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Volume 1. Information Acquisition, Sensing, and Input—

A Selective Literature Review

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Research and Development in the Computer and Information Sciences

1. Information Acquisition, Sensing, and Input: A Selective Literature Review

Mary Elizabeth Stevens

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National Bureau of Standards
Washington, D.C. 20234

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Foreword

The Center for Computer Sciences and Technology of the National Bureau of Standards has responsibility under the authority of Public Law 89–306 (the Brooks Bill) for automatic data processing standards development, for consultation and technical assistance to Federal agencies, and for supporting research in matters relating to the use of computers in the Federal Government.

This selective literature review is one of a series intended to improve interchange of information among those engaged in research and development in the fields of the computer and information sciences. Considered in this volume are the specific areas of information acquisition, sensing, and input, including the problems of character and pattern recognition.

Names and descriptions of specific proprietary devices and equipment have been included for the convenience of the reader, but completeness in this respect is recognized to be impossible. Certain important developments have remained proprietary or have not been reported in the open literature; thus major contributors to key developments in the field may have been omitted.

The omission of any method or device does not necessarily imply that it is considered unsuitable or unsatisfactory, nor does inclusion of descriptive material on commercially available instruments, products, programs, or processes constitute endorsement.

LEWIS M. BRANSCOMB, *Director*

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Information Acquisition, Sensing, and Input: A Selective Literature Review

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This report, the first of a projected series on research and development efforts and requirements in the computer and information sciences, is concerned with a selective literature review involving the operations of information acquisition, sensing, and input to information processing systems considered in generalized terms. Specific topics include but are not limited to: source data automation and remote sensing techniques, communication systems and data transmission links, audio and graphic inputs, preprocessing operations upon input items such as image enhancement and property filtering, character recognition, speech recognition, and various other aspects of automatic pattern recognition. Supplemental notes and a bibliography of over 640 cited references are included.

Key words: Audio inputs; automatic pattern recognition; character recognition; communication systems; data transmission; graphic inputs; image enhancement; remote sensing; source data automation; speech recognition.

1. Introduction

This report is the first of a series intended to provide a selective overview of research and development efforts and requirements in the somewhat overlapping fields of the computer and information sciences and technologies. The projected series of reports will attempt to outline the probable range of R & D activities in the computer and information sciences and technologies through selective reviews of the literature and to develop a reasonable consensus with respect to the opinions of workers in these and potentially related fields as to areas of continuing R & D concern for research program planning or review in these areas. In general, each individual report will be self-contained, and will provide notes in an appendix geared to the order of sections in the text.

1.1. General Introductory Considerations

It is, of course, presumptuous, as Licklider* and others have emphasized, to attempt to provide directives for the course of research and development planning in so broad an area as that of the computer and information sciences and technologies. Within the scope of Federal Government responsibilities, however, and with particular respect to the specific responsibilities assigned to the National Bureau of Standards under Bureau of the Budget Circular A–71 and Public Law 89–306 (the Brooks Bill of 1965), it is not unreasonable to try to provide a framework for program review and to pinpoint, so far as is practical, specific needs and difficulties to be noted in selective reviews of the literature and other appraisals of the state of the art. Such clues may often indicate the desirability of further research and development efforts whether Federally conducted, Federally sponsored, or independently initiated.

There is also the desirability of bringing together, in one place, a single perspective with regard to both current efforts and foreseeable future needs for research and development in the computer and information sciences, however biased that one perspective may be. This series of reports is thus intended to provide background material for the identification of research needs as a contribution to improved cooperation in the field. It is hoped also that a "framework" for considering R & D requirements in the computer and information sciences and technologies such as is proposed here may provide a continuing basis for annual reviews of continuing progress in the field.

In this introductory section to this first report, we will consider a few of the major background factors; outline the general plan of attack for the projected series of reports; provide some general *caveats;* discuss, with a few examples, a diagrammatic schema of a generalized information processing system which will form the organizational framework for at least the first few of the reports in

*A bibliography of all cited literature references, as well as other pertinent references of interest, is included as Appendix B. In addition, notes are provided in Appendix A for each of the discussion sections of this report. They represent selective samplings of corroborative opinions to be found in the literature, together with additional specific examples and citations to specific research and development efforts to which we have referred. See note 1.1, Appendix A.

the planned series; and summarize the scope and coverage of the present individual report.

1.2. Basic Background Considerations

Machines, especially radical new developments in computer, communication, and information processing systems, have made possible revolutionary gains in data acquisition and data manipulation over time, over space, over human limitations of reaction and responsiveness, over manually-inaccessible conditions, and more especially over human limitations of span-of-attention, consistency, and objective judgment.

When, in 1946, ENIAC was instructed to perform ballistic computations (at high speed and great accuracy), it was, in effect, substituting for many human fingers on many desk-calculator devices. In the early 1950's, computers could be used for payroll calculation, inventory control, accounting and bookkeeping, and similar processes, where the substitution was that of the machine for, roughly, high-school level actions and judgments of clerical personnel. Today, the challenge is of at least an order of magnitude greater: how can machines substitute for, or at least provide effective aids to, the air traffic controller, the professional meteorologist and the laboratory scientist, the architect or city planner, the reference librarian, the student or the professor?

Pressures of time-gap with respect to human response-time (whether measured in fractions of seconds or in terms of mastering the U.S. Patent Office backlog) dictate increasing use of machines. Pressures of concern in the accuracy of strategic forecasting, medical diagnosis, and predictions of actions necessary to avert foreseeable disasters (political, economic, social, ecological, and the like) again indicate the importance of machine aids and corrections to fallible and inconsistent human judgments. Thirdly, there are the related pressures to avoid duplication of effort, to shepherd the utilization of available scarce-manpower resources, and to challenge the most effective output of creative minds directed toward the most urgent problems of our times.

The rationale for research and development in the computer and information sciences and technologies is thus manifold. Among the currently most critical considerations are the following:

(1) Increasingly, the problems and decisions facing man impose conditions of organized complexity,[1,2] multiple interdependence of many uncontrolled and largely uncontrollable variables, a staggering number of possible outcomes with their comparative payoffs largely unknown, and limitations of both available-response-time and human span-of-attention.

(2) Steadily, the rate of technological advance, and concommitantly that of growth in the magnitude of problem factors to be resolved, cuts into the available lead-time in which laissez-faire applications or solutions are practical.

(3) Exponentially, the recording of potentially applicable information, from telemetered data captured in outer space through laboratory measurement recordings to published literature and computer-controlled graphic display of the probable consequences of decision choices, continues to increase in volume and in bulk. For every accretion to the sum of recorded, potentially usable information, there are corresponding accretions to the problems of location, selection, condensation, and validation.

(4) Critically, in terms of resource utilization, we need today an increased use of potentially available information to avoid replication of effort, to avert false starts and blind alleys, or to assist us by the suggestion of practical tools, techniques, and theoretical methods. We will also need increased release of human intellectual capabilities from machine-do-able tasks in order to free these capabilities for the truly creative and/or prudent action-choices that will still require human judgment and valuation.

For these reasons, we have seen over the past two decades the phenomenal growth of whole new industries involving computers, communication and control systems, and information processing technologies. For these reasons, there have been substantial research and development programs established in industry, the universities, non-profit organizations and private foundations, and Federal Government agencies. Despite substantial progress in many of these programs, however, there continue to be many areas of research and development requirements that are of major concern to the U.S. Government and in particular to the Federal Council of Science and Technology and its Committee on Scientific and Technical Information (COSATI).

Of particular concern in the United States as of 1967–1968 are the information processing system requirements in the anticipated phenomenal growth of multiple access networks and information processing utility systems, with concomitant problems of shared data banks and the measures necessary to protect privacy on the one hand, and with high promise for on-line problem-solving, machine-aided design, and machine-aided decision-making applications, on the other hand.

There are R & D requirements that stem from the desirability of foresighted consideration being given to probable future standardization or compatibility efforts; there are R & D requirements that arise because of current difficulties and bottlenecks, and there are those that relate to fact-finding, hypothesis formation, and experimental investigation in areas where we know so little of the underlying basic phenomena that it is not clear whether automatic information processing techniques could be feasibly applied at all.[1.3]

In addition, special R & D requirements can be foreseen in specific potential areas of application, such as library automation or question-answering systems for the personal use of the intelligence analyst. For example, we shall turn to a more detailed consideration of the problems of information storage, selection and retrieval (ISSR) systems in other reports in this series. In the first reports, however, let us discuss some R & D implications in system design requirements generally, with emphasis on certain recent developments in information acquisition; input-output subsystems and links to communication systems; processor subsystems and multiple access systems in particular; storage subsystems; advanced technological developments, and programming considerations including the special problems of on-line instrumentation and the mutual protection of clients and systems.

Any consideration of *generalized* research and development requirements in the computer and information sciences should obviously be based on one or more aspects of the fundamental information processing cycle—the acquisition of information; the processing of information to find, fix, and focus significant features present; the recording and storage of processed information for subsequent use, and the selective recall or retrieval of processed and stored information for use.

Certain themes will be necessarily recurrent: (1) System design must become more and more integrated and more and more dynamic and flexible; (2) Effective man-machine interaction at hardware, software, and behavioral factor levels is an increasingly significant problem; (3) Programming languages will require both more formal theoretic and also more user-oriented development, especially in the areas of man-machine dialog, parallel processing, multiprocessor systems, simulation, and self-diagnostic capabilities; (4) The essential interplay of man-machine reaction requires that much more must be realistically learned of *man*-in-the-system needs, of human advantages, frailties and prejudices in perception and apperception, and basic processes in man or machine procedures for pattern detection, concept formation and amalgamation, the tracing of associative retrieval trails, and the application of both deductive and inductive inference.

1.3. A Generalized Information Processing System

For preliminary purposes of indicating trends and defining certain obvious research and development requirements we provide in Figure 1 a generalized function chart of information processing systems.

The intended generality of Figure 1 can be illustrated by tracing through several examples of information processing system applications. First is a case of a relatively novel source data collection, processing, recording, and response system. Another example is a representative system designed for automatic character recognition. The third case involves both conventional and non-conventional techniques for the handling of recorded scientific and technical information—the areas of traditional library science, mechanized documentation, and information selection, storage, and retrieval systems.

It may also be appropriately suggested that, in human analogy, information acquisition, sensing and input operations are comparable to perception and ingestion systems in the human; pre-processing operations to digestive actions; processing to both metabolic and communication functions; and selective recall and output to effective psycho-physical reaction to the real world.

1.3.1. Automatic Production Control

In a relatively recent example of automatic production and control systems, the Bevercotes Company in England has designed techniques to provide for coal mining operations under remote control. Information acquisition, input and sensing operations (such as those indicated in Boxes 1 and 2 of Fig. 1) will involve the use of a nuclear sensor that emits gamma rays. The backscatter rates can be measured (preprocessing and processing operations in Boxes 3 and 4) to determine the thickness of the mine walls around coal veins and the thickness of coal remaining in a given vein. Direct output (Box 5 of Fig. 1) is to the automatic guidance control of the cutters, with provision for stopping them just short of the rock protecting the mine itself. Other inputs are processed to provide automatic monitoring of methane gas levels and to adjust ventilation equipment. Still other outputs (Box 14) go to human operators who govern, by appropriate processing specifications, the movements of hydraulic chocks that follow the cutters and support the mine roof. (Electronics **38**, No. 20, 213 (1965).)

This experimental production control system design thus emphasises automatic information acquisition (Box 1 of Fig. 1), sensing (Box 2), preprocessing (Box 3), post-processing by human operators (Box 13), and outputs (Box 14) fed directly back to the system itself as, in effect, processing service requests (Box 7) which may be used to develop processing specifications, such as the required amount of adjustments (Box 9) which are then "matched" (Box 10) with the actual processing operations needed to effect the adjustments.

1.3.2. Character Recognition Systems

In the generalized character recognition case, information acquisition (Box 1) involves the receipt of a carrier medium (such as paper or film) in or on which the character or characters to be read have previously been inscribed, typed, or printed. Box 2 of Figure 1, input and sensing, involves the

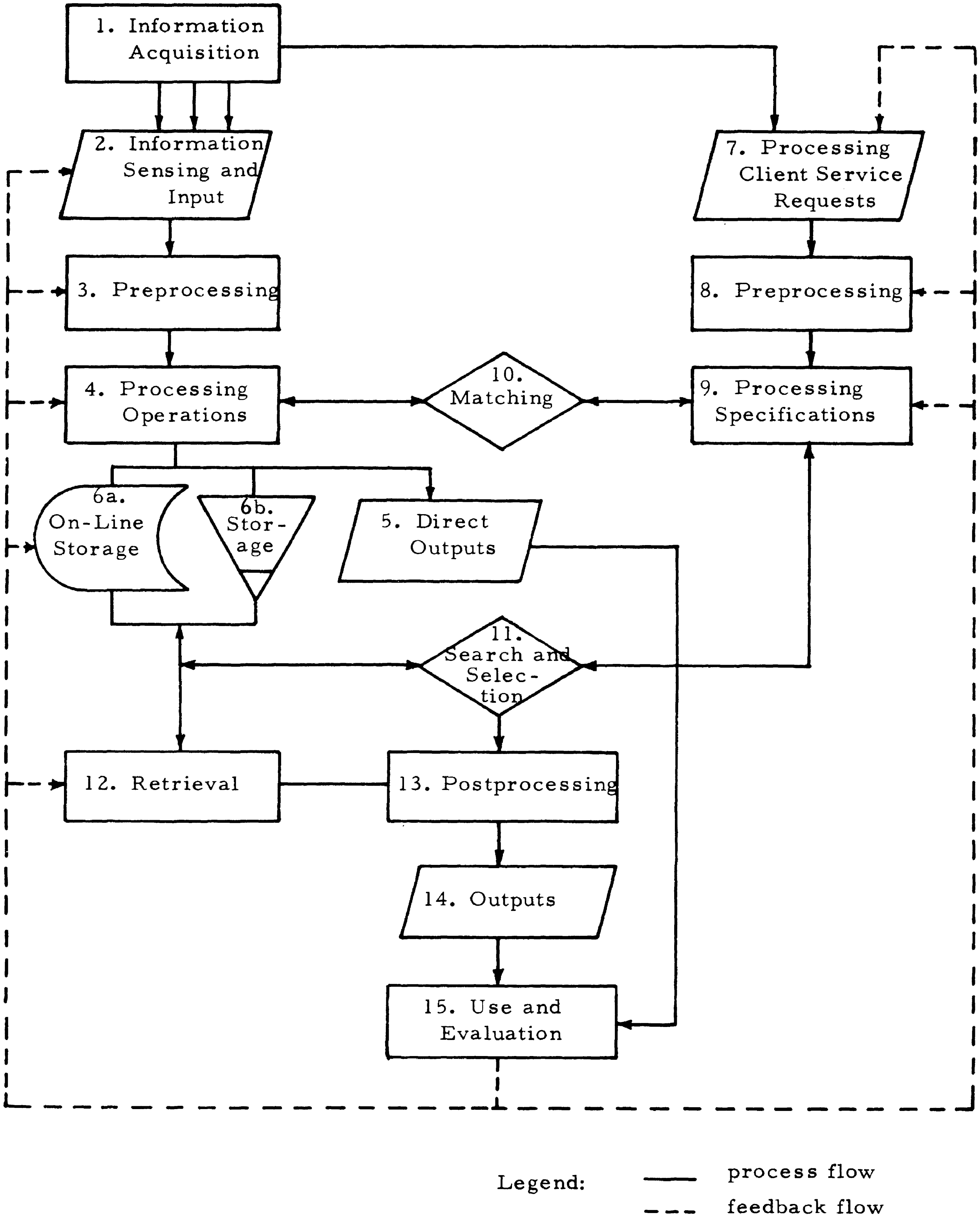

FIGURE 1. *A generalized information processing system.*

positioning and illumination of the carrier on which the character is recorded and the physical sensing of a source pattern—for example, by optical projection to a bank of photocells. By preprocessing operations (Box 3), such as integration over photocell response to particular subareas of the total source pattern image area, the sensed source pattern is transformed into an input pattern suitable for the subsequent processing requirements of the system.

The processing requirements are usually in the form of matching and "best-match" selection by comparison with previously stored *reference* patterns (exemplars of the salient characteristics of the various members of the character set to be recognized by the system) or *templates* (which, in their simplest form, might be the photographic-negative images of the set of characters in a particular font and type size).

Such reference patterns (whether merely simple templates or sophisticated pattern-property requirement listings involving syntax and context) serve the function of processing service requests (Box 7) in our generalized representation. For example, processing specifications (Box 9) in the photographic-negative mask-matching system may require check for matching against "F" before "E" in a sequentially processed match-decision procedure. Other possibilities involve feedback to threshold settings and the directed re-scanning and repetition of preprocessing operations to enhance signal-to-background contrasts or to eliminate noise in the case of "O" and "Q" in either sequential or parallel matching operations.

In a simple mask-matching system, the matching operations of Box 10, Figure 1, require that the suitably preprocessed input pattern will be optically superimposed against the various reference patterns and, when this input pattern coincides with its proper negative, light will be extinguished to a particular photocell. The resultant "blackout" (extinction of light to the photocell), together with suitable means for identifying the particular pattern for which the coincidence occurred, can then be used to effect appropriate *post*-processing operations (Box 13 of Fig. 1), such as to punch the appropriate machine-language for the character so "identified". These operations may also provide an output, (Box 14), which may include the information that the system was unable to decide as between two or more ambiguous input patterns. (It may be of interest to note that such a character recognition scheme was at least implicity disclosed by Goldberg as early as 1931.[1.4])

For later and more sophisticated automatic character recognition systems, Figure 2 illustrates how the basic schema of Figure 1 may be expanded, constrained, and made more specific in order to provide a generalized picture of automatic character and pattern recognition processes. In many actual or proposed systems for character or pattern recognition purposes, the importance of feedback with respect to threshold settings (e.g., to reset the gray-scale acceptance level so that more "gray" is sensed either as "black" or as "white") and preprocessing operations, especially those which affect local neighborhoods (or subsets of the source pattern image areas) are of particular importance and of significant concern for R & D efforts in this area; to be discussed in later sections of this report.

1.3.3. An Experimental ISSR System in the U.S.S.R.

Finally, although we shall consider information storage, selection, and retrieval (ISSR) systems in detail in one or more separate reports of this series, let us note a system combining optical character recognition, (OCR) thesaurus look-up, semi-automatic indexing, and machine expansion and reformulation of search query inputs, that is in experimental operation at VINITI, the All-Union Institute of Scientific and Technical Information of the Academy of Sciences, Moscow, U.S.S.R.[1.4a]

Information acquisition at VINITI relies on the submitted abstracts of scientific and technical papers that are supplied by a corps of some 10,000 or more scientists and engineers throughout the Soviet Union. Information input and sensing operations involve, first, a preprocessing operation in the form of manual re-transcription of the original input citations and abstract texts, using a somewhat stylized font (Cyrillic) typewriter. The typed material is then read by optical character recognition equipment and is fed to a computer for the experimental preparation of author and title indexes.[1.4b]

The input text has been limited, at least up until late 1966, to bibliographic citations and short abstracts for approximately 25,000 documents in the field of electrotechnology. The processing operations for this input material, whether manually prepared in machine-usable form or automatically read by the OCR equipment, involve operations of analysis and indexing by computer using thesaurus look-up to identify related terms, synonyms, and the like, and also to provide word-by-word translation of document input to a numerically encoded documentary language, which is that of a coordinate descriptor search system, involving 3,500 descriptors at the present time.

A machine-based, 4,000-item, Russian word-stem dictionary is used. For each text word, the appropriate stem is selected. Words not found in the dictionary are printed out, so that misspellings and possible new words can be caught on manual inspection. Print-outs may also be made of possible beginnings of complex expressions (e.g., where "installation" or "resistance" may be beginnings of phrases rather than single words). If a word found in the dictionary is not marked as being a possible "complex" or "homograph", it is translated directly into a 4-digit *concept* code.

The documentary language used involves the application of concept-codes or descriptors as manually established. Its code structure directly incorporates certain semantic relations, including

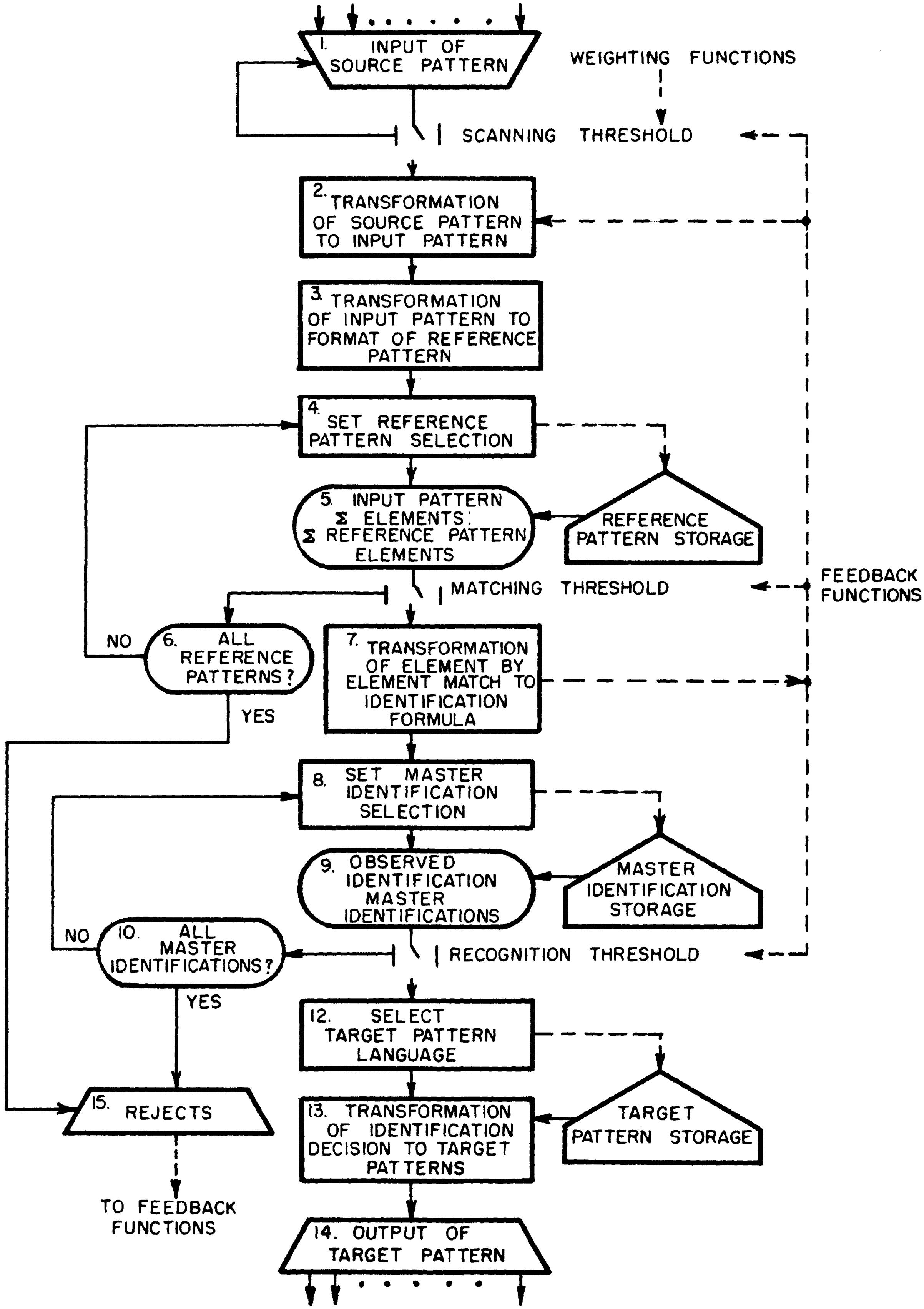

FIGURE 2. *A generalized character recognition system.*

some hierarchical relations, between descriptors. In addition, manually determined links or connections between descriptors have been set up for retrieval purposes. They have been tested by experimental searches for the total list of descriptors conducted independently but in parallel by machine and by subject specialists, and they have been subsequently refined for machine use on the basis of analyses of noise, omissions, and desirable improvements.

The retrieval logic depends upon these associational connections in the sense that, if a query term does not find a direct match, then search is made for match on related terms. If any descriptor in the question finds no direct or related term match with descriptors assigned to the stored item, the item is not selected.

Output of citation references for selected items is in the form of two listings—those which the machine considers positive responses, and those which because of the tracings of possible associational connections to presumably related descriptors are only probable responses. The machine also prints out listings of the connections that were used in the search specification modifications so that statistical analyses may be made as to the extent to which proper use is being made of these associational connections. Very preliminary results indicate that for 100 relevant documents in the collection, about 55 are selected by direct match and 25 by virtue of the pre-established connections. It is hoped that the latter procedure can be improved to 30 or 35 percent, to give up to 90 percent overall recall.

1.3.4. Implications of the Generalized Scheme

Certain features of the information flow and process schema of Figure 1 are to be noted in these examples. It is assumed, first of all, that information processing systems of the future should provide for automatic access from and to users at many points. This implies multiple inputs in parallel, interruptability, and interlacings of computer programs. Thus an obvious continuing research need is for the development of sophisticated executive and monitor systems, to control tie-ins from communication networks, to manage scheduling and priorities, and to provide for efficient utilization of system resources.

Other major assumptions include the following:

(1) The overall system involves a *hierarchy* of systems, devices and procedures.

(2) Processing involves *multi-step operations*, each step of which may be bypassed, curtailed, or expanded on the basis of man-machine evaluation of tentative results achieved at a present or immediately prior step.

(3) *Multi-mode operation* is possible, depending on job requirements, prior or tentative results, accessibility, costs, and the like.

It may often be desirable to record related information in several different input sensing modalities in parallel. In particular, temporal interval lapse-time data may be required for content and diagnostic analyses of verbal protocols [1.5] but also for "precise pin-pointing of time of occurrence of events of an oscillographic record of an experiment regardless of the speed of the chart during the recording." [1.6] For mechanized documentation applications in particular "Verbal, graphic, alphanumeric inputs and outputs are intermixed and intertwined." (Licklider, 1965, p. 186.)

The concept of effective interface involves not only the prospects and the problems of man-machine interactive collaboration but also those of a variety and intermixture of information inputs (by voice, drawing, keyboard, and so forth).[1.6a] As in the case of a multiplicity of forms and types of inputs, a generalized information system must also accommodate a variety of output modes and output media, whether as direct outputs (Box 5 of Figure 1) or as outputs derived from subsequent search, selection, and retrieval processing (Box 14).

It will be noted, next, that suggested techniques for a specific system may apply to more than one operational box or function shown in Figure 1. Speech synthesis developments, for example, using vocoder [1.7] and other techniques, are primarily directed to the *output* of artificially spoken messages, but, at the same time, R & D efforts in speech synthesis may have a direct impact upon improvements in speech recognition appropriate to information *input and sensing*. This is an approach currently being explored at Gunnar Fant's laboratory, Royal Institute of Technology, Sweden, and by King and Tunis (1966) [1.8] among others.

Similarly, in a given system configuration, specific operations or processes may occur in different sequences and several different ones may be combined in various ways. Thus, for example, questions of remote console desiderata may affect original item input, query or processing request input, output, or user feedback. Further, the specific solutions adopted may be implemented in each of these operational areas, or combined into one, e.g., by requiring all inputs and outputs to flow through the same hardware. Because of the difficulties in organizing the discussion of these reports, however, the choice of the most appropriate place or places to discuss a particular technique or topic has been somewhat arbitrary. It is to be noted, in particular, that the separation shown as between "Information Input and Sensing" (Box 2) and "Input of Processing Service Requests" (Box 7) is often, in a specific system, an artificial distinction.

Again, many of the processes can be iterative and recursive at many levels. Thus, in the spectrum analyzer developed by King and Tunis (1966) for their speech recognition experiments, the results of preprocessing operations (the instantaneous outputs of a contiguously tuned bank of band pass filters) become, in effect, inputs equivalent to

"Processing Service Requests". These are continuously compared (i.e., Box 10, Fig. 1, Matching Operations) in order to locate the instantaneous peaks in the envelope of the speech spectrum.[1.9]

The iterative, recursive nature of the process flow in particular exemplars of a generalized system (Fig. 1) is especially to be noted in the Soviet ISSR example. Thus, preprocessing operations (Box 3) occur first at the level of re-typing of input information, and then, within the optical character recognition part of the system, at the level of quantizing the input pattern to a 32 × 32 matrix (of which about 300 black-or-white cells are actually used for recognition purposes). Additional preprocessing operations involve the detection of significant "information areas" and may also involve the re-initiation and modification of both preprocessing and recognition processing operations. For example, there may be re-scanning of special areas of the quantized input patterns to decide between patterns that are near to each other in the sense of pairwise confusions. Such preprocessing operations may also be applied in holding a given character recognition-identification decision in store until the next character has been read, so that context-predictive rules, based upon digram and trigram probability statistics, may be applied.

Perhaps the single most important feature of the generalized schema (Fig. 1) is the provision for threshold requirements under feedback control. Let us consider, for example, some of the varied threshold factors that might be applied to input-scanning operations for various types of items to be stored and subsequently retrieved. These might include the following:

(1) The "purge" (or "stop"), lists used in key-word-in-context (KWIC) indexing to eliminate "common" (and presumably "nonsignificant") words from further processing.[1.10] Modifications (changes in threshold) may be applied on inspection of results either to restore words previously eliminated, but later considered as valuable access points, or to add words for general elimination because of the unmanageably large blocks of index entries that they generate.
(2) Time-interval sampling of experimental signals to reduce total volume of data to be processed, to eliminate redundancy, and to "smooth" minor data variations.
(3) Minimum gray-scale level quantization of graphic pattern input, such as printed or handwritten characters. Here, a particularly sophisticated approach to feedback threshold control is suggested by the work of Rankin et al. (1965) on the syntactic analysis of Chinese ideographs where "wellformedness" criteria are applied to reduce ambiguities of character-component recognition or errors of either transcription or encoding.

Then there is the further man-machine reactivity discussed by Bauer: "Consider the input of data which is relatively unstructured. The computer, of course, must finally accept and file the information in a highly structured form so that it may be retrieved efficiently. The computer can direct a procedure which allows the human to input the data in the order and in the form which the machine can accept." (1965, p. 19).

It should be noted, finally, that, in this and subsequent reports, when we discuss the systems implications of Figure 1, we will in some instances stress currently available examples, sometimes we will be pointing toward foreseeable trends of future application of advanced theories, techniques, media, and devices, and sometimes we will emphasize current difficulties.

1.4. Specific Background Considerations

The specific background considerations in the preparation of the projected series of reports involve both questions of the plan of attack and of necessary *caveats* which the reader should note. In particular, problems of organization of a wide range of materials, on a wide variety of topics, and with considerable logical overlapping between topics, do not appear to be soluble without many omissions, without some necessary repetitions, and without arbitrary allocations of specific topics and examples of current R & D efforts to particular discussion areas. For example, questions of boundary and contrast enhancement and property filtering in graphic data processing applications will be considered in the present report, but closely parallel operations in mechanized documentation applications (such as synonym reduction or homograph resolution) will be deferred for reports dealing more specifically with such areas of application. Similarly, many of the R & D requirements affecting more than one or two of the Boxes of Figure 1, such as programming languages, character sets, or advanced hardware developments, will be considered in a separate report in this series.

1.4.1. Plan of Attack

There are certain obvious difficulties with respect to the organization of the material for a series of reports on research and development requirements in the computer and information sciences and technologies. These problems stem, principally, from the overlaps between functional areas in which man-machine interactions of both communication and control are sought; the techniques, tools and instrumentation available to achieve such interactions, and the wide variety of application areas involved. For example, foreseeable applications range from astrophysical considerations of events that occurred many thousands of light years ago to investigations of on-going synaptic transfers in studies of human neurophysiology. Beyond this are many diversified areas of applied technology involving adaptive sensing, processing, and control operations in many fields.

How can we order, much less appraise, the massive body of experimental data and resultant literature that is already pertinent in these fields? This is a major problem in itself. The material that has been collected and reviewed to date is so multifaceted and so extensive as to require organization into reasonably tractable (but arbitrary) subdivisions. These are being grouped, first, in accordance with the diagrammatic schema of a generalized information processing system given previously as Figure 1.

The first few reports planned for this series can therefore be quite clearly identified. In this first report we consider, selectively, current problems and developments in information acquisition, sensing and input, and preprocessing operations with respect to computerized information processing systems (Boxes 1, 2, and 3 of Fig. 1). Next, we will be concerned with processor system management, with the organization and storage of data (at possibly many levels of storage and access), and with processing operations upon this stored data as such. Discussion of outputs from and use of generalized information processing systems will involve some necessary overlapping of research and development implications in the input-output and processing management areas. A separate report will be directed to some of the overall system design operations with respect to Figure 1.

Next, in view of widespread interest and concern, we plan to examine the domain of potential applicability of automated information processing techniques to the improved utilization of scientific and technical information and recorded knowledge. Then, a more detailed functional flowchart or schema of information processing operations as applied specifically to information storage, selection, and retrieval purposes will be discussed in one or more reports.

Other specific topics under consideration for inclusion in this series of reports include the current status of library automation developments, the problems of evaluation of information storage, selection, and retrieval systems and subsystems, and the questions of maintaining the integrity of privileged files (i.e., some of the background considerations with respect to the issues of privacy, confidentiality, and/or security in the case of multiply-accessed, machine-based files, data banks, and computer-communication networks).

In general, the plan of attack in each individual report of the series will be to give in relatively short and largely discursive text the topics of concern, supplemented by an Appendix of notes and quotations, and another Appendix giving the bibliographic citations of quoted references. It is planned, however, that there will be a comprehensive summary, bibliography, and index for the series as a whole.

1.4.2. Some General *Caveats*

Since problems of organization, terminology, and coverage have all been difficult with respect to the preparation of a series of reports such as is planned, certain disclaimers and observations as to the purpose and scope of this report, its necessary selectivity, and the problems of organization and emphasis are to be noted. Obviously, the reviewer's interests and limitations will emerge at least indirectly in terms of the selectivity that has been applied.

There is, nevertheless, heavy reliance placed on the experience and opinions of others, whether inside or outside of the Federal Government, and whether their projects are or are not supported by Government contracts and grants. In general, controversial opinions expressed or implied in any of the reports in this series are the sole responsibility of the author(s) of that report and are not intended in any way to represent the official policies of the Center for Computer Sciences and Technology, the National Bureau of Standards, or the Department of Commerce. However, every effort has been made to buttress potentially controversial statements or implications either with direct quotations or with illustrative examples from the pertinent literature in the field. Thus corroborative evidence, largely from the open literature, is adduced, generally, in terms of direct quotations in the notes of Appendix A.

The author of the present report must apologize for a necessary selectivity and for many inadvertent omissions in coverage. It will be appreciated if specific omissions are called to our attention. It is to be noted that neither inclusion nor citation is intended in any way to represent an endorsement of any specific commercially available device or system, of any particular investigator's results with respect to those of others, or of named project objectives. Conversely, omissions are in no sense intended to imply adverse evaluations of products, media, equipment, systems, project goals and project results, or of bibliographic references not included.

There will be quite obvious objections to our selectivity from readers who are also R & D workers in the fields involved as to the representativeness of cited contributions from their own work or that of others. Such criticisms are almost inevitable. Nevertheless, these reports are not intended to be state-of-the-art critiques as such, but rather they are intended to provide provocative suggestions for further R & D efforts. Selectivity must also relate to a necessarily arbitrary cut-off date. This factor is in itself an illustration of the limiting factors that affect the problems of preparing state-of-the-art reports and critical reviews.

The present series of reports, subject to the foregoing limitations, is offered as a possible contribution to the understanding of the general state of the art, especially with respect to long-range research possibilities in a variety of disciplines, potentially applicable to information processing problems. The reports are therefore directed to a varied audience among whom are those who plan, conduct, and support research in these varied disciplines. They are also addressed to applications specialists who may hope eventually to profit from the results of current research efforts. Inevitably, there must be some repetitions of the obvious and oversimplifications of certain topics for some readers, and there must also be some too-brief or inadequately explained discussions of other topics for these and other readers. What is at best tutorial for one may be difficult for another to follow. It is hoped, however, that notes and bibliographic citations will provide sufficient clues for further follow-up as desired.

1.5. Scope and Coverage of This Report

In the area of information acquisition, sensing, and input (Boxes 1, 2, and 3 of Fig. 1), which we attempt to cover in this particular report, a selective literature review has been conducted with emphasis on the 5-year period from 1962 to 1967. Some additional coverage is provided through mid-1968 and a few earlier references have also been included where especially pertinent.

We will consider first selected problems of information acquisition in the areas of source data automation, measurements automation and feedback control, and remote sensing techniques. Next, there are a number of considerations involving communication systems and data transmission links as means of input to information processing systems, including questions of services, networks, and facsimile transmission and consideration of some technical problem areas.

Direct audio and graphic inputs, including the special cases of pictorial and three-dimensional data processing, are next considered. Preprocessing operations such as filtering and image enhancement lead to topics of pattern recognition generally, including optical character recognition, voice recognition and speaker identification, and other areas of potential application. Finally, some theoretical approaches to pattern recognition are considered as portending future advances in information acquisition, sensing, and input.

2. Information Acquisition, Source Data Automation and Remote Data Collection

In the general area of R & D efforts affecting the operations of information acquisition, sensing, and input, we consider first, briefly, basic operations and input requirements and then discuss selectively some of the problems of source data automation, measurements automation and feedback control, and remote sensing and data collection techniques.

2.1. Basic Operations and Requirements

Under the basic operations of information acquisition, input, and sensing we include such input items as: Data collected at source, including that automatically collected at remote locations; laboratory measurements, on- and off-line; control and feedback information; photographic, acoustic, magnetic, light-pen, and other recordings of events and data; auxiliary control signals; machine-usable data records; written records and reports; communication system messages; documents, document surrogates, and feedback commentaries; processing service requests; search, selection, and recall requests; instructions and data for revision, correction, and updating of information; processing control specifications, and system operation and usage statistics.

Areas of continuing R & D concern with respect to the first process shown in Figure 1, that of Information Acquisition, are exemplified in Figure 3. First are the questions of the physical, environmental factors that affect observations, experimental manipulations, and recordings of both physical phenomena and various transactions in the human social, cultural, political, economic, and ideological world. Physical and environmental considerations are reflected, for example, in the physiological and cultural factors that aggravate the problems of automatic speech recognition.

Then, in the medical, biological, and physiological fields, there are systems for the sensing and transmitting of electrocardiographic and other data.[2.1] On-line or real-time monitoring and reporting of patient condition, not only for the critically ill,[2.2] but also for interchange of information between cooperating institutions,[2.3] is an important area for further development and possible networking applications.[2.4]

Figure 3 exemplifies one of several possible methods of identifying and predicting R & D requirements in the computer and information sciences and technologies. Thus, with respect to the problems of information acquisition raised with respect to physically and environmentally restrictive conditions, we may look to continuing efforts in science and technology generally for improvements in the scope, accuracy, and effectiveness of physical measurements. We may also count on developments and improvements by mathematicians and statisticians in both the techniques and the evaluation of statistical sampling.* Problems and prospects for R & D efforts in the computer and information sciences, however, are more directly concerned with the questions of effective sensing

*It should be noted that, because of necessarily selective coverage in these reports, not all of the possible considerations shown in various figures and tables will be explicitly discussed in the text.

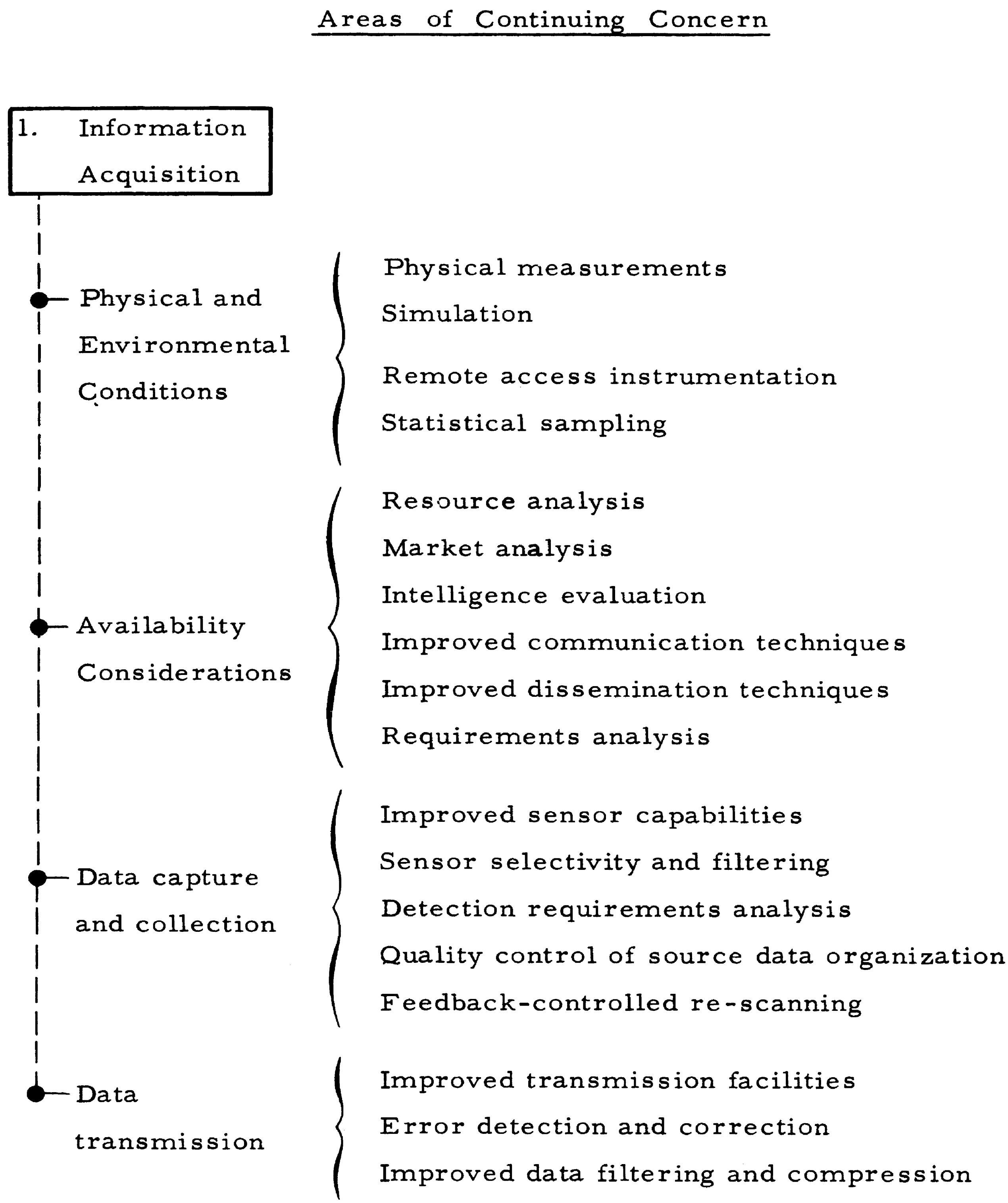

FIGURE 3. *Areas of continuing concern, information acquisition.*

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techniques and with the development of remote access instrumentation.

Problems relating to the availability of information dictate first the analysis of present and potential resources for its capture, recording, and use. Automatic information processing design requirements with respect to information acquisition, sensing, and input are of increasing concern because of the rapidly growing trend to attach analog sensors and transducers to computers. This enables the computer to be used for space vehicle control, process control, medical research, and the like. For example, telemetry monitoring of human reactions in unusual environments is provocatively described in the report of a 1966 panel discussion, covering, in particular, the monitoring of high-altitude climbers, the study of head injuries to football players by radiotelemetry techniques and of electrocardiographic reactions of spectators, as well as aerospace applications (Nevison, 1967).

In general, the areas of automatic production control, numerically controlled machine tools, and the like, will not be covered in this series of reports. Several examples, however, are illustrative of three-dimensional data processing and machine-aided design applications. In automotive design, for example, proximity probes have been used experimentally to measure the length, width, and height of clay mockups of new models and the measurements were then converted by computer to provide punched tape for the control of a drafting plotter[2.5], and electronically. sensed photographs of automotive parts have similarly been converted to numerical control tapes for machining.[2.6]

We can single out certain of these areas of continuing R & D efforts of interest, but we will hope to stress relatively new or novel examples (e.g., automatic or partially automatic remote sensing and control systems) rather than the more conventional areas such as analog-digital conversion techniques. We may note, however, such recent contributions as the use of hybrid computers for the analysis of feedback control systems, with special reference to the handling of non-linearities in equations of neutron kinetics and heat flow as reported by Sanathanan et al, (1966).

Let us consider next, a few of the current potentialities and implied research requirements for source data automation, remote data collecting, sensing techniques, and tie-ins to communication networks feeding input to automatic processing networks.

2.2. Source Data Automation

There is first of all the question of the physical relationships of the information processing equipment to the outside world, to people, and to other machines via a very wide variety of direct and indirect communication and display devices. Obviously, such relationships with respect to data processing systems design begin with the source data. Both "source data automation" and "remote data collection" have been significant systems planning concepts in business and management information processing applications over the past decade.[2.7]

The concept includes hardware possibilities that range from mark-sensing principles for Census-data gathering and microfilming principles (as in FOSDIC equipment for Census data-gathering and records management[2.7a]) or the taking of inventories of stocks-on-hand, through both magnetic ink and optical character reading devices, to the principle of automating and integrating the entire publishing cycle from typing of the author's original manuscript to computer-controlled typographic composition.[2.7b] The latter possibility includes not only the preparation-publication cycle for journal articles and books but also of machine-derived byproducts such as catalog cards, printed indexes, and abstracts.[2.8]

In a theoretical sense, "remote data collection" and "source data automation" might well be regarded as synonymous expressions. In practice, however, source data recordings that are collected automatically at remote or generally inaccessible locations fall within the area denoted by the first of these expressions and, conversely, "source data automation" is typically taken to apply to manual recordings of observations of data values—whether by physical marking, embossing, hand printing, keystroking, or alphanumeric reactive display operations.

In a special sense, source data automation implies the mechanization of information-carrying records at the point of origin, as in automatic employee identification and time-clock recording systems.[2.8a] Another common method is that of by-product or dual language recording as in the generation of a punched paper tape with the necessary information about a transaction produced automatically in the proper machine processing code by the device that records the transaction.[2.9]

Automatic character and symbol recognition devices are obvious tools for source data automation where the information to be processed has been pre-recorded in printed, typewritten, handwritten, bar-coded, color-coded and other visible forms. For example, the Honeywell data station accepts transfer of information from optical bar code readers[2.10] and IBM's System/360 provides for input from two different optical character readers, as well as magnetic ink character recognition devices (Data Processing Mag. **7**, 290–302 (1965).) Some character and pattern recognition processes may be applied directly on input, as in the sensing of optical marks.[2.11] A special feature of machine-controlled pattern recognition capabilities is represented by the Myocoder system developed by Philco's Bio-Cybernetics Engineering Laboratories.[2.12]

Other suggested developments of automatic recognition techniques include checking of labels during packaging processes.[2.13] An interesting similar suggestion for computer systems management is as follows:

> "What is needed is for the manufacturers to develop some system whereby an external graphic label can be prepared and attached to the reel and subsequently read by the tape unit. An adhesive tape with reflective dots and dashes encoded on it would be one possibility." (Lynch, 1966, p. 122).

System-performance monitoring applications of source data automation techniques are exemplified by a Sylvania system, developed in collaboration with the Association of American Railroads for the automatic identification and inventory control of freight cars.[2.13a]

Source data collection for direct transmission to a central processor or processor network is also achieved by touchtone dialing and voice telephone inputs.[2.14] More typically, automatic source data collection systems involve time clock and other measuring and identification device inputs in a variety of business and industrial applications. One example involves collection and scheduled forwarding of work hour distribution data from physically separate production facilities to a processing center for computer report generation.[2.15]

For another example, the source data acquisition system under development for the U.S. Post Office Department will link more than 5,000 data gathering, transmission and measuring devices in 75 major post offices to two collection and processing centers. (Commun. ACM **10,** No. 2, 132 (Feb. 1967).)

In 1961, eight major members of the aerospace industry established an informal study group on data transmission. The needs for data transmission were surprisingly similar for different members of the group. It has been reported that these mutually recognized needs could be described in four categories, as follows:

"a. Load sharing among major computer centers . . .

"b. Data pick-up from remote test sites (or from airborne tests). In some cases real-time processing and retransmission of results to the test site would be desirable.

"c. Providing access for Plant A to a computer center at Location B. Plant A might have a medium-scale, small-scale, or no computer of its own.

"d. Data pick-up from dispersed plants and offices for processing and incorporation in overall reports. The dispersed points might be in the same locality as the processing center, or possibly as much as several thousand miles away." (Perlman, 1961, p. 209.)

Other than for telemetry, data capture and collection technologies, as of 1967, still predominantly require human observation, monitoring, and recording processes, whether or not these processes are aided by remote-sensing instrumentation. Particular emphasis is placed upon the reporting of observed measurements in machine-usable form as close to the information or data source as possible. This involves the reduction of observed values, together with appropriate information about the conditions of observation, to a message-language that can be fed into appropriate data-transfer or communication links, transmitted, and subsequently processed by automatic data processing equipment. Recording and input techniques for these purposes will be considered in Section 2.4.2.

Improved techniques of source data automation and interrupt processing increase the potentialities of data collection under machine control.[2.15a] including those problems of collecting data from relatively inaccessible locations where conventional instrumentation generally fails either because of physical dimensions, interference with the phenomena being observed, or the fact that the phenomena are occurring in the remote reaches of space.[2.15b] Similarly, in the electric utility industry increasing attention is being given to combined computer/telemetry systems.[2.16]

General-purpose data acquisition and control systems, such as Digitronics Dial-O-Verter[2.17] or IBM's 1800, can "monitor an assembly line, control a steelmaking process or analyze the precise status of a missile during test firing, [and] can gather information at the rate of eight billion bits a second."[2.18]

Next, centrally located processing systems may accept digitally encoded input messages via a variety of information-carrier recording and transmission channels. Such techniques typically involve both the recording and encoding of messages at the source of transmission and decoding and re-recording at the destination. In many cases, several levels of recording may be involved in order to step up to progressively more stringent performance requirements, e.g., as in increasing the speeds of information transfer, through various stages, from the very slow (several characters a second only) rates of manual keyboarding to the many thousands of characters per second rates acceptable to modern computers.

2.3. Measurements Automation and Feedback Control

A second type of example of source data automation and/or remote data collection is found in automatic measurement techniques that provide for dynamic capture of data and for the feedback control of on-going experiments or tests.[2.18a] In the area of laboratory measurements automation, McGee and Petersen (1965), for example, discuss a microprogram control system for processing, display, and output printing of information derived from input data from CRT scanners, counters, pulse height analyzers, telemetry converters, and the like.[2.19]

Other projects for automatic measurement of filmed data of nuclear particle events include an on-line man-computer system at the University of Illinois,[2.20] and a system at Rutgers University.[2.21]

Other recent examples include the on-line collection and analysis by computer of data derived from nuclear physics experiments using the University of Wisconsin's tandem electrostatic accelerator (Commun. ACM **10**, 385 (1967), work at the Brookhaven Laboratories of the U.S. Atomic Energy Commission (Rabinowitz, 1968),[2.21a] and at the Lawrence Radiation Laboratory (White, 1968). In addition, the CHLOE film digitizing system developed at Argonne has been applied to spark chamber data (Hodges, 1968) as has the PIP device.[2.21b] Another approach is that of PEPR (*P*recision *E*ncoding and *P*attern *R*ecognition).[2.21c]

Another laboratory measurements automation example is provided by an IBM system for crystallographic analysis.[2.22] The University of Manchester computing center also uses x-ray diffractometer techniques for on-line measurements.[2.23] Cooper (1964) points out that while measurements automation might be expected in x-ray diffraction analysis where thousands of repetitive measurements of reflections must be made, automated techniques are also being applied in complex experimental situations with man-machine interaction.[2.24] Cooper also cites the PEXRAD (Programmed Electronic X-Ray Automatic Diffractometer) designed by Abrahams at the Bell Laboratories and work on neutron diffraction measurement and analysis at Brookhaven.

Other examples of measurements automation and feedback control include the following:

(1) Data Analysis by computer interfaced with gas chromatograph equipment.[2.25]

(2) Use of infrared radiometry to detect flaws in multilayer printed circuits.[2.26]

(3) A Public Health Service grant has been made to design and construct a scanner-computer for automatic observation and analysis of medical and biological specimens to identify micro-organisms and, further, for the computer to "direct the automatic petri dish machine to spray penicillin and a variety of other drugs of the growing microbial colonies in order to determine the drug sensitivities of possible disease-causing organisms which are found."[2.27]

At the National Bureau of Standards, computer scientists and engineers have worked on a variety of measurements automation projects designed to assist other agencies of Government and to serve other R & D programs at NBS. In particular, they have stressed a modular systems design program in which various previously developed components and sub-assemblies can be assembled in configurations dictated by different requirements in different areas of laboratory experimentation.[2.28]

Again, at the Argonne National Laboratory, a variety of laboratory measurement instrumentation techniques have been developed. These include on-line interrupt facilities for users of the accelerators and film scanning and track counting devices for analysis of data such as bubble chamber records.[2.29] Neilsen reports on radioactivity measuring instrumentation techniques using audio input and output techniques for transmission to and from the laboratory and a computer system.[2.30]

Earlier developments in telemetry; remote data collection, data logging and transmission; automation of laboratory measurement procedures, and on-line processing of remotely sensed data are being extended in many areas of experimental application.[2.30a] One such area is that of the automatic control of experiments and tests, based upon rapid transmission, processing, analysis, and feedback with respect to the input data. In particular, "the value of rapid transmission and processing of test data to allow decisions to be made while tests are in process has already been proven in the development of jet engines and rocket motors." (Perlman, 1961, p. 210.)

It is also to be noted that "machine-collected data are not only more accurate (being less subject to errors in reading, writing, or transcribing) and more conveniently obtained, but make possible experiments that produce data too fast, too infrequently, too irregularly, or over too long a period of time to be taken by a laboratory staff." ("Specialized Computational Equipment from General-Purpose Modules", 1967, p. 175).

2.4. Remote Sensing and Data Collection Techniques

Current experimental evidence indicates many potentially fruitful approaches to an extremely wide diversity of source data automation applications, with or without human monitoring and interaction. In addition, relatively direct sensor-processor linkages are being explored, especially for photographic, auditory signal, radar,[2.30b] and other electromagnetic sensing, recording and transmitting potentialities that are being investigated. A data logging example is provided in a 1963 NBS project to develop and test an automatic data acquisition system for hydrographic survey data, a high precision plotter to locate position fixes and to print out information on the soundings taken, and a computer program to convert the position-fix data into earth coordinates and then into x-y coordinates fed to the plotter.[2.31]

An example of commercially available modular data logging equipment is provided by Berkeley Scientific Laboratories.[2.32] Mobidac, for another example, is a mobile data acquisition system designed for use at remote test sites.[2.33]

More recently, large-scale data collection arrays and networks have begun to emerge. These include seismic arrays for the detection of earthquake and nuclear tremors[2.34] and a communication system used for the monitoring of water pollution.[2.35]

Meteorological observations are an important area of application.[2.36] Then it is noted that "the National Meteorological Service System and the World Weather Watch are planning the real-time data-acquisition system that will ensure continued improvements in the future." (Aron, 1967, p. 65.) Here again, system requirements for rapid processing of data received from multiple sensors and for real-time analysis of sensed data are emphasized.[2.36a]

Some of the more ingenious recent developments in source data automation, processing, and control include transmission of video photographs of Mars [2.36b] and the use of a 7094 computer not only to improve the quality of lunar photographs but also to prepare three-dimensional contour maps of the moon's surface (see The Computer Bulletin **9**, 62.) [2.37] Nathan, (1968) discusses picture enhancement procedures for television images transmitted from the moon and from Mars.

Hunt (1967) describes a laser system under development for the Air Force Cambridge Research Laboratories in cooperation with NASA, involving the reflection of laser beams from the lunar surface for purposes of detecting small variations in the motion of the moon and of measuring earth-moon distances.[2.38]

Remote sensing techniques also under advanced development include those using gamma rays, seismic waves and measurements of magnetic and gravitational fields (Parker and Wolff, 1965). Among examples cited are multiband reconnaissance, infrared mappings of forest fire boundaries, and multi-frequency radar detection of soil conditions down to 18 inches or more below surface. [2.39] An earlier paper by Cantrell (1964) emphasizes that as a new remote sensing tool an infrared scanning system can provide the geologist with unique information about the surface features of the earth. Similarly, remote infrared scanning techniques may be used from spacecraft or satellite to detect changing patterns of crops, coastal hydrologic features, and urban populations.[2.39a]

We note further that novel remote information acquisition procedures such as detection of crevasses in snow-covered surfaces by infrared measurements (Parker and Wolff, 1965)[2.40]; a radio-wave water prospecting system in the Soviet Union [2.41], and measurements of the patterns of light-reflecting properties of water and carbon dioxide frost to be used with space probes of Venus [2.42]) are merely scratching the surface of a potential wealth of future applications involving appropriate combinations of sensor devices; communication links; pre-processing operations to select, extract and enhance significant data, features or properties; computer processing; efficient storage, and subsequent search and selective recall, retrieval or reproduction.

Nevertheless, the very variety and ingenuity of these isolated examples suggests the importance of systematic investigations, at the earliest possible date, of overall source data acquisition requirements in a variety of subject fields for the foreseeable future and of both available and potentially available instrumentation, devices, techniques, and systems suitable for application. In particular, it is increasingly necessary to consider new research and development efforts in areas where "space flight and hostile environments now impose requirements on logical elements of adaptation and self-repair." (Swanson, 1966, p. 83.)

Space vehicle instrumentation and telemetering as such we have perhaps somewhat arbitrarily excluded from the general scope of this report. Nevertheless, we note that "our ability to acquire data is so far ahead of our ability to interpret and manage it that there is some question as to just how far we can go toward realizing the promise of much of this remote sensing. Probably 90 percent of the data gathered to date have not been utilized, and, with large multisensor programs in the offing, we face the danger of ending up prostrate beneath a mountain of utterly useless films, tapes, and charts." (Parker and Wolff, 1965, p. 31.) Moreover, a continuing R & D requirement for adaptive sampling techniques is noted.[2.42a]

Thus R & D requirements for the future include first the severe problems of sifting or filtering enormous masses of remotely collected data.[2.43] Another indicated area for research in remote data collection and source data automation is that "computer designers should search for a particularly adaptable form of sense input, ... Say a sense organ which could perceive spatial outlines of solid objects from a distance." (Strom, 1965, p. 111.) A special-purpose development in this direction is to be noted, however. Thus, Kroger reports on a helmet-mounted observation control system, in which ". . . polarized light sources and sensors are used to determine the head position in three rotational axes, locating the target in relation to the pilot and his aircraft." (Kroger, 1965, p. 269–270.)

In addition Parker and Wolff point out that "there are great gaps in our knowledge of spectral emissivity and reflectivity for natural materials, especially at wavelengths outside the visible portion of the spectrum. . . ." Further, "right now, not enough is known about natural materials to be certain of the role radar can play in identification. . . ." (Parker and Wolff, 1965, p. 27.)

Finally we note that in the space-data collecting area, for example, current new development considerations (to be discussed in another report in this series) range from small physical size, compactness, integrated circuit, batch fabrication techniques and components with ultra high-speed switching, storage, and read-out capabilities to fit the requirements of space-vehicle dimensional and weight considerations, through 'fail-softly' or 'graceful degradation' provisions and multiprocessor design[2.44] to the experiments in optical interspace message transmission tried out by Gemini VII with laser beams.

As was indicated in Figure 3 and in several of these examples, improved data transmission facilities and both error detection and correction capabilities are among the areas of continuing R & D concern with respect to information acquisition, sensing, and input. It is noted further that "a variety of adapters are being provided to permit the connection of computers to [communication] lines of differing qualities. This permits the computer to be used as a message switching center and it also permits separated computing installations to be linked together into a giant multiprocessor." (Clippinger, 1965, p. 209.)

3. Communication Systems and Data Transmission Links

The information sensing and input area broadly defined to include the typical physical relationships between the machine and its environment obviously involves the interconnecting links by which the machine system receives both information and processing instructions and then communicates the results of the processing operations that it performs. Of particular interest is the development of hardware and communication links suitable for timed-shared and remotely accessed networks and systems. For example, the July 1965 issue of the *IBM Journal of Research and Development* provides a sampling of research in the communications link aspects of such systems, with an overview by Andrews (1965). The technical papers cover such aspects of the problem as pseudonoise modulation techniques that enable better performance in random-access communication systems where many users communicate simultaneously without going through a central control[3.1] and questions of codes for optimum trade-offs between error rates and speeds of transmission.[3.2]

Under overall system design considerations for input to generalized information processing systems, we must obviously consider the R & D requirements for improved and more versatile data transmission and data communication systems.[3.2a] Increasingly, the computer and communication technologies are becoming interdependent.[3.3] In general, we will reserve consideration of communication-computer system complexes, especially for multiple-access applications, for a separate report in this series. However, in the sense of some of the areas of R & D concern with respect to information acquisition, as shown in Figure 3, we will outline briefly below some of the problems and prospects in communication systems and data transmission links.

3.1. Communication Links, Services, and Systems

Commercially available communication links of various types provide transmission-input and output capabilities for digital, voice, and even graphic information items (e.g., facsimile transmission, closed-circuit TV). For example, in addition to the relatively well-established techniques for the facsimile transmission of weather maps, we note much more complex systems as: an Automatic Map Compilation System[3.4] or the Automatic-Picture-Transmission recorder which transmits standard weather maps in one mode of operation and records direct transmissions from meteorological satellites in another mode.[3.4a]

3.1.1. Voice and Digital Data Transmission

Considering first the case of digital data and voice transmissions, currently available services include teletype, with both upper and lower case capabilities promised for forthcoming models; voice grade telephone lines for both data and voice transmission;[3.4b] broadband systems, and links via communication satellites.[3.5] In some cases, duplicate transmission may be made over more than one type of communication link, such as via microwave and also by coaxial cable.[3.6] In addition, there are a number of special arrangements such as private telephone exchanges,[3.7] Wide Area Telephone Service,[3.8] and Telpak.[3.9] One example of the use of the latter service is for data convertibility between computers.[3.10]

Then there is the Dataport, a terminal device that is claimed to be capable of being 'plugged in' to any computer in the country. (Commun. ACM **9**, 705, 1966). Increasing use is being made of Data-Phone, whether or not including automatic calling or polling mechanisms,[3.11] and of Touch-Tone telephones.[3.12] Davidson (1966), has described an economical way to add alphanumeric input capability to the Touch-Tone keyboard.[3.13] A similar approach is taken in the Tele-CUPL telephone input time-sharing system at Cornell University. (Conway and Morgan, 1967). When coupled to Automatic Calling Units, Data-Phone service allows computer-to-computer transmissions without the need for human intervention.[3.14] Higher data rates for Data-Phone services are now being offered.[3.14a] In particular, high speed burst transmission of data is provided for multiple users with Data-Phone 50.[3.14b]

The use of communication satellites for both data and video transmission is becoming increasingly commonplace.[3.14c] McManis (1966) predicts significant gains in communication channel capacity from further developments of synchronous satellites and from the use of lasers.[3.15] Goettel, however, is somewhat pessimistic as to the time scale. "A further step into the future, the laser, holds great promise for both voice and data transmission. The laser uses a beam of light to carry information. Although a great deal of work has already been done in this area, years of continued research remain before an economical laser-transmission system becomes a reality." (Goettel, 1966, p. 193).

Other advanced communication developments aimed at higher capacity, higher speeds, or lower costs include pulse code modulation systems for voice transmission,[3.16] millimeter wave guide techniques,[3.17] and improvements in microwave technology.[3.17a] Higher speeds of data transmission via voice and data networks, sometimes accompanied by significant reductions in error rate, are also under development.[3.18] The speed mark-up for textual data transmission already demonstrable is to be noted in contrasting a 1953 report of the long-distance transmission of the text of *Gone With the Wind* in a few minutes[3.19] with new technology that would make it possible to transmit the contents of *Webster's New Intercollegiate Dictionary* in less than a second.[3.20]

In terms of communication system networks, Swanson (1967) reports that the U.S. Army's STRATCOM with an annual workload of approximately 60 million messages ties together various agencies in more than 30 countries and provides connections to other Government networks including Autodin (the *auto*matic *di*gital *n*etwork)[3.21] and Autovon (for voice communications), with plans under way for greater use of communication satellites.[3.22] Increasing cooperation between Federal and local governments is exemplified in the case of the National Crime Information Center system.[3.23] A further example of U.S. Government interest is the Federal Government ARS (Advanced Records System) Data Transmission Network with tie-ins to teleprinter, facsimile, and other facilities as well as public carriers, Telex, and the Autodin system. This network is used extensively in support of social security and medicare programs.[3.24]

In the planning for the proposed EDUNET system (interconnecting a number of cooperating universities and other educational institutions), the discussants considered a variety of communication media from teletype to video, with the conclusion that each type presented difficulties of cost, speed, technical or administrative problems.[3.25]

In general, communication links for digital data transmission are required for alphanumeric data and for digitized forms of speech and television of facsimile signals.[3.26] In addition, there are increasing requirements for high-speed, but economical, graphic and facsimile transmission capabilities.

3.1.2. Graphic and Facsimile Transmission

Although facsimile transmission techniques have been available for more than a century, it has only been in the past dozen years that facsimile communication systems have been widely used,[3.26a] with emphasis upon use by the news services and for weather map transmission.[3.26b]

Crooks, reporting at the 1954 annual meeting of the American Documentation Institute, cited the use of Times Facsimile equipment by the U.S. Air Weather Network, the use by news services of Mufax and Hogan facsimile systems, Western Union capabilities for transmitting one lettersize page between New York and Washington in 45 seconds, a Japanese example involving 3,000 ideographs, the Federal Reserve Bank system, and a publication application at McCall's involving the transmission of raw copy from the publisher to the printer and the return of proofs.[3.27]

Ten years later, in 1964, Mayo predicted that the economics of "rapid error-free transmission of diagrams, signatures, and tests will, I feel, substantiate the apparent high cost." (1964, p. 78). In the following year, 1965, Gentle reported on a handwriting transmission system for both messages and hand-drawn sketches.[3.28] By 1967, handwriting transmission combined with two-way voice communication could be demonstrated.[3.29] An interesting example of the use of regular telephone lines for transmission of graphic information is provided in a system for remote optical character recognition proposed by Cogitronics Corporation. The system involves desk-top scanners at remote locations and a central recognition unit capable of handling multifont characters and on-line correction.[3.29a] In addition, color facsimile transmission is now available.[3.29b]

Currently available techniques for graphic and facsimile transmission include Long Distance Xerography (LDX)[3.30], wide band services[3.31], Magnafax[3.32], Stewart-Warner Dial Datafax equipment[3.32a], Muirhead developments[3.32b] and Picturephone[3.33], as well as TV transmission. Facsimile transmission links may be combined with voice message capabilities.[3.34] It is noted further that "facsimile signals can be digitized and encrypted for secure communications over telephone lines." (Schatz, 1967, p. 3). As in the case of digital data transmission as such, higher speeds of facsmile transmission, e.g., of TV signals, are being sought by means of digitalization.[3.35] Facsimile transmission of information or images stored in microform is also available.[3.36] Three examples are the Alden Electronic and Impulse Recording Equipment[3.36a], the General Precision Microteleviser[3.37] and the Alden/Miracode system as used, for instance, by the helicopter repair shops of the Army Materiel Command.[3.38]

Special purpose facsimile transmission networks include those providing medical video information to physicians;[3.38a] those linking libraries and other information centers, and those involving cooperative use of educational TV circuits.[3.39] The possible use of closed circuit TV mobile networks for a variety of law enforcement purposes is also to be noted.[3.39a] On at least an experimental basis, linkages between cooperating libraries using closed-circuit TV and other facsimile transmission techniques have been under investigation for some years. In particular, the development of cooperative "telereference" services has been a continuing concern of the Council on Library Resources.[3.40] The CLR annual report for 1966 comments, however, as follows: "The demonstration of closed-circuit TV between libraries at the University of Virginia in 1957–8 identified some of the problems. A demonstration in 1966 involving Reno and Las Vegas, Nevada, and Davis, California, showed progress in some particulars since the earlier data with further improvement still to be sought." (Council on Library Resources 10th Annual Report, 1966, pp. 24–25).

In the Houston Research Institute studies (1964–1965),[3.41] it was found that facsimile transmission of technical information was feasible via pipeline microwave network links, especially for off-shift periods, but it was concluded that "the establishment of a facsimile transmittal system is not justified until major improvements have been made in present library procedures for information storage and retrieval." (Schatz, 1967, p. 10).

Other recent library experiments in the use of facsimile transmission techniques include those conducted by the New York State public library system[3.42] and by the John Crerar Library.[3.43] For library applications, however, a requirement noted in 1953—that for direct copying and transmission from bound book pages—is still largely unsatisfied today.[3.44]

3.2. Computer Systems and Communication Networks

Direct input to computer from remote locations via communication links was first demonstrated by Stibitz of Bell Laboratories in 1940, using a console at Dartmouth to communicate over telegraph lines with a relay-computer in New York.[3.45] A second example is to be found in several demonstrations of SEAC results as transmitted to remote teletype printers in Washington during early 1950. Another example of NBS computer design and application dates back to 1954. At that time, a brief experimental demonstration of both a multiprocessor network (through the interconnection of SEAC and DYSEAC) and also of program time-sharing was run.[3.46] Overseas connections to computers via radio teletype links became feasible within the next 10 years.[3.47]

Of increasing interest in this area, today, are multiple access systems involving on-line transmissions to a central data processing system from remote locations. For example, the GE Datanet–70 system involves a multiline controller "which can handle simultaneously the access of up to 248 remote stations into the central computer via Teletype, voice grade and TELPAC–A communications facilities." (Commun. ACM **8**, No. 5, 343 (May 1965).) Although, in general, computer-communication complexes as used in university-oriented and other multiple-access system, especially for research purposes, will be discussed in another report in this series, a few additional examples may be given here.

