is provided to amplify the video signal to each of two scanner photomultipliers. A feedback voltage is developed which controls sensitivity and sets a threshold which pulses must exceed if a signal is to be produced. The pulses are squared and clipped at the appropriate voltage level. Further details are as follows:

> "The feed-back voltage operates to maintain constant voltage difference between the dark pulse and the observed document background. The dark pulse is then reduced to an arbitrary grey level marking the lightest printing safe for the machine to read. The threshold which pulses must exceed is then automatically adjusted by the grey pulse or scanning signals, whichever has greater amplitude. The resulting signals are sharpened, the grey pulse removed and the residual signal clipped. The processed signal has greatly improved contrast and a near optimum signal to noise ratio over the usable range of character darkness." 1/

Input pattern improvement achieved by treating as redundant adjacent source pattern information if there is contiguity in direction, color, etc., is found in many of the criterial feature extraction techniques. Baumann, in proposing what he calls "weighted area scanning" techniques, 2/ suggests first that there should be a reduction of character information at the transducer in order to reduce the complexity of the subsequent recognition logic. It is observed further that:

> "Since ... much of the character information does not uniquely describe the characters, and ... all of the allowable area is not covered by the character, some method of disregarding all the redundant information is implied in the desire to reduce the information at the transducer. Because the character information of the symbol is to be compared to a storage that also contains character information, a logical procedure is to compare the symbol to a photographic transparency which has opaque areas at all the character information positions which are not required to be recognized and therefore produces a substantial reduction of redundant information ...
>
> "The amount of reduction of information is dependent primarily upon the configuration of the mask ... The desired procedure is to have several different masks, each one designated to sort out a particular subclass of characters."

The system design problem with respect to the criterial feature (or area) improvements to the input pattern is of course to achieve a proper balance between elimination of information not necessary for discrimination and retention of sufficient redundancy to enable identification of somewhat noisy or poor quality characters. In many systems, it is necessary first to center or frame the character pattern.

As we have noted previously, several systems utilize a shift register technique either for multiple comparison matchings of the input pattern (i.e., the pattern in a number of successively displaced positions) with the reference patterns, or for transformations that bound, frame, or center the character. This latter purpose can be achieved by detection of the first coincidence of 'black' with top, bottom, and side edges, 3/ or by determination of the 'center of gravity' of the displayed 'black' configuration. Center-of-gravity positioning may be especially important in cases where the source patterns are likely to be badly smeared, in one or another direction. Smearing often results from the imprinting process, such as that of high speed printers. A special case of center-of-gravity positioning, with respect to both horizontal and vertical axes, is included in the photometric analysis recognition method of Lohninger, as previously cited. 4/

In addition to the obvious improvement in the input pattern by normalizing its location with respect to a particular reference pattern framework, some of the special transformations are

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1/ Shepard, D.H., P.F. Bargh, and C.C. Heasley, Jr. "A reliable character sensing system for documents prepared on conventional business devices", Ref. 419, p. 112.

2/ See Baumann, D.M., et al. "Character recognition and photomemory storage devices feasibility study," Ref. 43, pp. 3, 7. See also Baumann, Ref. 44.

3/ Evey, for example (Ref. 126), describes a 'lower right hand corner' position-normalization.

4/ See Ref. 278, and p. 130 of this report.

performed to carry out improvements which normalize size. Harmon has developed a special device for Gestalt-type recognition of line drawings of circles, triangles, squares, etc. discusses the use of a dilating circular scan. 1/ With this scanning method, similar transformations are obtained for geometrically similar figures, with variations of source pattern size being translated into time-of-arrival changes in the derivation of the input pattern. Topological relationships are preserved under rotation.

Optical filtering to produce Fourier transformations is another possibility. Thus, Kelly and Singer state:

> "Another useful property filter would be one which yielded Fourier components of the spatial pattern. The possibility exists of obtaining form information independent of pattern size and orientation from such a filter." 2/

The use of a variety of cleanup, line-thinning or line-thickening, integration over small local areas, edging, and similar operations, has already been mentioned. Similar techniques have been investigated in Russian work in the field. Blokh, for example, states:

> "As a rule, input images are subjected ... to specially designed transformations which emphasize the more distinctive characteristics, remove minor, unessential details, and even replace given images by others more convenient ... Such transformations, the more common of which are centering, contouring, filtering and others ... convert the input collection of images into others which will be termed preconditioned images." 3/

Various proposed operations to reduce noise by local sub-area averaging to standardize line widths, to extract criterial features, and to ascertain the relative location and size of such extracted features, are exemplified in the system utilizing local operations, described by Bomba. 4/ This has been tested on handprinted samples of 34 alphanumeric characters, using a scanner developed by Highleyman and Kamentsky 5/ and simulation on an IBM 704 computer.

In this system, the initial input pattern consists of a 60x90 array. Sub-areas that are subjected to local operations range from a 3x3 section for local averaging to a 15x15 section which allows for feature extraction for up to 70 cells extending from the local sub-area center. The local averaging operations to reduce noise are applied first. They tend to reduce irregularities along the character contour and small holes or missing black in the body of character strokes. For each 3x3 cell array, a center cell that was initially sensed as 'white' will be re-recorded as 'black' if at least 5 of the surrounding 8 cell positions are black, and a 'black' will be rewritten as 'white' if five or more immediately adjacent neighbors are white. Otherwise no change will be made of the center cell. The process may be repeated one or more times. Line-width normalization in this Bomba system thins down a character stroke line that is more than four cell units wide to a uniform average width of four units. Similarly, it thickens strokes which are narrow.

For criterial feature extraction by Bomna's local operations, a program called 'Feastract' is used. The local area operated upon is a radial pattern built up of the appropriate combinations of smaller local areas. To fine, for example, an L-shaped feature, a reference pattern element consisting of a cell, P, the seven cells directly above P in a vertical line, and the seven cells extending in the horizontal line to the right of P, is moved over the input pattern field. This is done in a scanning manner so as to detect coincidence of black cells in the input pattern local area so scanned with the cells of the L-feature extraction pattern. When there is coincidence for all the designated cells, then an L-feature signal is recorded in a buffer image for this feature at the same respective coordinates which the cell 'P' then has. By dividing these secondary input patterns (buffer images for each extracted feature) into zones, the recognition logic may take account of relative location and connectivity of the features that have been detected. The input pattern has thus been improved by noise reduction, line-width standardization, and discarding of non-criterial information.

1/ Harmon, L. D. "A line-drawing pattern recognizer." Ref. 194.

2/ Kelly, P. M. and J. R. Singer. "Bio-computer design," Ref. 251, p. 1-7, also Ref. 252, p. 221.

3/ Blokh, E. L. "The question of minimum description." Ref. 53, pp. 17-18.

4/ Bomba, J. S. "Alpha-numeric character recognition using local operations," Ref. 54.

5/ Highleyman, J. W. H. and L. A. Kamentsky. "A generalized scanner for pattern and character recognition studies", Ref. 211.

Criteria for local sub-area averaging or spatial transformations for noise reduction other than those used by Bomba are also available. Kamentsky, for example, considers both immediate-neighbor and 'directed connection' effects, allowing for greater influence of an immediate neighbor if this cell itself has an immediate neighbor in a given direction that is of interest, e.g., because of expected continuity of a line. As Kamentsky clearly implies, immediate neighbor local averaging is in effect a case of what he terms a two-valued Z-gate threshold logic, that is, the inputs to the Z-gates may have either the value 1, 'black', or 0, 'white'. Kamentsky also considers the case of three-valued Z-gating, described as follows:

> "The general elements N_j may have any number n of inputs X_{ij} each taking on the value 0, +1, or -1. All elements are controlled by setting a 'threshold Z'. Z can take on the values o to n. The elements have a single output Y_j . Y_j is either 0 or 1 based on the criteria:
>
> $$Y_j = 1 \text{ if } \sum_{i=1}^{n} X_{ij} \geq Z,$$
>
> $$Y_j = 0 \text{ if } \sum_{i=1}^{n} X_{ij} < Z.\text{"}$$ 1/

We note that this three-valued Z-gating logic might be required in certain possible implementations of the black, white, and grey (or indifferent) 'meshes' (cells) of the Japanese character recognition system discussed by Wada. 2/ Systems such as that proposed by Taylor 3/ offer the further complication that a given cell may have many values (recording the observed intensity of black in the sub-area of the source pattern which it represents). The question of proper thresholds for averaging, if used, and the design of Z-gating criteria for such systems would present formidable difficulties with respect to the many combinations of inputs active (neighbor cells black) and of weights of those active that would be equivalent for some particular value of Z. That is, under such conditions, certain different patterns would not be separable with respect to this type of operation. Figure 22 shows examples of patterns that would be equivalent with respect to the processing of the center cell of a 3x3 local area, allowing the values of 0, 1, ... 4 to any of the n (=8) inputs, and setting Z=n. For larger arrays, which are often considered desirable, 4/ the problem would obviously increase.

6.1.4 Examples of Criterial Feature Extraction

In the system for character recognition using local operations reported by Bomba, 17 different features are extracted as being useful in identification-decisions. These include horizontal and vertical lines, slanting lines at various angular displacements from the vertical, four orientations of both T-shape and L-shape line intersections, and selected orientations of V-shape intersections. 5/ Demer, Gaffney, and Rohland 6/ search for criterial features, which they term "signature components", such as enclosed white areas, long and short positive strokes, right and left "overhangs", and vertical lines before or after the encountering of these crossovers. A wide variety of different features, and different combinations of features, have been used in different criterial feature analysis systems.

Sometimes not only features but relationships between the features are required to be detected, as in Sutter's patent for recognition of handwritten numeric characters, such as the following:

> "The initial stroke of the symbol or numeral is inclined downward toward the right ....
>
> "Within the second zone there is a scanning line on which a second pulse occurs, this pulse being later in time than the first pulse or, in other words, there is a stroke to the right of the stroke being followed, ...

1/ Kamentsky, L.A. "Pattern and character recognition systems", Ref. 244, p. 306.

2/ Wada, H., et al. "An electronic reading machine", Ref. 521.

3/ Taylor, W.K., Refs. 478, 479, 480, 481, 482.

4/ Thus Sherman remarks: "In principle one would desire a decision function for an N x N aperture which would define the central element as a function of the entire aperture occupancy." Ref. 421, p. 234.

5/ Bomba, J.S. "Alpha-numeric character recognition using local operations", Ref. 54.

6/ Demer, F.M., J.F. Gaffney and W.S. Rohland. U.S. Patent 2,963,683, Ref. 89.

1	1	1
2	?	0
3	0	0

2	1	1
1	?	1
1	1	0

1	1	1
1	?	1
1	1	1

0	0	4
0	?	0
4	0	0

0	0	0
1	?	0
2	2	3

0	0	0
0	?	0
3	3	3

$Z = 8$

Figure 22. Examples of Equivalent Patterns in Z-Threshold Local Averaging

"Within the second zone there is a scanning line on which the stroke being followed is intersected by a horizontal line . . ." 1/

Similarly, several of the Farrington-IMR systems use not merely stroke analysis but also the detection of criterial combinations of strokes, described as follows:

"The machine does not recognize all strokes individually, but as a matter of programming convenience requires instead that some be recognized in the following patterns: long vertical left, long vertical right, horizontal top, horizontal middle, horizontal bottom, short vertical upper right and short vertical lower left, short vertical upper left and short vertical lower right, short vertical left and right (simultaneously) . . . .

"Characters are identified as combinations of the above strokes and stroke groups. A character is identified and its storage code signalled only if the strokes which describe it are detected and if strokes which do not describe it are not detected. 2/

Other types of criterial features extracted in various source-to-input pattern transformations include the covering by the character of a specific subset of 'index points' as in Maul's special font; 3/ the counting of the number of character stroke crossings encountered, as in a reader proposed by Pahl for a lower-case Cyrillic alphabet; 4/ the determination of a specific combination of points at which the relative rate of change of direction of a left-or right-half contour line is significantly altered (Sprick and Ganzhorn), 5/ and the computation of moments as proposed by Alt. 6/ Rochester, in the 'lakes' and 'inlets' method, claims that one of the novel aspects of the invention is: " . . . The use of mathematical topology in getting at the crux of distinctive features . . . little attention is paid to the lines of the character as such, but the lines are only important insofar as they bound regions." 7/ For identification of numerals only, Rochester distinguishes 8 basic shapes such as "tall true lake," "long vertical black line", and "small left inlet", which, in proper combinations, discriminate between the characters of the vocabulary.

Criterial feature techniques that combine various topological properties, distinctive area-covering subpatterns, and specific stroke-direction clues, include those of Grimsdale and Sumner, Sherman, and Frishkopf and Harmon. Grimsdale, Sumner, et al, at Manchester University, have used a 40x64 bit matrix on the Mark I computer to determine the number, size, curvature, relative length, and orientation of constituent parts or segments of character patterns. They have described the 'grouping' aspect of their feature extraction process as follows:

"The scanning programme operates by analyzing the patterns into 'groups'. Broadly, a group is defined as a two-dimensional collection of pattern points, the horizontal extent of which displays no sudden changes on successive lines." 8/

Sherman's investigations have been concerned with the problems of recognition of hand-printed characters, especially the search for character invariants where the source patterns may vary in size, slant, registration, rotation and the like. He notes first that the use of holistic templates would be completely impractical because of the enormous number of possible combinations of pattern parameters. Sherman has therefore turned to the field of mathematical topology, with particular reference to graph theory, for his criteria of recognizability. The use of graph theory enables the

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1/ Sutter, H. U.S. Patent 2,928,074, Ref. 466.

2/ Shepard, D.H., P.F. Bargh and C.C. Heasly, Jr. "A reliable character sensing system for documents prepared on conventional business devices", Ref. 419.

3/ Maul, M. U.S. Patents 2,285,296 and 2,294,679, Refs. 302, 303.

4/ Pahl, P.M. "Automatic character recognition", Ref. 350.

5/ Sprick, W., and K. Ganzhorn. "An analogous method for pattern recognition by following the boundary." Ref. 439.

6/ See p. 181 of this report.

7/ Rochester, N., et al. U.S. Patent 2,889,535, Ref. 388.

8/ Grimsdale, R.L., F.H. Sumner, C.J. Tunis, and T. Kilburn. "A system for the automatic recognition of patterns", Ref. 185.

encoding of a given pattern in the form of a connection matrix. The rows and columns of thie connection matrix correspond to the nodes of the graph, while its elements might correspond to the number of connections or line segments between the nodes. However, the connection matrix in this form would not discriminate between characters having 90° or 180° ambiguity, or otherwise having topological equivalence (e.g., "S" and "2").

Therefore, Sherman also uses the relative geometric positions of the nodes. A 3x3 local subarea is used for input pattern improvement operations, such as thinning of a line segment, and also for the derivation of distinctive features such as angle-of-connection identification, including determination of initial motion in exploring out from a given node. The lines connecting nodes are encoded in the form of a sequence of numbers, each of which represents a quantized local derivative. "The sorting process which will follow requires that each of these sequences be characterized as a concatenation of straight line segments, or of straight lines and arcs, or of arcs." 1/ Topological sorting is followed by geometric sorting, where two line segments are considered to be in the same class if they agree in number of line segment, the allowable range of angular measurement for each segment, and relative location of nodes. The proposed System has been programmed for the Whirlwind I computer.

A similar approach utilizing graph theory and topological differentiation has been proposed by Garmash, Pereverzev, and Tsirlin, in Russia. They also note as Sherman does that topological differentiation may be insufficient for final identification but that the use of subsequent non-topological criteria after preliminary sorting can be simplified. They attack the rotational ambiguity problem by specifying a definite point of origin, such as the lower left hand corner, for line segment tracing, and they propose use of a curve-tracking scanner. 2/

The problems of variability and the search for relatively invariant features in individual hand-printed or handwritten characters are still further aggravated when we consider the possibilities of automatic machine recognition of cursive handwriting. Research projects at the Bell Laboratories have been directed toward possible solutions for some of these problems. At the Fourth London Symposium on Information Theory (August 1960), Frishkopf and Harmon reported on automatic recognition of lower case cursive script, where the writer uses a captive stylus so that continuous X and Y signals are generated with the movements of his pen. 3/ The image field involves an 11x11 quantization. The writer is subject to the constraint of observing a baseline and that he attempt to fit those letters without ascenders or descenders into the space between the baseline and a parallel guideline above.

The first of the criterial features to be detected in this system is that of relative vertical extent, so that a rough first sorting provides groupings of characters with ascenders, characters with descenders, characters with both, and all others. A second discriminating characteristic is the presence or absence of retrograde strokes. Abrupt changes in slope, or 'cusps', are also detected together with determination of location of occurrence with respect to the zones of vertical extent. Closure, or the presence or absence of loops or near-loops, provides a fourth criterion. Finally, special marks such as the dotting of the "i" and the cross-bar of the "t" are used.

Appropriate combinations of these criterial features can be used for letter-by-letter recognition of handwritten words where the word can be segmented so as to locate its letter constituents with reasonable accuracy. Frishkopf and Harmon also consider possibilities of recognizing the handwritten word as a whole, again emphasizing that the highly variable and non-essential details of a particular source pattern should be eliminated as far as possible and that the significant features should be isolated and preserved.

6.2 Pattern Comparison Processing

After scanning and transformation of the input pattern have been carried out, whether by holistic, analytic, or criterial techniques, the input pattern and its elements must be matched with the reference patterns of the vocabulary. The processes used in various systems for comparison of input patterns with reference patterns generally fall into three distinct categories. These are: template matching, decision-tree processing, and parallel (or 'Pandemonium') processing.

The simplest case is, as we have seen, that of template matching. It requires that the input pattern as a whole or in each of all its parts be matched with some one reference pattern as a whole. Template matching techniques may be applied to holistic patterns that are photographic negative images of all anticipated character patterns, or that are complete coordinate descriptions of the quantized pattern, or that are exact descriptions of contour-tracings. Examples of different design

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1/ Sherman, H. "A quasi-topological method for machine recognition of line patterns", Ref. 421, p. 235.

2/ Garmash, V.A., V.S. Pereverzev, and V.M. Tsirlin. "Quasitopological method of letter recognition", Ref. 155.

3/ Frishkopf, L.S., and L.D. Harmon. "Machine reading of handwriting", Ref. 151.

characteristics used in template matching comparison techniques include those of Handel, Ayres, and McNaney.

Handel's patent, assigned to the General Electric Company, was filed in 1931 and awarded in 1933. [1] It provides that the reference pattern vocabulary be recorded as stencil images on a rotatable disk. The carrier item is illuminated by a suitable light source and a lens system projects the image of the source pattern for comparison matching against the disk. The stencils are exact duplicates, in shape and proportion, of the expected source patterns. As the disk is rotated, there is one and only position in each rotation cycle, "in which the image formed thereon exactly coincides with one of the stenciled numbers". At such time, a minimum value of light is transmitted through the disk to a photo-electric device. The photo-electric cell is connected with an amplifier so constructed that it will deliver a tripping voltage to means for controlling a selector switch only when the light received reaches a predetermined minimum value.

In the Ayres patent, [2] awarded in 1938 and assigned to IBM, a sequentially ordered processing of input pattern elements with reference pattern elements, by simultaneous scanning of both, is disclosed. It is assumed that both the source pattern and the reference patterns are illuminated and that the reflected light is transmitted to separate photocells. Scanning is provided by a disk having a number of apertures smaller than the character to be scanned, arranged so that each fractional area of the character is scanned successively. The system thus subdivides the patterns into a series of minute areas, and it is claimed that the scanning "is greatly refined in its exactness, as compared with a method of scanning the whole of the indicia". However, the actual comparison-matching, which is based upon a net difference balancing of the instantaneous current values of the two photocells, is effected only when all of the successively scanned sub-areas of the input and reference characters are similar.

In the template matching technique proposed by McNaney, a 'shaped beam tube', also patented by McNaney, is used. [3] This patent was awarded in 1958, and has been assigned to the General Dynamics Corporation. The inventor describes the system as follows:

> "The invention employs illumination or shadowing of printed, punched or typed images from paper, or the like, onto a light responsive screen of a cathode ray tube. The cathode ray tube so employed, is capable of displaying a plurality of like predetermined images electronically upon its target or screen. The screen or target of the tube is provided with a conductive layer disposed directly upon the tube, and has a light responsive layer, such as a photoconductive material, overlaid upon the conductive layer. Therefore, as an image is optically projected through the conducting layer onto the light responsive layer, the light responsive layer will become conducting in the areas illuminated by the image. When, therefore, the like image is projected by the electron beam of the cathode ray tube, there is established a condition of coincidence between the images and also of equilibrium in an external circuit, there being no current flow at that moment from the electron beam through the conducting layer to a means external of the tube which is capable of, circuitwise, establishing coincidence between the coded information furnished to the tube to project the character and at the same time present that coded information to an output. Therefore, only upon coincidence of the images at the target, will an output be generated which is the same output as that generated by a code generator for presentation of the image by the cathode ray tube. This system then provides a very simple and trouble-free image-to-code conversion system."

A somewhat similar technique to that of McNaney, also using an area-preserving, shape-dependent, position-dependent, template matching principle is discussed in British Patent 83,326. This invention involves projection of the input pattern onto an insulating plate with an arrangement of light-sensitive resistors, each connected to a specified bridge, such that different combinations of resistors are affected for each different character of the vocabulary. [4]

The template matching techniques for pattern comparison processing typically require that only the predetermined characters of a closed vocabulary can be recognized. The pattern comparison processing operations of either decision-tree or parallel processing types, on the other hand, are

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1/ Handel, P.W. U.S. Patent 1,915,993, Ref. 191.

2/ Ayres, W. U.S. Patent 2, 131, 911,Ref. 26.

3/ McNaney, J.T. U.S. Patent 2,859,427, Ref. 287.

4/ Standard Telephones & Cables Ltd. "Character recognition", British Patent 832,326, Ref. 448.

typically applied to analytic input patterns or to input patterns comprised of selected criterial features. These comparison techniques may therefore accommodate, to a greater or lesser degree, character pattern variants that are similar to, but not necessarily identical with, the characters of the reference pattern vocabulary.

The distinction between decision-tree, or sequential, processing of the input-to-reference pattern matching or subsequent identification formula matching, and parallel processing, has been stressed by many workers in the fields of automatic character recognition and pattern recognition research. For example, both Minsky and Neisser emphasized differences between these two approaches in a panel discussion of pattern recognition problems at the Eastern Joint Computer Conference, December 1959. 1/ Selfridge and Neisser have provided a simplified description of these differences as follows:

> "There are two fundamentally different possibilities: sequential and parallel processing. In sequential processing the features are inspected in a predetermined order, the outcome of each test determining the next step. Each letter is represented by a unique sequence of binary decisions. To take a simple example, a program to distinguish the letters A, H, V and Y might decide among them on the basis of the presence or absence of three features: A concavity at the top, a crossbar and a vertical line. The sequential process would ask first: 'Is there a concavity at the top?' If the answer is no, the sample is A. If the answer is yes, the program asks, 'Is there a crossbar?' If yes, the letter is H; if no, then: 'Is there a vertical line?' If yes, the letter is Y; if no, V ....
>
> "In parallel processing all the questions would be asked at once, and all the answers presented simultaneously to the decision-maker ... Different combinations identify the different letters. One might think of the various features as being inspected by little demons, all of whom then shout the answers in concert to a decision-making demon. From this conceit comes the name 'Pandemonium' for parallel processing." 2/

Examples of systems using a decision-tree procedure for pattern comparison and identification formula matching include various Farrington-IMR machines, Glauberman, Fitch, Greanias et al in the proportional parts method, and Bomba, among others. Quite commonly, several parallel paths through the decision-tree structure may be provided for the same character. Thus, Rochester notes that a '4' with serifs, a '4' without serifs, and a pica '4' will be processed through a logic-tree structure for the presence or absence of specified criterial features as though each were a separate and distinct character. However, the final result will be a single target pattern output representing '4'. 3/ The use of parallel paths, such as for example in the proportional parts method of Greanias et al, may in some cases provide a means of minimizing one of the disadvantages often associated with sequential processing -- that is, the fact that the technique usually requires each of the series of tests to be satisfied in a fixed order and that, therefore, the final decision rests upon the outcome of the worst or weakest test.

Bomba observes that with the decision-tree structure of his criterial feature analysis recognition logic, multiple paths do result from various branching possibilities. He concludes, therefore, that some character pattern redundancy must be retained in the system. 4/ On the other hand, related pattern recognition research efforts, such as those of Gill 5/ or Glovazky, 6/ are concerned not only with minimization of redundancy in the derivation of the input pattern from the unknown source pattern character, but also with eliminating redundancy in the comparison processing, by determining minimal paths through decision-tree structures. These efforts may be concerned with techniques such as those of criterial area, 'peephole', templates, or with other relatively invariant properties, such that, so far as possible, each property test should successively bifurcate or dichotomize the portion of the reference pattern vocabulary remaining to be searched.

1/ Bledsoe, W. W. et al. "Discussion of problems in pattern recognition". Ref. 49.

2/ Selfridge, O. G., and U. Neisser. "Pattern recognition by machine," Ref. 410, pp. 67-68. See also Ref. 408.

3/ Rochester, N., et al. U.S. Patent 2,889,535, Ref. 388.

4/ Bomba, J. S. "Alpha-numeric character recognition using local operations," Ref. 54.

5/ Gill, A. "Minimum-scan pattern recognition", Ref. 157.

6/ Glovazky, A. "Determination of redundancies in a set of patterns," Ref. 166.

Among other pattern recognition research efforts related to the use of decision-tree comparison matching processes are those of Unger and Blokh. Blokh discusses requirements for determining an optimum sequence for testing input pattern elements as a matter of maximizing the accretion of information. He also considers the possibility of utilizing independent information with respect to the probabilities of occurrence of various different source patterns, based upon the 'greatest conditional information' given that the previous decision-step element was black or was white. 1/

Unger notes that:

> "It is not necessary to ask all of the questions in every case. A sequential process can be carried out in which the answer to the first question determines a subset of the alphabet to which the input feature may belong. Depending upon the subset, a second question is asked, the answer to which further narrows the field of possible categories." 2/

Unfortunately, however, 'ideal' areas or other properties that would enable a minimization of decision-branch processing and a redundancy-elimination approximating the information-theoretic limits are not generally found in real-life character vocabularies.

In contrast to decision-tree logic as applied to matching and comparison operations, the parallel processing techniques make all tests, but without requiring, in the identification formulas, particular sequences of hits. Moreover, in most of the proposals suggesting this technique, not all tests need be used for a given identification. Instead, a majority-vote type of decision wins. Perhaps the most detailed example of the parallel processing techniques is that of Doyle with respect to the 28 criterial features used for the computer-simulation of recognition of handprinted alphabetic characters. Doyle stresses the distinction between sequential decision-tree processing and the parallel approach as follows:

> "In any recognition scheme the raw data are transformed or tested and from the results decisions are made. Usually the process consists of a sequence of tests together with rules for branching after each test, the final branch furnishing the decision. Any recognition method employing such a sequence of decisions to reach an ultimate verdict is evidently limited by the weakness of its worst test ... Unless the tests are good indeed or the samples to be recognized quite free of noise and distortion a parallel processing technique seems preferable." 3/

We should note that some confusion may arise on this point due to the use of the 'processing' terminology in contrasting sequential with parallel methods. The contrast is more properly between the decision-tree matching procedure in which each next test is dependent upon the results of a prior test or pattern-element-matching-result, and a procedure in which all tests are made for each input pattern and decision as to identification is based on all outcomes. The latter procedure may in fact be carried out in a step-by-step manner, sequentially.

Unless a given sequential ordering of test results is required in a particular identification-formula system, sequential in contradistinction to parallel processing involves rather a matter of time-to-recognize or of cost than a matter of pattern recognition principle. Moreover, as we have noted, a multiple-path decision-tree logic does not necessarily suffer the disadvantage of reliance upon the weakest test, even though the tests which determine the decision-criteria are carried out sequentially. Conversely, a parallel-processing system which requires an all-or-nothing basis for decision-making does suffer precisely this disadvantage. Usually, however, a decision-tree procedure is carried out with sequential processing during the matching operations, whereas the 'Pandemonium' principle may be implemented by either sequential or parallel processing in the actual matching and testing.

6.3 Bases for Recognition-Identification Decisions

Just as is the case for scanning and input pattern processing and for pattern comparison processing, a three-way differentiation can also be made with respect to the basis for recognition-identification decisions used in various operating or proposed character recognition systems. These commonly used bases are: (1) all-or-nothing, such as extinction of light to a photocell; (2) the 'best-fit' or closest match which allows some variability with respect to the exactness of match between the input pattern and the reference patterns or between the observed identification formula and the master

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1/ Blokh, E. L. "The question of the minimum description," Ref. 53.

2/ Unger, S. H. "Pattern detection and recognition", Ref. 501, p. 1746.

3/ Doyle, W. "Recognition of sloppy, hand-printed characters", Ref. 104, p. 103.

formula; and (3) the synthetic, where the probability that a given input pattern is in fact a given character of the vocabulary may be determined by various factors.

The all-or-nothing basis for identification is found not only in the early optical template systems, but also in certain analytic or criterial input processing techniques where the identification is effected by truth-table or decoding matrices in which one and only one output will be energized. The obvious disadvantages of the exact match requirements for early photographic template techniques due to light leakage from even minor misregistration or from imperfections in blackness of character strokes led rapidly to the development of techniques for integration over small sub-areas and to 'best-fit' determination techniques. Similar phenomena with respect to varying densities of ink deposited as well as character imperfections arise even in the magnetic ink recognition systems.

A variety of means have therefore been invented for better correlation of 'best-fit' decisions in the case of the characteristic waveform recognition techniques. For example, improvements in the ERMA-type magnetic ink recognition systems have been developed by General Electric. 1/ Similar improvements have also been developed for waveforms derived by optical scanning devices, as in a Glauberman patent assigned to the Laboratory for Electronics. 2/ Dickinson considers a system using matched filters, in which, in effect, vectors are formed from the sampled input waveform and from the reference pattern waveform so as to obtain the scalar product of the two. Thus, Dickinson claims:

> "It is clear that, if the scalar products of the unknown vector with a set of unit-length compare vectors are obtained, the compare vector with the smallest angular separation from the unknown vector will yield the largest scalar product. If the unknown vector increases in length, all scalar products increase proportionately. Thus, by taking the ratio between any two scalar products, a means of eliminating the effect of amplitude variations of the unknown vector is obtained." 3/

Minot, in his 1959 survey of automatic character recognition developments, considers three types of the 'best-fit' basis for recognition-identification decision. 4/ These are: (1) partial matching by location, in which more than a required percentage of the observed states of a quantized input pattern are found to be equal to the prescribed states for the locations considered; (2) tolerance in gray match, where all the observed states are either equal or close to the values of all the prescribed states; and (3) matching at critical locations, to which we would add the alternative of matching criterial features. This last type of best-fit criterion in the recognition-identification decision process obviously includes the case where it is effected by preliminary determination of indifferent locations as in the techniques described by Evey 5/ and Wada. 6/

Best-fit decision rules are also important in systems where the recognition-identification is based upon significant properties or features that are relatively invariant for different presentations of character configurations that are to be considered the 'same' character, in other words, a character class. In this sense, as Singer has noted, the 'best fit' can become "... the worst fit for a set of images which does not overlap with a different set of images." 7/ Farley discusses this problem with respect both to human and machine recognition of patterns, and notes certain implications for future research, as follows:

> "More should be said about the nature of the rules which determine the 'best fitting' class when comparison of classes is being made with incoming data. The exact nature of good rules of this type remain to be investigated, but it seems clear that the correlation should involve a threshold which, if exceeded, would indicate the choice of the appropriate class. A very simple rule would be majority vote of properties common to class and input, perhaps with some properties weighted more heavily than others. Note that correlation rules and thresholds need not be constant, and those property-classes under active consideration may also change with external conditions. Such changes could account for the psychological phenomena of 'set' or attention, and motivation. 'Context' can exert its influence in the same way--correlation thresholds for example, can change with time or space 'surroundings'." 8/

1/ See for example, Eldredge, K.R., M.D.Marsh. U.S. Patent 2,961,649, Ref. 110; Merritt, P.E., et al. U.S. Patent 2,924,812, Ref. 304; Elbinger, L. P. U.S. Patent 2,927,303, Ref. 108.

2/ Glauberman, M.H., et al. U.S. Patent 2,947,971, Ref. 164.

3/ Dickinson, W.E., "A character recognition study"; Ref. 95, pp. 337-338.

4/ Minot, O.N. "Automatic devices for recognition ..." Ref. 310.

5/ Evey, R.J. "Character recognition logic design", Ref. 126.

6/ Wada, H., et al. "An electronic reading machine", Ref. 521.

7/ Singer, J.R. "A self-organizing recognition system", Ref. 430, p. 545.

8/ Farley, B.G. "Self-organizing models for learned perception", Ref. 131, p. 19.

In the above quotation, both the best-fit and the synthetic bases for recognition-identification decision are implied. That is, what we have termed a synthetic basis is one which constructs a probabilistic decision criterion, frequently involving considerations such as context which are external to the input pattern per se. For example, the threshold for final identification in one of the Bledsoe-Browning experiments varies with the word context in such way that the output or target pattern character selected may actually have had a lower absolute 'score' from the matching process than another of the reference characters in the vocabulary. 1/

Another factor that may be considered in a synthetic identification decision is that of expected character frequency. That is, where the results of input-pattern-to-reference-pattern matching are ambiguous, final choice may be made on the basis of the character that occurs more frequently, for a given language and subject matter source. An example of considerations of this type is reported by Blokh. 2/ Chow considers the case where previously determined noise statistics, specifically including the ways in which various characters and noise are frequently combined, are used to determine the conditional probability density with respect to a corrupt and noise input pattern. 3/ Moreover, by associating the derived conditional probabilities with estimates of loss or risk involved in the substitution of a specific character for another, Chow suggests a means to optimize the recognition system performance by minimizing the risk-cost.