Examples of U.S. agency networks indicate the potential significance in a variety of applications. First is the interagency rapid communications test link that transmits data via teletype and dictaphone from survey ships operating at sea to the National Oceanographic Data Center.[3.48] On another front, ARPA's Nuclear Test Detection Office is sponsoring the development of a seismometer array and central data processing facility for the detection of underground nuclear tests. (Maguire (1965).) A third example is a Department of State proposal to link together officials stationed in the U.S., Canada, and Mexico.[3.49] Then it is noted that "in law enforcement a full scale nationwide system time shared between Federal Government and state agencies is currently in operation. This system is a typical example of a computer utility type application of data processing within the Federal-State-local government complex." (Johnson, 1967, p. 14).

Applications in business and industry include first the air and space industries with, in particular, airline reservation services[3.50] and computer load-sharing capabilities.[3.51] Banks,[3.52] insurance companies,[3.53] and hospitals[3.54] are among the customers for the newly emerging computer-communication system complexes.[3.54a] The communication industry is itself exploring increased provision of computer services to its customers.[3.55]

At Case Institute of Technology, Univac 1004 reader/printers are "connected to the 1107 via a half-duplex telephone line with 201–A MODEM units at each end. . . . Full error detection and correction is provided. The telephone line can be severed and reattached hours later without loss of data. . . . Error detection is accomplished by a horizontal and vertical parity bit scheme similar to that employed on magnetic tape. Error correction is accomplished by retransmitting a message until it is correctly received and a verification is correctly returned to the sender." (Lynch, 1966, p. 119).

Certain current difficulties are to be noted, however. Special problems may arise in multipath communication systems and systems where many users communicate simultaneously with a shared processor or data bank. In the latter case, for example, "high-speed digital data transmission is a vital requirement in many data processing systems. The reasons vary widely and include (1) the need for rapid processing of remotely gathered data, as in a satellite tracking and control system, (2) the desirability of load sharing among remote processors or files in large management information systems." (Andrews, 1965, p. 226). This example loops back to the need for improved communication techniques generally. For example, a question of continuing R & D concern is: what can be done to increase the rate of graphic transmission on voice communication lines by several times its present rate? [3.56]

Questions less likely to lead to breakthroughs in the near future are exemplified by Baker's complaint that "even though the slowest and noisiest loop in the system is the man-to-computer communications link, little research is being done to alleviate the problem" (Baker, 1965, p. 430), and by consideration of the fact that "the problem of high-speed communication of data between remote centers in an information systems network is largely unexplored. . . ." (Scientific Information Notes **6,** 4, 11 (1964).) Nevertheless, increasing importance of computer-communication complexes, and remote multiprocessor networks can be foreseen.[3.57]

Mills (1965) points to some of the difficulties of the use of presently available communication links with multiple-access systems, especially those involving interchanges of graphic data displays. He suggests that: "The transmission requirements for multiple-access systems probably cannot be met by straightforward extensions of the services available through the present common-carrier systems", but that: "The message-store-and-forward concept, together with techniques of multiplexing (i.e., time-sharing communication channels, offer the most promise." (pp. 237, 241).

3.3. Store and Forward Techniques and Delayed Response

Delayed-recording outputs may thus hold the promise of greater efficiency in priority scheduling and system utilization for multiple-access information processing facilities as well as at least the possibility of lower cost data transmission and facsimile communication links.[3.57a] Relatively early references in the literature include the discussion by Genetta et al. (1960), of the RCA Autodata system.[3.58] Helman et al., 1963, describe the ITT 525 equipment, a store and forward switching center capable of interfacing with both synchronous data and start-stop teletype lines. "Dalcode" (*Da*ta *L*ine *C*ombiner and *De*multiplexer) is a Western Union development.[3.58a] Advantages of store and forward techniques include protection against message loss or interruptions of service.[3.58b]

In a 1962 paper, Maass describes the possibility of using a special type of TV set than can turn itself on at a predetermined time and record information received onto tape that can be replayed at the client's convenience. This possibility suggests that transmissions can be made over the regular networks but in off-hour time and hence perhaps at lower cost. This investigator adds: "When you consider the advantages of product or process demonstrations in color, the possible applications for this specialized communication form [off-hour TV recorded for replay] develop rapidly." (Maass, 1962, p. 47).[3.59]

As another example, investigators at Standard Telecommunications Laboratories, Ltd., have developed a magnetic tape storage system to delay transmitted speech, detect breaks or pauses and fill gaps in the telephone circuit usage with coded data, IDAST (Interpolated Data And Speech Transmission). (Data and Control **3,** No. 8, 11, 1965). Delayed transmission is thus one possible solution to some of the problems of speed and economy with respect to communication links for input and output transmission.

Other advantages of using store and forward techniques are that they can be used in off hours,[3.59a] they enable batching until there is enough data accumulated to meet minimum transmission time period requirements,[3.60] and they allow both a permanent record for audit purposes and retransmission in the case of garbled transmissions.[3.61] Gains from delayed transmission, using a "burst" technique, are exemplified in Esso's transoceanic message system where up to 2,500 words per minute, in contrast to 100 wpm in leased teleprinter circuit systems, are transmitted.[3.62]

Then there is: "A trick devised by remote users [which] is the method of linking to a dummy station located in the system. Soon after being admitted into the system, they begin the production type run of the dummy station, and then quit the remote station. When the remote user feels that his production jobs are completed, he can be readmitted into the time-sharing system, link to the dummy station, retrieve his output and quit. Many hours of line charges have been saved with this method. There are undoubtedly many other methods that can be devised, and these should be investigated and encouraged when savings in time and money will result." (Fiala, 1966, p. 164).

3.4. Technical Problem Areas

The science, technology, and theory of communication systems represent areas as broad and as diversified as those that we attempt to cover generally in this report. Examples of some of the technical problem areas related to computer-communication networks may be mentioned briefly, however.

Directly related to input/output transmission via various communication links are questions of data and message compression. Problems of high-cost bandwidth requirements in communication links for both pictorial and voice transmission processes thus continue under R & D attack.[3.62a] Vocoding techniques may be applied, for example, to achieve efficient compression of speech while maintaining adequate quality at the receiver station.[3.63]

Relatively recent R & D work in this area is also exemplified by compression of words or segments of speech into short time-slots,[3.64] by square-rooting of analytic signals of speech,[3.64a] and by studies of the losses of intelligibility of digitized speech transmissions.[3.65] It is claimed by some that redundancy reduction, as for example by the use of channel vocoder techniques, may potentially reduce the bandwidth requirements for digitized speech from 48,000 or more bits per second to 2,400 bps, or less.[3.65a] It is also to be noted that speech compression techniques resulting in speeded-up speech playback are of value to certain special types of information users—notably to students and others seeking a rapid review of material and to blind persons using recorded books.[3.66]

For textual message data compression, R & D requirements may be exemplified by an ingenious scheme reported by White (1967), in which commonly used words or phrases are economically encoded by dictionary lookup and short-code substitution, with a resultant reduction of transmitted English-language message length of 50 percent or better.[3.66a]

In the picture-data transmission area, Huang and Tretiak (1965) report experiments of their own and of Schreiber and others on the reduction of redundancy in pictorial data transmissions.[3.67] They have used computer-simulation techniques, coupled to CRT displays, to evaluate the degradation of picture quality when various redundancy-reduction schemes are tried. These investigators have also considered problems of coding of digital color pictures and of motion pictures.[3.68]

Earlier investigations in this area by Cherry et al. (1963) and by Kubba (1963) stressed run-length coding and variable velocity scanning.[3.69] Julesz (1959) proposed the use of edge detection techniques as a means for coding television signals and Gabor and Hill (1961) investigated television band compression by means of contour interpolations. Inose and Yasada (1963) developed an experimental encoder for compressed digitalization of video signals.[3.70] Another approach to compressed storage of pictorial data is that developed by Pfaltz and Rosenfeld (1967), consisting of describing an arbitrary region as the union of "maximal neighborhoods" in terms of the centers and radii of these neighborhoods.

A pseudo-random scanning technique developed by Roberts (1962) preserves relatively good reproductibility at the receiver, with a reduced number of gray-levels to be transmitted.[3.70a] In addition, such transmissions lend themselves to some noise-elimination techniques[3.70b] and to encrypting.[3.70c1] Predictive coding, where redundancy is reduced by subtracting from a message those parts that can be predicted from previously transmitted and received signals (as discussed by Graham in 1958,[3.70c2] has been investigated, by Wholey (1961) for weather maps,[3.70d] by Atal and Schroeder (1968) for speech waveforms[3.70e] and by Lucky (1968) with respect to error control.[3.70f]

Developments at Bell Laboratories involve an 8:1 reduction in data transmission requirements for TV pictures, using a conditional replenishment technique. That is, after a first full frame has been sent (with eight bits for amplitude at each sampled picture point), thereafter only significant changes need to be transmitted. Results of subsequent scans are routed through a buffer of two-frame capacity and replenishment occurs in accordance with significant-change thresholds that vary with the relative amount of motion in successive frames.[3.70g]

Also related to the communications link aspects of generalized information processing systems are questions of error detection and error correction in messages transmitted via such links. Advanced technological investigations may also be directed, for example, to minimization of noise in TV transmissions, by introduction of "noise only" and "picture plus noise" redundancy such as has been considered by Poppelbaum and Faiman (1968).[3.70h]

Redundancy to improve correct message reception can be achieved by various coding schemes which can be subsequently processed not only to detect the occurrence of errors but in some cases to restore garbled messages. To a significant extent, however, such error-detecting and error-correcting codes increase the complexity of receiver-decoding equipment and decrease the efficiency of use of the communication channels themselves, or both.[3.71] Franco et al. (1965) provide a review of relative advantages and disadvantages and current developments with respect to this problem.[3.72]

The question of the extent of error control coding to be applied will involve clientele requirements[3.72a] including tolerances for delays, the desired data rates and expected error rates, factors of channel efficiency, characteristics of the transmission medium,[3.73] and special factors such as the protection of privileged communications.[3.74] In the latter case, special R & D requirements are noted by Geddes et al. (1963) with respect to facsimile transmission.[3.75]

Finally, we note in this, as in many other areas of information processing system design R & D requirements, the incidence and effects of human errors. Franco et al., point out that "in setting the error rate requirement for teleprinter transmissions, it is necessary to keep in mind that errors can be introduced by the operators and terminal equipment. It is not profitable to specify undetected bit error rates which are more than 10 times greater than the error rate of the information source, simply because the improvement will not be discernible in the output error rate. Experience has shown that operator-caused character error rates may be greater than 1×10^{-3}." (Franco et al., 1965, p. 130).

4. Audio and Graphic Inputs

If the process of item input and sensing is to be speeded, improved, or made less costly by increased use of machine techniques, then expanded and more intensive research and development efforts in audio signal input and graphic sensing, including pictorial and three-dimensional data input, are required. In Figure 4, we see the operations of information sensing and input and of preprocessing of inputs together with some of the areas of specific research and development concern. First, inputs in the form of auditory signals of various types will be required.

4.1. Audio Signal Inputs

Auditory signal inputs, to date, have largely been limited to touch-tone telephone techniques and to the use of telephone lines to carry meta-information about other input items. Examples of references in the literature to touch-tone and Data-Phone systems used for direct input and processing include Balkovic (1967), Conway and Morgan (1967), Dale (1966), and Davenport (1965).[4.1] Examples involving audio inputs as developed in remote sensing and data collection techniques have been noted previously (Sec. 2).

Hogan (1966) provides a survey of voice input/output developments, concluding that the telephone will become an increasingly important computer I/O device. A review conducted by Business Forms International, Inc., includes the prediction that "when the voice input is fully developed it will inaugurate the beginning of living in an area of complete convenience. Not only will the voice method of input be used by business firms for business transactions, it will be used for many operations not directly linked with business." (Business Forms International, Inc., 1967, p. 4.)

Mills (1967), Van Dam and Michener (1967), and Lee (1968) are somewhat more pessimistic, however, particularly with respect to the time-scale in which

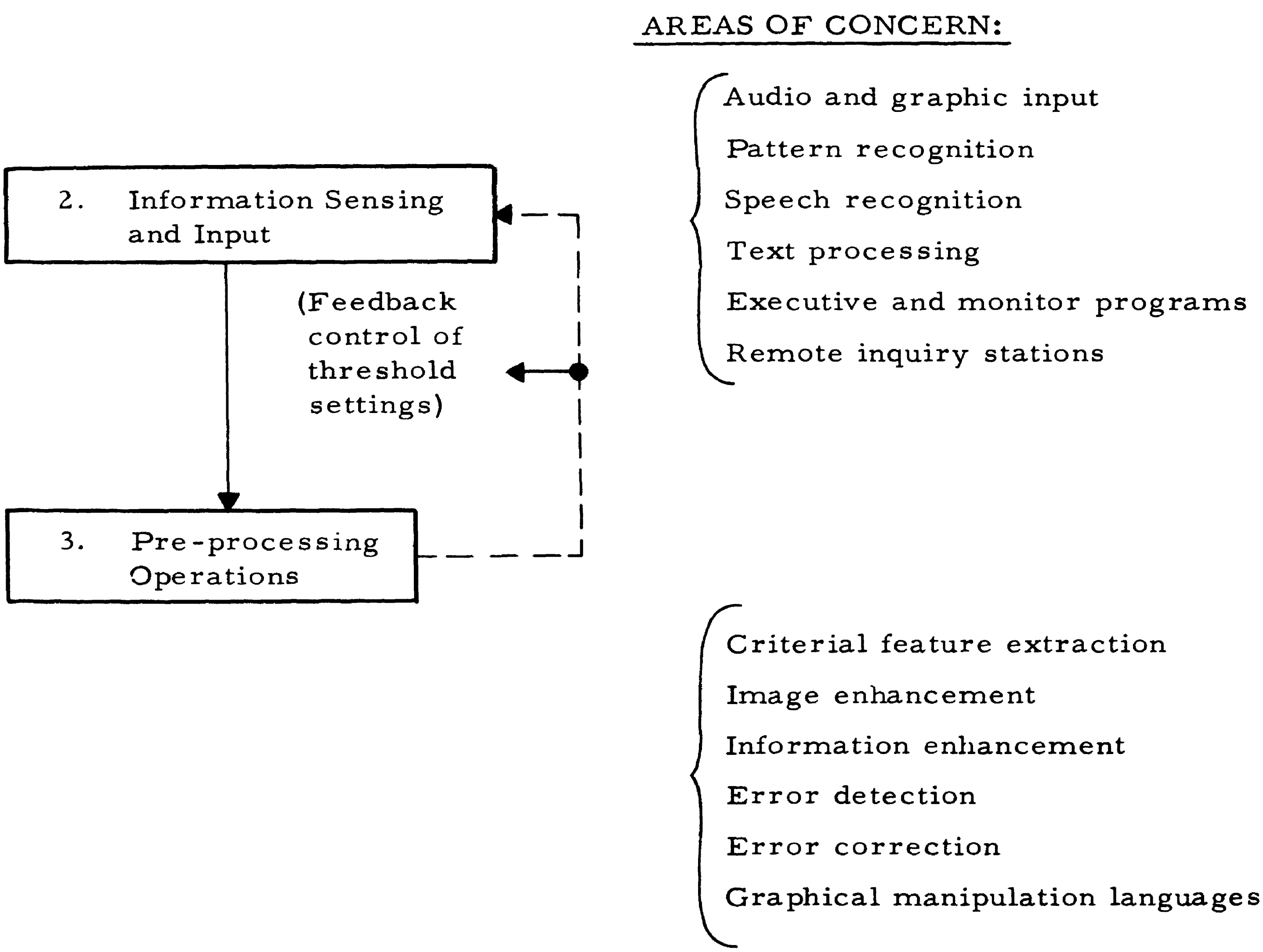


FIGURE 4. *Areas of concern; information sensing, input, and preprocessing.*

speech and speaker recognition experiments might be reduced to practice.[4.2] A simple special-purpose exception is noted, that of the experimental Cogitronics system which can ask a certain set of questions and can understand the answers "yes" or "no".[4.3] Beyond this, moreover, "when the technique reaches a stage where a spoken word or letter can be translated to an impulse that uniquely types out the required work, what will be the efficiency, the freedom from errors, the stress imposed on the 'dictator' and what training will be necessary? Research is needed on all these questions." (Van Geffen, 1967, p. e).

An interesting experiment involving acoustic signal inputs is described by Neilsen (1965).[4.4] The area of application is that of radioactivity measurements instrumentation where the hardware techniques combine use of a scintillation detector and a scaler-counter at a remote laboratory to reduce the number of detector pulses to be fed to computer via a telephone data link and with simple codes and timing indicia being transmitted via the telephone dial.

In the area of sonic wave measurements, we note first that "in 1963, Bogert, Healy, and Tukey discussed an approach to the detection and timing of echoes. Later Noll successfully applied these techniques [nonlinear filtering of convoluted signals] to the detection of pitch in speech waveforms." (Research Laboratory for Electronics, M.I.T., Quarterly Progress Report No. 80, 168, 1966). Another example is provided by Douglas Aircraft studies of target identification in terms of three-dimensional echo reflections of acoustic energy. (Dreher, 1966). Similarly, in Sweden, Dr. Wennerbarig of the Institute for Acoustics is concerned with general problems of marine acoustics, especially considering problems of methods of detection, decision-making, and the elimination or reduction of noise emanating from sources other than those of primary interest.[4.4a1]

The long-range possibilities for input-output in terms of natural or artificial spoken language will involve close relationships between research in speech compression, speech synthesis and automatic speech recognition (see Sec. 5.5). In general, the more sophisticated types of auditory signal input, like many graphic input developments, will involve to a greater or lesser degree advanced preprocessing and pattern recognition capabilities, to be considered in Section 5.7 of this report. Thus, "the problem in speech recognition is one of identifying, within the total acoustic output of the human voice or its mechanical reproduction, those elements which are significant for communication." (Garvin, 1963, p. 111).

4.2. Graphic Inputs

In the area of graphic inputs to generalized information processing systems, the questions of entry of alphanumeric information are first to be noted. Next, there are problems of machine processing of information derived from special symbols such as those used in mathematical equations and in chemical and other types of structural diagrams. A number of relatively new devices permit on-line drafting and direct entry of two-dimensional information into the data processing systems. In some cases, the graphic input may consist of handprinted or cursively handwritten characters, words, or signatures. Automatic recognition of such input, typically for a small, known "family" of users,[4.4a2] has been successfully demonstrated and some examples are given in Section 5.4 of this report Finally, in this area, we consider some of the prospects for pictorial and three-dimensional data processing.

4.2.1. Alphanumeric Inputs

First, graphic input requirements for generalized information processing systems may involve the direct entry of hand-printed or hand-written information and the automatic extraction of words from text. Entry of hand-drawn material may be by stylus with x and y coordinates fed to the computer, or by light pen movements on the face of a console screen. For example, light pen inputs have been used since the early 1950's, notably with the M.I.T. Whirlwind computer and in certain military systems.[4.4b] Special equipment such as an elastic diaphram switch device[4.5] may be used. Another handwritten character input example is the Data Trend "MIMO" Hand-Print Model input-output terminal for use in real-time on-line operation with a data processor, where the user writes his message on a platen with a special stylus. Teletype-to-computer transmission is to be used.[4.6]

Automatic extraction of words from text was apparently first proposed as a physical process guided by manual selection in terms of a "light pencil" proposed by RCA and discussed at a conference on mechanized documentation held under the auspices of the Welch Medical Library of Johns Hopkins University in 1953. If the proposed "pencil" were to be moved across a page of text, words or phrases of interest could be picked up and recorded so that, in effect, an *underlining* of words or phrases could result automatically in machine-useful input recordings. (A somewhat Orwellian prediction has been made that in the future automatic word extractions from voice signals could result in further invasions of privacy.)[4.7]

More modern versions of the word-from-text extraction concept are represented by the IBM "Scanistor",[4.8] the Institute for Scientific Information "Copywriter",[4.8a] and by the Eccetron device reported by the National Science Foundation as being in use at the Bureau of Geological and Mining Research in Paris. (Current Research and Development, No. 13, 1964, pp. 68–69). A future possibility has been suggested by recent advances in the technology of coherent optical systems.[4.8b] In general, however, automatic word extraction operations require given texts to be in machine-usable form.

Among the methods available for conversion of such textual material to machine form are the following:

(1) Initial recording of the material in dual language form: that is, in a form legible to the human eye and simultaneously in a form readable by machine, such as the hard copy typescript and the punched paper records produced by a tape typewriter.[4.8c]
(2) Manual re-transcription by various keyboarding operations such as a keypunch operation to prepare punched cards, the use of punched paper tape typewriters, or the use of stenotyping techniques.[4.9]
(3) Scanning of the printed, typed, or handwritten record by optical character reading devices and automatic re-transcription into the desired computer-usable form.
(4) Various combinations of any of these methods, as in the re-typing of original documents in a standardized font readable by available character recognition equipment.[4.9a1]

The state-of-the-art in optical character recognition, both practical and experimental, is promising, but many challenges still remain (see Sec. 5.3 of this report). Current success in terms of practical applications is largely limited to those cases where there is a high degree of control over character input quality, where the character sets to be recognized are limited (and often consist of specially designed character fonts),[4.9a2] and where the alternative of key-stroking the input material is excessively costly in terms of available manpower and time.[4.9b] The latter factor is ironically emphasized in those situations where it has been determined to be desirable to keystroke the source data information using a typewriter with a type font amenable to character reading equipment requirements and then to "read" such typed re-transcriptions by machine.

This would appear, in principle, to be a backward step in the light of modern technology. Yet it is faster than most alternative keystroking methods as currently available and the combined economics may therefore be more favorable at the present time.[4.10] Hopefully, such expedients will be of temporary duration, pending the advent of more versatile character-readers and/or improved means for initial generation of source data in machine-useful form.

Where the documentary input contains interspersed graphic material as well as text, additional problems arise.[4.11] For example, it may be required that manual pre-editing operations mark off areas of the page which the character reading device is to ignore.[4.12] On the other hand, in the future we may find input scanning systems capable both of recognizing printed or typed characters and symbols and also of processing complex pictorial material.[4.12a]

4.2.2. Special Symbol and Diagramatic Inputs

Wigington (1966) defines "graphical input-output as those forms of I/O in which are employed graphs, pictures, charts and other forms of information where the two dimensional positional relationships of information elements have importance beyond that of the ordinary formats of printed texts and lists." (p. 86). It is noted further that "the acquisition of data directly from graphical sources such as maps (for terrain, land-use data, etc.) is a developing capability which is proving its worth to the planning and design of transport facilities." (Breuning and Harvey, 1967, p. 262).

Graphic information of a highly stylized or schematic nature, such as electrical circuit or chemical structure diagrams, should eventually be amenable to pattern recognition techniques that can be demonstrated, and at least the beginnings have been made on problems of pictorial data recognition. Diagrammatic representation of chemical structures, circuit diagrams, word-association "maps" and other two-dimensional complexes of information are of obvious importance in man-machine interaction operations. Burger points out, for example, that the early work "of Opler and Baird in drawing chemical structure diagrams on a computer controlled CRT gave much promise for the future applicability of such devices." (1964, p. 2.) As of 1967, however, the input of special symbols and diagrams depend almost exclusively on the encoding and digitalization of the two-dimensional information, either by keyboard, light pen, or scanner techniques.

Keyboard devices for such purposes have been explored as in the Army Chemical Typewriter system,[4.13] studies at Monsanto[4.14] and at Redstone Arsenal,[4.15] and in a system described by Cossum et al. (1964). In the latter case, an optical scanner looks for black areas, applies a feature detection logic for symbol and character recognition, and constructs and checks the connection table. Both in this system and in the earlier Monsanto experiments, a degree of error detection is provided, especially to check whether or not there is a well-formed structure with every element connected to at least one other and with all connections recorded in both directions.[4.16]

Amann and Klerer (1966) report on a modified Flexowriter device for two-dimensional input of mathematical equations where the machine system will subsequently recognize even badly formed symbols[4.17] and Klerer and May (1965) describe the two-dimensional programming and other details associated with this device.[4.17a] Another system for on-line input and display of mathematical symbols and equations is AMTRAN (*A*utomatic *M*athematical *Tran*slation), described by Reinfelds et al. (1966) and Clem (1966).[4.17b] A special terminal for keyboard entry of mathematical symbols has been developed by the Oceanographic Laboratory, Columbia University.[4.17c]

Hoffman (1965) discusses the use of the Army Chemical Typewriter in the IDEEA (*I*nformation and *D*ata *E*xchange *E*xperimental *A*ctivities) network and points out that, by interfacing the ACT with a computer, error checks and preprocessing such as data classification can be performed on input of both alphanumeric data and symbol representations.[4.18] Tate (1967) includes in a review of developments in the handling of chemical compound information references to modified key punch devices to record structural diagrams directly (Waldo and de Backer, 1959, and Horowitz and Crane, 1961), modifications to tape generating typewriters, and the INVAC–TT–200 structure typewriter that records directly onto magnetic tape.[4.19] Bozman (1967) describes information control codes for encoding and decoding the use of "Typits" in the special typewriter designed by Duncan and Weissberg at NBS, with applications for chemical diagram input.[4.20] Later NBS developments are incorporated in the "Document Image Code System",[4.20a] as shown in Figures 5 and 6.

Scanner input examples include investigations by Meyer (1965), Ledley (1963), and again Cossum et al. (1964).[4.21] Many of these developments will be discussed in more detail in another report in this series, in connection with character set requirements for both input and output. There are questions, however, as to the development of effective means for the regeneration in two-dimensional form for display of chemical structure information represented in linear ciphers, connection tables, and other special notations. There is also the question of the further operational development of techniques whereby the chemist enters the two-dimensional structural information directly into the machine.[4.22]

4.2.3. Graphic Inputs and On-Line Drafting

With respect to two-dimensional graphic data inputs we note generally, of course, that analog-to-digital conversion and hybrid analog-digital techniques are required in many applications such as the use of the sound spectrograph [4.22a] and the automatic processing of electrocardiographic and electroencephalic recordings. In this connection we note also that computer analysis of encoded electrocardiographic and electroencephalographic data has been the subject of a number of investigations over the past several years. By 1965, Bobrow et al. (pp. 125–126) could report 93 and 94 percent accuracies of electrocardiographic amplitude values as measured by computer and could conclude that: "The computer actually provides a more precise standard than does visual measurement. An automated system can accurately identify and measure the waveforms of an electrocardiogram." [4.23]

Klingemann and Pipberger (1967) emphasize that automatic techniques of EKG analysis are needed because a large number of measurements and more efficient classification methods are not practical without the use of computer facilities. A Japanese example is provided by Okajima, et al., 1963.[4.24]

Another illustration of progress in this application area is provided by Whipple et al. (1965) who discusses an electrocardiograph analysis program relating also to special communication networks, that is, the use of frequency-modulated transmission of the data from the Massachusetts Memorial Hospitals to a GE225 computer and teletype display of the resulting diagnosis.[4.25] Stark et al. (1965) also report on remote access computer diagnosis of EKG data.

Man-machine interactive input of two-dimensional data typically involves the use of such devices as the RAND Tablet [4.26] and commercially available equivalent devices including Data Equipment Company's Grafacon 1010 [4.27] Itek's EDM (Electronic Drafting Machine) [4.28] Sylvania's Data Tablet [4.29] or an IBM handprinting input device.[4.29a] At the IIT Research Institute, Chicago, the "Electrosketch" is similar in function to the RAND Tablet, but it consists of "a small plastic knob or stylus which the user grasps and is free to move about the working surface." (Cameron et al., 1967, p. 350). Simek and Tunis (1967) describe a development also similar to the RAND Tablet, but using conventional paper and pencil.[4.29b]

It is claimed that the III (Information International, Inc.) Computer Eye is a sensor and processor capable of selectively measuring, inputting, and processing a variety of graphic images. Suggested applications of the III Computer Eye include microscope measurement and classification of biological samples, digitization of drawings, maps, and photographs, and measurement of the texture granularity and color of various materials.[4.30] The IBM Cartographic Scanner is used by Canada's Geographic Information System to develop maps of land use.[4.30a]

Still other examples of techniques available for on-line drafting and graphic input obviously include the SKETCHPAD System at M.I.T.[4.30a2] and the "Light Handle" at the Aiken Computation Laboratory, Harvard University,[4.30b] as well as systems developed by SDC [4.30c] Control Data Corporation,[4.31] RCA,[4.32] General Motors Research Laboratories,[4.32a] and Computer Sciences Corporation.[4.33] At the National Bureau of Standards, the MAGIC System (*M*achine for *A*utomatic *G*raphics *I*nterface to a *C*omputer) is used for a variety of man-machine communication and display experiments. (Rippy et al., 1965).

Then we note that the "Eyeball" device developed at the Lawrence Radiation Laboratory provides for the digitizing of pictorial data for regeneration on computer output interspersed with text. (Conn, 1967), and that, in a Bolt, Beranek and Newman system, "the visual pattern to be analyzed by the system is drawn on the face of the computer CRT display scope by means of a light pen." (Marill et al., 1963, p. 27). Pictorial data input is described by Ledley as follows: ". . . The computer must

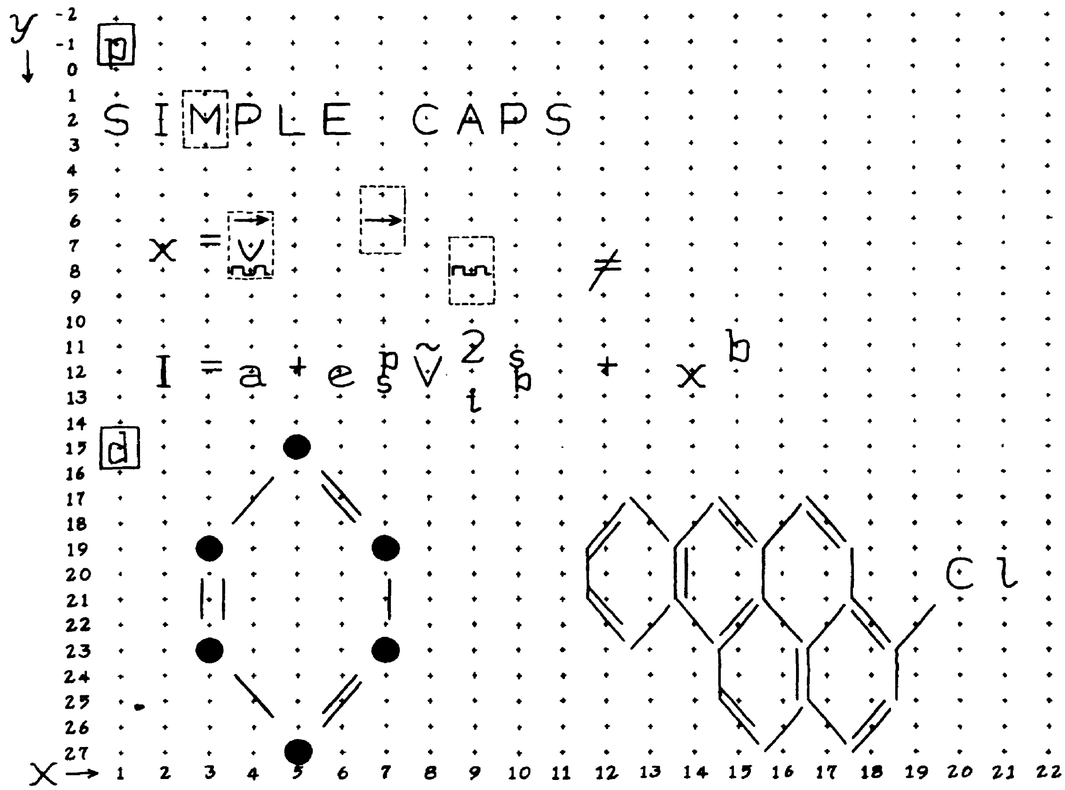


FIGURE 5. *Model typescript page at expanded scale.*

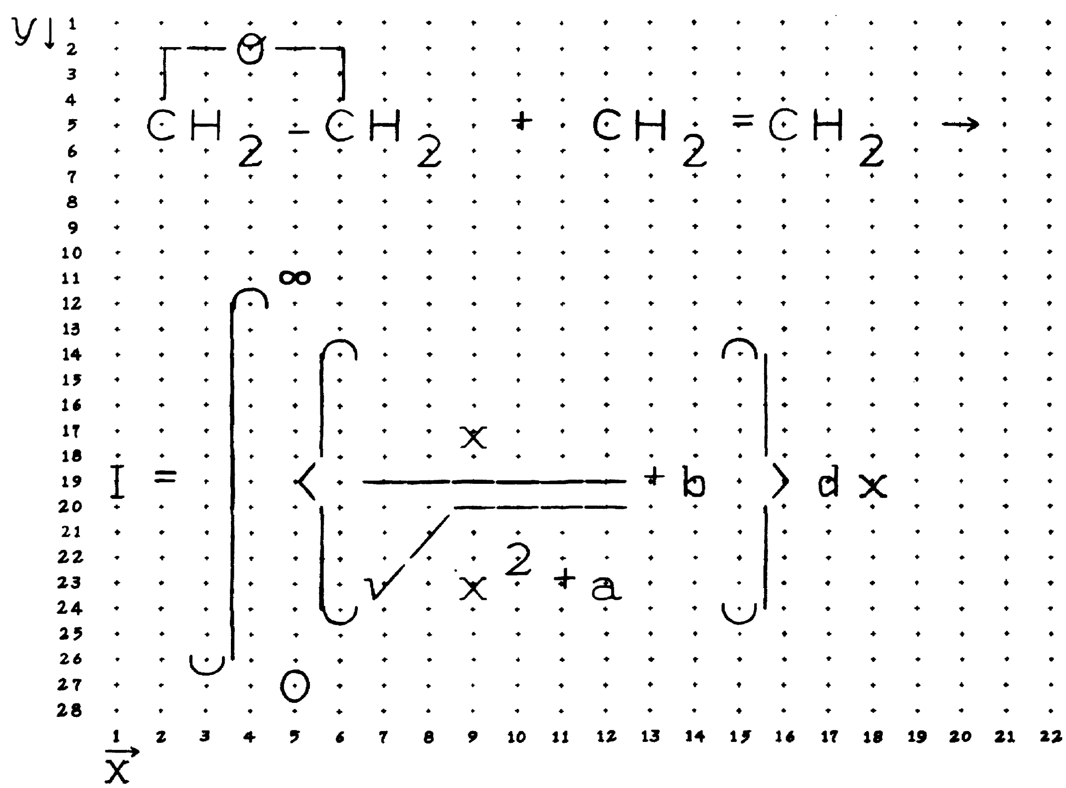


FIGURE 6. *Two illustrative display formulas.*

then interpret the symbols and structural relationships of the drawing, in preparation for the final coding task. The picture scanning is accomplished by a device called FIDAC (Film Input to Digital Automatic Computer). Pattern recognition techniques are used for the structure and relationship analysis." (Ledley, 1963, p. 201).

4.2.4. Pictorial and Three-Dimensional Data Input

Other areas of graphic input of current R & D concern are for the pickup and processing of diagrams, drawings, and photographs.[4.34] Rushforth (1965) provides one example, among many, of pattern analysis, identification and classification by computer as applied to aerial photographs. Bertram provides an example of mixed input requirements for such applications, that is, to provide such pertinent camera data as the position and altitude for each stereoscopic pair of photographs as taken, the focal length, and the distortion characteristics of the lens.[4.35] A scanner developed at NBS, described by Moore et al. (1964) digitizes 9-inch aerial photographs for computer analysis of stereographic differences.[4.36] At Aeronutronics, a PDP–7 system will be used for film-scanning experiments designed to test techniques for automatic detection and analysis of data contained in aerial photographs.[4.36a1]

Stereoscopic initial data recording and three-dimensional depth reconstruction by machine processing and computational techniques is of obvious significance in the automatic or semi-automatic analysis in such areas of application as aerial photograph interpretation,[4.36a2] target identification,[4.36b] map or contour matching,[4.36c] and analysis of bubble-chamber data with respect to the detection of high-energy-particle collision events.[4.36d]

As noted previously, McGee and Petersen report on a computer-controlled CRT scanner used to measure automatically bubble chamber tracks as recorded on film but applicable also to pulse height analyzers, telemetry converters, and other data collection systems. Also at the University of Illinois, a relatively early computer program, FILTER, was designed for recognition, separation and measurement of star-type nuclear events.[4.37] The use of ILLIAC III as a processor of visual information with application to problems of cloud pattern detection was described at an IFIP Congress 65 symposium. (McCormick et al., 1966.)[4.37a]

Research and development interests in the area of three-dimensional data input and manipulation are exemplified first by Sketchpad III, which is a computer program to facilitate the entry into the M.I.T. processing system of three-dimensional drawings. (Johnson, 1963).[4.37b] Roberts (1965, p. 211) reports that: "Sketchpad III extends the graphical construction process to three dimensions by enabling one to draw in any of three views on the scope, thus constructing a computer representation of a three-dimensional drawing."

He suggests (p. 185) further that: "After a list of three-dimensional objects has been obtained in some manner, it should be possible to display them from any point of view. The sections of objects behind other objects should not be seen, nor should the back lines and construction lines of individual objects. The three-dimensional display program will do all this and more."[4.38]

Roberts also briefly describes earlier work by Julesz[4.39] on machine depth perception applied to binocular images. This is a procedure which shifts the two images to find the areas at different depths using texture, rather than detected edges, to develop this information.

An approach to two-dimensional scanning, data analysis, and three-dimensional reconstruction is being investigated by Kirsch at the National Bureau of Standards (Lipkin et al., 1966)[4.39a] Here there is a multi-level gray-scale scan applied to a series of microphotographs of successive cell tissue slices which by their transparent nature give defocused images that are out of their focal plane. A computer differentiation program then enables the determination of proper plane for the image with respect to its original locus in the tissue.

In 1966, Roberts described the Lincoln WAND, extending tablet principles to three-dimensional input by the use of a hand-held receiver accepting signals from four ultrasonic transmitters,[4.40] and Denil reported on an IBM development of a language and three-dimensional light pen input technique for computer-aided design applications. In 1964, McDonough suggested placing an object between two grids and using light beam reflectance measurements to determine the thickness of the object at various points.[4.41] A similar technique had been proposed even earlier by Russian scientists. (Garmash, 1961).

Then we note that three-dimensional x-ray photographs may be used to measure automatically the distances between components in a potted module and in medical applications to measure the depth of a bone infection.[4.42] There are also important three-dimensional aspects in machine-aided design processes, especially in the aircraft and automotive industries, for which far more progress is promised in the near future. Proximity probes and a light-scanning measuring machine (Ex-Cello-O) have been used to measure length, width and height of clay models. A proposed laser device would also operate as a fixed scanner above a movable table on which the model is mounted. However, Gomolak reports: "Because of its coherent beam and resolution, the laser probe closely approaches measuring with a true point . . .. Reported accuracy of this new laser machine is 0.0001 inch in all three coordinates (1965, p. 66)."[4.43]

An idealized graphic input-output system, potentially capable of processing "three-dimensional curve and surface perspective projections into two dimensions" is reported by Parker (1965, p. 100). Certain developments in new technologies, such as those of holography (to be discussed in a later report in this series) offer additional possibilities for pictorial and three-dimensional data processing, storage, and retrieval.[4.44] For another example, Okaya (1966) considers an automated method for three-dimensional data-gathering, in the case of single-crystal crystallographic diffraction studies.

As of today, it is feasible to scan graphic and photographic input and convert the initial two-dimensional and grayness level information into digital form which in turn may be reproduced as a reasonable facsimile of the original, either for transmission purposes (most spectacularly in the case of Surveyor's color photographs of the moon's surface), for purposes of digital storage, and for purposes of further computer processing as in the case of qualitative pattern recognition, that is, situations where certain pattern transformations are performed either to obtain desired end-products directly or to facilitate further processing, recognition, or classification.[4.44a] In addition, advanced experimental work includes the automatic analysis of three-dimensional scenes, even although represented in two-dimensional forms. Examples include the Cyclops I experiments at Bolt, Beranek and Newman (Marill et al., 1963),[4.45] work by Rosenfeld[4.45a] and by Kanal and Randall[4.45b] an experimental program described by Evans (1964),[4.46] and current research under Minsky at M.I.T.[4.47]

However, techniques of automatic pattern detection and recognition of two- and three-dimensional data are as yet highly experimental and much further research and development must be pursued before they can be advanced far enough for practical applications. Most of the techniques that are being explored for automatic pattern recognition are highly dependent upon efficient preprocessing operations. These operations typically include the extraction of significant or criterial features; image and information enhancement processes designed to reduce noise in the input pattern, to eliminate redundancies of the input signals, and to sharpen selective areas such as either edges or "skeletons" or, in another case, the "medial axis transformation" of a pictorial pattern to be described, identified, or classified.[4.48]

5. Preprocessing Operations and Pattern Recognition

Closely related to the problems of character, shape, and pattern recognition for information input and sensing are operations upon the input patterns that are sensed, which we show as pertinent to Box 3 of Figure 4 (p. 21). These include image improvement operations such as boundary and contrast enhancements; noise and redundancy reduction as in stroke thinning; extraction of salient or criterial features and the development and use of property filtering techniques.

There are, for many applications, important requirements for noise and redundancy eliminations, for filtering, and for feature extraction operations as close to the data source as is possible.[5.1] That is, "a reduction is necessary, for otherwise the tasks involved merely in obtaining input data in a suitable form for processing in concepts become overwhelming—the field of visual pattern recognition is a vast one in which certain problems have baffled the experts for years, and in which breakthroughs come slowly." (Strom, 1965, p. 110). Then there are processes designed to reduce or eliminate background noise, as by the use of infrared or ultraviolet scanning techniques that will sense only the printed characters to be recognized on paper forms that may have been overstamped or subjected to extraneous superimposed noise such as dirt, coffee stains and the like.[5.2]

5.1. Preprocessing Operations, Image and Information Enhancement

Contrast enhancement in optical character recognition developments is often achieved by a quantization process in which subareas of the input pattern are checked against threshold values in accordance with which it is determined that the particular subarea is "black" or is "white" (or, in other cases, the determination is in terms of some set of specified gray-scale levels). In other cases, however, analog values are first processed[5.3] because, for example, of Nadler's argument that black-white quantization of a character 'rivets the noise to the signal',[5.3a] and that therefore as much processing as possible should be done on the raw video signal before quantization.

Boundary and contrast enhancement preprocessing operations are of particular importance in input patterns involving multilevel gray scale.[5.3b] For one example, boundary and contrast enhancement techniques developed at the National Physical Laboratory, Teddington, England are being applied to pictorial data processing of fingerprint and chromosome patterns. These preprocessing techniques are based on Fourier transforms resulting from apertures placed in the plane of an imaging lens to suppress selected spatial frequency components. The basic pattern to be processed is in the form of a photo transparency, illuminated by a laser or other monochromatic light source whose collimated output is brought to a focus by a lens, which re-images the input, via various Fourier plane and band limiting stops, to a processing-image plane such as a TV camera, whose video signals may then be fed to pattern-processing or recognition system.

Demonstration photographs for output results for chromosome photographs show both outlining effects (elimination of areas of relatively constant gray-scale density by low-frequency-component sup-

366-107 O - 70 - 3

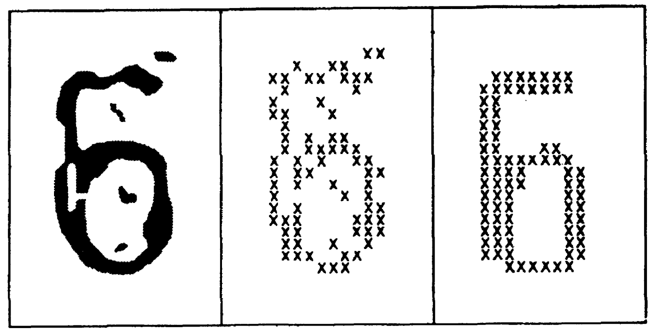
pression) and reduction of noise and fine granular structure (by suppression of high-frequency components).[5.4] Similarly, with respect to a multispectral imagery program at the University of Michigan, a primary goal "is to see if the information content in the multiple channels can in some way be processed and combined electrically to produce an image with enhanced target-to-background contrast." (Parker and Wolff, 1965, p. 24).

Preprocessing operations of various types such as reduction of solid black areas to their outlines, were developed for pictorial data processing applications at the National Bureau of Standards in the mid-50's. (Kirsch et al., 1957). Extensions and further development of these techniques have been carried out by Moore (1964) with particular reference to quantitative analyses of photomicrographs with the scanner on-line to the computer. More specifically, photographic material can be read directly into the computer, subjected to various logical manipulations and analyzed mathematically for 20 numerical parameters.[5.4a] Schreiber et al. (1968) indicate, for another example, that pictures, including printed material, can be reconstructed from efficiently encoded contour information.[5.4b]

In a 1966 survey, Hart points to two major types of preprocessing operations for information enhancement as "dimensionality reduction" (where the pre-processors are designed to reduce the computational load on the processor in its decision-making by taking a large number of measurements and reducing them to a smaller number) and "feature extraction" (where the purpose is to make only those measurements that are likely to provide a great deal of information about the pattern). In this survey, Hart covers slightly more than 50 papers and reports concerned with the theory and application of preprocessing techniques in pattern recognition.[5.5]

Preprocessing operations designed to enhance the information content of an input pattern typically involve either reductive transformations and normalization, or both. Thus, in optical character recognition, stroke width normalization may be applied.[5.5a] One example is a development at International Computers and Tabulators, Ltd., where one, two, or three cell widths in the input pattern are processed through logical networks to provide a three-cell stroke output. For photointerpretation applications, it is reported that "another recent processing operation, known as phototone, consists of the edge enhancement of an aerial photograph. The enhanced image is then added to the image to produce a more legible photograph; the total process can be considered as a type of pre-emphasis filter." (Tobler, 1968, p. 267). Image enhancement for noise reduction as developed by Gattner and Jurk (1963) is illustrated in Figure 7.

It may occur that the information enhancement and noise reduction processes are interdependent to a high degree. Thus, if a small black area is



a Original image *b* Scanned image converted into black-and-white picture *c* Character after reduction of noise

FIGURE 7. *Image enhancement for noise reduction.*

sensed in the lower right-hand vicinity of an input image otherwise probably identifiable as an uppercase "O", there are very real questions as to whether contrast enhancement and reductive operations should be performed (in the case that the black area is a flyspeck or other accidental noise) or whether, on the contrary, gray-level-threshold settings should be relaxed (in the case that the black area results from broken connectivity for a defectively printed "tail" of uppercase "Q"). Rabinow points out, moreover, that "an 'O' and a 'Q' may only differ by 5 percent in area, but the difference in electrical output between the correlation circuits can be made to be 30 percent, or more." (Rabinow, 1966, p. 23).

Similarly, in speech analysis and synthesis research, Liljencrantz (1965) reports of a filter bank speech spectrum analyzer developed at the Royal Institute of Technology, Stockholm, that the band-pass filters in the bank "can be set in a number of different combinations of center frequencies and bandwidths. In this way it is possible to make a gross analysis for orientation as well as detailed analysis with a high resolution in either frequency or time." (p. 1).

The appropriate interaction between noise elimination and information enhancement operation should obviously be subject to control by system-feedback inputs and threshold setting. Another obvious example is height-and-width-parameter re-scanning in the case of character recognition techniques that are intended to discriminate between upper- and lower-case inputs and between ascender and descender indicia, whether for individual character or for specific character-string sequences.[5.5b]

Consider the feedback mechanisms involved in a gross scan followed by a more refined scan pattern upon the detection of certain pre-designated indicia. Such indicia may include the "finding" of a fiduciary mark and the subsequent alignment of the detail scan to follow a tilted page or line (FOSDIC);[5.6] the "first-finding" of a black line of type or print as the scan comes up from the bottom of an envelope in an early Farrington reader for postal addresses,[5.7] and the adjustable scan focus-defocus settings based upon relative height-width determinations of an initial character of an address-line.[5.8]

Image enhancement operations may also depend upon feedback factors with respect to neighboring cells of a given cell in a quantized graphic input matrix. That is, a black cell may be retained as "black" in an improved image according to the number of orthagonally adjacent cells that are similarly black, or it may be erased if a majority of its immediate neighbors are "white". Thus, such operations may serve both to thicken or fill in a black line, area, or character stroke and simultaneously to smooth rough contour edges and to eliminate small areas of apparent noise.[5.9]

Distance transformations, based upon such local neighborhood operations, have been explored by Rosenfeld and his associates, among others.* Detection of clusters, edge or boundary enhancements or their converse—skeletonizing, and noise elimination or smoothing—are all possible applications of these preprocessing techniques for pictorial data.[5.10] For example, Rosenfeld and Pfaltz (1966) describe sequential operations that label components of a given subset of pictorial data and compute distances from every picture element to this subset. In terms of the distance function, a "skeleton" subset can then be defined that serves to minimally determine the original subset.

5.2. Property Filtering and Feature Extraction

Tou and Heydorn (1967) emphasize that the preprocessing operations which reduce dimensionality have as the goal the minimization of entropy—that is, to provide transormations from many to few dimensions or properties, selecting those most discriminatory for one class as against all other classes.[5.11] Similarly, Hughes and Lebo state that "the term 'feature' implies a combination of two or more measurements which, taken together, describe some pattern aspect relatively invariant within one class, but with a different characteristic set of values outside that class. A feature is a set of two or more measurements taken as a vector measurement pair." (Hughes and Lebo, 1967, p. 19).

Extraction of criterial features, feature detection, and determination of class-membership properties have the objective of isolating and identifying the most *salient* characteristics of input data in terms of pattern recognition or categorization requirements.[5.11a] However, as Hart remarks, "there is no good conceptual framework in which to view attempts at feature extraction, and consequently a success on one special problem seldom sheds light on a solution to a slightly different problem." (Hart, 1966, p. 29). Chen (1966) suggests that recursive feature-*ordering* will have significant advantages [5.11b] and Chu and Chueh (1967) claim that if a sufficient number of well-selected features is used in character recognition, the error probability of a Bayes decision function can be made arbitrarily small.

Among the many techniques for feature extraction that have been investigated are those of stroke direction encoding, edge and corner detection, detection of "lakes" (fully enclosed white areas) and "bays" or "inlets", and the use of other topological properties of input patterns.[5.12] Schultz (1963), for example, has expanded the number of such features previously included in patented systems of this type and has included the use of contextual information to separate alphabetic from numeric characters.

At Siemens in West Germany, for another example, the recognition philosophy is that of the extraction of criterial features from character shapes, largely independent of character size, location in the input image field, and, to some extent, orientation (Gattner and Jurk, 1963). Noise reduction is first applied to eliminate isolated noise and to smooth ragged edges. As early as 1958, a computer program involving the application of majority logic to a small, sliding submatrix (as in some other local neighborhood preprocessing operations) was developed. The features (or "form elements") used include determinations of convergence or divergence of character strokes. Ledley's "Bugsys" procedures are a special case in which it is desired to locate and trace the features essential to pattern detection for digitalized photographic input data.[5.13]

Then, at the M.I.T. Research Laboratory for Electronics "a character-recognition procedure for the identification of letters and numbers in newsprint has been developed. The approach is based upon automatic tracing of the outer black-white edge of each letter. After nonlinear smoothing, of the 'gear backlash' type, the horizontal and vertical position-coordinate waveforms are processed to detect the sequence of horizontal and vertical changes of direction, together with low-resolution information on the spatial locations where such changes occur. The result is a 30-bit code word from which the letter is identified by look-up in a stored list, in which there may be several different code words associated with the same letter." **

Criterial feature techniques that combine various topological properties and stroke direction clues developed at a relatively early date include those of Grimsdale et al. (1959) to determine the number, size, curvature, relative length and orientation of constituent segments of character patterns, Sherman (1960) with respect to recognition of hand-printed characters, and Frishkopf and Harmon

*A comprehensive study of pictorial data processing by Rosenfeld (1968), was unfortunately received too late for discussion in this report.

**Quarterly Progress Report, Research Laboratory for Electronics, No. 80, RLE, M.I.T., 218 (1966) (further references are given to: J. K. Clemens, "Optical Character Recognition for Reading Machine Applications", Ph. D. Thesis, Dept. E.E. M.I.T., Sep. 1965 and H. Teager, "Multidimensional Visual Information Processing", Conf. Advances Biomedical Computer Applications, N.Y. Academy of Science, N.Y., June 3–5, 1965).

(1960) with respect to constrained cursive handwriting. (See also, Sec. 5.4 of this report.)

Current projects under Steinbuch at the Technische Hochschule, Karlsruhe, further exemplify the importance of preprocessing operations in different areas of automatic pattern recognition. First, investigations of automatic processing of pictorial data contained in aerial photographs are under way.[5.13a] The objectives include the location of streets and the recognition of objects such as vehicles and the determination of their coordinates. The scanner provides a variety of scanning modes and varying resolutions, under programmed control, including line scans, point scans, rotating a spot of variable diameter around a point, and the capability of illuminating a line on the screen and rotating it so that intersections with small, fine lines are detected.

In the detection procedure, the presence of parallel lines is first looked for at relatively low resolution and then within the indicated area vehicles are looked for with high resolution. The scanning system preprocessing capabilities include an analog-digital converter to process 64 levels of gray-scale information. Preprocessing operations include evaluation of density gradients, detection of contrast boundaries by detecting phase of signal and determination of boundary directions.

Preprocessing operations of feature extraction may also provide means for some degree of data compression for either storage or transmission. Thus, "the ability to reconstitute patterns from features suggests a means to transmit a set of high-resolution photographs over a low-bandwidth channel. . . . If the total number of features for any set of patterns is less than the total number of retinal cells, then the feature-detection technique can be a means for achieving bandwidth reduction in an image-transmission system." (Block et al., 1964, p. 83).

For another example, at M.I.T., "the nonlinear processing of pictures, for elimination of all features other than the principal edges, is being investigated. The aim is to simplify pictures to the extent that tactile display and perception of the principal edge patterns becomes practical." It is reported however, that "edge extraction, which involves processes related to spatial differentiation of the picture intensity function, is a nontrivial operation, especially for noisy pictures. Edge extrapolation and smoothing, which are desirable operations from the standpoint of noise elimination, place the problem in the realm where general pattern-recognition considerations become important." (Quarterly Progress Report, Research Laboratory for Electronics, No. 80, M.I.T. 219 (1966).)

Minsky (1962), 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 extraction 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. 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.[5.13b]

In many of these areas of development, an important R and D objective is to identify those criterial features that are relatively invariant under transformations of size, location in the input image area, and orientation. One approach is that of "autocorrelation".[5.14] The CYCLOPS machine at the National Physical Laboratory, Teddington, England, is an electronic version of the earlier Parks technique for detecting criterial areas in character autocorrelations as originally realized in an optical system by Clowes (1962). Analog techniques are used to carry gray-scale information along to the recognition logic. Extraction of criterial features of this type in the case of whole words or multicharacter sequences is exemplified in the work of Clayden and Parks (1966), also at NPL.[5.15]

Other character recognition techniques that have been experimentally developed, such as that of Alt (1962), provide considerable invariance to size, rotations, or placement in the input image field. Hu (1965) also has proposed the use of moment invariants for recognition. These moments are derived by a summation of products of the density distribution and the distance from an arbitrary axis.[5.15a] Various optical techniques have been exploited for such purposes, including the derivation of the Laplacian function,[5.15b] or Hilbert transforms,[5.15c] as well as several variations on the use of Fourier transforms, although at a relatively high processing cost.[5.15d]

From these examples, it is evident that character and pattern detection and recognition techniques are of interest with respect to the current state of the art in the computer and information sciences on at least a two-fold basis. First, such techniques offer automatic means of sensing, transcribing, and re-recording of data values or textual interpretative statements as originally marked in a prepared format for marksensing, visually encoded as by means of a bar or color code, or handprinted, drawn, typed or printed as alphanumeric characters and other graphic symbols. Secondly, insofar as these techniques incorporate adaptive or self-organizing features, they are themselves fruitful areas for the development and application of advanced research principles.

5.3. Optical Character Recognition

The area of automatic pattern recognition R & D effort that has had the greatest practical application to date is that of optical character recognition (OCR), especially for relatively limited or standardized fonts and character sets. Looking first to the techniques for the automatic recognition of printed, typed, or machine-embossed alphanumeric characters, considerable progress is to be noted in the field of the limited-character-set category. Several hundred optical character reading machines of this limited type are now in operation, largely for commercial data processing applications such as insurance premium billing, credit card accounting and subscription renewals.[5.16] Some 14 to 15 commercial suppliers offer OCR equipment in the United States alone.[5.16a]

However, it is noted that "the scope of applications for character readers is currently limited primarily by their inability to read a variety of different fonts, by their poor performance on handwritten documents, and by the lack of standardization within the industry. Consequently, considerable development effort is being put into these areas, as well as into improvements in reliability and speed." (Feidelman and Katz, 1967, p. 0210:30). The special case of retyping to a specialized font has been mentioned previously (Sec. 4.2.1).

5.3.1. Multifont Character Reading

On the other hand, there are potential breakthroughs promised in the relatively recent operational installations of variable-format-page-reading and multifont machines. Devices incorporating one or both features include both the pioneering and the more recent Farrington machines,[5.17] Recognition Equipment Inc.'s "Electronic Retina Character Reader",[5.18] and Philco's multifont page reader.[5.19] Huntley (1964, p. 94) cites reject rates for two operational alphanumeric page reader installations as 1 in 100,000 and 6 in 100,000.

Among the advantages to be expected from multifont page readers are capabilities for reducing the amount of proofreading required in the preparation of manuscripts and other copy,[5.20] and for various decentralizations of input preparation operations.[5.21]

Other important developments in multifont page reading are the operational IBM 1975 Optical Page Reader,[5.22] the experimental Link Page Reader developments at the Link Division, General Precision, Inc.,[5.23] and laboratory investigations at Sylvania.[5.24] Earlier investigations of multifont possibilities at IBM included the development of computer programs for the design of recognition logics to be applied to multifont inputs, including two Cyrillic fonts (Kamentsky and Liu, 1963).

The Control Data 915 variable-format page reader was designed for use with the recommended optical character font (upper case) of the American Standards Association[5.25], but Hustvedt (1967, p. 3) notes that "the CDC reader Rabinow is now building for Bank of America will operate with the loosest possible constraints of a controlled operation . . . it is expected to read the output of all typewriters the bank owns and with very little or no constraint on format and other variable factors." A recent Japanese entry in the multifont field may also be noted: the Toshiba OCR developments are directed to the reading of six or more stylized fonts and handwritten numerics.[5.26]

In general, however, it is still reasonable to assume that: "The multiple font recognition problem is probably the most intriguing challenge of character sensing. When requirements for large quality tolerance, and cost compatible with value, are added to this problem, basic recognition philosophy, as well as the means for implementation, must be re-evaluated." (Greanias, 1962, p. 145).

Nevertheless, multi-font optical character readers are in use by or on order for such U.S. Government agencies as the Social Security Administration,[5.27] the Army Finance Office, the National Security Agency, the Defense Intelligence Agency, the Library of Congress, and the Rome Air Development Center. In addition, a special Philco reader for Zip code recognition is being tested by the U.S. Post Office Department.[5.28] The versatility of automatic character readers is still quite limited, however, both with respect to the number of fonts that can be processed without extensive manual handling[5.29] and with respect to format differentiation for inter-mixed input of varied type items.

Thus, a continuing R and D requirement in the area of information sensing and input is the development of more versatile, large vocabulary, multifont page readers.[5.30] In a survey of the OCR field reported in 1966, Feidelman concludes: "The character recognition field is relatively new, with much work to be done on improving equipment performance and developing character readers at lower cost. Consequently, it is in an active state of developmental flux that can be expected to continue for several years. In the near future we can expect to see the multi-font capability in all standard character readers. Further away, possibly in five years, character readers able to read handwriting should be commercially available. By that time, we can expect to see the character reader replacing punch cards as the primary computer input medium." (p. 52).

For obvious reasons, it would appear likely that commercial interests in R & D in the computer and information sciences are now and will continue to be largely oriented to those areas which promise the relatively largest continuing markets. Multifont page-reading automatic character recognition techniques may therefore be expected to be achieved for a wide variety of preformatted schedules and reports used extensively by business and industry or as required by Governmental practice, yet such developments are unlikely to be extended to the typical page of a scientific or technical journal, in English; much less to those printed in Russian, Japanese, or Chinese.

Programmed scanning and directed re-scanning as preprocessing operations are becoming available for certain types of character recognition requirements, such as the processing of variable formats when several different forms are inter-mixed.[5.31] Further, "with a stored-program controller, the system can determine three very important things during a single reading pass: (1) Whether or not there has been a mistake in data preparation, (2) Whether or not there has been an omission in data preparation, and (3) Whether or not the machine has read the data correctly. Also, the system can edit, accumulate, balance, verify check-digits, check parity, and condense data to provide easier access and reduced storage costs. Exception documents can be marked and sorted during the single reading pass, and details can be printed on a peripheral printer so that corrections can be made easily." (Philipson, 1966, p. 128.)

In other potential applications, incoming textual materials 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 example is analogous to the rough sorting of incoming mail, where a preliminary distribution by subject-matter or field-of-interest 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. Conversely, the reader equipment may be designed so that it reads only underlined material, such as the specific words in a patent text indicated by an analyst as those to be converted to appropriate code symbols for subsequent mechanized search. However, much remains to be done before recognition equipment can successfully "read" a typical documentary page.[5.32]

How is a machine system to be given the necessary detailed instructions that will enable it to distinguish in automatic page reading applications between the same symbol (such as ".") being used as a punctuation mark terminating a sentence, as a denotator of an abbreviation, or an indicator of numeric fractions?[5.33] 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 preprocessing steps such as the sorting of material by font type or the masking out of graphic material and of footnotes appearing in small point size.

There are also many unresolved problems involved in the development of suitable rules so that machine techniques can be used to distinguish between title, heading, or page number and the text itself, author's name in a cited reference and the title of the reference cited, and so forth. Automatic recognition of discrete characters at input is difficult enough for character and font vocabularies of adequate size for text-processing purposes in any case, but Garfield (1965) points to "fantastic syntactic problems even if the machine has a universal multifont reading capability. For example, in the citation, J. Chem. Soc. 1964, 1963, which number is the year and which the page number? These are not trivial problems." (p. 189).

A particularly severe variant of this problem arises in the processing of texts involving intermixed languages, alphabets, and meta-textual emphases. The problem of subclass within a pattern class is especially acute in character recognition applications involving mixed alphabet input, where either many-to-one or many-to-many identification transcription is required. Thus, it may be required to recognize the character shapes "A", "a", "α", and "Я" as all identifiable and transliteratable to ASCII code 10000001 (='A'), *or* it may be required to separate the Greek and Cyrillic from the Roman versions of the same character as separate identification classes. The problem is aggravated by the fact that the existence of orthographic identity in character shapes does *not* necessarily imply identity of character denotation. Consider that the mix is Cyrillic and Roman. When does the input character pattern "H" denote 'H' and when 'N'? or "C", indicate 'C' and not 'S'?

The current state of the art in optical character recognition thus leaves much to be desired other than for routine, massive operations involving large volumes of simple, format-controlled messages and records, which typically utilize limited, special-purpose, standardized fonts and character sets. Beyond the questions of multiple fonts and large character repertoires are problems of recognizing noisy and degraded characters.

It is to be emphasized that "there is no known shortcut to optical character reading, stylized fonts included. The real problem is reading degraded material, not different or stylized fonts."[5.33a] Vander Lugt et al., point out further that: "In the design of any practical system, one must know how the system performs when the input characters are noisy. Three kinds of noise are considered: changes in the signal size, changes in the signal orientation, and changes in the signal quality." (Vander Lugt et al., 1965, p. 131).

5.3.2. Performance Requirements and Quality Control

The problem areas of continuing concern therefore include those of paper handling, quality control and performance monitoring, dealing with noise and with degraded characters, reject handling, and error detection and correction techniques.[5.34] First, paper handling represents a major factor in OCR equipment cost and a constraint on the speed of automatic reading.[5.35] Quality and performance control efforts include the further development of measurements of print characteristics [5.36] such as ink smudge and bleed,[5.37] or of light stability,[5.38] and of instrumentation such as the Kidder optical character tester,[5.39] or the Optical Print Quality Monitor of International Computers and Tabulators, Inc.[5.40]

The need for extensive quality control measures in OCR applications is further attested by Hustvedt as follows: "The day of successful, economical optical character recognition is here, as several hundred operating installations attest. In all successful operations, however, control is exercised over the preparation of documents to be scanned." (Hustvedt, 1967, p. 2.)

Controls are also required in the selection of good quality paper and in minimizing the effects of careless handling.[5.41] Paper with extraneous material likely to interfere with clear imprinting, or even with watermarks, should be avoided if possible.[5.42] The system planner considering possible OCR applications must next consider the quality controls available in terms of line and character registration tolerances both for the input items and for each of the equipments under consideration.[5.43]

In experiments reported by Vitale (1965) the objectives are to obtain figure-of-merit measurements on sampled characters both to determine degrees of degradation and to determine what error and reject rates might be expected if recognition logics were adjusted to given levels of noisy printing. Uffelman et al. (1967) have investigated the character- and stroke-dependency of noise.[5.44]

However, it has been pointed out that "unfortunately, procedures for handling rejected and error documents are quite necessary at present. In all fairness, it should be noted that most causes of rejects are due to the source document rather than the OCR device. Nevertheless, one must consider the entire operation with its good and bad documents against the present operation." (Auerbach Corp., Source Data Automation, 1967, p. 3–133.) Moreover, while the IBM 1975 multifont reader operating at Social Security can read between 50 and 60 percent of typical inputs, "any improvements in the portion read must come from improvement in the preparation of reports by employers—a difficult matter." (Hustvedt, 1967, p. 3).

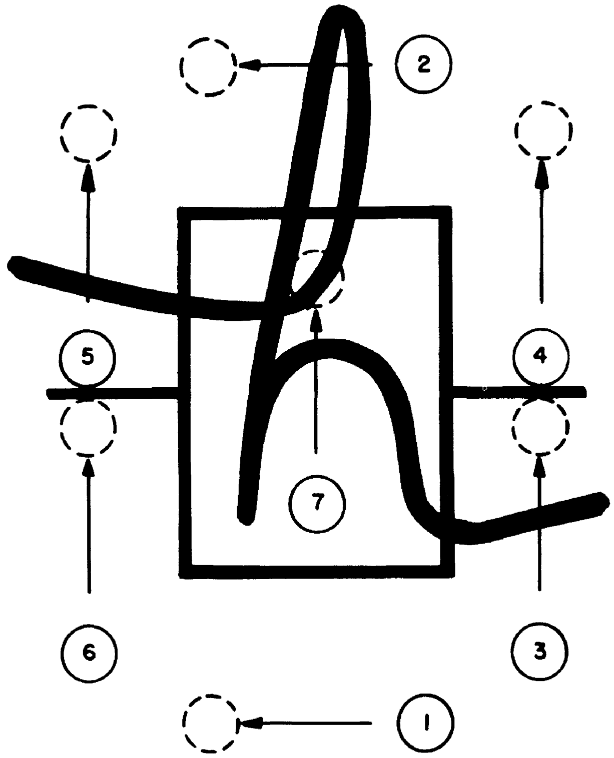
The factors that are critical for the development of performance specifications for any given application of automatic character recognition techniques are directly related to the objectives that are to be served in that intended application.[5.44a] Similarly, the operational requirements for a character 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 rapidly 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 then 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.

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.[5.44b] 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 a position-dependent as versus shape-dependent recognition logic, of permissible reject rates, and of speed or rate of recognition. In particular, 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.

5.4. Recognition of Handprinted Characters, Handwriting, Geometric Shapes, and Line Drawings

In terms of continuing experimentation there are a number of R & D requirements with respect to many other areas of potential application of optical character recognition techniques. The case of constrained handprinting may be noted first. The most rigorous constraints are those involved in handprinting the character within a specified area (such as a preprinted box) but with arbitrary embellishments as in a patent issued to Dickinson and



FOSCRIPT SCANNING FORMAT

FIGURE 8. *FOSCRIPT decoding criteria.*

Wheeler in 1941 [5.45] or in a FOSDIC development.[5.46] It is to be noted that, in the latter case, since the FOSCRIPT scanning technique scans only for black in specified areas outside or inside the guide-line boxes (as shown in Fig. 8), these need not be in a separate color of drop-out ink, as is the case in most of the other constrained handprinted or handwritten character recognition techniques.

5.4.1. Constrained Handprinting

Typically, constraints involve the use of restrictive guidelines to control variations of size in characters as printed, including, for example, ascender-descender lengths relative to other characters; the requirement that characters be drawn as closely as possible to an exemplar shape (e.g., "4" rather than "4"; see also Fig. 16, App. A, p. A.116), or arbitrary centering and "crossing" requirements, as about preprinted dots, and combinations of these controls.[5.46a] The acceptability of such constraints to typical users must of course be considered.[5.46b]

Then there are techniques that involve what might be termed critical area or vector "crossings" detection, e.g., that character strokes cross or do not cross superimposed lines or do or do not occur in certain arbitrary areas of an image field. These techniques have been investigated with particular reference to constrained hand-printed characters, as developed, for example, at IBM (Johnson, 1951) and at Bell Laboratories (Dimond, 1957).[5.47]

In developments at Standard Elektric Lorenz, Stuttgart, West Germany, Dietrich has also made some investigations of possibilities for recognizing constrained handwritten numerals, to be inscribed in boxes with two preprinted dots, in a manner similar to the IBM and Dimond techniques. Then there is a patent issued to Vernon and Walsh (1962) which considers the use of a six dot and a 'forbidden area' constraint for handwritten characters.[5.48]

Somewhat closely related to some of these dot-constrained techniques, especially those involving use of the sequence of stylus movements for identification purposes, are several systems for on-line input of graphic patterns, specifically including handprinted or handwritten characters.[5.48a] Groner (1966), for example, reports a relatively simple recognition scheme together with convenient editing features.[5.49] Earlier investigations in this area include patents issued to Crane (1964) [5.50] and Harmon (1964),[5.51] and work by Roberts [5.52] and others at M.I.T. and in cooperating organizations such as Mitre Corporation and Bolt, Beranek, and Newman.

On-line handprinted or handwritten character (or word or signature) recognition techniques are of increasing importance in many man-machine-interactive experimental operations. One recent example is the "SHAPE SHIFTER".[5.52a] Another example is to be found at S.D.C.[5.52b] (It should be noted, of course, that many of the techniques involving stylus, light-pen, or equivalent on-line input are highly dependent upon the sequence of character or word or signature formation and thus are not generally transferable to other handwriting recognition applications).

Commercially available equipment in the constrained hand-printed area is represented by IBM with a sales check application as early as 1965 [5.53] (and more recently the 1287 reader has been introduced; [5.54]), and by Recognition Equipment, Inc.,[5.55] Information International, Incorporated (III),[5.56] Philco and CDC,[5.57] and the Optical Scanning Corporation.[5.58] A capability for recognition of handprinted numerics has also been claimed for the Cognitronics ROCR (*R*emote *O*ptical *C*haracter *R*ecognition) development previously mentioned. (See p. 17 and note [3.29a]). The REI equipment, in particular, combines high-speed multifont typewriter or handprinted alphanumeric recognition at high speed with high speed sorting of input documents. An entry by Toshiba in Japan has been noted previously (see p. 31 and note [5.26]).

For another example, at Olivetti in Italy, the basic recognition concept being investigated involves a multi-topological system for the detection of line directions, connections, intersections and relative positions of intersection as applied not only to the ISO stylized A and B fonts but to handwritten numerals as well. A distinctive feature of the Olivetti approach (i.e., in contrast to multifont techniques involving shifting from one font to another) is claimed to be the capability of handling a family of fonts, so that the system can recognize characters varying as to pitch, size, stroke widths and edge tolerances.

Other present or potential suppliers of OCR equipment who have considered applications to constrained hand-printed characters, include Sylvania,[5.59] Farrington,[5.60] Bull [5.60a] and work on possible Zip Code applications by Burroughs, Control Data (Rabinow), and Philco-Ford [5.61] as well as by NCR,[5.62] but, in general, it is to be noted that: "Some of the techniques currently being investigated in connection with hand written documents are curve tracing, detection of selected features, and context recognition . . .. Although a number of companies are working on the problem, most of the work has been kept confidential." (Feidelman and Katz, 1967, p. 0210:31).

5.4.2. Handwritten Characters and Handwriting

Stylus and light pen input techniques for the direct entry of handprinted or handwritten information have been mentioned previously (Sec. 4.2). Here, we are concerned with the property filtering and recognition techniques. Pioneering approaches to the recognition of relatively unconstrained hand-printed or hand-written characters by Selfridge (1955, 1956), Dineen (1955), and Clark and Farley (1955) stressed the problems of extracting the significant features from a background of noisy or irrelevant detail. In simulations of machine recognition of handdrawn characters they specifically developed various types of filtering of the source pattern in order to extract such features, especially the detection of edges and corners. Later developments at M.I.T. have included the work of Doyle, Sherman, Roberts, and Teitelman, among others.

In a 1965 survey of automatic recognition of handwriting, Lindgren covers the work of Earnest,[5.62a] Frishkopf and Harmon, and Mermelstein and Eden. Doyle (1959) provided an early example of computer simulation of a scheme for the recognition of largely unconstrained handprinted alphabetic characters, using 28 criterial features. The machine simulation of the technique resulted in computer recognition, which was correct approximately 87 percent of the time, of "sloppy" handprinted characters.

The emphases in this program were 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. 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', 'H') where the source pattern would be almost equally ambiguous for a human reader.

Sherman's investigations (1959) were 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. Since the use of holistic templates would be impractical because of the enormous number of possible combinations of pattern parameters, Sherman 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 encoding of a given pattern in the form of a connection matrix. The rows and columns of this connection matrix correspond to the nodes of the graph, while its elements 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").

In Roberts (1960) experiments 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.[5.63] Other hand-printed character recognition experiments of interest include those of Highleyman (1961, 1962),[5.63a] Spinrad (1965),[5.63b] Uhr and Vossler (1962);[5.63c] and Brill (1968).[5.63d]

To date, the most common approach to feature-extraction recognition of relatively unconstrained handwritten characters has involved some form of contour-following or of extraction of angles, slopes, and directions of junctions and disjunctions of contour strokes.[5.63e] For example, at IBM, in a handwriting reader system, "the flying spot actually traces the outline of the character it is looking at. These tracings are converted to voltage wave forms internally. These wave forms are then compared against statistical probability tables that were generated in conjunction with Tufts University [from] unconstrained handwriting samples . . .. About 100,000 numerals were fed into the system, and reliability and accurate reading of about 98½ percent was developed." (Merz, 1964, p. 84.)[5.63f]

Kuhl's (1963) approach, involving an angular mapping transformation derived from contour following, resulted in 95 percent correct recognition of several hundred hand-printed numerics and upper-case block letters.[5.64] At the British General Post Office Research Station, computer simulation investigations of the recognition of handwritten alphanumerics have been carried out using a technique that encodes directions of connections from a matrix cell for quantized, thinned character stroke with respect to its eight nearest neighbors. (Deutsch, 1966).

Variations on contour-following techniques have been or are being used.[5.64a] In discussions of a paper by Sprick and Ganzhorn (1959) at the International Conference on Information Processing, several techniques were described. For example, Elkind obtained 85 percent 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. Work at the Dahlgren Proving Ground has also been reported in which curve tracing was employed, but the input pattern elements consisted of indications of horizontal and vertical motion and of transfers from one mode to another.

A variation of contour following that is non-reentrant was used in a prototype reader for handwritten numerics at Rabinow Engineering, a subsidiary of Control Data (Holt, 1964). Greanias et al. (1963), for numerics only, used a helical scan to trace large segments and a small circular scan to examine detail.[5.65] A principal difference between the Greanias developments at IBM and the Control Data approach is that, in the latter case, Holt's "watchbirds" involve the use of conventional scanners and tracking circuits that record beginnings, joints, splits, and ends of lines together with their positions relative to one another.[5.65a]

Marill and Green (1960) have used a variation of a vector crossing scheme in a proposed model of pattern recognition as applied to handwritten characters. In this scheme, involving in effect a polar scan 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 (1960) have also investigated means for obtaining characteristics of curves, for character recognition purposes, by measuring distances from the center of gravity with respect to radial vectors.

Various operations to reduce noise by local 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 described by Bomba.[5.66] This has been tested on handprinted samples of 34 alphanumeric characters, using a scanner developed by Highleyman and Kamentsky (1959) and simulation on an IBM computer.

Sometimes not only features but relationships between the features are required to be detected, as in Sutter's 1960 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, . . .

In Unger's SPAC, or "*Spa*tial *C*omputer" (1958), a rectilinear network of logical modules was proposed 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.[5.66a] For character recognition operations, the Unger technique consists first in smoothing, image enhancement, and clean-up operations. These operations fill in holes in otherwise black areas or small indentations in otherwise straight edges, they eliminate isolated "black" cells including those that create small protrusions from an edge, and under certain conditions they fill in missing corner points.

For 34 alphanumeric characters tested, 34 features or properties were 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." Although the processing operations are carried out simultaneously and in parallel over the entire image field, the choice of the 'next step', given the outcomes for any one operation, follows a decision-tree structure. Fritzsche (1961) has further considered applications of the basic Unger approach.

Other character recognition experiments involving hand-printed characters include those at the Astropower Laboratory,[5.67] and those of Fischler,[5.68] Lewis,[5.69] Minneman,[5.70] Spilerman,[5.71] Uyehara,[5.72] and Weeks,[5.73] among others. A particularly difficult case is indicated by reports of experiments in recognizing hand printed *Chinese* characters at Purdue University.[5.74] An approach to the recognition of handwritten Katakana characters (table of Japanese word-syllables), which are composed of nearly straight strokes, has been described by Noguchi et al. (1967).

Another variant on raster-interception techniques, such as those of Weeks, is provided by Glucksman, who proposes that characteristic locations of types of interceptions can be utilized for recognition of multifont characters, including those that are handprinted.[5.74a] An approach also somewhat similar to that of Weeks is reported with respect to developments for handprinted character recognition in the U.S.S.R., where iterative scanning processes are applied to a normalized rectangular matrix covering the input character image, with changing inclinations of 'vertical' rows and correlations with each of the reference patterns are obtained for each scan. For computer simulations of this technique, 20 persons contributed 50 handprinted characters each and the results were that "from the total of 1,000 characters about 96 percent were correctly recognized." (Kovalevsky, 1966, p. 567).

"Learning" models such as the various Perceptron models, those developed in Steinbuch's laboratory at the Technische Hochschule, Karlsruhe, Gamba's 'PAPA' devices, and Conflex I, have been designed primarily to test various theories with respect to simulation of human processes of perception and concept formation or to artificial intelligence problems, rather than with respect to the development of practical character readers. These will therefore be considered briefly in Section 5.7, on theoretical approaches to pattern recognition and characterization.

A number of R & D efforts directed toward pattern recognition and classification problems in general have involved the use of handprinted characters for tests and demonstrations. Among the many possible examples we note the following:

(a) McLaughlin and Raviv (1968).[5.74b]
(b) Chen (1966).[5.74c]
(c) Prather and Uhr (1964).[5.74d]
(d) Chow and Liu (1966).[5.74e]

The problem of automatic *signature* identification is also being explored, for example, at the Technische Hochschule, Karlsruhe, where an off-line input device permits conversion of either light-pen input or microfilm images to magnetic tape. The account number of the presumptive writer is known and the problem is to identify the signature for recognition purposes.[5.75] Studies reported by Mauceri (1965) involve on-line verifications of signatures to prevent highly expert forgeries, and include considerations of relative acceleration and pen-to-writing-surface contacts.[5.76] Marzocco (1965) has investigated the automatic identification of first-name signatures.[5.76a]

Longer range R & D concerns involve the problems of cursive handwriting in general. The original research approach at Bell Laboratories involved input from the writer via a captive stylus so that *X* and *Y* coordinates were automatically generated by his pen. The first significant feature detected in this system was that of relative vertical extent within or beyond a baseline and a parallel guide line above it. A rough first sorting then provided groupings of characters with ascenders, those with descenders, those with both, and all other characters. A second criterial feature was the presence or absence of retrograde strokes. Abrupt changes in slope (or 'cusps') were also detected as were the presence or absence of loops or near loops and special marks such as the dot of the "i" or the cross-bar of the "t".[5.77]

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.[5.77a] Frishkopf and Harmon (1960, 1961) also considered possibilities of recognizing the handwritten word as a whole, again emphasizing that the highly variable and nonessential details of a particular source pattern should be eliminated as far as possible and that the significant features should be isolated and preserved.[5.78]

D. A. Young in 1960 suggested the automatic input and recognition of handwritten computer programs, and current investigations along this line include work at the Technische Hochschule, Karlsruhe, with respect to handwritten words as used in ALGOL programming. Also under investigation at Karlsruhe are techniques for the automatic classification of handwritten characters, involving consideration of various methods of determining the discriminating criteria as derived from large samples of characters. The methods used are similar to those suggested by Kamentsky (1961)[5.78a] and by Uhr and Vossler (1961), and Simplex methods are also being tried. An integrated scanner-computer system can be used to simulate linear classifying networks and to investigate automatic classification techniques under feedback control.[5.79]

Eden and Halle (1960) have discussed both the synthesis of cursive handwriting and its analysis, finding that 18 strokes appear to be discriminative for well-formed Latin scripts.[5.79a] Neisser and Weene (1960) 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.

Mermelstein and Eden (1964) have based their handwriting recognition experiments upon analyses of the intrinsic hand movements that are involved in writing cursive script. Words were segmented into strokes and the strokes were recognized in terms of the statistical probabilities of their belonging to pre-selected classes.[5.80] Still other examples in this area are provided by current investigations at MIT,[5.81] by Simek and Tunis (1967)[5.81a] and by Teixeira and Sallen (1968).[5.81b]

5.4.3. Shapes and Drawings

Techniques being developed for automatic character recognition should also eventually be applicable to the recognition of simple geometric shapes and of 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 include the problems of machine encoding of chemical structures. 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. Investigations in this latter area by Cossum et al. (1964) have been mentioned previously (p. 23).

The first approaches to machine recognition of simple shapes in line drawings had already been demonstrated in the 1950's, for example, by Shepard (1959), Harmon (1960), Hodes (1961), and Singer (1961) among others. At the Western Joint Computer Conference held in Los Angeles in May 1961, Uhr and Vossler (1961) reported additional results from a pattern recognition program, including recognition of outline drawings of shoes, chairs, and comic strip cartoon faces. Fain (1960), a Soviet scientist working in the field, has been reported as investigating possibilities for recognition of three-dimensional object by a technique involving possible projections in terms of a grid mask.

Questions of machine-usable techniques for shape-recognition in the abstract (e.g., triangles as vs. squares, regardless of size or of position in the input-image-plane), have been explored by Harmon, (1960), Unger (1958, 1959), Deutsch (1955), Stevens (1961), and Glucksman (1965), among many others.

Harmon, in particular, developed a special device for Gestalt-type recognition of line drawings of circles, triangles, squares, etc. With the use of a dilating circular scan, 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. The problems of detecting relatively invariant features for the recognition of geometric shapes have also been attacked, both by criterial features extraction and by "para-propagation" techniques.[5.82]

In general, however, continuing R & D requirements for automatic character recognition progress require increased attention to: esoteric alphabets; hand-printed characters other than the numeric set alone (and, here, for improved efficiency for the numeric case such as Zip-coding); cursive handwriting for both automatic signature and word identification; the further exploitation of context-predictive techniques; and detailed fact-finding investigations as well as experimental development of format differentiation and field-content-identification procedures.[5.82a]

The automatic recognition of cursive handwriting shares with automatic speech recognition, moreover, difficult problems of segmentation.[5.82b] The problems of automatic speech recognition comprise a particularly difficult area of pattern recognition R & D requirements for other reasons as well.[5.82c]

5.5. Speech and Speaker Recognition

Some of the difficulties of automatic speech recognition relate to the physical, physiological, and psychological phenomena of vocalization;[5.82d] others to cultural phenomena, such as broad variations in the evolution of spoken languages and the continual emergence of dialects at many levels;[5.83] and still others to differences which occur for one and the same speaker.[5.83a]

In the first category, that of physiological factors, marked differences are found as between male and female speakers.[5.84] In the second category, it is noted that "another difficulty arises from the different dialects in common use. Here the same *words* or *phrases* spoken by different talkers will have different phonetic content. Thus transliteration from a sequence of phonetic elements to English words may involve complex linguistic structure." (David and Selfridge, 1962, p. 1098). The converse of this problem is that of homonyms—words that are pronounced the same although they have different meanings and may be spelled differently, such as "bear" and "bare". Thus Hogan remarks: "Problems of recognition from continuous text and the linguistic resolution of acoustic ambiguities (e.g., two, too, to) are problems that will be with us for a long while." (Hogan, 1966, p. 93.)

Investigations into the possibilities for automatic speech recognition began early at the Bell Telephone Laboratories (David, 1958, cites unpublished work of Kersta in 1947 and of Galt in 1951 with reference to recognition of spoken numbers from sound spectrograms [5.85]), at the University College of the City of London (Fry and Denes, 1956, 1958) and at M.I.T.[5.85a] Early work in automatic recognition of spoken digits includes the investigations of Davis et al. (1952) and Sebesyten (1962). At the NPL Symposium on the Mechanisation of Thought Processes, held in Teddington, England, in 1958, a recognition device was demonstrated that served, in effect, as a phonetically operated typewriter. Other approaches to a phonetic typewriter principle include work at Kyoto University, Japan (Maeda and Sakai, 1960; Sakai and Doshita, 1962, 1963), and at RCA (Meeker and Green, 1961; Meeker et al., 1962). A vowel recognition technique, using clustering methods for the classification of presumably representative samples, is described by Dammann (1966).[5.85b]

Continuing R & D efforts in the United States in speech analysis and recognition are exemplified by projects at the Air Force Cambridge Research Laboratories (Petrick and Willett, 1960), at the Massachusetts Institute of Technology (Forgie and Forgie, 1959), the University of Michigan (Peterson, 1963, 1966), and work at Philco-Ford,[5.85c] among others. Other Japanese examples include work at the Electrotechnical Laboratory, Kokusa Deusin Denwa Company, Tohoku University, and the Electric Wave Research Laboratory.[5.86] Further British efforts in the field may be exemplified by work reported by Lavington and Rosenthal.[5.86a] Some recent European examples will be discussed below. It is to be noted that a 1966 review by Bhimini et al discusses both speech analysis and recognition problems in the context of man-machine systems.

In terms of experimentation and instrumentation difficulties, there is first the question of analytical equipment available to detect and measure the properties and characteristics of speech in a given speaker's utterances, and there are secondly the problems of adequate sampling to set up a comprehensive basis for recognition of many vocalized sounds and many different speakers.[5.87] Also, it has been noted that "the acoustic power available for speech recognition appears to be rather small. The significant fact here is that this small percentage tends to be masked by the rest." (Garvin, 1965, p. 112.)

The effectiveness of preprocessing operations such as is so important in character recognition is thus at least equally critical in speech recognition. For detection and extraction of criterial features in speech, there has been frequent use of filter bank analyzers[5.88] and sonograph equipment which provides a continuous record of frequency and amplitude as against time.[5.89] A sound spectrograph developed at the Communication Sciences Laboratory, University of Michigan, incorporates special features including the automatic marking onto the spectrogram of time, frequency, and amplitude scales. (Dunn et al., 1966).

In general, "feature detection performs a transformation on the primary measurement space, with the intention of producing a secondary measurement space in which the effects due to . . . distortions are largely normalized out." (King and Tunis, 1966, p. 70). However, there is much less agreement among speech recognition workers (and in fact there is much continuing controversy) with respect to the choice of *which* features in speech are significant and discriminating. The 1963 remarks of Garvin and Karush are largely still pertinent today: "The phonetic substance of language clearly lends itself physically to both reproduction and measurements, but very few of the parameters required for the recognition of the linguistic content of the acoustic signal have as yet been found." (p. 369)

One of the most obvious attacks on problems of mechanized speech recognition is that of the measurement and anlysis of "formants".[5.90] However, while it has been argued that "the success of speech synthesizers based on Dudley's model has adequately demonstrated that it is the frequency spectrum (specifically, the energy concentrations in the frequency domain, or 'formants') of the speech waveform . . . that is the information carrier" (King and Tunis, 1966, p. 67), various investigators are not convinced that formants are good measures for use in automatic speech recognition systems.[5.91]

David and Selfridge (1962, p. 1098), point out that typical recognition techniques use either "spectral templates or parametic property lists", giving as examples formant locations, overall intensity, and voice-unvoiced status. Earlier, David had suggested that the appropriate parameters of speech analysis should be functions of the voice pitch and that "pitch detection is fundamental to the whole problem of speech analysis, and quite likely to speech recognition as well, for a variety of talkers and pitches." (1958, p. 307.)

Gold (1962) has investigated computer programs for pitch extractions from recorded speech. Reddy (1967) describes a computer process that determines pitch periods by the recognition of the peak structure of the speech waveform. This work at Stanford University, supported by ARPA, should be useful in speech analysis since changes in the pitch of a sound contain information about phrase boundaries and points of stress. Moreover, it is claimed that "more intelligible and higher quality speech can be obtained in speech communication using Vocoders by transmitting pitch information along with the bank-compressed spectrum of the sound." (Reddy, 1967, p. 343. Further references are to Flanagan, 1965, and Schroeder and David, 1960). Elsewhere, Reddy (1966) has considered some of the problems of segmentation of speech sounds.

The approach of Kusch (1965) at the Telefunken Laboratories, Ulm, West Germany, is based on the assumption that the formants (or characteristic frequencies) do not provide sufficiently reliable information for speech recognition because of frequency displacements of sounds from one speaker to another. Instead, Kusch is concerned with the derivation of characteristics from both the fine and the coarse structures of the continuous speech signal.

For the recognition of spoken numerals (where, in German, a number of different pronunciations are found), Kusch first uses two coding matrices, the first for detection of sound groups specified by the binary formulas for presence or absence of high amplitudes at five time intervals. The second coding matrix relates the detection of presence or absence of sound-group indicia to the identification of the 10 spoken numerals, in either German or English. It is claimed that, for well pronounced digits and for small differences in sound intensity, the equipment gives excellent automatic recognition.

However, in colloquial speech, many sounds may be pronounced indistinctly, too loudly, or too softly, often with large differences in sound intensity occurring within a single word. Therefore, the one component is divided into two parts with low and high sensitivities respectively. In tests to date, for experiments with 37 male and 37 female speakers, an overall average recognition accuracy of 87 percent was obtained without adjustments of the equipment for the different speakers, and without compensation for wide variations of natural sound intensity and wide spreads in pitch. A second set of experiments involved normalization of the sound intensities to the same level and achieved improvement in average recognition accuracy to 93 percent correct automatic identifications.[5.91a]

Von Keller (1966) at the Technische Hochschule, Karlsruhe, has also explored several alternatives, including frequency analyses, autocorrelation, and zero crossings of the speech wave. He points out that the measurement of formants automatically involves difficulties because they tend to lie between the lines of the frequencies. He is therefore concerned with first zero crossings of autocorrelation functions for the first two formants. Other aspects of the zero crossing analysis approach includes determinations of the time intervals between zero crossings on the speech wave curve and the number of such crossings that fall within certain time intervals.[5.92]

At the Institut für Phonetik und Kommunikationsforschung, University of Bonn, under the general direction of Ungeheuer (1965), developments for speech analysis and recognition include phase spectrum analyses and derivation of auto-correlation functions of fricatives in the initial position; equipment to measure width of intervals between zero crossings for clipped speech. A system of Ungeheuer's design is used to separate high and low frequency components, to integrate filter outputs every three seconds, and to provide output results to an X–Y oscillograph. A prototype word recognizer was begun in 1962 and demonstrated at the ICA Congress in Belgium in 1965.[5.93]

Sakai and Doshita (1963) also make use of zero-crossing analysis, using the phoneme as the basic recognition unit. They report satisfactory recognition with respect to Japanese monosyllables as being at the 90 percent level for vowels and 70 percent for consonants with some exceptions.[5.93a]

In the U.S.S.R., also, it is to be noted that "automatic machines discerning sounds of speech, are being designed with the aim of searching general peculiarities of the spectrum that are retained after various transformations." (Ivanov, 1961, p. 15).[5.94] A spoken-word recognizer involving adaptive features is also under development at the Standard Telecommunication Laboratories in England. (Hill, 1966).[5.95]

Returning to the United States, relatively recent speech recognition research is to be noted at the Communication Sciences Laboratory, University of Michigan (Peterson, 1966), the National Cash Register Company (Otten, 1965), Lockheed's Palo Alto Research Laboratory (Bhimani et al., 1966), and elsewhere. Tappert (1966), uses computer simulations to investigate neural models of the speech recognition process, incorporating preprocessing operations that detect time sequences of features. In an ONR-sponsored project at Columbia University the objective is to investigate problems of automatic speech recognition and synthesis with emphasis on spectrum analysis using Gaussian filters and subsequent computer processing of the data. (Harris, 1966.)

A correct recognition rate in the 90 percent range has been reported by King and Tunis [1966] for different male speakers using limited, arbitrary vocabularies of 15–30 words (i.e., those used in a specific programming language).[5.96] However, we may emphasize the limited nature of results in speech recognition research and development to date by noting that these authors claim: "It may be concluded that the techniques investigated in this work are adequate for achieving a forced decision recognition rate of at least 98 percent over a range of male speakers and for *arbitrary vocabularies of up to thirty words.*" (King and Tunis, 1966, p. 78 (underlining supplied).) Petrick and Willett (1960) claimed similar accuracy for a vocabulary of up to 83 words. A demonstration model of an adaptive recognition device, "Cynthia III", successfully recognized up to 25 words after training with a particular speaker. (Lesti, 1963).[5.96a] By contrast, it is suggested that "no serious forecast about computer systems in the 1970's can omit voice recognition systems with several-thousand-word vocabularies." (Diebold, 1966, p. 297).

Voice recognition, recognition of cursive handwriting and the isolation of particular characters or shapes in multiple-pattern or noisy background share problems of both segmentation and reintegration. For example. Davies points out that one of the more difficult problems of speech recognition resembles that in machine stenotype recognition where it is necessary to go to the level of syntactic analysis before word separations can be made. (Davies, 1962, p. 67). Then we note that "as K. N. Stevens succinctly puts it, 'the segmentation problem is the fact that you can't segment'."

(Lindgren, 1965, p. 51). [based on private communication].

Garvin points to "the very difficult speech-recognition problem of recognizing the boundaries of stretches within a semicontinuous signal" and, further, that "the natural vocal signal is semi-continuous. That is, the number of physically observable breaks in the continuity of the stream of human speech is much smaller than the number of discrete elements into which the signal may be decomposed in either alphabetic writing or linguistic analysis." (Garvin, 1963, p. 112–114).

In addition, phonetic signal strings raise special problems of segmentation and of junctures (or interruptions to the continuity of a stream of speech). It is therefore suggested that: "Linguistic and acoustic research on the phonetic characteristics of junctures will undoubtedly make significant contributions to this aspect of speech recognition." (Garvin, 1963, p. 113).

Thus, the input to direct machine processing of spoken messages, for other than a severely restricted vocabulary of approximately two dozen words, awaits considerable further research and development effort in the area of automatic speech recognition.[5.96b] In particular, it can be emphasized that "a practical device should be capable of automatically segmenting a continuous stream of speech, correcting for the individual's speech characteristics and dialect patterns, and recognizing the information content of the incoming speech signal." (Bhimani et al., 1966, p. 279).

In speech recognition, also, as in sophisticated types of character recognition and in graphic pattern recognition generally, there are continuing research requirements for the design of appropriate measurement spaces [5.97] and increased appreciation is developing that many of the problems will not yield to solution until far more attention has been given to underlying semantic and contextual factors.[5.98] Specific research requirements are suggested by King and Tunis (1966, p. 78) as follows: "Other areas which require additional work include the problems of word segmentation, and discrimination of voiced, unvoiced, and mixed speech from background noise." To these problems Bhimani et al. (1966) add those of time normalization of speech.

We note again possible avenues to cross-fertilization in the fact that in many language-data-processing operations (to be discussed in a later report in this series), the problems of determining proper segmentation as between word roots and affixes are often critical,[5.99] but may yield to the same types of solutions as may be developed for speech recognition and the recognition of cursive handwriting. King and Tunis point to still another continuing research difficulty as follows: "Transformations that will eliminate the effects of variations in speed of talking and other differences in format structure between speakers must still be found." (King and Tunis, 1966, p. 78).

The converse of the latter point (that is, to find *the speech characteristics peculiar to a given* speaker), is required in the case of automatic speaker identification which is a special, limited case of voice recognition. Thus, at the University of Bonn, Ungeheuer's system provides the capability for photographing the different domains for movements (on the *X-Y* display) of coordinate positions specific for different speakers and of the characteristically different vowel triangles (see Fig. 9). Further processes involve separations of the first and second formants by density distributions of zero crossings, and determinations of the number of zero crossings per 3-second intervals, giving other plottings. Using such data, it is possible to identify speakers independently of the text uttered, and significant differences between professional imitators and the public figures whose voices they are imitating can be shown graphically.

A related problem is that of speaker or "voice print" identification when the speakers are uttering certain code words. Tillman (1965) has analyzed 100 to 200 classes of sonograms of a particular word as uttered by 10 different speakers in order to detect differential features, particularly those of a general nature. Then it is noted that "Prestigiacomo at Bell Labs has produced contour spectrograms that show relative intensities that do not show up on the conventional spectrograms. These relative intensity patterns are claimed to be the clue to individual speaker identification." (Lindgren, 1965, p. 127).

Earlier investigations at the Air Force Cambridge Research Laboratories suggested a possible program whereby "an unknown speaker says his word into the computer and obtains one of the following types of responses: 'That was John Jones speaking the digit three; I don't know who you are, stranger, but you spoke the digit two, I don't have the slightest idea who you are or what you said; speak more distinctly and repeat your word again, please'." (Petrick and Willett, 1960, p. 15).

Another example is provided by investigations at Scope, Inc., which stress the importance of nasals. The approach uses 25-element vectors to represent spectra of 30 different speakers with respect to a 50-word vocabulary. Test results to date show 45 percent recognition accuracy for single test utterances ranging up to 93 percent for 10 utterances. Pierce points out that "progress is being made in the automatic identification of speakers by voice, as a substitute for a handwritten signature, and this could play an important part in banking and other credit transactions." (Pierce, 1966, p. 148).

A commercial approach to the solution of voice-print identification problems is represented by the recent purchase of Voiceprint Laboratories, Summerville, New Jersey, by Farrington Manufacturing Company.[5.100]

A 3-year program to explore the use of voice-prints in criminal identification has been initiated

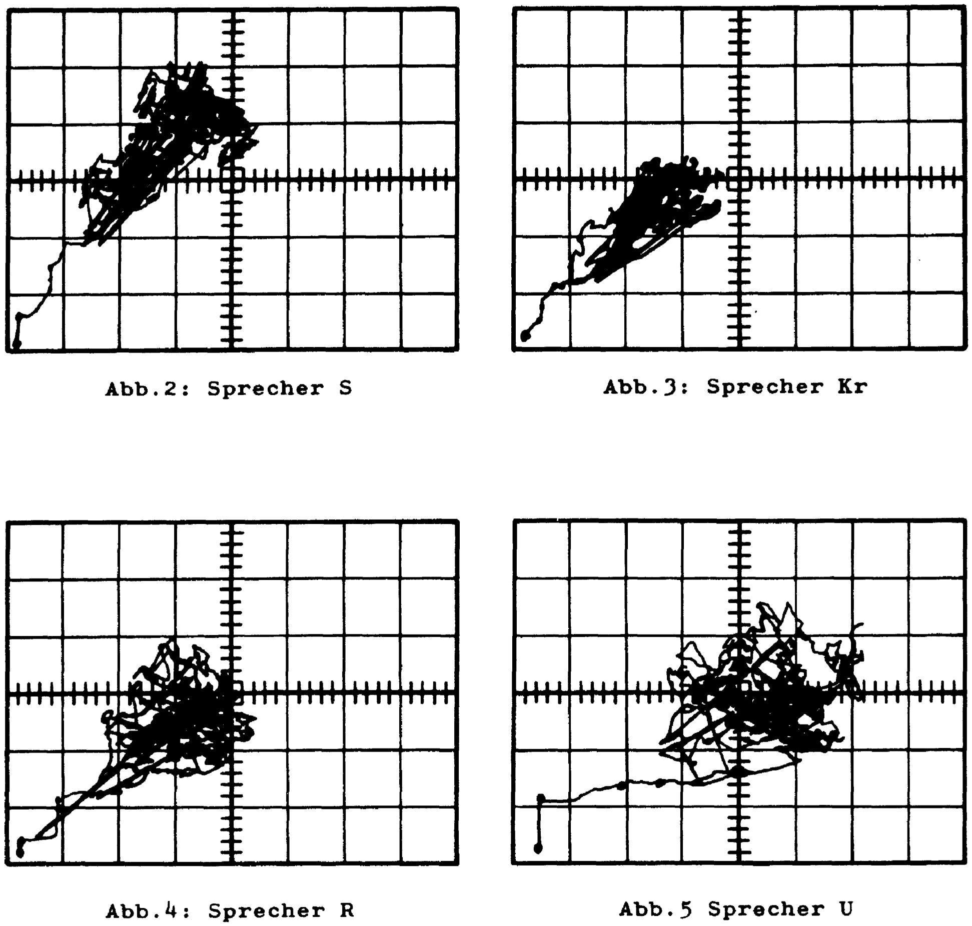


FIGURE 9. *Patterns for different speakers.*

by the Justice Department in cooperation with the Michigan Department of State Police.[5.100a]

We note of course that to identify a new "sample" of handwritten signature or vocal utterance of a password or impression of a fingerprint as being sufficiently "like" prior samples as to warrant access, for example to privileged files, is theoretically far less of an R & D problem than to detect and identify patterns of speech, or fingerprints, or cursive handwriting, as such.

5.6. Other Pattern Identification and Recognition Areas

The difficulties with respect to the automatic pattern identification of fingerprints relate on the one hand to the extreme complexity of these patterns and on the other hand to the very large numbers of patterns on file (i.e., typically, in the tens of millions) against which an input pattern or set of patterns is to be searched. Some relatively recent approaches to problems of fingerprint identification are represented by the work of Gaffney at IBM, Cuadra at System Development Corporation, and Wegstein at the National Bureau of Standards, among others. Other investigators include Fulton,[5.100b] Trauring,[5.100c] Van Emden,[5.100d] and Hankley and Tou.[5.100e]

At the Argonne National Laboratory, the CHLOE equipment, consisting of a flying spot scanner under the control of a small general purpose computer, has been used for experiments of machine classification of fingerprints (Shelman, 1967).[5.100f]

The achievement of rotational invariance in fingerprint scanning and processing by optical or holographic means is discussed, for example, by Marom, 1967[5.100g] and by Horvath et al., 1967.[5.100h] The continuing interests of the F.B.I. in this area of pattern recognition are discussed by Voelker.[5.100i] Semi-automated systems are also to be considered, as in the case of the New York State Identification and Intelligence System (Kingston, 1967).[5.100j]

Gaffney, of the Federal Systems Division, IBM, has developed a method of encoding fingerprints based upon information about bifurcations (ridge splits) for processing against a similarly encoded file.[5.101] The SDC project is similarly concerned with ridge characters but in the context of man-machine interaction in the process of location and identification.[5.102] In terms of continuing R & D concern, it is well to note the following comments by Cuadra:

"Various researchers concerned with the automation of fingerprint identification have been exploring quite different approaches to the problem. Some are attempting to use fine details of the fingerprints, automatically identified by optical scanners, as the basis for fingerprint description; some propose to use automatically derived measures based on the slope of the ridges in various areas of the print; and some are attempting to derive measures based on the fingerprint pattern as a whole. *What is significant about all this work, little of which is described in the open literature, is that there has not yet been sufficient research to provide a rational basis for choosing a particular approach.*" (Cuadra, 1966, p. 8, underlining supplied.)

The approaches of Freedman and Hietnanen at Bendix [5.102a] and Wegstein (1968) at NBS are also based on minutiae of the fingerprint pattern, specifically ridge ending and bifurcations (Fig. 10), and with constellations or groupings of these minutiae. Descriptors corresponding to the identification of constellations are computer-generated and degree-of-match scores can then be computed for the same and different fingerprint patterns. An important advantage of this technique is that identification can be achieved from minutiae occurring in only a portion of the total print pattern, so that searches based on chance or latent partial prints may be successful.[5.102b]

Hankley and Tou (1968) are investigating techniques involving elementary spatial filtering, image enhancement operations to close ridge gaps or to separate contiguous ridges, and topological encoding of features detected in the center region of a single print. These investigators point out that "the chief obstacle to automatic fingerprint processing is print quality. Even good quality fingerprints are subject to a variety of imperfections. . . . Most common are ridge gaps, usually caused by skin folds, and contiguous ridges, which may be caused by spreading of ink (or skin oils) due to finger pressure, by particles on the skin, or in the worst cases by excessive inking or by smearing during rolling of the finger.[5.102c] Somewhat less bothersome are light prints, thin ridges, and excessive pore structure, which appear as dotted or perforated ridges. Print processing must also allow for damaged or scarred fingers." (Hankley and Tou, 1968, pp. 417–418).

Then there are some areas of R & D concern with respect to relatively less obvious applications of pattern recognition techniques. Some quite exotic examples include recognition of plant species from leaf venation patterns,[5.103] terrain and cloud cover analysis,[5.103a] the recognition and identification of audio waveforms in coughing,[5.104] the recognition of printed sheet music,[5.105] or even the rumps of migrating baboons! [5.105a] In addition, various other types of "pattern" detection, identification, analysis, and, in some cases, generation are to be noted in various types of musicological, as in literature, research.[5.105b] For example, for purposes of structural analysis of atonal music, Forte (1967) manually encodes music scores in a special notation.[5.105c]

The application areas of electrocardiographic and electroencephalographic analysis have been mentioned previously.* Additional examples are provided by Weihrer et al. (1967), who discuss computerized electrocardiographic analysis developments at the Instrumentation Field Station of the Public Health Service.[5.106] European examples include the work of Sneddon at the University of Glasgow [5.107] and of Karlsson at the Royal Institute of Technology in Sweden.[5.108] Related medical data processing applications include x-ray and radioisotope interpretation,[5.108a] phonocardiographic,[5.109] and radiocardiographic analysis.[5.110] Ledley et al. (1968) have used machine analysis to prepare mitotic indexes (i.e., measures of the extent of cell division).[5.110a]

We also note the case of pattern detection in seismic recordings (Rosen, University of Uppsala, for example), and that pattern recognition in the case of bubble chamber data has been reported at the Centro Italiano di Studi ed Esparienze in Milan. (Swanson, 1966, p. 9). However, it is to be emphasized that "bubble chamber picture scanning defines a context for visual data processing and pattern recognition in which the concepts 'prototypes' and 'images' become virtually meaningless." (Narasimhan, 1966, p. 167). Particularly difficult are requirements for three-dimensional data processing and for "scene" analysis such as have been explored in the CYCLOPS 1 project at Bolt, Beranek, and Newman [5.111], and in continuing work by Minsky and others at M.I.T.[5.112]

Looking forward, in the area of automatic preprocessing operations upon input, we can foresee increasing development and use of techniques of automatic analysis as applied to graphic, auditory, three-dimensional, and other types of source data inputs. This area will thus include extensions and improvements to character and pattern recognition methods and equipment, to developments and extensions of voice recognition techniques, and to continuing research in the areas of pattern recognition, detection, and identification. Wooster suggests that "the most exciting step of all will come when we are able to study pattern recognition in text. . . . How does a scientist realize that a piece of work in, say, psychoacoustics contains the clue to solving his problems in cloud cover analysis?" (Wooster, 1964, p. 13).

5.7. Some Theoretical Approaches to Pattern Recognition and Categorization

Finally, in the area of preprocessing operations and pattern recognition we may consider a few of the problems and prospects for automatic pattern detection and pattern classification. There are problems of both pattern detection (emic analysis or classification concentrating upon similarities among events or sequences of events) and of pattern differentation (etic classification).[5.113]

*See p. 24.

FIGURE 10. *Fingerprint pattern showing bifurcation and ridge ending.*

R & D attacks on the problems of pattern identification and detection, generally, have to do with the problems of automatic means for the detection of memberships in classes,[5.113a] based both upon properties that are similar for members of the same class and upon properties that differentiate between members of different classes.[5.113b] Observed properties of both types may be considered to define a multidimensional or metric space in which distances between given property vectors of different input patterns can be used to separate one class from another. For example, questions of feature selection, feature effectiveness estimation, and various measures of distance between pattern vectors in n-dimensional feature space in terms of recognition-error probabilities are explored by Fukunaga (1968). For another example, work by Bledsoe (1966) concerns the mathematical treatment of problems in multicategory pattern recognition operations. A continuing R & D question is the extent to which hardware considerations may dictate the measurement space.[5.114]

Secondly, there are both practical and theoretical problems with respect to the choice of the properties to be measured and used in defining the recognition space. The methods involved may range from designation of probably significant features on the basis of intuitive, *a priori* grounds to extensive computer analyses of the similarities and differences among many samples of each of the various classes to be recognized. A generalized consideration of measures of similarity in terms of pattern classification tasks of various types is provided by Baker and Triest (1966).

Next, there are the theoretical problems of minimizing the number of property measurements to be made on input patterns (reduction of the dimensionality of the recognition space) and of optimizing the discriminating power of the set of properties that are retained.[5.115] Important in this area of theoretical pattern recognition research is the increasingly recognized need to use machine techniques for the systematic evaluation of possible criterial features held in common by exemplars of members of useful sets or classes.[5.116] An important example of recursive random generation of feature-detection operators for automatic character recognition is provided by Uhr and Vossler (1961).

Representative of relatively recent approaches to solution of some of the problems in this area is an ONR-sponsored program at Information Research Associates, Inc. Objectives are to determine those feature, property, or character extraction techniques that will best exploit differences between classes, that will exhibit minimum sensitivity to variations within a pattern class, and that will be of maximum efficiency as class distributors.[5.117]

The RADC-supported program of Cooper at Sylvania Electronic Systems has as its objective the development of "a mathematical theory of pattern recognition, with present emphasis on techniques for performing nonsupervised 'learning' with efficiency, tractability, and generality, and with minimal amount of prior information." (Cooper, 1966, p. 1).[5.118] At the Ballistic Research Laboratories, U.S. Army Materiel Command, investigations have included problems of pattern separation by linear programming techniques (Taylor, 1967) and consideration of mixtures of variates as a separate class in pattern recognition problems. (Sacco, 1967).

Adaptive principles and feedback mechanisms are employed to a greater or lesser extent in most of these techniques. In the simplest systems, involving mask- or template-matching, adaptation is especially to be found in training sequence or 'teaching sample' procedures in which a number of exemplars of each character in the set of characters to be recognized are analysed in terms of the particularly discriminating or criterial areas of each proposed mask, so that these areas may be differentially weighted for optimum discrimination between the various members of the set. To the basic adaptive mechanism based upon sample data there may be added other decision-functions, such as those designed to minimize risks of misrecognition. (Chow, 1959, various references, and others).[5.118a]

The most obvious criterion of choice for a minimal set of properties or features would be the application of information theoretic considerations.[5.118b] Liu (1964), for example, considers the problem of generating weighted area correlation masks for alphanumeric character recognition. The solution proposed uses an information-theoretic measure to identify "high-information" points from among all retinal points, and a random selection procedure for picking out five to seven points at a time from among the high-information points. The mask elements are assigned plus or minus values in such a manner as to maximize the value of the information measure. The final selection of recognition logics . . . "is made on the basis of a distance measure between classes." (Hart, 1966, p. 15).

Unfortunately, for practical applications, such patterns of interest as character shapes and sounds of human speech reflect a variety of other factors, some of them of physiological or even aesthetic origin which do not necessarily accord with the requirements of information theory.[5.118c] For example, in the Roman alphabet, the upper-case character "O" is distinguished from the upper-case "Q" only by the presence or absense of a descender tail. In the Cyrillic, the characters "Schah" or "Schahchah" are similarly distinguished, but both characters are wider than the normal character matrix requirements.

For such reasons as these, information theoretic considerations do not necessarily apply to optimal design of character recognition techniques. These reasons are, in effect, additional evidence of the current lack of techniques to isolate, discriminate between, identify, and use effectively, pattern-discriminatory and selection criteria.

As has been pointed out,

"Estimation is basic to pattern recognition where a class of observation waveforms or vectors describe a pattern. This is because the number of classes, the statistics for each class, and the *a priori* class probabilities are in general unknown. Both supervised estimation (where samples are classified) and unsupervised estimation are important. One reason unsupervised estimation is important is that the performance during operation can improve if and only if unsupervised estimation is utilized." (Monds and Carayannopolis, 1968, pp. 9–10).

Chow and co-workers have suggested that the detailed structure of a recognition system can be systematically derived in the functional form of probability distributions.[5.118d] The nearest neighbor dependence method goes beyond the assumptions of statistical independence.[5.118e] The recognition network consists of three levels: a layer of and/or gates, a set of linear summing networks in parallel, and a maximum selection circuit. Formulas for the weights of the recognition parameters are derived as logarithms of ratios of conditional probabilities. These formulas then lead to a procedure for estimating weights from sample characters which are then used in subsequent recognition. (Chow, 1965).

Other measures proposed include the use of statistical decision and probability theories.[5.119] As previously noted, some techniques under continuing investigation involve systematic searches for features of properties that remain relatively invariant under translations of magnification, rotation, or translation in the input image area.[5.120] For example, Giuliano et al. (1961) developed a computer simulation program based on the measurement of the first ten moments of the character pattern, normalized as to position and scale, and on discrimination by means of a distance-measuring algorithm to give quantitative measures of similarity between characters. They concluded that the experimental system showed reasonable discriminating power in the presence of print disturbance in addition to being insensitive to variations in positioning, scale, line thickness, or heavyness of print which, in this system, are compensated for by normalization.

In the area of pattern detection and classification research, an obvious possibility is the investigation of *adaptive* systems. Techniques of continuing R & D interest include the use of statistical inference methods and the use of learning models. Both techniques have been studied, for example, by Kanal et al. (1962) for potential applicability to recognition of underwater sounds, speech with respect to a limited class of utterances, transmitted complex wave forms, and multifont character recognition.

Statistical *inference* methods may generally be based on various statistical association techniques that provide measures of similarity derived from co-occurrences of properties among the members of a presumptive class. A continuing R & D requirement is indicated by the fact that apparently not enough is known as yet about the comparative efficacy of various statistical association formulas,[5.121] of which more than 50 can be identified,[5.122] and that finding a suitable method for making comparison represents "a very sticky problem." (Baker, 1965, p. 153).

Maron suggests that "it would be useful to strengthen the theories (which presently are not always clear) behind some of the current techniques in order to provide logical justification for their preference (over alternatives); i.e., to have some *measures* of the *goodness* of alternative association techniques." (Maron, 1965, p. 12).

Adaptive pattern recognition systems based upon learning models and "forced learning" procedures are another important area of continuing research and development. For example, Greenberg and Konheim describe experiments in the computer generation of separating hyperplanes, on 32×32 scanner output for training sequences of alphanumeric typed characters, with error rates for test characters ranging from 0.7 percent (original typing) to 1.7 percent for inputs including carbon and Xerox copies. A second experiment on similar training and test data, with comparable results, generated binary search separations. "Here linear functionals were formed to successively split the alphabet into two groups, each of those two more, and so on until individual letters were identified. Linear separability was demonstrated." (1964, p. 306).

Historically, the first investigations into adaptive or self-organizing methods of pattern detection and recognition are exemplified by Uttley's "conditional probability machine" experiments, where the device "learns" to detect and follow black-white boundaries. (1956, 1958, 1959) Gamba's learning-recognition systems (the "PAPA" devices) are based on a criterial-crossings technique, where the interactions sought between input patterns and stored reference patterns are those of intersections of the input image with a pre-established intermediary pattern. In this case, a configuration of random lines is produced by a computer-based pseudo-random generator, and associational or probabilistic-inference weights are built up from a training sequence of sample "characters" in terms of sub-units of the random configuration. Specifically, the "features" or "properties" of the input image that are extracted include such possibilities as whether the total number of intersections are even or odd, the number of intersections in the first half of the image area as compared to those in the second half, whether more or fewer intersections occur to the left of the center of gravity of the input image than those occurring to the right, whether there are more or less than *n* intersections, and so on.[5.123]

In the United States, pioneering efforts in the area of self-organizing are usually associated with the "Perceptron" research begun by Rosenblatt in 1957. Extensions of this technique by Rosenblatt and his colleagues and by other investigators go to multi-layer devices capable of feature extraction and to multiple levels of training and "learning". For example, Block et al. (1964) describe a procedure for adjusting the associational weights (built up as a result of reward-punishment feedbacks) in the first layer of a two-layer Perceptron model in such way as to improve detection of significant features, without regard to the manner of training and weight adjustment in the second layer as related to desired responses.[5.124] At M.I.T., Minsky and Papert are concerned with similar problems (1967).

Adaptive majority-logic schemes are represented not only by multi-layered Perceptrons, but also by the Conflex devices of Scope, Inc.,[5.125] and by developments at the General Post Office in Great Britain.[5.126] Kovalesky (1965) and Barus (1962, 1966) have been concerned with nonlinear transformations realized when the association units have many inputs during the "teaching" process.[5.127]

A "learning" model for a machine system to recognize three freehand characters ("S", "R", and "I") has been developed at Stanford Research Institute. These techniques are also being considered for application to the classification of cloud photographs and to problems of speech recognition and speech intelligibility. (Hall, 1964). At Bolt, Beranek and Newman, an ONR-sponsored project involves the design of a pictorial input system and research in character recognition, including work on handwritten characters and simple pictorial diagrams. (Strollo, 1966).

A large number of additional examples might also be cited, including Hughes Aircraft's 'Multivac' (*Multi-V*ariant *A*daptive *C*omputer) which has been used experimentally to recognize alphanumeric characters, to play simple games, and to differentiate between different kinds of sounds,[5.128] the Minos II at Stanford Research Institute and the ISODATA (*I*terative *S*elf-*O*rganizing *D*ata *A*nalysis *T*echnique *A*) procedure for its use,[5.129] or CHILD (*C*ognitive *H*ybrid *I*ntelligent *L*earning *D*evice) at the Information Processing Laboratory, Rome Air Development Center.[5.130]

Bonner (1962) describes a multi-level program to derive or enhance automatically recognition logics for determining the significant properties of samples of the various members of the population to be discriminated. The method involves: "1) Use of nonexhaustive heuristic algorithms to find 'valuable' properties . . . 2) Employment of various devices to make the requirements expected of heuristic method (1) less stringent. These include a method of dividing a problem into a number of simpler problems equivalent to the original problem . . . and a decision process which can operate effectively without requiring properties of very high 'value'." (p. 353).[5.131] Bonner's program, further, takes properties found to have "high" and "good" values for some but not all samples, or "good" for some, but not "high", and to convert them to "high and good for all" by logical combinations of "and" and "or". (p. 356).[5.132]

Of particular interest to future automatic pattern recognition capabilities, therefore, are experiments aimed at developing methods for adaptive extraction of significant features or properties of sample patterns, especially where those properties likely to be most useful in discriminating between members of different pattern categories are not known, or are not well-known, in advance. In such cases, a training sequence of representative or sample patterns may first be used. A continuing R & D requirement of a fact-finding nature is, therefore, for studies of the true representativeness of samples and of the applicability of results based upon such samples to real-life situations. Beyond these questions are serious technical problems as to the extent to which classes are in fact separable and/or of whether such classes as can be separated constitute useful or meaningful groupings of their respective members.[5.132a]

In adaptive systems using linear threshold decision elements,[5.133] iterations with varying pattern samples over time either produce convergence to optimal system performance or else the lack of convergence indicates that these patterns are linearly inseparable.[5.134] Problems of linear separability, then, are important areas for further investigations of useful classes of patterns or sets of pattern property measurements.[5.135]

Similarly, for the areas of automatic classification or categorization generally and for those applicable to documentary items in particular, it has been suggested that "the most fruitful approach to automatic classification research is not so much in the development of new models for classification as in investigation of how useful classes of objects are to be efficiently constructed from large universes." (Lehmann, 1964, p. 5–1).

There are several major causes of difficulties with respect to overlapping and non-separability of classes. The first and most obvious is the incidence of noise in the case of inputs from the real world. Then there are problems of irreducible ambiguities between input patterns, whether because of additive noise or multilation or because of the fact that the character was poorly formed to begin with, as in most handwriting examples.

Then there is the problem of the use of context to resolve problems or ambiguous or indeterminate pattern identifications. We shall, in general, reserve discussion of context expectancy and context-predictive-analyses to later consideration of natural language processing techniques and problems (in another report in this series), but we note here that, with respect to automatic speech recognition "the same spoken form may well correspond to more than one written form, and this ambiguity then has to be resolved by context searching, which is a syntactic operation analogous to its equivalent in machine translation" (Garvin, 1963, p. 114), and that "even with very legible handwriting, machines are bound to make mistakes, which they will need contextual information to resolve." (Lindgren, 1965, p. 105).

Some other examples of the importance of context checking for purposes of resolving ambiguous possible pattern identifications were given in the 1961 NBS state-of-the-art report on automatic character recognition. (Stevens, 1961). Dictionary lookup techniques have been proposed by Bledsoe and Browning (1959) and Baran and Estrin (1960), among others, and have been disclosed in a Rabinow patent.[5.136] Further considerations were raised by Alt (1961), and extensive investigations have been reported by Thomas and Kassler (1967).

An intriguing use of context is provided by an IBM experimental system for automatic reading of natural language text, involving cluster-seeking to identify the distinct types of characters encountered and a cryptogram-decoding procedure involving pre-stored digram frequencies and permuted-identification letter translation frequencies.[5.136a]

Edwards and Chambers (1964) simulated a recognition program, introducing noise by random number generator with respect to Alt's calculated moments to provide distorted moment values to the point where erroneous or ambiguous identifications would be made. "The same program was then rerun by inserting the digraph statistics. In the latter case the computer narrowed the choice down to two or more letters, using the distorted moment values. It then noted the letter it had identified, correctly or incorrectly, immediately preceding the letter under investigation and picked the letter of those under consideration which was most likely to succeed the preceding letter." (p. 468).

Edwards and Chambers note human use of context to correct nosiy characters, e.g., C–W must be either COW or CAW if it occurs in English text. They continue: "While it would no doubt be difficult to 'teach' a computer enough facts to perform this type of reasoning, there is good data available on the occurrence of digraphs or combinations of two letters in the common languages." (p. 465).

The use of digram and trigram frequency statistics has also been proposed by David and Selfridge (1962),[5.137] Harmon (1962),[5.137a] Sebestyen and Edie (1964),[5.138] Steinbuch and Piske (1963),[5.138a] Sakai and Doshita (1963) for Japanese speech recognition,[5.138b] and the Astropower Laboratory 1964 report, among others. An intriguing example is presented by Carlson (1966), where a computer technique was developed to replace garbled characters in genealogical records based upon trigram frequencies for proper names.[5.139] An accuracy of better than 90 percent error correction is claimed.

Other proposed techniques for context checking and error correction in the case of ambiguous characters and "misspelled" words, combine digram or trigram frequency statistics with dictionary lookup procedures[5.139a] or cyclic permutations of the input text.[5.139b] In a system investigated by Vossler and Branston (1964), combining a small dictionary (3,737 words) and digram data, special algorithms were proposed which would "collect in groups all words which were similar in most of their letters but yet differed from dictionary words. Such an algorithm might group together the garbled words: GAMBODIA, CAMBIDIH, CAMEODIA, CAMEOOIA, CHMBODIA. By determining the most frequent letter in each position the de-garbled word CAMBODIA can be constructed." (Vossler and Branston, 1964, p. D2.4-7).[5.139c]

Another intriguing example of context checking is in the case of recognition of chemical structure diagrams.[5.140] In general, however, an Auerbach survey has concluded: "Context recognition will certainly involve an enormous increase in the storage capacity and logical capabilities of character readers, but this may be justified by the increase in efficiency that can be attained. However, the economics of context-recognition readers will remain highly speculative until considerably more development work has been undertaken." (Feidelman and Katz, 1967, p. 0210:32). Similarly, "although the syntactic, semantic, and higher order constraints on the language would seem to be applicable to our problem, we do not yet have any very good ideas on how to use them." (Earnest, 1962, p. 462).

Another factor that may be considered in an ambiguous identification decision is that of expected single 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 (1960).

Chow (1957) 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 noisy input pattern. 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.

Finally, in the area of theoretical approaches to pattern recognition that we have reviewed, there are the problems of automatic detection of "classes" whose definitions and extensions are not known in advance—that is, the area of automatic categorization.[5.140a] In this area, a number of techniques have been experimentally investigated for a variety of applications, e.g., factor analysis, discriminant analysis, and clumping or clustering methods.[5.140b] A taxonomic approach to automatic classification is exemplified by Tanimoto (1958, 1962). (We will defer discussion of some of these techniques to a later volume of this report in connection with document grouping and automatic indexing applications, briefly discussing here only the latter technique).

First, Le Schack provides some useful definitions and distinctions: "A particular case of the classification problem is considered here. The basic raw data are estimates of the pairwise similarity between members of the population. It is desired to identify subsets in which the members are so similar to one another, and so dissimilar to nonmembers, that it is most useful to consider them as a unit. This process has been termed 'clumping' or 'clustering'. It is clear that an exact formulation of the clustering problem must be in terms of *optimization;* for the goal is the best balance between loss of precision, which is the inevitable consequence of representing each individual by the typical or average characteristics of his cluster, and gain in economy, which is the result of replacing many individuals by a few clusters." (1964, pp. XIV–3).

Further, "the intuitive notion of *perfect clustering* is best explained by considering a population of elements which can be partitioned into nonoverlapping subsets, such that within each subset there is a nonzero linkage between each pair of elements, but no linkage between a member of the subset and an element which is not a member. To generalize to the idea of *strong clustering*, assume that we are able to distinguish between *strong* and *weak* links; the definition is then modified to read: . . . Within each subset there is a strong linkage between each pair of elements, and at most a weak linkage between a member of the subset and an element which is not a member." (Le Schack, 1964, XIV–3).

It is to be noted first that the linkage or connection strengths are derived between items on the basis of the degree of similarity or association between them such as the sharing of some number of common properties. Thus, for example, "it is appropriate to take as a connection measure the 'Boolean nearness'; that is the connection between two objects is the number of columns in which their rows agree." (Needham, 1961, p. 9).

Initial work on clustering techniques assumed that the clusters would be known in advance.[5.141] The clumping techniques of Kuhns, Parker-Rhodes and Needham of the Cambridge Language Research Unit (CLRU), however, are largely addressed to the finding of unknown clumps.[5.142] Then we note also that "Bonner, Hyvarinen; Rogers and Tanimoto; Firschein and Fischler; Glazer; Stark, Okajima, and Whipple; Jakowitz, Shuey and White; and Ball and Hall have considered the problem of unknown clusters." (Mattson and Dammann, 1965, p. 296)[5.142a]

Computer programs to apply clumping techniques to the properties of a variety of objects have been used in experiments in automatic classification of archaeological artefacts such as pottery vessels and shards both at CLRU and elsewhere.[5.143] Also at CLRU an experiment was conducted with respect to classification of medical symptoms, with promising results in terms of selection of clumps corresponding to recognized diseases with the notable exception of Hodgkin's disease. In the latter case, however, it was noted that "patients show a chaotic collection of symptoms, some being practically complementary. The only unifying characteristic is that there are a lot of positive symptoms. I can scarcely conceive of a clump definition that would be likely to group these patients: I am unsure whether this is a reflection on clump theory or on Hodgkin's disease." (Needham, 1961, pp. 44–46).

Techniques of automatic classification or categorization based upon the clumping methods of Parker-Rhodes and Needham have continued under investigation, notably at the Linguistics Research Center at the University of Texas.[5.144] Dammann reports on the use of clustering techniques for experiments in voice recognition as follows: "Within the limitations imposed by the number of points within the clusters of the sample space, this experiment resulted in the satisfactory separation of eight unknown clusters of complex patterns in an arbitrary sample space, identified aberrant samples, and suggested an output code." (Dammann, 1966, p. 88). Karlsson and Arvidsson at the Royal Institute of Technology, Sweden, have applied cluster-seeking techniques to EKG recordings.

A marked increase of interest in cluster-seeking is to be noted in the recent literature, in the broadened areas of application being explored at CLRU (Spärck-Jones and Jackson, 1967), and in proposed practical applications for "autonomous" text-reading machines (Rabinow and Holt, 1966; Casey and Nagy, 1968).[5.144a]

The selection and retrieval systems in which statistical associations between text-word-association frequencies, index term associations, and document-document associations may be implemented to offer additional possibilities of useful clusterings.[5.145]

Present constraints on the practicality of the application of clumping and other techniques for automatic categorization and classification include those of computational requirements, memory requirements, adequacy of sample size, problems in the manipulation of large, sparse matrices, and questions of whether the material does in fact lend itself to meaningful partitionings. Thus Doyle remarks: "As to the future of *research* in automatic classification, we can certainly predict that it is going to be very interesting and productive. As to its application, the future is less bright—the immediate future at least. The major barrier is that of expense. The required cluster analysis and document grouping techniques are characteristically voracious in consumption of computer time." (Doyle, 1964, p. 29).

Beyond cost are questions of computational capabilities adequate for the handling of realistically large universes. It is further to be noted that "certain combinatorial problems are beyond the capacity of even the largest and fastest computers."

(Hayes, 1963, p. 284). Then, with respect to realistically large universes of items to be categorized or classified, the following "main point to be made is that theoretical elegance must be sacrificed to computational possibility: there is no merit in a classification program which can only be applied to a couple of hundred objects." (Needham, 1963, p. 8).[5.146]

Finally it is to be noted that over-simplifications of pattern categorization problems are to be found in various analytical approaches to problem solution. For example: the usual assumptions of independence and/or normality crop up continually to restrict the usefulness of the results obtained. "One is reminded of Tukey's injunction to the effect that "what is needed is not optimal solutions to carefully formulated, ideal problems, but merely 'good' solutions for nonideal situations." (Hart, 1966, p. 11).

An unfortunately not-well-coordinated thinking still persists in the areas of character, voice, and other types of pattern recognition. Thus, in Kovalevsky's words: "Designers of reading devices and speech-recognition systems sometimes were not interested in theory, and mathematicians disregarded applied problems. This resulted in a number of important tasks being left unsolved." (1965, p. 42).

Another point to be observed is that, despite the wide differences in the language used to describe particular recognition techniques, there is a far greater commonality of approach among different systems than might be suspected at first glance. Of particular promise for progress in automatic techniques for categorization, generally, therefore, are possibilities for increasing convergence of pattern recognition and pattern detection techniques in many fields.[5.147]

"Pattern analysis, as provided in the proposed system, can be used to discover relationships which pertain to vast bodies of data which would be almost impossible to obtain through any known manual techniques. Intelligent use of pattern analysis should assist in evaluating new trends in crime, testing new approaches to the administration of criminal justice, and discovering patterns of structure and activity of criminal and special organizations." (Geddes et al., 1963, p. 266).

Future prospects for even more sophisticated and complex pattern detection and pattern classification techniques in a wide variety of fields can certainly be foreseen. Examples of areas of continuing R & D challenge are as follows:

(1) "The pattern recognition problems of the future are apt to involve a tremendous latitude of variation in the patterns. Design by humans will be difficult because of the large amount of data that must be manipulated. Computers will have the ability to handle these data and can do so if we can tell them how." (Bonner, 1962, p. 353).

(2) "Research in this area [information recognition] is needed to acquire knowledge of such subjects as: the interrelationship between the analytic and Gestalt aspects of visual-pattern recognition; how and what subsets of point stimuli are perceived as unitary entities; the figure-figure, and figure-background separation mechanizms; and the meaning of the direction and limitation of attention." (Office of Aerospace Research, 1965, p. 26).

(3) "It has been shown, then, that any talk of an ideal adaptive language teaching machine must remain premature until a number of serious problems have been solved. It is clear that most of these problems are inherently theoretical rather than technical: their solution is tied to the development of a complete and satisfactory theory of language and of speech. The consideration of what is involved in developing such a machine highlights the complexity of language. Fundamental is the fact that language allows a great deal of redundancy, but any specific speech event contains only a selection of those features. Thus, speech recognition depends on using those features that may be present to decide on those that are absent. It is, for instance, possible to understand speech in the presence of considerable noise provided that syntactic and semantic information is available to the listener; but specification of exactly what this information is has proven to be extremely difficult." (Spolsky, 1966, pp. 494–495).

6. Conclusions

As we have seen in the preceding Sections of this report, research and development efforts in the broad area of automatic pattern recognition are of particular importance to the improvement of information sensing and input processes. This area extends from successful techniques for magnetic ink and optical character recognition to research investigations of potentialities for automatic detection and classification of cloud formation patterns and to theoretical developments with respect to questions of linear separability, determinations of membership in classes, and the like. Other problems under attack include those of voice recognition, automatic detection of patterns of interest in electrocardiograph and bubble chamber data, and simulation of observed human or animal perception phenomena.

The scope of the field of pattern processing research is indeed surprisingly broad. The term "processing" is chosen deliberately in order to beg terminological controversies with respect to pattern "identification," pattern "classification," and pattern "recognition," as variously used in the literature.[6.1] In the pattern-processing R & D area, we are concerned either with the identification of a given input pattern, or with the meeting of membership-qualification requirements for a pre-established class of patterns, or with the properties or features that a given input pattern shares or does not share with some one or more classes of previously encountered patterns; and with the determination of which properties or features of some set of patterns significantly distinguish them from other possible sets or classes.

Input problems for automatic analysis of text (to be considered in a later report in this series) involve questions of multifont, exotic alphabet, and multilevel character recognition and difficulties in more advanced techniques for speech recognition and for pattern recognition generally. Thus, as Wyllys points out: "When character readers reach that level of development [multi-font page reading of a typical scientific journal], it will be possible to utilize the positional and editorial features of printed text—e.g., paragraphing, sub-heading, captions, italization, and capitalization—to furnish clues for automatic abstracting and other purposes." (Wyllys, 1963, p. 7).

Pattern recognition as an area of R & D concern is directed to the identification or the detection of arbitrary patterns, some of which can be visually perceived (such as photographs, charts, textual patterns and three-dimensional real-world objects) and others which require nonvisual perception such as speech and electromagnetic signals. Character recognition is considered as a specific case of pattern recognition and is often dealt with as a separate field of investigation because of the emphasis that has been placed upon it. Much of the effort to date has been limited to the development of print readers which are usually limited to small alphabets, single font, and often with a specially designed type style.

In addition, computer experiments have enabled demonstrations and simulations of much more sophisticated pattern recognition schemes including at least elementary target pattern detection, electrocardiograph analysis, some automated photo interpretation, cloud pattern detection, detection and tracing of bubble chamber tracks, limited speech recognition, recognition of contrained handwritten and some limited identification of words in cursive handwriting.

Research requirements in the area of pattern recognition were summarized for a Task Force of COSATI in 1965 by Davis and Stevens, substantially as follows:

1. *Character recognition*—including conventionalized shapes and symbols, as in chemical literature, circuit diagrams, flow-charts, and the like.
   a. For the printed character reading systems:
      (1) Research on format clues—e.g., to skip interspersed graphics, to ignore page numbers and short titles, to differentiate between period, decimal point, and the like, prior to multi-format, multi-font page reader design and application.[6.2]
      (2) R & D efforts on the difficult alphabets not likely to be tackled by commercial interests: Cyrillic, Arabic, Chinese, etc.[6.3] Special problems to be investigated include the common European practice of spreading out the letters of a word or proper name in lieu of italization.[6.4]
      (3) Development of error-detecting, error-correction techniques for input likely to be noisy or difficult, e.g., RCA and NBS-Chinese context-checking operations.
   b. For conventionalized symbols, we need:
      (1) R & D investigations to provide for size, translation, rotation and other symbol invariances.
      (2) Development of "picture-language equivalence", e.g., how to name shapes that have been recognized; for example whether, given the name, we can find a corresponding symbol or shape.[6.5]
      (3) Research concerned with two-dimensional well-formedness, e.g., for structural and circuit diagrams, also for character-components as in Chinese ideographs, and two-dimensional grammars.
2. *Pattern recognition*—including speech, EKG, EEG, star plates, cell tissue, microphotographs, regularities in signal sequences, Stenotype records, Morse code signals, maps, drawings, gray scale images, photos, three-dimensional objects, and so on.
   a. Research on limited multi-speaker speech input, e.g., dictation of data from instrument observations.
   b. Research on programming languages and compilers for manipulation of two- and three-dimensional graphic data.
   c. Research and development of automated photointerpretation, specifically including photomicrographs.
   d. Research and development on acoustic and speech analysis, recognition, and synthesis.[6.6]
   e. Research on techniques of recognition of three-dimensional objects, on derivation of dimensional data, on reconstruction of two-dimensional representations of three dimensional objects, on normalization of perspective drawings.

3. *Word and item patterns detection and recognition:*
   a. Research on patterns of citedness, citingness and of overlap of indexing terms previously assigned to co-cited items.
   b. Research on patterns of word co-occurrence with sample assignments of category names, descriptions, etc., of prior term-term or word-term associations in the collection, and automatic indexing based thereon. This includes devices such as ACORN for display of patterns automatically detected.
   c. Content analysis, e.g., of verbal protocol records using both clue-word and temporal patterns.
4. *Automatic categorization and determination of membership in classes:*
   a. Research on mathematical theories of determination of membership in classes, linear separability and threshold logics, factor analysis, and the like.[6,7]
   b. Research in automatic classification and indexing, where syntactic and semantics are not involved and where it is equally applicable to properties or attributes other than words or text.
   c. Research on detection of patterns of signals embedded in noise.
5. *Research and development of adaptive systems and techniques for pattern recognition.*
6. *Research and development of self-organizing systems for pattern recognition.*
7. Research and development of techniques of simulation of human behavioristic modes of pattern recognition including experiments in automatic deductive and inductive inference, and concept formation.

For the long term, the combination of scanner developments, languages for pictorial data processing, and a "syntactic structure" and "context expectancy" approach will be important for applications such as patent searching where information is found in drawings as well as in text.[6,8] More generally, such research points to the handling of a wide variety of information where the meaning or message is conveyed as much by two-dimensional arrangements, orderings, and juxtapositions of symbols as by the identification of the symbols themselves.

Looking forward, in the area of automatic operations upon input, we can foresee increasing development and use of techniques of automatic analysis as applied to graphic, auditory, three-dimensional, and other types of source data inputs. This area will thus include extensions and improvements to character and pattern recognitions methods and equipment, to developments and extensions of voice recognition techniques, and to continuing research in the areas of pattern recognition, detection, and identification.

Appendix A. Background Notes on Research and Development Requirements in Information Acquisition, Sensing, and Input

In this Appendix we present further discussion and background material intended to highlight and emphasize currently identifiable research and development requirements in the broad field of the computer and information sciences.

A number of illustrative examples, pertinent quotations from the literature, and references to current R & D efforts has been assembled. These background notes have been referenced, as appropriate, in the text of this report.

1. Introduction

1.1 In a provocative and challenging discussion of a research team's findings with respect to a desirable mechanized documentation system of the future, Licklider (1965, p. 40) states: "the reason for setting forth such a plan is not to guide research and development, which would be presumptuous, but to provide a kind of checklist or scorecard for use in following the game. If the technology should take care of most of the items in the plan but fall behind on a few, then it might be worth while for an agency interested in the outcome to foster special efforts on the delinquent items."

1.2 "Information processing systems are but one facet of an evolving field of intellectual activity called communication sciences. This is a generic term which is applied to those areas of study in which the interest centers on the properties of a system or the properties of arrays of symbols which come from their organization or structure rather than from their physical properties; that is, the study of what one M. I. T. colleague calls 'the problems of organized complexity'." (Wiesner, 1958, p. 268).