In general, the synthetic basis for character recognition decision provides principles that are in marked contrast to those used for either all-or-nothing or best-fit techniques. This contrast reflects important distinctions that have been made between pattern (and character) detection and pattern (and character) recognition. 4/ Metzelaar distinguishes between systems that sort different input patterns into preassigned classes, where the possible patterns that may occur are known in advance, and systems where it is necessary to determine features found in common for various subsets of a set of observed patterns. 5/ Recognition techniques that employ synthetic decision criteria belong to the latter category. The contrast can be equated, in large part, with the typical differences in objectives and approach as between designers of equipment and researchers concerned with general problems of pattern recognition. However, the contrast is also related to prospects for further progress, specifically with respect to design characteristics that would allow greater flexibility and open-ended vocabularies.

4 General Characterization and Relative Advantages and Disadvantages of Selected Systems

The various categories of scanning and input transformation processing, pattern comparison processing, and bases for recognition-identification decision, are combined in different ways in various specific systems. Table IV gives examples for some of the possible combinations as found in certain operating or proposed systems.

Other methods of characterizing the overall system design of various character recognition proposals include those based on the type and extent of information-destructive transformations that are performed. These would range from little or no reduction of the original information of the source pattern to the highly reductive criterial feature extraction and analysis systems. Kamentsky, for example, classifies systems on this basis as belonging to the following categories: (1) 'element matching', comparable to coordinate grid template systems; (2) 'feature matching'; (3) 'searching for features', which includes both curve-tracing and vector crossing techniques; (4) 'feature extraction by spatial transformations', which would include both the Bomba-type local operations techniques and 'blobbing', and (5) 'spatial computers', involving the use of devices to provide feature extractions and other local operations by parallel processing. 6/

1/ Bledsoe, W. W., and I. Browning. "Pattern recognition and reading by machine", Ref. 51, see also pp. 97-98 of this report.

2/ Blokh, E. L. "The question of the minimum description", Ref. 53.

3/ Chow, C. K. "An optimum character recognition system using decision functions", Ref. 74, pp. 122-123.

4/ Unger, for example, applies the term 'recognition' to operations in which the input pattern is to be identified as equivalent to some one of several known reference patterns. Pattern 'detection', on the other hand, is: "the process of examining a set of figures and selecting those that fall into some particular class of patterns..." (Unger, S. H. "Pattern detection and recognition", Ref. 501, p. 1737.

5/ Metzelaar, P. "Mechanical realization of pattern recognition", Ref. 305, p. 4.

6/ Kamentsky, L. A. "Pattern and character recognition systems...", Ref. 244, pp. 305, 306.

In a survey conducted by Budd Electronics. 1/ primarily concerned with the more general problem of pattern recognition as in the requirements for target identification from aerial photographic data, distinctions are made between non-abstractive and abstractive techniques, and between non-adaptive and adaptive systems. The non-adaptive techniques, which are employed in most of the reader systems that have been actually demonstrated to date, follow fixed comparison processing steps and use predetermined recognition criteria as bases for identification decision. The non-abstractive techniques, in addition, provide recognition criteria that result from relatively straightforward processes of direct, all-or-nothing matching or of best-fit correlations. In the abstractive techniques, which we have previously considered under the term 'criterial', selected properties that can be measured are extracted both from reference and input patterns, and the measures of these properties provide the basis for matching. Finally, the adaptive systems are those in which no specific recognition criteria are preset. Instead, the system in effect 'learns' from experience with many samples to discriminate common patterns. Thus it is considered that adaptive recognition systems properly belong to the general category of self-organizing systems. Such distinctions re-emphasize the differences we have observed between development of automatic reading equipment and research investigations of pattern recognition and pattern detection.

Various schemes for the comparative characterization of different systems often reflect presuppositions as to the relative advantages or disadvantages of particular techniques. In the absence of operational usage data for most systems, however, such supposed advantages or disadvantages are clearly related to different objectives and different possible applications. Uhr, for example, identifies optical-template and atomistic-matching (coordinate description template) approaches as "simple-minded and fallible" and considers the analytical and criterial techniques to be both more reasonable and more promising. 2/ Similar conclusions are reached by others who, like Uhr, are primarily concerned with problems of pattern recognition. 3/ Where the problems of character recognition are extended to the case of handwritten and handprinted source patterns, the assumed disadvantages of the template methods are even more strongly indicted. For example, Sherman describes the typical difficulties as follows:

> "The use of templates fails for hand-printed character recognition where writers are permitted freedom of size, location, slant, rotation and other characteristics which personalize hand-printing. One extension of the template technique to overcome these difficulties would be the use of two-dimensional correlation or Fourier analysis. Here the kernel of the correlation integral should include a number of independent parameters whose value is varied until maximum correlation with the distorted master is achieved. To account only for linear distortions would require that each character be matched against the entire file of masters, in which each master has been given an allowable range of magnification in each dimension, of translation in x and y directions of horizontal and vertical shear, and of movement of the center and angle of rotation. Unfortunately the number of allowable combinations of these parameters and the range of values discourages one from the use of correlation techniques. Since the individual distortions of hand-printing include non-linear as well as linear parameters, the necessity for some other recognition techniques becomes apparent." 4/

On the other hand, for many practical character reading applications, template matching systems provide advantages of speed, simplicity, economy, ease of maintenance. Optical templates such as photographic negative reference patterns tend to mask out both background noise and fragments of other characters which may overlap the source pattern image field, provided there is

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1/ Rosenfeld, A. private communication, February 1961.

2/ Uhr, L. "Intelligence in computers: the psychology of perception in people and in machines," Ref. 494, pp. 179, 180.

3/ Compare, for example, the following: " . . . Programs for pattern recognition are relatively successful when original preparations of the patterns are strictly controlled. These programs are, however, relatively incompetent to identify patterns within simple transformations. To solve this problem of form distortion, a more general logic for information extraction and identification is needed. Preferably, this general logic should not be one that is based upon a specific simplified problem of identifying points of contrast in a small, unambiguous array" -- Research Directorate Quarterly Report No. 1, System Development Corporation, Ref. 469, p. 45.

4/ Sherman, H. "A quasi-topological method for machine recognition of line patterns", Ref. 421, p. 233.

TABLE IV

Combinations of Design Characteristics in Selected Systems

Scanning-Input		Comparison			Decision			System Examples
Holistic	Analytic	Criterial	Template	Decision-Tree	Parallel	All-or-Nothing	Best-Fit	Synthetic
X			X			X			Davis-Hinton patent
X			X			X			Tauschek patent
X			X				X		DOFL First Reader
	X		X			X			Rabinow cut font machine
	X		X				X		W. K. Taylor
	X			X			X		Greanias - proportional parts method
		X	X			X			Farrington-IMR Selfchek
		X		X			X		Bomba
		X		X				X	Bledsoe-Browning
		X			X			X	Doyle

uniform spacing per character in any line and that the registration of the first character in the line can be determined with sufficient accuracy to permit control of the scanning of the rest of the line.

Various techniques are available which permit the simultaneous matching of the input pattern to a number of reference patterns in parallel, without moving parts or complicated logic circuitry. Various mechanisms may be employed to allow shifting from one set of vocabulary reference patterns to another if the total vocabulary contains more characters than can be matched in a single parallel comparison step. Such parallel matching, coupled with best-fit decision-making, solves the problems of ambiguity where the template for one character is included in (covered by) the template for another. The template systems, however, have inherent limitations as to the allowable size and the requirements for prior specification of the vocabulary, and they are particularly susceptible to nonrecognition or to misrecognition where the source patterns are frequently mutilated and degraded.

In general, then, we find that devices intended for limited special-purpose applications, for closed vocabularies of from 20-200 characters, or for situations where consistently high quality input can be expected, require a less sophisticated logic and often offer higher speeds of recognition than do more general-purpose systems. The more complicated logics, however, that are suitable for larger vocabularies, that provide reasonable flexibility in accommodating a variety of type styles, and that can handle relatively poor quality source patterns, require additional hardware at increased expense and usually with considerably increased total size and complexity of equipment. Thus questions of relative advantages and disadvantages of various techniques and different systems are clearly related to specific operational requirements for specific proposed applications or particular objectives, whether these are those of research investigations or those of time-saving economy.

7. FURTHER PROSPECTS FOR CHARACTER RECOGNITION DEVELOPMENT

Research and development efforts are being actively pursued by a number of organizations and individuals interested in the practical realization of automatic character reading techniques. These efforts range from those which have to do with basic questions of pattern recognition and pattern perception to those which are concerned with detailed techniques for reducing the redundancy of information or process steps and with the determination of minimal paths through particular decision-tree logics.

We shall consider in this section those efforts which appear to be directly related to the development or improvement of practical character recognition systems. For example, statistical sampling studies of variations in source pattern presentations of the same character, whether based on manual 1/ or machine observation and test, are in this category if the objective is the design or modification of a specific recognition logic or the design of an improved font.

In particular, promising areas for further development of character recognition systems for large vocabularies (such as foreign language and script materials) include machine simulation of proposed recognition processes, the development of self-adjusting and self-setting systems, and the use of context for improved recognition-identification of both characters and words. Each of these areas is discussed briefly below.

7.1 Machine Simulation

Digital computers have been used to simulate the performance of a proposed reading system, to test the proposed recognition logic with sample characters, and to adjust recognition sequences (identification formulas) for maximum discrimination. In addition, the coupling of a suitable scanning system to a digital computer can provide the basis for systematic studies of the performance of specific recognition logics for varying degrees of skew of source patterns or for varying degrees of character deterioration in the source material. Such a system also provides means for study of the incidence of random noise about symbols of varying design so as to optimize the shapes of characters to be used in a standardized font.

Greanias and others at IBM have made extensive use of computer simulation for design of optical character recognition logics, for development of improvements in magnetic character reading systems, and for determination of typical noise and degradation characteristics for representative input material. 2/ In the development of the proportional parts method for recognition, the use of

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1/ In the special case of decision-tree logic disclosed by Fitch, for example, subsequent manual observations can be used to modify, by pluggable jumper wire connections, particular paths through the tree-network, which provides both multiple paths for the same character and path-sharing of common branch points. See Ref. 135.

2/ Greanias, E.C., C.J. Hoppel, et al. "Design of logic for recognition of printed characters by simulation", Ref. 175; Greanias, E.C. and Y.M. Hill. "Considerations in the design of character recognition devices", Ref. 172.

computer simulation allowed testing of details of the proposed logics for adequacy of character symbol differentiation. These tests were conducted for a wide range of quality of source patterns and for different vocabulary sets. The use of the 650 computer in simulation also provided a means for determining the specific modifications to be made to plugboard-wired logic for a new or modified vocabulary set. Continuing use of the computer for this purpose was anticipated in order to provide accommodation of new input materials.

Other studies of typical noise characteristics that affect the required scanning resolution, recognition and identification thresholds, and limits of character discriminability, which were simulated by computer experiments, include those of Glover, 1/ Evey 2/ and Weeks. 3/ Glover used the TX-0 Computer at M.I.T. to test a vocabulary of 13 characters for both translation and noise. The original 12x12 coordinate description templates for these characters were subjected to machine-controlled distortions to create given percentages of superimposed random noise. When these machine-manufactured 'unknowns' were placed in an 18x18 source pattern image space, a 12x12 input pattern extraction 'window', shifting through this space, enabled a series of comparisons to be made for all the translational possibilities and for specified noise distributions. Data from the analyses of these tests led to criteria for thresholds which, if exceeded, indicated that good registration had been achieved.

Conversely, where obtainable samples of vocabulary characters deviate from 'ideal' character patterns because of ineradicable noise, machine simulation methods may be used to generate the ideal characters desired. Flores and Ragonese, for example, describe a computer technique for deriving the waveform that should be generated by a noise-free magnetized ink character. 4/ These studies have as objectives both the facilitation of system design and the determination of the effects of such variables in the source patterns as chemical composition of ink, fiber structure and absorbency of the paper carrier, and the like. It is claimed that the computer synthesizing procedure enables the designer to investigate predictable changes in waveforms generated by characters that have been altered in various specific ways.

Developmental research efforts directed to improvements in magnetic ink character recognition systems at General Electric, Remington Rand, IBM, and elsewhere, have used machine simulation techniques for the design of improved fonts, for improvements in means to detect particular signals in the presence of noise, and to test proposed techniques. Dickinson in particular emphasizes the contribution of the use of the computer as an aid in the design of the type font, given that particular components and techniques are to be used. 5/ Jakowatz, Shuey, and White suggest not only machine tests of many samples but also an experience-adapting storage of waveforms to be used as reference patterns. They describe their techniques, in part, as follows:

> "The input consisted of randomly occurring fixed waveforms buried in additive Gaussian noise of known bandwidth. No prior knowledge of the time occurrence or the shape of the waveform was known to the system. After a sufficient length of time, the system developed in its memory an approximation to each of the fixed waveforms. Furthermore, it gave, with high probability, an indication each time one of the fixed waveforms occurred . . . .
>
> "If several adaptive filters are properly interconnected, the resulting system is capable of separating several non-overlapping signals buried in noise. In such an interconnection there is associated with each adaptive filter a memory for storing one waveform. The various waveforms are separated into their respective memories by means of inhibition circuitry associated with each threshold . . . The memory with the highest correlation with the incoming waveform is the only memory that is altered by that waveform. 6/
>
> "To date we have successfully demonstrated an adaptive filter capable of selecting invariant waveforms from a background of Gaussian noise. The adaptive filter may be

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1/ Glover, E.B. "Simulation of a character recognition system utilizing a general purpose digital computer", Ref. 167.

2/ Evey, R.J. "The use of a computer to design character recognition logic", Ref. 126.

3/ Weeks, R.W. "Rotating raster character recognition system", Ref. 528.

4/ Flores, I. and F. Ragonese. "A method for synthesizing the waveform generated by a character, printed in magnetic ink, in passing beneath a magnetic reading head", Ref. 137.

5/ Dickinson, W.E. "A character-recognition study." Ref. 95.

6/ Jakowatz, C.V., R.L. Shuey, G.M. White. "Adaptive waveform recognition," Ref. 239, pp. 1, 11.

viewed as a matched filter whose characteristics can be altered by altering the memory associated with the device. With experience, the contents of the device's memory approaches the signal being sought..." 1/

Howard has described the use of computer simulation to generate and test various recognition logics with respect to different coordinate descriptions of the 'same' character and to derive optimum decision rules, most useful test criteria, and the like. For an 8x10 array, approximately 200 different patterns are generated for each character. To find test criteria that can be satisfied for all versions of a given character, all combinations of 2-tuples are considered for 4 inclusive-or and 2 exclusive-or functions of the 2 variables. Finally, an iterative process is used to select the specific tests that are most useful in discriminating between the set of representations associated with one character from the sets for other characters.

Statistical studies of the incidence of noise, using machine processing so that large samples may be handled and so that effects on particular logics may be evaluated, are particularly important for the development of automatic reading techniques which would be capable of coping with varied natural language materials. For potential mechanized translation application, for example, diacritical marks used in the alphabets of various languages, such as grave, circumflex, and acute accents, tilde, dieresis, vowel point, may be essential to discrimination between different inflectional forms of words or stems in the source language dictionary. Similarly, in machine processing of natural language texts in linguistic analyses, automatic abstracting, and the like, it may be essential for character reader input devices to identify the punctuation marks as well as the alphanumeric character symbols.

Finally, we note the use of computer programs and machine simulation for investigation and design of the type of recognition logic which is based upon the identification of unique black and unique white areas for each symbol in the vocabulary. For example, design for the matrix weightings in a proposed Philco reader was developed on the basis of simulations on the Philco 2000 computer. Routines developed for this purpose typically compare a large number of different character symbols (in the same or different fonts as desired) and determine the parts of the viewing raster that are black for all symbols tested, white for all symbols, or sometimes black and sometimes white. This last set of sub-areas is the only part of the source pattern image field that can be used to discriminate between the various characters. This type of logic is obviously sensitive to rectilinear translations of the source patterns in the image field. To overcome this difficulty, other operations can be used that calculate the center of gravity of any input pattern image and then shift the derived input pattern so as to move the center of gravity to any desired position with respect to the reference patterns with which they will be compared.

Examples of computer simulation for determining such significant or criterial areas are reported in papers by Wada 2/ and Evey, 3/ among others. Stearns 4/ considers the case where determination of comparative discrimination is made on the basis of binary encoding of coordinate positions as either black or white. He is then concerned with the derivation of a Boolean product for families of possible coordinate descriptions of the same character pattern. This establishes possibilities for combining several variants of a given pattern into a reduced pattern, discarding those elements which for that given pattern might be either black or white, and retaining only those that must be either white or black. Stearns used the 704 computer not only to derive such reduced 'output equations' (master identification formulas) but also to test the system for the identification of typewritten numeric characters.