The terminology apparently originated with Warren Weaver (1948). Weaver noted first that the areas typically tackled in scientific research and development efforts up to the twentieth century were largely concerned with two-variable *problems of simplicity;* then from about 1900 on, powerful techniques such as those of probability theory and statistical mechanics were developed to deal with *problems of disorganized complexity* (that is, those in which the number of variables is very large, the individual behavior of each of the many variables is erratic or unknown, but the system as a whole has analyzable average properties). Finally, he points to an intermediate region "which science has as yet little explored or conquered, where by contrast to those disorganized or random situations with which the statistical techniques can cope, the *problems of organized complexity* require dealing simultaneously with a considerable number of variables that are interrelated in accordance with organizational factors."

He says further that "these new problems, and the future of the world depends on many of them," will require science to make a third great advance that "must be even greater than the nineteenth-century conquest of the problems of simplicity or the twentieth-century victory over problems of disorganized complexity."

1.3 Some examples are as follows: "One field of science now moving forward at a rapid pace can be singled out as offering unusual scientific and economic challenge. This is the broad area of information manipulation. Included are the broad areas of information theory, computation and communication. To the basic scientist there is presented the question as fundamental as the nature of light or gravitation, namely, what is information; what is knowledge; what constitutes consciousness of existence; are there immutable laws of the physical universe governing the nature of information and knowledge as yet undefined and perhaps unsuspected that await discovery in the next 5 decades?" (Bowie, 1962, pp. 609–610).

"One difficulty in the endeavor to match mechanical to human behavior . . . is that it is far from clear what sort of activity counts as recognition of a pattern by a human being. It is not clear consequently what sort of behavior is to be duplicated or approximated by mechanical devices.

"Although some investigators seem aware of this problem, there is little evidence of any sustained attempt to sharpen our understanding of human pattern recognition. The deficiency at point is not the admitted lack of a comprehensive psychological theory of recognition, but rather the lack of a clear description of what humans do in various situations which normally would be taken as instances of pattern recognition." (Sayre, 1962, p. 27).

"The next fifty years will see electronic information processing systems brought to a stage of sophistication comparable to that of today's electronic communication systems. This will require two things. In the first place, the basic principles underlying the brain's method of digesting information must be discovered and translated into simple electronic systems. This is as necessary as our simple theory of electromagnetism was for developing detector, amplifier, and transmission systems. In the second place, capacity for electronic storing and processing of information, on a scale equal to that of the human brain, must be developed. The electronic information handling systems of the future will be able to receive information in visual and auditory form, just as humans do." (Van Heerden, Proc. IRE **50,** 621 (May 1962).)

"Concern with meaning introduces a parameter ignored in the simplifying assumptions of communication theory. Such Air Force problems as automatic abstracting and indexing of scientific papers, information storage and retrieval, mechanical translation, and even automatic distribution of messages depend upon a deeper understanding of the meaning of meaning than has heretofore been necessary or possible. This understanding may even come from such esoteric fields as analytical philosophy, epistemology, and taxonomy." (Wooster, 1961, p. 17).

1.4 Goldberg, in his 1931 U.S. Patent, 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 extra-ordinary 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."

1.4a For example, "for automatic input of documents to an automatic IRS, the descriptor type language without grammar is used. Chernyavsky and Lakhuti . . . apply the first approach rigorously; the text of a document (a short abstract) is compared word-by-word with a descriptor dictionary prepared in advance (the subject being that of Electrical Engineering), in which the significant words are grouped together in equalizing classes (i.e., sets of words which are synonymous or related in meaning), each of which stands for one descriptor; the result will be a set of descriptors forming the search pattern of the text in the IRS concerned. The difficulty here is to distinguish the homographs, but the experience has shown that this difficulty is well resolved by lexical analysis of the context environment of the homographs." (Mikhailov, 1968, p. 35).

1.4b *"Laboratory of Electromodeling (LEM) of the All-Union Institute of Scientific and Technical Information (VINITI) of the Academy of Sciences of the USSR.* Development of a reading automation was begun here in 1959. The operational reader . . . reads typewritten texts and inputs them to a Ural–4 computer." (Stephan, 1967, p. 5).

"An operational automation for reading typewritten texts and inputting them to a Ural–4 computer to solve a number of problems of an information processing nature has been developed in the Laboratory for Electromodeling of VINITI, under the Academy of Sciences of the USSR . . .

"Pattern recognition in the operational reader is based on a method . . . for comparing the pattern under investigation against a set of fixed image-field regions which yield invariant descriptions of patterns in binary or any other coding system. The information distinguishing areas were called distinguishing fragments and the method, correspondingly, the fragment method . . .

"The technical implementation of the fragment method, developed in the Laboratory for Electromodeling, has made it possible to devise an analysis unit by extremely simple means. The unit for storing the fixed symbol variants (that is, the fragments) is a ferrite matrix in which the fragments are inscribed in the form of output-threaded core wirings . . . The device turns out to be small, simple, and reliable in operation . . .

"A coded description of the character being scanned, selected from the matrix of fragments, is fed into the decoder which contains code descriptions of all characters of the set being examined and previously obtained as a result of statistical processing of large masses of observed characters in an actual reading device and digital computer system. The encoded description of the symbol is compared with all the encoded descriptions of symbols in the decoder, and a minimal signal is obtained on the decoder bus for the character most closely corresponding to the encoded character. The index of this bus is transmitted to the output unit, where this index, with the aid of an encoder device, is transformed into Ural–4 machine code and is then relayed to the computer's memory and onto papertape (for monitoring purposes) . . .

"The reader's speed is determined by an electromechanical system of character scanning and the operational characteristics of the ferrite-diode modules; at present, the rate is 10 characters/sec." (Avrukh, 1967, pp. 20–23).

"Three cabinets painted in traditional computer-grey stand in a small room of the Laboratory of

Electromodeling . . . this is the reading automaton.

"In the first cabinet there is a page of typewritten text on a revolving drum. A greenish band of light from a cathode-ray tube shines down on a line. To the side is a photomultiplier whose eye is focussed on the line running under the band of light. Scanning the letters, the ray of light is constantly transmitting signals to the photomultiplier: 'white, white, black, white . . .' These signals transformed into electrical pulses enter the second cabinet which is tightly packed with an intricate ligature of varicolored conductors connecting ferrite and semiconductor elements.

"There are frames covered with an openwork screen in the cabinet and there are miniature ferrite cores at the intersections of small wires. In several places the screen has been 'darned' by additional intersections of small wires. The electrical pulses from the first cabinet are stored and analyzed in this screen-matrix. The automation has features stored in it by which it is possible to describe any typewritten alphabetic character. One or another combination of features allows the machine to recognize the letter being read.

"The complex cobweb of electronic circuits in the third cabinet examines the results obtained by the recognition matrices in the second cabinet. Here the final determination is made as to which letter has been read. From here the letters are fed by cable into the memory of a Ural–4." (Koltovoj, 1967, pp. 38–39).

An actual example is shown in Figure 11. It will be noted that the font uses large-sized and well-spaced upper-case alphabetic plus numeric characters. Stylization has been applied to narrow some characters that are normally wider than others, to add a small connecting bar to the character 'bl' and to accentuate punctuation marks. A relatively poor print quality may also be noted, leading to obvious variations of stroke thickness and to problems of correct discrimination between members of some character subsets. To date, over 2,000,000 characters have been read by optical character recognition equipment and fed to a computer for experimental author and title index preparation.

1.5 For example, in work at the William Alanson White Institute by Jaffe and his colleagues. "Jaffe also indicates the necessity for analyzing nonverbal as well as verbal behavior. For this purpose he and his coworkers developed an automated device for the extraction of time-sequence behavior in the transaction between client and therapist (Cassotta, Feldstein and Jaffe, 1962) . . . the new device permits the recording of time-sequence data (not actual content) from microphone inputs to punched cards without manual intervention." (Ford, 1963, p. 5).

1.6 See account of the Chrono-Log Model 3,000 Oscillographic Time Code Generator, Data Proc. Mag. **7**, No. 2, 54 (Feb. 1965).

1.6a Thus, "this is the era of the interface, especially the custom interface. The industry is willing to couple anything to everything including people, analog and digital computers, and a large variety of input-output devices." (Ware, 1965, p. 472.) Ohlman, looking forward in 1963, suggested that "another interesting possibility is audio interrogation and reply, involving telephone lines and tape recorders . . . Any combination of these modes is possible—*a store might be interrogated orally* and a reply obtained visually, etc." (Ohlman, 1963, p. 193).

1.7 "In 1936, Dudley [1936] invented the vocoder, a device for compressing the bandwidth of speech signals in order to transmit them over channels of very limited capacity. The vocoder measures the speech power in a number of frequency bands and transmits these measures as signals over a series of narrow low-frequency channels (Fant and Stevens, 1960). At the receiver the speech is reconstituted by modulating the spectrum of a broad band source in accordance with the frequency region and amplitude of each of the measure-signals derived from the original speech. Normally this reconstituted speech signal is presented acoustically for a listener. Alternatively, vocoded speech signals can be displayed visually or tactually." (Pickett, 1963, p. 2.)

"The first computer application was probably in the design of the so-called 'vocoders'. The vocoder is a telephone system that utilizes long distance transmission lines with greater efficiency than conventional systems. At the sending end, the vocoder extracts and transmits only certain features of the speech wave picked up by its microphone. At the receiving end, it uses the transmitted information to reconstruct a simplified version of the original speech wave. The transmission economy is achieved by not transmitting the whole sound wave but only those parts of it that contribute to speech perception. As we do not fully understand the essentials of the speech process, we are not always sure which features to extract or how to extract them. A wide variety of circuits has therefore been tried in attempts to achieve acceptable vocoders." (Denes, 1966, p. 250).

1.8 They report: "A more promising 'measurement space' for speech recognition is suggested by a consideration of a theoretical model for the generation of synthetic speech sounds." (King and Tunis, 1966, p. 66).

1.9 "The equipment consists of a voice spectrum analyzer acting as online input to an IBM 1620–II digital computer system. The basis of the spectrum analyzer is a contiguously tuned bank of bandpass filters whose instantaneous outputs are continuously compared in such a way as to locate the instantaneous peaks in the envelope of the speech spectrum. The output of the spectrum analyzer is a binary coded representation of the peaks of the envelope of the frequency spectrum as a function of time; it serves as input to the IBM 1620." (King and Tunis, 1966, p. 65).

See also Section 5.5 of this report.

1.10 In KWIC indexing, the texts of titles are prepared for input to the computer and this text

5 ГI48 О ЦИФРОВОЙ ТЕХНИКЕ СЧИТЫВАНИЯИ
АНАЛИЗА КОНТУРОВ/ПОЛЯКОВ В.Г./
5 ГI5I РАСПОЗНАВАНИЕ РУКОПИСНЫХ ЗНАКОВ
С ПОМОЩЬЮ СЛЕДЯЩЕЙ РАЗВЕРТКИ/СЕМЕНОВСКИЙ/
8 ГI83 П ЧИТАЮЩЕЕ УСТРОЙСТВО/НАРИТА АКИРА
8 ГI76 К ВОПРОСУ ЭФФЕКТИВНОСТИ ПАРАМЕТРОВ
ОБРАЗОВ/ТАЛЬКСНИС Л.А./
8 ГI75 К ВОПРОСУ ОПОЗНАВАНИЯ ОБРАЗОВ МЕ
ТОДОМ МАСОК/БУЛОВАС В.В./

G 148 About Numerical Technical Computations and Analysis of Contours/Polyakov, V. G.

G 151 Recognition of Handwritten Symbols With the Aid of Curve Following/Semenovsky

G 183 Reading Device/Narita Akira

G 176 The Problems of Sensitivity to Parameters of Shapes/Talexnis, L. A.

G 175 The Question of Recognizing Shapes by a Method of Masks (?)/Bulovas, V. V.

FIGURE 11. *Material read by Soviet print reader*

is then processed against the stop list in order to eliminate from further processing the more common words, such as "the," "and," prepositions, and the like, as well as words so general as to be useless for indexing purposes, such as "introduction" or "progress" or "preliminary," which will, however, be printed out in the title as it appears in the final index.

In the original proposals of the late H. P. Luhn for KWIC indexes, he stressed that "since significance is difficult to predict, it is more practicable to isolate it by rejecting all obviously nonsignificant or 'common' words, with the risk of admitting certain words of questionable value. Such words may subsequently be eliminated or tolerated as 'noise'. A list of nonsignificant words would include articles, conjunctions, prepositions, auxiliary verbs, certain adjectives, and words such as 'report', 'analysis', 'theory', and the like." (Luhn, 1960, p. 289).

2. Information Acquisition, Source Data Automation, and Remote Data Collection

2.1 "A new system from 3M allows EKG's to be transmitted and viewed at long distances in seconds. Heart data is transmitted via telephone or transmission lines to a Model 1260 recorder. The images are displayed on the unit's CRT where they can be viewed at once or photographed by a microfilm processor camera." (Data Proc. Mag. **9**, No. 6, 10 (1967).)

"An FM data transmission system was designed to transmit a fetal electrocardiogram utilizing the normal telephone circuits." (Hagan and Larks, 1963, p. 147.)

"The major work in the medical field in 1965 took place in three areas: machine-aided record keeping, machine-aided physiological analysis, and machine-aided medical communication. Vallbona, Caceres, and others are trying to use detailed physiological data derived either directly from sensor or indirectly from sensor tracings as suitable input to a medical computer system. Caceres utilizes a recording cart or remote telephone link to go directly from the EKG leads to the computer, while Vallbona telemeters the physiological data to a paper tape punch from which cards are prepared that are then fed into the computer." (Baruch, 1966, p. 258.)

2.2 "A computer system using an IBM 1620–1710 for high speed monitoring and real time reporting on critically ill patients . . . [has been developed by the Shock Research Unit, USC School of Medicine at the Los Angeles County Hospital.] The system currently accepts analog signals from 11 transducers on the patient's body . . . Additional information . . . is obtained by manually entered data." (Rockwell et al., 1966, p. 357.)

"Greanias [1965] points out that 'primary data from the patient himself may be processed by the computer . . . on-line. . . . The on-line data such as electrocardiographs and respiration rates can be automatically monitored by the computer and directly fed into storage without human intervention.' He mentions one of the earliest projects to develop an on-line system for direct patient monitoring, being carried out in the Shock Research Unit of the University of Southern California's School of Medicine and the Los Angeles County Hospital under the direction of Dr. Max H. Weil. 'The primary measurements are processed by a remote computer, and the measured and derived variables are printed out on an output typewriter in the ward, and displayed on a screen at the patient's bedside'." (Davis, 1966, p. 248).

"It appears there is a need for hardware assistance in caring for the critically ill in order to reduce human error and to provide permanent records and displays which the human senses are not trained to assimilate entirely. This would provide for better care of patients as well as production of hard-copy records." (Brown et al., 1967, p. 77.)

"Valid statistics on physiological processes require substantially more data than can be manually recorded. As a result, many separate biomedical instruments, as well as integrated physiological monitors, are being built to collect useful data. An ultimate, but difficult, objective is the use of real-time data-acquisition systems to provide patient data that can be analyzed for immediate use by the attending physician." (Aron, 1967, p. 65.)

2.3 "There is need for the monitoring of patients for intra-hospital use, but also for network use in terms of exchange of information (with other hospitals) on techniques, etc." (Brown et al., 1967, p. 77.)

2.4 "In a broader sense, telephone telemetry may help to interconnect research laboratories and even universities, making possible that degree of inter-university cooperation which seems indicated in this epoch. Several of Marquette's neighboring universities have expressed great interest in this field [telephone telemetry of low-level biologic signals] and a regional net, including at least four states, is planned." (Hagan and Larks, 1963, p. 150.)

2.5 "In an experiment for the Chevrolet division of the General Motors Corp., the Boeing Co., used computer graphics last year to run off sketches of Chevy's Sting Ray . . . Proximity probes reportedly were used to measure the length, width and height of a clay mockup. These coordinates were then punched into cards and fed into a computer. Punched tape was made and used to run a numerically controlled drafting machine, or engineering plotter . . ." (Gomolak, 1964, p. 65).

2.6 "The General Electric Co., reports . . . that it has provided the Ford Motor Co., with an experimental NC system for making automobile parts. A model of the part is photographed and an electronic system converts the photos into a numerical control tape, which controls the machining of the part." (Electronics **38,** No. 20, 25 (1965).

Other examples are as follows: "In a steel fabrication detailing application, the computer accepts basic design criteria and determines the exact dimensions of steel members, how they should be cut, and the size of the connecting members. The number of bolts and lengths of welds to be used to interconnect members are determined.

"The CONSTRUCTS (Control Data Structural System) seeks out possible obstructions and connection problems, and automatically provides special solutions as required.

"Once calculations have been completed, full-sized drawings are produced on a plotter." (Bus. Automation **12,** No. 7, 55 (1965).

"An advanced concept in the calculation and transmission of machinability data was demonstrated by GE's Metallurgical Products Dept. Machinability problems were posed to a remote GE–225 computer via a Datanet–760 terminal. Near-instantaneous answers on recommended feed, speed and carbide tool grade for turning operations were displayed on a TV monitor." (Data Proc. Mag. **7,** No. 11, 12 (Nov. 1965).)

"An integrated computerized system has been developed at the Sun Oil Company for the production of isometric drawings with accompanying bills of material, requisitions, purchase orders, and cost estimates for piping configurations. . . . A significant feature of the operation is a single input sheet initiating the process whether it be for the entire procedure or only part of it. These procedures can produce fabrication sketches for piping fabricators and/or construction site personnel. They will yield cost estimates for cost engineers as an aid in the evaluation of material, line size or configuration changes for a single drawing or any combination of drawings describing a section of the plant or the entire plant. Requisitions are provided for ordering material and updated lists of the status of items ordered are produced for project engineers. The purchasing department by writing a cover letter can use the requisition as an appendix and, thus, produce a purchase order. The material inventory control group at one of our refineries can use output cards from this system to interrogate their computer as to the inventory status of items being requisitioned. In an integrated system such as this, justification and advantages accrue from the integration over and above any of the single components. In this paper the discussion will be limited to the isometric drawings and bills of material phase of this system." (Aicher, 1967, p. 134).

2.7 "In commercial data processing systems where there is a strong profit discipline, the cardinal rule is 'Capture data at its source—Capture it only once—Use it, and use it, and use it'." (Kroger, 1965, p. 267).

"It is hard to conceive of a great expansion in management information systems unless there is a breakthrough in source data automation." (Voltin, 1967. p. 8).

2.7a "The Bureau has developed a new model of FOSDIC (Film Optical Sensing Device for Input to Computers) to assist the Bureau of the Census in processing the data to be received from the 1960 decennial censuses. This electronic machine rapidly reads microfilmed census documents and transcribes the data on magnetic tape for direct input to an electronic computer. It was designed by M. L. Greenough and C. C. Gordon of the NBS staff and E. S. Stein of the Bureau of the Census.

"The central element of FOSDIC III, like its predecessors, FOSDIC I and II, is an electronic scanning assembly. Light from the screen of a cathode-ray tube is focused upon the microfilm image, and the transmissivity of small, discrete areas on the film—corresponding to the handwritten marks on the original document—is measured with a photoelectric cell. By moving the electron beam around on the face of the cathode-ray tube, any selected area of the image can be examined. Control of the position of the illuminated area, and interpretation of the signals from the photoelectric cells are functions performed by the associated electronic circuitry. Through positional control, or scanning, the point of light travels in prescribed manner from one point to the next in turn. Since there is only one electron beam in the cathode-ray tube, the scanning over the image is serial in its time sequence. Then, as soon as one image is scanned, the film is automatically advanced to the next frame.

"FOSDIC can read off any part of all of the information on a document, depending on what the programer instructs the machine to do. The instructions are in terms of the horizontal and vertical coordinates of the index mark next to the desired information. Program control is through a plugboard into which the detection logic has been wired." (FOSDIC III to Assist in 1960 Census, 1959).

"A key factor is . . . FOSDIC, or more properly, Film Optical Sensing Device for Input to Computers. This equipment transforms microfilm pictures of special paper forms into impulses on magnetic tape . . . One FOSDIC sheet takes the place of a dozen punched cards and FOSDIC can process 100 of these sheets, in the form of microfilm images, in one minute." (Census Bureau Slashes Record Handling Time, 1964, p. 32).

A related development, FOSDIC IV, is designed for programmable scanning of the microfilmed images of punched cards: "An improved model of FOSDIC . . . has been completed by the National Bureau of Standards for use with the computers of the National Weather Records Center . . . FOSDIC IV reads data on past weather conditions from microfilms of punched cards from the Center's archives. The machine performs logical operations on the data it reads and also selects certain data to be recorded on magnetic tape for later input to digital computers." (FOSDIC IV Reads Microfilmed Weather Data for Computer, 1967, p. 63).

2.7b "With advancing technology, input from authors may be in machine-readable form or may be converted directly to this form by scanners. Electronic display and light-pen techniques seem likely to play important roles in composition and in making editorial corrections and also in the transmission of stored information to users." (American Institute of Physics Staff, 1967, p. 372).

2.8 "A record from a relatively simple input typing operation can be processed to form a multiplicity of high typographic quality, complex output products . . . This procedure allows the primary record to be processed into a variety of secondary products, regardless of their typographic forms. A computer processing system has been developed to produce the primary journal typesetting tape, an author index typesetting tape, and an abstract journal entry typesetting tape." (Buckland, 1965, pp. 2–20).

2.8a "Miller Electric Co. uses Control Data 180 data collectors on the shop floor of its plant in Appleton, Wis., to capture data in punched tape. The collectors are portable and have self-contained punches. Data on production status and attendance is entered into the devices by the people who work on the welders and welding equipment which Miller sells. Plastic identification cards are used to input employee identification. Pre-punched cards identify each part being manufactured, dials are used by the employee to enter variable information, and a clock module automatically records time of input on the tape." (Menkhaus, 1967, pp. 33–34).

2.9 "Automatic data collection (ADC) implies the recording, in machine-readable form, of the pertinent data about a transaction at the time the transaction occurs. Some data collection systems collect and record the transation data in machine-readable form for later batch processing, while others feed the data directly into real-time computer systems to provide up-to-the-minute information for operational decisions." (Hillegass and Melick, 1967, p. 50).

2.10 "Honeywell's modular, multipurpose Data Station can optically scan documents, read punched cards, print at high or low speeds, and punch and read paper tape and is designed as a remote terminal for Honeywell 200 and 2200 computer systems . . . The optical scanning unit reads up to 50 documents a minute imprinted in a special bar code." (Data Proc. Mag. **7,** No. 2, 47, 1965).

2.11 "Hewlett-Packard Co., Redwood City, Calif., unveiled its desk-top optical mark reader . . ." (Commun. ACM **9,** No. 6, 468 (June 1966).)

British examples of optical mark reading equipment include an ICT (International Computers and Tabulators, Ltd.) device and the "Autolector" of English Electric, Leo.

"The Leo-Parnall Autolector is an automatic optical scanning device which reads both computer printed and hand marked forms directly into a computer." (Dig. Comp. Newsletter **16,** No. 4, 26 (1964).

2.12 This technique "changes electrical impulses into numerical values. These numbers are fed into a computer which then examines the series of numbers to produce a standard pattern for each motion. The pattern can then be used to design control circuitry for complex movement patterns." (Bus. Automation **70, 12,** No. 10, (Oct. 1965).)

2.13 "Techniques are being developed in several laboratories which will permit the use of optical character recognition in industrial control applications, for example checking labels on bottles during packaging processes and material control on assembly lines." (Daniels, 1967, p. 10).

2.13a "Kartrak . . . utilises an unmanned, weather-proof, trackside scanner which sends out beams of white light and receives coloured reflected light from strips of durable reflective material. The strips, attached to each car, are arranged to form a colour code representing the identification number of the car and its weight when empty." (Data and Control **2,** No. 12, 9 (Dec. 1964).)

"Automatic car identification adopted nationwide by America's Railroads. Thomas M. Goodfellow, president of the Association of American Railroads, has announced the adoption of industry-wide automatic car identification system to monitor the 1.8 million freight car fleet. The KarTrak automatic car identification system, selected by the AAR, is designed and manufactured in Bedford, Mass., by the Commerical Electronics Division of Sylvania Electric Products Inc.

"Major components in the new system are a trackside electronic 'scanner' made by Sylvania and the 3M Company's 'Scotchlite' reflective sheeting. Strips of reflective sheeting are coded by color and design in such a manner as to represent numbers to the scanner. A light beam from the scanner 'reads' numbers from bottom to top. The retro-reflective sheeting 'bounces back' numbers to the scanner which feeds them into a centralized computer. The system works at train speeds of up to 80 MPH and is unaffected by weather conditions. The system makes possible instantaneous location of any freight car in the country.

"The TeleRail Automated Information Network (TRAIN) recently established by the AAR will be tied in with the nationwide ACI system and the advanced information systems of individual railroads. TRAIN, based at the Association's Washington headquarters with computer links to all Class I railroads, will provide the AAR Car Service Division with complete reports of car locations by railroads and car flows through principal rail gateways, and will permit more rapid distribution of the equipment to meet shipper needs for freight cars." (Computers and Automation **16,** No. 12, 61 (Dec. 1967).

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2.14 Davenport (1965) summarized some of the advantages of this technique as follows:

"(1) Cost is relatively low, only two or three times that of an ordinary telephone.
(2) The remote input station can be used interchangeably for either voice or data transmission.
(3) The keyboard is as easy to use as a small adding machine.
(4) The station can be connected to both local and long-distance telephone facilities.
(5) The input device can be portable and capable of sending from any phone jack.
(6) Transmission can be either to paper tape and card punches or on-line to a computer.
(7) Effectually real-time operation can be achieved at low cost."

2.15 "The data that is accumulated and stored is information relevant to flow of work and accumulated charges in a production facility. The information is entered by workmen at numerous data collection devices in the time keeping and production areas. The production facilities are physically separated by several hundred miles from each other and corporate offices but because of the competitive nature of the business it is important to provide status reports three times daily. The amount of data accumulated at each facility during an eight-hour shift, including material purchase requisitions, distribution of hours worked by product and stock status, adds up to 100,000 characters of information. This data is accumulated during each eight-hour shift and then transmitted from each facility one at a time. Actual call time for each facility at 200 characters per second is nine minutes. The five facilities can be polled in less than one hour to provide a computer compatible tape to start a computer report cycle." (Hickey, 1966, p. 177).

2.15a We note with Clippinger that: "There is a steady trend to move the computer interface with data collection closer and closer to the source. The use of interrupt processing makes it feasible to process these data as collected, to keep files updated, using a negligible amount of computer time." (1965, p. 209).

2.15b Moreover, it is noted that "if current trends continue, the system and circuit designer will have to solve many new problems associated with an extremely low-temperature environment. This environment occurs in space but there are many terrestrial applications for devices requiring low temperatures—masers, lasers, parametric amplifiers and infrared detection devices." (Allen and Niehenke, 1965, p. 75.)

2.16 "The electric utility industry's first integrated computer/telemetry system . . . at the Public Utility District No. 1 of Chelan County, located in Wenatchee, Wash. . . . The telemetry and data collection system is under direct computer control . . . Important on-line programs include load frequency control, actual and estimated encroachment, telemetry control, pondage accounting, scan, log and alarm, spill calculation, and operator's information programs." (Computers & Automation **14**, No. 7, 38–39 (1965).)

2.17 "A new data-message communications system is now being marketed nationally by Digitronics Corporation . . . The 600 Dial-O-Verter, collects information from many remote sources and automatically separates the computer-bound data from the message traffic." (Commun. ACM **9**, 782 (1966).)

"Digitronics is currently marketing three distinct product lines, each of which represented roughly one-third of the company's bookings of about $8 million last year. These three lines are:

- The Dial-o-verter line of communications terminals;
- The Data-verter line of data acquisition and transmission devices; and
- A component line consisting of paper tape readers and spoolers.

"The Dial-o-verter line is oriented toward the transmission of large volumes of data over the public telephone network or a half-duplex leased voice-band line. The Data-verter line is designed for comparatively lowcost, low-speed collection and transmission of data using specialized components. The devices in the Digitronics component line are sold primarily to other manufacturers of data processing equipment." (Axner, 1967, p. 45).

2.18 See Data Proc. Mag. **7**, No. 2, 41 (Feb. 1965). Further, "the IBM Hardware Monitor is an example of a general data acquisition system seeking to capture a continuous stream of events for off-line analysis." (Estrin et al., 1967, p. 647.)

2.18a "Data analysis is preceded by data acquisition. During analysis, intermediate results are the basis for the proper choice of strategies, during acquisition, for the choice of experimental conditions. Proper conditions for an experiment may be short-lived, hence the need for interaction must be recognized while the experiment is still in progress." (Lockemann and Knutsen, 1967, p. 758).

"The PACE (Precision Analytical Computing Equipment) System provides one solution to the analytical data processing needs of industry. PACE is a computer-based system which automatically and simultaneously processes the electrical signals generated by a variety of analytical instruments. Therefore, the system can be put on-line with: (1) chromatographs; (2) mass spectrometers; (3) spectrophotometers; (4) NMR spectrometers; and (5) physical testing machines. . . . The data reduction program examines, classifies and reduces the 'raw' input data from each instrument into a compact form. The condensed data contains just the information needed to characterize the particular instrument." (Lichtenstein, 1966, p. 10).

"A digital data recording system that automatically converts signals from laboratory instruments into computer language is available from Beckman Instruments, Inc., Fullerton, Calif.

"The versatile system readily translates output from a variety of atomic absorption, ultraviolet and infrared spectrophotometers into digital form. Output can be visually displayed or recorded punched paper tape, magnetic tape or standard IBM cards. Identification data may be introduced and recorded by the setting of 10 thumbwheel, parameter switches.

"The system can be economically expanded as users' needs increase. Eight operating models are available. Up to three encoders may be used simultaneously, permitting wide latitude in the handling and calculating of analytical data.

"Capabilities range from the simplest digital recording of ordinate values on manual command, to automatic and simultaneous recording of ordinate and abscissa data while detecting and recording spectral peaks and valleys." (Computers and Automation **16,** No. 11, 60 (Nov. 1967).)

2.19 McGee and Petersen, 1965, p. 90. The immediate objective in their research has been the automatic measurement of bubble chamber tracks previously recorded on film.

"PEPR is a computer-controlled CRT scanner used to automatically measure bubble chamber tracks which have been recorded on film. The PEPR cathode ray tube defocuses the electron beam into a short line segment whose angular orientation and location can be independently controlled by the system . . .

"Control of any CRT scanner would be similar to the PEPR scanner. In other data collection systems, counters, pulse height analyzers, telemetry converters, etc., may all serve as sources of input data. The controller output registers may be used for a variety of external control purposes as well as data sources for display and printing devices." (McGee and Petersen, 1965, pp. 82–90).

2.20 "The on-line man-computer system is employed in the measurement on pictures of nuclear particle events obtained from high-energy accelerator experiments . . . An operator guides an ingenious light sensitive measuring device, SMP (Scanning-Measuring Projector), across an image of the film projected onto a flat table. The SMP device transmits a stream of measured data to the CSX–1 computer for validation and analysis . . . Through a question and answer procedure controlled by the computer, ancillary data are fed concerning the nature of the vent, the film number, the operator number, etc.

. . . A calibration procedure is performed to measure fiduciary marks on the film . . .

. . . The measurement of three separate stereoscopic views of the same event is conducted." (Brown, 1965, p. 82. [U. Illinois]

"A second pattern recognition computer using a cellular organization has been proposed by McCormick and coworkers for particular use in analyzing photographs of particle tracks obtained from spark chambers and bubble chambers used in high energy physics. The pattern recognition computer requires a "Pattern Articulation Unit" (PAU) for preliminary processing of photographs and a Taxicrinic Unit (TU) and Arithmetic Unit (AU) to provide summary information on photographs and complete their analysis. The PAU is of cellular design and reduces input images to idealized line drawings or graphs and has been designed in some detail. The TU and AU are computers of more conventional design and have not been described in detail. We shall describe the PAU as a device having properties similar to CAM. . . .

"The PAU contains a network of identical processing modules organized on a 32 by 32 grid. A one-bit principal register (PR) with each module is capable of accepting the contents of any of its eight nearest neighbors. The set of PR's forms a two-dimensional shift register whose contents may be shifted in any of eight directions. Associated with each PR is a "stalactite" or multibit memory register which communicates only with the PR. Logical transformations may be performed in parallel on contents of stalactites under central control, the transformations being identical for all stalactites. Local logical transformations involving points in a discretized binary pattern and their nearest neighbors are performed by first shifting neighbors in each PR, shifting them down into stalactites, performing transformations on stalactite contents and finally storing results in the PR." (Fuller, 1963, p. 25).

2.21 "The Physics Department of Rutgers University will use a PDP–6 computer for elementary particle analysis. The Rutgers System will evaluate the photographic record of an experiment on four film-scanning machines. Two will search for useful tracks and two will define their locations by positioning crosshairs along and at the ends and vertices of a track in each of three views." (News and Notices, Commun. ACM **7,** 557 (1964).)

2.21a "The work . . . is based on the use of a mechanical flying spot digitizer to automate the initial scanning and measurement steps. The increasing volume of bubble chamber film being produced at many high energy physics laboratories around the world makes some form of automation essential. Two experiments currently in progress at Brookhaven National Laboratory and Columbia University . . . [use] the flying spot digitizer . . . on-line to an IBM 7094 computer." (Rabinowitz, 1968, p. 159).

2.21b "There are specific instances of productivity improvement by automating a normally human graphical interpretation procedure. One example is PIP, a spark chamber photograph interpreter. Scanning and interpretation of 5000 frames per hour was possible, as compared to 50 frames per man hour." (Wigington, 1966, p. 88).

2.21c "PEPR ('Precision Encoding and Pattern Recognition') is a device proposed in 1961 by Pless and Rosenson for the scanning and measuring of photographs of events in bubble chambers. It uses a high precision cathode ray tube connected on-line to a computer." (Watts, 1968, p. 207). [Reference is to an internal M.I.T. report dated Feb. 1961].

2.22 A computer-controlled x-ray diffractometer (CCXD) system developed and operated by the Thomas J. Watson Research Center (IBM) provides structural information on crystalline materials. (Cole and Okaya, 1965, p. 32): "This advance in the speed of crystallographic analysis was achieved by making all necessary x-ray measurements automatically with an experimental system, developed by scientists at the IBM Thomas J. Watson Research Center two years ago. Under the control of an IBM 1620 computer, the crystal is turned so that the x-rays are reflected by different planes of atoms in the crystal and the intensity of the reflected x-rays is measured. The system is run 24 hours a day, without supervision. The computer is operated in a time sharing mode, so that it can perform many preliminary computations while the experiment is in progress."

"Several years ago after a crystallographer had joined the staff at the IBM Research Center, the question arose as to how best to get the data for him that he needed in order to work at a high professional level. The solution seemed to be to automate an x-ray diffractometer, an instrument which could produce the needed data, and finally, the nature of the data taking task seemed to indicate that the instrument should be on-line to a computer for real-time feedback and instrument control. An IBM 1620 computer was rented, the control program written, and the system has been in steady operation since late in 1963." (Cole, 1966, p. 1).

"The data taking and justification is not the only computer oriented part of the crystallographic work. The data analysis, the determination of the atomic positions from the diffraction data, involves extensive calculations. And finally, with the output increased as it has been, the graphic display of intermediate calculations and the drawing of the views of the molecular configuration become bottlenecks if use is not made of computer plotting. Thus computers play a role in each step of these experimental studies." (Cole, 1966, pp. 2–3). See also Cole et al., 1963, and Abrahams, 1963.

2.23 "Special peripherals can be on-line to the jobs . . . The Manchester Installation has an x-ray diffractometer and an audio I/O device in this category." (Morris et al., 1967, p. 68.)

2.24 "The surprising thing is the trend to automation in the research laboratories, you find it in those experiments that are characterized by large numbers of repetitive measurements . . . But you find it also in experiments that are characterized more by complexity than by repetitiveness. There the hub of the automation comes in the analysis of the data—it's done on line, in real time, most often with a small computer located right at the experiment and, in fact, incorporated into it. The analyzed data are displayed before the experimenter and guide him in the performance of experiments that otherwise would be too big for him to handle." (Cooper, 1964, pp. 20–21).

2.25 "GasChrom–8, a new computer-based system for analysis of data from multiple gas chromatographs, has been announced by Digital Equipment Corp., Maynard, Mass. The new system includes the company's latest general purpose computer (PDP–8/I), a specially designed chromatograph interface, easy-to-use conversational software and Teletype.

"Other types of instruments can be connected to the computer using interfaces available from Digital Equipment Corp. Specially developed software packages, designed for the PDP–8/I, extend the computer's capability to serve other instrumentation such as mass spectrometers, NMR spectrometers and a variety of other instruments.

"The new system detects peaks and shoulders, calculates peak areas and peak retention times, allocates overlapping peak areas, corrects for baseline drift, and calculates component concentrations. It also identifies peaks, applies responsive factors, and types out a complete analyses report immediately after a run is finished. In addition, GasChrom–8 allows parallel operation of a strip chart recorder and attention switching." (Computers and Automation **17**, No. 4, 63 (Apr. 1968).)

2.26 "Small defects in multilayer printed circuit boards can be swiftly and accurately repaired—but first they have to be found. To pinpoint such common faults as short and open circuits, the Autonetics Division of North American Aviation, Inc., has developed a computer-controlled, infrared radiometer that scans and analyzes a board's thermal radiation pattern." (White and Jones, 1965, p. 96.)

2.27 "The objective of the unique and ambitious program is to construct a high speed electronic scanner-computer for automatic 'visual' observation and analysis of medical specimens and biological system." ("PHS Grants . . .", 1965, p. 8.)

Further details of the project plan under the direction of Glaser of the University of California are as follows: "With this automatic system it is believed that identification of the causative organism and determination of their drug sensitivity or resistance can be made much faster and with higher reliability than is possible with present hospital techniques. It is expected that essentially the same techniques will be useful for monitoring levels of contamination of food, water, and medical supplies where it is important to know how many living organisms are present and of what kinds." ("PHS Grants . . .", 1965, p. 8.)

2.28 "The systems assembled at NBS automatically obtain and record data from unattended experiments at rates up to 50 datum points a second. The system can also be programmed to vary experimental parameters, such as voltage or wavelength." ("Transistorized Modules for Data Logging Systems", 1966, p. 42.) See also Stein (1966).

2.29 "Argonne National Laboratory's CDC 3600-based system represents user-manufacturer co-operation for adaptation to local needs. ANL is modifying CDC's SCOPE system to use the 826 disk for scheduling and handling input/output functions. ANL developed programs that link a cathode-ray-tube display and camera recorder to the system for recording graphic and tabular data. ANL's Standard Peripheral Processor, a 160A package, includes an ANL modification for introducing a microwave link for high-speed data transmission. The Processor allows tape-to-tape transmission in either direction and tape-to-printer transmission from the user to the computer system. A data link from an ASI–2100 computer allows real-time interrupt to users of the 4.5 MEV and 12 MEV Tandem Van de Graaff accelerators. ANL's PAULETTE is a computer-controlled device that counts tracks made by subatomic particles in a fine grain photoemulsion. A hybrid computing system recently installed joins two PACE analog computers to a PDP–7. The hybrid enables analysis of dynamic systems that yield discrete and continuous data. CHLOE, an automatic film-scanning system, digitizes data from bubble-chamber photographs and oscilloscope traces. The system is being evaluated for fingerprints, radiological photographs, optic nerve signals, galactic shapes, etc." (Swanson, 1967, p. 37.)

2.30 "It thus appears that standard radioactivity measuring instrumentation (and this is intended only as an example) encodes information in a form that can be transmitted to and processed by the computer in a simple, practical and very inexpensive way." (Neilsen, 1965, p. 635.)

2.30a "Multiple graphic display drivers, radar scanning equipment, map digitizing devices and earthquake sensor arrays are typical examples of data acquisition or distribution systems. Data are received from sensors, formated and stored in mass storage for acquisition, and then prepared for distribution. Periodically, data are transferred from mass storage to other media. Here there is one basic function—to compile data—but as many processes as there are independent sensors or distributors." (Gaylord, 1968, p. 27).

"Current efforts to increase the power and sensitivity of radar observations, to reduce processing time and enhance picture resolution, and to significantly improve microwave and data processing hardware will no doubt have major effects on the future of radar astronomy.

"In the data processing area, the immediate goal is obvious: to develop total display systems capable of permitting the continuous display of radar data. This, together with the need for solutions to the special problems imposed by planetary observations and the constant search for better resolution, should provide enough work to keep researchers busy for a long while." (Wells, 1967, p. 32).

2.30b "The first real indication that radar probing might yield significant information on the moon came in 1946, when the United States Army Signal Corps first succeeded in bouncing a signal off the lunar surface. Even then, some of the advantages radar might have over optical methods were evident. For example, certain quantitative changes in the polarization and absorption of reflected signals resulting from transmissions at different wavelengths might give us insight into the depth, and even the nature, of the surface layer; extremely accurate determinations of range and surface features, as well as of lunar periods and possible unexpected perturbations, might be made; and perhaps of greatest eventual value since neither distance to the target nor atmospheric conditions constitute major problems, the methods developed for studying the moon could be readily adapted to planetary use." (Wells, 1967, p. 26).

2.31 See Meissner et al., 1963. Figure 12 illustrates the process flow for the automatic preparation of "smooth sheets" (i.e., charts containing substantially all the readings from a particular survey trip). Digital recordings of the data collected include information on the sounding in feet or fathoms, including the phase number for the echo sounder; a serial number identifying the reading; the time of the reading; the position fix data; the heading of the ship, and data entered manually, such as the ship's draft, tide corrections, and sound velocity.

2.32 "A new system, called the Laboratory Data Collector and General Purpose Interface, was designed to provide a reliable, flexible and yet inexpensive digital data acquisition and recording capability for those who must collect, record, and process digital data from laboratory instruments or other sources, and record this data in digital form. The standard system allows the interfacing and control of a wide variety of digital output devices and instruments with almost any digital data recording device or direct computer interface. It eliminates the need for a new expensive "black box" for each new or different connection between such devices that becomes necessary in a laboratory or digital data acquisition system. The Laboratory Data Collector can be programmed and operated by laboratory technicians in a few simple steps, and does not require the experience of a computer programmer. It also allows automatic identification of data and automatic formatting and separation of data samples. It has built-in error checking and maintenance features which guarantee the validity of data processed and allows rapid repair of the unit by the technicians if this becomes necessary. The basic Laboratory Data Collector unit which will interface standard analog-to-digital converters and digital voltmeters, and control punched paper tape or incremental magnetic tape units, sells for $6,400. Various options including built-in analog-to-digital converters, digital multiplexors, digital data compressors, and digital clocks can be provided on a modular basis. Berkeley Scientific Laboratories, Berkeley, Cal." (Computer Design **5**, 68, Feb. 1966).

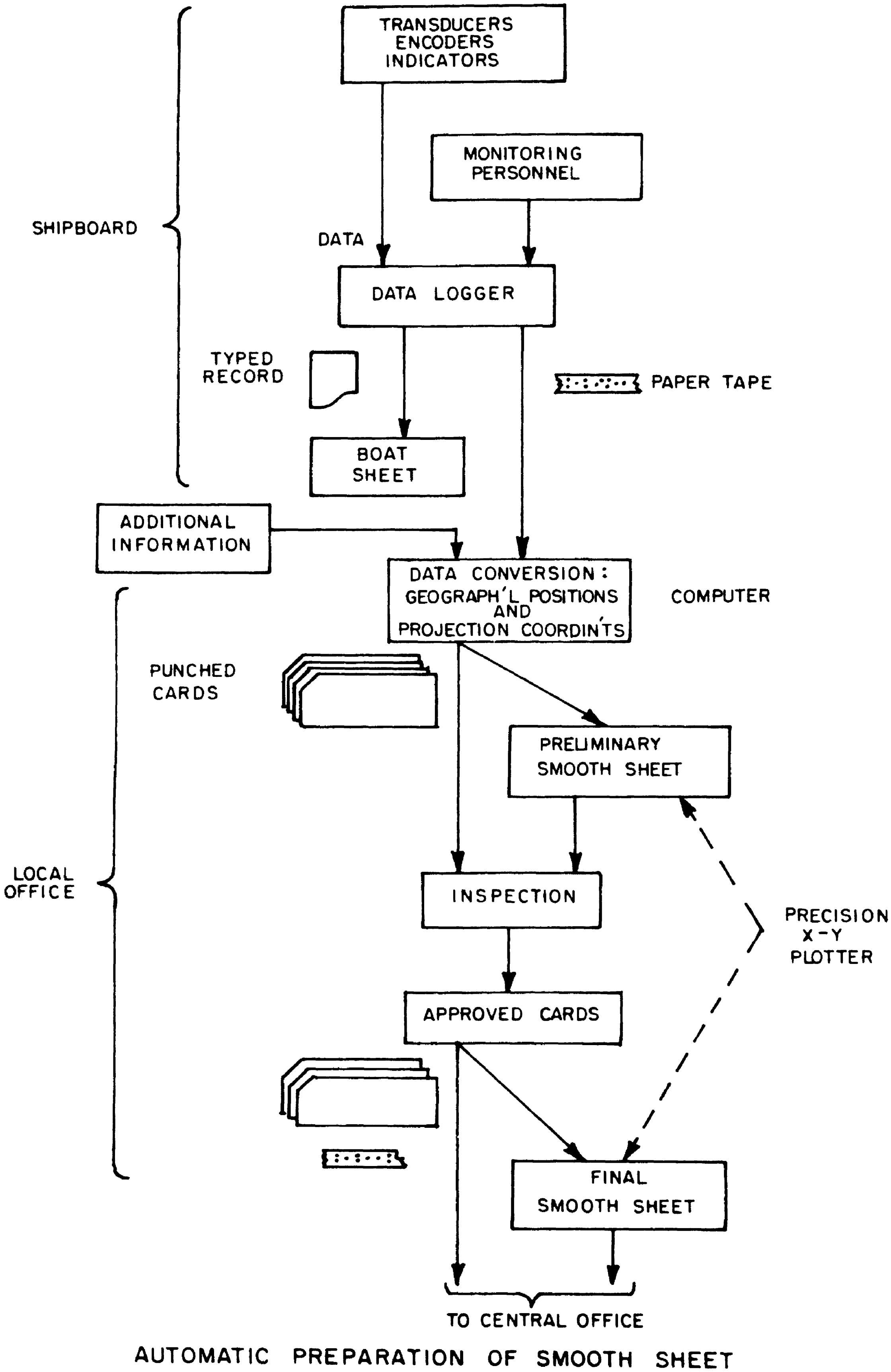

FIGURE 12. *Automatic preparation of smooth sheet.*

2.33 "An improved mobile data acquisition system was designed for maximum flexibility in obtaining data and producing computer compatible tapes at remote test sites. This completely portable system allows engineers to easily check operating conditions in industrial or scientific equipment in isolated plant locations or in the field. Inputs representing pressures, temperatures, strains, flow rates, speeds, and other variables are recorded at rates up to 20,000 samples per second. The recorder is an integral part of the system, called Mobidac, the system accepts fifty low-level analog inputs, seven high-level analog inputs, and two digital inputs which may originate either internally or externally. Patch panel programming permits selection of either binary or BCD formats, any one of several data acquisition rates, and allows high-level and low-level inputs to be intermixed in the program sampling sequence. Lower sampling rates than those obtained by subcommutation are available by start/stop recording. Nixie displays are provided for read-out of data and for record count. Data values are recorded in gapped or gapless format for direct analysis by a computer. System Engineering Labs, Inc., Fort Lauderdale, Fla." (Computer Design **5**, 74 (Feb. 1966).)

"An improved Mobidac (mobile data acquisition) system designed for maximum flexibility in obtaining data and producing computer compatible tapes at remote test sites has been introduced by Systems Engineering Laboratories Inc. In the portable system, inputs representing pressures, temperatures, strains, flow rates, speeds and other variables are recorded at rates up to 20,000 samples/sec." (Information Display **3**, 63 (Mar/Apr. 1966).)

2.34 "The Large Aperature Seismic Array (LASA) project is being planned as a real-time data-acquisition system for detecting and evaluating earth tremors (earthquakes or man-made tremors)." (Aron, 1967, p. 65.)

"Montana Array. This network is used for detection of earthquakes and nuclear explosions by linking together 525 seismic detectors covering an area of 30 thousand square miles. Large quantities of information are sent to M.I.T. for processing. One reel of magnetic tape is generated every 10 minutes." (Brown, et al., 1967, p. 20.) See also Maguire, 1965, and Press and Brace, 1966.

"The large aperture seismic array, or LASA . . . is a system of seismometers, signal transmission facilities, and signal processing hardware designed to provide a greatly improved detection and identification capability for remote seismic disturbances (teleseisms) of small size. Figure 1 shows a map of the area around Miles City in eastern Montana where the experimental LASA has been installed, and it indicates schematically the disposition of the 525 seismometers over the 200 km aperture, as well as the 500 miles of open-wire telephone line and 275 miles of microwave facilities that provide the signal transmission. . . . Each seismometer is at the bottom of a 200-ft deep hole, at the top of which a solid-state parametric preamplifier is located. Buried cable connects groups of 25 seismometers into clusters or 'subarrays'. . . . In a concrete vault near the center of each subarray a Subarray Electronics Module (SEM) multiplexes and digitizes the 25 seismometer outputs into a single bit stream which is then transmitted to the LASA Data Center in Billings by means of open wire and microwave circuits, terminated at sending and receiving ends with suitable Modulator-Demodulator (Modem) units. At the Data Center the bit streams from the 21 subarrays are combined, processed by digital computer, and the results appropriately displayed or transmitted to remote locations for further processing." (Green et al., 1966, p. 328).

2.35 "The Advanced Record System is being used in connection with remote sensors to monitor water pollution in certain rivers on a 24-hour-a-day basis." (Johnson, 1967, p. 20).

2.36 "The AMOS (*A*utomatic *M*eteorological *O*bservation *S*tation) systems have been developed in a cooperative program between the National Bureau of Standards and the U.S. Weather Bureau for the purposes of storing and processing weather data gathered at a number of remote stations." ("The AMOS IV Computer for a Prototype Automatic Weather Station, National Bureau of Standards, Tech. News Bull. **45**, 13–15, Jan. 1961).

"Plans are currently being generated for a dedicated network to process nationwide weather information which includes file maintenance for subscriber query. Messages are periodically received from a worldwide weather sensing network. The computer will format incoming data according to preprogrammed needs of a subscriber and will also maintain an updated data base so that subscribers may randomly query the center for the latest weather at any point in the world. Although this network is presently planned as a limited access system, expansion of the service to total government operations thru general purpose communication facilities is foreseen." (Jacobellis, 1964, p. N2. 1–3).

2.36a "There are a variety of potential applications for a real-time analysis system. Examples are air traffic control using Doppler radar techniques, Doppler radar measurements of meteors or terrestrial orbital objects, vibration measurements during non-destructive testing, and medical monitoring during intensive care or surgery. In many other applications rapid availability of results from a number of data sensors is needed for efficient operation, as in seismic exploration." (Larson and Singleton, 1967, p. 665).

2.36b A few details from the Mariner mission to photograph the Martian landscape are as follows: "Spacecraft Mode 4 was Television Playback. Mode 4 consisted of approximately 40,000 words, or 240,000 bits of information per picture. The television format contained a 31-bit PN sequence . . ., then 30 bits of identification followed by 200 6-bit elements for each TV line. Two hundred TV lines constitutes 1 complete picture." (Gianopolos and Curl, 1966, p. 38).

2.37 "Scientists at the California Institute of Technology Jet Propulsion Laboratory, using an IBM 7094 computer, have been able to improve the quality of the most recent photographs of the moon's surface by a factor of two . . .

"Each picture [from Ranger VII] is made up of about 90,000 points and there are about 64 possible shades of gray for each point. The signals are recorded on magnetic tape and fed into the IBM computer in digital form. The computer then plays a brightness-level matching game . . . It is possible for the computer to correct smudges in the picture where signals were not picked up evenly. It does this by comparing one scan line with neighboring lines and correcting the extreme variations caused by the electromagnetic interference. After the computer has processed the information, a visual image is recreated by a film reproducer." (The Computer Bull. **9**, 62 (1965). See also Data Processing **7**, 267 (July 1965).)

2.38 "Two experiments are under consideration, one ranging, the other photographic. For the ranging experiment, a 10-joule ruby-laser pulse is transmitted from the ground through a special-purpose telescope with a 1.5-meter aperture. It is returned from the lunar reflector back through the same telescope to a photomultiplier . . . For the photography experiment, a 40-joule laser signal is transmitted through the special-purpose telescope but it is returned by the reflector to a separate general-purpose telescope . . . displaced approximately 1.5 km to the east of the transmitting telescope. This displacement compensates for relative transverse velocities between the earth and moon.

"There are many uses for precise information on the range to a specific point on the lunar surface. For example, laser observations throughout the lunar libration cycle could give independent checks on the moon's mechanical figure and provide observations useful in calculating an improved physical ephemeris of the moon. Such observations could also provide an independent check on the earth's equatorial radius, and on lunar theory dealing with the eccentricity of orbits." (Hunt, 1967, pp. 5–6).

2.39 For example, "the idea behind multiband reconnaissance is that by comparing two or more photographs of the same object made in different regions of the spectrum we may learn something about the object we could not learn by studying the tonal values on just one photograph . . .

"Infrared mapping of large forest fires . . .

"The U.S. Army Engineer Waterways Experiment Station . . . [used] a radar at four different frequencies (as well as with other sensors like gamma-ray spectrometers) to analyze soil conditions as far down as 18 inches." (Parker and Wolff, 1965, pp. 23, 26, 27).

2.39a "The quality of near-orthography, coupled with the great speed of spacecraft, makes it possible for earth scientists to have up-to-date base maps, to include distributions of dynamic features, and to readily assess changes in distributions by comparing repetitive coverages." (Fischer, 1968, pp. 45–46).

"In the study of vegetation the presence of the high, near-infrared reflectance spectrum—a fundamental feature of leaf moisture in all healthy plant growth—enables sensors of various types to define the vigor of growth. The visible and near-infrared regions, combined with the time of the seasons, enable the crop type and vigor to be predicated with high precision." (Lyon, 1968, p. 46).

"At the national and international levels, hydrologists are initiating studies in the use of remote sensing and data relay for a wide range of hydrological purposes . . . Current studies indicate that present space technology can provide substantial benefits. These include basic studies of the hydrologic cycle, snow and ice mapping, real-time communications of ground-based hydrological data, survey of coastal hydrologic features and large lakes, and remote sensing of soil moisture." (Bock, 1968, p. 46).

"Purdue University engineers, working in the NSF-funded LARS (Laboratory for Agricultural Remote Sensing) program, have developed remote sensing and pattern-recognition techniques which can be used to gather information on crops from the air. The system entails sensing and recording of infra-red reflections from plants and could be used with a low-level satellite (such as a Tiros) equipped with a spectrophotometer and a tape recorder. From the tape input, the computer recognizes signal patterns and maps the area, designating, for example, what crops are grown in each field. This technique reportedly could be modified to aid such projects as water and oil explorations, planet fly-bys, and icecap and drought investigations." (Datamation **14**, No. 5, 113 (May 1968).

It is noted also that: "Aero Services and Spectra Physics are incorporating a gas-laser ranging device and a barometric-pressure transducer into a system that has demonstrated a capability for accurately profiling the surface over which the aircraft is being flown . . ." (Parker and Wolff, 1965, p. 30) and that ". . . the U.S. Army Electronics Laboratories . . . reported sounding through 1500 ft. of cold ice from low-flying helicoptors with a . . . pulsed radar system . . ." (Parker and Wolff, 1965, p. 28.)

2.40 ". . . Theories pertaining to crevasse detection have been substantiated by infrared measurements over snow surfaces in Michigan and in the Arctic, and an airborne technique has been devised for finding snow-bridged crevasses that often cannot be seen by visual means." (Parker and Wolff, 1965, p. 20.)

2.41 "Long radio waves are helping prospectors search for water in arid regions of the Soviet Union. The system, developed at Moscow State University, operates on the principle that damp ground absorbs radio waves better than dry ground does." (Electronics **38,** 216 (1965).)

2.42 "Graphic 'fingerprints' of water frost and of carbon dioxide 'frost' have been obtained in recent measurements at the NBS Institute for Basic Standards . . . by H. J. Keegan and V. R. Weidner . . . The fingerprints—clear patterns of the light-reflecting and absorbing properties of the two types of frost at wavelengths in the infrared region of the spectrum—will be checked against infrared spectra to be obtained from Venus in future space probes." (NBS Tech. News Bull. **50,** 20 (1966).)

2.42a "Adaptive sampling is a means by which the sampling rate of a given sensor can be adjusted to correspond to its information rate . . . Most of the time present telemetry systems greatly oversample the data. In nearly all cases, the sampling rate is set on the basis of the fastest expected response from the source and not on the basis of the quiescent or normal value. However, to match the sampling rate to the data activity would require an extremely complex machine and to date a practical mechanization has not been developed." (Kortman, 1967, p. 133).

2.43 "Much of the work [with AFCRL's Experimental Dynamic Processor DX–1] has been to find better techniques for on line control of real time data filtering operations. Associated programs are carried out in network theory, mathematical analysis and pattern recognition." (Mazzarese, 1965, p. 69.)

"What is needed is a means of programming our sensors to provide the interpreter only with the data he needs for his particular purpose." (Parker and Wolff, 1965, p. 31.)

2.44 "The military is becoming increasingly interested in multiprocessors organized to exhibit the property of *graceful degradation.* This means that when one of them fails, the others can recognize this and pick up the work load of the one that failed, continuing this process until all of them have failed." (Clippinger, 1965, p. 210.)

"Systems are designed to provide either full service or graceful degradation in the face of failures that would normally cause operations to cease." (Bonn, 1966, p. 1865).

"From our experience we have concluded that system reliability in the medical community must provide for several levels of failure, leading to the term 'fail-soft' rather than 'fail-safe'." (Baruch, 1967, p. 147).

"On-line systems are still in their early development stage, but now that systems are beginning to work, I think that it is obvious that more attention should be paid to the fail-safe aspects of the problem." (Huskey, 1965, p. 141).

3. Communication Systems and Data Transmission Links

3.1 "A type of pseudo-noise modulation has been developed recently for use in random-access communications systems. Here, many users may communicate simultaneously without going through a central switch or control . . . Code-division multiplexing using pseudo-noise modulation is . . . [a] technique in which each transmission is modulated with a code that identifies the user and to which the addressed receiver is set to respond." (Andrews, 1965, p. 227).

3.2 "Two basic types of codes are found suitable for the burst type errors. The first is the forward-acting Hagelbarger code which allows fairly simple data encoding and decoding with provisions for various degrees of error size correction and error size detection. These codes, however, involve up to 50 percent redundancy in the transmitted information. The second code type is the cyclic code of the Bose-Chauduri type which again is fairly simple to encode and can detect various error burst sizes with relatively low redundancy. This code type is relatively simple to decode for error detection but is too expensive to decode for error correction, and makes retransmission the only alternative." (Hickey, 1966, p. 182.)

3.2a "The ever increasing utilization of computer complexes from remote sources imposes a new dimension to the almost overburdening task of systems design. Remotely accessed systems require a tight integration of communication services and equipment in order to effect a system which is both efficient and responsive." (Hittel, 1966, p. 395).

3.3 ". . . Many workers in both communications and data processing have come to realize, in the course of making further progress, that the two fields are becoming more interdependent. . . .

"The most obvious bases for such interactions have been the physical extension of data processing systems and the increasing complexity of traffic in, and control of, communications systems . . .

"The major areas of interaction [communications and data processing systems] can be identified as (1) high-speed digital data transmission, (2) digital modulation techniques, and (3) computer-controlled communications." (Andrews, 1965, p. 226).

"Data processing systems and communications systems are being created in such a fashion that it is no longer easy (nor proper) to differentiate between the two." (Franklin, 1965, p. 182.)

"Both a single computer utility and a network involve a conjunction of two fields, computer technology and communications technology." (Pyke, 1967, p. 163).

"Although data transmission predates electronic data processing by more than a hundred years, the blending of the two technologies is a relatively new art; a demanding one with few practicing specialists. Each of the various aspects of an information gathering, processing and transmission system—hardware, software, communication channels, forms, etc.—has its share of specialists. But the man knowledgeable in all phases of the blended technologies is still a rare individual." (Menkhaus, 1967, p. 30).

"Western Union estimates that within five years some 60% of all computers will be tied into the nation's communication networks. . . .

"The Bell system predicts that eventually half of the information transmitted over its network will be data. . . .

"Data transmission lines thrust the common carriers to the forefront as prime candidates for entry into the information utility field." (Irwin, 1966, pp. 22–23).

3.4 "The Automatic Map Compilation System, developed and operating at Thompson Ramo-Wooldridge, abstracts terrain altitude information from aerial photographs by correlating the imagery appearing on stereo pairs, and outputs contour information and new photographs in which the imagery appears in 'true' orthographic projection position." (Bertram, 1963, p. 108).

Further, "the input data for a given compilation is in the form of a pair of aerial photographic transparencies together with pertinent camera data; i.e., position and attitude of camera for each transparency, focal length of camera and distortion characteristics of the lens. . . .

"The Automatic Map Compilation System . . . outputs a chart showing the altitude contour intervals over the stereo area and a new photograph in which the imagery has been moved so as to appear in correct orthographic projection position to a selected scale. The system utilizes a combination of digital and analog techniques to achieve the required accuracy and speed of operation . . .

"Data printout takes two forms: (1) An altitude chart exposed by computer control of the brightness of one scanner in accordance with the measured altitude. Three brightness levels are used in a rotary sequence to show successive contour intervals; (2) A new photograph exposed by reproducing the image picked up by one of the photograph scanners and imaging it appropriately on the photosensitive film sheet." (Bertram, 1963, pp. 105–107).

3.4a "The dual-mode Automatic-Picture-Transmission (APT) recorder . . . has the unique capability of being able to receive transmissions from meteorological satellites, but between satellite transmissions it can be switched over and operated as a standard weather-map recorder at 120 rpm and 166 lines per inch. It presents and prints out a large display in sepia-tone on a special Alfax paper . . . Transmission can be received over land lines or via radio with an appropriate converter." (Bliss, 1966, p. 3).

3.4b "Data sets are available from the common carriers for use with a wide range of standard communications facilities. Among the most widely used are the Bell System Data-Phone 200 Series Data Sets, which permit use of the public telephone network for data communications at speeds of up to 2,000 bits per second. In addition, several other companies (such as Collins Radio Co. and Lenkurt Electric Co.) manufacture data sets for use with private communications facilities or, in some cases, with leased common-carrier facilities." (Reagan, 1966, p. 66).

"*DATEL*. This is a new international data transmission service being offered by ITT World Communications Inc. DATEL 100 is a full-duplex 100 bits per second facility. DATEL 600 can be used for 600 to 1200 bits per second transmissions. Additional DATEL services are being made available." (Hittel, 1966, p. 397).

3.5 Thus, "the operational Intelsat I (Early Bird) and Intelsat II satellites and associated earth stations that comprise the present commercial satellite communications system provide a capacity of close to 720 voice circuits between major earth stations. All but a limited portion of the inhabited globe is now within the line of sight of a commercial satellite relay. In addition, it is expected that by 1968, with the operation of Intelsat III, a truly global international satellite communications system will exist." (Martin and McKee, 1967, p. 63).

". . . A series of demonstrations last June in which an RCA computer and the Relay I communications satellite were used to transmit news copy between the U.S., England, and Brazil. In some of the experiments, the 301 computer justified type lines, and the resulting signals were fed directly into linecasting machines." ("The (R)evolution in Book Composition . . . IV", 1964, p. 71.)

"The heart rate, brain waves and sleep pattern of a U.S. Marine patient in a hospital near Tokyo were transmitted to Houston by satellite yesterday in a demonstration of how medical data can be sent around the world.

"The data was sent from the Marine's bedside at Camp Drake Hospital in Japan to Intelsat, a satellite in orbit 22,300 miles above the Pacific. Signals from the satellite were relayed to a U.S. receiving station at Brewster Flat, Wash.

"The demonstration was arranged for the National Telemetering Conference. It was believed to be the first time that several medical measurements on the same person have been transmitted simultaneously by satellite.

"Regular telephone circuits fed the signals from Brewster Flat to the conference here and to computer centers at the U.S. Public Health Service in Washington, D.C., and the University of Texas.

"The demonstration showed that the best medical care group potentially can be extended to any person in the world by bringing his data to any physician or to a computer for analysis, said Dr. Fred Vogt.

"Vogt, department chairman of biomedical engineering at the University of Texas School of Biomedical Sciences, said the cost someday may be as little as $10 to have a patient's records displayed to any medical expert anywhere.

"Dr. Cesar A. Caceres of the U.S. Public Health Service suggested that hospitals begin thinking about computers to watch patients in surgery. He noted the development of tiny electronic instruments to monitor such medical functions as heartbeats and mental activity.

"The principles and techniques employed to monitor astronauts in flight can be used effectively to monitor patients undergoing surgery, Caceres said." (The Washington Evening Star, Apr. 10, 1968, p. A. 18).

3.6 "Dual routing, using both microwave and cable, can be used to improve the reliability of any telecommunications systems, if required. This has been successfully accomplished by the Power Authority of the State of New York and others." (Eldridge, 1967, p. 179.)

3.7 For example, O'Sullivan (1966) describes Raytheon's private telephone branch exchange for varied use of several different commercially available time-sharing services.

3.8 "A service provided by one of the common carriers is called WATS which stands for Wide Area Telephone Service. This provides for a flat rate for some number of calls from one point within one of several sizes of geographical areas. It is possible at some point to show that the cost of the flat rate is less than the cost of some number of individual calls. The use of the automatic subscriber calling feature of the A–1200 allows this decision to be made anytime, because the central terminal places all poll calls. The remote stations normally do not initiate calls although provision is in the equipment for them to do so. The frequency with which the central terminal polls subscribers automatically can be selected on the console." (Hickey, 1966, p. 178.)

3.9 "*Telpak Service.* Telpak is a private line service that provides communications capacities of various sizes suitable for large-volume point-to-point transmission of voice, data, or other forms of communication. Telpak capacities can be arranged so that they constitute a group of voice channels suitable for use for voice or data communications or a group of channels suitable for use with teleprinter equipment. The Telpak capacity can also be used as a single large channel for high-speed data services such as magnetic tape, computer memory and facsimile transmission." (Goettel, 1966, p. 197.)

"Cost of a telegraph channel in a private line is $1.10 per mile per month; in Telpak, it is about 10 cents." (Titus, 1967, p. 63.)

3.10 "A new compatible communications adaptor . . . that permits UNIVAC 1004 and 1005 systems to be used a high-speed data communications terminal with non-Univac computers . . . The new DLT–9 uses the 4-out-of-8 code and format at synchronous data transmission rates of 2000 and 2400 bits per second. A higher speed model of the DLT–9 operates up to 40,800 bits per second using a TELPAK service." (Commun. ACM **9**, No. 9, 707 (Sept. 1966).)

3.11 "The first major Data-Phone business installation was made for Firestone Tire and Rubber Co. in October, 1958. Using data sets sending up to 200 words a minute, the company has centralized much of its general accounting by transmitting payroll and similar information between distant points." (Marks, 1964, p. 16).

"Another approach . . . is the Data-Phone. Currently the Associated Press is transmitting justified stock market copy all over the United States. This is on the wire minutes after the markets close in New York." (Blondeau, 1963, p. 89).

"There also are DATA-PHONE data sets available that automatically establish calls for the transmission of data between business machine terminals without the aid of any operators. This is possible by using a device called an Automatic Calling Unit. When directed by the associated business machine, this device automatically dials the telephone call. These units are capable of dialing telephone calls by using the conventional rotary dial technique or the new Touch-Tone dialing system." (Goettel, 1966, p. 195.)

"There are conditions which require extensive data manipulation such as pay-roll transactions, while others involve very little calculation at all but consist primarily of a message store and forward operation. Some of the machine aids to communications include scheduled automatic calling or polling of remote transmitters from a central console, with automatic error detection and retransmission. In other cases the hardware does little more than prepare a magnetic tape in computer usable form that is then mailed to the central site." (Hickey, 1966, p. 176).

3.12 "The touch-tone telephone, already in service in many localities, is finding ever-increasing use as the key ingredient of low-cost data collection and management information systems . . .

"There are several outstanding advantages of using touch-tone telephones for gathering data:

1. The cost of each transmitting station would be only two or three times that of an ordinary telephone.
2. The station can be used interchangably as a telephone or as a data transmission device.
3. It is as easy to use as a 10-key adding machine.
4. It can readily be connected to any existing telephone system, local or long-distance.
5. It is easily made portable, and can send from any phone jack.
6. It can transmit to a wide variety of machines, ranging from paper-tape or card punches to computers.
7. It approaches real-time performance at the lowest possible cost.
8. Its applications can range in size from a small in-plant system to a complex nation-wide network." (Davenport, 1965, p. 36.)

"With touch-tone telephone, people can call a computer and, after the initial connection has been made, use the calling buttons as an input keyboard to communicate unambiguously to the computer, thereby temporarily bypassing the very difficult problem of speech recognition. With computer-generated speech, we can foresee the use of touch-tone telephone sets as the only remote terminal device for large and complex information retrieval systems." (Lee, 1968, p. 333).

3.13 "A 12-button version of the new pushbutton telephone might be used in a rather simple way as a mixed alphabetic-numeric input device for modern computer systems, without interfering with its ordinary use in placing telephone calls." (Davidson, 1966, p. 27.)

3.14 "Bell System's Data-Phone service now enables business machines transmitting at speeds up to 2,000 bits-per-second (about 2,700 words-per-minute) to converse with one another without any human intermediary. Operating in conjunction with Bell System's 801-type Automatic Calling Units, the 201A Data-Phone data set now is compatible with computer-to-computer transmission as well as with machines that transmit punched paper tape, magnetic tape, and card media. With this new feature of the 201A Data-Phone data set, companies with several branch offices will be able to poll these offices automatically over the regular telephone switched network for sales, production, and other information. By making such polls in off-hours, companies will be able to take advantage of lower evening telephone rates and also reduce the transmission traffic which their telephone service must handle during regular hours. The typical equipment configuration would consist of an automatic calling unit and a data set at the headquarters location and a data set at each branch, along with the business machines. The telephone numbers of the locations to be polled would be stored in the computer system. Bell Telephone System, New York, N.Y." (Computer Design **5**, 69, (Feb. 1966).)

"Data phones now available for switched telephone networks provide approximately 2,000 bits per second of [display] data, but within the near future this rate may be approximately doubled . . ." (Haring, 1968, p. 38).

3.14a "Innovations are also being planned to improve the effectiveness of our existing plant to carry data signals. For example, a new DATA-PHONE data set, capable of transmitting 3,600 bits per second over the dial telephone network, is now in the technical trial stage and will be available in the near future. A similar data set has been developed for private line service, but this one is able to handle 7,200 bits per second. Even higher speed versions are being planned for later on." (Quirk, 1967, p. 521.)

"A new data set is being developed to permit substantially higher bit-rates on voice grade lines than is possible with the presently available data sets. One arrangement intended for use on the network will operate at 3,600 bits per second with simultaneous 150 bit per second reverse channel. On private-line voiceband circuits, the data set will operate at 4,800 bits per second, and there is a possible extension to 7,200 bits per second. These increases in speed have been made possible by two techniques. First the digital information has been efficiently packed into an analog signal format well matched to the channel (a technique called multi-level vestigal sideband). Second, compensation for distortion introduced by the channel has been made possible by the application of automatic adaptive equalization. In addition, the application of a simple but efficient forward-acting error control method well suited to the noise statistics of the channel is possible on an optional basis. The redundancy associated with it reduces data rates by about one-sixth, but it improves the average error-free interval by factors from one-hundred to one-thousand. The costs expected to be higher for these data set arrangements than for those operating at lower speeds, but studies show that many systems with long-haul requirements will find the additional speed economically attractive." (Simms, 1968, p. 23.)

3.14b "At the wide band of the data spectrum we find requirements for the transmission of occasional high speed bursts of data—to update computer memories, to load-share a computer or just for back-up in case of computer failure. While these and other applications need wideband channel capacity, they can't justify the costs of full-time wideband private lines. Recognizing this need, we are now introducing on a trial basis a service called DATA-PHONE 50—a 50 kilobit per second common user switched service. Initially, it's being offered in Chicago. Additional trial offerings may be made in other cities in the near future." (Quirk, 1967, p. 521).

3.14c "Score, carrying Signal Corps electronics in an Atlas pod, went up in December, 1958. Although Score is best known perhaps as 'Eisenhower's Christmas Card', the first voice transmission from space achieved with its delayed-repeater capability, it also provided real-time relay. Score spanned the continent as a real-time system, and also carried some 140,000 words of delayed-repeater ('Mail Bag') traffic before re-entry. Its eight-watt output at UHF served ground stations based on the then-current missile telemetry technology." ("Communicating by Satellite", 1966, p. 8).

"Through the advent of the communications satellite techniques modern communications technology has made it possible to have rapid, adequate, and secure communications throughout the world." (Johnson, 1966, p. 99).

"Satellite communications technology offers the potential of essentially unlimited wideband communications." (Johnson, 1966, p. 100).

3.15 ". . . Synchronous satellites with the capacity of 80,000 voice telephone channels or 160 one-way television channels, available to and from rooftop antennas without complex switching arrangements . . .

"Coherent light from lasers will provide a revolutionary increase in the volume of communication that can be sent over a single pathway." (McManis, 1966, p. 28).

"Television signals have been transmitted over infrared beams from diodes and diode lasers of GaAs. Of course the objection to the infrared laser for transmission stems from its atmospheric absorption properties, which make it a fair-weather device. We may consider the possibility, however, of transmitting the radiation through tiny hollow waveguides . . . with laser diodes as repeaters, such an arrangement may provide the basis for a large-capacity communication cable." (Lax, 1965, p. 72).

"To accommodate this expected volume, the capability of existing channels—wire, cable, microwave and satellites—is being upgraded and new channels are being added. Bell, Raytheon, General Electric, International Telephone and Telegraph Co., IBM and others are experimenting with laser beams as possible data-carrying channels. There's a rumor that IBM will demonstrate the use of light beams to transmit data during the international fair in Canada this year. Guesses as to when this technique will emerge from the laboratories to be applied to everyday use, on a significant scale, vary widely—from three to 15 years." (Menkhaus, 1967, p. 37).

3.16 "A second development which promises to be useful in the future is a pulse code modulation system now being introduced for voice transmission. This system digitizes a number of voice channels and places the resulting information from each channel in a time division way on a single one and one half megabit per second channel. In the future, this high speed data channel may provide a lower cost form of high speed data transmission and may make possible a high speed facsimile system of a more economical type. However, much work remains to be done in this area." (Wier, 1965, p. 107.)

"The advantages of planned, systematic innovations are demonstrated by the Bell System's T–Carrier program. We are now installing T–1 digital carrier systems to meet growing communications needs—both voice and data. These systems, by using pulse code modulation, can transmit up to 1.5 megabits per second or 24 simultaneous voice calls over two regular twisted cable pairs. We are adding these facilities wherever the needs warrant it. Today these digital systems are available only in selected locations, but eventually a large part of our plant will be of this type. Even higher speed digital systems are now being developed. A 281 megabit per second T-type facility is planned for 1971." (Quirk, 1967, p. 521.)

3.17 "Scientists view the millimeter wave guide as another interesting potential means of transmitting data and telephone conversations. The wave guide is a precision-built hollow tube capable of carrying a wide spectrum of radio waves. Its potential for data transmission is great, but the development of this type of transmission channel is still some years away." (Gentle, 1965, p. 93.)

3.17a "The transmission technology has developed over the years in areas associated with the categories of distance over which it is applied. Local loop transmission connects subscribers to the common carrier wire and repeater centers and local exchanges up to 15 miles in distance. Tributary transmission spans up to 150 miles to larger centers or tributary exchanges. Medium haul transmission extends over distances spanning continents. Long haul covers up to 5,000 miles of transmission between continents." (Kaplan, 1968, p. 121.)

"The microwave technology for tributary and medium haul transmission has permitted increases in data carrying capacity through the use of extended radio spectrum and digital modulation methods. Digital baseband microwave systems are capable of transmitting data time division modulated at a rate more than an order of magnitude greater than conventional microwave frequency division modulated. As an example, a modern type microwave system operating within a 30 MHz channel bandwidth in the 6 GHz carrier band has the approximate capability as shown in Table II. The microwave analog transmission system has a greater capacity for analog signals." (Kaplan, 1968, p. 121.)

"The advancing technology in transmission has been in the direction of large capacity digital baseband systems. Digital baseband microwave and T-systems are important advances, allowing greater than an order of magnitude increased data transmission capacity over conventional frequency division subdivided channels. The high data rate systems should contribute significantly to reduced transmission error rate and costs. The application of these wideband data systems ought to be accelerated because analog transmission can be included as economic users on some of these high data rate facilities." (Kaplan, 1968, p. 129).

"The advancing digital multiplexer and modem technologies are making it possible to more efficiently use the existing standard voice, base group, and super group carrier channels for data communications. The data communication switching systems of the future are expected to be a hybrid combination of a computer controlled circuit switch and a message store and forward system. Efficient time division multiplexing systems can be extended to perform concentration and switching, obviating the need for complex, relatively unreliable electromechanical hardware in the data communication exchanges. The store and forward operation, depending on the speed and length of message, might involve storage for one bit or one or two characters, in which case the system will function as a circuit switch, or it might store a block of characters or the entire message itself. Programmable common control equipment can be used to flexibly provide the convenience and load leveling services." (Kaplan, 1968, p. 129).

3.18 "ITT World Communications is working on a high speed overseas voice-data communications network. Speeds up to 9,600 bits per second . . ." (Data Proc. Mag. **9,** No. 6, 60 (1967).)

"Experimental work is under way on the transmission of more bits per second over existing long-haul coaxial and microwave systems." (Pierce, 1966, p. 154).

"The ADEM concept has been successfully demonstrated for data modem operation over schedule 4B quality channels at data rates of 2400 and 4800 bits per second. The modem error rate of better than 1 in 10^7 at 4800 bits per second represents a two order of magnitude performance improvement over presently available modulation techniques, most of which require manual equalization of the channel prior to data transmission. Manual equalization of a channel is a lengthy and cumbersome process which is not at all amenable to the practical operational environment and does not compensate for variations in channel characteristics during data transmission. ADEM, on the other hand, provides initial data equalization automatically within seconds and continuously maintains this equalization throughout data transmission." (Northrup et al., 1968, p. 8).

"MILGO Electronic Corp., received a $1.8 million contract from University Computing for a specialized version of its narrow-band high speed data transmission set, Modem 4400/48." (Data Proc. Mag. **9**, No. 6, 60 (June 1967).)

"General Electric Company has announced its full-scale entry into the digital communications business with the unveiling of eight new data transmission products. The 'DigiNet Series' is the trade name for the broad new family of solid state data sets to be manufactured and marketed by the General Electric Company's Communications Products Department, Lynchburg, Va.

"The new family of products will be used to translate computer and business machine language into special radio and telephone signals for long-distance transmission, and then reconvert them at the other end. The series includes voice speed desk sets which permit computers to call automatically and 'talk' to other machines; acoustic couplers for connecting portable teleprinters by telephone to central time-sharing computers without special wiring; and high speed devices for sending computer information long distances via microwave or satellite.

"The product line covers speed and bandwidth requirements ranging from 300 to 230,000 bits per second. The DigiNet 100 and 200 Series operate in single voice channel circuits offering various options of speed from 300 to 2400 bits per second, simplex or duplex, direct or acoustically coupled, with or without a reverse signalling channel. The DigiNet 400 and 500 Systems operate at bit rates of 50,000 to 230,000 bits per second with means to get these signals over single wire pairs to local exchanges where they can be picked up to be carried further within a multiplex group or supergroup." (Computers and Automation **17**, No. 1, 58 (Jan. 1968).)

3.19 "A few years ago, a transmission system referred to as 'Ultrafax' conferred even greater distinction upon the complete text of *Gone With the Wind* by transmitting it from Washington to New York within a few minutes." (Fussler, 1953, pp. 225–226.)

3.20 "Another trend emphasizes the development of new types of communication channels. These channels not only will have the advantage of making higher speeds available, but also will reduce the cost of data communication channels. One system currently being developed will be capable of transmitting 220 million bits per second. This extremely high rate of transmission is more fully appreciated when one realizes that such a speed would make it possible to transmit the entire contents of Webster's New Collegiate Dictionary in less than one second. Of course, there are few users who would generate a volume of data sufficient to justify this speed. But there would also be benefits for smaller users. This new type channel would mean that more data messages could be carried on one channel with no increase in circuit cost. It would enable the communications common carriers to use their channels more efficiently for common user circuit arrangements." (Goettel, 1966, p. 192; see also Gentle, 1965, p. 93.)

3.21 "The AUTODIN telecommunications system, developed to meet the data needs of the Department of Defense, has been called 'a unique marriage between data processing devices and communications facilities in a computer-controlled system.' AUTODIN represents a joint effort of Western Union, RCA, Teletype Corporation and IBM; the latter three were selected as subcontractors to furnish equipment to Western Union. This equipment in AUTODIN switching centers routes data with requisite speed and accuracy over transmission paths to the correct destinations. Conventional wire, radio, ocean cables and microwave beam facilities are all at the disposal of the world-wide network." (Marks, 1964, p. 14).

"Autodin (*Auto*matic *Di*gital *N*etworks). Worldwide in scope, used by the U.S. Government for defense purposes . . . Automatic switching—uses common carriers; also Autocon, uses voice network." (Brown et al., 1967, p. 20).

3.22 "Today's communications load is twice as heavy on the Army Strategic Communications Command (STRATCOM) as it was in World War II; about 60 million messages were transmitted in 1965. The STRATCOM network extends into more than 30 nations and connects with systems of the Department of Defense (DoD), Department of State, other federal agencies including Civil Defense, AUTOVON (automatic voice network), AUTODIN (automatic digital network), and satellite systems. AUTODIN has six switching centers in the United States; three others are planned in the U.S., three in Europe, and seven in the Pacific, including Alaska and Panama. The DoD expects shortly to realize limited communications capability with the Initial Defense Communications Satellite System. The system has benefited from NASA and Communications Satellite Corp., experience and will be used instead of commerical systems only for unique and vital and national security needs. In discussing DoD's decision to proceed with its own system, Lt. Gen. Starbird itemizes some of the stringent factors imposed on military as distinguished from civilian systems: survivability, reliability, flexibility, remote-area mobility, and security." (Swanson, 1967, p. 19).

3.23 "The new FBI National Crime Information System operates on line in real time so as to complement computerized systems already in operation or planned for local and state law enforcement agencies." (Johnson, 1967, p. 15).

"January 27, 1967, marked a major milestone in the history of law enforcement. On that date the complex electronic information system known as the FBI National Crime Information Center (NCIC) became operational in a testing or pilot phase. For the first time local, State, and Federal government agencies throughout the nation were linked in one computerized network to serve a common need . . .

"Low speed leased lines are used for the initial phase of the system. These lines, handling transmissions up to 135 words per minute, link each terminal agency directly to the center's computerized file. One or more lines are assigned to each terminal device so that no contention factor exists. Each terminal is able to communicate directly and immediately with the NCIC computer. A constant polling of these terminals is conducted, and responses to all messages are made on a 'one for one' basis, with no buffering or queuing of incoming or outgoing messages . . .

"Terminals now in use range from IBM Model 1050 and teletypewriter Model 35 devices to computers of various makes including the RCA 301, IBM Model 7740, and Univac 418. With respect to the latter terminals, direct computer-to-computer interfaces exist, and the terminal computers are in turn serving numerous remote terminal devices connected to their own systems. By using this arrangement, the local remote devices can communicate with the NCIC computer through the terminal computer . . .

"There are presently over 260,000 active records in file. These can be roughly broken down into 115,000 stolen vehicle and license plate records, 95,000 stolen gun records, 30,000 stolen article records, and 20,000 wanted person records . . .

"The system is operational 7 days a week and 22 hours a day with limited down time. Transactions with the NCIC computer, entries and inquiries, are approaching 10,000 a day . . . Responses are averaging less than 15 seconds from the time the last character of the incoming message is received until the first character of the reply goes back to the transmitting terminal . . . Actual incidents have demonstrated that an inquiry from the street by radio or phone to a dispatcher at an NCIC terminal can be answered back to the street in 90 seconds." (NCIC Progress Report, 1967, pp. 2–5).

3.24 "A nationwide voice and data network has been established to support Social Security and Medicare. Computer services have been interlinked with Federal Telecommunication System communications network so as to provide rapid transmission and processing of information in this area." (Johnson, 1967, p. 17.)

". . . About 225 million words per year between the [725] field stations and Baltimore . . . Each field station is equipped with a Model 33 (or 35) teletypewriter(s), with automatic transmitters, that transmit or receive at 100 words per minute. The field originated traffic is concentrated by the ARS Message Switching Computer and written on magnetic tape at either Romney or Berwick, or both. From here it is sent via high speed, dedicated circuits to Baltimore, where it is received on magnetic tape ready for input to the Social Security Administration's computer without conversion." (Johnson, 1967, p. 18).

"A nationwide network is in operation to support the flow of information required in Medicare and Social Security. This system does not yet provide for the most advanced time sharing techniques, like time service and direct access, that has been incorporated into the law enforcement medium. Further improvements are sure to come." (Johnson, 1967, p. 14.)

"The Social Security Administration also maintains magnetic tape to magnetic tape transmission systems from the National Blue Cross Headquarters to Baltimore." (Johnson, 1967, p. 18).

3.25 "The various communications media (e.g., digital signals, voice and facsimile messages, one- and two-way video) were extensively considered. Each medium presents its own difficulties in cost, time schedule, and technical and administrative problems." (Brown et al., 1967, xiv).

EDUNET listings of available communications services show voice grade 4kc rates at 2000 bits per second; dial network with 2400 bits/second on private lines; Telpak A, C & D ranging from 48 kc to 1 mc rates and from 40,800 to 500,000 bits/second; "Half video" at 2 mc and video at 4.5 mc. (p. 31), the T–1 carrier with 1.5 million bits/second for short distances such as the local campus and the T–2 carrier at 6 million bits/second. (Ibid, p. 32).

3.26 "The digital communications channel must transmit many kinds of messages including alphabetic and alphanumeric data (teleprinter), computer-to-computer data and digitized forms of speech, television and facsimile." (Franco et al., 1965, p. 130).

3.26a "Since its inception, facsimile communication has not been exploited to any great degree. Early development of facsimile was hindered by more successful means for communication and by the lack of techniques that were not available until after World War II. Facsimile communication today is still secondary to digital communication, but some knowledgeable people in the communication field refer to facsimile as a sleeping giant. Facsimile originated in 1842 when Alexander Bain, a Scottish physicist, developed an electrochemical recording telegraph. This rudimentary system functioned by swinging a pendulum across metallic type; contact with the type caused an electric current to flow over wires to a remote swinging pendulum synchronized with the first. Chemically treated paper, positioned beneath the pendulum, produced a brown stain when an electric current passed from pendulum to paper. Bain's facsimile was widely used in the United States, but was abandoned because of the rising demand for electromechanical printers, which provided a faster means of communication and were simpler to operate. The widespread use of telegraph equipment also decreased the popularity of facsimile." (Axner, 1968, p. 42).

3.26b "The Westrex development program for this type of equipment was begun in 1956 when The New York Times asked for machines to transmit a 10-page special edition from New York, N.Y., to San Francisco, Calif., every morning during the Republican National Convention in August of that year. One hour a day was allowed for transmission. Video facilities were obtained from the American Telephone and Telegraph Company to test stability and continuity through 300 microwave repeaters for extended periods. The facilities were eminently satisfactory and work was started on the equipment to generate and record the signals." (Shonnard, 1962, p. 176).

"Japanese newspapers are now using this high-fidelity facsimile system. It is ideally suited to their needs because of the thousands of intricate fine detailed characters or ideographs that make up their written language." (Shonnard, 1962, p. 176).

"The equipment is now transmitting newspaper pages from Tokyo to Sapporo, Japan, a distance of about 600 miles, and on May 27, 1962, The Wall Street Journal began use of this system to transmit pages between San Francisco and Riverside, Calif. According to an article appearing in the newspaper's May 29 Pacific Coast Edition, 'The Journals printed at Riverside were exact duplicates of the Pacific Coast Edition of The Wall Street Journal prepared by conventional methods at the Journal's San Francisco plant. The two printings cannot be told apart, even on close inspection'." (Shonnard, 1962, p. 178).

3.27 "The United States Air Weather Network transmits weather maps over land lines and radio to approximately 600 locations, including some foreign installations. These maps are 18 × 12 inches and are used by the Air Corps, the Navy, the Army, the Weather Bureaus, the commercial airlines and by several miscellaneous commercial users. This equipment is furnished by the Times Facsimile Corporation, and the recording medium is Times-Fax paper.

"A similar network of about 100 recorders is operated in Canada. The equipment is Mufax, manufactured by Muirhead & Company, Ltd. in Great Britain. The paper used is electrolytic paper manufactured under license of Faximile, Inc., the patent holding subsidiary of Hogan Laboratories

"Time and Life use this 18 inch Mufax recorder to transmit last minute page proofs and corrections between their editors and printers.

"The most exacting use to which facsimile is now being put is the transmission of pictures by the three U.S. news picture agencies—Associated Press, United Press and International News Service. These services offer facsimile in place of Wirephoto, Telephoto and Soundphoto to television stations for the reception of news pictures . . .

"The AP now used Mufax recorders, UP and INP use Hogan recorders manufactured by General Electric. All three use Hogan Fax paper, and electrolytic recording paper . . .

"For its own use Western Union also has developed a high speed facsimile system which transmits telegraph messages between New York and Washington, and perhaps now between other points, at the approximate rate of one standard letter-size page in 45 seconds.

"The recording medium used by Western Union is Teledeltos paper . . .

"One present use for facsimile has implications that may interest you. Jiji Press is a Japanese news agency specializing in financial and business news. This organization has been licensed under Hogan patents and—in cooperation with Kyodo, the leading general news agency—is producing facsimile for the transmission of news. Now all the 3,000 or more ideographs that make up the Japanese alphabet can be utilized and users will be freed of the stringent limitations placed on them by the Japanese typewriter and the teletype . . .

"The Federal Reserve Bank transacts millions of dollars in business over fax circuits with member banks; a large utility transmits charts and tabular information from plant to control headquarters; a large suburban bank with many branches connects these branches for the exchange of credit information, bank balances and for signature verification; a department store is connected to its warehouse . . .

"Publishers (for example, McCalls with editorial offices in New York and printing plant in Dayton, Ohio) will send raw copy from editor to printer, get galley proofs back by fax, correct the faxcopies and re-transmit these back to the printer, get page proofs, correct and return them—all over a telephone line." (Crooks, 1956, pp. 41–42).

3.28 "Handwriting transmission terminals transmit written messages or sketches over communication lines . . .

"The message originating at the transmitter is written with a ballpoint pen on regular paper. As the pen moves on the paper, varying tones are generated and transmitted by means of the data set over a communication line to the receiving data set and its associated receiving business machine. There the tones are interpreted and the receiving pen reproduces the handwritten copy." (Gentle, 1965, p. 129.)

3.29 "Sylvania's Educational Communication System Model 100 is a good example of the application of transmission methods to special cases. With the ECS–100, information may be distributed over telephone lines to any terminal-equipped remote location, using graphic illustration and two-way audio conversation. As the user handwrites with an electric "pen" on a 6″ × 8″ writing frame, the pen's position is encoded into electrical signals and then transmitted over the telephone line. The graphical information is received at the remote locations, decoded, and displayed (in real-time as it is being written) on a direct-view storage tube." (Van Dam and Michener, 1967, p. 201.)

In addition, we note that: "Bolt Beranek and Newman (BBN) has introduced and demonstrated a new Teleputer System, a man-machine communication system capable of transmitting graphical information over ordinary telegraph and telephone lines, utilizing novel coding and logical techniques. Bandwidth compression of an order of magnitude has been realized in display generation, permitting normal telephone communication lines to handle 16 or more independent displays simultaneously. Both alphanumeric and graphical information, in the form of lines, drawings, functions and arbitrary forms, can be communicated simultaneously in two directions between the user and the computer." (Information Display **3**, 64, Mar./Apr. 1966).

3.29a "Cognitronics Corporation has announced development of a remote optical character recognition system that solves data processing problems with accurate and efficient conversion of information into computer language. The system is called Remote Optical Character Recognition (ROCR). ROCR uses a small desk top scanner reached at remote locations and connected by ordinary telephone lines to a powerful central recognition unit capable of converting multifont data to punched paper tape, magnetic tape, or punched cards.

"The system visually signals recognizable characters and permits their manual insertion while data from other readers continues to flow. Computer program validity checks of the document being read eliminates the search through the input for incorrect data.

"The entire system operates under computer control in a timesharing mode. This enables all operations such as facsimile transmission, recognition, error corrections, validity checks, data formation, as well as output creation to flow without time delay.

"Images of characters on a document are transmitted to the central recognition system over regular telephone lines. The use of a laser light source in a high resolution scanning system assures quality document facsimile in reliable character recognition.

"The remote unit sends a line by line analog signal to the converter of what is scanned, using a bandwidth-saving coding system which cuts down the transmission time. Recognition is then performed centrally where such problems as multifont and hand-printed digit recognition can be overcome.

"Cognitronics' method of on-line correction permits unidentifiable characters from one scanner to be held at the converter until corrected, while processing from other readers continues. When a character is unrecognizable, it is automatically displayed on the screen of a video unit at Cognitronics service center." (Commun. ACM **11**, No. 7, 532 (July 1968).)

3.29b "Most facsimile units presently marketed are capable of transmitting colors as varying shades of black and white." (Axner, 1968, p. 46).

"A new portable telephoto transmitter has been developed [Rudolf Hell] with which color photographs can be transmitted to the editorial offices of press agencies. The dimensions of the picture drum are adapted to the picture size of the Polaroid Land Camera. The main advantage of this new transmitter is the separation of the three basic colors, and the transmission in an uninterrupted 3-stage process over telephone lines. This equipment also permits the transmission of black and white photographs in one scanning process, or the scanning of color photographs which have to be published as black and white pictures." (Bliss, 1966, p. 3).

3.30 ". . . Xerox Corporation's work in facsimile . . . LDX, which stands for 'long distance xerography' . . . The equipment, at the output end, is much like our Xerox 914 or 813 copier. The input, however, may be some distance away, up to thousands of miles away, if necessary . . . We propose, in order to produce high quality, that we scan the original document at approximately 200 lines per inch.

"The LDX system is presently designed for full-size originals at the transmitting end, but it is a straightforward design job to provide means to accept the input in the form of microfilm." (Mayo, 1964, pp. 77–78).

"One of the projects at the University of California's Institute of Library Research involved the use of Xerox LDX facsimile transmission equipment in library applications. Morehouse & Shoffner report that 'the LDX system appears to be capable of providing rapid, high-quality transmission . . . from one library to another, with elaspsed time for each transaction averaging 2½ hours instead of the week or more now typically required' although they find cost to be prohibitive at current service levels. The authors find great potential for LDX to expand access to existing large central collections of serials, by establishing an LDX network that would serve several smaller libraries, each of which would have to retain small collections of only the most frequently used titles." (Markuson, 1967, pp. 277–278.)

". . . the adaptation of Long Distance Xerography (LDX) to computer input/output. LDX takes bit-by-bit raster scan information (131 lines per inch) and converts it to graphical information on standard paper, at a maximum rate of 768 lines of characters a minute. The main advantages of this output system are that no limit exists on the character set and that graphical information can be printed directly. However, the low speed—slower than a high-speed impact printer—and high cost ($550 per month for the printer and $1050 per month for the computer adapter) make it economically feasible only in special cases." (Van Dam and Michener, 1967, p. 191.)

"In order to explore advanced facsimile systems operation and to provide the corporation with a very rapid communications system, Xerox has installed a telephone-dial-controlled, 10-station LDX network in its own plant. The network spans a third of the continent, tying together New York and Chicago." (Bliss, 1966, p. 9.)

3.31 "High-Speed Facsimile. The high-speed transmission of graphics is now practical with the use of wideband communications service. Considerable work is also under way to enable the transmission of high-speed facsimile over regular voice-grade channels. Although a technological breakthrough is first required it is conceivable that documents and pictures will someday be transmitted over such channels in less than one minute per page." (Gentle, 1965, p. 92.)

"One promising development is Western Union's Broadband Switching Network, which provides a dial-up broad-band system on a toll basis that services 39 major cities." (Berul, 1968, p. 31.)

3.32 "Xerox's Magnafax Telecopier, another facsimile device using normal telephones for transmission, is portable, since it contains an acoustic coupling mechanism like those described previously. Because it is only slightly larger than an office typewriter and weighs less than 50 pounds, it can be carried easily. $8\frac{1}{2}'' \times 11''$ documents can be transmitted in six minutes. The copier is a continuous-scanning facsimile transceiver; light reflected from the document is picked up by photocells and converted into frequency-modulated audio that is transmitted through ordinary telephones. At the receiving end, the document is reproduced by pressure changes of two mechanical styli that make contact with a special carbon-backed paper. This paper-pecking method of reproduction, while not as reliable as xerographic copying, is quite inexpensive." (Van Dam and Michener, 1967, p. 200.)

". . . A Magnavox-developed system is about to be marketed by Xerox for remote facsimile reproduction via acoustic coupling to ordinary telephones. You place your telephone receiver in a cradle next to this Magnafax machine; it operates on audible beeps at a reproduction rate of 6 min/page." (Herbert, 1966, p. 37.)

"A portable facsimile machine that delivers the message over any distance by telephone . . . the Magnafax 840 . . . . The paper is electronically scanned and its contents converted into a series of tones that are picked up by the telephone handset . . . claimed that an $8\frac{1}{2} \times 11$ inch letter, on any kind of paper, can be transmitted and received in six minutes." (Electronics **38**, No. 24, 26 (1965).)

"Plans call for the use of Magnafax machines, manufactured by Magnavox, with transmission by telephone circuit between the University of Nevada library at Reno and the University of California library at Davis. In a second phase of the experiment, transmission between Reno and the University of Nevada's branch at Las Vegas is planned.

"The experiment is expected to yield information on techniques and on the quality of reproduction of material transmitted and its adequacy as a substitute for the inter-library loan of books, periodicals, and other material." (Lib. Res. & Tech. Serv. **9**, 461 (1965).)

3.32a "Stewart-Warner was the first company to develop and market a facsimile system to operate over switched voice facilities using the Bell System 602A Data Set. Since it is now possible to 'dial a picture' by either long distance or local telephone, at regular voice rates, this system has been widely accepted and is especially attractive to subscribers of the Bell System WATS service." (Bliss, 1966, p. 6).

"The Stewart-Warner Dial Datafax equipment includes the Dial Datafax transmitter and receiver; both devices are specifically designed for use on the public telephone network. Both units employ vacuum-tube construction and require a minimum warmup period of 30 seconds." (Axner, 1968, p. 52).

3.32b "A special version of the Muirhead K-300 automatic photofacsimile receiver has been developed for use by the National Aeronautics and Space Administration (NASA) in the reception of APT pictures from Nimbus and TIROS weather satellites." (Bliss, 1966, p. 4).

"Muirhead and Company, Ltd., has a . . . device, called the Mufax Courier 500, that can transmit an $8\frac{1}{2}'' \times 11''$ page in approximately two minutes." (Berul, 1968, p. 31).

"The prime conclusion to be drawn from the large number of line tests carried out is that page facsimile transmission is a workable system over all the common forms of 'group' telephone circuits . . . The performance of exchange lines as local ends for facsimile working in the relatively high frequency band employed is also encouraging. Most of the prospective users of page facsimile equipment are situated within a short distance from the local carrier terminal." (Phillips, 1962, p. 13, 16).

3.33 "In the first place, the experimental use of a telephone combined with a picture service is being explored in Picturephone. Here, using a 500 KC band, a 275-/line TV picture is being sent between selected locations. Such a unit could be useful for the retrieval of printed documents, provided a restricted field of view is employed to limit the amount of information sent in any frame, thus making it possible to obtain suitable resolution. The realization of a completely satisfactory service of this type, however, awaits the arrival of a switching system to provide service on a common user basis." (Wier, 1965, p. 107.)

3.34 "Facsimile equipment normally requires a Schedule 2 telephotograph channel. For a small additional terminal charge, the same line can be used alternatively for voice messages." (Alden, 1964, p. 11.)

"In recent years, facsimile has been directed toward business applications as an important alternative to data communications. A key to the future success of facsimile in the business world is the Bell System 602 Series Data-Phone Data Sets which enable the public telephone network to be used for low-speed facsimile communication. These units were introduced by AT & T in 1962." (Axner, 1968, p. 43.)

"Western Union has also developed its own facsimile equipment employing a special dry recording paper called Teledeltos. Teledeltos paper resulted from Western Union investigations to produce a recording paper that did not require processing after recording. In addition to AT & T's facsimile channels, Western Union inaugurated facsimile service for photographs and telegrams over its own circuits. Both common carriers, at present, offer wirephoto service for the press in addition to voice-band and broad-band facsimile channels for business use." (Axner, 1968, p. 43.)

3.35 "An experimental pulse code modulation system that transmits 224 million bits per second over coaxial cable has been developed at Bell Telephone Laboratories. The system converts television, voice, and data signals into a stream of digital pulses capable of being transmitted over transcontinental distances. Signals can be taken from the digital stream and new signals can be added as desired along the route.

"Designed to handle various combinations of signals, the experimental system can handle the transmission of 144 T1 signals, equivalent to 3456 voice channels. (T1 is the Bell System's commercial pulse code modulation system, which has a capacity of 24 voice channels on a 1.5 million-bit-per-second pulse stream.) Alternately, 46 T1 line signals, one television signal, and a "master-group" signal, comprising 600 frequency multiplexed voice channels, may be simultaneously transmitted on the 224-million-bit-per-second line." (Computer Design **5**, 20, Feb. 1966.)

3.36 "Microfilm Transmission. A requirement has developed during the last few years for transmitting images that are recorded on microfilm records. Work has already progressed in this area, and a few terminals of this type are available today." (Gentle, 1965, p. 92).

"Facsimile scanners are available which operate with microfilm chips or slides; hence can be used to transmit microfilm records and reproduce them in enlarged form at remote locations." (Schatz, 1967, p. 3.)

"The Alden ALSPEED 18-inch system can be operated over dial telephone networks, 3-kc voice conditioned networks, and 16-kc bandwidth networks such as the Western Union Wide-band or the AT & T Telpak A–3. At the high speed of 960 lines per minute, it can be operated over a 32-kc band similar to the Western Union Wide-band circuits or the AT & T Telpak A or A–2 . . . This equipment has been operated both land-line and microwave circuits. A special feature of the system's flat-bed scanner is the expandable head that accepts drawings up to 60 inches wide and scans 18 inches at each pass. . . .

"The 35-mm microfilm ALSPEED scanners transmit directly from 35-mm microfilm aperture cards to ALSPEED 18-inch recorders when both are operating at the same system speed. The line advance on this recorder is 96 lines per inch, and the comparable or corresponding advance of the microfilm is 1360 lines per inch. . . .

"The Alden 16-mm microfilm scanner has the capability of looking at any one of 2,000 frames on a 100-foot reel of 16-mm film. The image on the selected frame can be recorded on a facsimile scanning head for transmission to any distant point for printout on an Alden 11-inch facsimile recorder." (Bliss, 1966, p. 2).

"Further complicating the picture is the virtually limitless choice of input/output equipment (terminal devices) available to the user. Devices most commonly used are those which handle perforated tape, punched cards or magnetic tape. But, computers are 'talking to each other' in increasing numbers—nearly all third generation machines have this capability. Display/keyboard terminals, in which data appears on a TV-like screen, are becoming more common. Facsimile transmission is winning acceptance, although devices for this purpose are not numerous. Xerox, Stewart-Warner and Alden Electronics are in the market now. Bruning Div. of Addressograph Multigraph is poised to enter it, as is Electronic Transmission Systems Inc. Transmission of microfilm images also is possible. Alden and Eastman Kodak have jointly developed a system for that purpose, and 3M has one under development." (Menkhaus, 1967, pp. 30–31).

3.36a "Alden Electronic and Impulse Recording Equipment has developed a number of facsimile units that can be linked directly to an automated microfilm retrieval system. The transmission speed of the system ranges from 4 minutes down to $\frac{1}{2}$ minute for an $8\frac{1}{2}'' \times 11''$ page, depending upon the type of communications channel used." (Berul, 1968, p. 31.)

3.37 "Using TV, microfilm may be viewed at distances of several feet or several miles, for use in both airborne and fixed station environments. The Microteleviser accepts any film image, magnifies it to the desired size, and—when coupled with an automatic microfilm retrieval system—allows a remote operator to select a microfilmed document and view any area at the magnification desired." (GPL Division, General Precision Inc., press release of August 24, 1965.)

"General Precision, Inc., Pleasantville, N.Y., has been working for a number of years on equipment designed to transmit microfilm images by closed circuit television. Earlier equipment allowed a user to view remotely any portion of an aperture card image with a wide choice of magnifications. The latest version shown at the 1965 Western Electronic Show included the GPL TV Printer which allows the user to take a hard copy of whatever he is viewing on the screen." (Veaner, 1966, p. 208.)

3.38 "Transmission devices can now be linked directly to microfilm retrieval systems, and thus provide a hardcopy alternative to closed-circuit television. The Alden/Miracode system, which integrates Alden's Alpur-Fax facsimile system with Kodak's Miracode automated microfilm retrieval system, scans documents in the microfilm viewer and transmits the information via telephone lines (at a rate of three minutes per page) to make hardcopy at remote locations. In this manner the retrieval and transmission of documents is made almost completely automatic. The Department of Defense's Engineering Data Systems Project uses Alden/Miracode to make engineering drawings and component descriptions in the central library available at remote locations. The Army Materiel Command's helicopter repair ships also use this system to ensure realtime distribution of parts lists and drawings from a central microfilm storage library to the repair shops within the ship. An entire installation of both the Alden Facsimile transmission system and the Miracode retrieval system costs under $100,000; a modification of an existing Miracode system costs less than $65,000. Receiving units can be furnished for $90 per month, plus 25c for an $8\frac{1}{2}'' \times 11''$ page. The Alden system can also be easily interfaced with other automatic retrieval systems." (Van Dam and Michener, 1967, p. 200.)

3.38a "Fifteen . . . universities with television production capabilities produce medical video tapes. Video tapes are transmitted to scrambled TV receivers at scheduled times for the remote physician." (Mayeda, 1967, p. 9.)

3.39 "Smart et al., have reported on the experience at UCLA School of Medicine with encoded two-way medical television used for continuing education of the physicians in 15 hospitals. By questionnaire, the participating physicians agreed that there was a good-to-excellent future for television in post-graduate medical education. The authors claim for their method 'most of the advantages of closed-circuit television [privacy of medical communication and an audience which can be measured, evaluated, and controlled], as well as the cheap, potentially wide coverage of open-circuit television.' They note that the development of inexpensive videotape records permits the hospital to replay the programs whenever they wish." (Spring, 1967, p. 328).

"In the field of education, educational television is leading the way in the development of nationwide systems." (Johnson, 1967, p. 14).

3.39a "CCTV can be provided with two-way audio-video – multiagency use of long lines between points would then provide TV circuitry to be used for highway surveillance and education between insitutions or schools, crime detection, law enforcement training, disaster damage assessment, etc. Only organization of agency time on line is required. The night hours might well provide Freeway Rest Stop surveillance or on highway point watch. Criminal suspect viewing by picture could bring the far near. Live, direct or taped picture for delay send or file requires only line time scheduling. Inexpensive camera and video tape records might be in every law enforcement vehicle. Ready pictures of damage or accident could be directed to central office at any time. The actions of a law officer at the point of a stopped, on highway, suspect could be video recorded from patrol car, on every case if desired. Unused closed circuit TV time on long line could transfer any action for file or staff viewing. The door is open to many possibilities." (Penterman and Casey, 1967, p. 88).

3.40 " 'Telereference' is a name, coined by the Council, to designate a system for consulting card catalogs by television . . . [but] less expensive equipment is necessary . . ." (CLR 2nd Annual 1958, pp. 13–14).

"On October 2, 1957, a proposal was submitted to the Council on Library Resources by a manufacturer of closed-circuit television equipment for design and construction of a prototype, remotely controlled, catalog card viewing system. The proposed 'Telereference' system would permit a researcher to view catalog cards in a central catalog from a remote location by the use of closed-circuit television and a remotely controlled card manipulator." (Bacon et al., 1958, p. 1).

"The University of Nevada Library has received a grant . . . from the Council on Library Resources, Inc., for an experiment in the library application of telefacsimile . . ." (LC Inf. Bull. **24**, 389 (1965).)

"The Council has made a small grant to the Institute of Library Research, University of California, to enable it to plan an experiment with telefacsimile in comparison with interlibrary loan." (CLR 10th, 1966, p. 49).

3.41 ". . . The Houston Research Institute . . . has begun a study to determine the usefulness of existing facsimile transmission systems for communicating technical information . . . Use will be made of the extensive microwave transmission network employed by the petroleum industry for the conduct of its business . . ." (Scient. Inf. Notes **6**, 4, 11 (1964).)

3.42 "As a prelude to these networks, the New York Times announced an experiment using facsimile transmitters that link the New York Public Library with the State Library in Albany. Before the end of the test in July 1967, 25 libraries will have been included. The New York Legislature allotted $700,000 to the test. Library patrons could request through their local library up to 12 pages of material at 25c per page transmitted from any of the participating libraries. The experiment was part of New York's reference and research resources (the "three R's") program. This plan, as described by Nyquist, includes the development of a coordinated statewide reference program that will include the academic and research libraries in the state. It also includes various phases of library automation, and a study of the research libraries which have subject strengths that could be incorporated into a statewide network." (Hammer, 1967, p. 408.)

3.43 "Each 'on-system' group was connected with the Project Staff at the John Crerar Library by a facsimile system. The facsimile system was leased from the Dictaphone Corporation." (Rath and Werner, 1967, p. 59.)

"The facsimile system transmits a letter size page in six minutes over lines leased from Illinois Bell Telephone Company. The original must be a flat copy, and therefore material from books and journals must be reproduced before transmission. The output from the system is on a continuous roll of light-weight paper. Although the output paper is moist before transmission, it is dried automatically during transmission and can be trimmed for permanent storage." (Rath and Werner, 1967, p. 59.)

3.44 "What is required here is a machine with a reliable automatic page turner, which would transmit hundreds of pages, perhaps, in a few minutes." (Fussler, 1953, p. 226.)

"The essential feature that is missing from currently available machines is the ability to scan directly from the pages of a bound book. Fortunately, several manufacturers are making progress in this area and new developments are forthcoming." (Schatz, 1967, p. 19.)

". . . The inadequacy of available page-turning equipment has already been found to be limiting in the case of the interlibrary televising of book materials in the University of Virginia project . . ." (Council on Library Resources, 2nd Annual Report, 1958, p. 24.)

3.45 "In 1940, George Stibitz demonstrated for the first time the remote operation of a relay-type computer from a console at Dartmouth College in Hanover, New Hampshire, over telegraph lines to a computer in New York." (Commun. ACM **9**, 49 (1966). See also, Remote Control of the Computer, letter to the editor by T. C. Fry, Elect. Eng. **73**, 297–298 (Mar. 1954).)

"The Bell Telephone Laboratories operated some of their early relay computers with remote consoles, and so deserve the credit for the first 'time-sharing' system." (Samuel, 1965, pp. 4, 8.)

3.46 Stevens, 1955. Figure 13 illustrates the general scheme of what was probably the first multiple-access, time-shared program to be demonstrated. "The first computer-tie-up (known to this author) was implemented by personnel of the NBS in 1953–1954, where a cable link was made between the SEAC and the DYSEAC." (Nisenoff, 1966, p. 1824.)

3.47 "An experiment conducted between Buenos Aires, Argentina, and Cambridge, Mass., has shown that a large, complex computer can be operated by a distant user via a radio teletype link. Civil engineers from the Massachusetts Institute of Technology and from the University of Buenos Aires carried out the unique experiment, using commercial radio teletype facilities from Buenos Aires to RCA Communications, Inc., in New York City. There, the channel was patched into the Western Union Co.'s commercial Telex system to put the researchers in Buenos Aires into direct contact with a time-shared IBM 7094 computer at M.I.T. in Cambridge. At the same time, some 20 other persons also were using the computer from consoles located at remote stations around Cambridge and linked to the central machine through telephone lines.

"Previous experiments have been conducted in which the time-shared computer has been used from as far away as Edinburgh, Scotland, and Oslo, Norway. But in those experiments, connections were through commercial wire and cable systems. The Buenos Aires experiment was the first in which a radio link was used." (Computer Design **4**, 8, June, 1965.)

"International data communications provides a plethora of opportunities. One dramatic example of what already is being done is the link-up of stock brokerage offices in Hong Kong with a master computer center operated by Ultronic Systems Corp. in Pennsauken, N.J. Information on American stock and commodity exchanges is transmitted to Hong Kong from New Jersey via the Ultronic satellite computer in Montreal, Canada, through transpacific cable. If there were limitations to the amount of international traffic that could be handled by carriers, these will undoubtedly vanish with the use of earth satellites in microwave channels and the addition of new transoceanic cables." (Menkhaus, 1967, p. 37).

3.48 ". . . An inter-agency rapid communications test link [teletype-dictaphone] has been established for transmission of data from survey and research ships operating in the tropical Atlantic . . . to the National Oceanographic Data Center . . ." (Scient. Inf. Notes **8**, 2, 13 (1966).)

3.49 "Informatics Inc. . . . will implement an Automated Inquiry System under a contract awarded by the Department of State. This system will operate in an online, multiprogramming environment and will enable Department officials stationed in various cities in the United States, Mexico and Canada to interrogate specialized information files maintained on large, direct access storage devices." (Commun. ACM **9**, 401–402 (1966).)

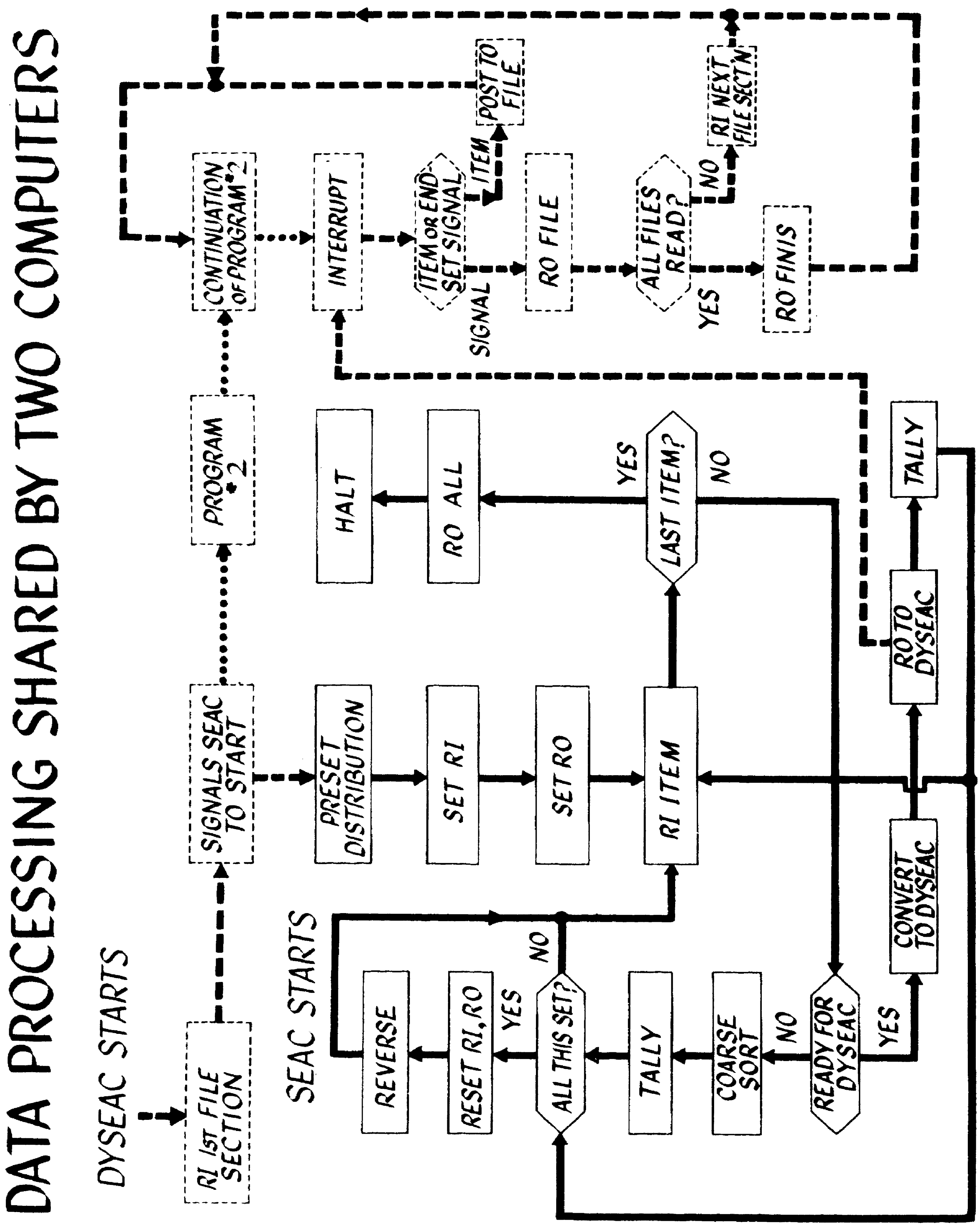

FIGURE 13. *Data processing shared by two computers.*

3.50 "On December 15, 1965, United Air Lines contracted for what is believed will be the largest on-line computerized information system in the business world. It will be built around a centralized complex of three Univac 1108 computers that will be accessible by some 2000 cathode ray tube input/output devices on a nation-wide basis with one second response times. The system will be designed and built by the Univac Division of the Sperry Rand Corporation, and represents an overall investment of $56 million for United." (Porter and Johnson, 1966, p. 74.)

"The airline industry was among the first to use real time processing in conjunction with a national communications network. The distribution, volume, and pace of their business left them little choice. The main function of the system is to process reservations. The result is that any reservation clerk can provide accurate information on the availability of a particular flight and confirm a reservation for that flight within seconds. The hub of their system is a centrally located digital computer. The computer is accessed by one or more multipoint voiceband-width lines. Each point on the line has a high-speed data set and an interchange terminal. The interchange terminal interfaces the high-speed line to many telegraph lines. A teleprinter device terminates the telegraph lines at each reservation counter and serves as the input/output device." (Balkovic, 1967, p. 155.)

3.51 "In the aerospace industry, load sharing among a company's computer centers can generate very large daily transmission volumes, in some cases on the order of 50 reels of IBM low-density magnetic tape, or more." (Perlman, 1961, p. 209.)

"NAA (North American Aviation). Used for load-balancing via broad band microwave of multiple computers (7094's). Transmission is at the rate of 62 thousand ch/sec." (Brown et al., 1967, p. 21.)

"Organizations that have two or more computers in geographically separated locations may find it advantageous to connect them by means of communications links. This permits more effective utilization of each of the interconnected computers because the slack time in one computer's schedule can be used to help smooth out the peaks in another's. Reliability is greatly enhanced because the communications links make it easy for one or more computers to take over another computer's workload when a breakdown occurs. The data flow pattern in this class of application is bidirectional; input data and results are transmitted between each pair of interconnected computers, and the volume of data flow depends upon their relative workloads at any given time." (Reagan, 1966, pp. 22–23.)

3.52 "Systems operated by different companies could be interconnected in such a way as to appear to their customers as an integrated computer network. Commercial banks form at present a network of this kind." (Fano, 1967, p. 35).

"A central 40-million bit memory stores unposted interest, customer balances, and other information for each savings account. Proper information is visually displayed to the teller and updated by the teller within seconds, thus providing new and improved customer service. Branch office tellers are served from the home office by a data-phone link." (Bowers et al., 1962, p. 101).

3.53 "Metropolitan Life is operating what could ultimately become the world's largest commercial information processing network, a $15 million system . . . will link 900 field offices with a Honeywell H–1800 in New York and one in Canada . . ." (Data Proc. Mag. **9,** No. 6, 3 (June 1967).)

"One of the largest installations now serving business is in use by Hardware Mutual-Sentry Life Insurance group. The company is speeding transmission of information from 34 branch offices to its data processing center in Stevens Point, Wisc., providing faster and better service to customers. Hardware Mutual reports that Data-Phone service is saving the firm more than $1 million annually in operating costs. . . .

"An even larger system of data transmission is now being developed for Metropolitan Life Insurance Co. This titan has contracted with Honeywell Electronic Data Processing for a setup to link its Wellesley Hills, Mass., headquarters with its more than 800 district offices.

"By providing on-line communications from each district office directly to its central electronic office each day, the system is planned to permit Metropolitan Life to maintain up-to-the-minute premium, loan and insurance records of its 29 million policyholders." (Marks, 1964, p. 16).

"Met Life's 800 district offices are being equipped with desk-size communications consoles consisting of: a Honeywell optical code reader, a control and adapter unit, a Teletype teleprinter (with page printer, keyboard, paper tape reader and punch), a Tally high speed paper tape reader, and a data set. District offices in the Boston area have been phased into the system and new offices are being added at the rate of three a week." (Menkhaus, 1967, p. 34).

3.54 "One of the most ambitious shared EDP systems was established by a group of hospitals in Minnesota in cooperation with the Minnesota Hospital Service Association (Blue Cross). . . . private telephone lines . . . . model 35 . . . teletypewriter . . . Data Phone sets . . . Honeywell H–200 communications computer." ("Hospitals Share . . .", 1967, p. 13).

3.54a "U.S. industry is recognizing, at an ever-increasing rate, the advantages of company-wide data communications networks and of the closely related concepts of real-time data processing and integrated management information systems. Although only about 1 per cent of the computers sold in 1965 were linked to a data communications system, Western Union has predicted that 60 per cent of the computers likely to be sold in 1975 will be so linked. A. T. & T. expects that the volume of information transmitted in the form of digital data will eventually equal the volume transmitted by voice." (Reagan, 1966, p. 20).

3.55 "ITT Worldcom has won FCC approval for a computer-based switching service that will sort, store, and route messages and data between the U.S. and other countries for subscribers to the company's privately leased international circuits . . . Rate is one cent per 220-character message. Center of the system, called Automatic Retransmission Exchange, is a dual ADX 7300 computer at Worldcom headquarters in New York City. Like Western Union, the ITT subsidiary has long-range plans for offering computer services through the network." (Datamation **12,** No. 11, 88, Nov. 1966.)

3.56 "Although graphic transmission may be sent on a wide range of frequency bandwidths, with the lowest and slowest a 3-kilocycle voice bandwidth, Mr. Stafford reported that a technological breakthrough in the near future might increase the rate of graphic transmission on voice communication lines by two, four, or even eight times its present rate." (LC Inf. Bull. **25,** App. 288 (1966).)

3.57 "When wide band communications become available on a practical basis, the concept of many interconnected computers as a single multiprocessor will be even more appropriate." (Clippinger, 1965, p. 209.)

"With modern communication links in their present accelerating stage of development, it certainly appears that remote multicomputer networks will be common by the end of the decade." (Wagner and Granholm, 1965, p. 288.)

"Over-all, the outlook for computer communications complexes is one of increasing importance to the realization of national objectives and to the effectiveness of government at Federal, State and local levels." (Johnson, 1967, p. 21.)

3.57a "The distinguishing characteristic of a message-switching network is that messages are stored and forwarded. The originator transmits a message into the switching center at his own speed, with no waiting for a direct connection. As soon as this input transmission is completed, the sender is free to send other messages, thus realizing maximum utilization of his input channel. Meanwhile, the network takes on the responsibility of relaying the message to its destination when channels become available." (Shafritz, 1964, p. N2.3–1).

"Present-day 'hard copy' written-text military communications networks are slow-speed store-and-forward systems. Long-time intermediate storage is used at the switching nodes to improve high-cost long-line-circuit usage. When the traffic volume arriving at the intermediate switching center from the many feed points is greater than the output circuit can handle, messages must be backlogged." (Baran, 1964, p. 5.)

3.58 "AutoData is an automatic, fully transistorized store and forward message switching system. It is designed for use in common user communication networks in which message traffic in digital form may be relayed throughout the world. When the message switching system is used, many advantages may be obtained, some of which are:

- Economic utilization of communication facilities
- Automatic transfer of messages through the network
- Effective utilization of communication facilities operating at different data rates, with different codes, and with different coordination procedures
- High degree of message protection all with
- Building block expansibility to provide increased service as required.

"The design features of the system are presented by first describing the configuration of a communication network, then explaining the basic switching center functions, outlining them in system design considerations, and finally reviewing the flow of messages through a typical switching center." (Genetta et al., 1960, p. 365).

3.58a "The Dalcode is a multiplex system in operation for over a year. It is a Western Union acronym that stems from the equipment use as a *da*ta *l*ine *co*mbiner and *de*multiplexer. Similar types of equipment have been produced by other manufacturers. Basically the system accepts asynchronous characters from TTY units and higher speed terminals and multiplexes them onto one synchronous data stream. It may be regarded as a wired program type store and forward system that operates on a single character per input line rather than on a message basis." (Kaplan, 1968, p. 128).

"The characteristics of the communication for interconnected computer systems are such that the information will be transmitted in real time with a minimum of delay and it shall have characteristics of store and forward systems since it deals with message flow. Ideally, the system should have the best features of both message and circuit switching systems: negligible waiting time that favors the high priced human, and an efficient message interface to favor the high priced computer." (Kaplan, 1968, p. 128).

3.58b "The ability to handle several kinds of terminal equipment makes message switching particularly valuable in the integration of existing systems into major networks. Subscribers are not limited in their communications, nor is a high-speed device ever forced to keep step with a slower one. Finally, the techniques of store-and-forward service insure against interruption of service or loss of messages, and facilitate monitoring of the switching service and evaluation of its operation." Shafritz, 1964, p. N2.3–4).

3.59 "Television offers some very interesting possibilities for specialized communication . . . Most specialized use of television has been in the form of 'closed circuit' transmission, utilizing coaxial cables. Because of its cost, use has been limited to very selective audiences located in a limited number of broadcast centers. However, future developments in cable design may make it possible to utilize standard telephone cables for closed circuit transmission. . . .

"A special type of television set . . . is in limited use at present. It turns itself on at a pre-set time and records the program on tape . . . Recently, the president of one of the major television networks told me that this approach is technically possible right now." (Maass, 1962, p. 47).

3.59a "For example, leased lines may currently carry little or no traffic at night; these lines could be used for the transfer of data during the slack hours at no increase in the present cost of communications facilities other than for switching, termination, and terminal devices. Use of present facilities requires close coordination between the company personnel responsible for general communications and the personnel responsible for data communications. The local common-carrier communications consultants should be contacted for help in determining the ways in which existing facilities can best be used or modified for data communications." (Reagan, 1966, p. 24).

3.60 "In another area, the trend toward higher speeds will also affect the operation of some business information systems. With a higher rate of transmission, less circuit time per call will be required. When a large volume of information can be transmitted over a line in a very short length of time, the minimum time period for the call is frequently not fully used. In such instances users may find potential savings in storing and batching messages until enough data exists to fill the minimum calling time." (Goettel, 1966, p. 192).

3.61 "In any event, even with private lines there is still some advantage to storing or batching the data at the remote terminal and keeping the final transmission of that data under control of the central terminal. One such advantage is the possibility of retransmission of the data when reception is garbled. Another is the advantage of permanent record or audit trail which the magnetic tape storage of the A–1200 affords at the remote site. Still another advantage is that by storing the data at remote sites and allowing the central terminal to initiate and control the transmission, we eliminate any scheduling or user query problems." (Hickey, 1966, p. 178).

3.62 "Instead of operating a continuous teleprinter circuit, traffic will be allowed to accumulate to, say, 15,000 to 20,000 words and then a normal telephone call put through, probably four or five times a day. The messages will be sent at up to 2,850 wpm, using phase-modulation, in sessions lasting about 10 to 15 minutes. This 'burst' technique is confidently expected to prove considerably cheaper than the use of leased teleprinter circuits working at 66 or 100 wpm. About 25 million words of routine plain-languages will be transmitted by Esso across the Atlantic during 1965. This would have required 4,300 hours of teleprinter operation, but with the new equipment can be handled in 172 hours." (Electronics Weekly, May 26, 1965, p. 8).

3.62a "Noise is the great enemy of bandwidth compression schemes. Any device which measures picture detail must do so in such a way as to discriminate between true signal and noise, perhaps on some statistical inference basis." (Cherry et al., 1963, p. 1508).

"In an automated information storage, retrieval and transmission system, encoding of images by linear scanning, as in ordinary facsimile, is not generally satisfactory. It may take too much time on the communication channel or (depending on the trade-off of time and bandwidth) may require a very large memory for storage. Since most document images have considerable redundancy, code compression can profitably be introduced to minimize the time-bandwidth product. Although savings of the order of ten to one hundred are possible, the factor in practical coding systems is much lower (roughly three to five) because signal distribution properties vary so much from image to image. The practicability of code compression depends upon the structure of the total system, particularly upon the availability of processing logic and processing buffer memory. It should be possible to develop an optimum code compression system for each class of documents—typescripts, drawings, photographs, etc. If a prescanning device could determine the kind of document being processed, the logic could then switch to the appropriate compression coding system and much greater economy would be possible. Before we can design such an adaptive system, we must know the types of documents to be classified, develop means of automatically identifying each class, and select the best code-compression scheme for each class." (Dodd and Wood, 1968, p. 60).

"It has been shown that for two-dimensional band-limited functions, such as those imaged by an optical system, there are in general an infinite number of different optimum scan patterns that yield data sufficient for the reconstruction of the original picture. The scan patterns involve the sampling of the intensity and its directional derivative at equally spaced points along the direction of scan with the scan lines themselves parallel and equally spaced. The word *optimum* here means that the area density of points sampled is a minimum." (Montgomery, 1965, p. 206).

3.63 "It has been estimated that the information content of the digital voice signal is as low as 50 bits per second. Direct digital encoding of an analog speech signal by sampling, quantizing, or pulse code modulation techniques requires a bandwidth of 56,000 bps. With fixed channel vocoding techniques, the bit rate required to transmit . . . [speech] in digital form with adequate scores on intelligibility, articulation, and speaker recognition tests, has been reduced to 2,400 bps. There are other vocoding techniques which will eventually reduce this bandwidth still further to 1,200 bps, and even to 300 bps but with markedly reduced quality." (See Franco et al., 1965, p. 130).

"The use of vocoder techniques enhances coding efficiency and permits reduction, by a factor of 10 or more, of channel capacity necessary for speech transmission . . . The reduction of the required channel capacity facilitates computer input/output operations and permits a larger quantity of speech signals to be stored and processed in a given computer." (Rothauser, 1966, p. 455).

". . . Many speech-bandwidth compression systems have been developed, such as vocoders, amplitude or frequency limiters, and formant coders. These machines do not recognize speech; what they do is transmit sufficient verbal clues so that a human listener can piece together the linguistic content of the utterance." (Lindgren, 1965, p. 116).

3.64 "A process has been developed in IBM to compress words or segments of speech into 500-millisecond time-slots. Words having a time duration greater than 500 milliseconds are placed in 2 or more time-slots or tracks." (Urquhart, 1965, p. 860).

3.64a "Results of the present simulation demonstrate the practicability of a speech transmission system based upon analytic-signal rooting. In the present instance the system has been implemented for a square rooting of the input signal, and a consequent 2-to-1 saving in transmission bandwidth. Roots higher than the second appear feasible with concommitant bandsaving." (Schroeder et al., 1967, p. 401).

3.65 "Tests to determine the loss of intelligibility of digitized voice transmissions show that an error rate of 2×10^{-2} is tolerable. In fact, over-all speech quality does not degrade significantly until the error rate exceeds 5×10^{-2}." (Franco et al., 1965, p. 131).

3.65a "Certain economies of storage can be achieved by the use of the channel vocoder mainly because of the redundancy of human speech . . . By the use of this technique it is possible to store reconstructable digitized speech so that approximately twenty-four hundred bits represent one second of speech. This is a considerable saving in space over the minimal 24,000 bits and the desirable 48,000 bits." (McDonald, 1966, p. 53).

See also note 3.63.

3.66 "Compressed speech, a method of increasing the rate of speech, and expanded speech, a means of lengthening normal speaking rates were demonstrated by Leo Levins of the American Foundation for the Blind . . ." (LC Inf. Bull. **25**, App. I, 425, (1966).)

"It will be possible, for example, to make the computer pronounce aloud any word upon which the subject maintains fixation for more than one second. It would be interesting to find out whether quick feedback of this general sort can accelerate children's learning." (Quarterly Progress Report, No. 80, Research Lab. for Electronics, M.I.T., 425, 1966).

"*A conference on compressed speech,* sponsored by the Division for the Blind . . . The method may be used by students as a review technique and by blind persons to increase their reading rate appreciably when using recorded books." (LC Inf. Bull. **24**, 674, (1965).)

3.66a "The encoder operates by looking up segments of the input text in a stored dictionary that contains commonly occurring words and phrases as well as letters and letter combinations. The encoder obtains the longest possible character match between the input text and a dictionary entry and sends out a code designation for the selected entry. On the average the code designation can be specified with fewer binary digits than the entry itself, and thus a compression of the input text is obtained . . . An important feature of this type of encoding is that no information is lost, but the time required to transmit a page of text will vary with the amount of compression achieved." (White, 1967, p. 390).

"For the present encoder simulation, the initial dictionary contained 400 of the most frequently used English words and 200 commonly occurring digrams and trigrams were taken from lists that were tabulated for cryptographic purposes." (White, 1967, p. 394).

"The simulation of a dictionary encoder indicates that a printed English compression of 50 percent is realizable for a broad type of English language text when using a 1000-entry dictionary." (White, 1967, p. 396).

3.67 "To get a digital picture with quality comparable to that of commercial television pictures, one needs about 500×500 samples and 6 bits (64 levels) for each sample: hence 1.5×10^6 bits per picture. Since the bandwidth required of a channel increases with an increase in the number of bits one has to send through it, one would like to reduce the number of bits needed to transmit a picture.

"Schreiber's synthetic highs system took advantage of the fact that the human eye tends to emphasize edges (abrupt changes in brightness) in a picture but is relatively insensitive to the amount of changes in the brightness over edges: on the other hand, in areas where the brightness changes slowly, quantization noise is easily discernible. Therefore, edges and the slowly varying parts of a picture were treated differently." (Huang and Tretiak, 1965, p. 48).

"Schreiber implemented a real-time system of edge detection in one dimension along a scanning line, run-length coding the edge location and magnitude, and then generating a 'synthetic highs' signal from the edge information. The synthetic highs signal was added to a low-pass signal to give a good-looking output picture with a reduction in bandwidth by a factor of four." (Graham 1967, p. 337).

"In Schreiber's system . . . the edge information was sent by run-length coding (essentially, the magnitude and the position of each edge point were transmitted). A reduction of 4:1 was achieved with rather good received pictures.

"A picture coding scheme investigated by Huang could be considered as an extension of Schreiber's system to two dimensions . . . A set of basic points (e.g., one out of every sixteen samples . . .) were transmitted for all picture frames. These points essentially constituted the low-frequency part of the picture. In addition, extra edge points . . . were sent for each frame. Whether any given point was an edge point or not was determined by a threshold function which depended only on the basic points. Therefore, if the transmitter and receiver agreed on the threshold beforehand, the positions of the edge points need not be sent. At the receiver the blanks were filled in by linear interpolation." (Huang and Tretiak, 1965, pp. 49–50). [Illustration shows good quality at 7:1 reduction].

"Huang studied the subjective effect of pictorial noise. The main goal was in finding out how the objectionability of a two-dimensional low-pass noise depends on its bandwidth.

"Cunningham investigated several systems of transmitting monochrome motion pictures . . . Besides introducing temporal filtering as a band-limiting process, the systems transmitted picture sequences by correcting a fixed fraction of the picture sample points during each frame transmission time. The results indicate that a saving of 6:1 in bandwidth is possible using such methods." (Huang and Tretiak, 1965, p. 52).

"In the search to reduce the required channel capacity an obvious procedure is to attempt to reduce the number of picture samples. If this reduction is accomplished by selecting samples either at random or according to some regular system which takes no account of the properties of the picture, then all that has been done is to exchange channel capacity for picture quality. While this is a perfectly acceptable procedure a more interesting effort is to attempt to reduce the number of transmitted samples without reducing the quality to the same extent as the procedures mentioned previously. When this is the goal the problem divides itself into three parts: the selection of the points to be transmitted, the coding procedure for transmitting the required information about the points, and the decoding procedure by which an image may be produced from the received information. In this paper, we describe an approach to this problem in which the points along the outlines or contours in the picture are transmitted. . . .

"The gradient approach was first suggested by Schreiber and later simulated on computer by Graham. Here a point is considered a contour point if the magnitude of the gradient at that point exceeds a certain threshold. In addition to gradient information at the contour points, a two-dimensionally low-passed version of the picture is also transmitted. At the receiving end, the gradient information is passed through an appropriate two-dimensional linear filter to give rise to the high frequency part of the picture, which is then added to the low-frequency part to form the reconstructed picture. Graham transmitted the gradient information by following the contours. For each continuing contour point, he transmitted the changes in contour direction, gradient direction, and gradient magnitude using a Huffman code. From the probability distributions of these quantities, he estimated that compression ratios of 4 to 23 (depending on picture complexity) could be achieved on 256×256-point, 6-bit (64-brightness level) pictures. Graham's reconstructed pictures were of good quality except that some of the texture information in the original were lost. Work is now in progress at M.I.T. to try on the one hand to increase the compression ratio of this scheme by curve-fitting the contours, and on the other hand to improve the quality of the reconstruction by the additional transmission of texture information." (Schreiber et al., 1968, pp. 1, 5).

3.68 "Other experiments aimed at reducing the redundancy in motion pictures, and at the optimum coding of digital color pictures.

"The research program of this group [Picture Processing Research, RLE, MIT] has been to investigate schemes for reducing bandwidth required for transmission. It was realized that in order to solve this problem, it is necessary to better understand how the human observer perceives the image, what features of the picture are important, so that a collateral interest of the group has been to investigate ways of mathematically representing pictorial data, of finding out details of what features of the picture are important." (Huang and Tretiak, 1965, pp. 45–46).

"If the received picture is to be viewed by humans, then one can take advantage of the properties of human vision. Here, the purpose is to distort the picture in such a way that the distorted picture can be described by a smaller number of bits, yet the change is not noticeable to human viewers." (Huang and Tretiak, 1965, p. 48).

3.69 "Briefly, a run-length may be defined as a continuous segment of the signal over which some stated property may be considered as constant, within stated criteria." (Kubba, 1963, p. 1518).

"This 'reduced' signal . . . consists essentially of a continuous sequence of *run-lengths* over which the video signal is assessed as being of 'constant' brightness (or other parameter, if desired) by the Detail Detector according to criteria built into that detector." (Cherry et al., 1963, p. 1508).

"Visual communication signals, generated by conventional scanning techniques as in facsimile and television systems, make very poor use of the bandwidths allocated for their transmission." (Kubba, 1963, p. 1518).

"Variable velocity scanning provides an excellent, accurate means for reconstructing pictures at the receiver. It also leads to a relatively cheap receiver." (Cherry et al., 1963, p. 1508).

3.70 "The design and the characteristics of an experimental encoder for digital transmission of video signals [using a unity bit coding method] are described . . . The experimental results show that considerably good reproduction of video pictures is obtained with sampling frequency as low as 30 Mc . . ." (Inose and Yasada, 1963, p. 1524 (abstract).)

3.70a "The human eye objects much more to noise with strong structure, such as quantization noise, than to random noise. Therefore, a smaller number of quantization levels can be tolerated, if means can be found to transform quantization noise to random noise. An example is the method of Roberts, who added pseudo-random noise to a picture before quantization, and later at the receiver subtracted the same noise from the quantized picture. It can be shown that by this maneuver the quantization noise is transformed into random noise with the same rms value. This method gives acceptable pictures with only four bits per sample." (Huang et al., 1967, pp. 332–333).