Computer simulation has thus been used for the design of fonts, for the statistical analysis of probable location and extent of noise likely to occur with real-life characters, for the derivation of criterial areas in sampling-scan or weighted area coordinate description systems, for the identification of criterial features, for the 'learning' of appropriate recognition formulas on the basis of a number of samples of the expected character population, and for the determination of minimum decision-making paths for particular recognition logics.

Machine simulation may also be of value in the determination of other design parameters, such as the optimization of clipping levels for scanner thresholds for a given range of relative black and relative white in input material, and the like. In addition, computer simulation has been extensively used in general pattern recognition research.

1/ Howard, P.H. "A computer method of generating recognition logics for printed characters." Ref. 221.

2/ Wada, H. etal. "An electronic reading machine", Ref. 521.

3/ Evey, R.J. "Use of a computer to design character recognition logic," Ref. 126.

4/ Stearns, S.D. "A method for the design of pattern recognition logic", Ref. 451.

7.2 Self-Adjusting and Self-Setting Systems

Possibilities for improvements in automatic character reading techniques, in terms of system self-adjustment, include, first, a variety of operations designed for improvement of the input pattern prior to further processing. Such improvement may consist in repositioning as a result of feedback from a preliminary scan, by movement of the source pattern in the image field, or by movement of the scanning mechanism, or both. It may also consist of finding guides or reference marks to control micropositioning. Input pattern improvement operations that are involved in self-adjusting systems may also consist of the framing or masking out of unwanted portions of the image field, once the location of the source pattern in the field has been determined, or the servoing of a peephole-type matching array so that its center coincides with the center of the detected source pattern.

Other possibilities in self-adjusting input pattern improvement operations reduce the redundancy of the information to be scanned and identified. Such operations include cartooning or skeletonizing of the source pattern in a reductive transformation to the desired input pattern. Similarly, character strokes may be automatically thickened to an average width for a given line of characters, once the character spacing for that line has been determined. Input improvement operations intended to improve the quality of the source pattern range from contrast enhancement to a variety of normalizing processes such as edge-smoothing, integrating over stroke-body areas, and filling in of missing portions by statistical techniques.

Secondly, character frequency probabilities may be explored and applied for use in self-adjusting systems. Such information can be used for error detection, reject reinstatement, and interpolations for obviously garbled material. The use of letter frequency probabilities for English, Russian and other language material to fill in missing or nonrecognized characters of an input message, or to provide the basis for choice between alternative readings of an ambiguous character symbol, would be of particular value in automatic dictionary or mechanized translation applications of reader devices.

Thirdly, adjustments for variable size can be developed for reader devices such that the system is capable of readjusting its thresholds or its input pattern transformations in accordance with the detected characteristics of a leading character symbol. A preliminary step in this direction was achieved in an early Farrington-IMR reader for Post Office envelope sorting applications. This was to assume that the first character in an address destination word is an upper case symbol and to adjust thresholds for subsequent detection of lower case letters having ascenders in accordance with this detected size. Recent Philco developments, also for the Post Office, propose self-adjustments in the scan mode, with several possible tries at height-width ratios, so that variable size address characters can be normalized for quantization in a fixed 22x12 format. There are also possibilities for developing a peephole template logic where the criterial aperture array can be automatically expanded or contracted in accordance with the detected boundaries of a preliminary input symbol.

The idea of self-setting systems, in contradistinction to self-adjusting recognition devices, presupposes that the input material will be quite varied and that a large, general purpose machine would be used to determine the characteristics of particular incoming material. Such a machine would then either proceed to direct recognition-identification processing of that material or would determine proper routing to other special-purpose readers. It is assumed, that is, that the machine would be capable of looking at a particular sample of input material, determining what type style, contrast levels, etc., are involved, and perhaps adjusting master identification formulas or other recognition logic requirements in accordance with the observed characteristics of the sample.

Such an operation would presumably require either control over the input such that each piece of material to be read has, preceding the message proper, a sample alphabet in that font, or else pre-editing to select and designate for machine inspection such a sample alphabet. In the latter case it must be recognized that many texts may not include a complete alphabet, and that very few would include complete alphabets in both upper and lower case. However, in the practice of human recognition of different type-styles, considerably fewer characters than a complete alphabet are typically used. Karch, 1/ for example, classified approximately 1,500 different type-styles on the basis of the discriminating characteristics found in only seven sample characters, specifically, lower case "g", "a", "t", "e", "d", and upper case "E" and "G".

1/ Karch, R.R. "How to recognize type faces," Ref. 245.

Unfortunately, even this significant reduction in the number of sample characters that would need to be inspected in order to determine a particular style so that the machine may select or adjust an appropriate recognition logic is not too helpful. Random samples of text were taken from several of the references listed in the Appendix of this report in order to test this point. In several of these texts, no upper case "G" was found at all, and in most cases upper case "E" was found only after scanning a large number of sentences. Table V lists the observed frequencies of the upper case letters found in this particular sample. Table VI lists the frequencies of the upper case characters found, excluding those used in proper names. Table VII shows the observed frequencies of the most commonly used initial words of sentences in the sample. These results suggest that much more extensive analysis of character frequencies for representative samples of expected input text might contribute to the development of improved self-setting reader systems.

7.3 Use of Context in the Automatic Recognition of Characters and Words

The possibilities for both self-adjusting and self-setting reader systems may be enhanced by the extent to which it is practical to make use of observed context, both within character symbols and between characters. For example, where a scanning procedure samples the image field at selected points, the pickup heads at these points may be weighted in accordance with their relative reliability in identifying the symbols of the vocabulary. Such weightings may be specially designed in order to improve reliability of sensing and reading of poor quality material. That is, assuming random incidence of superimposed noise, bleeding, missing portions and broken strokes, the probability of such factors effecting recognition can be reduced by looking only at small number of points in the source pattern, or by giving variable weights to input pattern elements.

In an adaptation of the peephole-template logic that was simulated on SEAC, it was found that 12 apertures, suitably placed, can discriminate between the 32 lower case characters in a particular Cyrillic script, but that to identify any one character not all of these 12 decision points need to be checked. That is, if aperture 1 in the upper-left most corner of the image area is black, and if aperture 3 which is on a line with aperture 1 but in the center of the image area is also black, and if aperture 6 in the geometric center of the image area is also black, "T" may be identifiable without any further steps. The aperture template array, which serves as a master reference pattern, may require some positions to be used if and only if other elements in the input pattern meet specified criteria, as for example the aperture necessary to distinguish between 'shah' and 'shchah' (Fig. 13). This procedure obviously involves taking advantage of the context of a particular input pattern element in order to determine what other elements to look at, thus minimizing the number of steps in either the pattern-element matching or in the checking out of identification formulas.

In this special sense, context dependency may also be considered to be a factor in optimization of other types of recognition logics, especially those employing decision-tree recognition processing. That is, the choice of next-decision-step is dependent upon the results of preceding decision steps. Examples are Glovazky's "code mobile" 1/ and Gill's minimum scan pattern recognition principles. 2/ Chow is concerned with a much broader context, namely, the expectancy of a given character occurring in a given population in order to arrive at minimum risk criteria. 3/

The use of context to resolve potentially ambiguous decisions has been mentioned in the case of Bledsoe and Browning, and a similar type of 'dictionary-filtering' is advocated by Baran and Estrin. 4/ However, Uttley is probably the first to consider context-weighting in terms of machine methods for pattern recognition, specifically in his 'conditional probability' models. Thus he is concerned with simulating possible mechanisms for progressive adaptation to variable environments in which conditional probabilities are built up for a signal (or feature) B, given A, and for these probabilities in the context of a signal or signal sequence, C. 5/

Similarly, Cook has suggested 6/ that in systems where it is desirable to reject doubtful recognitions, rejects might be re-read with a readjustment of thresholds or logic, or both, so as to take cognizance of significant portions of the character image in terms of the information gained on

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1/ Globazky, A. "Determination of redundancies in a set of patterns", Ref. 166.

2/ Gill, A. "Minimum-scan pattern recognition," Ref. 157.

3/ Chow, C.K. "An optimum character recognition system using decision functions," Ref. 74. See also Refs. 73, 75, 201.

4/ Baran, P. and G. Estrin. "An adaptive character reader," Ref. 34.

5/ See Uttley, A.M. Refs. 510, 513, 514, 515.

6/ Cook, H.D. "A study of print reading systems," Ref. 80.

TABLE V. Frequencies of Upper Case Characters

Rank	Character	Incidence
1	T	420
2	A	187
3	I	161
4	S	111
5	F	81
6	C	76
7	B	56
8	M	56
9	W	50
10	H	45
11	O	43
12	R	41
13	P	33
14	N	32
15	E	29
16	D	24
17	L	13
18	U	12
19	J	8
20	V	8
21	G	7
22	K	7
23	Y	7
24	Q	6
25	Z	1
26	X	0

TABLE VI. Frequencies of Upper Case Characters, Excluding Proper Names

Rank	Character	Incidence	% Incid.	Acc. %
1	T	408	36.2%	
2	A	149	13.2%	49.4%
3	I	145	12.9%	62.3%
4	F	69	6.1%	68.4%
5	W	46	4.1%	72.5%
6	O	41	3.6%	76.1%
7	S	40	3.5%	79.6%
8	C	34	3.0%	82.6%
9	H	33	3.0%	85.6%
10	M	30	2.7%	88.3%
11	B	23	2.0%	90.3%
12	E	17	1.5%	91.8%
13	P	17	1.5%	93.3%
14	D	14	1.2%	94.5%
15	N	13	1.2%	95.7%
16	R	13	1.2%	96.9%
17	U	11	1.0%	97.9%
18	V	8	0.7%	98.6%
19	L	6	0.5%	99.1%
20	Q	6	0.5%	99.6%
21	G	3	0.3%	99.9%
22	K	2	0.2%	100.1%
23	J	0		
24	X	0		
25	Y	0		
26	Z	0		

TABLE VII. Frequencies of Initial Words

Rank	Word	Incidence	% Incid.	Acc. %
1	The	244	21.6%	
2	In	67	5.9%	27.5
3	This	66	5.9%	33.4
4	A, an	50	4.4%	37.8
5	It, its	40	3.5%	41.3
6	Figure, Fig.	32	2.8%	44.1
7	These	26	2.3%	46.4
8	If	23	2.0%	48.4
9	However	21	1.9%	50.3
10	Thus	18	1.6%	51.9
11	As	16	1.4%	53.3
12	At	16	1.4%	54.7
13	For	16	1.4%	56.1
14	Since	15	1.3%	57.4
15	On	11	1.0%	58.4
16	To	11	1.0%	59.4
17	There	10	0.9%	60.3
18	We	10	0.9%	61.2
19	Apparatus	9	0.8%	62.0
20	But	9	0.8%	62.8
21	During	9	0.8%	63.6
22	While	9	0.8%	64.4
23	All	8	0.7%	65.1
24	Magnetic	8	0.7%	65.8
25	When	7	0.6%	66.4
26	Of	6	0.5%	66.9
27	Therefore	6	0.5%	67.4
28	Another	5	0.4%	67.8
29	Check, checks	5	0.4%	68.2
30	Code, codes	5	0.4%	68.6
31	Ink, inks	5	0.4%	69.0
32	Obviously	5	0.4%	69.4
33	One	5	0.4%	69.8
34	Under	5	0.4%	70.2
35	After	4	0.4%	70.6
36	Also	4	0.4%	71.0
37	And	4	0.4%	71.4
38	Automatic	4	0.4%	71.8
39	Because	4	0.4%	72.2
40	Even	4	0.4%	72.6
41	Furthermore	4	0.4%	73.0
42	No	4	0.4%	73.4
43	Reading	4	0.4%	73.8
44	Such	4	0.4%	74.2
45	Verification	4	0.4%	74.6
46	With	4	0.4%	75.0

the first reading. . A pattern recognition research project at the Laboratory for Electronics is concerned with possibilities for an adaptive system in which preliminary matching is to be made on a topological basis, but in which additional features will be sought, depending upon within-character context for a class of topologically equivalent patterns.

These examples are illustrative of possible use of context within a single source pattern, whether it be an individual printed character or an address-word for envelope sorting. The use of context for a series of input patterns (again, either single characters or whole words) holds promise for situations where some inaccuracy can be tolerated, such as preliminary translations of foreign text material to determine the general subject matter content of an input document. As previously noted, letter frequencies for the language and subject matter concerned could be used, subject to check of context, to supply identifications of ambiguous or missing symbols.

Check of inter-symbol context for an ambiguous character, such as that of Figure 23 which might be either a broken "o" or a "c" which has 'bled', may be carried out by machine processing in accordance with well-defined rules. Table VIII, for example, illustrates the rules that might be used to identify the ambiguous symbol in Figure 23 if it occurred in combination with various other characters. Thus, Reitwiesner and Weik suggest that checking "can be based on the inherent redundancy of the written source language text, the 'impossibility' of certain letter combinations, and a restricted list of permissible characters." 1/

8. POTENTIALLY RELATED RESEARCH IN PATTERN RECOGNITION

In the preceding section we have considered research and development efforts specifically related to prospects for further progress in the design and use of automatic character recognition systems. When we look ahead to possibilities for significantly large symbol vocabularies, potentially related research on problems of pattern recognition in general also becomes of interest. For example, if significantly larger vocabularies are to include characters in many different sizes and styles and alphabets, characters that are handprinted and handwritten, and abstract geometric shapes that are involved in diagrams and other graphic material, then progress in research on pattern generalization and the search for invariance will be relevant to further progress.

Research in pattern recognition generally is usually directed to quite other objectives than the development of practical character reading equipment. Among the purposes to which it may be directed are those of developing models that simulate observed neurophysiological structure and function. To an extent, the demonstration of a mechanism that works as the brain is assumed to do may also add information to the knowledge derived from neurophysiology and related sciences. Quite different approaches may be followed, however, ranging from the neuron network simulation work to such work as Uhr's where an attempt is made to simulate the perception phenomena stressed in the Gestalt school of psychology.

The results of work in these research areas may not be obviously applicable to recognition system design, but it is recognized by many workers in the field that these results may provide the necessary impetus and insight for future progress. In particular, some workers feel that the directions toward which the more general pattern recognition research efforts point are precisely those that have been most neglected in character recognition developments to data. Thus Uhr states:

> "There is a critical need for better perceptual mechanisms in machines. The sensory mechanism problem is probably close to solution, with a rapid advance in the art of flying-spot scanners and contour tracers, photo-electric cell arrays, and similar optical-mechanical-electronic gadgets. But the true perceptual processes, the information-processing and recognizing of the inputs sensed are still at a primitive stage." 2/

1/ Reitwiesner, G. W. and M. H. Weik. "Survey of the field of mechanical translation of languages." Ref. 380.

2/ Uhr, L. "Intelligence in computers: the psychology of perception in people and in machines," Ref. 494, p. 178.

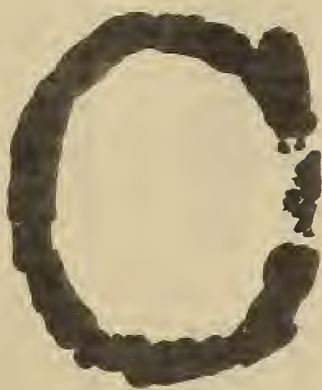

Figure 23. Ambiguous Character

TABLE VIII. Sample Rules for Interpreting the Ambiguous Character of Figure 23

	X	?			=	O		
X	X	?		Space	=	O		
X	?	X		Space	=	C	or	O
X	X	?	B	Space	=	O		
X	X	?	D	Space	=	O		
X	X	?	E	Space	=	C,	except in shoe, aloe, oboe	
X	X	?	F	Space	=	O		
X	X	?	G	Space	=	O		
X	X	?	H	Space	=	C		
X	X	?	K	Space	=	C	or	O
X	X	?	L	Space	=	O		
X	X	?	M	Space	=	O		
X	X	?	N	Space	=	O		
X	X	?	O	Space	=	O		
X	X	?	P	Space	=	O		
X	X	?	R	Space	=	O		
X	X	?	T	Space	=	C	or	O
X	X	?	W	Space	=	O		
X	X	?	Y	Space	=	C	or	O

. . . .

X	A	?	K	Space	=	C		
X	E	?	K	Space	=	C		
X	I	?	K	Space	=	C		
X	O	?	K	Space	=	C	or	O
X	U	?	K	Space	=	C		
B	X	?	K	Space	=	C	or	O
B	O	?	K	Space	=	O,	or	C (bock)
C	X	?	K	Space	=	C	or	O
C	O	?	K	Space	=	C	or	O
D	X	?	K	Space	=	C		
H	X	?	K	Space	=	C	or	O
H	O	?	K	Space	=	C	or	O
L	X	?	K	Space	=	C	or	O
L	O	?	K	Space	=	C	or	O
M	X	?	K	Space	=	C		
N	X	?	K	Space	=	C	or	O
N	O	?	K	Space	=	O		
P	X	?	K	Space	=	C		
R	X	?	K	Space	=	C,	or	O (rook)
J	X	?	K	Space	=	C		
T	X	?	K	Space	=	C	or	O
T	O	?	K	Space	=	O,	or	C (tock)

. . . .