3.70b "Since the noise contained in the pictures from the Roberts method is random and independent of the signal, it can be reduced by some averaging process, such as the snow-removal technique of R. E. Graham . . . Although Graham's technique by itself does smear the edges in a three-bit Roberts picture, with the additional information (about 0.1 bit per sample on the average) on edge points, a picture almost as good as the continuous original can be obtained." (Huang et al., 1967, p. 333).

3.70c1 "Pseudo-random scanning can also be used for cryptographic purposes." (Huang et al., 1967, p. 334).

"The so-called pseudorandom scanning . . . can be used for secrecy transmission. In pseudorandom scanning, the scanning beam hops from point to point in a seemingly random fashion. However, the transmitter and receiver scanners are synchronous, so the receiver scanner can reconstruct the picture. The coordinates of the successive scanning points are specified by a sequence of pseudorandom number . . . Anyone who does not know the particular pseudorandom sequence will not be able to reconstruct the correct picture even if he should intercept the one-dimensional signal." (Huang, 1965, p. 60).

3.70c2 "A system is described for digital encoding of continuous information sources based on quantizing the difference between the original continuous signal and a predicted version thereof, as opposed to quantizing the original signal itself." (Graham, 1958, p. 147, abstract).

3.70d "Statistics were gathered on the number of times each of the 2^{12} different neighborhoods of black and white elements was followed by $y=B$ and the number of times by $y=W$.

Examples:

B B B B B

a) B B B B B

W W y.

A white element would usually occur in the *y* position, following *this* neighborhood.

W W B W W

b) W W B W W

W W y.

A black element would usually occur in the *y* position following *this* neighborhood." (Wholey, 1961, p. 99).

"For each of the different neighborhoods, a unique prediction *y* is determined as the color which is most likely to follow the neighborhood (on the basis of the statistical survey). We thus obtain a 'prediction function', a table in which each of the possible neighborhoods 'predicts' (i.e., is paired with) the color of *y* which is most likely to follow it." (Wholey, 1961, p. 100).

"Now each matrix representing a picture is paired (in a one-to-one fashion) with an 'error matrix' which indicates the elements *y* of the picture matrix for which the prediction function gives an incorrect value. In order to make possible a uniform prediction procedure, the picture is treated as if it were surrounded by a white border two elements wide. For each element *y* in the picture matrix, the actual color of *y* is compared with the color predicted by the function above, on the basis of the neighborhood of *y*. If the colors are the same, then a 0 is stored in the corresponding position in the error matrix; otherwise a 1 is stored there . . .

"The error matrix (which under ideal conditions should contain a small percentage of 1's) is now coded by some process like run-length coding (which gives the number of 0's between successive pairs of 1's). . . .

"To reverse the process and obtain a picture from its code number, we first obtain the error matrix from the run-length code. Then, the output of the prediction function for each successive element of a new picture matrix is compared with the corresponding element of the error matrix. The color predicted is entered in the new matrix if the corresponding element in the error matrix is a 0; if the corresponding element is a 1, the other color is entered." (Wholey, 1961, p. 100).

"Our experiment was made on weather maps, in view of military requirements for efficient storage and transmission of information of this type. . . . [Average compression coefficient for 10 maps = 0.38].

"Greater compression (i.e., a smaller average compression coefficient) is expected for the high-resolution data which might be required in a military or commercial display device, since the high-resolution data would tend to be smoother and the proportion of errors, therefore, to be smaller." (Wholey, 1961, p. 100).

3.70e "The aim of efficient coding methods is to reduce the channel capacity required to transmit a signal with specified fidelity. To achieve this objective, it is often essestial to reduce the redundancy of the transmitted signal. One well known procedure for reducing signal redundancy is predictive coding. In predictive coding, redundancy is reduced by subtracting from the signal that part which can be predicted from its past. For many signals, the first-order entropy of the difference signal is much smaller than the first-order entropy of the original signal; thus, the difference signal is better suited to memoryless encoding than the original signal. Predictive coding offers a practical way of coding signals efficiently without requiring large codebook memories." (Atal and Schroeder, 1968, p. 1).

"Previous studies of predicitive coding systems for speech signals have been limited to linear predictors with fixed coefficients. However, due to the nonstationary nature of the speech signals, a fixed predictor cannot predict efficiently at all times. For example, the speech waveform is approximately periodic during voiced portions: thus, a good prediction of the present value of the signal can be based on the value of the signal exactly one period earlier. However, the preiod varies with time, and the predictor must change with the changing period of the input speech signal. In the predictive coding system described below, the linear predictor is adaptive; it is readjusted periodically to match the time-varying characteristics of the input speech signal. The parameters of the linear predictor are optimized to obtain an efficient prediction in the sense that the mean-square error between the predicted value and the true value of the signal is minimum. . . .

"The study reported here shows that predictive coding is a potent approach to digital encoding of speech signals for high-qualtiy transmission at substantial reductions in bit rate. Unlike past speech coding methods, the predictive coding scheme described here attempts to accurately reproduce the speech *waveform* rather than its spectrum. Listening tests show that there is only slight, often imperceptible, degradation in the quality of the reproduced speech. Although no detailed investigation of the optimum encoding methods of the predictor *parameters* was made, preliminary calculations suggest that the binary difference signal and the predictor parameters together can be transmitted at bit rates of less than ten kilobits/second, or several times less than the bit rate required for PCM encoding with comparable speech quality." (Atal and Schroeder, 1968, pp. 1, 7).

3.70f "The philosophy of predictive systems has been widely studied for its application in bandwidth compression of telemetry data and of television; for example, see Kortman, Davisson, and O'Neal. In these examples the error samples e_k are quantized and transmitted by pcm. Because of redundancy, that is, predictability, in the source data, fewer digits per sample (and consequently less bandwidth) are required for transmitting the error samples than for transmitting the original samples for a given fidelity of reconstruction." (Lucky, 1968, p. 550).

"When noise is added in the transmission channel there is some probability of the received digits being incorrectly detected by the slicer. Even though the transmitted power might have been substantially reduced by the redundancy removal, the probability of an initial error is identical to that of a full power system. Once an error has been made, however, the probability of making subsequent errors is increased because of the incorrect symbol being used in redundancy restoration. Thus, errors tend to bunch together in the reveived data. Besides increasing the average probability of error this error propagation considerably complicates the problems of error control in the entire system." (Lucky, 1968, pp. 561–562).

3.70g "It is intuitively evident that there is much more correlation between TV picture elements in the frame-to-frame time dimension than there is between adjacent elements in a single frame. By using delay lines, sufficiently long enough to contain a complete frame, and high-speed digital logic to compare and operate on elements from frame-to-frame, it is possible to take advantage of this fact in picture coding.

"Early experiments showed that simple frame repeating could be used to reduce the rate of picture transmission, avoiding flicker by displaying each frame several times before replacing it with a new frame. Still better was replenishment of a fraction of the picture elements in each frame, thus avoiding even the jerky motion characteristic of the cinema, but leaving some peculiar small area patterns around rapidly moving elements of the picture." (Mounts, 1968, p. 28).

3.70h "The on-line Fourier Transform is used to eliminate periodic noise from long distance television transmissions by noting that this noise gives rise to a striation of each frame and that this striation corresponds to a constant Fourier Transform, independently of translation in the input plane. Sending a sequence of frames containing respectively 'noise only' and 'video plus noise', it becomes possible to subtract out the noise portion of the transform and to display a cleaned up version of the incoming signal. . . .

"A spatial filter is located in the back focal plane of the first lens where the Fourier Transform of the picture on the crystal is formed. Filtering of the video is accomplished as follows: The remote camera transmits alternate frames with its shutter closed and open, so that at the receiver the incoming information is of the form 'noise only' followed by 'picture plus noise.' The noise frame is inscribed on the crystal which is briefly illuminated (during vertical retrace) by a burst of laser light, thereby forming the noise spectrum in the Fourier Transform plane where the spatial filter is located. The filter is adaptive in the sense that it can store this information (or some approximation to it) for one frame. At the end of the following (picture plus noise) frame the crystal is illuminated again, and from its Fourier Transform the filter 'subtracts' the spectrum of the previous frame. The difference is reconstructed by the second lens and the resulting image, picked up by the vidicon, is displayed on a monitor." (Poppelbaum and Faiman, 1968, pp. 1–2).

3.71 For example, "any attempt to increase redundancy by coding implies an increase in channel bit rate for a fixed user information rate. But, as the bit rate is increased, the basic error rate of the channel usually increases. This means that any improvement in output error rate gained from the additional code redundancy, could be partially or completely negated by the deterioration of the channel error rate." (Quarterly Progress Report No. 80, Research Laboratory for Electronics, M.I.T., 195 (1966).)

3.72 ". . . Decoder complexity increases drastically as one strives to approach channel capacity (100% efficiency) for a fixed error rate. Furthermore, . . . for a fixed efficiency, operation at low output error rates also demands high decoder complexity. The search for ways to overcome this equipment barrier has been a motivating force in the development of techniques such as sequential and threshold decoding, low density parity check codes and error detection with automatic request to retransmit information received in error." (Franco et al., 1965, p. 130).

3.72a "Many communications equipment manufacturers can provide error detection and correction (EDC) equipment. The sophistication of these devices varies and so does the price. Most systems correct errors through retransmission, but there are some which make possible error correction without retransmission; generally, the latter are more expensive. The potential trouble an error could create must be weighed against the cost involved in preventing the error in the first place." (Menkhaus, 1967, p. 35).

3.73 "Two considerations affect the selection of the most appropriate error-control code. The first involves the requirements of the user, the tolerable delays, error rates, data rates, channel efficiency, and other factors; the second deals with the characteristics of the transmission medium." (Franco et al., 1965, p. 125).

3.74 "The method chosen to avoid dilution of single-error-detection capability is that of representing each of the additional (transparent-mode) controls by a sequence of *two* characters from the 'wrong' parity subset. This method provides the required security, since a single-bit error within a string of ASCII characters could falsely generate at most only one character of such a sequence . . ." (Transparent-Mode Control Procedures . . ., 1965, pp. 204–205).

3.75 "The gross modification of the facsimile signal would very likely not be available as an off-the-shelf feature of existing facsimile equipment and therefore would require some research and development to produce the required equipment modification. In spite of the need for research and development, it is very likely that this approach would be considerably cheaper than the use of electronic scramblers." (Geddes et al., 1963, p. 133).

4. Audio and Graphic Inputs

4.1 For example, "the main ingredient of a touch-tone data gathering system is the touch-tone card-dialer telephone made by the Bell Telephone Systems . . . Depression of a key causes tones to be generated within the set by its solid-state circuitry. The only power required is obtained from the telephone line. Tones are also generated by the insertion of a plastic pre-punched card into the card reader, which is an integral part of the telephone set . . .

"The function of the data subset [Data-Phone 401, 403A or 401J] is to receive the tones generated by the touch-tone telephone and convert them to relay contact closures. The relay contacts are cable-connected to the code translator through a multi-pin interface." (Davenport, 1965, pp. 36–37).

"There are systems utilizing this capability today. The majority of these are of the Digital Inquiry-Voice Answerback (DIVA) type. The system consists of a computer which is configured as a station on the Switched Telephone Network and the various TOUCH-TONE telephones that can access the computer via the network. An attendant at the TOUCH-TONE phone calls the computer as he would call another telephone station. The data set at the computer automatically answers and puts the computer on line. The attendant is now capable of keying signals into the computer. Replies generated by the computer are received audibly by the attendant through the telephone handset. One technique used at the computer is to generate voice reply with the aid of speech segments prerecorded on magnetic tape. The computer assembles these segments in the proper sequence to produce the required replies. Another technique that can be used is computer generated synthetic speech. This approach has been the subject of considerable research. Signals corresponding to voice pitch, loudness, tongue position and other speech variables are combined to produce the consonant and vowel sounds. These are generated in the proper sequence to produce sounds that are like human speech." (Balkovic, 1967, p. 156).

4.2 "Voice input is quite another matter. In spite of the existence of some interesting work, this reviewer feels that it will be five to ten years before any significant amount of computer input will be received in the form of human speech. The intensity of the work in this field is interesting and gratifying: Hogan includes 21 books, articles, and documents in the bibliography of his survey of the voice input/output literature. Almost every entry deals with some aspect of speech recognition. It is Hogan's opinion that we are approaching the point of having a limited amount of spoken input to a computer system and that the telephone will become an important computer terminal. If this latter prediction is realized any time soon, which is not unlikely, it will be because of Touch-Tone 'dial' input and voice response, not voice input. The reason is simply that, unlike voice-recognition equipment, devices for 'recognizing' Touch-Tone signals are fully developed, inexpensive, and commercially available." (Mills, 1967, pp. 233–234).

"The use of voice input to computers is still in the research and development stage. One reviewer feels that the state-of-the-art permits reliable recognition of digits spoken by a speaker for whom the recognition program has prior information. To date, no operational speech recognition systems have been designed." (Van Dam and Michener, 1967, p. 194; see also Gentle, 1965, p. 87 and Goettel, 1966, p. 191).

"For many years man has been receiving messages from machines in printed form. Teletypes, computer console typewriters, high-speed printers and, more recently, character display oscilloscopes have become familiar in the role that they play in machine-to-man communication. Since most computers are now capable of receiving instructions from remote locations through ordinary telephone lines, it is natural that we ask whether with all of the sophistication that we have acquired in computer usage, we can communicate with the computer in normal speech. On the input of the computer, there is the automatic speech recognition problem, and at the output, the problem of speech synthesis from messages in text form. The problem of automatic speech recognition is substantially more difficult than the speech synthesis problem. While an automatic speech recognizer capable of recognizing connected speech from many indiviudal speakers with essentially no restriction on the vocabulary is many years away, the generation of connected speech from text with similar restrictions on vocabulary is now well within our reach." (Lee, 1968, p. 333).

4.3 "Cognitronics, however, has developed a conversation machine that can ask questions, using a Cognitronics Speechmaker, and can understand the spoken words "yes" and "no." This machine could be used to access a well-defined and tightly structured data base both quickly and cheaply. . . .

"The computer may ask a question such as "do you enjoy golf?" If the response is "yes", the next query might then be "Do you like the mountains?" If the answer is "no" the subsequent question may by "Do you like the seashore?" Depending upon the "yes" or "no" answers to questions like these, the computer selects the next logical question and finally chooses a pre-selected vacation package for the customer based upon the entire range of responses. Simple as it may seem, a basic telephone serves as the inquiry device for this system. All that is required is the ability to talk to and listen to the computer." (Gentle, 1965, p. 87).

4.4 "At the remote laboratory the scaler-counter which accepts the raw data from the scintillation detector . . . provides an output pulse for every 100 (or whatever scaling factor is desired) detector pulses . . . [reducing] the pulse rate to an acceptable rate for the telephone data-link. It has proved convenient to use the telephone dial to transmit simple order codes and timing marks to the computer. For example, in the application being described we dial '0' to indicate to the computer the moment of injection of the radioactive tracer into the venous systems . . .

"At the computer the pulses are picked off the telephone by an inductive pickup coil which clips to the phone. The pickup signals are amplified and those exceeding a threshold level (set to discriminate against line noise) are fed into the computer. The intervals between pulses are measured by the computer itself by comparison with its internal clock. Actually a program loop is used as a time base and the number of times the computer executes the loop between pulses is counted . . ."

"If the computer is not available at the moment when data are being generated, the information pulses can be stored on an ordinary inexpensive 'home-type' magnetic tape recorded for transmission as soon as the telephone line and/or the computer becomes available." (Neilsen, 1965, pp. 634–635.)

4.4a1 Information obtained from Moore, Dr. Rolf, private communication, Aug. 11, 1966.

4.4a2 "There has been progress in research into the problem of optical recognition of printed text characters (Potter, 1964) but there is real difficulty in developing the type of flexibility needed to handle the various idiosyncrasies of an individual's handwritten print or script. It has been shown that high reliability of recognition of handwritten words can be obtained when the machine is programmed to deal with the handwriting of four subjects: reliability decreases when the program is based on a larger group, and deteriorates further when attempts are made to deal with the writing of subjects, samples of whose script has not been included in the programming (Mermelstein and Eden, 1964)." (Spolsky, 1966, p. 493).

4.4b "Whirlwind (at MIT) had a cathode ray tube and light pen in the early 1950's. A prototype of the APT system (computer controlled machine tool) was programmed on Whirlwind in 1955." (Wigington, 1966, p. 86).

"The light pen, which was originally used in military air-surveillance systems for target identification . . . has been adapted by means of tracking programs to permit direct entry of hand-drawn information." (Ward, 1967, p. 48).

4.5 "The Elastic Diaphram Switch Technology (EDST) is being used in an experimental device created by . . . [IBM's] Advanced Systems Development Division which can enter handwritten information directly into a computer's memory." (Commun. ACM **8,** 718 (1965).)

4.6 "With Data Trend's MIMO Hand-Print Model input-output terminal for real-time on-line operation with a data processor, the user writes his message on a platen with a special stylus. All the alpha-numerics and several symbols may be used. Little or no operator training is required. Information concerning the character written is transmitted via a teletype code to the computer which identifies it and takes whatever action is appropriate." (Data Processing Mag. **7,** 50 (Feb. 1965).)

"Data Trend's Solid State Keyboard MIMO (*M*an *In-M*achine *O*ut) systems-oriented input/output terminal provides real-time on-line operation with a data processor." (Data Proc. Mag. **7,** No. 2, 50 (1965).)

4.7 "If a speaker's previously recorded 'voice-print' . . . could be fed into the computer as the object to be found, the computer could monitor telephone conversations or search masses of tapes, printing out only where the conversation included the voice-printed subject. . . .

"It may also be possible to use phoneme sounds . . . to enable computers to spot particular words in oral communications, such as 'atomic', 'Pentagon', 'Rockefeller', or 'Costa Nostra', and to take off only conversations containing these signals." (Westin, 1967, p. 87).

4.8 "A solid state, optical scanning device, the IBM Scanistor, converts images into analog voltage output representing amount and position of light detected, with high resolution and fast response, and has been suggested for development as "a hand-held 'reading' device which could be passed over a line of printed text to enter data into a computer." (Commun. ACM **8,** 82–83 (Jan. 1965).)

"The scanistor (an integrated diode resistor array) shows promise for future application in the character recognition field." (Henle and Hill, 1966, p. 1860).

4.8a "For some years the Institute for Scientific Information has been working on the Copywriter, a portable device for selectively reproducing a word, line, sentence or paragraph from a printed page. Its developers estimate that 10% of the total copying market would find a selective copier appealing." (Veaner, 1966, p. 208).

4.8b Thus Vander Lugt et al. (1965, p. 139) propose "the use of spatial filtering in coherent optical systems to construct filters for the detection of key words in printed material. Such a system might be used in the Post Office Department for routing mail to given areas by using the Zip Code. It might also be useful in abstracting and cataloging operations where one looks for certain descriptor words."

4.8c This includes the possibility that "the coded tape produced in the keyboarding of manuscripts may be used in all subsequent phases of disseminating and handling scientific information." (Kuney, 1967, p. 136). However, "until we have progressed first of all to the graphic insertion promised by Photon, IBM, and others to the actual computer storage of both line diagrams and half-tone images and their recall and production along with the text, when called for by the editor or makeup man, we cannot pretend that we have a satisfactory comprehensive automated publishing system." (Duncan, 1967, p. xi).

4.9 "Another data coding scheme might be explored for application beyond its original purpose: Galli (1962) has described a method for transcribing text into machine form using the stenotyping technique, where individual phonetic syllables or common words and phrases are manually transcribed into a 23-bit code. The principal application is rapid data transcription using the stenograph machine, with decoding performed by photostore dictionary lookup technique. But one can envision other applications that relate to storage compression (not necessarily text storage), where the steno symbols are stored and only decoded at output time." (Climenson, 1966, pp. 117–118).

"Stenotype devices will be an attractive alternative to the keypunch or typewriter for preparing inputs for the optical readers." (Berul, 1968, p. 32).

4.9a1 Another type of combination is represented by the following: "Depending on the specific application at hand, two separate, modern mechanical input techniques have been used to replace keypunching.

1. For alphanumeric data, we are using NCR 731 key-operated magnetic tape recorders. Applications include master file conversions, file updating, program entry and program editing.
2. For entry of numeric transaction data, we are utilizing optical font sales registers and adding machines." (Lee, 1968, p. 51).

4.9a2 "The use of highly specialized fonts as exemplified by the Farrington scanner has been limited primarily to systems that are self-contained within an agency. The United States Department of Agriculture is an example of use of the Farrington process. This process is limited to the recognition of unique characters produced by specially equipped typewriters. It costs approximately $40 per instrument to convert to Farrington characters. In essence this process is restricted to internal processing of documents which originate and end in the using organization. The psychological factor of 'difference' has been a deterrent to broader usage for alphabetic data." (Lannon, 1967, p. 48).

4.9b "Input to a computer is still one of the slowest elements in automatic data processing. If we compare the internal speed of the computer system scheduled to be installed at the National Institutes of Health of my Department we find that the central processor is 8,000 times faster than the card reader of the system. The card reader is by no means slow and processes 1,000 80-column cards per minute. . . .

"Dependent upon a variety of factors it takes in the range of 16 manhours of key punch and key verifier time to keep the card reader busy for one minute, which in turn keeps the central processor busy for .075 seconds. It becomes quite apparent that the input process is quite expensive and still quite slow." (Lannon, 1967, p. 48).

4.10 Some examples are as follows:

"The monthly *Bibliography of Agriculture* now is issued by using an optical scanner-computer combination." (Brown et al., 1967, p. 33).

"The Council is assisting the [Los Angeles County Public] Library to evaluate a procedure by which bibliographic records would be prepared from the beginning in a form suitable for optical scanning." (Council on Library Resources, 10th Annual Report, 1966, p. 42.)

"It might be noted parenthetically that, from the typist's viewpoint, the simplest solution would be to use optical scanning. The Olivetti-Underwood Praxis 48 typewriter, for example, is used by Documentation Incorporated to provide input to an REI scanner. The font is a standard gothic, only slightly modified as to descenders; the scanner does not sense red, making forms typing possible. This approach entails the least disruption to the typist's routine." (North, 1967, p. 5.)

"One other agency reporting a large use of optical readers in the place of other input conversion methods was the Department of the Agriculture which uses 2 CDC 915's, fed by 25 typewriters in the home office, and numerous, a thousand or more, in the field." (Auerbach Corp., Source Data Automation, 1967, pp. 2–13.)

"For large conversion tasks the OCR exceeds all other methods in economic excellence, even when including typing cost." (Moore, 1967, p. 95.)

"Probably the greatest interest is in optical readers, and studies have shown its high-speed potential (since it is not dependent on direct human operation), and flexibility to formats to be advantageous to cost reduction in large-scale operations. This has been demonstrated even when an initial conversion step from source data to typewriter input must be made." (Auerbach Corp., Source Data Automation, 1967, p. 2–12.)

"The results of a comparative cost analysis showed that keypunching would cost approximately 3.5 times as much per year as optical scanning; therefore, the committee published a formal justification recommending the purchase of at least three optical scanners, one for BuPers in Washington and two for Navy Finance Center . . ." (Auerbach Corp., Source Data Automation, 1967, p. 2–13.)

"Retyping after making *clean* erasures has been found to be an acceptable correction method for OCR. The use of an erasing shield is recommended to avoid disfiguration of adjacent characters." (Greenly, 1966, p. 47.)

"A simple formula for determining this cost [keypunch vs. OCR] is to evaluate:

$$F = \frac{a}{b + c}$$

Where:

F = number of characters processed per dollar.
a = total characters processed per month.
b = monthly equipment rental and overhead costs.
c = monthly employee salary costs, including supervision and fringe rates."

(Feidelman and Katz, 1967, p. 0210:28.)

"By dividing the cost of the key punch operator into the cost of the reader the break-even point is to the advantage of character reading when the load exceeds the capacity of 15 key punch operators." (The British Computer Society, 1967, p. 155).

The British Computer Society survey also shows that a comparison of costs of key punching cards and typing and optical reading (with a typical cost reduction of close to 50%) indicates "the potential of typing and reading to reduce considerably the costs of data conversion, particularly for large volumes of mainly alphabetical content." (1967, p. 156).

"One may readily ask: 'If the input data must be rekeyed, what is the advantage of rigid font scanning?' The answer lies in the fact that many typewriters equipped with normal font can be readily changed to rigid optical font by mere selection. The ordinary typewriter can then become a substitute key punch device . . . What are the economics of the rigid font optical scanners? The typing in Fig. 3 could be read by a device costing $120,000 or renting for $3,500 per month. Such an optical scanning device is made by the Control Data Corporation. This device could maintain a rate of input reading that could remain well ahead of 40 operators keying difficult textual material." (Wishner, 1965, p. 240).

"On the other hand, the typewriters used by the catalogers could be obtained with the Farrington Selfchek font and the preparation process could be continued just as it is now. Then, once a catalog card had been completely prepared, the card itself could be optically scanned and a 'magic' typesetter used to produce the cards. This process would also offer economy, speed, and efficiency. The machines exist now; nothing is stopping us except ourselves and, perhaps, the funds." (Patrick and Black, 1964, p. 39.)

4.11 "One [of the problems that cause particular difficulty] . . . is the presence in a large proportion of all input documents of non-alphabetic material which cannot be recognized or dealt with as text. This includes graphical material, pictures, special field defining lines or formatting marks, characters from strange alphabets or bizarre and exotic fonts. . . . Perhaps the simplest example of this kind of problem is that caused by underlining a word or phrase with a solid line. This causes a major problem with every simple character separation system we have conceived. . . .

"For certain applications, such as the input system to a translator, some portions of non-alphabetic material may have to be made available for insertion in the translated text. An indication of where this material is located, and how extensive it is, would need to be recorded by the recognition system." (Potter, 1964, pp. 321–322).

4.12 For example, in relatively early Baird Atomic developments, "the ½" strip is automatically placed along the left hand margin of each page by the camera when photographing it onto the 70 mm film. This serves both as a reference for grey scale calibration during scanning and as a means for instructing the text reader to start scanning a line. The ¼" strip is manually placed along both sides of all graphics prior to scanning. The reader stops scanning when it encounters the first strip and resumes scanning when it crosses the second strip. The space between the strips is sensed and recorded by the reader which produces appropriate control signals for the translator." (Buck et al., 1961, pp. IV–4.)

4.12a "With the current research on pattern recognition devices, we may soon expect automatic processing of at least simple graphic diagrams. With an oscilloscope input into a computer, one might draw graphs with a light pen and let the computer itself, in whatever ways it is capable, reorganize this data for storage and manipulation." (Barnes, 1962, p. 29.)

"Most character recognition machines now in use require either a fixed format document, where the material to be read appears in well-defined fields, or manual editing with colored pencil or magnetic ink to outline the areas to be processed. More versatile readers would find application in massive file conversion and information retrieval projects, and in automatic translation, abstracting, and indexing. . . .

"In an interactive system it should be possible for the operator to direct the scanner only to areas of the page of interest by virtue of their meaning, and set in a typeface compatible with the recognition logic of the machine. 'Graphics', including photographs, line drawings, graphs, charts, and esoteric symbols, could be scanned without any attempt at recognition, and stored in binary arrays for eventual redisplay by some type of facsimile device. Important headings, equations, footnotes, and other non-machine readable textual material would be typed in by the operator on an alphanumeric keyboard and stored in code. Alternatively, the operator would have the option of keying in a few lines of a new font in order to provide the machine with an identified training set to adjust its decision parameters. A function keyboard would allow labeling the various portions of the text to facilitate subsequent retrieval. Some preliminary experiments, designed to expose the problems likely to be encountered in implementing these ideas, are described . . . (Nagy, 1968, p. 481).

4.13 In the Army Chemical Typewriter developments of Jacobus and Feldman at Walter Reed Army Medical Center, a set of characters and conventions of usage have been established. "Then, as the structure is typed, a tape is perforated with the codes of the characters typed, and the codes of the coordinates of the position of the characters on the typewritten page." (Feldman, 1964, p. 206. See also Feldman et al., 1963).

4.14 "The rules established for coding structures are integrated in the program so that the computer is able to take a fairly sophisticated look at the chemist's coding and the keypunch operator's work. It will not allow any atom to have too many or too few bonds, nor is a '7' bond code permissible with atoms for which ionic bonds are not 'legal'. Improper atom and bond codes and misplaced characters are recognized by the computer, as are various other types of errors." (Waldo and DeBacker, 1958, p. 58.)

4.15 "Provisions have been made to accept input data on magnetic tape in BCD or binary format. The input is coded into machine media from line-a-time devices such as flexowriters, card punching equipment, computer programs, and the Army Chemical Typewriter." (Burger, 1964, p. 8.4.)

"The Chemical Typewriter produces X and Y coordinates to locate the characters on a grid which enumerates, respectively, the horizontal spacing positions and relative to zero vertical positions of its platen." (Burger, 1964, p. 8.)

4.16 ". . . The molecular formula, which is printed adjacent to its corresponding structural diagram and read with it, is an inventory of the atoms which appear in the diagram, and so the computer identification of each alphabetic character in the diagram can be checked against this inventory . . .

"The complete prototype system . . . consists of a general purpose binary computer and an optical scanner. On a signal from the computer, the scanner transfers the entire image to computer core storage by a series of subprograms to search for black area . . . , to recognize each character and supply a machine language representation . . . and to construct and check the connection table." (Cossum et al., 1964, pp. 271–272).

4.17 "The typing and language rules are quite flexible, unrestrictive, and easy to learn. Typing errors are easily corrected by back spacing and overtyping or pressing a special "erase" button. Superscripts and subscripted arithmetic expressions can be typed conveniently and summation, product, integral symbols, etc., of arbitrary size can be constructed from elementary characters or formed by selecting the desired symbol or subprogram from an accessory console keyboard. Since the system has been designed for human interaction, it is not necessary to type neatly formed or symmetric symbols. The system will recognize even badly formed symbols. Usage may be off-line or in an on-line conversational mode." (Amann and Klerer, 1966, abstract).

4.17a "Our input device is (similar to the MADCAP device (Wells, 1961)) a Friden Flexowriter that has been modified so that subscript and superscript positioning can be done automatically under keyboard, paper tape reader, or direct computer control. In addition, the 88 available typable symbols have been chosen to give flexibility both in the typing of equations and the construction of mathematical operators of arbitrary size. These may be composed manually by typing stroke by stroke or by pushing an appropriate key in an optional console keyboard." (Klerer and May, 1965, p. 103).

"The purpose of this paper is to describe some new applications in the realm of two-dimensional input-output by typewriter terminal. . . . The principal elements of this approach consist of a versatile programming language and a reverse-indexing typewriter equipped with a special character set. This set permits not only normal alphanumerics but also the construction of arbitrarily-sized symbols by the use of a few interlocking primitive strokes. The reverse-indexing and indexing, together with spacing and backspacing, allow full two-dimensional keyboard control of the typed document. Typing errors are corrected by moving to the desired point and overtyping, or by pressing an 'erase' button." (Klerer and Grossman, 1967, p. 675).

4.17b "Our objective has been to devise a remote computer terminal through which the scientist or engineer can converse with the computer in the natural language of mathematics. For example, he can enter an equation exactly as it appears in a textbook and receive an immediate graphical and alphanumerical display of the results." (Clem, 1966, pp. 119–120).

"For the last 18 months we have endeavored to develop such a system called AMTRAN (for Automatic Mathematical TRANslation) and this paper will review our progress so far. AMTRAN was inspired by a similar online system developed by Culler and Fried and it shares many basic principles with the Klerer May system. The development of AMTRAN was initiated by Seitz and it is at present carried on by several of us in Huntsville. The basic goals of AMTRAN are:

1. To use the natural language of mathematics as a programming language without any arbitrary restrictions whatsoever.
2. To obtain immediate graphical output of intermediate and final results.
3. To retain a hard copy of useful results and programs.
4. To retain copies of programs in an easily reusable form.
5. To retain utmost flexibility in the system so as to allow its use from the level of existing programming language up to the level of advanced calculus," (Reinfelds et al., 1966, p. 469).

4.17c "In the improved terminal area I mentioned above, I'm aware of only one outstanding attempt—the work done by Columbia University's Oceanographic Laboratory. They've built a terminal that permits keyboard entry of a wide range of commonly used mathematical symbols. Although the transcription task is thus more difficult, the programming task is simplified since the oceanographers use their familiar mathematical notation. This approach has not been used widely because it is difficult to build an inexpensive, easy-to-operate machine that directly transcribes many special symbols. But this experiment shows clearly the importance and value of being able to use, in a programming language, the necessary symbol." (Reynolds, 1967, p. 29).

4.18 "The Army Chemical Typewriter (ACT) . . ., was developed by the Walter Reed Army Institute for Research as a means for inserting chemical structural diagrams into a digital computer for storage and subsequent searching. This is accomplished by typing the chemical symbols and bond configurations into a matrix from which is then reduced to a linear coded representation on a paper tape. The ACT will be used in the IDEEA network as the man-machine interface. All communications with the systems computers will be accomplished through the keyboard of the ACT. Thus both alphanumeric and symbolic data can be inputted and outputted." (Hoffman, 1965, p. 95.)

"By interfacing the ACT with the FADAC, we create an input/output device that has both memory and arithmetic capability. Thus we can perform error checks on the input data as it is typed. The marriage of these two devices further allows for a good deal of preprocessing of the data at the input end, such as screen derivation and data classification." (Hoffman, 1965, p. 96.)

4.19 "Three basic methods of input are used to convert into machine language the structural diagrams prepared by a chemist. Two of these, the keypunch and the typewriter, require clerical processing steps. The third method involves direct scanning of the diagrams into the computer record. Waldo & DeBacker, and Horowitz & Crane have used a 48-character keypunch to record structural diagrams directly. This method in input provides no direct hardcopy of the keyboard data for editing, though key-verifying is applicable. Moreover, because of the restricted character set, keypunching requires a great many conventions both in the form of character substitutions and in the representation of angular bonds required in the diagrams. Newer keypunches have as many as 64 characters, but this limited extension of the character range does not provide for inclusion of an adequate number of special structure-composing characters to simplify diagrammatic input." (Tate, 1967, p. 296).

4.20 Some details are as follows: "Besides automatically producing punched paper tape, the modified typewriter has the capability to provide coordinate positioning of each type character on the page. In addition, the machine can automatically encode any one of approximately 90 selected (commercially available) auxiliary type faces inserted at the platen. This device has been named the 'taxywriter' by the NBS staff to indicate a type face augmented X–Y recording typewriter.

"The machine can operate either as a standard tape typewriter or in an augmented mode in which it produces four punched codes for each typed character. The four codes are those for the character, its X-coordinate, its Y-coordinate, and an item separator. Insertion of a modified type face element inactivates the standard coding for the typewriter keys; striking any key then produces on paper tape five codes, which are a type-face-element precedence followed by the auxiliary character, X- and Y-coordinates, and item separator. The modified type face element has four pin holes on each side, into which metal pins may be inserted to signify an 8-bit, odd-parity, binary code. The pins make electrical contact with a guide at the platen of the typewriter to activate the coding. . .

"The Office of Standard Reference Data intends to use the new machine to prepare scientific text and tabular data. Any application in which superscripts, subscripts, special symbols, or coordinate-oriented material must be prepared in machine-sensible form could benefit from its use. Its principal advantages are:

(1) Immediate visual verification by the typist of the copy being produced.
(2) Rapidly prepared proof copy available on a day-to-day basis (as output from an extended character printer) for technical review.
(3) Daily editing on a line correction basis in conjunction with technical proofing.
(4) Availability of typewriter-quality scientific text with adequate symbols for preparation of manuscripts.
(5) Preparation of machine-sensible copy for use in producing publications by computer-generated photocomposition.
(6) Rapid, low-cost preparation of selected portions of recorded scientific text on cards or paper stock for manual filing." (NBS Tech. News Bull. **50,** 118 (Apr. 1966).)

"The thing that is special about this typewriter is that these "Typits", as they are called, are coded by pins placed in the sides so that the information can be read by small switches and can be punched into a paper tape at the same time that the symbol is being typed onto the hard copy.

"Up to 4 pins can be placed in each side of a "Typit", giving an 8-level code. When a key is struck with a "Typit" in place, a precedence code is automatically punched, the code for the particular symbol is read and punched, and a code returning to the normal mode is automatically punched." (Bozman, 1967, pp. 2–3.)

". . . 3 Nixie tubes . . . are used to display the numerical code of the "Typit", when reading back a punched paper tape. When the tape reaches a place which calls for one of the special symbols, the coded number for that particular symbol is shown on the Nixies. The operator can then place the correct symbol in the typewriter, type that character and restart the automatic typing process again." (Bozman, 1967, p. 3.)

"Another feature of this typewriter is that the rotation of the platen is also punched into the paper tape." (Bozman, 1967, p. 3.)

"The typist can make up the formula in whatever order seems most convenient, rotating the platen up or down, as needed. Since the information is all punched into the paper tape, the computer can reconstruct the formula line-by-line, if necessary, for the final typesetting." (Bozman, 1967, p. 3.) See also "Modified Tape-Recording Typewriter", 1966.

4.20a "Part of the program of the NBS Office of Standard Reference Data is the development of a General Purpose Scientific Document Image Code (GPSDIC) system . . . The design and development of this system is being carried out by Blanton C. Duncan and David Garvin . . . As designed, the system permits a scientific typescript, with all its complex symbolism and highly structured page format, to be transferred to digital machine form with virtually no limitations on the notations employed. . . .

"The system was designed to assure broad applicability by emphasizing: (a) exchange of information via telecommunication devices compatible with the USA Standard Code for Information Interchange (USASCII), (b) design of hardware to permit the use of proven skills of ordinary scientific typists in the record capture process, (c) exploitation of the capabilities of commercially available extended character high-speed line printers for direct computer output, and (d) publication using this type of machine record as the 'typescript' input to computerized typesetting." (NBS Tech. News Bull **52,** 86, Apr. 1968).

4.21 "The third method of recording structural diagrams is by scanner. Meyer has developed a photocell scanner for structure input. This scanned input, supplemented by a limited amount of keyboarded data that identify noncarbon, nonhydrogen atoms, bond multiplicates, and special structural features, provides a combination scanner-keyboard input record that is transferred by the computer into a single structural record. Ledley, and Cossum et al., have developed direct input of structural diagrams drawn freehand. Though these systems are claimed to offer economic advantage and increased reliability, only Meyer's system is presently scheduled for operation." (Tate, 1967, p. 297).

4.22 "What a chemist would most like to do is to simply draw a structural formula on a sheet of paper. We therefore built a machine which by means of photocells can scan structures written on paper and punch the information obtained into punched cards or paper tape." (Meyer, 1963, p. 131.)

4.22a "The importance of the sound spectrograph lay in the fact that it provided a visual image of the spectra of speech sound. It was in effect the automation of Fourier analysis of speech spectra. It immediately made evident acoustic factors of speech that had not been suspected, and helped to consolidate or eliminate various aspects of the theories that analytical methods had only gradually been yielding." (Lindgren, 1965, p. 127).

4.23 These authors suggest, further, that: "Computer measurement of ECG's is now sufficiently accurate to provide a basis for an automated diagnostic classification . . . In a computer diagnostic program, 'abnormal' measurements are given diagnostic significance only when present in certain combinations of leads. This computer diagnostic program is being written and tested". (Bobrow et al., 1965, p. 126.)

4.24 "The program employs a multiple adaptive matched filter system with a variety of normalization, weighting, comparison, decision, modification, and adapting operations. The flexibility of the method has permitted study of the effects of experimental variations of these operations on the pattern classification process to simulate human interpretation of electrocardiograms more closely." (Okajima et al., 1963, abstract.)

4.25 For example: ". . . (a) a series of typical filter patterns for P, QRS and ST-t segments of the EKG has been developed, (b) a diagnostic program for rhythm analysis has been prepared, (c) an interpretation matrix and a diagnostic matrix have been devised that incorporate pattern recognition, rhythm and extracted parameter data with some stratifying clinical information for the determination of an EKG interpretation, (d) the loop of the diagnostic system has been closed by the frequency-modulated transmission of EKG data by telephone lines from the Electrocardiography Laboratory of the Massachusetts Memorial Hospitals to a GE 225 digital computer at the . . . M.I.T. . . . and the subsequent return of a diagnosis to the laboratory for teletype display . . ." (Whipple et al., 1965, p. 49).

4.26 "The system is entirely digital and the tablet is relatively inexpensive. In addition, thin paper sheets can be inserted between the tablet surface and the pen for tracing maps and curves." (Lewin, 1965, p. 831).

"The RAND tablet consists of a thin Mylar sheet containing on one side, an array of etched copper lines in the X direction and, on the other side, a similar array of fine lines in the Y direction. By means of capacitor encoding networks, also etched on the same sheet, a unique voltage pulse train is applied to each X and Y line from a common pulse pattern generator. The pen in this case is merely a metallic electrostatic pickup connected to a high input-impedance amplifier. The pulse train picked up by the pen depends on the X and Y lines nearest to its tip. This serial pulse pattern (in Gray code to eliminate errors) is converted into a parallel binary address with appropriate peripheral logic, which includes a shift register and a code converter." (Lewin, 1965, p. 831).

"The RAND tablet device generates 10-bit x and 10-bit y stylus position information. It is connected to an input channel of a general-purpose computer and also to an oscilloscope display. The display control multiplexes the stylus position information with computer-generated information in such a way that the oscilloscope display contains a composite of the current pen position (represented as a dot) and the computer output. In addition, the computer may regenerate meaningful track history on the CRT, so that while the user is writing, it appears that the pen has 'ink.' The displayed 'ink' is visualized from the oscilloscope display while hand-directing the stylus position on the tablet . . . . Users normally adjust within a few minutes to the conceptual superposition of the displayed ink and the actual off-screen pen movement. There is no apparent loss of ease or speed in writing, printing, constructing arbitrary figures, or even in penning one's signature." (Davis and Ellis, 1964, p. 325).

4.27 "The Grafacon 1010 is based on the Rand Tablet, has a 'writing' surface and control electronics. It does not require a computer-controlled scanning system to locate and track the stylus. The 10 x 10-inch writing surface can accommodate 106 input locations with 100 lines/inch resolution in both x and y." (Datamation **11**, No. 5, 99, 101 (1965). [Data Equip. Co., Santa Ana, Calif.].

"Two-dimensional digital graphic input system, based on the Rand Tablet, consists of a "writing" surface, stylus, and associated control electronics. It is said to permit the plotting of a wide variety of input information directly on an integral screen. Pulses sensed by a high-impedance, pen-like stylus are encoded as serial X–Y Gray-code information. This data is then strobed, converted to binary code, assembled in a shift register, and gated in parallel to computer interface circuitry. It does not require a computer-controlled scanning system to locate and track the stylus. The printed-circuit screen, with capacitive-coupled encoding, is the hub of the system. The 10″ x 10″ writing surface can accommodate 10^6 input locations, with excellent linearity and 100 lines/inch resolution in both X and Y. The stylus contains a pick-up probe, amplifier, and a control-signal switch which is actuated by tip pressure. Data Equipment Co., Div. of BBN Corp., Santa Ana, Cal." (Computer Design **4**, 74, Nov. 1965).

"A new graphical input system for off-line digitizing of graphic drawings, strip charts, maps, etc., or from projected slide or film images onto computer magnetic tape—has been introduced recently by Bolt Beranek and Newman's Data Equipment Div., Santa Ana, Calif. The Grafacon 205–1 Magnetic Tape Digitizing System is claimed to be several times faster to use than other graphic digitizing systems currently available.

"The new system consists of the Grafacon 1010A Digital Tablet—a $10\frac{1}{2}''$ square production version of the RAND Tablet Graphic Input Device—with a stylus, alphanumeric keyboard, incremental magnetic tape recorder, and associated electronics assembled in a $30'' \text{ H} \times 8\frac{1}{2}'' \text{ L} \times 20'' \text{ D}$ cabinet.

"Optional off-line digitizing equipment includes either the Model SS Storage-Oscilloscope for visual display of the data as it is digitized, or the Model PL X-Y Recorder Monitoring System for tracking the Grafacon stylus position." (Computers and Automation **16,** No. 12, 50 (Dec. 1967).)

4.28 "To beat the language barrier between man and machine, Itek has, in effect, hitched the digital computer to the draftsman's stylus. With a photoelectric light pen, the operator of an EDM can formulate engineering problems graphically (instead of reducing them to equations) on a console that looks like a flat, unflickering television screen. The operator's designs pass through the console into an inexpensive computer, which solves the problems and stores the answers in its memory banks in both digitalized form and on microfilm. By simply pressing buttons and sketching with the light pen, the engineer may enter into a running dialogue with an EDM, recall any of his earlier drawings to the screen in a millisecond and alter its lines and curves at will. The whole system, Itek engineers claim, can be hooked up to permit long-distance design conferences between field sites such as a missile launching pad and the home office." (Time, Mar. 2, 1962, p. 76).

4.29 "Sylvania is offering an electronic ballpoint pen which translates graphic material to computer language as it writes, and simultaneously transmits data to computers for storage and analysis. Called the Data Tablet . . ." Data Proc. Mag. **9,** No. 6, 72 (1967).

"Sylvania Electronic Systems, a division of Sylvania Electric Products Inc., Waltham, Mass.—The Sylvania Data Tablet is transparent—has a protective coating on the surface—and does not require contact by the stylus. Any nonconductive material such as paper or film up to $\frac{1}{2}$ inch in thickness, can be interposed between stylus and surface. An operator can write on a pad of paper placed over the tablet, and his writing will register. An inking capability on the stylus provides the option for creating hard copy simultaneously with electronic entry. The DT–1 can be used as a desk, console, or as a transparent overlay for a CRT or other display, such as the map on the cathode ray tube at the left. The operator can post new information graphically on the tablet which the computer will accept for up-dating the map. This graphic input device is easily interfaced with almost any computer. It is suitable for many diverse applications such as military command and control, machine-aided design, training devices and as a general research tool." (Computers and Automation **16,** 54 (Dec. 1967).)

"Use of phase measurements to obtain position as in the Sylvania Data Tablet is apparently a fairly new concept or at least one which was not developed fully in the past. Its greatest advantage in this application (over other conductive film techniques dependent upon voltage gradient) is that capacitive coupling to the conductive film by the pen can be used even through dielectric layers such as a protective glass covering or sheets of paper. The latter items and the fact that the pen used in the Data Tablet contains a standard ball-point pen stylus offers the ability to produce a hard copy simultaneously with the data entry. . . .

"A drive network excited by the electronics package drives the film at discrete points along its circumference in such a manner that a traveling wave (in a mathematical sense) is established parallel to each orthogonal axis. This wave has the property that its phase is a linear function of position as in the relationship:

$$V = K \sin(\omega t - \alpha X)$$

were α, ω are constants and X is the position coordinate. (It should be mentioned that a true propagating wave does not exist on the writing panel since a frequency in the hundreds of megahertz would be required to give a significant phase shift along on eleven inch path. Actually, only one kilohertz is used as the phase shifted frequency.)" (Teixeira and Sallen, 1968, p. 316).

4.29a "The actual writing is done on ordinary paper (with any desired printing format) placed on top of the array. The pressure of normal printing forces the paper and the top membrane down onto the bottom set of conducting lines, producing a contact point between the two orthogonal sets of lines in the location directly under the printing stylus. As this stylus moves from point to point, successive momentary contacts are made, and a raster-type image of the character, as it is traced out, is signaled to the electronic system. The stylus can be any natural implement, such as a ballpoint pen or a leadpencil." (Simek and Tunis, 1967, p. 77).

4.29b "A necessary requirement for the system, and a novel contribution of this present work, is the development of an extremely low-cost hand-printing transducer. Functionally, it is similar to the Rand Tablet, but conventional paper and pencil may be used." (Simek and Tunis, 1967, p. 72).

"Basically, the system makes use of a square glass tablet as a drawing medium and as an ultra-sonic delay line, through which mechanical vibrations are transmitted periodically and alternately by stationary transducers installed along two adjacent edges of the glass tablet. A separate transducer is built into the pen used to make the drawings; when the pen comes into contact with the glass top, the mechanical vibrations can be detected by the pen transducer. Since mechanical vibration can be propagated with a constant velocity through an isotropic and homogeneous solid such as glass, the time delay between transmission of a wave and its reception by the pen transducer is an accurate measure of the distance between the edge of the drawing board and the pen position. . . .

"When mechanical pulses are rapidly and alternately transmitted in the *X* and *Y* directions of the glass tablet, the coordinates of the pen can be determined. This information is converted into digital form and stored in a computer memory. When recycled out from the memory and reconverted into the graphical form, the information is projected through a CRT system to the back of the glass tablet." (Woo, 1964, p. 609).

4.30 "The III COMPUTER EYE is an optical information sensor and processor capable of measuring and interpreting real world scenes. The sensor of the EYE . . . differs from the tv camera in that, under control of the Image Processor (a stored program general purpose computer), it selectively examines points in its field of view. The EYE may seek out a significant part of the image, concentrate on it, and then move to other areas under guidance of a pattern recognition program." (Information International, Inc.)

4.30a1 "Canada's Geographic Information System as now set up makes use of an IBM System/360 Model 65 computer along with equipment to create a central data bank—bringing together all existing geographic and geodetic data on capabilities and uses of land in Canada.

"Of necessity maps comprise the main input. Hence the call for the now installed IBM Cartographic Scanner, as it is named, specially designed and built by IBM's Systems Development division in Kingston, N.Y., under contract with the Canadian Government's Agricultural Rehabilitation & Development Administration. GeoIs in fact has become the key to the entire Canadian Land Inventory (CLI) program.

"Maps are stored in the system by two devices. The first is the Cartographic Scanner which records information on magnetic tape and produces a map in line form.

"The second is a manually operated XY digitizer which translates geodetic data on maps into punched cards. Classification data also is punched into cards." (Boggiss, 1967, p. 64).

4.30a2 "As more and more applications have been made, it has become clear that the properties of Sketchpad drawings make them most useful in four broad areas:

"For Storing and Updating Drawings: Each time a drawing is made, a description of that drawing is stored in the computer in a form that is readily transferred to magnetic tape. A library of drawings will thus develop, parts of which may be used in other drawings at only a fraction of the investment of time that was put into the original drawing.

"For Gaining Scientific or Engineering Understanding of Operations That Can Be Described Graphically: A drawing in the Sketchpad system may contain explicit statements about the relations between its parts so that as one part is changed the implications of this change become evident throughout the drawing. For instance, Sketchpad makes it easy to study mechanical linkages, observing the path of some parts when others are moved.

"As a Topological Input Device for Circuit Simulators, etc.: Since the storage structure of Sketchpad reflects the topology of any circuit or diagram, it can serve as an input for many network or circuit simulating programs. The additional effort required to draw a circuit completely from scratch with the Sketchpad system may well be recompensed if the properties of the circuit are obtainable through simulation of the circuit drawn." (Sutherland, 1963, p. 332).

"For Highly Repetitive Drawings: The ability of the computer to reproduce any drawn symbol anywhere at the press of a button, and to recursively include subpictures within subpictures makes it easy to produce drawings which are composed of huge numbers of parts all similar in shape." (Sutherland, 1963, p. 332).

4.30b "A more serious drawback of keyed numerical input is that it cannot be used to achieve continuous variation of parameters in the manner of a shaft encoder or a tracker-ball. Many display installations do not include any input devices of this type, and a graphical technique has been developed [Aiken Computation Laboratory, Harvard University] to achieve a similar effect using a light pen. This technique has been called the *Light Handle*, as it simulates the effect of winding a handle or rotating a knob. Any coordinate-input device such as the RAND Tablet (Davis and Ellis, 1964) or the SRI Mouse (English, Engelbart and Berman, 1967) may be used to control the Light Handle." (Newman, 1968, p. 63).

4.30c "Most of the required components already exist and have been put together at System Development Corporation, as a prototype system. For the hardware, the user terminal is a RAND Tablet (Grafacon 1010A), for input to the computer, and a CRT display for output. The CRT image is rear-projected onto the Grafacon, so that input and output images are coincident. The terminal is connected through a peripheral processor (a PDP–1 computer) to the AN/FSQ–32 computer, which is the central processor for the system. Details of the terminal and computer interface were described by Gallenson at the 1967 Fall Joint Computer Conference." (Bernstein and Williams, 1968, p. 28).

4.31 "Control Data Corporation announced the development of the Digigraphic 270 series . . . Combining free hand drawing using a light pen and automated drawing (activated through control registers and buttons on a keyboard) for production of perfect circles, angles and lines, the operator can create any type of graphic representation on the screen of the Digigraphic console. Drawings are transmitted to the CDC 3300 as thousands of individual vectors, the position of each given as relative to a built-in *x*- and *y*-axis." (Commun. ACM **9**, 468 (1966).)

"Experimental work being performed at the Control Data Digigraphic Laboratories in Burlington, Massachusetts, uses electronic drafting boards and light pens supplemented by keyboards to permit the man to provide input to the computer comfortably." (Macaulay, 1966, p. 579).

"Control Data Corporation, Minneapolis, Minn., is marketing a Digigraphics System designed for use with a small-scale Control Data 1700 Computer System. Digigraphics refers to a CDC system in which an operator seated at a special console equipped with a large TV-like display screen is able to enter data in graphic form—using a light pen and keyboard—directly into a computer system for processing, storage and retrieval.

"The controller used in the 274 Digigraphics System has a 4096 word buffer memory—expandable to 8192 words—for operating a single Digigraphics console. A vector-oriented, 22-inch diameter, flatface visual display screen on the console is capable of displaying the equivalent of 2000 inches of curves, or up to 1800 characters of variable size or font. . . .

"The software package (Function Control Package) provided with the system offers a large number of universal design features. This means that the user, rather than structuring a software system from scratch, need only interface his application program(s) with existing routines to achieve full operational capability. Integration of user oriented programs with the FCP software is accomplished via FORTRAN IV CALLS.

"Upgrading any general purpose Control Data 1700 Computer System to Digigraphics capability requires only the addition of the 274 Digigraphics Controller, the 274 Digigraphics Console, and 24,000 words of core and disk pack memory." (Computers and Automation **16,** 60 (Nov. 1967).)

4.32 "The [RCA] system . . . utilizes the pen as the signal generator and the writing surface as the address detector. The pen contains in its tip a small magnetic head which periodically generates a localized magnetic field pulse. (Since the coupling is magnetic, it is not shielded by most materials placed between the pen and the tablet). The writing surface contains a number of thin winding layers in a laminated structure . . . There are as many layers as there are address bits, each developing a positive or negative induced voltage as a function of the pen position." (Lewin, 1965, p. 832.)

4.32a "The initial goal of the Design Augmented by Computer project was the development of a combination of computer hardware and software which (a) would permit 'conversational' man-machine graphical communication and (b) would provide a maximum programming flexibility and ease of use for experimentation. This goal was achieved in early 1963." (Jacks, 1964, p. 344).

"The IBM 7960 Special Image Processing System was designed and built by IBM to specifications provided by the General Motors Research Laboratories. The system is the man-machine and image processing hardware for the GM Research DAC-I System." (Hargreaves et al., 1964, pp. 384–385).

"The DAC-I System for design augmented by computer at the General Motors Research Laboratories . . . facilities sketching and designing on the cathode-ray screen. It provides on-line access to large, computer-processible files of 'blueprint' information. Automobile components designed through DAC-I are now on the street." (Licklider, 1967, p. 9).

"Of considerable historical interest, a program which roughly paralleled the M. I. T. work has been carried on independently at General Motors since about 1959. It was kept in complete secrecy until its disclosure in the fall of 1964." (Prince, 1966, p. 1698).

4.33 "It is possible, in conjunction with the light pen and a suitable program, to read to progressively greater levels of detail in an area of interest selected by the light pen. Looped playbacks of the successive reads on a visual scope can be enlarged to reveal discrete points. It is possible to apply the differential principle in reading around curves in order to produce a center line of high quality. It is also possible to recognize patterns of objects, and to combine code-generated pictures, computer-controlled visual input and light pen visual input in a single operation. The recorded output of the computer can be stored on film and read back into the computer visually at any time. Overlays can be quickly accomplished on standard maps by reading the maps with the computer-controlled CRT reader and combining them in memory with elements to be displayed. The result can be put out on film. . . .

"A computer-controlled television camera is a general-purpose visual input device capable, when properly programmed, of reading any gauge or instrument panel or observing an experimental situation and, through its computer, controlling it rapidly. . . .

"Several computer programs have been written to permit an operator to perform drafting using the visual scope and the light pen. The computer-controlled CRT reader enhances this operation by permitting the introduction of photographs and drawings." (Fulton, 1963, p. 38, 40).

4.34 As examples of current hardware capabilities for this purpose we note the following: "A new photographic data processing system which will speed post-flight analysis of photographic data . . . was developed by David W. Mann Co. . . . The new Microdensitometer system . . . measures the position (in two coordinates) and the relative lightness or darkness of micron-sized images while scanning photographic plates at rates up to 625 millimeters per minute." (Data Processing Magazine **7,** No. 2, 40 (1965).)

"A new, low cost method of input to computers of diagrams, drawings, and photographs has been developed by D-Mac Ltd. The device, the Pencil Follower, allows outlines to be traced and converted to computer input, or entered on cards or tape for subsequent processing on a computer." (Data & Control **3,** 32 (1965).)

"The imagery . . . was processed in IMITAC (Image Input to Automatic Computer), a specially constructed scanner which converts images to computer language, and can also convert computer output to images. The Philco IMITAC can scan a 3-by-3 inch image with a 1024 line raster, each line being sampled at 1024 points. An analog-to-digital converter encodes the photographic density to 64 levels. This 6-bit code is then transferred to the UBC (Universal Buffer Controller) of the Philco 2000 computer system, and then to magnetic computer tape." (Kanal and Randall, 1964, p. D2. 5–5).

4.35 "The input data for a given compilation is in the form of a pair of aerial photographic transparencies together with pertinent camera data; i.e., position and attitude of camera for each transparency, focal length of camera and distortion characteristics of the lens." (Bertram, 1963, p. 105).

4.36 "We have constructed a scanner system that will look at a resolution element 1/200 inch on a side, that will assign one of eight gray levels of light density to each element, and that will put the information in a systematic way on a standard magnetic tape. We have computer programs that will then manipulate the information contained on the tape. We can display it by means of a pictorial printout; we can list the actual density values for any area of interest." (Moore et al., 1964, p. 927).

4.36a1 "Aeronutronics Div. of Ford Motor Co., has ordered a Digital Equipment Corp. PDP–7 to use in an experimental film-scanning operations. They plan to mechanize and automate many steps in detecting and analyzing the data contained in aerial photographs." (Data Proc. Mag. **7**, No. 7, p. 12 (July 1965).)

4.36a2 "The system for automatic photointerpretation in Karlsruhe, which is still under development, will be used for scanning and preprocessing negative films such as aerial photographs, bubble chamber photographs or X-ray photographs without any restriction as to special structures of the pictorial information. Aerial photographs will be the chief subject of investigation, since they have the most general structure." (Kazmierczak and Holdermann, 1968, p. 45).

"Considerable work has been done on the simplification of the information content of aerial photographs by, e.g., successive processes of averaging and differentiation." (Rosenfeld, 1965, p. 114).

4.36b "The digital filters are designed to produce silhouettes on the basis of broad target and/or background characteristics but not to depend on specific target shape or configuration. Every silhouette produced represents a possible target and is individually tested as such in a final stage recognition system. . . . The generated silhouettes not only include a large number of nontarget shapes which must be reliably rejected to achieve a satisfactory false alarm rate, but may also include imperfect silhouettes of targets which must be reliably recognized as such. Some noise effects are inevitable, but consistent imperfections are not noise as long as nontargets do not also generate silhouettes similar in characteristic to those generated by any target." (Holmes, 1966, p. 1681).

"The CAL [Cornell Aeronautics Laboratory] Flying Spot Scanner . . . can sample a 3″×3″ photographic transparency with a spatial resolution of 1024 × 1024 sample points with better than 95% independence and with a density resolution of 64 levels of gray. Of particular value to this research is the fact that the scanner can sample the pattern scene transparency in a random-access fashion, under control of our IBM–7044, so that it can sense directly those portions of the scene required by the object extraction process. . . .

"In research reported earlier by Trabka and Roetting objects in a complex scene are located by performing an optical cross-correlation of the pattern scene and an aperture filter of the shape of the object to be located. This technique locates the desired object in the object scene, but it does specifically define its boundaries or extract it from the scene. However, the technique is very fast, as it can process a whole scene in parallel, and is very tolerant of changes in shading in the interior of the object, since it detects objects by the shape or their edges." (Muerle and Allen, 1968, p. 5, 3–4).

4.36c "A prototype *M*ap *An*alysis *S*ystem (MANS) has been developed as an experimental first approximation to . . . a general picture description system." (Pfaltz et al., 1968, p. 361).

"Within the geographical profession, the map is the traditional data-storage and nomographic-analysis device. These two functions of the map are being 'computerized' as rapidly as is economically feasible. The theoretically more important use of the map as a 'hypothesis-generation' device would require a computer that can read—that is interpret and not just scan—maps. In spite of intensive efforts on the part of the military to develop an automatic photointerpretation capability, the results fall largely into the category of data reduction rather than pattern recognition. For this reason maps remain an oft-desired output format. The art of computer mapping has been developed fairly extensively using offline printers, graphic plotters, and cathode ray tubes to produce statistical atlases, contour-like maps, and so on." (Tobler, 1967, pp. 57–58).

4.36d "The bubble chamber is one of the most versatile tools for high energy physics research. It is used to detect the passage of particles and to measure their trajectories, momenta and velocities. Nuclear events are produced by the interaction of beam particles from the accelerator with nuclei of the chamber medium." (White, 1968, p. 175).

"Charged particles which pass through the chamber during the sensitive period of its expansion cycle cause formation of strings of bubbles along their trajectories, with bubble density determined by the particle velocity. A magnetic field is present to allow particle momentum to be measured by the radius of its trajectory. Generally three cameras photograph the bubble chamber during the sensitive period of its expansion cycle, so that by intercomparison of views a space reconstruction of particle tracks can be made." (White, 1967, p. 175).

4.37 "Dr. Bruce McCormick has proposed a scanning technique which allows rapid recognition, separation and measurement of the photographic records of star type nuclear events. A device known as the Spiral Reader measures background and star type event features impartially, discriminating against non-radial patterns by the geometry of its rotating scanning element. The event measurements are separated from the background measurements by an IBM 704 computer under the direction of a program called FILTER. The separated nuclear event measurements are subsequently reconstructed in space for physics analysis." (Innes, 1960, p. 25.)

4.37a "Visual input to the computer enters through flying spot CRT scanners: two for 70-mm film, two for 46-mm film, two for 35-mm film and two for microscope slides. Two modes of raster scanning are provided: *raster mode*, where cell-by-cell the image is encoded uniformly in 1, 2, 4, or 8 bits of gray scale; and *coordinate mode*, where each black/white transition triggers the readout of 16 bit X(Y) coordinates. Raster mode is the normal recognition scan input; coordinate mode is primarily reserved for precision measurement purposes." (McCormick et al., 1966, p. 359.)

4.37b "Because the part [i.e., design component] can be rotated to any position in space, lines can be drawn directly in three dimensions by drawing in a plane. The part is rotated until the area in which the line is to be drawn is parallel to a viewing quadrant. The line is then drawn true length; the depth coordinate remains constant as the pen moves across the plane of the scope screen. Specification of the single depth coordinate is done by program interpretation . . . This program, called the Pen Space Location program, is the backbone program of three-dimensional sketching. Sophisticated drawing is made possible by this program." (Johnson, 1963, p. 350.)

It is noted, however, that "general three-dimensional graphical communication, which deals with arbitrary surfaces and space curve intersections, presents many difficult problems; the beginning has been modest and much work remains before the complete graphical communication problem is solved." (Johnson, 1963, p. 347.)

4.38 "Sketchpad has been extended to three dimensions by Johnson. In Sketchpad III, the user can add a line to a plan and have it appear simultaneously in the front field, the side view, and the oblique representation. When he rotates the oblique representation, the orthogonal views change appropriately, etc." (Teitelman, 1966, p. 11.)

4.39 "The only work I know of on machine depth perception is that on binocular images. Julesz has reported a procedure which shifts the binocular pictures to find the areas at different depths. This procedure uses only texture, not edges, to develop the depth information . . ." (Roberts, 1965, p. 161.)

4.39a "It is possible to obtain a spatial derivative of the scanned image which simultaneously rejects those parts of the original image which are out of focus and preserves the boundaries where the value of the derivative exceeds some threshold." (Lipkin et al., 1966, p. 1006.)

4.40 "Special equipment developed by the Electronic Systems Laboratory at M.I.T. makes it possible to draw with the light pen a three-dimensional object and display its projection on the face of the cathode-ray tube just as if the objects were continuously rotating in three dimensions under control of the viewer." (Fano, 1967, p. 31).

"Another device that is in many ways superior to the light pen and RAND tablet is the Lincoln WAND*. It uses 4 ultrasonic transmitters and one receiver to obtain digital delay measurements that determine the stylus position, and can operate over a working area four feet square with a resolution of 0.02 inches." (Coggan, 1967, pp. 73–74) [Ref. to Roberts, 1966]

"The Wand is an interesting development presently being tested at Lincoln Laboratory for inputting three-dimensional data to the display. Four acoustic transducers located around the periphery of the display transmit pulses which are detected by a microphone in the wand. Counting circuitry measures the four distances which are converted into xyz display coordinates by the computer." (Prince, 1966, p. 1699).

"Research continues actively in the areas of new input devices and display media. The Lincoln WAND, described by Roberts at the FJCC, allows the operator to position a hand-held ultrasonic receiver in three-dimensional space. The sensor receives signals from four transmitters aligned in in a plane near the scope face and allows the computer to resolve its position in three dimensions. Thus, the 'menu selection' area used for pointing at program alternatives can be significantly increased from that of the two-dimensional scope face used with the light-pen. In addition, three-dimensional 'drawing' can be simulated." (Van Dam and Michener, 1967, pp. 197–198.)

"The well-known 'light pen' or 'light gun' has been used since the early 1950's as a mechanism for drawing or pointing on the face of a CRT. Roberts describes the so-called 'Lincoln WAND,' a related device for pointing in three-dimensional space. The pointer contains a microphone, which detects pulses from several ultrasonic transmitters in the vicinity. The result is a sort of small-scale ultrasonic LORAN (Long Range Radio Navigation) which is already good enough to give a positioning accuracy of about two-tenths of an inch. A few suggestions are given as to the importance of adding a third dimension and considerable spacial freedom to conventional pointing schemes. A final item of display hardware is the Stratton description of a novel replacement for the conventional light pen. The general idea involves direct detection by the 'pen' of the CRT electron beam rather than of the light emitted when it strikes phosphor. Stratton's paper describes the hardware in intensive detail and will be of greatest interest to other hardware designers and implementers." (Mills, 1967, p. 232.)

4.41 "I would estimate that within the next two decades a three-dimensional scanner will be available that will describe the shape of an object in terms of a grid . . . which can be as fine or as coarse as the investigator desires. The object would be placed between two such grids, and where the beam could pass between two parallel points of course the object would not be in between these points, and where the beam was reflected back the distance on either side would be calculated, and the difference would be the thickness of the object at that point." (McDonough, 1964, pp. 34–35.)

4.42 "Three dimensional x-ray photographs are being produced . . . by the Giannini Controls Corp., . . . to see the distance between component leads in a potted module . . . also has medical applications. For example, it has been used to determine the depth of a bone infection." (Electronics 37, 26, 1964.)

4.43 "Ford is reported to be using a light-scanning measuring machine, built by the Ex-Cell-O-Corp., to inspect clay mock-ups for X (length), Y (width) and Z (height) coordinates . . .

"Ranging circuits in the scanning machine measure the light's travel time, convert it into distance from the source, and feed the data into a cardpunch." (Gomolak, 1964, p. 66).

4.44 "The method records the light's electromagnetic field exactly as it existed, so that the images it regenerates are three-dimensional images indistinguishable from the original scene . . . on the fringes, three-dimensional television." (Stroke, 1965, p. 53).

4.44a "This paper is involved with one aspect of the pattern recognition problem, namely, that of qualitative pattern recognition. A pattern recognition problem is qualitative if certain transformations of the pattern are either the end result in themselves or are necessitated for ease of further processing or recognition. One can extract partial information (both qualitative and quantitative) about the pattern through such transformations. . . .

"The transformations of interest cannot, in general, be expressed in terms of known mathematical transformations. Even if such transformations were found, it may not be presently possible to obtain the corresponding physical realizations. For these reasons, qualitative pattern recognition will be a challenging area of research in future, both in terms of new mathematical tools and new physical components." (Hemami, 1968, pp. 1–2).

"Although qualitative pattern recognition has not been emphasized, there are numerous applications of these techniques to qualitative problems. For instance, the techniques could be used to accentuate specific features on contour maps, such as regions with steep slopes or regions which are nearly level. Another application is compact information transmission of graphical forms. Since the transformation technique reduces the information content of a contour or graphic representation to a compact form, it is ideal for information transmission. Two other potential applications include analyses of handwriting and recognition of signatures. The representation of a signature's boundary by Fourier harmonics presents especially interesting possibilities. The areas of filtering and smoothing also offer many possibilities for applying these techniques." (Brill, 1968, p. 9).

"Most of the applications of optical systems to qualitative pattern recognition deal with transformations that directly involve spatial frequencies. Many other simple transformations that are useful in qualitative pattern recognition are not well understood, and cannot be realized by simple optical systems. A few of such transformations are noted here.

1. Interpolation and extrapolation, elimination or retainment, rotation and translations of specified lines and curves in a pattern.
2. Increasing or reduction of thickness (width) of a pattern in a specified direction or vicinity.
3. Separation of superimposed patterns with overlapping spatial frequencies.
4. Nonlinear transformation such as clipping, thresholding and clamping the pattern amplitude for which simple analog realizations do not yet exist.
5. Transformation from defined shapes to other shapes such as simultaneous mapping of triangles into circles and squares into ellipses in a pattern consisting of a number of triangles and squares.
6. Conformal transformations." (Hemami, 1968, pp. 6–7).

4.45 For example, "the program may be commanded from the typewriter to analyze a complex scene. Such a scene may consist of *known items*, i.e., shapes which have been defined as being significant (the alphanumeric characters); and of other items, some of which may be significant to the viewer but not to the system, and some of which may be merely background 'noise'. An arbitrary number of known items may be present simultaneously; they may be of different sizes and orientations; they may overlap, or be inside each other; they may be super-imposed on an arbitrary background." (Marill et al., 1963, p. 28).

4.45a "In dealing with . . . a photograph, conventional techniques of shape and pattern recognition are not directly applicable, since there is no natural distinction between figures (= shapes or patterns) and background in the photograph. . . .

"Statistical analysis of the input image . . . is used to determine the boundaries of the conspicuous figures which the image contains and to generate a simplified description of the 'visual texture' of various parts of the image. . . .

"An arbitrary point pattern (or figure made up of straight lines) is determined if certain lengths of line segments or angles between them are specified.

More generally, an arbitrary shape is determined by specifying the curvature of its boundary as a function of arc length." (Rosenfeld, 1962, p. 114).

"What makes picture processing a subject in its own right is that it deals with pictures which are not merely arbitrary functions or matrices, but which are pictures *of* something—which purport to represent a real scene (terrain, microscope slide, . . .) or an ideal symbol (such as an alphanumeric character)." (Rosenfeld, 1968, p. 1–10.)

"Experimental work . . . suggests that . . . detailed contrast frequency analysis provides enough information about the visual texture of the image to make possible the automatic identification of many basic terrain types." (Rosenfeld, 1962, p. 115).

"The extraction of conspicuous figures from the photographic image also involves the concept of visual texture, since the boundaries between adjacent areas having significantly different textures will define such figures." (Rosenfeld, 1962, p. 115).

4.45b "A two-level statistical classification procedure has been applied to the problem of detecting complex targets in aerial photography. At the first level, a set of classification functions designed on the basis of samples from the target class and from other images is used to make subdecisions on local-area statistically-designed features associated with the target class. At the second level these subdecisions are combined into a single decision as to the presence or absence of the target. The nature of the data does not allow for the direct application of classical methods of multivariate discriminant analysis; rather, modifications of classical methods are used. This procedure has been simulated on a digital computer with the aid of a special input-output device which converts imagery to computer language." (Kanal and Randall, 1964, p. D2.5–1).

"Thus the imagery screening system consists of (a) a high-speed flying spot scanner, (b) a Laplacian preprocessing stage that converts the video to binary data, (c) a shift register correlator with statistically designed coefficients, and (d) the final decision logic. The result is a machine that can rapidly search large amounts of photography and reliably detect a variety of tactical targets in any position. . . .

"The work described here and other related efforts lead to a (preliminary) conclusion concerning the relative merit of some competing design approaches. For the identification of small targets in aerial survelliance photography, the two-layer statistical classification method based on local-area statistically designed features and using Laplacian pre-processing is far superior to the 'random-mask' methods used (at least in the past) in Perceptrons and other 'trainable' networks." (Kanal and Randall, 1964, p. D2.5–7).

4.46 "The first step taken by ANALOGY is to decompose each problem figure into 'object' (subfigures) . . . While a decomposition program of the full generality desirable has not yet been constructed, the most recent version of the program is capable, in particular, of finding all occurrences of an arbitrary simple closed figure x in an arbitrary connected figure y; for each such occurrence the program can, if required, separate y into two objects: that occurrence of x and the rest of y. . . .

"Next, the 'objects' generated from the decomposition process are given to a routine which calculates a specified set of properties of these objects and relations among them . . . [e.g.,] that the object labeled P2 lies inside that labeled P3 and generates a corresponding expression . . ." (Evans, 1964, pp. 329–330.)

4.47 ". . . We are now able to begin serious study of the most difficult problem facing the project: The analysis of real-world three-dimensional scenes." (Minsky, 1966, p. 12).

"Programs have been developed to read selected parts of the visual scene, analyse them for parts of polygonal objects, and then transform them to real-world coordinates. The present programs are still rudimentary, and their extension is vital to the project." (Minsky, 1966, p. 16).

"Our goal is to develop techniques of machine perception, motor control, and coordination that are applicable to performing real-world tasks of object-recognition and manipulation." (Minsky, 1966, p. 11).

"The sensory equipment includes two visual-input devices. TVA, a vidicon television camera, and the more precise TVB, an image-dissector device for controlled-scan analysis." (Minsky, 1966, p. 13).

4.48 ". . . The problem is to make measurements on a curve . . . Since the lines are thick, the measurements must be made from points in the middle of the lines." (Ledley et al., 1966, p. 79).

"The transform of a pattern consists of a locus, called the medial axis of the pattern, together with a function defined along this locus, which describes the exact shape of the pattern . . . The function . . . is the distance from the curve to the pattern boundary. The transform is generated by causing the pattern to shrink down in size, or equivalently by allowing the area outside of the pattern to propagate with uniform velocity into the pattern. The medial axis of the pattern is described as the locus of self-intersection of the propagating area." (Philbrick, 1968, pp. 395–396).

5. Preprocessing Operations and Pattern Recognition

5.1 ". . . Filtering for irrelevancy should be performed at the sensor site in most cases in order to reduce the demands on information transmission facilities." (Edwards, 1965, p. 148).

5.2 For example, in standardized OCR font readers being developed for European postal check handling and similar applications, Standard Elecktric Lorenz and Telefunken use infrared-range scanning, while Olivetti has a prototype reader under development using ultraviolet. "In general, use of the infrared range makes interferences from fountain and ball-point pens, colored pencils, office stamps, colored paper, and finger smudges tolerable, while materials containing carbon or graphite have a reflectance similar to printing inks and thus cause trouble." (Dietrich, 1965, p. 319.)

5.3 The technique of carrying analog gray-scale values rather than quantizing early in the recognition process is associated first with Taylor (1958, 1959, 1960).

5.3a ". . . We find almost universally that the very first operation after linear amplification of the video signal obtained from the scanning process is a 'black-white' clipping. From the detection point of view, this nonlinear process irretrievably rivets the noise to the signal, and now all kinds of logical acrobatics are required to save the situation." (Nadler, 1963, p. 814). See also Hart (1966) p. 17.

5.3b "If there is a contrast boundary at the scanned point, the preprocessing of the scanned information consists in computing the gradient of the contrast. If there is no contrast, only the grey value in this location will be measured. While the grey value can be measured on a scale of 64 levels, the contrast gradient will be measured on a scale of 40 steps in a 360° range with an accuracy of ±4.5°." (Kazmierczak and Holdermann, 1968, p. 49).

5.4 "It is well known that, due to diffraction effects, the image of a point source produced by a convex lens is surrounded by the Fourier transform of any aperture placed in the plane of the lens. If this aperture is a photo-transparency then the image plane contains the Fourier transform of any pattern in the transparency. The spatial frequency components of the pattern are displaced radially about the optical axis, displacement increasing with spatial frequency. Opaque stops can be introduced into the image or Fourier plane to suppress selected frequency components, an image of the aperture pattern is then transformed according to the transfer function defined by the stops. The Fourier transform, being, in effect, a modified image of a fixed point source, is independent of the position of the pattern in transparency, and hence also of any part of the pattern so that patterns may be processed without precise location, alternatively several patterns may be processed simultaneously. If the low frequency components of the Fourier transform are suppressed areas of sensibily constant density in the pattern are eliminated and an outline effect is obtained; the suppression of high frequency components reduces fine granular noise and fine structure. By the use of appropriately shaped stops a large range of transfer functions can be obtained and this technique may conveniently and economically be used to preprocess patterns before more elaborate analytical processes are applied. The operation of spatial filtering of optical signals (patterns) is directly analogous to electrical filtering of electrical signals but performed in two dimensions. The concepts of bandwidth, frequency and rejection or pass bands are directly applicable. Since, in the Fourier plane frequency increases with distance from the optical axis, a circular axial stop will reject the d.c. and low frequency components of the pattern. A circular axial aperture will reject high frequency components. Clearly an annular aperture will pass only middle frequencies.

"The collimated output from a laser, after passing through a phototransparency, is brought to a focus by lens L_1. This focal plane contains the Fourier transform of any pattern in the transparency. The plane containing the transparency is itself imaged, again by L_1, onto the photocathode of a television camera. The video signal from the camera could then be input to a pattern processor/analyser proper." (National Physical Laboratory, n.d., pp. 2–3).

5.4a See Moore (1968), as follows: "STRIP–3 provides for the use of a number of different raster sizes appropriate to pictures in most net print sizes from 30 millimeters up to 24 × 24 centimeters. All images used in any one run of the program must however be of the same size. In the anticipated machine configuration, a minimum of two '8 × 10 inch' (24 × 19 cm) binary phase images can be held in the active memory, while up to 8 binary images in '4 × 5 inch' or smaller size can be retained and processed in combination. Logically modified images can be stored without destroying the originals. Where operations directly upon the multiple level density scale may be necessary, these are accomplished by logical combinations of binary images representing the 8–4–2–1 or 4–2–1 bits of the density characters. While this method appears indirect, it is in fact several times faster in operation than the arithmetical methods which would of necessity be performed one gray character at a time . . .

"A . . . powerful series of image transformations are accomplished through the use of 'BIT OPerations'. These are processes in which new image bits are determined for each raster point as a function of both their original value and the value of each of the eight neighboring bits. Thus individual points of the image can be classified as being within the body of particles, in specific edge positions, or in isolated situations . . ." (Moore, 1968, pp. 287, 296).

5.4b "In the case of two-level pictures, such as printed matter, the entire image can be reconstructed from the contours. For pictures with a continuous tone scale the contour information can be used to reconstruct the high frequency component of the complete picture. In either case efficient coding of the contour data is essential. Since the contour is by nature a highly connected set of points advantage may be taken of the inherent correlation to reduce the total required channel capacity." (Schreiber et al., 1968, p. 1).

5.5 "Most approaches to preprocessing can be classified as either attempts to reduce the dimensionality of the sample space or attempts to build up a description of the samples by isolating features. The former approach, which is usually analytical, suffers from the use of narrow assumptions which severely restrict the applicability of the results. The latter approach is usually based upon intuitive considerations." (Hart, 1966, p. 29.)

He suggests further that "one might first try to isolate a number of features and then use a dimensionality-reducing technique to condense the description of the pattern further. This combined approach is, in fact, not often seen, and perhaps deserves closer attention." (Hart, 1966, p. 4).

5.5a "Many measurements which seem otherwise very useful in discriminating printed characters are sensitive to line width—certain first order autocorrelation measurements, for example. One technique for filtering this out has been designed by H. B. Baskin at our Laboratory. It utilizes a combination of local analog and binary operations on the video signal from a scanner to reduce line width variations." (Andrews, 1962, p. 291).

5.5b See also the following:

"Although large character size variations might be considered as font variations, it is worth considering them separately since it is possible to filter them at an early point in a recognition system by automatically varying magnification. What seems to be the simplest way to accomplish this is to vary the scan resolution of a CRT type optical system in response to previously sensed average character height." (Andrews, 1962, p. 290).

5.6 See note 2.7a.

5.7 "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 1½ inches wide to determine where this last address 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." (Stevens, 1961, p. 56).

"The work done by E. Milbradt and J. Bauldreay in solving registration problems for the recognition of mail addresses utilizes the edge of the character as a datum line for decision making. A preliminary reading is made to obtain a registration error. This error is fed back to correct the optics such that the character placement is correct at the second reading station. Pre-biasing is also established to take advantage of *a priori* knowledge of character drift along the line." (Stein, 1965, misc. notes).

5.8 "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 . . . may also arise where any input pattern, or input pattern element, determines the selection of succeeding elements of the source pattern. 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." (Stevens, 1961, pp. 56–57).

5.9 ". . . The probability with which the various elements may be black or white can be determined by examining them in relation to their neighbors. . . .

"The analog image signal . . . consists of about 500 picture elements per character and is converted by a trigger amplifier into a digital black and white image. Noise due to imperfect printing is reduced by comparing each picture element with its neighbors and subsequently the appropriate form elements are detected by line following, whereby character height serves as a relative dimension. In parallel with this operation the automatic reader determines the size of each character along with its position in the scanning field, and compares it with limit values." (Gattner and Jurk, 1963, pp. 392–393).

"The commonly used spatial filtering techniques are differential or edge enhancing, filtering, and lowpass filtering . . . Lowpass filtering smooths data, for example, by replacing each matrix element by a weighted average of itself and the surrounding eight elements." (Hankley and Tou, 1968, p. 421).

5.10 "A 'noisy' picture can often be effectively 'smoothed', or an unsharp picture 'enhanced', by a single neighborhood operation which takes a local average or computes a finite-difference Laplacian. Similarly, a picture which contains thick 'roads' (lines or curves of points having given values) can be 'thinned' by iterating a 'border element deletion' operation, perhaps alternated with a smoothing operation, where the number of iterations required is relatively small since the roads are narrow compared to the picture size." (Rosenfeld and Pfaltz, 1966, p. 473).

"Edge differentiation may be used to obtain more accurate area values, and the tone scale may be enhanced or corrected if the original transcription is inaccurate." (Moore, 1968, p. 285).

"The procedure we have implemented ('STRIP') . . . results in an object which consists of

(i) arcs: connected sets in which all points have exactly two neighbours in the object

and

(ii) nodes or nodal regions: 'tips' consisting of single points with one neighbour only, and 'nodes' in which each point has more than two neighbours." (Rutovitz, 1968, p. 127).

"Two-dimensional filtering with nonlinearities introduced can produce interesting and useful results. The necessity for nonlinearity precludes optical processing for the present and makes the digital computer a unique tool for research, and probably an essential element of a final system.

The scope available for further research on two-dimensional, nonlinear, digital filters favors continued work in this area. The work should concentrate in three fundamental regions.

(1) Filters to define and measure the orientation of low-curvature contours. Initially, nonnoisy contours should be studied but, ultimately, the straight but locally irregular contours, characteristic of the boundaries of wooded areas adjacent to cultivated land should be included.

(2) Filters to incorporate texture as well as amplitude distribution continuity in an extension of the K–S filter approach.

(3) Processes to assemble silhouettes fragmented by shadow effects and close the gaps created. The processes may take advantage of proximity, edge alignment effects, or target size requirements (that is, assembling proximate silhouettes to make silhouettes of approximately the correct size)." (Holmes, 1966, pp. 1685–1686).

5.11 "Classification or the arrival at a category assumes a matching or near-matching of something with something, or the failure to achieve such a matching . . . data-reduction processes reduce things that are non-matching in detail to things which are matching in some overall aspect. In some sophisticated types of pattern recognition, matching or near-matching within tolerance is done only after considerable data reduction has taken place." (Minot, 1959, p. 11.)

"Reliance is normally placed on differences in color or tone density, or on general logical processing, to eliminate features for which measurements are not desired. The numerous parameters measured for individual particles or objects may, when appropriate, be used in suitable combinations to classify the measurements into groups pertinent to single classes of objects. Such edited data may then be used to compute summary information on individual classes of objects." (Moore, 1968, pp. 324–325).

"The effectiveness of a recognition system will depend upon how well the significant differences between pattern classes are characterized by the prescribed set of measurements, and the accuracy with which the decision criterion categorizes the pattern measurements." (Greanias et al., 1963, p. 14).

"Thus, the problem of feature selection consists of three parts as follows:

1. To find criteria for measuring the separability of pattern classes.
2. To evaluate the effectiveness of each feature or each mapped feature to the criteria.
3. To find the mappings which allow us to use smaller dimensions, keeping the criteria at certain values." (Fukunaga, 1968, p. 1).

5.11a "The purpose of data analysis is to extract those features most valuable for discrimination among the allowable characters; i.e., those features which have consistent values over variations of a particular symbol, yet which have different values for different symbols." (Groner, 1966, p. 592).

"The total number of features is not necessarily the most critical consideration. The reliability with which these shape features can be detected in all significant type fonts is much more important, and will probably be the subject of much additional work in the development of multifont and handwritten character readers." (Greanias, 1962, p. 145).

5.11b "The main purpose of feature-ordering is to provide, at successive observations, the feature which is most 'informative' among all possible choices of features, for the next observation." (Chen, 1966, p. 552).

"The importance of utilizing measurements of the order of encountering points as one traverses the branches of a pattern is especially pointed up by the comparison of the results obtained with the Highleyman data. . . . Closely associated with the point-ordering feature is the use of topological data." (Minneman, 1966, p. 95).

5.12 Some examples of stroke direction analysis techniques are provided in Shepard's 1953 patent for an "apparatus for reading". Bomba (1959) used local operations to extract horizontal and vertical lines, slanting lines at various angular displacements from the vertical, and selected orientations of F-, L-, and V-shaped line intersections.

Selfridge (1955) and Dineen (1955) were early exponents of property filtering techniques to select significant features such as edges and corners. In 1966, at the University of Naples, a pattern perception study involves use of a curve analyzer to detect maximum and minimum inflections and the investigation of coding into a discrete number of symbols of scanned line connections, corners, and other characteristic features. (Stevens, 1968, p. 17).

Rochester et al. (1959) claim with respect to the "lakes" and "inlets" method that "the use of mathematical topology is 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." Further extensions of this technique are exemplified by Kamentsky (1962), Schultz (1963), and Sublette and Tults (1962).

5.13 "The main concept of the system is the use of a collection of programmable pointers, which are visualized as a family of 'bugs' . . . the PLACE statement initiates or sets up a bug by assigning a name and initial coordinates to it . . . The MOVE statements move the bug a specified distance (i.e., number of spots) in either the x or type y directions . . . A series of statements . . . TEST the grey-level value of the picture at the location of the bug . . . A bug's grey-level may be changed in statements that are particularly useful for 'thick line' analysis are the STICKs. If a bug wishes to walk along the middle of a 'thick line', these statements will readjust the bug location to the 'middle' . . .

"Bugsys can be used for any types of applications . . . (including the analysis of photomicrographs of neuron dendrites and . . . processing of Schlieren photographs taken for molecular weight determination when using ultracentrifuges." (Ledley et al., 1966, pp. 79, 81–82.)

"The x- and y-coordinates of the curve are measured by taking the distance between bugs AA and origin for x and the distance between bugs AA and BB for y." (Ledley et al., 1966, p. 83).

5.13a "The processing of pictorial information contained in aerial photos has been considered in detail." ("Technische Hochscule, Karlsruhe, Research on Pattern Recognition . . ., 1966, abstract, p. 1).

"A system development consists of special scanning and preprocessing devices for pictorial data is going on. The scanner and preprocessor combines analog and digital techniques. The scanner is realized as flying spot scanner. The scanning modes are controlled by a computer Control Data CD 3300. The processor generates directions of contour gradients, grey shades, contour coordinates and other line elements." ("Technische Hochscule Karlsruhe, Annual Report 1966", 1967, p. 52).

"The Karlsruhe system for automatic photointerpretation is a scanning and preprocessing system under computer control." (Kazmierczak and Holdermann, 1968, p. 47).

5.13b "There are other methods currently in vogue in the field of character recognition for eliminating the effects of such distortions as stretching, skewing, magnification, etc. Many of these may be referred to as 'feature detection' methods, although they variously go by the names: n-type detection, zoned n-tuples, stroke detection, lakes and bays, etc." (King and Tunis, 1966, p. 70).

5.14 The phraseology, "autocorrelation techniques for pattern recognition", is in a sense ambiguous and misleading. Target pattern *identification* operations in these techniques (whether applied to printed character characters or to spoken numerals or words) are as much dependent upon cross-comparisons and cross-correlations of the input pattern with the set of available *reference* (or master) patterns as in other techniques. The point is rather that, in the autocorrelation techniques, the transformations performed upon the source pattern to generate the input pattern or further to process the input pattern depend upon autocorrelation functions of the source pattern as it is variously manipulated in order to extract those criterial features or properties that are to be used in the recognition-decision process.

5.15 In particular, a multi-layer hierarchical system is currently under investigation that applies some of the original ideas of auto-correlation but no longer integrates. Instead, both positive and negative copies of the input image are superimposed and shifted in various directions and with special screens to provide mappings that discriminate criterial features. In the second level of operations, coincidences are detected for relative dispositions of the features in the characters making up the alphabet. For example, "h", "u", and "n" will have the same parallel-verticals feature, the possibility of "u" will be eliminated by the mapping for curves, and a long-ascender feature will show "h" rather than "n", or, conversely, the negative of the long-ascender will detect "n".

It is to be noted that the input image may be a *sequence* of characters, such as a complete word of text, with or without spacing between its characters. Thus, prior segmentation is not required since in effect, the technique scans the text through a moving aperture, and checks continuously for specific groupings of local features that will identify the characters, one by one. In this connection, simulation experiments have been run on computer for all possible pairs of 10 alphabetic characters with no space between them, detecting 12 different local features in the first level of operations and 4 different possible definitions for each character at the second level. While false recognitions occur (e.g., two quantized "o" 's detected at one stage as an "x"), the results appear promising. Further research will apply threshold requirements with respect to clumps of the most probable character values. Statistical data from tests to date is available as to the extent by which recognition improves as spacing or segmentation is introduced. (See Stevens, 1968, pp. 6–7 and Clayden et al., 1966).

5.15a "Characters may be recognized in terms of properties more abstract than geometrical features. For example, Giuliano, Jones, Kimball, Meyer and Stein (1961) and Alt (1962) have obtained the higher moments of patterns, blackness being analogous to mass; and Horwitz and Shelton (1961) and Clowes and Parks (1961) have used autocorrelation as a first stage of automatic recognition. Generally speaking, the output of the first (preprocessor) stage is a set of numerical values. It is often found expedient to multiply these values by weights in the decision process, and several methods for determining suitable weights are now well known. Statistical weighting was proposed by Selfridge (1955) and implemented for example by Doyle (1960) on results of fairly complicated geometrical tests. Following Roberts (1960), Duda and Fossum (1966) have experimented with a perceptron-type systematic trial and error method for finding weights, and also for finding more than one set of weights per character." (Ullmann, 1967, p. 256).

"Misregistration arises not only from the characters out of line on the document, but also from variations or instability in the doucument handling and optical equipment. A general method of eliminating such effects is to make use of measurements or transformations on the image which are invariant with respect to displacement within an allowed field. One such transformation which has been developed by several workers is first order autocorrelation. Its use with variations has been reported by G. L. Shelton and L. P. Horwitz of IBM, and by Clowes and Parks. Higher order autocorrelations involving products of three or more displaced images have also been studied." (Andrews, 1962, p. 288).

5.15b "Since the [Laplacian] function is determined by brightness derivatives rather than by brightness itself, it produces no output on large uniform areas. In the presence of line boundaries or corners, the output is high. Thus the function tends to outline objects and emphasize their contours." (Kanal and Randall, 1964, p. D2.5–4).

5.15c "Another application in which Hilbert transform filtering can aid the sensitivity of a processing operation that follows is in signal detection by optical matched filtering. By performing an operation on the input that is related to a differentiation, viz, a Hilbert transform, and the same transformation is made of the reference image or filter, then the matched filter performs, in effect, a derivative correlation. In this manner it is possible to achieve a high degree of correlation for a signal and a reference filter, even though significant differences in the low frequency noise content of the two may exist. There is the added advantage that, at least in the ideal case, no loss in signal energy is incurred as a result of the two transformation operations." (Haagen, 1968, p. 9).

5.15d "Of late, considerable interest has centered on the generation of the Fourier Transform of pictorial information, largely for the purpose of performing contrast enhancement and other types of selective filtering. To this end a number of algorithms have emerged—in particular, the 'fast Fourier Transform'—for producing digital approximations to the Fourier Transform on a computer. All of these are, however, basically of an off-line nature, since none of the algorithms is fast enough for real time applications, at least where standard video frame rates are concerned." (Poppelbaum and Faiman, 1968, p. 1).

"This paper describes an approach for transforming the exterior boundary of a character into a unique one-dimensional waveform. This waveform is neither sensitive to character orientation nor affected by scale, and it offers exceptional possibilities for implementation into recognition schemes. The waveform is expanded into Fourier series and the coefficients of the series are used as descriptors of the character. It is shown that certain recognition techniques, employing these Fourier descriptors, can be developed which eliminate or significantly reduce all the shortcomings mentioned above.

"These recognition techniques were simulated by discrete methods on a digital computer, producing excellent results in recognition experiments with both machine-generated and hand-written characters. However, in practice, real time analog systems are to be preferred over digital computations because, in general, they are faster and less costly. The design of real-time optical or electro-optical systems to achieve the analog of the above mathematical transformation poses challenging problems." (Brill, 1968, p. 1).

5.16 "The number of optical readers presently in use is estimated at 1,200 (200 being character readers), with a steady increase foreseen." (Auerbach Corp., Source Data Automation, 1967, p. 2–106).

"There are currently nineteen different scanning machines manufactured in the United States." (Bus. Forms Int'l., Inc., 1967, p. 1).

"There are five major competitors for a basic scanner business that is estimated at $100 million. The companies are the Burroughs Corp., Farrington Electronics, Inc., National Cash Register Co., Philco Corp., and the Rabinow Engineering Co." (Kornberg, 1964, p. 116).

5.16a "At present, there are 14 manufacturers in the business segment of the field, and a 15th, Scan Data in Norristown, Pa., which is believed to be staffed by ex-Philco-Ford personnel, is expected to have a hardware announcement later this year. In addition, Western Union is working on character readers, but these developments are still in the laboratory stage." (Drattell, 1968, p. 38).

5.17 "Farrington Electronics, Inc. . . . Model 3030 Page Reader reads multi-lined pages—as many as seventy lines per page." (Business Forms International, Inc., 1967, p. 8.)

"The Farrington Model 3030 is a machine that can read ledger or bond paper documents, or pages up to legal size. Each line of information to be read may contain up to 75 characters and spaces. Characters are read at the rate of 400 per second." (Business Forms International, Inc., 1967, p. 17.)

"The Rome Air Development Center, Information Processing Laboratory has the only page optical scanning equipment which reads both upper and lower case alphabetical letters, the numerals zero to 9, and punctuation marks for a total of 70 characters. This Optical Character Recognition equipment [Farrington] has been in operation in testing auxiliary research on lexical data handling for over two years." (Shiner, 1962, p. 335).

"And at Time, Inc., in Chicago, where two Farrington page readers and one Farrington document scanner are being used by the publishing company as basic input on all subscriptions (including new, change of address, payments), OCR is estimated to be 15 percent cheaper than other input sources." (Drattell, 1968, p. 36).

5.18 "The Electronic Retina Computing Reader presently is reading with a substitution or error rate of less than 1 error per 100,000 characters. To achieve this degree of reliability with keypunching would require 100% verification." (Perry, 1966, p. 132).

"The system consists of: A rapid index page carrier, an Electronic Retina and recognition unit, a Scientific Data system 910 computer, and two Ampex magnetic tape stations which are compatible with RCA. Hard copy is fed into the system,

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and the characters are read by the Electronic Retina. This hard copy, prepared with special typewriters developed for us by Olivetti, can be editorial text matter, classified advertising set solid, semi-display, display, legals, accounting data, or any other alphanumeric information. The Electronic Retina converts the typewritten characters and spaces into predetermined electrical impulses which are stored on magnetic tape. The magnetic tape, in turn, produces justified paper tape to drive the linecasting machines—either hot or cold type. Printed or typewritten copy is read up to the rate of 2,400 cps (approximately 28,000 words per minute)." (Perry, 1967, p. 86).

Text corrections can be accommodated as follows: "The typist then retypes the lines, or segments of lines affected by the changes, using a new piece of copypaper as a correction sheet. The correction sheet then is fed into the Electronic Retina ahead of the original copy which is to be corrected. The reader stores these corrections and its coded instructions concerning them in its memory system. Then, as the regular text comes in behind the correction sheet, the Electronic Retina's computer determines whether there is a correction in each line. If there is one, the Retina wipes out the original copy and accepts the corrected line, or lines, inserting the revised material until the correction is completed." (Perry, 1966, pp. 130–131).

"Another Electronic Retina Computing Reader, recently delivered to the Swedish Postal Bank in Stockholm, automatically processes part of the daily banking transactions for more than 500,000 account holders. Daily banking volume averages one to one and one-half million transactions, but sometimes reaches two and one-half million. The OCR system reads information from original turnaround documents, formats it, converts it directly to magnetic or paper tape, and prints out a list of specified information and totals to each account holder. The system processes 900 to 1,200 documents per minute, depending on their size and the number of lines read from each. Previously, daily transactions were handled manually for sorting, preparing totals, checking, and booking on ledger cards." (Philipson, 1966, p. 130).

Recognition Equipment, Inc.'s deliveries, beginning in 1964, now include use by a service bureau agency, the Data Corporation of Los Angeles (Business Automation **12,** No. 6, 86 (1965).)

5.19 "The Philco General Purpose Print Reader, which employs the flying spot principle, is a multi-font reader which can be programmed to read a variety of different type styles throughout a fixed customer installation. A good potential application would be an installation where there's a variety of different typewriters involved, with different fonts. This scanner will read up to 2000 characters per second and transmit this information directly from the document it has read onto magnetic tape units for later data processing functions." (Janning, 1966, p. 114).

"We have a no-compromise machine that takes advantage of the matrix technique. . . . Our character display . . . is a 680-element display which we believe is currently the highest resolution being offered in matrix type recognition systems. It combines feature recognition and template recognition. The machine has five common type faces . . . five [more] come at slightly extra-cost options." (Gibbs and MacPhail, 1964, p. 96.)

"The General Purpose Reader recognizes all of the common business font styles in upper- and lower-case alphanumeric, and symbols. Up to 10 fonts may be included in one machine." (Commun. ACM **8,** 255 (1965).)

"Cards or documents on paper up to legal size ($7\frac{1}{2} \times 13$) may be read." (Commun. ACM **8,** 255 (1965).)

Further, a New ERA Data Systems advertisement in the October 1966 issue of *Business Automation* said: "If you're an average reader you'll read this ad in just 34 seconds. Our Philco Reader read it—and put every word directly onto magnetic tape in 0.6 sec."

5.20 "Another possible application . . . of a page reader would be the ability to reduce proofreading. To take the original manuscript, read it into a type-composition system, through a page reader, set the type, make galley proofs, and compare these through a page reader with the original manuscript which was stored on discs or tape . . ." (Merz, 1964, p. 85).

"Additional areas of applicability of automatic character recognition techniques include the checking, verification, and proofreading 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." (Stevens, 1961, p. 15).

5.21 "When a scanner for ordinary typing becomes available at a reasonable price, the pages of an author's manuscript can be fed directly into the scanner, without retyping for conversion to magnetic tape. Colored pencil marks can be made at points where editing is desired." (Markus, 1965, p. 3).

"The potential advantages of a page scanner are:

1. The input keying of the library surrogate can become decentralized. The elements of the surrogate can be typed on a document 'traveler' and added by one station after another, the final station performing the final editing on the surrogate." (Wishner, 1965, p. 240).

"One method of cost reduction that looks promising is the use of multiple remote scanning equipment to feed a single recognition logic assembly. Thus, if a user has only a small number of documents to be read, a simple device can scan the documents, transmit this video information to a central processor or to a magnetic tape recorder." (Rabinow, 1966, p. 24).

5.22 ". . . The IBM 1975 Optical Page Reader (which is installed at the Social Security Administration). The 1975, with a contour pattern recognition process controlled by an IBM/360 model 30, can recognize characters in more than 200 different type faces, and probably in wellblocked handprinting. Reading 650 lines a minute from a standard Social Security form, it can read and record in eight hours what a keypunch operator can produce in 100 days." (Van Dam and Michener, 1967, p. 189).

"The Page Reader system processes the employee earnings at a rate equal to 120 to 150 keypunch operators with an equivalent or better error rate." (Hennis, 1967, p. 2.)

[IBM 1975 Optical Page Reader]. "New techniques in video processing such as contrast control, dynamic video thresholding and data reduction circuits have been added to minimize the usual difficulty in recognizing seriously degraded forms and printing." (Commun. ACM **9**, No. 9, 706 (Sept. 1966).)

"The 1975 Model 3 Optical Page Reader has an effective speed of 64,800 input lines per hour . . . Approximately 50 per cent of the total load is suitable for scanning. The scanner will be able to do the work of approximately 200 key punch operators in approximately 2,000 manhours and relieve computers used to convert cards to magnetic tape of about 885 hours of work per year. . . .

"Rough calculations indicate that from 35 to 40 key punch positions would have to be displaced if the necessary capital investment [$\geq$\$800,000] is to be written off over 5 years." (Lannon, 1967, p. 50).

5.23 "A peephole template matching technique developed by General Precision's Link Group employs a mask or template in which only a relatively small number of selected sub-areas of the image field are used as apertures for matching . . . A laboratory page reader having a vocabulary of four type fonts has been successfully demonstrated." (Maass, 1965, pp. 18–23).

"Link Division, G.P.I., for several years, has been actively engaged in programs directed towards the development of advanced optical character recognition techniques . . . Several reading techniques have been investigated; however, the most successful one uses an electronic peephole matching principal in which only selected sub-areas of the image field are used as apertures for matching. The method allows complete disregard for serifs and other typographic and stylistic embellishments . . ." (Greenly, 1966, p. 3.)

"Each character is scanned by a column of photodetectors and converted into a digital waveform from which selected portions are matched against a reference vocabulary, the recognition criteria being the least value of the time integrals of the total number of absolute differences between the incoming video and stored descriptions of each character in the vocabulary." (Greenly, 1966, p. 3.)

"The addition of two fonts . . . to the Link Page Reader required minor modifications . . . The system had previously been designed to read two type fonts one of which consisted of 55 characters while the second included 19 characters. The memory for each of these fonts and for each of the fonts investigated under the subject [RADC] program is operator selectable." (Greenly, 1966, p. 4).

5.24 "Sylvania is now developing an extremely versatile page reader capable of reading up to 30 typefaces, where the size of each one may range from 6 to 36 points, at speeds above 1000 characters per second, on pages of complex format such as those found in technical books and journals.

"Early in 1961 a decision was made to build a feasibility model of a general-purpose page reader with the aim of proving the practiciability of certain newly devised techniques for character recognition. The initial design goal was to attain maximum versatility. This led to the following specific requirements for this machine: Speed—a reading speed of at least 1,000 characters and preferably higher; Type Fonts—the machine must read characters independently of size within broad limits, and must have a capacity for at least 30 distinct type styles; Optics—the machine should read the original paper document, not a photographic negative; Accuracy—the undetected error and reject rates should be as low as possible; Flexibility—the machine must use a control and scan technique capable of being programmed to read pages with complex formats, such as those encountered in translation and information retrieval applications. This class of applications is characterized by a wide variety of printing and formats, and relatively high quality. The techniques also show promise of being suited to lower quality print such as typewriting.

"Design and construction of a reader with most of these properties is complete, and feasibility of the above goals has been demonstrated. Further testing and design improvements are now being made." (Gray, 1963, p. 85).

5.25 Rabinow demonstrated this machine at Interdata 65, see also Business Automation **12**, No. 7, 44 (1965): "Control Data Corp., has introduced the 915 Page Reader which reads information prepared on a typewriter equipped with American Standard Assn. optical character reading font . . . can handle documents from 4 to 12 in. wide, 2½ to 14 in. long, and continuous fanfold sheets." (Bus. Automation **12**, No. 7, 44 (1965).)

5.26 "Multifont Optical Unit Reads 2000 Characters per Second. Tokyo Shibaura (Toshiba) Electric Co. has developed a high-speed multifont optical character reader capable of reading 2000 characters per second and 1200 lines per minute.

"Developed by Toshiba central research laboratory, the device's character-recognition logic needs no adjustment to read as many as six of the widely used numerical fonts.

"A spokesman said the characters are recognized by their features, rather than by stroke, thickness or position.

"He said the new OCR can be used with journal tapes produced by comparatively inexpensive printers. Another OCR, which that can also reconize hand-written numbers, is under development at the Toshiba laboratory.

"Characters that can be handled by the Toshiba OCR are ISO–A, ISO–B, IBM, NCR, Farrington 12F, Toshiba Stylized Font and others (optional).

"Main components of the new OCR are a paper-feeding mechanism, a photoelectric scanning device and a recognition logic.

"The width of journal tapes that can be fed into the unit can vary from 56 to 100mm. Line pitch is $\frac{1}{4}$ inch or more per line. Character pitch is 10″." (Electronic News, 7/10/67).

5.27 "One large user—the Social Security Admin.—maintains that its custom-made OCR system, an IBM 1975, will do the work of 120 to 140 keypunch operators, but the agency says that no one will lose his job. The operators will be reassigned to other recordkeeping operations." (Drattell, 1968, pp. 35–36).

5.28 "The U.S. Post Office in Detroit, Michigan, has completed the initial testing of a pilot-model OCR mail sorter developed by Philco-Ford. First test results show that 15% of total mails can be optically read at present, with a 45% figure anticipated in the near future." (Feidelman and Katz, 1967, p. 0210:16).

5.29 "Since there are a wide variety of font types in existence, multi-font readers have been developed (up to 128 fonts). These depend however on *manual* modification of plugboards to accommodate different styles with the result that mixing of documents, containing different fonts, is not possible . . . and will be possible in the future, if automatic sensing is developed, only at great expense." (Auerbach Corp., Source Data Automation, 1967, p. 2–10 to 2–11).

"The manual method, consisting of altering the recognition logic by manual replacement of such machine parts as plugboards and optical masks, is low in cost but inadequate for reading a stack of documents in which the character fonts are mixed." [As also on a typical journal page]. (Auerbach Corp., Source Data Automation, 1967, pp. 3–103).

5.30 "Today's optical readers will take selected type fonts; some very sophisticated versions will take several type fonts. None, however, will take the number of type fonts found in a scientific journal, nor will any handle the number of type fonts found in the Encyclopedia Britannica. Due to the rapid increase in computer technology in the publishing industry, more and more textual materials are becoming available in the form of computer-readable tapes. We have recently discovered though that having materials computer-readable is not the entire answer—it is still necessary to write programs that bring this material into the form that we desire. This is no trivial task." (Simmons, 1965, p. 220).

5.31 "The most flexible method is to include a stored-program controller as part of the OCR system. This permits dynamic format changes based on the information being read and makes convenience to the human user the primary consideration in forms design and data preparation. . . . (Philipson, 1966, p. 128.)

"With recent OCR use of programmed controllers the use of variable format is suggested since the machine is much more efficient in formatting than the human." (Auerbach Corp., Source Data Automation, 1967, pp. 2–17).

"The Farrington Page Reader, Model 3030, . . . has a programming repertoire of some 66 instructions." (Feldman and Katz, 1967, p. 0210:03).

"Others who have done significant work on programmable scanning and pattern recognition are the Link Group of General Precision, Inc., Scope, Inc., The Cornell Aeronautical Laboratories, and the Stanford Research Institute." (Hustvedt, 1967, p. 7).

"The Programmed Controller [SDS–910 computer] enables the Electronic Retina Character Reader to perform context editing functions, control document sorting operations, and effect other logical operations such as justification and word hyphenation for automatic typesetting operations." (LeBrun, 1963, p. 150).

5.32 Cf., for example, the following opinions or recommendations: "Such 'auto-encoding' processes would have to be based on considerable insight into the physical properties and make-up of documents." (Luhn, 1958, p. 211.)

"The U.S. Government is sponsoring investigations into the feasibility of recognizing the formats of intermixed inputs from several technical journals. This research is directed toward producing a system which can recognize the format and then read and assemble the information for later computer processing." (Stevens, 1965).

5.33 "Amongst the difficulties encountered in the processing of machine readable texts, inconsistencies in the use of punctuation marks, compounds, capitals, spacing and indentations have been a problem way out of proportion with respect to the simple functions these devices stand for. For instance, even with the aid of a dozen different tests performed by the machine, the true end of a sentence cannot be determined with certainty. It is hoped that publishers of scientific literature will in time sacrifice some of the niceties and aesthetic aspects of the printed page for the sake of clarity in communication." (Luhn, 1955, p. 22).

5.33a "Two main types of degradation are encountered, misplaced characters and unclear or smeared characters. The causes are threefold: mechanical, human, and accidental. Mechanically, for example, typewriter ribbons wear, leaving light or smeared impressions. Soft paper leaves fuzzy-edge characters. Pinion wear and jammed keys cause tilt or skew in the typed symbol. Human mistakes typically cause misregistration, misalignments and palimpsests (where two characters are superimposed, one only partially erased), and smears. Accidents account for overlays of foreign material, ranging from grease to egg foo yong." (Frank, 1964, p. 2, reprint).

5.34 "For optimum reader performance, print quality is by far the most critical document property. Since quality control of printing cannot be done on a 100% inspection basis, the procedure that is used must be able to maintain adequate performance of the system with only periodic checks of critical items. Certain conditions, such as proper selection, and quality control of ribbons and paper, can be handled on a routine basis. Other conditions, such as end-of-ribbon life and the need for printer readjustments must be detected by inspection of the printed characters. Experience has shown that optimum performance can be achieved in the reader with a reasonable printer control effort, if the character stroke width is maintained between 10 mils and 18 mils. Characters with stroke widths that range beyond these limits also can be recognized currently. But the probability that unacceptable characters will occur increases beyond the level for optimum performance when more than 25% of the stroke width of the inspected character ranges down to 8 mils or up to 23 mils." (Greanias, 1962, pp. 143–144).

"The essential requirements for optical character recognition are paper handling techniques, positive control of random formats, automatic error correction, system reliability and accuracy, and economical equipment." (Shiner, 1962, p. 335).

5.35 "Paper feeders, format controls, information buffers and output devices make a practical reading machine cost many times the cost of the recognition logic itself." (Rabinow, 1966, p. 18.)

"The factor limiting present OCR speed is paper handling. Speed of paper handling can be increased by multiple scanning of documents, or by multiplexing the input. One solution is to overlap the functions of reading and transporting documents. A Philco reader under development uses a vidicon scanner that deposits an image of the entire document on a CRT and then scans the CRT surface while the next document is moved into position. Another method of increasing speed is selective scanning (scanning only the necessary parts of the document) with variable-format readers, like the Philco General Purpose Print Reader. The complex paper-handling mechanisms are also very expensive: it was stated at the 1966 IEEE Pattern Recognition Workshop that the reading equipment of a typical OCR is only one-quarter of the total cost, and that the other three-quarters is for paper movers, format control, and other handling mechanisms." (Van Dam and Michener, 1967, p. 190).

5.36 "Measurements of print characteristics such as stroke width variation, edge irregularity, voids, extraneous ink, paper to ink optical reflectivity, etc., are commonly used techniques for specifying acceptable tolerances of printed text. . . .

"[The high-resolution optical] scanner used in this study was designed and constructed . . . and has been used by G.E. for various pattern recognition studies which require high resolution. . . .

"One of the most appealing approaches from a theoretical viewpoint would be to classify print quality in terms of print noise statistics. For simple noise statistics, such as independent additive, gaussian noise, this approach can be realized. It is also possible to design optimum recognition logic and predict the adverse effects of this type of print noise on machine performance. For practical situations, however, such simplified assumptions for print noise statistics are inadequate . . ." (Vitale, 1965, pp. 1, 17, 28.)

5.37 "Ink Smudge—In OCR, the displacement of ink under shear beyond the original edges of a printed character." (Unpublished definition, American Standards Association, X3 Committee on Computers and Information Processing).

"Ink Squeezeout—In OCR, the displacement of ink from the center to the edges of a character during printing resulting in a character with 'darker' outlines than the center." (Unpublished definition, American Standards Association, X3 Committee on Computers and Information Processing).

"Ink Bleed—In OCR, the capillary flow of ink beyond the original edges of a printed character." (Unpublished definition, American Standards Association, X3 Committee on Computers and Information Processing).

5.38 "Light Stability—In OCR, the resistance to change of color of the image when exposed to radiant energy." (Unpublished definition, American Standards Association, X3 Committee on Computers and Information Processing).

5.39 "The Kidder [Press Company, Inc.] Model 081 Optical Character Tester was designed to check the print quality of documents for optical scanning and can be used for analytic measurements or for routine inspection. Physical measurements are made on a large viewing screen on which a magnified image is displayed. Reflectance measurements, in two spectral ranges, are made on a meter giving readings in print contrast signal directly and also in percent reflectance . . ." (Business Forms International, Inc., 1967, p. 33.)

5.40 "Designed to check that printed characters are of sufficient quality to be read by machines, the Optical Print Quality Monitor can measure paper whiteners and blemishes, and the dimensions, density and quality of print characters against parameters set up beforehand." (The British Computer Society, 1967, p. 126).

"Equipment for monitoring OCR characters also provides a CRT display, in this case of the magnified outline of a character as 'seen' by a 0.2 mm scanning spot. The observed density gradient at a stroke boundary and the severity of voids or of extraneous inked areas are obviously functions of scanning spot size and thus Monitor and Reader should have comparable optical characteristics. The displayed boundary can be selected for any brightness level between the white of magnesium oxide and absolute black. Fig. 14 illustrates the effect of varying this level from 0.51 to 0.70 on the PCS scale where white paper gives 0 and absolute black gives 1.00." (The British Computer Society, "Character Recognition 1967", p. 22.)

5.41 ". . . *Handling* of paper can result in curl of the sheet, creasing, local distortions through uptake of moisture, and discolouration and scuffing of the printed characters; none of these effects can be dealt with very specifically. The best way to minimize the effects of handling would be to select a fairly stiff, smooth, not too glossy paper, of good dimensional stability and with high tear strength." (The British Computer Society, 1967, p. 22). In particular, "tear resistance is relevant to general handling and may be an important consideration for the preparation of documents on line printers, in which circumstances the direction of the grain of the paper may be in conflict with the direction desirable from the standpoint of the paper transport of the reading device. The choice of the optimum combination of characteristics must be a matter of selection according to the particular application." (Ibid, p. 33).

5.42 "The inclusion in the body of the paper of material to which the reading device is sensitive is to be avoided as much as extraneous ink . . . In OCR applications this takes the form of specified maximum dirt count . . . Fluorescent additives are sometimes used as brighteners for paper but should be avoided for OCR use as they may have a significant effect upon the reflectivity of the paper. Water marks deserve special attention because they may offend both against the requirements for a flat surface and for minimum opacity and are better avoided at least in the clear band." (The British Computer Society, 1967, p. 33).

5.43 "Minimum line spacing must be sufficient to allow adequate separation between the highest character boundary in a line and the lowest character boundary in the line above, in addition to the height of the character itself. The width of the clear band specified is commonly as large as 5/8" (16 mm.) . . . The permissible character skew may be as little as $1\frac{1}{2}$ degrees and the vertical misalignment as little as 0.007 inch." (The British Computer Society, 1967, p. 30).

5.44 "Noise in the character field is dependent on the character . . . Noise is not scattered about in the character field in a random, equally probable manner. The spatial distribution of noise resembles the character printed on the field." (Uffelman et al., 1967, p. 42.)

"The spatial distributions of additive ink-noise about character strokes have been determined. Ink noise has been shown to be stroke-related, hence character dependent." (Uffelman et al., 1967, p. 63.)

5.44a "The functional value of available readers has been another important factor in the growth of optical character recognition. Like any other commodity, the value of character recognition must be measured by comparing its cost to that of performing equivalent functions by other means. The actual cost of reading is not always the controlling economic factor. Sometimes the value of associated editing and classifying that must be done manually may offset the potential savings of faster and cheaper reading by machine. In other applications, the reduced document preparation cost that can be realized by printing machine readable documents on a single pass through an accounting machine or computer is enough to tip the balance in favor of machine reading." (Greanias, 1962, p. 130).

5.44b "The desirable features of O.C.R. as I see them are as follows.

(1) Economically to replace key-punch operators from the point of view of:
   (a) Cost of salaries and cost of equipment.
   (b) Cost of space and the amount of space occupied.
   (c) Burden of administration and supervision of staff of large punched card sections. (It has been estimated, however, that when our centralization is complete on all computer applications (not just Billing), we will still require 85 operators even with O.C.R. equipment.)

(2) To increase the accuracy of data fed to the computer, since there is less chance of copying or punching errors.
(3) To reduce the time to prepare and read data into the computer in order to avoid punching bottlenecks, and to lessen the elapsed time required to produce the final printed output—e.g., bills and meter reading slips—so as to have more chance of giving a 24 hour service to consumers.
(4) To be able to use the same type fount as will be used for the rest of the document, and a fount which will be acceptable to consumers.
(5) To have a high rate of correctly reading the characters and marks, and also a low rate of machine breakdown.
(6) Not to increase significantly the cost of the stationery.
(7) Not to increase significantly the operator effort on the printer or the maintenance attention on the printer, and to not reduce the speed of printing." (Paine, 1966, p. 221).

5.45 Figure 14 illustrates the proposed Dickinson-Wheeler embellishments.

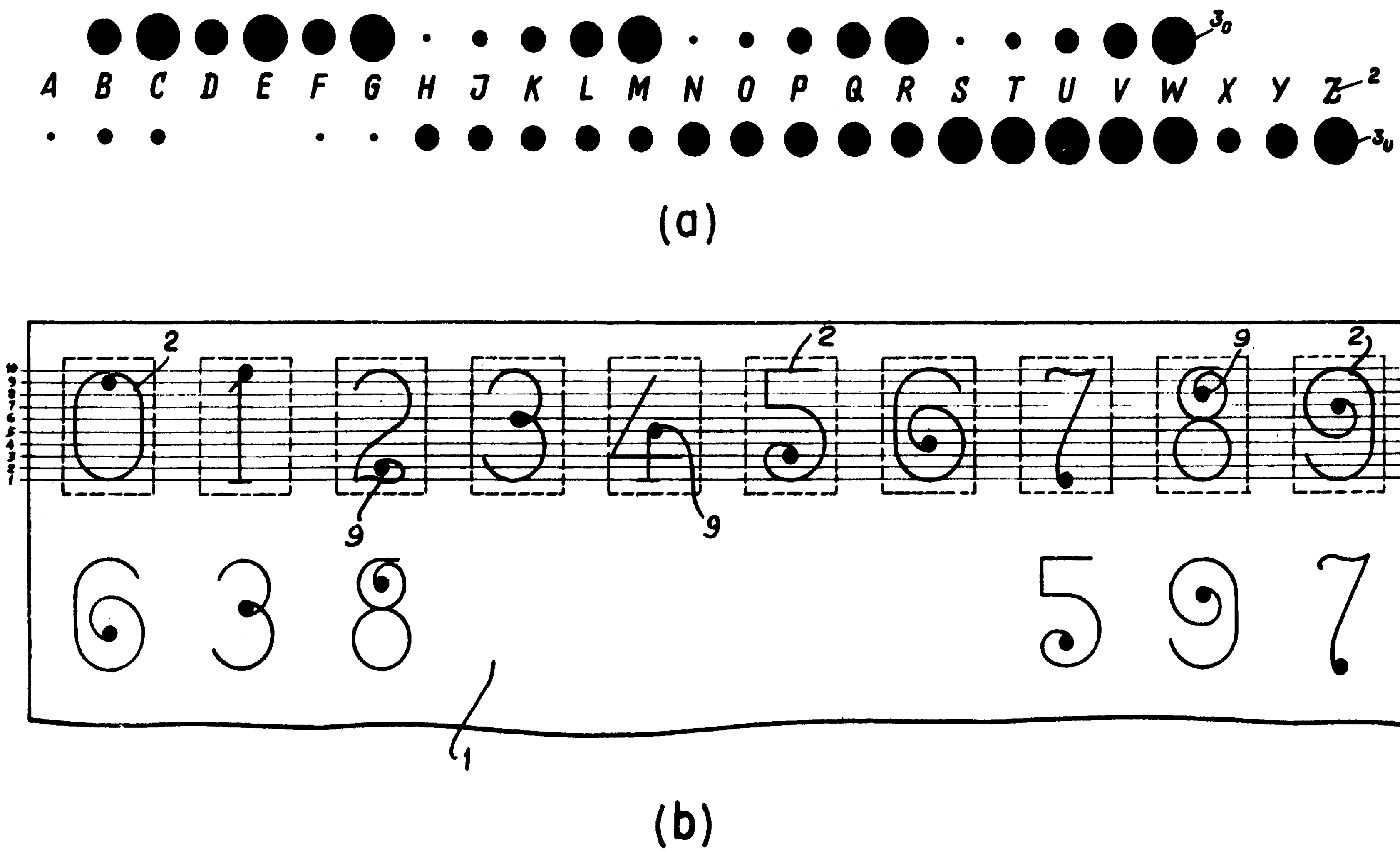

FIGURE 14. *Dickinson hand-print embellishments.*

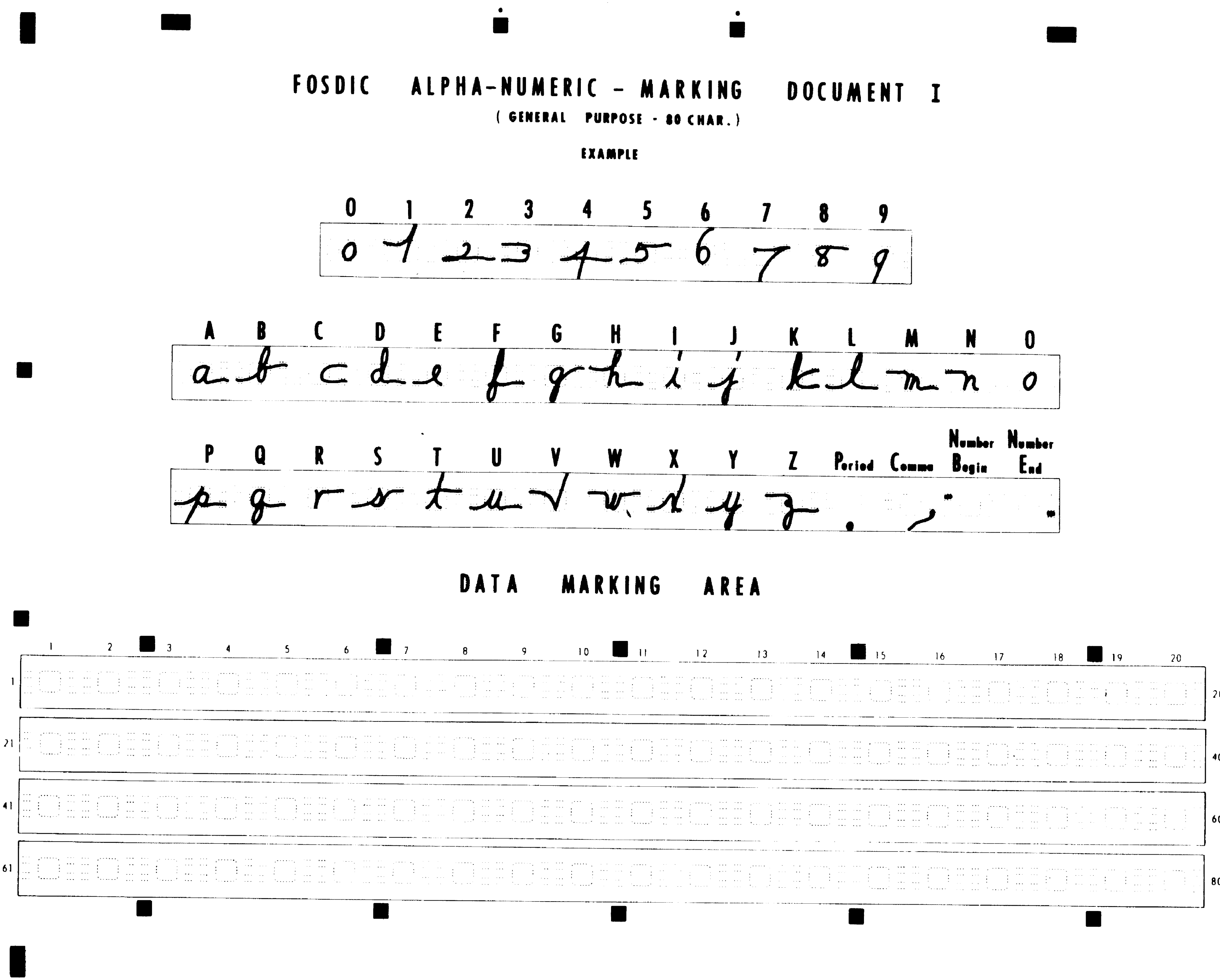

FIGURE 15. *FOSDIC alpha-numeric marking document.*

5.46 One type of application is shown in Figure 15.

5.46a For example, "in the production of script to be identified three constraints are placed on the writer. First, he is asked to observe a base-line and a guide line above it. The second constraint is that no capitals are used. Finally, the writer is asked to be careful and legible in his script; we seek to identify reasonably good writing before considering scrawl and scribble." (Harmon, 1962, p. 151).

5.46b "It is obvious that the use of controlled or constrained writing may hamper the writer in at least two ways: 1) he might not write as fast as he could have, had he not been using a controlled writing system; 2) the writer may not be able to adhere to the control." (Kamentsky, 1961, p. 491).

5.47 An 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. Dimond of the Bell Telephone Laboratories reported at this 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, and portable. 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." (Dimond, 1957, p. 236).

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. 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(b) represents source patterns correctly read and recognized. In Figure 16(a), 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.

5.48 "H. C. Vernon and R. R. Walsh were granted a patent on a character recognition method and apparatus which attempts to perform recognition on constrained characters. The character is scanned by a flying spot scanner in three segments. Each segment is oriented so that its long dimension is vertical. The scanning within each segment proceeds bottom to top in a television raster fashion with the retrace occurring between segments. The three scans are assumed to be non-overlapping.

"Several methods for constraining the handwritten characters are suggested, among them a six dot constraint and a 'forbidden area' constraint. A variation of this system is also described in which the rasters are oriented horizontally one above the other. Truth tables are constructed showing the results of these scans on representative characters.

"Registration is accomplished by a separate detector and logic system. The characters are assumed to be constrained within a rectangular marked area which is detected as a separate operation by a set of horizontal and vertical registration detectors. Once registration has been established the registration logic gives way to the recognition scheme." (Stein, 1965, misc. notes).

5.48a For example, "handwriting can be separated into x, y component waveforms for dynamic analysis or transmission using the analog or digital versions of stylus position." (Rose, 1965, p. 639).

5.49 "Groner reports some interesting work in handwriting recognition for real-time computer input. The system involves the use of a RAND tablet and a fountain-pen-like device together with a CRT display. The recognition scheme used is surprisingly simple, yet rather successful, and a number of editing features are included to permit the user to make corrections quickly. This reviewer, who had an opportunity to use the system for a few moments, found the use of a "scribble" character as the rubout command delightfully natural, although some other results of this short trial were not as satisfactory. Some much more meaningful test results are described in the article. An indication that recognition of handwritten characters has perhaps

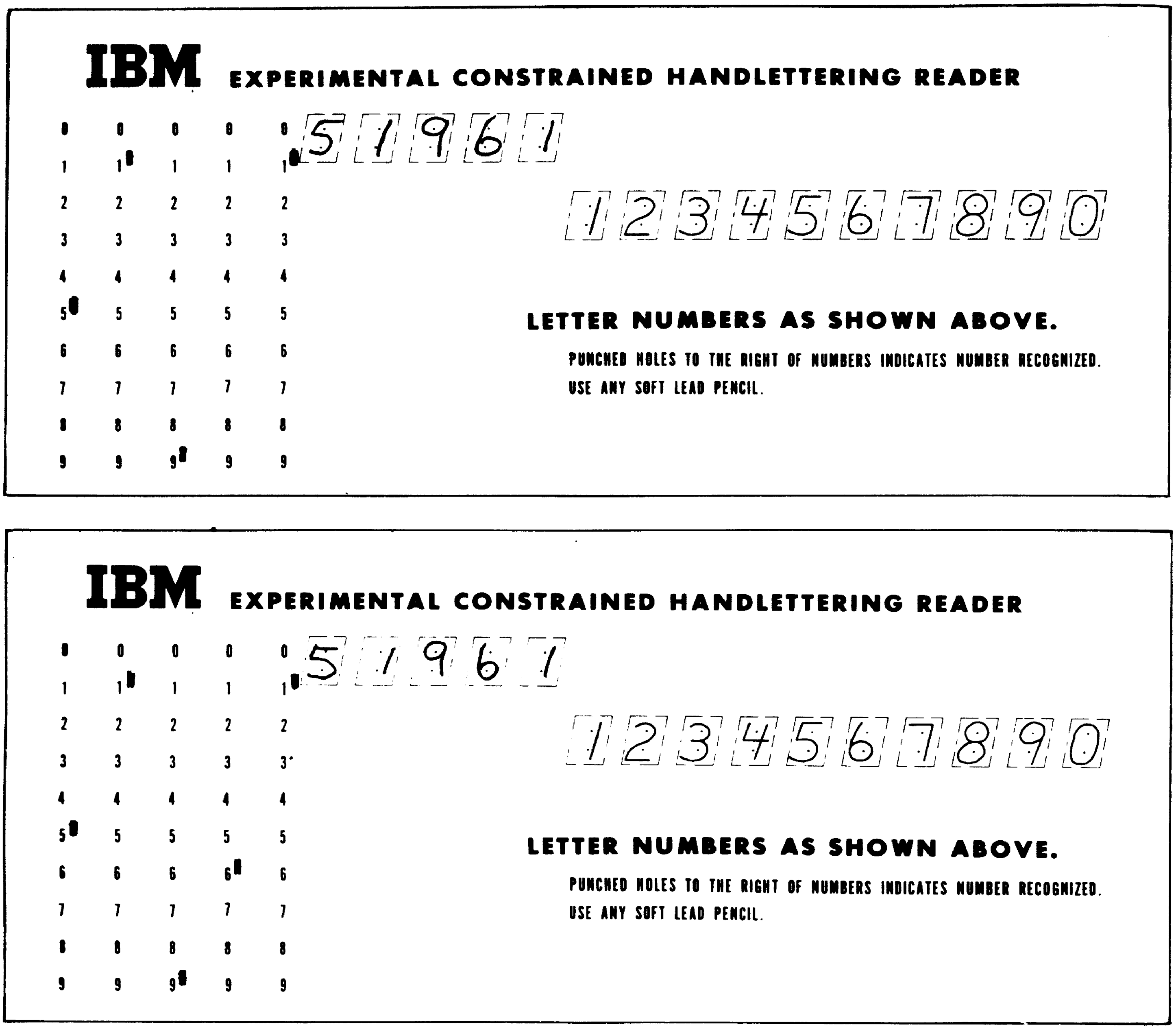

FIGURE 16. *Handwritten numerals, vector crossing technique.*

not quite 'arrived' commercially is a short new-product announcement on a commercial device capable of reading the ten digits and five alpha-numeric characters; the purchase price is quoted as $162,000!" (Mills, 1967, p. 233.)

"The scheme responds very quickly even though it recognizes a fairly large set of symbols. Moreover, it imposes few constraints on style, speed, or position of writing. It makes use of contextual information to distinguish symbols which cannot be distinguished by shape alone. This scheme has been used daily at The RAND Corporation for using computer code, drawing flow charts, and editing. The symbol recognition scheme is written in IBM System/360 Assembly Language and runs on an IBM System/360 Model 40." (Groner, 1966, p. 591).

5.50 "A patent was issued to H. B. Crane on a device which is hand held and which can be used as input for the recognition of hand-written numerals or characters as they are written. The device consists of a series of contacts surrounding a stylus. As the hand is moved in the writing of characters, the contacts are made in a sequence which is peculiar to the character being written. An analysis of the sequence and duration of contact closures then reveals the identity of the unknown character." (Stein, 1965, misc. notes).

5.51 "A patent has been issued to L. D. Harmon on a device for automatic reading of cursive script. As an operator writes the word in question, his stylus moves across a writing platen. The surface is made of electrically conducting strips arranged horizontally. Features are extracted as the stylus is moved. These may include loops, parts of characters extending above or below certain horizontal strips, etc. The horizontal reference of the logic is controlled by the stepping of a time commutator which is stepped by every crossing of the stylus over the zero axis line. Thus differences in the horizontal direction are normalized." (Stein, 1965, misc. notes).

5.52 "An 'electronic drafting board' constructed at M.I.T. has been described by L. G. Roberts. X-Y coordinate information is produced in real-time for direct input to the computer by moving a stylus consisting of a pin and a set of coils across a 20 × 20 inch sheet of paper laid over a specially wired base. The base is cross-wired in two directions and selectively wound in and out of pulse transformer cores to provide coded drive current. As the stylus is moved over the wires, the currents that are picked up provide coordinate information for the computer by means of the code selected by the wired cores. Approximately 100 machine instructions are sufficient to identify a character from a list of characters that the particular user has previously drawn." (Stein, 1965, misc. notes).

"Earnest has developed a set of simple tests on the strokes in a word which enables a computer to pick likely words from a dictionary. Presently these tests are to count the closed loops, the tails above and below the small letters, and the axis crossings at the center of the word." (Roberts, 1962, p. 210).

"For separated letters, Teager estimates that 100 machine instructions are sufficient to identify a character from a list of characters that the user has previously drawn." (Roberts, 1962, p. 211).

5.52a "The character recognizer included in SHAPESHIFTER was written by Kenneth Ledeen at Harvard University. With a training program the user teaches the computer his own handwriting; this information is punched on paper tape and is read into SHAPESHIFTER at run time. In effect each user has a version of the character recognizer tailored to his own writing style. . . . The recognizer must supply five pieces of information: the *name* of the character and its four descriptive coordinates, the *x minimum*, *x maximum*, *y minimum*, and *y maximum* of the area where it was written on the tablet.

"After a character has been printed and recognized, a canonical form of the character, in the same form and of the same dimensions as the printed character, replaces the 'ink' on the scope. This both 'neatens' the display and tells the user how the written character was interpreted." (Lewis, 1968, p. 721).

5.52b "The major software component of the system is the Q–32 Time-Sharing System (TSS). TSS currently serves in excess of 30 users at one time with a limitation of 47K words as the maximum program size. To support the terminal, we have prototype versions of a handprinted-character recognizer, an editor, and an expression analyzer, all of which operate under TSS.

"The character recognizer is in the final stages of development. It uses a character dictionary built for each individual user, and can recognize alphabets in excess of 80 characters. The editor permits characters to be erased or written over; entire expressions may also be deleted. The analyzer is a part of the PLANIT course-writing and computer-assisted instruction system. It will compute the value of an expression written in ordinary mathematical notation. Figures 3 and 4 show some of the input forms and resultant displayed output. The parsing algorithm and allowable notation are still quite limited, but we are working on more sophisticated parsing and editing facilities that will allow the user the same freedom of expression he has using a blackboard or a pencil and paper." (Bernstein and Williams, 1968, pp. 28–29).

5.53 "As customers make purchases at Higbee's, sales clerks write pertinent information on specially designed IBM card sales checks . . . This handwritten information indicates the quantity, department number, merchandise number, and amount of the transaction." (Greanias, 1965, p. 62.)

5.54 "IBM MACHINE READS HANDWRITTEN NUMBERS. A machine that reads handwritten numbers is IBM's latest offering. The IBM 1287 optical reader can recognize numbers and five different handprinted alphabetic characters pencil-written on a wide variety of business documents. The first with this capability to be offered commercially, it feeds this information directly into a computer for processing.

"There are two models of the 1287. Model I reads hand-pencilled, printed, imprinted and pencil-marked cut-form documents. Model II reads printed cash register and adding machine journal rolls in addition to cut-form documents. The 1287 is designed to be used with System/360 Model 30, 40 or 50.

"Both 1287 models will be available during the first quarter of 1968. Monthly rental of the 1287 model I begins at $3,600; purchase price begins at $162,000. Monthly rental of the 1287 model II begins at $4,000; purchase price begins at $180,000." (Commun. ACM **9,** No. 11, 829 (Nov. 1966).)

"Only two OCRs capable of reading handprinted data have been announced. IBM recently released the 1287, which reads handprinted numbers and five letters but imposes strict constraints on the printing. The computer-controlled 1287 can read 300 machine-printed numbers a second, but slows down when reading handprinted numbers. An interesting error-checking mechanism in the 1287 causes any machine-unrecognizable character to be displayed on a CRT for the operator to recognize, rather than immediately rejecting the document. [This same feature is discussed as it applies to film scanning in Michael's forum and by Gott.] The 1287 costs $180,000 and rents for $4000 a month." (Van Dam and Michener, 1967, pp. 189–190.)

"Both International Business Machines Corporation and Recognition Equipment Incorporated announced late in 1966 that they had developed equipment capable of reading hand-printed or hand-pencilled characters." (Business Forms International, Inc., 1967, p. 5.)

5.55 "Recognition Equipment announced in late 1966 that it had developed a scanner that reads hand-printed characters intermixed with typed or printed characters in a variety of different, standard type styles at the rate of 2000 characters per second and processes documents containing this information at rates up to 1200 per minute. The system can be supplied with the ability to recognize a variety of hand-printed character shapes tailored to the individual user's specific requirements." (Business Forms International, Inc., 1967, p. 29.) "Recognition Equipment, Inc. (Dallas, Texas) have announced a new module for its Electronic Retinal Computing Reader which enables the automatic recognition of handprinted letters and numbers with a claimed speed and reliability previously possible only when reading machine-printed information. The module, which can have a vocabulary of up to 40 alphanumerics, permits a considerable variation in characters and reportedly provides computer input that is 200 to 300 times as accurate as that provided by unverified keypunching." (Composition Information Services Newsletter, Oct. 1, 1967, p. 3).

5.56 "Information International Incorporated . . . has a system known as Programmable Film Reader-3 which performs a variety of pattern recognition tasks controlled by computer program. Included in its capability is character recognition of a large number of type fonts and hand drawn characters. Scanning is done by a programmed flying spot. Recognition is done by a variety of means: matrix matching, feature analysis, curve tracing and others. The recognition logic can be updated on the basis of experience, and it will purge itself of statistically insignificant erroneous entries." (Hustvedt, 1967, p. 7).

5.57 "Several manufacturers, including IBM, Philco, REI, CDC, and III, have scanners which can do fairly well at reading carefully hand drawn numbers, but at rates considerably slower than for typed material; some also read upper case letters. None holds out any current hope of reading script." (Hustvedt, 1967, p. 2).

"Philco-Ford has several developments. The company has been testing a hand-print unit that reads alphanumerics at Educational Testing Service in Princeton, N.J., a not-for-profit company that, among other things, administers and scores college board exams. In addition, Philco-Ford will deliver next December an optical film reader that reads photographic film. The system will be installed at Pacific Telephone & Telegraph Co. in San Francisco, where it will read photographic film of trunk line registers. It is believed to be the first successful marriage of microfilm and optical scanning capabilities." (Drattell, 1968, p. 54).

5.58 "A character reader which reads hand-printed and machine-printed figures (on the same line, if desired), characters, and symbols, converting the data for magnetic tape has been introduced by Optical Scanning Corp., called the OpScan 288 . . ." (Data Proc. Mag. **9**, No. 6, 72(1967).)