Similarly, Young in his 1960 evaluation of the state of the character reading art, 1/ has noted advances in scanning, sensing, and comparison processing, but points out the relative neglect among the system designers, of the "semantic" features of character patterns. It is precisely these 'semantic' features that are presumably involved in the development of criterial feature, parallel testing and synthetic decision-making systems capable of handling open-ended vocabularies in a general purpose manner.

System design decisions to employ criterial feature extraction and analysis for automatic character recognition are usually based upon one or more of the following objectives:

(1) To reduce the redundancy of the pattern information to be processed;

(2) To provide economy in reference pattern storage requirements;

(3) To provide flexibility with respect to possibilities for discriminating characters regardless of variations in position-registration, in size, and to some extent in specific details of character shape;

(4) To increase the likelihood of correct identification even although the exact source pattern has not previously occurred, that is, to provide for some open-endedness of vocabulary;

(5) To increase the flexibility of the system with respect to the number and variety of fonts that can be accommodated without major re-design of logic, and without requirement for precise advance identification of a particular font; and

(6) To simulate processes that are presumed to be involved in human perception and pattern recognition.

The choice of specific criterial features to be used in a particular recognition system may be based either on a priori assumptions as to the relatively invariant features of characters that are to be accommodated or by various processes of empirical testing and measurement. Areas of basic research in pattern recognition which are related to the design or improvement of criterial features extraction methods therefore include investigations of relative invariance of pattern features in both human and machine perception, computer simulation and testing of proposed property-filtering measurements, and experimentation with self-organizing systems.

Determinations of pattern invariance under various transformations, computer simulation, and experiments with self-organizing systems are also used in recognition systems that depend on statistical analyses and randomly generated operators. In particular, computer programs designed to simulate pattern-learning are usually directed either to the determination of sets of defining features for classes of patterns or toward investigation of the results that may be achieved by testing a retinal field statistically. 2/ The latter is exemplified in neuron network simulation projects which use statistical techniques for the building up and reinforcing of explicit response behaviors in place of initially random connections.

Both the criterial and semantic and the random or statistical approach may be brought together, however, in research programs in pattern-recognition. Thus Uhr has made a series of investigations starting with a bias toward abstractive, criterial analysis techniques, based at least in part on a priori ideal properties of given characters and shape. He has more recently explored the possibilities of an adaptive, criterial analysis technique, based on a posteriori results derived from random concatenations of input pattern elements in a 'teaching', then 'recognizing', sequence. These later Uhr-Vossler adaptive methods are still abstractive in a processing sense as are those of Novikoff, for example, but they are so with respect to syntactic rather than necessarily semantic features. In other words, the criterial features that discriminate between the vocabulary characters of systems such as those of the Uhr-Vossler, Novikoff, Bledsoe-Browning, Alt for computer moments, and similar systems, are not necessarily recognizable as criterial by the human perceiver.

For both the random and the criterial approaches, then prospects for further progress in pattern recognition systems appear to lie in at least three areas of related basic research, defined by Gill as follows:

1/ Young, D. A. "Automatic character recognition", Ref. 539, p. 6: "Despite the large quantity of research work that is being undertaken, however, most of it is concentrated around problems of sensing, filtering, and high-speed sorting of scan data, and too little attention is being paid to the fundamental semantic features of character patterns."

2/ Compare Ref. 59, p. 5.

"(a) Deeper analysis of the redundancies inherent in the various classes of pattern sources,

(b) Formulation of procedures for determining optimal sets of transformations required for recognizing given sets of patterns,

(c) Simulation of learning processes with digital computers." 1/

We shall therefore consider briefly certain aspects of these areas of potentially related research in pattern recognition, including the areas of search for invariant features, search for criteria of pattern separability, possibilities for machine abstracting and automatic classification, and machine models of perception, recognition and pattern generalization.

8.1 The Search for Relative Invariance

In the character recognition systems that have been considered, we have noted certain attempts to provide for some measure of identification-criteria invariance, despite variability of source pattern presentations of the same character. For example, source-to-input pattern transformations in some systems allow some minor variability with respect to noise and minor differences of character style, such as serifs. Moreover, what we have called the 'criterial features' approach does include recognition principles which emphasize precisely those features that are relatively invariant for vocabularies including characters that may occur in different, but similar styles. Thus Rochester claims:

> "The subject character recognition mechanism looks for the basic features most invariant throughout the range of fonts. In an ideal system, these features should be completely independent of such features as the absolute size of the character, slant proportions and the presence of serifs. The criterion of the basic form of the character is its continued existence through all conceivable distortions of the character up until the point where a human observer becomes uncertain of the identity of an isolated specimen." 2/

Similarly, Greene has noted that most of the existing devices for reading written characters fall into that class of pattern recognition systems where the device is designed to respond to any one of a class of patterns in terms of the answers to questions that are built into the machine. He goes on to suggest that: "Designing these devices means finding a combination of stable and reproducible perceptual determinants that serves to discriminate just the class you are looking for." 3/

The choice of criteria to improve the recognition process for variable character forms has been variously based, as we have previously noted, on a priori or theoretical assumptions as to the characteristics most likely to be significant in a given vocabulary, or on empirical observation, machine simulation, and trial-and-error testing. 4/ Examples of the latter include Stone, 5/ Weeks, 6/ and Howard, 7/ among others. In the Russian type style study made at New York University, 8/ manual observations for different Russian fonts and for a wide range of defects and mutilations of any given character led to recognition of the need to establish "character-discriminating procedures based on essentially invariant gross aspects of characters". Some of the

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1/ Gill, A. "Pattern recognition", Ref. 159, p. 677.

2/ Rochester, N., et al. U.S. Patent 2,889,535, Ref. 388.

3/ Greene, P.H. "Networks for pattern recognition," Ref. 179, p. 1.

4/ Compare, for example, Minsky and Selfridge: "... patterns can often be defined by listing the properties which distinguish their exemplars from those of other patterns. In the important case of patterns whose definitions are not known in advance but for which examples are available, we can use experience to gather (statistical) evidence about the distribution of properties among the patterns." (Ref. 312, p. 5.)

5/ Stone, W.P. "Alpha-numeric character reader," Ref. 464.

6/ Weeks, R.W. "Rotating raster character recognition system," Ref. 528.

7/ Howard, P.H. "A computer method of generating recognition logics for printed characters," Ref. 221.

8/ Boni, C. "Russian type study," Ref. 55.

aspects suggested for this purpose in the Russian study were: measurements of the extent to which characters exceeded a constant-height band, total width, open or closed structure, symmetry as determined with respect to the optical center of gravity, compactness as determined by whether the optical center of gravity coincides with figure or with ground, and articulation as determined by effects of dissecting the character either at various levels or by a superimposed grid.

Since one of the major requirements for a discriminant or property is that it be: " ... invariant under the commonly encountered equivalence transformations," 1/ we also find the gathering of statistical evidence, especially by machine simulation, in this area. In recent work directed by Alt at the National Bureau of Standards, 2/ there has been an investigation of the extent to which quantized patterns are characterized by their moments. Certain combinations of these moments provide such information as relative distribution of black with respect to distance from center of gravity, symmetry about the x and y axes, and the like. Computer simulation has been used to determine combinations that, for a given vocabulary set, are invariant for input members of the set under transformations of location, size, stretching and squeezing, rotation to the extent of the slanting found in italic as versus Roman versions of the same character, some noise, and minor changes or embellishments such as serifs.

In the search for relative invariance among hand-drawn patterns (including handwritten characters, geometric shapes, line drawings, and the like), both the intuitive (a priori) and the heuristic (empirically determined, machine-tested, machine-generated) methods for property-selection have been used. 3/ Techniques that have already been mentioned include those of Doyle, 4/ Sherman, 5/ and Grimsdale, 6/ for example. A special combination of theoretical and empirical approaches to the search for invariant features is, however, involved in certain areas of pattern recognition research. That is, it is assumed on theoretical grounds that factors important in human or animal perception and pattern recognition may also be important in machine recognition.

The Himmelman and Chu work at RCA previously mentioned with respect to the machine idea of an "E", 7/ included detailed studies of human performance with systematically deteriorated character samples, with the determination of the relative importance of various critical areas in the identification of badly degraded characters, and with determination of what character stroke combinations are associatively clustered. Eden and Halle 8/ have discussed both the synthesis of cursive handwriting and its analysis, finding that 18 strokes appear to be discriminative for well-formed Latin scripts. Neisser and Weene 9/ have also studied human recognition performance, using the same handprinted upper case letters used in the Sherman machine experiments, to determine types of error, overall accuracy, and confusion data.

Others who have considered the factors in human perception as potentially applicable to machine recognition of patterns include Uhr and investigators at the System Development Corporation. Typical of conclusions reached are the following:

1/ See Minsky, M. "Steps toward artificial intelligence," Ref. 314, p. 13.

2/ A report on results by F. L. Alt, tentatively titled: "Digital pattern recognition by moments," is in process of preparation.

3/ Compare Gill, A. "Pattern recognition", as follows: "The program invariably involves a set of transformations performed on the unknown patterns, followed by a comparison of the transferred pattern with a precompiled library of reference patterns. ... Thus far, no universal procedure has been formulated for selecting a necessary or sufficient transformation set for a given pattern source; rather, each investigator uses intuitive or heuristic arguments to propose such a set for the specific source under investigation." (Ref. 159, p. 676.)

4/ Doyle, W. "Recognition of sloppy, hand-printed characters," Ref. 104.

5/ Sherman, H. "A quasi-topological method for machine recognition of line patterns." Ref. 421.

6/ Grimsdale, R. L. "Automatic pattern recognition, new morphological system using a digital computer," Ref. 184.

7/ Himmelman, D. S. and J. T. Chu. "Topological nature and logical properties of a computer-simulated alphanumeric recognition circuitry." Ref. 213.

8/ Eden, M. and M. Halle. "Characterization of cursive writing", Ref. 106.

9/ Neisser, U. and P. Weene. "A note on human recognition of handprinted characters", Ref. 326.

"Psychophysical and introspective data provide elements into which figures might be decomposed with maximal retention of important information. These elements are second degree curves, 8 lengths, 8 slopes, 5 curvatures, with differentiations along each of their dimensions. Humans make similar differentiations in absolute judgment experiments. These geometric elements, along with information about their interconnections, seem to contain all of the information that is usually elicited when someone is asked to give a complete, detailed description of a line pattern." 1/

"Consider lines of eight possible lengths, eight possible slopes and eight possible curvatures. This is, roughly, the capacity of the human perceiver when he makes absolute judgment. . . A program I am now coding will . . . follow line segments, while under the control of an assessing subroutine, until it has identified a complete element as one of this 9-bits worth of possible elements . . . It will identify the next element, store the relative location at which elements touch, and continue until it has completed the figure. These elements seem almost 'natural' ways of describing figures--especially man-made figures such as letters. For an example, an 'A' equals a vertical left and a vertical right touching at the top; with a horizontal line joining their middles . . .

The letters to be 'recognized' are stored in the computer's memory, along with their characterization lists--literally, what they look like." 2/

Investigations of factors in perception presumed to obtain in lower order animals, from the standpoint of machine simulation of pattern recognition include those of Loebner, who uses differencing between vertical and horizontal pairs to simulate the horizontal-vertical discrimination found in the eye of the frog, 3/ and Deutsch, who has proposed a shape recognition technique based, in effect, upon the projection of a contour upon an opposing one. 4/ Van Bergeijk and Harmon have recently built a model of a small neural net that is capable of identifying curved as opposed to straight lines. 5/ Kamentsky, with a photoelectric model of a retinal mosaic, develops methods for the identification of angles, endpoints, closed loops, and the like. 6/ Platt, however, suggests that straightness, curvature, equidistance, and similar primitive elements of visual pattern recognition arise not from direct operations on the pattern as received by the retina, but rather from the self-congruence of the sources of the pattern in the external world under the rotations which the spherical eyeball can perform. 7/

A different approach to the use of a priori or theoretical assumptions with respect to significant features of patterns that may provide criteria of relative invariance is provided in consideration of applicability of theoretical principles such as those of graph theory (Sherman, 8/ Garmash 9/), and integral geometry. Novikoff and others at the Stanford Research Institute have been investigating the applicability of theoretical principles of integral geometry to the problems of determining relatively invariant features of patterns. One of the techniques proposed as a result of these studies involves, for example, the construction of reference patterns or master identification formulas by detecting the most probable intersections of samples of the characters to be included in the

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1/ System Development Corporation. "Research Directorate quarterly report, no. I." Ref. 469, p. 45.

2/ Uhr, Leonard. "Intelligence in computers: the psychology of perception in people and in machines", Ref. 494, p. 180.

3/ Loebner, E. E. "Image processing and functional retina synthesis," Ref. 216.

4/ Deutsch, J. A. "A theory of shape recognition," Ref. 91.

5/ Van Bergeijk, W. A., and L. D. Harmon. "What good are artificial neurons?" Ref. 516, see also Uhr, L. " 'Pattern recognition' computers as models for form perception", Ref. 496.

6/ Kamentsky, L. A. "Pattern and character recognition systems; picture processing by nets of neuron-like elements." Ref. 244.

7/ Platt, J. R. "Functional geometry and the determination of pattern in mosaic receptors," Ref. 358, also Ref. 359.

8/ Sherman, H. "A quasi-topological method for the recognition of line patterns," Ref. 421.

9/ Garmash, V. A. V. S. Pereverzev, and V. M. Tsirlin. "Quasitopological method of letter recognition," Ref. 155.

vocabulary with one or more randomly tossed reference pattern elements. [1]

In several of the contour-following or curve-tracing proposals that we have previously mentioned, [2] there has been an emphasis on the search for relatively invariant features and an assumption that properties such as curves and slopes are reasonably stable under transformations of size and location. Weiss and Johnson in a recent patent assigned to IBM for a 'form recognition' system, claim the following:

> "In the system of the present invention the registration problem is essentially eliminated by basing the comparison and recognition not upon geometrical coordinate information concerning the unknown curve or shape as such, but rather by basing it upon a comparison of computed values of the curve which are invariant, or at least semi-invariant, with respect to transformations of translation, rotation and magnification. For the purposes of this application, a property of the curve will be said to be invariant with respect to a given transformation or set of transformations when the property has a value which varies with a point traversing the curve but which, for a given point on the curve, does not change when the curve is mapped on another curve by any succession of applications of the transformation or transformations with which the property is invariant. Similarly a property of the curve is said to be semi-invariant with respect to a given transformation when it has a value which changes by at most a constant additive term when the curve is mapped on another curve by any succession of applications of transformations with respect to which the property is semi-invariant. Furthermore, it can be shown that the functional relationship between any two invariant properties characterizes the whole class of plane curves which can be mapped onto one another by a succession of applications of the transformations with respect to which the properties are invariant." [3]

Weiss and Johnson provide a computing means to derive the values for an unknown curve for a comparison with standard values for known curves or shapes.

Computer simulation has been used not only to arrive at invariant properties in curve-tracing techniques for recognition of line drawings but also to test such systems. Haller, in a 704 simulation program, [4] provides for a tracing head which traverses successive small areas of attention along the contour lines of a quantized pattern. This tracing head can be oriented in any one of eight directions and it follows the line along a given direction as long as possible. However, the head may explore for short distances at right angles to this direction, following small fluctuations and avoiding minor gaps which may be caused by noise. The input pattern elements are, in effect, the beginning and end points of the runs occurring with the tracing head in a single orientation and indication of whether or not the run was terminated by an end of the line. Thus, this is a reductive curve-tracing input technique, and it is followed by a decision-tree program for recognition-identification.

Two other proposed computer programs for search of relatively invariant properties by curve-tracing techniques make use of list-processing languages, Hodes with Lisp, [5] and Shepard with IPL-V. [6] Hodes summarizes his studies as follows:

> "A method for mechanically processing line drawings is being programmed. The process begins with a pattern that takes the form of marked points in a 100x100 square array. First the pattern is converted to a readily usable form by a line-follower program, which collects information about the lines and vertices and prints out a list-structure description of the pattern. The original input pattern is then discarded, as LISP programs process the list-structure description. LISP programs which have been written include one to tell whether two patterns are the same under renumbering of vertices and one for regaining simple components of overlapping patterns." [7]

Shepard similarly uses an initial 100x100 matrix and derives a list-structure description. In the Shepard description, lines through various small overlapping subregions are noted and their local

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1/ Novikoff, A. B. J. "Integral geometry as a tool in pattern perception." Ref. 340; see also Refs. 58, 59, 305, 341.

2/ See pp. 53-55 of this report.

3/ Weiss, P. and C. W. Johnson. U.S. Patent 2,968,789, Ref. 529.

4/ Haller, N. M. "Line tracing for character recognition,"

5/ Hodes, L. "Machine processing of line drawings," Ref. 215.

6/ Shepard, R. N. "Application of IPL:V to the simulation of perceptual learning," Ref. 420.

7/ Hodes, L. "Recognition of outline figures", Ref. 216, pp. 35-36.

slopes, lengths of arc, and whether there are end-points, branch-points, or direction-changes (corners) are recorded. The sublists constructed in this way are connected together in order to preserve the topological structure of the original pattern. Various property-extraction routines are then applied to the list-structure representation, yielding a series of yes-no indications for a given stimulus pattern. Finally, the program is intended to display certain "learning" mechanisms. These are described as follows:

> "At the heart of this program is a list of the names of the property-extractor subroutines... Associated with the name of each property extractor on this list are two other things: The first is a weight that determines the probability of application of that property extractor (via the stochastic selection operation J-16 of IPL-V). The second is a sublist of responses that the learning program has found to be associated with that property together with weights that the learning program attaches to the responses so as to reflect the frequency of those associations." 1/

Techniques designed to search for relatively invariant features are thus often intended to combine theoretical assumptions with subsequent empirical observations, followed by readjustments and modifications, such that, for a large number of samples, a type of 'learning' may be said to occur. We shall discuss other examples where a degree of learning is claimed in terms of machine models of perception, recognition, and pattern generalization. We note, however, that an important distinction can be made with respect to the hypothesis that criterial features or characteristics significant for discrimination can be isolated by essentially random operations upon learning samples (Rosenblatt, 2/ Bledsoe-Browning, 3/ Novikoff, 4/ and others), as against the hypothesis that the significant features reflect semantic-dependency with respect to specific recognizable patterns (Barus in contrast to the Perceptron techniques; 5/ Unger; 6/ Kamentsky; 7/ Uhr; 8/ Kelly-Singer, 9/ etc.). In particular, there is in the one case a breaking-up or disregarding of connectivity and other characteristics of interdependence of pattern elements, and on the other an emphasis, at least in part, on precisely such interdependence.

With respect to the latter case, Kamentsky has defined the technique which he terms 'feature matching' as follows:

> "The individual elements on many patterns... are <u>not independent</u>, since recognizable patterns contain constraints on form. Parts of patterns can be classified in terms of independent groups of elements... Some of these groups include the geometrical parameters, straight, curved, closed or open, and breaks or corners. These may be independent of absolute position, size, noise, and some changes of form. We shall call these 'features of the pattern'. Recognition of patterns is possible if a sufficient set of relevant features can be extracted from the signal field." 10/

1/ Shepard, R. N. "Application of IPL:V to the simulation of perceptual learning." Ref. 420, p. 4.

2/ Rosenblatt, F. "The Perceptron: a perceiving and recognizing automaton (Project PARA)," Ref. 393.

3/ Bledsoe, W. W. and I. Browning. "Pattern recognition and reading by machine," Ref. 51.

4/ Novikoff, A. B. J. "Statistical properties of geometric figures invariant under translation and rotation." Ref. 341.

5/ Barus, C. "Machine learning and pattern recognition; a progress report on 'A study of learning machine' ", Ref. 39, and "Pattern recognition by statistical overlap", Ref. 40.

6/ Unger, S.H. "Pattern detection and recognition", Ref. 501.

7/ Kamentsky, L. A. "Pattern and character recognition systems...", Ref. 244.

8/ Uhr, L. "Machine perception of forms by means of assessment and recognition of Gestalts", Ref. 495.

9/ Kelly, P. M. and J. R. Singer. "Bio-computer design...", Ref. 253.

10/ Kamentsky, L. A. "Pattern and character recognition systems; picture processing by nets of neuron-like elements", Ref. 244, p. 305.

Derivation of such 'relevant' features by means of machine measurement of samples and subsequent tests of identification has, as we have noted, been investigated by Selfridge, Dinneen, Farley, and Clark, at M.I.T., 1/ by Grimsdale et al at the University of Manchester, 2/ and by Unger and others with respect to machine models or spatial computers. 3/ Uhr has recently reviewed a number of such techniques. 4/

Minsky, considering the case of visual pattern recognition with respect to the more general area of so-called 'artificial intelligence', has grouped together both interdependent and independent feature possibilities in a listing of the operations and transformations that may be useful in the search for relative invariance for various interesting sets of patterns. 5/ These he classifies as: local transformations, including local averaging, edging, and recognition of particular local configuration or feature extraction; global or holistic transformations, including translation, rotation, expansion, contraction, filling in of hollow figures, location of optical center of gravity, and operations to determine connectivity; and "functionals", or operations that count or encode, such as 'blob' counters, moment of figure with respect to a given point, slope of line, distance between two points; and other transformations such as projections onto a line or axis, or the mapping of a pattern perimeter along some reference axis. The search for relative invariance includes investigation of area-preserving transformations, shape-preserving transformations, image enhancement, contour projection, contour-direction sequences, and selection of criterial features.

Thus we find a variety of research approaches to problems of relative invariance in the pattern recognition field, many of which may provide useful cues for further progress in the development of general-purpose character recognition techniques.

8.2 The Search for Pattern Separability

The search for relative invariance of character patterns in terms of significant, relevant, and interdependent features provides one basis for separating patterns into classes or categories, which is the requirement for pattern detection in contradistinction to recognition as one of a finite number of known pattern-types, as we have previously noted. This is, in effect, a criterion for pattern separability using 'Gestalt'-type principles. In addition, however, research efforts in pattern recognition which may be applicable to future improvements in automatic character recognition systems include investigations of linear separability, probabilistic separability, and statistical separability.

The question of linear separability is in the first and most obvious sense related to the consideration of the Boolean functions of n-variables, which are the black-white determinations per cell of a grid superimposed on the source pattern. For example, Stearns states that the general problem of pattern recognition is to be regarded as: "A problem wherein the recognition device is presented with a plane array of black-or-white elements and must decide to which general class (pattern) this array belongs." 6/ Various techniques for the minimization of decision paths with respect to two-valued coordinate descriptions, including those of Glovazky, 7/ Gill, 8/ Blokh, 9/ and Howard, 10/ are related to the problem of linear separability.

1/ Selfridge, O.G. "Pattern recognition and modern computers." Ref. 409; Dinneen, G.P., "Programming pattern recognition", Ref. 100. Farley, B.G. and W.A. Clark. "Activity in networks of neuron-like elements." Ref. 129.

2/ Grimsdale, R.L., F.H. Sumner, C.J. Tunis, and T. Kilburn. "A system for the automatic recognition of patterns". Ref. 185.

3/ Unger, S.H. "A computer oriented toward spatial problems", Ref. 500.

4/ Uhr, Leonard. " 'Pattern recognition' computers as models for form perception." Ref. 496.

5/ Minsky, M.L. "Heuristic aspects of the artificial intelligence problem", Ref. 311.

6/ Stearns, S.D. "A method for the design of pattern recognition logic", Ref. 451, p. 48.

7/ Glovazky, A. "Determination of redundancies in a set of patterns", Ref. 166. Note also that Lowenschoss, O. in "A comment on pattern redundancy", Ref. 279, suggests improvements over Glovazky's technique for finding minimum separation paths.

8/ Gill, A. "Minimum-scan pattern recognition", Ref. 157.

9/ Blokh, E.L. "The question of the minimum description", Ref. 53.

10/ Howard, P.H. "A computer method of generating recognition logics for printed characters." Ref. 221.

A concept involving the representation of the space of possible patterns as a binary n-cube in n-space, with each vertex of the cube defining a specific combination of n binary variables, and the use of hyperplanes as partitioning surfaces to achieve pattern separation, has been explored by Mattson. 1/ Kirsch, 2/ in a discussion of Mattson's 1959 paper, assumes that the criterion of linear separability is to be applied in the case of reference patterns that are the direct binary quantizations at the input level of a coordinate description of a source pattern. More generally, and more significantly, however, the Mattson proposals are applicable to any binary representation of characteristics of patterns, specifically including the case where this is a two-valued (yes-no) property list score.

As we have observed previously, criterial features extraction techniques often result in a form of property list and thus may be encoded either in a binary code indicating the presence or absence for a given pattern of each of the properties considered or in a code statement indicating a particular value or range of values as detected for each property. In this sense, the criterial features techniques involve 'linear statistical classification', defined by Laemmel as follows:

> "It is desired to tell which of K classes an individual belongs to. The classification is to be based on the results of n tests or measurements which are made on the unknown individual. The method of classification...is called 'linear' because the results of the separate tests are combined in a linear way, and 'statistical' because the result of the classification is usually known to be correct only with some probability less than one." 3/

Results of applying tests for various character features in character recognition techniques such as those of Weeks, Doyle, and Grimsdale et al, are probabilistic in this sense and thus provide examples of application of linear statistical classification techniques. Weeks, for example, claims the following:

> "First a number of statistical properties of the character to be recognized are studied and tested. An example...is a determination of the number of crossings encountered when the light beam moves across the character in a particular direction and position... The probability of occurrence of different numbers of crossings by a particular scan line can be measured by testing a large number of characters and determining the fractional occurrence of the number of crossings for each character." 4/

In the Grimsdale, et al, techniques, properties to be used are again determined by tests on many samples, and, when an unknown is thereafter tested the method results either in identification or, if there is ambiguity, in printout of the probability scores of the several characters the source pattern may represent. 5/

Criteria for probabilistic separability in addition to those cases where interrelationships betwen properties or features are assumed include those where the results of tests or measurements are assumed to be independent, as in the technique for finding optimum sets of such tests described by Howard. 6/ Closely related are differential weightings allowed in some of the coordinate description techniques, such as that of Taylor. 7/ Weightings of single cells, in terms of conditional probabilities determined by experience with samples, was apparently first suggested by Uttley 8/ and one of his conditional

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1/ Mattson, R. L. "A self-organizing binary system", Ref. 299; also "An approach to pattern recognition using linear threshold devices, Ref. 297.

2/ Kirsch, R.A. in Ref. 49.

3/ Laemmel, A. "Linear statistical classification", Ref. 265, p. 1.

4/ Weeks, R.W. "Rotating raster character recognition system", Ref. 528, p. 1.

5/ Grimsdale, R.L., F.H. Sumner, C.J. Tunis, and T. Kilburn. "A system for the automatic recognition of patterns", Ref. 185.

6/ Howard, P.H. "A computer method of generating recognition logics for printed characters", Ref. 221.

7/ See Taylor, W.K., Refs. 478-482.

8/ See Uttley, A.M., Refs. 510-515.

probability machine models, demonstrated at the Teddington Symposium on the Mechanization of Thought Processes in 1958, successfully recognized "T" shapes. Related work ranging through pattern recognition research to practical suggestions for character recognition has also included that of Highleyman and Kamentsky, 1/ Stearns, 2/ and Baran and Estrin. 3/

Highleyman and Kamentsky have re-investigated the Bledsoe-Browning technique of point-pair n-tuple probabilistic sampling with considerably less success than was reported by the original investigators. On the other hand, Highleyman has recently been awarded a patent, assigned to Bell Telephone Laboratories, in which probability matrices are used in conjunction with weighted area scanning methods. A representative claim is as follows:

> " . . . Apparatus for classifying fine trace patterns comprising a record containing a line trace pattern, scanning means for detecting those portions of said pattern that occupy preselected portions of a matrix of areas that encompass said pattern, means for storing a plurality of probability matrices, the individual areas of each of said probability matrices being suitably weighted in accordance with the occupancy probability of that area by a pattern from a selected ensemble of patterns, means for systematically comparing said detected pattern portions with corresponding areas of all of said probability matrices, means for developing a signal whose magnitude is proportional to the degree of correlation between said portions and each of said stored matrices." 4/

Stearns has achieved recognition of typewritten numerals, to an accuracy of 99%, by statistical analysis of a large number of representative samples to determine probabilities of black, white, and gray (ambiguous) for each cell, to which a probabilistic decision-tree logic can then be applied. 5/ Baran and Estrin have worked with deteriorated numeric characters, in a "learning" -type system, in which they also determine the probabilities of black in each cell for a large number of samples of each possible pattern. They report further:

> " . . . first, the a priori probability distribution of each black and white cell for each of the possible characters is computed. Next, a set of hypotheses is established that the unknown character is each of the possible characters of the allowable set.
>
> "The a posteriori probability of each of these hypotheses being true is tested with Bayes' formula, using the data from each cell position as a separate measurement." 6/

Similarly, Chow has studied techniques for pattern separability directed toward minimization of pattern redundancy and toward a basis for decision-making that is probabilistic and that minimizes risks of misrecognition. 7/ Chow's work has been characterized as follows: "The problem is regarded as one of testing multiple hypotheses in statistical inference, that is, testing the hypothesis that the observed pattern is indeed the given character against the hypothesis that it is not." 8/

In investigations at United Research, 9/ mathematical analyses for the 'decoding' aspect of character recognition systems - that is, recognition-matching and identification-decision operations -

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1/ Highleyman, W.H., and L. A. Kamentsky. "Comments on a character recognition method of Bledsoe and Browning", Ref. 209.

2/ Stearns, S.D. "A method for the design of pattern recognition logic", Ref. 451.

3/ Baran, P., and G. Estrin. "An adaptive character reader", Ref. 34; "An aided adaptive character reader for machine translation of languages", Ref. 35; "A digital simulation of an aided adaptive character reading machine", Ref. 36.

4/ Highleyman, W.H. U.S. Patent 2,978,675, Ref. 208.

5/ Stearns, S.D. "A method for the design of pattern recognition logic", Ref. 451.

6/ Baran, P. and G. Estrin. "An adaptive character reader", Ref. 34.

7/ Chow, C.K. "An optimum character recognition system using decision functions", Ref. 74.

8/ Hawkins, J.K. "Self-organizing systems - a review and commentary", Ref. 201.

9/ See "Mathematical techniques for identifying certain stochastic binary patterns", Ref. 502.

have been explored. 'Expectation matrices' for each character in the vocabulary set are to be established on the basis of sampling such that the probability of a given cell being black, given that the source pattern is a member of the Rth character-class in the vocabulary, is determined. These results are to be mapped onto a line, and a scalar score developed, such that non-overlapping intervals along the line can be used to identify unknown characters. The research problem involves the weights that can be found to satisfy the expected value of the score, given that the source pattern is the Rth character in the vocabulary set, and to avoid purely intuitive arbitrary choices of tests to be made on source patterns. This research is therefore clearly directed to the question of probabilistic pattern-class separability, under conditions involving a varying degree of noise. 1/ The initial research investigations make the assumption that all R characters of a given vocabulary set are equiprobable and that the costs of error, for any character in the set, are equally important. Possible implications for future research, however, include first, extension of linear sum weighting schemes, or vector multiplications, to the use of more general matrix operations. On the other hand, the proposals suggest that the determination of reliability measures might also include considerations of relative frequency of character occurrence and of relative risk-cost associated with specific possible misrecognitions. Weightings based on white as well as on black areas, and the elimination of areas that are always black or always white, regardless of which character is presented, are also considered.

Many of the pattern recognition techniques using independent measures of probabilistic separability have been criticized in the literature on various grounds. First, it is pointed out that highly reductive, but random-operator, techniques such as the 75-point-pair logic of Bledsoe and Browning, are often severely limited as to the number of patterns they can successfully distinguish, even without allowing for invariance under commonly encountered transformations. Difficulties have been met by other investigators in trying to replicate the original results. 2/ Bailey, for example, has remarked that every possible point-pairing is necessarily more powerful than that of Bledsoe-Browning, since it includes all random-pair configurations and must therefore do at least as well as any of them. He says:

> "While many examples may be submitted to demonstrate the effectiveness of a system, yet if one reasonable example can be shown for which a system fails, the validity of the technique becomes subject to question. The essence of these remarks is that for many paired-point configurations, negative examples may be found. In these cases, the point-paired principles must be less effective than a simpler technique, such as point-by-point comparison." 3/

A second point of cricism against many of these techniques is that of the neglect of the special relationships or the criterial features that occur at adjacent points in the image field. In a survey of pattern recognition research conducted by Stanford Research Institute, it was concluded that since patterns are generally made up of connected points in the field, schemes which do not make use of adjacency relationships tend to lose in recognition efficiency. Techniques considered by the S. R. I. to fall in this category included Bledsoe-Browning, Baran-Estrin, Highleyman-Kamentsky, Stearns, and Novikoff. 4/

Closely related to the question of neglect of the interdependence of features in many patterns is the criticism of the use of independent measures on theoretical grounds. Thus both Minsky and Hawkins suggest the need for considering joint conditional probabilities and point out the restrictive nature of assumptions of statistical independence in systems using probabilistic tests. 5/

The criterion for pattern separation that has been termed 'statistical separability', however, not only assumes the independence of specific character features but also emphasizes the introduction of strictly random elements in the organization of the system. This approach has been most

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1/ Up to an 'upper bound' of probabilistic distribution variance: namely, the assumption that cells, given that the source pattern was a particular Rth character, have an equally likely probability of being either black or white.

2/ See Refs. 209, 498.

3/ Bailey, J. M., Jr. "Point-pair reading logic," Ref. 32, p. 2033. We note, however, that the suggested alternative involves the disadvantages of the enormous number of reference patterns required, discussed in connection with coordinate description techniques.

4/ Brain, A. E., A. Macovski, et al. "Graphical data-processing research study and experimental investigation," Ref. 59.

5/ Minsky, M. L. "Steps toward artificial intelligence," Ref. 314, and Hawkins, J. K. "Self-organizing systems - a review and commentary", Ref. 201.

extensively used in the simple Perceptron systems. In the simple, or alpha-type, Perceptron, there is first an array of sensory units, simulating a retinal mosaic. Each sensory-unit is randomly connected to cells in another array, that is, to 'association' or 'A-units'. Each A-Unit, in turn, is randomly connected to a 'response' or R-unit. As the Perceptron is shown various examples of a pattern, A-units that have resulted in a 'correct' response are reinforced, increasing the likelihood that the correct response will become more and more consistently activated for additional samples of the same pattern.

The importance of the statistical, or random, organizational principle for single perceptrons has been described by Rosenblatt as follows:

> "It should be noted that for any given perceptron, regardless of which table of random numbers was used in its construction, it would be possible in principle to write a complete McCullough-Pitts logical equation, describing the set of all possible states of the system as a logical function of the set of all possible inputs ... The fact is, that the logical specification equation is a particularly idiosyncratic function of the specific network and is apt to be totally different for two networks having identical performance characteristics... Nonetheless (if the systems are large enough) those functional characteristics which we are most concerned with, such as the ability correctly to discriminate a particular pair of forms would be found to vary little, so long as the statistical rules remain unchanged. It appears, therefore, that the statistical rules come closer to a canonical specification of what is most important for the system to operate properly. The number of logical specifications which fit the bill is astronomical, and for the most part these constitute interchangeable variations on a theme; but any violation of the statistical structure of a perceptron is likely to radically alter the performance of the system." 1/

A more sophisticated type of Perceptron will be discussed briefly in connection with mention of research on machine models of perception.

8.3 Automatic Classification of Patterns

Techniques for discovery of relatively invariant features of patterns and for determination of effective procedures for separating patterns may provide useful clues for improvements in character recognition systems. They may or may not, however, involve the kind of generalization that is assumed to be involved in human perception and pattern detection. Thus, a distinction that has been made with respect to human or animal perception and recognition involves "discriminative skill" on the one hand, and "discriminative matching" on the other. In defining this distinction, Bruner et al, 2/ include under "skill" such operations as abstracting relevant from irrelevant stimulus details, comparable to criterial features extraction, and overcoming distraction, such as is involved in image enhancement and weighting operations. Under the term "discriminative matching" they include not only the processes of sorting into categories but also those of learning what categories to use.

With respect to the similar processes in pattern recognition by machine, Kelly stresses the following points, among others:

> "Webster's dictionary defines recognize as meaning to know again, implying that the cognitive mechanisms has seen the object before and learned to know it. The related process of classifying objects which have never been previously observed is covered by the topic of generalization....
>
> "A recognition device which is restricted in the world of patterns to which it is exposed and reliably classifies all members of that world into their proper groups has not the flexibility that is associated with bionics. For such flexibility the recognition scheme should include provisions for generalization and/or abstraction. To generalize, is defined as meaning to derive or induce from particulars. It is required that the bio-computer, after having learned to classify a set of members of its world of patterns, be sufficiently flexible in design that it will then be able to classify all possible members of that world with some reasonable probability that patterns similar in the features to which the sensory field is sensitive will be classified in the same group." 9/

1/ Rosenblatt, F. "Perceptual generalization over transformation groups", Ref. 397, pp. 67-68.

2/ Bruner, J.S., G.A. Miller and O. Zimmerman. "Discriminative skill and discriminative matching in perceptual recognition", Ref. 64.

3/ Kelly, P.M. "Problems in bio-computer design", Ref. 252, pp. I-1, I-9.

In considering progress in the field of character recognition and related research, therefore, it is not surprising to find techniques and proposals for automatic classification of patterns ranging from those which involve no generalization at all, through those which involve generalization only to a limited degree, to those which attempt to provide for machine acquisition of suitable classification categories and for subsequent modification. In the first category are the various template techniques. Systems or techniques that utilize a limited degree of apparent 'generalization' include those that select the particular tests or criterial features which effectively discriminate among the members of a particular vocabulary.

In the recent Stanford Research survey of pattern recognition techniques certain distinctions between possibilities for automatic pattern classification involving various degrees of 'generalization' are brought out in a discussion of so-called 'learning' systems. Thus:

> "In the 'learning machine' type of program, the reference information against which the incoming retinal data is compared, is developed by correlating, and superimposing in storage, signals derived from a series of typical patterns. The operator identifies each pattern as it arrives during the learning cycle, and controls the information that is stored. The equivalent of a template is prepared against which the incoming retinal field is matched; the excellence of the match is a function of the homogeneity of the information presented during the learning cycle, and of the correlation between the particular pattern under examination and the stored data. Variations of size are likely to be highly significant.... By dividing the retinal information into several channels at each data point, it is possible for the machine to learn a particular pattern in several orientations or positions, but in many schemes it is necessary for the machine to learn every pattern in every orientation. It does not transfer to other patterns the transformations it has 'learned' for a specific pattern - it has not learned the transformation. This is really the fundamental difference between template matching and learning, and it would be desirable to restrict the use of the term learning machine to a system that generates an internal structure which can transfer to new patterns the facility it acquired with respect to a previous pattern." 1/

- That is, to the potentialities for automatic classification or generalization of patterns, based upon adjustments and modifications derived from sequential experience with a variety of samples of each pattern class.

In addition to this distinction, we should first note that considerable emphasis has been placed on self-organizing principles in the development of models of "learning" processes regardless of the degree of generalization achieved. 2/ Simultaneously we note that, on the other hand, studies of general techniques of automatic classification (Baum, 2/ Laemmel, 3/ McLachen. 4/ Mattson, 5/ Sebestyn, 6/ and others are in order. Thus, more generalized studies of methods for determining appropriate membership in classes, given that 'class' definitions have been derived from the property-vectors of the samples of the class, are obviously pertinent to further progress in this area of pattern recognition research. Sebestyn, in particular, has experimentally demonstrated automatic recognition of membership in pattern classes whose definitions are derived from machine observations of representative samples, for the case of spoken numerals.

On the other hand, problems of relative weighting of input pattern elements, dependent on sequential-experience histories, involved in some adaptive systems for pattern-classification, are sometimes simplified for purposes of facilitating mathematical analysis. A consideration of adaptive switching circuits, by Widrow and Hoff, has been considered to be of this type. By comparison with the Taylor, Rosenblatt, Farley-Clark, Roberts, and related systems, Farley considers the Widrow-Hoff proposals to represent an essentially simpler system. In a review of the Widrow-Hoff paper, he comments, in part, as follows:

1/ Brain, A.E., A. Macovski, et al. "Graphical data processing research study and experimental investigation", Ref. 59, p. 8-9.

2/ See Baum, W.R., and S. Goldman. "Multidimensional information theory", Ref. 42.

3/ Laemmel, A. "Linear statistical classification", Ref. 265.

4/ McLachen, D., Jr. "Description mechanics", Ref. 286.

5/ Mattson, R.L. "The design and analysis of an adaptive system for statistical classification", Ref. 297.

6/ Sebestyn, G.S. "Recognition of membership in classes," Ref. 406.

"... Several systems make use ... of combinations of nonlinear threshold-elements each of which has a number of inputs whose effectiveness or 'weights' are adjustable. If an input mosaic is suitably connected to elements of this type and appropriate rules are used to adjust the weights while presenting sequential 'experience' in the form of examples of inputs and their desired classification, it has been found that the weight parameters can converge on values which will effect the desired classification more or less closely ...

"In the present paper ... by Widrow and Hoff ... a simpler system is considered in which each mosaic point connects through its own individual adjustable weight to a single time-invariant threshold-element. This simplified system is more amenable to analysis, and the authors show that the problem of finding suitable weights in this system involves searching for the minimum of a multidimensional parabolic surface... This and .... other systems .... exhibit the 'overlap' generalization in which two sets tend to be 'similar' if they have elements in common." 1/

A special case of very limited generalization is provided in methods such as used in an early Clark and Farley model 2/ and in the simple Perceptrons. This has been termed 'contiguity' or 'preponderance' generalization 3/ and requires that the pattern to which generalization is to be applied must share a number of retinal cells in common with patterns that have been previously classified in the desired response category. That is, the method relies on the fact that minor displacements, shape variations, or modifications due to noise may still result in an input pattern which shares most of its elements with a prototype pattern. In effect, a statistical overlap or border-zone template is thus provided, to which an exact fit is not required, but for which a best-match is obtained. In addition to the Clark and Farley and Rosenblatt experiments with this type of approach, Barus 4/ has investigated statistical separability criteria in which, say the contour of a new circle is found to approximate more closely to the family of contours of previously seen circles than it does to those of previously identified squares.

In the University of Manchester computer studies of character recognition techniques, the effects of a limited generalization are achieved not only by screening of suitable property tests, noise-elimination operations, and grouping of interrelated properties, but also by use of automatic classification principles in the recognition-identification decision processes. The system is described, in part, as follows:

"The result of the scan is to produce descriptions of segments of the figure, i.e., divisions which are conveniently produced by the scanning process... The scanning process also includes measures to allow for figure imperfections, dirt on the paper, and other forms of 'noise'.

"In the 'assembly' part of the programme which follows, the segments of the figure obtained in the scan are analysed and connected wherever appropriate, into true figure parts: a description is given of the length and slope of straight-line parts and the length and curvature of curved portions. The scan and assembly sections of the programme together produce the 'statement', which gives a complete description of the figure. This description is independent of the orientation and size of the figure, the lengths of the various parts being given relative to one another. It is, in effect, a coded representation of the pattern. It may be regarded as a one-dimensional pattern which consists of symbols chosen from a restricted range ... "In the 'recognition' section which follows, a comparison is made between the one-dimensional pattern or statement describing the unknown pattern and the statements already stored within the computer, together with the names of the patterns they describe. A considerable time would be wasted if every stored statement had to be examined; to prevent this, an automatic classification system is provided; this examines the stored statements and arranges them into classes according to common features." 5/

1/ Ref. 534, review by B. G. Farley, p. 107.

2/ Clark, W.A. and B.G. Farley. "Generalization of pattern recognition in a self-organizing system," Ref. 76.

3/ Rosenblatt, F. "Perceptual generalization over transformation groups." Ref. 397.

4/ Barus, Carl. "Machine learning and pattern recognition; a progress report on 'A study of learning machine'." Ref. 39; "Pattern recognition by statistical overlap", Ref. 40.

5/ Grimsdale, R.L., F.H. Sumner, C.J. Tunis, and T. Kilburn. "A system for the automatic recognition of patterns", Ref. 185, p. 211.

In the area of basic or long-range pattern recognition research, Farley has discussed some of the possibilities for generalization and automatic classification more nearly akin to what may be called 'learned perception'. 1/ He considers first the simpler examples of generalization by ignoring differences, as in border-zone or overlap situations, and by storing results of tests and measurements on properties of large numbers of representative specimens of a particular class. Next, he considers rules for compiling and grouping sets of properties, such as properties which frequently co-occur spatially or which are related in a temporal sequence. To the property-grouping rules derived from frequency of occurrence, contiguity, and the like, may be added results of certain key decision-properties, including a 'name' that has been repetitively associated with a property-class.

If the various property classes are intercompared, various subgroups of properties or property-measurement values might be identified which are common to many input patterns. In this way, for example, a new property or 'concept' might be developed, such as that of the idea of a triangle, with three straight line-segments joined at three corners. Finally, Farley suggests that where cases occur of source patterns having many input properties which, in combination, give a strong correlation with some property class, the system might 'lock on' to that class even although some of the properties or some of the property values might be in conflict with that class. "As a result", Farley states, "A percept would have been attained which did not altogether correspond with the real sensory stimulus." 2/

8.4 Machine Models of Perception, Recognition, and Pattern Generalization

Various aspects of pattern recognition research are involved to a greater or lesser extent in proposed machine models which simulate perception and pattern recognition, or generalization, abstraction, and pattern detection. Early suggestions developed by Pitts and McCullough 3/ related to a model that would provide relative invariance with respect to size. Schade has developed an analog of the eye in which photoelectronic simulation of scanning and sensing is used, 4/ and suggestions of Hebb 5/ have been explored with respect to simulated neural networks, especially those which utilize random connections in self-organizing operations. Machine models capable of demonstrating a type of 'conditioned reflex' behavior have been investigated by Uttley 6/ and more recently by Steinbuch and associates at the Technische Hochschule, Karlsruhe. 7/

Machine models that involve some degree of "learning", by virtue of continuing adjustment to new combinations or new probabilities of occurrence of specific examples, especially with regard

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1/ Farley, B.G. "Self-organizing models for learned perceptron", Ref. 131.

2/ Farley, B.G. "Self-organizing models for learned perception." Ref. 131, p. 20.

3/ Pitts, W., and W. S. McCullough. "How we know universals," Ref. 357.

4/ Schade, O.H., Sr. "Optical and photoelectric analog of the eye," Ref. 402.

5/ Hebb, D.O. "The organization of behavior, " Ref. 206.

6/ Uttley, A.M., Refs. 510-515.

7/ Steinbuch, K., Refs. 452-460. See also, for example, Auerbach, who reports: "The Karlsruhe group has devoted much study to the philosophy of learning machines... One approach to the conditioned reflex problem uses the multistep characteristic of ferrite cores in a matrix, with the sensors connected to one axis and the reactors to the other. By repeatedly exposing the sensors to the situation, a conditioned reflex is built up so that, when the reactors are interrogated, a learning-type reaction is obtained." Ref. 21, p. 334.

to prechosen criterial features or methods involving overlap-generalization, have been mentioned.[1] In addition to the machine models which have been previously cited, such as those of Harmon, Clark and Farley, Loebner, the alpha-type perceptrons of Rosenblatt, etc., current progress in this area of research that is potentially applicable to problems of automatic character recognition may be exemplified by the work of Estavan, Roberts, Singer, Rosenblatt with respect to more sophisticated type of perceptrons, Barus, and Uhr-Vossler, as well as by the so-called "spatial computer" models.

The Estavan learning-machine model, a program which can be simulated on the IBM 709 computer, involves first a quantized pattern-input-matrix, scanned in sequential order from left to right and the bottom to the top. The behavior of the model, is based initially on a simple S → R learning paradigm. However, search for critical features and for interrelationships between these features is provided. Moreover it is claimed that:

> "The program may be given some hypotheses, that is, it may be given means for choosing responses on bases other than habit strengths increased or decreased by fixed amounts. For example, it may be written with the ready-made hypothesis that similar sense patterns call for similar behaviors." [2]

In the Roberts experiments at the Lincoln Laboratory, M.I.T., models of adaptive networks were investigated with respect to recognition of the same handprinted characters used in the Sherman tests of the quasi-topological method for character recognition.[3] For discrimination between two pattern types, a network of 2,048 cells (simulated on a digital computer) was divided into two groups. Each cell, being connected randomly to eight input bits, had a weight preassigned, and reinforcements were applied to weights of cells in the correct response set for each trial. After normalization with respect to center of gravity of the input characters, two character patterns could be distinguished with 95% accuracy after 20 trials, and after 100 trials the model was able to accommodate rotations and systematic distortions. For six character-pattern categories, a reinforcement procedure was utilized that modified the random connections between the cells as well as cell weights, and that facilitated a search for 'good' connections.

Further investigations have resulted in models in which connections are not random, but in which the input pattern elements to a single cell represent a specific local operation on a character. In these later models various reward-reinforcement functions have been studied. Roberts concludes that it is possible to recognize the characters of a complete alphabet with an accuracy of 94%, after a training period of 40 trials per character, using these networks and a suitable reward function.

The machine model experiments investigated by Singer are concerned with elaboration of the Pitts-McCullough method of optically centering the image by schematizing the structure of this type of form recognition in some detail.[4] In effect, the principle is to convert spatial aspects of pattern configurations into temporal changes, and to compensate differences in arrival-time for processed patterns so as to provide size invariance. Singer summarizes this aspect of the proposed technique as follows:

> "Size invariance is accomplished by a group transformation of the image. The transformation utilized here is a dilation group transformation which is best described as a set of electrical impulses, each representing a resolved point of an image border, all traveling uniformly outward from the center of delay lines arranged in a polar network. By considering time coincidences of these pulses at selected points of the polar array, recognition of an image is accomplished." [5]

1/ Compare, for example, the approach of Baran and Estrin: "Samples of a set of characters are first identified by a human operator. From such inputs, a probability matrix is computed and used to derive a set of weighted filters or stencils which distinguish each character relative to the set of possible characters. When unknown characters are read, the proposed pattern recognition machine produces estimates of the confidence of the identification." (Ref. 34, p. 29.)

2/ Estavan, D. "Pattern recognition, machine learning and automated teaching," Ref. 125, p. 6.

3/ Roberts, L. G. "Pattern recognition with an adaptive network." Ref. 387.

4/ See Singer, J.R., Refs. 425-430.

5/ Singer, J.R. "Model for a size invariant pattern recognition system," Ref. 429, p. 239.

In later developments, Kelly and Singer report the incorporation of "learning" principles involving a 'captive state' feature such that once a pattern has been 'learned' the model will cease to modify the reference pattern but will continue to recognize. 1/

Kelly and Singer have also reviewed various examples of machine models of perception and recognition. They have stressed the differences between adaptive-abstractive systems and systems that may be adaptive in the sense that performance improves with increased experience on representative samples but that do not rely on criterial features and properties or interrelationships between pattern elements. Thus they contrast the assumptions of Von Foerster and of Greene, with respect to pre-organization, abstracting, and property-filtering as necessary to generalization, 2/ with the emphasis in the randomly connected, overlap template models such as the simple Perceptrons.

Recent work at Cornell Aeronautics Laboratory and elsewhere, however, has suggested improvements, modifications, and new organizational schemes to produce Perceptrons of greater flexibility. It has been noted that the simple Perceptron has little or no capacity for generalization. 3/ The simple Perceptron is a 3-layer device, involving two levels of transformation, from sensory cell (S-unit) to association (A-unit) and from A-unit to response (R-unit). Because of the randomness of the S $\longrightarrow$ A connections, the original geometric configuration, specifically including the relationships of connectivity, is lost in the transformation of the input pattern in A-unit space. By providing for both inhibitory and excitatory connections, in the randomly organized net, problems such as one pattern covering another ("E" and "F", "O and Q") can often be resolved. However, most of the experience with Perceptrons of this type has been with relation to discriminations between specific pairs of patterns only, and difficulties remain with respect to size, translation, and rotation variance, 4/ as well as to the fundamental question of whether the kinds of patterns that can be discriminated consist of interesting or useful classes of patterns. On the other hand, if these kinds of patterns can be equated with significant or criterial features of patterns, then perceptron-type systems might find application in precisely the preorganization stages of a more complex perception-recognition-detection system which "make the sensors particularly sensitive to important features of possible patterns." 5/

Moreover, Rosenblatt and his co-workers have continued investigations into possibilities for more versatile Perceptrons. They have, for example, explored an automatic classifying system in contrast to the forced training techniques used in the earlier studies. That is, in the early experiments, an operator forced responses to the training samples to which the Perceptron was exposed. Results of the later work have been reported, in part, as follows:

> "It should be emphasized that no attempt is made in the course of this experiment to direct the system or to influence it in any way in its choice of response; stimuli from the

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1/ Kelly, P. M. and J. R. Singer. "Bio-computer design. Part 1: Problems in bio-computer design, by Peter M. Kelly. Part 2: A specific device for bio-computers, by Jay R. Singer. Ref. 251.

2/ Greene, whom they cite, is concerned with such questions as the following: "The investigation summarized here aims to show how a rather simple type of network could exhibit many of the pattern-stabilizing and perceiving abilities that make human vision meaningful ... The model to be investigated is not intended to do the entire job of pattern recognition; rather its purpose is to 'notice' and hold together good Gestalten, or perceptual units, in order that the pattern recognizer would have stable and meaningful units with which to operate." (Ref. 179, p. 2, see also Refs. 178, 180, 181.)

3/ On this point, Kelly and Singer (Ref. 251), cite investigations by Warshaw (Warshaw, M., "An analysis of the Perceptron", Ref. 525.)

4/ These include, for example, the number of training organizations that would have to be developed to accommodate different 'points of view' of the same pattern (Kelly, P. M., Ref. 252, p. 222), the difficulties in arriving at proper reinforcement schemes for size variance (Murray, A. E., "A half-perceptron pattern filter", Ref. 319), the number of representative samples that must be provided for even a restricted overlap generalization. On this last point, Rosenblatt himself notes that: "It is necessary for the perceptron to see the letter 'N' in a large number of intermediate positions so as to form a chain or 'contiguity' sequence." Ref. 397.

5/ Kelly, P. M. "Problems in bio-computer design," Ref. 252, p. 216.

two classes are presented in a random sequence, and the only rule of operation is that whenever the response R-1 occurs, the A-units are 'reinforced' ... There is an optimum value of the decay rate ... If the decay is too small, the system becomes rigidly set in a 'wrong' pattern of response, while if the decay rate is too great, the perceptron forgets too rapidly, and learning is unstable ...

"We had found a system which could spontaneously differentiate dissimilar forms, while assigning similar forms to the same class. It soon became evident, however, that a perceptron designed in this fashion is exceedingly temperamental, and will perform properly only under a limited spectrum of environmental conditions." 1/

Subsequent Perceptron research has included study of "transform association systems" in which the objective is to provide generalization over area-preserving transformations. The methods considered consist in so-called "cross-coupled gamma systems". That is, the improved Perceptrons have reinforcement rules whereby gains for active units are balanced by compensating losses for inactive units, and both inhibitory and excitatory connections are permitted between A-units as well as from A-units to R-units. Under these design principles, it appears that features such as local connectivity of source patterns may be preserved, and that biases favorable to detection of pattern similarities for a given one-to-one transformation may be built up.

Barus, as in the early Perceptrons, assumes a reductive border-zone template principle with overlap generalization, but he also assumes a cross-coupling as in the later Perceptron systems. 2/ Moreover, in the Barus proposals the cross-coupling is directed, not only in terms of prior rewards but also in terms of current firings. In the Barus system, the input pattern elements as such are indeed originally disassociated from their spatial adjacency relationships, as in Baran and Estrin and the Perceptrons, by random connections of S-unit energizations and A-unit activations, but the observed identification formula will consist not only of A-units directly activated but also of A-units previously linked to these active A-units by reward-reinforcements for previously associated firings. Thus the Barus system differs from Perceptron systems in at least the following aspects:

(1) There is, in the Barus system, an imposed separability of A-cell to R-cell connections. Although these connections are randomly organized, a particular A-cell does not participate in the reward given for more than one response connection;

(2) The Barus system is cross-coupled from the beginning of operation, and laws are provided such that if one A-cell fires, then those cells that have been previously linked to it in a rewarded-response have lowered thresholds for firing.

(3) In the Barus system, an initial randomness of firing is provided, such that accidental noise, the activation of an S-unit connected to a particular A-unit, and the adjustable weights affecting A-unit firing thresholds in accordance with previously-linked firing responses, may all contribute to a particular A-unit $\longrightarrow$ R-unit reaction.

Thus, notwithstanding the incorporation of different types of randomness into the self-organizing aspects of his perception-nets, Barus in effect provides a special form of context-dependency in behavior, that might well be termed 'context-expectancy.'

Finally, we note that in the recent Uhr-Vossler models for pattern recognition of line drawings, both 'learning' and self-organization in the sense of selection from machine-generated random operators are displayed. This system has been reported, in part, as follows:

"We are now in the process of testing and extending a pattern recognition program, for the IBM 709, that is supposed to learn to recognize patterns such as alphanumeric letters and line drawings of simple objects. In this program, patterns are initially presented to a computer without any operators or any output space about meanings of output sets. Operators are generated by two methods: (a) by extracting (if you will, 'imitating') fragments of the inputs-as-known to the computer via the input transducing elements, and (b) by generating of random Boolean functions, or 'n-tuples' of these input element states ... These operators then map inputs into output sets, and feedback as to the appropriateness of the mapping controls generation and refinement of subsequent operators.

1/ Rosenblatt, F. "Perceptual generalization over transformation groups," Ref. 397, pp. 71, 72.

2/ Barus, C. "Machine learning and pattern recognition; a progress report on 'A study of learning machines' ", Ref. 39; and "Pattern recognition by statistical overlap", Ref. 40.

" ... At present, two psychologically plausible constraints have been placed upon the generators of operators ... These have been (a) generation of operators that are functions of connected elements only, and (b) generation of these operators within the space of a smaller matrix 1/ and translation of this matrix across the larger space.

" . . . in the last machine run to date, the program began without any operators, but merely the rule to generate five new operators by extraction from each unknown input, up to a limit of 40." 2/

These investigators claim that the restrictions make the machine-generated operators equivalent to neural networks that are repeated in parallel.

Turning now to the machine models that emphasize the use of local operations and spatial transformations in the recognition process, we note that those of Unger 3/ and Kamentsky 4/ also presuppose the use of parallel processing. Holland has also indicated the area of pattern recognition as one of the important applications of the iterative circuit machine that he has described. 5/ However, while the logical modules of the Holland machines have built-in program and path-building as well as storage capabilities, in the earlier Unger model the logical modules are under the direction of a master control unit, which can be programmed much as the conventional digital computer is programmed.

In Unger's SPAC, or "Spatial Computer", there is a rectilinear network of logical modules in which each module has direct contact with its four immediate neighbors, and in which all modules simultaneously receive an identical command or instruction from the master control unit. Programs have been written and tested to simulate SPAC in the recognition of handprinted alphanumeric characters and in the detection of L- and A-shaped features in sets of randomly drawn patterns. For character recognition, the spatial transformations in the Unger technique consist first in smoothing, image enhancement, and clean-up operations. These operations fill in holes in otherwise black areas and small notches or indentations in otherwise straight edges, eliminate isolated 'black' cells including those that create small protusions from an otherwise straight edge, and under certain conditions fill in missing corner points.

For 34 alphanumeric characters, 34 features or properties are used by Unger for discrimination. These are primarily features that can be detected by contour-tracing (horizontal cavity open above, vertical cavity open to the right, for example), but the list includes some relative-position-dependent and proportion-dependent properties as well, such as "leftmost point of a vertical cavity open to the right lies in the upper two thirds of the figure", and "height of the left leg of a V-shaped figure less than half the height of the right leg." 6/ Although the processing operations are carried out simultaneously and in parallel over the entire image field, the choice of 'next step', given the outcomes for any one operation, follows a decision-tree structure.

In Kamentsky's spatial computer model, the image field is also systematically transformed by a predetermined network of threshold-responsive elements, called 'speurons' in that they are neuron-like with respect to multi-input, single-output characteristics and in that they are connected in spatial arrays. The speurons may be connected so that there is excitatory or inhibitory gating between these elements and particular points in the image field or between inputs and the output of a given element. They operate simultaneously on all points of the image field, under control of a program, both to reduce noise or normalize and also to extract features such as straight lines, curves, closed loops, and corners. 7/

1/ I.e., smaller than that of the entire pattern input space.

2/ Uhr, L. and C. Vossler. "Suggestions for self-adapting models of brain function," Ref. 499, pp. 92-93, passim. These investigators have also reported even more recent promising results at the Western Joint Computer Conference, May 1961. (Ref. 497.)

3/ Unger, S.H. "Pattern detection and recognition", Ref. 501; "A computer oriented toward spatial problems", Ref. 500.

4/ Kamentsky, L.A. "Pattern and character recognition systems...", Ref. 244.

5/ Holland, J.H. "Iterative circuit computers", Ref. 218; and "A universal computer capable of executing an arbitrary number of sub-programs simultaneously", Ref. 219.

6/ Unger, S.H. "Pattern detection and recognition", Ref. 501, p. 1747.

7/ Kamentsky, L.A. "Pattern and character recognition systems...", Ref. 244.

Thus we find a variety of machine models of perception, abstraction, generalization, recognition, and pattern detection. Experiments on these models provide, as do the results of other pattern recognition research efforts, suggestions that may be useful, even if they are sometimes contradictory, in the development of improved character recognition systems.

9. CONCLUSION

In summary, then, we find that the present state of the art in automatic character recognition is characterized by progress, paradox, and promise. In the past several years, activity in systems design and development has increased. This increase in activity is found not only in the development of new and improved techniques and the exploitation of various methods to extend vocabulary size, but also in the entrance of new organizations to the field. Progress is also marked in the availability of higher recognition rates, better carrier item handling capabilities, and the actual installation of alphanumeric page-readers for field trial.

At least half a dozen potential suppliers would presumably consider undertaking the development of alphanumeric character recognition equipment, for vocabularies of several hundred characters, at recognition rates ranging from several hundred to several thousand characters per second, and for either paper or microfilm carrier items in sizes including the full page. This would be at typical costs of, say, $350,000 or less for the prototype system and with anticipated delivery schedules of 12- to -18 months. Additional organizations are optimistic about the extension of techniques developed for small vocabularies, but in many cases they have not yet actually demonstrated extrapolation of their techniques from the limited specially designed vocabularies to larger and more variable vocabulary situations. These indications of progress, however, are subject to the following significant limitations:

(1) There is a direct relationship between the size and variability of the vocabulary and the cost and complexity of the equipment.

(2) There is an inverse relationship between the consistency with which truly high quality input can be maintained and the tolerance for rejects that must be allowed for in performance specifications.

Paradox is to be noted, first, in the fact that the increased activity on the developmental side has not been accompanied by any significant increase in the number of reader installations that are in productive use. Only in recent months have equipment deliveries been made by suppliers other than Farrington-IMR, and there is as yet insufficient experience with them to draw conclusions with respect to performance.

A second paradox that appears to mark the current state of the art in the field lies in an apparent failure on the part of potential users of automatic character reading equipment to fully appreciate the second of the limitations noted above--that is, relationship between quality of input and error and reject rates. The limited data available about operational performance under conditions of usage in the field is almost exclusively restricted to applications in which there is little or no administrative control over imprinting or inscription operations. Thus, in the systems used at many oil industry service stations, where the carbon impression from the customer's charga-plate is recorded for subsequent automatic reading, smudging from improper insertion or registration of plate and carbon is complicated by the likelihood of greasy fingerprints and other dirt in handling. The supposedly 'high' reject and error rates for such applications are therefore more likely to be a measure of the lack of high quality input than they are of the performance of the reader. Similarly, in Figure 1, there is shown only one example of many in a relatively small sample, where the administrative control instruction, "Do not make strike-overs" was clearly ignored.

We have noted previously that one of the apparent paradoxes in the failure to date to realize some of the potentialities for automatic character reading which are now available is that of expecting unusually high performance specifications to be met at relatively low cost. For example, minimum reject rates are often specified which are not normally met in various manual methods. For accounting purposes, of course, accuracy and reliability of data are at a premium. In certain other applications, however, a relatively high reject rate can be accepted as economic, provided that errors are low. For example, Lieske of the U.S. Post Office Department has been quoted as saying:

> "We're willing to accept a high reject rate if it makes greater accuracy. Even if a machine rejects half its input, it would still be an enormous benefit, but we can't afford very many misroutings." 1/

1/ Cf. "Progress being made", Ref. 363, p. 17.

A third type of paradox lies in the lack of objective evidence as to the extent and variety of actual requirements for automatic character reading equipment and the apparent lack of appreciation of the potentialities for cost and time saving through the use of techniques already available. It is hoped that continuing documentation of representative examples of the variety of possible solutions offered may promote a greater appreciation of potentialities, an incentive to explore requirements in specific areas of possible application, and a greater willingness to try, test, and exploit the techniques that are already available.

Promise for future progress, therefore, lies first in the recent organized interest on the part of potential users in fact finding as to actual requirements and actual variety and quality of prospective input, in possibilities for arriving at standardization recommendations for well-defined, specific applications, [1/] and in possibilities for establishing realistic performance specifications. Such promise is evidenced in the organization of special committees and task-force groups to explore the situation on the part of the National Retail Merchandising Association, the Office Equipment Manufacturers Institute, the American Standards Association, and others.

The other major area of promise lies in the related basic research progress with respect to pattern recognition, machine models of perception and concept formation, and self-organizing systems. Progress in such research fields points to more than character recognition per se, that is, to problems of machine recognization of even more complex patterns such as those that are significant in aerial photographs and in other complex graphic material. When we consider the future possibilities for machine processes in machine translation, information selection and retrieval, and other aids to the improved utilization of scientific information, however, the need for both automatic character recognition systems and general pattern recognition techniques is obvious.

1/ Compare de Paris, J. R.: "Certainly more and more standardization of type will come about. This fact alone will accelerate the growth and applicability of optical scanning." (Ref. 90, p. 39.)

AUTOMATIC CHARACTER RECOGNITION: A STATE-OF-THE-ART REPORT*

APPENDIX

Bibliography on Character Recognition

The bibliographic citations which follow constitute an appendix to a state-of-the-art review of the field of automatic character recognition, prepared as of May 15, 1961. Several different categories of material are included in thie bibliography. Surveys and summaries of progress in the field, discussions of specific developments, pertinent patents, and technical papers covering potentially related basic research in pattern recognition are listed together in alphabetic order by first-named author or by source. A few references to other material specifically cited in the text of the state-of-the-art report are also included.

In general, bibliographic references to work in the field covering proprietary information are not included in the bibliographic listing below. However, some material that is available only on a restricted basis is included. In particular, certain unpublished reports available through the Armed Services Technical Information Agency (ASTIA) are included, with ASTIA numbers shown. It should be noted that ASTIA services are available only in support of military research or development projects and contracts. If a request to ASTIA for material is based upon the requirements of such a contract, the necessary forms and related information will be sent to the inquirer upon receipt of the request.

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* This bibliography was prepared and checked by F. Y. Neeland and M. E. Stevens, with the able assistance of F. G. Gottlieb.

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U. S. DEPARTMENT OF COMMERCE
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Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

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Atomic Physics. Spectroscopy. Infrared Spectroscopy. Solid State Physics. Electron Physics. Atomic Physics.

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Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry.

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Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

Radio Systems. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

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