"New System Reads Hand-Printed Characters as Data for Direct Input to Computers. A new optical character scanning system which reads both hand- and machine-printed characters and transfers the data directly to magnetic tape for input to computers has been developed by Optical Scanning Corporation, Newtown, Pa. . . .

"The system is free-standing and operates offline. The basic price is $98,088, or a customer may rent one for a monthly fee of $1,988. . . .

"OpScan 288 reads at a rate of about 600 one-line documents a minute. The unit can distinguish 10 digits, six letters, and the signs for plus and minus. As many as 25 hand-printed or 80 machine-printed characters can be accommodated on a single scanning line. Both hand-printed and machine-printed characters can be placed on the same scanning line. . . .

"OpScan 288 accepts documents of from 2-1/2″×3-1/2″ to 4-1/2″×8-1/2″. The documents can be on paper ranging from 20-pound to tabulating-card stock. . . .

"OpScan 288 is compatible with all major computer series." (Commun. ACM **11**, No. 5, 386, May 1968).

The OpScan 288 allows the 10 numerals, the letters C, N, S, T, X, Z, and plus and minus signs either machine printed or constrained handprinted. (See Fig. 17.)

5.59 "We have plans to use constrained hand-printing whereby the hand-printing is placed in individual character boxes." (Brick, 1964, p. 87.)

5.60 "We have work going on in our development labs on reading handwritten material." (Huntley, 1964, p. 95.)

"Other new products are on the horizon including a unit from Farrington to read hand-printed numeric characters. The machine, to be announced shortly, will join hand-printed numeric character recognition systems now marketed by IBM and REI. The latter will install a hand-printing reader module for its Electronic Retina Computing Reader in July. The device reads ordinary hand-printed letters and numbers at speeds up to 1,200 documents per minute." (Drattell, 1968, p. 54).

5.60a "As a basis for the subsequent stroke analysis, we decided that our elementary decisions should supply information on the orientation of the stroke in each elementary area in which it has been detected. This led us to a system yielding . . . a *vector* field, obtained by a detection process carried out on the raw, unquantized video signal.

"Such a field can be obtained from a set of space filters matched to the various possible orientations of the character strokes. Each time that the scanning pattern sweeps across a stroke, that filter

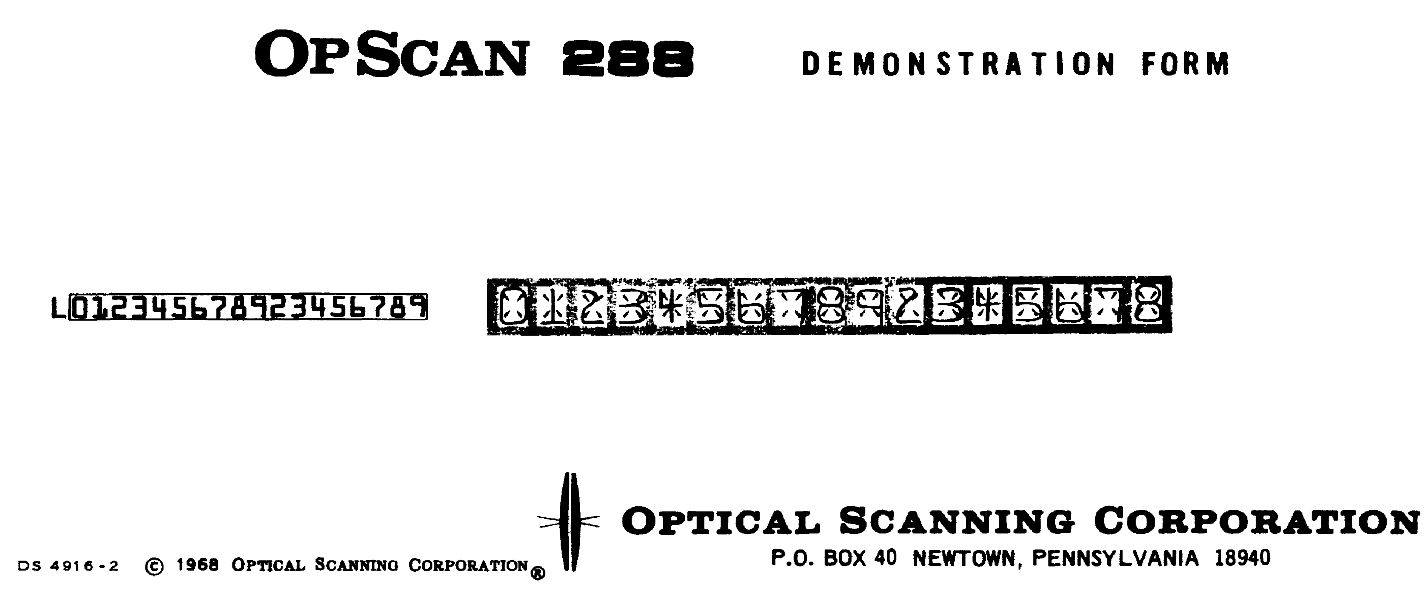

FIGURE 17. *OpScan document.*

which is matched to the corresponding stroke orientation should give an output exceeding a certain decision threshold; the other filters should remain silent. . . .

"A suitable measurement for this purpose is the measurement of the ink-density gradient, a vector perpendicular to the edge of the character stroke . . . This gradient is quantized in direction to $\pm 22.5°$, and after the decision threshold, it is normalized in amplitude. The input pattern is thus a set of unit vectors corresponding to the (directionally quantized) orientations of the detected character strokes." (Nadler, 1963, p. 815).

"The model also read (carefully drawn) handwritten numerals, along with the three design fonts." (Nadler, 1963, pp. 815, 821).

"Since we are looking for the boundary between the area which 'belongs' to the character and the 'outside', it appeared natural to us to seek a measurement system which would give us this boundary directly, rather than to attempt to deduce it from the usual type of OCR measurement (the generation of a rectangular matrix containing merely information on positions presumed 'black' and positions presumed 'white'). We detect the contours directly in terms of their local orientation in the scanning matrix. We distinguish only eight directions, in jumps of 45°; thus, in place of simple yes-no information, at each point we decide whether we are observing an element of the contour, and its direction. . . .

"At the first, and most global, level the principal structural elements of the sign are determined. Thus the 'O' is defined as a simple loop, the '4' as a loop with a tail, descending, the 'd' as a loop a tail ascending, etc. It is quite clear that at this level we cannot do more than to regroup the various signs into classes, within each of which the structural descriptions are equivalent. Thus 'B, 8', 'O, D', etc. For high-quality print, such as electric typewriters with onetime ribbons, these classes will correspond to our intuitive decomposition into classes. For degraded print, or hand-lettered 'block' letters and numerals, the noise will cause the classes to be enlarged. Thus, if the tail on the '4' gets lost, as happens all too often, it enters into the 'O, D' class. A second level of description will enable us to distinguish, within each class distinguished at the first level, the differences defined by the general form of each of the contours composing the elements of the ideal figure. Thus, in the class 'O, D, 4', we shall find that at the left there is an arc in the 'O', a vertical straight line terminated by two right angles in the 'D', and an oblique slanting upwards to the right in the '4'." (Nadler, 1967, pp. 36–37).

5.61 "The only commercially available reader of handwritten characters is the IBM 1287, although Philco-Ford, Control Data, and Burroughs have developed such readers for the U.S. Post Office Department." (Feidelman and Katz, 1967, p. 0210:11.)

"Burroughs [Zip reader] uses a five-shift-register and the 'best match' code-comparison method, with a flying-spot scanner." (Kornberg, 1964, p. 116).

"Rabinow's [Zip reader] . . . light pipes, in an image converter tube, pick up the moving address, reproduce it on the back surface of the tube and shift it up and down at high speed.

"The characters are scanned by a light-sensitive cell behind a pinhole. The cell generates electronic signal patterns corresponding to the specific character on the envelope. These are recognized and compared with the address-directory on a 'best match' basis." (Kornberg, 1964, pp. 116, 119).

5.62 The Zip Code Reader designed for the Post Office Department by NCR includes multi-level feature recognition logic. Eleven blocks of logic are used, known as reference functions. Analog cross correlation is done in three separate levels. The result passes through an A/D encoder, and then goes in to a recognition matrix before being fed to the final decision logic. (Stein, 1965, misc. notes).

"National Cash Register [Zip reader] also uses a flying-spot scanner, but substitutes a set of photographic 'feature' templates as the analyzing device . . . The machine has a 2,000-bit optical shift-register and a 19-lens beam splitter. Separate cathode-ray tubes are used to find the address lines and scan them. The read scan-signals are fed to a storage tube that displays each character sequentially. The character image is superimposed on a group of photographic templates, each template looking at a small segment of the character." (Kornberg, 1964, p. 116).

5.62a "In Earnest's system . . . the writer is constrained to write more or less horizontally, and he uses a 'lite' pen to write single words on the face of a cathode-ray tube (thus deferring certain problems related to actual writing on paper). The present [Mitre] system, which is set up on the M.I.T. Lincoln Laboratory TX–2 computer, recognizes about 10,000 common English words. The system deals only with whole words, and so circumvents, in part, the segmentation problem." (Lindgren, 1965, p.107).

"Using the estimated envelope as a guide, a matrix program finds the following key features:

1. significant strokes above the envelope (as in *b*, *d*, *f*, etc.) and whether such strokes have a crossbar (i.e., *t*),
2. significant strokes below the envelope (as in *f*, *g*, *j*, etc.),
3. significant closed curves entirely within the envelope (always in *e*),
4. the number of times the pattern crosses an axis midway between the envelope lines. . . .

"The feature detection programs are based on connectivity within a given region, so that when crossbars overlap adjacent tall letters (as in *little*), the overlapped sequence is detected as a single grand feature. . . .

"Once the key features have been identified, a 7-bit category code is constructed as follows: The highest order bit tells whether any crossbars were found, the next three bits tell the number of *high* strokes, and the last three tell the number of *low* strokes. . . .

"The next step in the process is a comparison of the predicted number of axis crossings of each word in the chosen category with the observed values (within a certain tolerance) . . . Finally, a crude model of the handwriting process steps across the pattern from left to right, checking the X-coordinates of extracted features against corresponding features (if any) in each word remaining on the list. . . .

"Five subjects . . . were recently asked to write words selected at random from the dictionary. Out of a total of 107 words, the computer correctly listed 65. . . .

"It appears that reliable mechanical recognition of cursive writing is not out of the question, though it has not yet been achieved. It will apparently be necessary to make the most of graphic, linguistic, and dynamic constraints on the writing process." (Earnest, 1962, pp. 463–465).

5.63 For discrimination between two pattern types, a network of 2,048 cells (simulated on a 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 . . . 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 were studied. Roberts concluded 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. (See Roberts, 1960, and Stevens, 1961).

5.63a "The recognition of hand-printed numbers was attempted with a linear decision function. The set of measurements which was used involved quantizing the number into a 12×12 binary matrix. A matrix element was given a weight of one if it contained a mark and weight of zero if it contained no mark. The quantized number was then positioned in the matrix by aligning its center of gravity with the center of the matrix." (Highleyman, 1962, p. 276).

"The implementation consists essentially of a transparency-photomultiplier combination for each character. The transparency represents the average character. When the image of the unknown character is focussed upon the transparency the transmitted light, measured by the photomultiplier, is a function of the desired cross-correlation value . . . Consider a piece of film in which the transparency at each point is proportional to the probability of occurrence of a mark at that point for a particular character. That is, the transparency of the film represents an average character . . ." (Highleyman, 1961, p. 510).

"This method, with centering by shifting and a penalty threshold of 0.04, was applied to the hand-printed alphanumeric alphabet of 1,800 samples. No rejection criteria were applied. The total recognition rate was 77.2 per cent." (Highleyman, 1961, p. 507).

5.63b "While the techniques developed were applicable to generalized line patterns, the particular subset chosen for detailed test were hand printed letters . . . The printing samples used were collected from 35 individuals." (Spinrad, 1965, p. 125).

"The Scan program starts by determining all the line segments, at eight angular steps, which can be fitted into the source pattern. A series of four 'filtering' programs are then employed to successively 'weed out' those line segments which do not represent a good fit. . . .

"The representational scheme we have selected has a matrix format in which the rows are a description of the line segments and the columns describe their relationships to the pattern's centroid. [Angular displacement from horizontal reference, bearing direction]. . . .

"A sample of 243 letters, different from those used in the Accumulate program, was run through the classification program. The program correctly identified 93.5% of the input set. . . .

"The Scan line recognition program, with its constituent filters, acts as a very effective 'noise' rejection mechanism . . . Extraneous blots, spots, etc., are not fitted with line segments because they are too small or because the program cannot abstract just one representative line segment. Further, because the Scan program initially fits a multiplicity of segments, the final abstraction is relatively tolerant of the void areas within the character's boundaries." (Spinrad, 1965, pp. 127–128, 140–141).

5.63c "The program that has been tested to date generates and searches for its operators at what might be termed the first synaptic level, immediately behind the input matrix. A program that is now being written first pre-processes inputs by means of this first synaptic layer. Specifically, it performs a two-dimensional differencing operation, which transforms a surface into its contour (e.g., Rashevsky, 1948). Operators are then generated, and successful and optimally adjusted operators searched for, at this level, to work on these contours. The contour differencing operation will allow us to begin to examine the problems of recognizing patterns of graded intensity. . . .

"The speeded up program has been tested on several different types of input patterns. . . . In most cases, results were quite similar on both 'known' examples (that is, examples the program had previously processed and hence had learned from) and 'unknown' examples (that is, different from the ones used in learning, and also produced by different people) . . . Results for several different sizes of pattern arrays, all of handprinted capital letters, printed by different people . . . show relatively little decrease in the program's abilities as the array size is increased, at least up to the 26 letter alphabet. Thus, on the sixth pass through the 26 letter alphabet the program was 100% correct on known patterns and 96% correct on unknown patterns." (Uhr and Vossler, 1962, pp. 321–322).

". . . Results for two 10-pattern arrays. These were: (1) line drawings of cartoon faces and simple objects (such as shoes and pliers), each copied from a different picture, as found in cartoon strips and mail order catalogs . . . and (2) handwritten arabic letters, written by the same person. The program achieved 95% success on known and 70% on unknown pictures, and 60% success on known and 55% success on unknown arabic letters (segmented handwriting) in the fifth pass. . . . Results from two 5-pattern arrays: (digitized and degraded sound spectrograms of speech (the numbers 'zero', 'one', 'two', 'three', and 'four', as spoken by different speakers) (Uhr and Vossler, 1961c), and (2) segmented lower-case handwriting, written by different people. The program achieved 100% success on both known and unknown spoken numerals by the fourth pass, and 100% success on known handwriting by the third pass. It achieved 60% success on the unknown handwriting, but it is likely that it would have improved further on these inputs if it had been given more opportunity to learn (once it achieves 100% success on known patterns it does not benefit appreciably from subsequent learning experiences)." (Uhr and Vossler, 1962, pp. 322, 326).

5.63d "This paper . . . [assumes] that an adequate structural description of a character has been extracted from the character's environment and passed to the information selector. This structural description consists of an ordered sequence of (x, y) coordinate values recorded at points around the character's boundary where its edge changes direction. The underlying philosophy for this particular structural description is the same as that of Zahn. To paraphrase Zahn, a sequential trace of a character's boundary yields the most useful information for distinguishing one character from another because curves defining the boundaries of letters and numerals have certain properties which are invariant over several fonts and that any specific letter or numeral observed on the basis of its boundary would hardly be confused with any other letter or numeral. Furthermore, it is felt that discrimination based on the trace of boundary edges will encounter difficulty at about the same level as the human observing characters out of context. . . .

"The paper presents a mathematical model of a proposed information selector. It offers some interesting possibilities because of its simplicity and power. The model introduces the Angle Versus Length (AVL) representation, a technique that traces the boundary of a character from its structural description to produce a characteristic waveform. It generates this waveform by plotting the tangent angle versus arc length around the figure's boundary in such fashion to form a closed contour. The resultant waveform is unique and complete because it preserves the relationship of each boundary feature with every other boundary feature so that the original and only the original character may be reconstructed from it. The Fourier series transform of the characteristic waveform is performed and the resultant coefficients are used as descriptors—hence the term Fourier descriptors. . . .

"The AVL representation and Fourier descriptors were conceived by Cosgriff in 1960 and subsequently refined and developed by Fritzsche, Raudseps, and Borel. The research reported here is an extension of previous work by the above researchers. . . .

"The recognition scheme was tested with two data samples. One was composed of more than 600 machine-printed characters representing all the numeral classes of 50 different commercial fonts and the other contained over 400 hand-printed numerals chosen from 40 styles of handwriting. A reference set of 21 Fourier descriptor representations was used with the machine-printed numerals and a different reference set of 17 representations was used for the hand-printed numerals. The recognition technique identified 98.6 percent of the machine-printed numerals and 90.5 percent of the numerals from the hand-printed sample." (Brill, 1968, pp. 1–2, 7).

5.63e "The curve tracing technique is one of the more recent concepts. Its basic advantage of being able to handle relatively wide variations in the shapes or sizes of the characters makes it a useful method for recognizing hand-printed characters. By following the character outline, the recognition unit determines certain features which it uses to identify the character. Among these features are character splits, line intersections, line magnitudes, and the straightness of lines. The major disadvantage is difficulty in reading characters having broken lines or holes within their block boundaries." (Feidelman and Katz, 1967, p. 36).

5.63f An earlier report on these IBM contour-following techniques provides such details as the following: "The characters are scanned optically along a variable path that depends upon the information obtained as scanning proceeds. The actual character on the document serves as the primary store of raw character information. The scanner is the means for retrieving the information as required from this 'memory'. Specific regions of the character are scanned selectively (and repetitively, when necessary), according to their significance in character identification. The scanner is also made to seek significant features in new areas of the character when prior scanning does not provide conclusive results. . . .

"To accomplish recognition, the contours of each character are traced two or more times. During the first tracing, the extreme positive and negative excursions of the character's outer contour in x and y are stored. On subsequent passes around the character, the beam is located relative to the character extremities and therefore is not dependent on the character location or the point of initial contact. . . .

"The analysis of the filtered beam deflection signals is based on two properties of the line edges that they represent:

(a) The relative location of the line edge within the character.
(b) The approximate direction of the line edge.

"By considering both properties simultaneously, the significance of most line edge signals can be detected without resorting to precise measurements of location and direction. In some instances, such as certain 8's and O's, identity cannot be established by coarse measurements on the outer contour of the character. For these cases, the scanner is redirected to obtain more information from the interior of the character . . . Since accurate recognition can be accomplished without resorting to precise measurements of line locations or directions, this system provides large tolerance for shape variations. . . .

"The reading capabilities of this model were determined in an experimental study at Tufts University . . . Approximately 200 untrained subjects wrote 20,000 numerals, of which 92% were correctly recognized." (Greanias et al., 1963, pp. 14–16, 19).

5.64 "A deterministic pattern recognition system for hand and printed numbers and capital block letters was developed and tested by F. Kuhl. Here an angularly quantized peripheral code was used to approximate contours of character images. The transformation is called angular mapping transformation (AMT) and together with redundancy-erasing reduced the patterns to a few numbers. The condensed numerical description is used in a one-dimensional correlation scheme. It is insensitive to major variations in the particular representations of a character but still can distinguish between the characters of interest.

"AMT is similar to the edge sequences proposed earlier by Unger, except that here each vector encodes in incremental change in position, length and directional angle of the trace.

"Of some 385 test characters drawn in pencil, over 95% were recognized correctly. This transformation, like all contour following recognition schemes, is quite sensitive to flourishes and curlicues." (Stein, 1965, misc. notes).

5.64a "Other parameters which are useful in important special cases, such as that of hand printed or written characters, include numbers of intersections with a raster, numbers of branch points of various orders, and so on." (Rosenfeld, 1962, p. 114).

5.65 It is to be noted that "considerable tolerance was provided for:

- Character registration. If necessary, characters can be located anywhere within an area several inches square.
- Character size. The height of characters can vary over a 4-to-1 range.
- Shape. The tolerance for shape is defined in terms of the shapes that occur in unconstrained handwritten numerals. The initial recognition criteria were selected to cope with more than 90% of the character shapes found in 3000 samples of unconstrained numbers.
- Line quality. Lines from medium hard pencils and dark-ink ball point pens in reasonably good condition are acceptable.
- Character rotation or slant. Normal characters can be rotated $\pm 20°$." (Greanias et al., 1963, p. 15).

5.65a "My invention requires no special nor complex scanning. I use any successive line producing scanner, e.g., the scanner shown in the J. Rabinow Patent No. 2,933,246 or a row of photocells or others. This is possible because my invention is only in the nature of a curve tracer.

"To the best of my knowledge, my invention entails a new system of character identification based upon a new philosophy. Specifically, if a scan line crosses a character line, my invention remembers in time, or voltage, or space, or digits, etc., the crossing point, and if the next scan line (of the same character) crosses the character within a given area (of time, voltage value, space, etc.), it is concluded that the character line being investigated is continuous and this information is remembered . . .

"In one embodiment of the invention, when a vertical scan line first crosses a character line the crossing point is remembered and a gate system is set during a portion of the next (second) scan line. The duration or width of the gate is made to include a time, area, etc., slightly above and slightly below . . . a horizontal projection of the first remembered crossing point, enabling the said next scan line to interrogate the character in a restricted area alongside of the first crossing. Now, if the second scan line crosses the character line within the interrogated sensitive area, the scanner output falls within the width of the gate system and is remembered; and the same way, but for the next scan line and this process continues to the end of the character line. . . .

"By examining the behavior of the follower, a characteristic trace of the line of the character being examined, can be developed and remembered. For example, if I assume a horizontally moving character area and a vertical scan made of a scan element moving from bottom to top of the character, my invention easily recognizes whether the characteristic trace is sloped up or down, curved or straight by observing whether the hits are early or late in the width of the gate system. . . .

"More than one follower is required to distinguish characters from each other . . . For example, consider the letter X. The first follower is assigned and begins to function when a scan line crosses the lower left corner and there will be a wide space in the same scan line, and then another crossing. The second crossing assigns a second follower to operate simultaneously with the first but it investigates a different portion of the character. Now consider the letter F. The first crossing is long and the scanner will produce a long pulse. Means are provided for identifying such a pulse. The next few scan lines will produce a hit in the first follower gate system corresponding to the first horizontal leg of the F, and a second follower will be propagated along the upper horizontal bar of the F." (Holt, 1964, p. 1).

5.66 "The programme described by Bomba employed a cross-correlation technique to extract features from a character. The method may be visualised as the comparison of the two-dimensional input pattern with a set of standard patterns or templates representing the features to be detected. For optimum performance the templates should be matched with the unknown in the correct orientation and position, and the templates should be of the correct size and shape. The basic principle underlying detection by auto-correlation is the use of the features actually present in the input pattern as their own templates thus making it unnecessary to position and orientate the pattern." (Clowes, 1962, p. 306).

For criterial feature extraction by Bomba's local operations, the area operated upon is a radial pattern built up of the appropriate combinations of smaller local areas. For example, to find an L-shaped feature, a pattern element detector 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 to detect coincidence of black cells in the input pattern local area 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. (See Bomba, 1959, and Stevens, 1961, p. 94).

5.66a "SPAC has been suggested for use in recognizing handwritten alpha-numeric characters (perhaps for inputting handwritten programs to a digital computer), recognizing diagrams of molecular structures in patent searches and recognizing biological cell structures. It could also be used as an aid in analyzing photographs of particle tracks as required in high energy physics." (Fuller, 1963, p. 24).

5.67 "To demonstrate the effectiveness of this design procedure utilizing time-varying threshold logic units, the technique was used in the simulated design of a character recognition device. The input patterns were a set of 240 hand-printed alphabetic characters, divided into 12 classes with 20 characters in each class . . ." (Astropower Lab., 1964, p. 194).

5.68 "M. Fischler has reported on experiments on several thousand characters hand-printed by approximately 100 people. The decision-making system was a special purpose computer (PIP) which simulates a network of threshold elements designed to identify a pre-selected set of typical patterns. The characters were constrained within rectangular boxes.

"A flying spot scanner with quantized output was used. Feature words made up of 350 bits were derived to describe the 'upper black', 'right diagonal', 'solid black', etc. Of the identifications attempted, some 71% were successful." (Stein, 1965, misc. notes).

5.69 "P. M. Lewis conducted a search for 'good' statistics relating patterns to relevant characteristics. He chose fifteen alphabets of 62 characters each. From these he evolved thirteen characteristics and his resulting system recognized 81.9% of letters. The fifteen alphabets included nine machine-printed and six hand-printed. One sample of each symbol from each alphabet was included. Upper case, lower case and numerals were represented in the 920 samples which also varied in height by a factor of four. Lewis suggested that more samples would have to be looked at in order to derive a more effective code." (Stein, 1965, misc. notes).

5.70 "Defining the vector spaces and deciding whether an unknown branch is an element thereof constitutes the main part [of Minneman's 1966 paper on handwritten character recognition]." In order to define vector spaces one examines several copies of the same character . . . as drawn by different people, for 'learning' the reference configuration thereof. The mean of the resulting vector space is used for point-by-point comparison with an unknown. The criterion of acceptance . . . is based on a conditional probability and distance relationship." (R. Jessup, review, Computing Reviews **8**, 113–114 (1967).)

"Samples were obtained of the characters 1, 2, . . . 9, 0 from 26 individuals. They were instructed to letter neatly, but in their own style, avoiding breaks (except at top of 8), and to try to make their characters fit within a ⅜-inch diameter circle. Closed top 4's were not allowed. . . .

"The 260 design samples were then tested against the 35 standards derived from them to determine the internal consistency of the system. The results were as follows.

Correctly recognized.....	253 = 97.3 percent
Not recognized...........	2 = 0.8 percent
Incorrectly recognized...	5 = 1.9 percent

"The number of subclasses necessary to define all variants of a character type was found to range from one for a *one* or a *zero* to eight for a *four.* On average, 4.3 variants were found per character type." (Minneman, 1966, p. 93).

"To test the performance of the system an additional sample of 260 characters was obtained . . . The results of the test were as follows:

Correctly recognized.....	254 = 98.5 percent
Not recognized............	0 = 0.0 percent
Incorrectly recognized...	4 = 1.5 percent

[2 characters not processed because of program deficiency]. (Minneman, 1966, pp. 93–94).

5.71 "S. Spilerman has revealed a classification scheme for the alpha-numeric set which is insensitive to common variations in hand-printing. This method is based on invariance in angular change along certain segments of a line pattern.

"The system groups many variants of a pattern together and yet breaks the character set into a large number of subsets, each containing a small number of characters. A method for quantizing and representing simply connected segments of a pattern is first introduced. It is then used to convert two-dimensional line patterns into one-dimensional statements.

"The most detailed one-dimensional statement contains a record of the slope. The most condensed is a quantized angular description of the pattern. The condensed patterns are then compared with a list in memory to determine an initial classification. One-third of the characters can be identified this way. The remaining are divided into sub-classes containing two to six members. More detailed pattern statements or additional tests can be applied to extract the proper identity from the sub-class. The patterns covered do not cover cases where loops occur. Reasonably well-printed characters were used for the study. Constraints were placed on (1) flourishes and (2) gap size.

"This work was simulated on a 7090. A curve follower constructed to input the necessary information would have to be backed up by considerable logic to avoid retracing previously encountered curve segments at crossovers." (Stein, 1965, misc. notes).

5.72 "Fifteen modular criteria were developed by G.U. Uyehara for reading numerals either typewritten in multifont or hand printed. Five criteria were used to describe the inter-connections and ten described shape and tread of individual 'streams.' Uyehara uses a modular criteria detector which analyzes the character during scanning. The results of this are then inserted into a buffer store and from there they are organized into a pattern lattice network. Two kinds of recognition are used. The Gestalt criteria are used to recognize beginning, end, continuation, convergence or divergence of streams. The single stream criteria are listed as: first quadrant compound wedge; second, third, fourth quadrant wedges; first/fourth quadrant compound wedge; second/third quadrant compound wedge; positive diagonal line, negative diagonal line, horizontal line segment; and vertical line segment.

"Uyehara reports that the Gestalt criteria are sufficient if the character can be identified from the inner connections alone. Otherwise, the single stream criteria as organized in the pattern lattice network are necessary to supplement the features. Synchronism between the scanner disc and delay lines, and the accuracy of construction of the slits in the disc were among the worst engineering problems encountered in the construction of the first model of his equipment." (Stein, 1965, misc. notes).

5.73 Weeks, 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.' . . . There is then processing which determines the first scan line crossing and the last and then divides the intervening area . . . 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 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." (Stevens, 1961, p. 50–51.)

5.74 "A model of a pattern recognition computer, whose design is based on electronic simulation of a nerve cell, has been developed by two electrical engineers at Purdue Univ. Thus far, the small-scale model, built by Prof. King-Sun Fu, and Wen C. Lin, has recognized hand-printed Roman and Chinese letters.

"The system consists of a photo-cell grid, which scans and converts the black and white patterns into digital signals, joined to a box enclosing 200 interconnected circuits, or 'neurons', and an I/O panel board . . .

"The circuits are arranged into three banks: (1) the transformation layer, which receives and reduces the pattern from 144 to 24 bits; (2) the correlation layer, which compares the 24 bits with the pattern references stored in memory, feeds the correlation coefficients back to the first layer via a learning loop to inform it how to adjust its threshold for succeeding patterns and fires the same coefficients to (3) the decision layer, which indicates to which class the pattern belongs. A second learning loop may correct the decision layer." (Datamation **11**, No. 7, 71 (1965).)

5.74a "We shall now describe a technique, at present under investigation at AFCRL's Data Sciences Laboratory where it was originated by the author, for reducing alphabetic patterns to feature vectors. A printed letter is composed of line and background. In the case of a letter printed on a white page, the inked part is the line and the white part the background. In the following manner we give any background point a four-digit ternary code, where ternary means that each digit is 0, 1, or 2. We draw imaginary horizontal and vertical lines through the background point, forming a cross. The cross has four arms that extend left, up, down and right. Each of these arms determines one of the four code digits for the point. The digit is 0 if the arm does not intersect the line of the pattern. It is 1 if the arm intersects the pattern just once. It is 2 if the arm intersects two times *or more than two*. In forming the code, we write the digits from left to right, taking first the digit determined by the left arm, then the upward arm, then the downward arm, and lastly the right arm . . .

"Now consider the locus of all background points that . . . have the code 2012 . . . This locus consists of the lower part of the interior of the triangular upper cavity of the M. The upper part of this cavity is the locus of points whose code is 1011. Clearly, every point of the background of a pattern must have a ternary code, according to this scheme; and clearly, all points having one code, for example 2012, combine to form a locus. We may call this locus the locus 2012. The locus of one code is usually in one piece, but it is occasionally in two or more pieces. It is hard to imagine a capital M that does not have a locus 2012. On the other hand, it is hard to imagine an A, B or C that has a locus 2012. In fact, the locus 2012 is rather characteristic of an M . . .

"To form the feature vector of a pattern, we list the codes in a consistent order and, after each code, write the area of the locus of that code as it appears in the pattern. If the locus does not appear, we write zero; otherwise we write the relative area of the locus, that is, its percentage of the sum of the areas of all the loci. Since every pattern has each locus to a greater or lesser degree, even though this may be zero, the vector thus formed is somewhat characteristic of the pattern . . .

"The scheme can be implemented by a special-purpose device attached to a digital computer. The computer can, of course, be the very one that will use the printed information that is read by the system. The basic cell of a grid of identical cells has been designed so that, with a pattern impressed on the grid of cells, each background cell can compute its own four-digit ternary code. The computer then communicates with the cell grid to determine the pattern's vector. With the decision functions derived in an earlier training mode stored, the computer then classifies the pattern." (Glucksman, 1968, pp. 13–14).

5.74b "In exploring the use of *n*th-order autocorrelation functions for pattern recognition, we conducted experiments with typewritten samples of the characters *a*, *e*, *s* and handlettered samples of numerics. . . .

"This [handlettered numerics] was run with a set of 3100 characters (distinct from the set used for finding the subspaces W_i), and 38 classification errors were made." (McLaughlin and Raviv, 1968, pp. 131, 137).

5.74c "The samples used in the experiment were obtained by asking three subjects to print characters in a two inch square or to write characters in a circle with a two inch diameter. The characters are fairly centralized and normalized. Eight features . . . were selected for handprinted characters, and eighteen features . . . for handwritten characters . . . Each feature is assigned by a number which is the distance, measured along the predetermined path, from the edge of the square or the circle to the first intersection of the character." (Chen, 1966, p. 557).

5.74d "The first program, or 'preprocessor' converts any pattern of black-and-white cells on a 20×20 matrix into a one-dimensional description of its contour. . . .

"Of these classes, the one most extensively used was a set of 27 rather badly distorted examples of the hand-printed alphabetic characters D, E, F, and G. On this set, versions of the program frequently gave about 75 per cent correct answers after about three learning experiences with each example." (Prather and Uhr, 1964, p. D2.2–1, 5).

5.74e "Samples of handwritten numerals were collected from a group of salesclerks . . . These samples were scanned by a contour analysis scanner and recorded on digital magnetic tape. The measurements provided by the contour analysis were all binary and are therefore directly suitable for the present simulation program. . . .

"Two sets of 3,000 samples were used in this experiment. One set was used to design the recognition network and the other set to test the network. Twenty-four measurements were used to characterize each sample.

"Interating on design data, a tree structure . . . was obtained, and the number of recognition errors was 42. The error count of the linear structure for the same design data was 84. The computing time on an IBM 7094 was about one hour.

"Recognition of the test data set was then attempted with the tree structure. There were 59 recognition errors. With the linear network, there were 84 errors in the test data." (Chow and Liu, 1966, p. 79).

5.75 "Research on multifont, handwritten character and cursive word recognition and signature identification has been done by simulation on a computer Telefunken TR 4." ("Technische Hochschule Karlsruhe, Annual Report 1966", 1967, p. 52).

5.76 "Considerable information, from initial studies performed, appeared to be present in the dynamic sensing of two signals: pen-tip acceleration and pen-paper contact. Successive signatures from a subject appeared to be well correlated visually, using acceleration and contact signals obtained from strip recordings. . . .

"The instrumentation of the pen to provide tip-acceleration and paper-contact signals was considered to be a step forward. Neither of these variables is normally available to the handwriting expert; thus, the speed of writing—the invaluable time function—is lost to the expert when confronted a posteriori with a specimen. . . .

". . . During the course of this study, persons found themselves able to identify the signers from the acceleration time plots by looking at the pattern of the acceleration peaks . . . A plot might be made of the height of each peak versus its position when ranked by size . . . There would be complete information as to the peak pattern in the shape of this curve and in the information which represents the ranking of the peaks. Thus, if the eighth peak were largest, the fourteenth peak were second largest, the sixth peak were third largest and so on, then the numbers 8, 14, 6, . . . would also identify the signature. . . .

"Using a . . . vector, whose components consist of such indices as zero-crossing counts, number of pen-paper contacts, etc., this comparison system correctly classified 226 signatures out of . . . 250." (Mauceri, 1965, pp. 8, 9, 50, 54–55.)

5.76a "Patterns whose names were to be learned by the stimulus-sampling program consisted of two hundred first name signatures. Twenty exemplars were collected for each of . . . ten signatures . . . Individual signatures were written inside a 5-inch by 12-inch rectangle. Although subjects were instructed to fill the rectangle as much as possible, the instruction was difficult to follow, and few signatures touched the edges of the rectangle. Each exemplar . . . was projected against a grid with 20 rows and 48 columens. The image was expanded when necessary to reach three sides of the grid, giving preference to the top and left sides. No other attempt was made to normalize the image. . . .

"Exemplars of names collected in the second session were treated in a different fashion. No attempt at all was made to normalize the figures. Each signature was traced directly on a graphic input device developed at the RAND Corporation and attached to the RAND JOHNNIAC computer. . . .

"The ten signatures collected from any subject in a given session tended to resemble one another fairly closely, but there was a considerable difference between sessions. The difference occurred in part because of changes in the general appearance of the signatures and in part because of the different methods of processing. . . .

"Each signature to be recognized or learned was described within the computer program by a property vector with 960 components, where each property reflected presence or absence of part of the figure in a fixed portion of the visual field." (Marzocco, 1965, pp. 210–211, 214).

". . . The probability is less than 0.02 that four or more responses will be guessed correctly if no systematic effects are present. Since this level of performance is reached by the time 2 or 3 signatures sets are presented under any condition of administration, it is apparent that learning occurred under every condition. . . .

"A set of properties useful for recognizing the handwritten first name signatures results from the digital encoding without need for further processing to isolate specific topological features of the patterns." (Marzocco, 1965, pp. 215–216).

5.77 In a later patent issued to Harmon in 1964, the stylus is moved across a writing platen whose surface consists of electrically conducting strips arranged horizontally. Features including loops, ascenders, and descenders are extracted as the stylus is moved.

5.77a "Tests are made for a number of 'local features' such as differential vertical extent, cusps, closure and retrograde strokes. Other tests establish individual letter domains, thus grouping the detected features into clusters. . . .

"The accuracy of letter identification is greater than 90 percent over a sizable population of writers and test sentences. Those errors due to segmentation inaccuracies amount to less than 3 percent. Most of the other errors are due to imprecise 'feature' extraction. . . .

"Recognition accuracy thus approaches 93 percent. Studies are currently being made to use context at a more complex level and to investigate the extent to which the constraints on the writer may be relaxed." (Harmon, 1962, pp. 151–152).

5.78 ". . . An attempt is made to identify script on a letter-by-letter basis. We seek a minimum set of 'local features' which are common to a large selection of reasonably legible handwriting samples. Characteristics such as differential vertical extent, cusp, retrograde strokes and closure are used. Recognition decisions are based on the outcomes of tests for unique combinations of these local features." (Frishkopf and Harmon, 1961, p. 301.)

"When the same writer is the source of both dictionary and test words, correct identification is achieved for 32 per cent of all test words written by all subjects . . . When comparison is made between test words written by one writer and a dictionary written by another, correct identification is achieved in 26 per cent of all cases." (Frishkopf and Harmon, 1961, p. 314.)

"*Method 1* was tested by processing 19 sentences (412 letters total) written by five persons. The correct letter-identification for the entire group was 58.9 per cent." (Frishkopf and Harmon, 1961, p. 313).

5.78a "The parameters used are here called the 'loop configurations' of numbers. In the 'loop space', Arabic numbers are considered to be made up of lines forming fully-closed loops or loops which are open on one, two, or three sides." (Kamentsky, 1961, p. 492).

5.79 "Investigations on multifont and handwritten character recognition are under way. A character recognition scheme for hand-printed numerals has been realized. For the simulation of handwritten character recognition a special light-pen off-line input device has been developed. The use of shape elements as features has been studied and linear classifying networks have been considered. An integrated computer-scanning-classifying system with feedback control is being developed." (Technische Hochschule, Karlsruhe, "Research on Pattern Recognition . . .", 1966, abstract, p. 1).

"Methods of contour description and line segmentation of characters have been investigated with regard to storage capacity requirements, operation time and redundancy. Other methods are based mainly on sequential decision techniques." (Technische Hochschule, Karlsruhe, "Annual Report 1967", 1967, p. 63).

5.79a "Handwriting analysis was begun and very well characterized by Eden and Halle. They found that only 18 strokes are used to construct all of the English characters. These strokes can be generated and joined together by simple rules in a computer so as to 'write' any word. By finding the ranges of the stroke parameters for an individual, the computer can forge his handwriting." (Roberts, 1962, p. 210).

5.80 "An algorithm for the segmentation of the pen displacement signal of handwriting into function segments corresponding to strokes has been presented. This procedure, when repeatedly applied to a collection of handwriting samples yields function segments that may be classified into categories based on topological similarities, thereby yielding a representation for every cursive letter by means of a small number of permissible alternative sequences of stroke categories. Such categories are defined by means of statistical averages of the numerical representations of the member functions, and the likelihood of membership of new function segments in each particular category is estimated by means of the multidimensional distance between the representation of the new function and the average for the category. . . .

"Constraints are recognized to exist on two levels, those between stroke categories, sequences of which must form valid letter representations, and those between letters, sequences of which must form words within the vocabulary of the system. The result of the recognition process is that word which is generated from the stroke category sequence, the constituent strokes of which correspond to a maximum total likelihood. Methods are presented which implement the stroke sequence to word mapping in an efficient manner." (Mermelstein and Eden, 1964, p. 334).

5.81 ". . . The development of a limited-capability handwriting recognition system that can handle a very large font without significant size or orientation constraints. The remaining constraints of language style and segmentation are now being removed. . . .

"The user can teach the program to recognize his set of characters. The learning process for the program involves modifying individual decision trees, changing the weights on each tree, and where necessary, introducing new decision trees with their corresponding properties into the system. Because the program was written as an input device to a larger man-machine system, the description of the implementation stresses the human engineering features. A qualitative evaluation of the system as implemented is offered, together with possibilities for expanding and generalizing the program." (Teitelman, 1964, p. 559).

"Essentially the only things that can be said about a program of this type relate to its convenience and usefulness. The program has been taught to recognize, on separate occasions, Russian characters, Hebrew characters, Greek characters, upper- and lower-case English characters, and a large collection of mathematical symbols. It has been used by many different people, and the combination of control panel and punch-out and read-in features make it at the very least enjoyable to operate. With a little experience, after the user becomes accustomed to the idiosyncracies of the light pen, and trains the program in the variations of his handwriting (surprisingly many people are not aware of the fact that they vary their style of handwriting from sample to sample), the resulting man-machine system becomes quite effective. Again no quantitative results can be offered here other than observations on use of the program by a considerable number of individuals. . . .

"The results seem to indicate that the use of the time sequence is a powerful tool in pattern recognition. It enables a program using fairly simple properties to achieve a high rate of recognition. One way to improve the program might be to include more sophisticated properties other than the position of the pen. An immediate improvement would be to include a property that detected sharp corners by noticing changes in the velocity of the pen. Other properties might note curvature or angle. Developing a language that described a wide class of properties would generalize the program even further. The user would then be able to communicate subtle differences in forms by means of fairly abstract concepts." (Teitelman, 1964, p. 574).

5.81a "Although this particular work emphasizes handprinting input, the transducer is clearly applicable to allowing the input of more general information such as mathematical symbols, drawings, or graphs. . . .

"The output of the printing transducer is transmitted into an IBM 1620 data-processing system . . . The decision procedure uses adaptively derived linear boundaries . . . The use here of the adaptive system allows the recognition to be trained for a variety of individual printers and for a variety of printing fonts. . . .

"The measurement space used describes the character in terms of straight-line segments . . . Eight types of segments are allowed, corresponding to the eight directions of the compass . . . The printing area is divided into nine zones, or regions, and the region in which a particular segment begins determines where in the measurement space its occurrence is recorded. The number of times the printing stylus is lifted off the transducer during the creation of a particular character is also recorded . . . as is the number of times a particular segment occurs in a particular zone." (Simek and Tunis, 1967, pp. 72–74).

"The circuitry tests the sequence of x, y location points for incremental changes. When a predominance of these changes is established in one of the eight possible directions, a valid measurement has occurred. An indication of the segment is transmitted to the computer; subsequent segments are recorded only if they differ from the the segment immediately preceding them. For printed alphanumeric characters, an average of seven such measurements is obtained per character; for the character '8' a maximum of 14 such measurements occur. Note that we are breaking up curved sections of a character into a sequence of straight-line segments. . . .

"The experimental results are based on fairly large samples (approximately 300 alphabets, where an 'alphabet' is one example each of the characters to be treated) obtained from two individuals . . . The two printers were not trained and used their normal printing style. . . .

"The performance on the test sample is dependent on the size of the analysis sample. In effect, the analysis sample must statistically represent the test sample. . . .

"The recognition performance on the test sample of one individual, given a set of weights adapted on the analysis sample of that individual, showed that both individuals obtained a recognition performance in excess of 99.4 percent." (Simek and Tunis, 1967, pp. 75, 79–80).

"In another study, samples of handwriting were fed into the system, employing intentionally 'sloppy' characters to test recognition capability. The set of weights used was based on a sample of 200 alphabets [numerics] of printer one. . . . [approximately 26%] were not identified correctly. Many of the characters identified incorrectly are noticeably smaller; they were undoubtedly not recognized because of system resolution. . . .

"The handprinting input device and recognition system described has been shown to be technically feasible. Its use awaits its economic justification in particular applications. . . .

"As might be expected, an increase in alphabet size results in a decrease in recognition performance. However, with the largest alphabet size used [26], the recognition rate is still in excess of 92 percent, a level which should be acceptable in many applications if some method of feedback, allowing retransmission or correction, is included. . . .

"The performance level achieved by one individual, using the weights generated by the analysis sample of a different individual (but both using the same font), is in the vicinity of 95 percent." (Simek and Tunis, 1967, pp. 80–81).

5.81b "Studies were made into the usefulness of various recognition schemes for handprinted alphanumeric characters and ease to which subjects adapted to program-forced constraints. The Sylvania Data Tablet proved extremely useful in this application for several reasons: First, the inking capability allowed the subjects to write on a sheet of blocked paper in a very natural manner. Second, the multiple threshold Z axis feature allowed the programmer to use one level (contact with the surface) to indicate stroke and a second level (about 1/8 inch above the surface) to indicate completion of a character. In other words, multiple stroke characters are formed with the tip of the pen always below the 1/8 inch level, and once the pen is raised above that level the completion of a character is indicated to the computer. Third, the high resolution provided minute details needed for recognition of small characters. The 1 per cent accuracy of the tablet proved more than adequate for accommodating letter sizes of $\frac{1}{4}$ inch or more." (Teixeira and Sallen, 1968, pp. 320–321).

5.82 "The word parapropagation is intended to signify the interruption of a propagation by an interposed barrier. It will be shown that patterns can be classified by a process based on the interruptions of propagations." (Glucksman, 1965, p. 435).

5.82a "Very simple, automatic methods are sufficient to decompose a printed page into text set in one, or a few, predetermined type styles, and other material. While there appears to be no convenient standard for measuring the accuracy of the decomposition, it would seem that more complicated and time-consuming methods of spectral analysis need not be invoked for this purpose.

"With documents of the order of complexity of technical journals, automated scanning at this level, coupled with existing character recognition devices, would not produce a computer storable reproduction suitable for all of the intended purposes of the original document. A limited range of functions, such as automatic indexing, and perhaps extraction, could be performed on the coded version. Simpler page structures, such as the 'claims' section of patent documents, could be processed for natural language search procedures and complete redisplay." (Nagy, 1968, p. 486).

"The IBM experimental character recognition system on which these experiments were performed already incorporates a number of fairly sophisticated features for registration, normalization, noise suppression, threshold adjustment, and character separation. When presented with a noncharacter field, it attempts to convert what it finds into familiar symbols by means of protracted and agonizing convulsions. What is needed, then, is a rapid 'prescan' of the entire page, or a sizable fraction thereof, to indicate to the control unit which areas are to be read, and which ones skipped or copied onto magnetic tape without further processing. The logic used to derive this information from the prescan is discussed in the third section of this report." (Nagy, 1968, p. 481).

"The percentage of correctly identified letters in the words underlined varied from 95–98 percent from day to day depending on the care taken to adjust the video circuits of the scanner. This includes only lowercase characters, since there was no recognition software available for capitals, punctuation, and ligatures (fi, ff, fl, ffl, and ffi)." (Nagy, 1968, p. 483).

"The method to be discussed stems from the simple observation that character fields are readily distinguishable from almost everything else by the average density of the lines and of the blank spaces above and below the lines." (Nagy, 1968, p. 483).

5.82b "Because handwriting presents a more or less continuous signal, it too raises the specter of the segmentation problem." (Lindgren, 1965, p. 105).

5.82c "Automatic recognition of speech would be particularly useful for information, communication and control engineering. With its help it would even be possible to control machines by means of the spoken word, to carry out switching operations of all kinds, to dial telephone numbers, to write texts on typewriters, to feed data into computers and to simplify the transmission of messages." (Kusch, 1965, p. 201).

"Voice recognition for purposes of translation, control, or recording for printing will eventually be handled with the aid of large memories . . . Schemes for building up words by recognizing individual phonemes will be replaced by systems wherein whole words at a time are recognized by an indexing process. The index terms will be characteristics such as energy distribution at various frequencies for a succession of phonemes. Simple language-structure rules will make it possible to distinguish between words which sound the same but are spelled differently." (Astrahan, 1958, p. 313).

5.82d "Still another area of experiment that has grown more germane to the problem of automatic speech recognition are the psycholinguistic studies, which have begun to give new insights into how humans process speech." (Lindgren, 1965, p. 46).

5.83 "A futuristic system must cope with problems such as dialect variations, slurring of words in continuous speech, and the resolution of homophones." (Bhimani et al., 1966, p. 275).

"Another difficulty arises from the different dialects in common use. Here the same *words* or *phrases* spoken by different talkers will have different phonetic content. Thus transliteration from a sequence of phonetic elements to English words may involve complex linguistic structure." (David and Selfridge, 1962. p. 1098).

5.83a "Not only were there variations between speakers in their acoustic outputs, but there were variations by the same speaker in different circumstances, in differing emotional states." (Lindgren, 1965, p. 121).

5.84 "Visual examination of the quantized spectrograms on the display matrix revealed that the location of the lowest frequency format using this technique is much more erratic with female voices. This result demonstrates the fundamental weakness of the short-term Fourier Analysis in locating the poles of the vocal tract." (King and Tunis, 1966, p. 73).

"The same words spoken by a man and a woman differ drastically in their acoustic content, but the listener has little difficulty in establishing that they are the same words." (David, 1958, p. 294).

"It is not merely a question of the differences in speech of a man as compared with a woman or a child, but also of the variations in dialectical pronunciation, with the added factor of emotional colouring." (Kusch, 1965, p. 201).

5.85 "R. H. Galt in 1951 decided to draw up a set of rules for recognition of ten spoken numbers from spectrograms." (David, 1958, p. 301).

"L. G. Kersta in 1947 . . . assumed a selected vocabulary consisting of ten spoken numbers, and took spectrograms of them from each of nine men and five women. He divided each spectrogram into a mosaic of square elements. If the integrated density in a particular element were $1/2$ or greater than the integrated density then it was represented as being entirely black. [otherwise, white] . . . For each digit he then compiled two master patterns . . . all black elements common to the utterances of the fourteen speakers. . . . The second master pattern consisted of all common white elements. . . . Now if the black and white masters are applied in tandem with a logical 'and' requirement; that is, both black and white elements must match, . . . the maximum error probability for any digit is less than one percent, while the average over all digits is about 0.2%." (David, 1958, pp. 305–306).

Lindgren cites other early work at the Bell Laboratories as follows:

"In the Wiren-Stubbs electronic implementation, the properties separated were the voiced sounds from the unvoiced, the turbulent (noise like) from the nonturbulent; then the nonturbulent sounds were separated . . . into groups . . . and the unvoiced turbulent sounds were separated into the stops and fricatives . . . Fairly good results were obtained with this system. For instance, for vowels in short words pronounced by 21 speakers, accuracy was above 94 per cent . . ." (Lindgren, 1965, p. 118).

"Another version of the Bell Labs system (called Audrey) was developed later in the decade (1958) by Dudley and Balashek. It would recognize acoustic patterns corresponding to 16 different basic linguistic elements . . . The incoming acoustic signals were broken down into specific patterns, which were compared with patterns stored in the machine. Best-matches were determined by cross-correlation methods." (Lindgren, 1965, p. 118).

5.85a Berkeley describes briefly a project at MIT under the direction of William N. Locke supported by the National Science Foundation to construct a machine that will recognize spoken sounds and write them down as English phonemes. "A prototype machine distinguishes successfully between vowels and consonants and also between the consonants sounds 'F', 'SH', and 'S'. Efforts are currently being made to distinguish electronically between the sounds 'P', 'T' and 'K'. The essential difficulty at present comes in designing circuits which will distinguish the sounds when different speakers clearly enunciate the same phonemes. The final stage will come in distinguishing different sounds spoken by anybody in normal rapid speech. The principles being used in the MIT study are those of recognizing distinctive differences, rather than recognizing patterns—on the theory that when a man is trying to find his way with a map, a small number of judgments made correctly is sufficient for him to tell where on the map he is. None of the work being done at MIT at present includes the problem of subsequent correction of the sounds heard by clues from context." (Berkeley, 1956, p. 9).

5.85b "The clusters for this experiment were generated by taking measurements on sustained spoken vowels. The utterance of each vowel was sampled at a 20-millisecond rate through 15 levels, and the outputs of the filters were quantized into 13 levels. Each time sample was taken as a pattern, thus producing a cluster of patterns from an utterance of one vowel. Eight vowels were used . . . The set of 250 patterns, viewed as samples of unknown space for purposes of this experiment was subjected to a series of analyses to determine whether clusters existed and whether the method would separate them . . . Within the limitations imposed by the number of points within the clusters of the sample space, this experiment resulted in the satisfactory separation of eight unknown clusters of complex patterns in an arbitrary sample space, identified aberrant samples, and suggested an output code." (Dammann, 1966, pp. 80, 87–88).

5.85c "A developmental speech recognizer demonstrated by Philco-Ford Corporation is expected to be the forerunner of practical and economical voice control equipment for applications such as: direct voice input to a computer, phone dialing by voice, voice control of machinery, and many other specialized applications both military and non-military in nature. The compact device responds to words from a limited vocabulary (presently OH through NINE) with typical acuracies between 90 and 99 per cent depending upon the speaker, his microphone technique, and his familiarity with the recognizer. . . .

"Input to the word recognition logic comprises three measurements that are made continuously on the speech waveform. The resulting unique set of parameters are based upon a transformation of the information carrying resonances (formants) of the human voice into a single equivalent frequency representation. The three measurements are (1) the frequency of this single equivalence resonance, (2) the amplitude, and (3) the state of voicing, i.e., whether the sound is originated by the vocal chords, or by noise due to air flow over a constriction in the vocal tract (as when speaking the 's' sound). These three parameters are subsequently quantized to provide digital inputs to the word recognition logic." (Killet, 1967, p. 3).

5.86 "At the Electrotechnical Laboratory, where analysis and synthesis of both the hearing and the speech organs are under investigation they are trying to develop a unique method of recognition based on testing the correlation between generated and received speech. . . . Researches [in speech analysis, synthesis, and recognition] are also being done at the University of Kyoto, Kokusa Densin Denwa Co., Tohoku University, and the governmental Electric Wave Research Laboratory. Their present situation is that not more than vowels can be recognized." (Niwa, 1962, p. 65).

5.86a "At the present time there are several projects in existence involving the analysis of speech waveforms. Such fields of study are: (a) development of communication systems that use digitized and/or parametric speech; (b) experiments with automatic recognition of spoken commands; (c) study of phonetics through models of the vocal system and synthetic speech; (d) segmentation of words, and human perception tests. For many of these applications conventional devices for examining speech, such as the fixed-filter spectral analyzer, are inadequate. Additional specialized equipment is required and there is increasing interest in prior digital simulation of these experimental systems as an aid to design.

Alternatively digital, rather than analogue, processing of the speech waveform may be used. This method is capable of greater flexibility and accuracy, and new techniques such as zero-crossing analysis readily lend themselves to computer calculations. In the setting-up of digital speech processing facilities, two problems may be distinguished: (1) provision of an input/output device to convert the analogue speech waveform to a numerical representation which may be stored on magnetic tape; (2) development of programs to perform various kinds of analysis on the digital record." (Lavington and Rosenthal, 1967, p. 330).

"A simple 16-word vocabulary has been used to assess the effectiveness of these measurements. The vocabulary consists of monosyllables formed by combinations of one of four initial consonants (S, F, T, N), one of two vowel-sounds ('EE', or 'OR'), and one of two final consonants (S, N). A recognition program has been tested on a total of 70 words spoken by 19 speakers (14 male, 5 female; various accents including Cockney, Lancashire, Glasgow, American, and Southern English). Average computing time on the University's Atlas was 1·2 sec per utterance, of which about 0·35 sec was spent in assembling the digitized speech from magnetic tape to the main store prior to analysis. (The speech was previously put onto tape via a tape-recorder or direct microphone input to the Speech Converter.) The main program was written in Atlas Autocode, and is at present being converted to machine code. Preliminary tests have shown that this will reduce the overall time (including data-assembly) to below 0·7 sec per utterance. The size of the Atlas Autocode object-program is 3,000 machine-instructions." (Lavington and Rosenthal, 1967, pp. 338–339).

5.87 "In a case such as the present experiment where the patterns [eight classes of vowel sounds] emerge from the real world rather than from a pattern-generating rule, there can be no assurance that any particular sample belongs to its parent class in accordance with any reasonable objective criterion." (Dammann, 1966, p. 87).

". . . The analysis sample of one speaker is not a good statistical representation of the test sample of a different speaker. It must be noted, however, that the performance of the system was significantly better than chance, implying that there is some degree of statistical invariance in the measurements . . . from one speaker to another." (King and Tunis, 1966, p. 74-75.)

"A particularly difficult requirement to fulfill is that the recognition process must produce the same results from the voices of different speakers with different personal characteristics." (Kusch, 1965, p. 204).

5.88 "Filter bank analyzers have been much used (e.g., by Abramson, et al., Denes and Mathews, Olson and Belar, Davis et al. (1952), and Talbert et al.) . . ." (King and Tunis, 1966. p. 65).

The speech analyzer presently in operation at the Royal Institute of Technology, Stockholm is a band-pass filter-bank speech spectrum analyzer, with 51 channels that can be set in various combinations of center frequencies and different band widths. Input signals are digitalized after filtering in order to allow synchronous sampling of all channels. Output may be presented visually or recorded on magnetic tape in digital form, or it may be reconverted to analog form for display via CRT or on X–Y plotter. Investigations can be made of effects of different frequency transpositions upon input signals, changes in the time code system, and the like, and the analyzer results can be compared with those obtained from the speech synthesizer.

A number of different techniques for the improvement of the basic low-pass filter have been tried and, as a result of the experience so gained, later investigations have provided for the use of two or more filters in parallel so that the disadvantages of a particular system can be compensated by circuits having complementary characteristics. (Risberg, 1962 see also Stevens, 1968).

5.89 "(The output of the sonograph [Kay Electronics Co.] is a continuous record of a frequency and amplitude vs time; this record is called a sonogram.)" (King and Tunis, 1966, p. 67).

5.90 "A simple model for human speech was originally formulated by H. W. Dudley. It relies on the observation that during a human speech utterance (especially during the 'voiced' portions), the acoustic energy is mainly concentrated in only a few relatively narrow regions of the frequency spectrum . . . These energy concentrations are known as *formants*. During the utterance of a word the position and relation of the formants change, creating a characteristic 'pattern' distinctive of a word and, to some extent, the speaker." (King and Tunis, 1966, p. 66.)

"The second major characteristic of interest is the marked tendency of frequency selective energy concentrations, referred to as formants." (Fant, 1959, p. 6). Other definitions are as follows: "Vowel sounds are characterized acoustically by formants, which are frequency regions of high energy concentration corresponding to the passbands of the throat and mouth cavities." (Phonetics Laboratory, University College, London, 1963, p. 1).

"The vocal tract resonances, called *formants*, are determined by the shape of the vocal tract which, in turn, depends on the position of tongue and lips. As we pronounce phoneme after phoneme, we change the position of these vocal organs, and therefore also the formants, the spectrum, and the character of the resulting sounds." (Denes, 1966, pp. 246–247).

5.91 "A new speech perception theory . . . known as the Single Equivalent Formant and its associated parameters developed by Philco Advanced Communications Laboratory can provide a sound economical basis for a speech recognition system." (Scient. Info. Notes **7**, 21 (1966).)

5.91a See Kusch (1965). For example: "Recognition is effected with the help of a coding matrix for sound groups and another for digits. . . .

"The relevant characteristics are obtained from the form analysis of speech oscillogram . . . Two vibrations can be extracted from the overall signal with adequate reliability by means respectively of a low-pass and a high-pass filter with non-critical cut-off frequencies. The vibrations show different amplitudes, which are to be distinguished as 'large', i.e., the vibration is present . . . And as 'small', i.e., the vibration is absent . . .

"The spoken numbers were on the average correctly indicated to the extent of about 87%." (Kusch, 1965, pp. 201–203).

"The speech signal is essentially resolved into its component frequencies by means of filters, as for example in the vocoder technique. The frequency components that predominate in the frequency analysis are termed formants (characteristic frequencies). These formants, which have already frequently been used as parameters, do not constitute a reliable basis for the recognition of all sounds because of their frequency displacement from one speaker to another. Account has to be taken not only of the sounds themselves, but also of the sound transitions between consonants and vowels." (Kusch, 1965, p. 204).

5.92 In particular, von Keller has tested a procedure, using 300μs. time intervals, to determine the number of zero-crossings in order to separate the different vowels. Using as criteria the mean lengths of distances as compared to pre-determined values, he has been able to separate five of the eight vowels. (Stevens, 1968, p. 27; von Keller, 1966).

5.93 In the word classifier developments, the objectives are to discover criterial features that are *not* phonemic segments but that will successively discriminate more different classes as additional features are considered. A speech recognition device was constructed for twenty classes consisting of the ten numbers and ten words, in Italian, for Euratom, ISPRA.

"The University of Bonn has developed a machine that understands Italian and types out answers on command. Known as DAWID, Device for Automatic Word Identification and Discrimination, the machine, at the moment, has a vocabulary of 20 Italian words. It is claimed that it makes fewer errors than IBM's Shoebox system which only understood 16 words and had an error rate of 6 per cent.

"Dawid contains circuits which detect the explosive sound at the beginning of a word and measure delays on the remainder of the word. The energy level of sounds below 400 c/s is also detected and the formants of the sound are frequency analysed. A phonetic and easily readable language in which such a machine could write down messages has also been developed." (See also Data and Control Systems, May 3, 1966, p. 65, Tillman et al., 1965).

5.93a "In considering the recognition system, we intended to accept all the vocabulary commonly used and not be limited to a certain category of words. To satisfy this requirement the phoneme was selected as the basic recognition unit. . . .

"The zero-crossing pattern of the original signal is closely related to the spectra of the original signal and its peak corresponds to the formant. . . .

"The score of the machine for the Japanese monosyllables (which contain a consonant and a vowel) is more than 90 per cent for the vowel part and more than 70 per cent for the consonant part except nasal consonants, and /r/ and /b/ sounds for the pronunciation of several males." (Sakai and Doshita, 1963, pp. 836, 839, 845).

"Segmentation of the vowel interval is performed by extracting the parameters that describe the aforementioned intervals from the digital pattern of speech sound analyzed by the zero-crossing wave analysis. We defined two quantities called 'distance' and 'stability'. Stability expresses the stationary property of pattern, that is, the property that the parameter remains in an almost constant state over a certain interval. On the contrary, distance is the quantity that expresses the change of the pattern. Stability is useful for discovering the vowel sound and the fricative sound, and distance is for the sound with burst, such as stop consonant." (Sakai and Doshita, 1963, p. 837).

5.94 Further, "the means of automatic discernment (analysis) and automatic production (synthesis) of sounds of speech require the rules under which a plurilogical system, i.e., a collection of plurilogical elementary units and a manner of thesis contributing, can be correlated with real sound manifestations. Apparently, a relative simplification this task is to select a plurilogical system consisting of a collection of differential signs . . .

"In correlating the constructed system of differential signs with real sound manifestations, the main difficulty consists of differences between the phonetic norms characteristic for the speech of any person. Similar problems appear in the study of a correlation of the system of graphic differential signs with the systems of graphic norms, determining differences between various handwritings and typographical faces. A solution of the latter task is required for programming operations for reading automatic machines." (Ivanov, 1962, pp. 14–15.)

5.95 "STAR (Standard Telecommunications Automatic Recognizer) is a research machine being built at STL to further work on speech recognition . . . Four types of pulses (beginning and end of rise, and beginning and end of fall) are derived from the short-term mean power envelope of the speech wave representing an isolated word. Any or all of these may then be used to provide grouping of the other features detected, thus simplifying the order information. There are two main advantages in this approach. The grouping is related to the broad structure of the word to be recognized, and there is automatic time normalization meaningfully related to the word." (Hill, 1965, p. 357).

5.96 It is claimed for this experimental speech recognition system that "this work extends the results existing in the literature in that it deals with significantly larger sample sizes than have been commonly used, with a limited number of limited vocabularies, and with the effect of transformations of the primary measurement space on recognition performance." They state further that "the recognition performance did not drastically deteriorate as the number of words in the vocabulary was increased and suggests that good performance on vocabularies larger than 15 words is achievable." (King and Tunis, 1966, p. 65).

5.96a "CYNTHIA III is an adaptive hybrid computer, developed by Andromeda, Inc., of Kensington, Maryland, which can learn to recognize highly variable statistically distributed signals. It must go through a preliminary learning process before recognition is effective. After learning is finished it will quickly recognize the respective signals applied to its input by producing an unambiguous output coded response which identifies the signal class to which an input signal belongs. The machine is capable of extrapolating or generalizing so that new signals, never presented in the learning operation, are recognized correctly if they belong in the learned classes. The machine also provides an internal digital memory and a visual display of the characteristics of the statistical signals which render them separable. . . .

"The machine does not learn individual signals when a large number of signals are presented, but learns output classes to which certain significant signal characteristics belong. All responses which deviate from any of the averages of a set of classes are extrapolations. The average itself may not be present in an actually previously presented and learned signal, but is established by learning. The machine ignores other characteristics not in the recognition classes and which are unnecessary for identification. The present machine can deal with isolated signals such as words or short sentences taken as meaningful wholes, but cannot cope with continuous speech. Extension of its powers are being planned for the recognition of continuous speech." (Lesti, 1963, p. 279).

5.96b "To use phonetic notation is clearly simplest for the first stage, converting the continuous speech signal to discrete symbols. It is theoretically feasible to develop a method of analyzing and segmenting the acoustic signal, using phonetic symbols for specific patterns recognized, but in practice this has proved to be extremely difficult. Thus, by 1960, all that could be claimed was the ability to recognize spoken digits and some vowels in isolation (Marrill, 1960)." (Spolsky, 1966, p. 493).

"In the speech recognition system described . . ., the speech sound was divided into several segments (that seem to correspond to the phoneme) from the time variation of the analyzed pattern and then discrimination was performed for each segment. But the parameters of distributions of a segment are affected by the phonetic contextual effect from the neighboring phoneme. The speech sound, therefore, must be recognized as a whole pattern considering phonetic context. This principle, however, is difficult to apply to the recognition system of general conversational speech." (Sakai and Doshita, 1963, pp. 842–843).

5.97 See, for example, a report of work by King and Tunis based on the hypothesis that the spectrum analysis of speech waveforms will provide measurements containing or comprising statistically invariant measures of the spoken word. They describe a programming system that applies various transformations to the input measurement space. "This transformed measurement space then is used as the input to the categorizer section of the recognition system. The categorizer section consists of linear decision functions in which the weights are obtained using an adaptive algorithm." (King and Tunis, 1966, p. 65).

5.98 See Wooster, 1964, p. 13, as follows: "It is becoming increasingly clear that speech recognition can not be done on the basis of the acoustic properties of the speech signal alone; that general solutions will rely upon the interplay of linguistics and semantics."

Similarly, Lindgren reports: "Somehow, ways must be found of incorporating linguistic information in the decision-making functions of possible speech recognizers." (Lindgren, 1965, p. 121).

"Some observers place the resolution of speech recognition problems squarely on the determination of the laws of language." (Lindgren, 1965, p. 46).

"It becomes clear, then, that quite apart from its own problems, the success of automatic speech recognition depends in the last analysis on the successful solution of the problems involved in parsing and semantic analysis." (Spolsky, 1966, p. 494).

It is to be noted in particular that: "Our understanding of these contextual factors is, as yet, slight. We believe that the mechanical and anatomical properties of the vocal tract play an important part as well as a wide range of grammatical, linguistic and semantic factors. The anatomical, physiological, linguistic and other factors have a great influence on the acoustic features produced when a phoneme is pronounced in context as opposed to when the same phoneme is pronounced in isolation; it is also more than likely that as listeners we make use of our knowledge of the operation of these factors—acquired unconsciously when we learn to speak—to unravel the ambiguities of the acoustic cues. The study of these factors, of the *dynamics of speech*, is at present the major research interest of Speech Science." (Denes, 1966, p. 249).

5.99 See, for example, Dolby et al., 1965, p. 3–3: "It is one question to ask whether a particular letter sequence is an affixing sequence, and quite another to ask whether it is an affix in a particular word."

5.100 "The Farrington Manufacturing Company, New York, N.Y., a leading producer of Optical Character Readers, is expanding into the voice identification field by agreement to purchase Voiceprint Laboratories, Inc., Norville E. White, Chairman and President of Farrington has announced. The agreement provides that Voiceprint Laboratories, with headquarters in Somerville, N.J., will be operated as a Farrington subsidiary.

"Voiceprint identification is a method of identifying individuals by a spectrographic examination of their voices which is nearly as accurate as fingerprint identification. Mr. White said that Voiceprint identification 'will become a useful and valuable tool in the data processing field. In addition to use in credit verification systems, it is expected that during the next few years voice identification will be used for direct communication between depositors and a bank's computers via telephone'." (Computers and Automation **16,** No. 10, 55 (Oct. 1967).)

5.100a "The Justice Department last week launched a $500,000-plus study of the human voice as a means of identifying criminals. The work could revolutionize law enforcement.

"The program is planned as a 3-year project, but the Department is committed only to the first year's research. Tuesday, it awarded a $146,509 grant to the Michigan Department of State Police for the first phase of the project.

"Justice officials said the study will cover such voice characteristics as pitch, timbre, resolution intensity and the phase spectrum of sound waves.

"They also want to learn the degree of precision needed for adequate voice identification.

"'You may say a certain word one way one day and another way the next. We want to know where individual peculiarities become unreliable', an official explained.

"The project, a new venture for the Department, was proposed by the Michigan police.

"First year's work will be channeled into three subcontracts:

- "The Department of Audiology and Speech Science at Michigan State University will make a validation study of spectrographic equipment already on the market.
- "Stanford Research Institute will make a statement-of-the-art examination and probe alternatives to present equipment.
- "Michigan State's School of Police Administration will cover law enforcement aspects.

"Justice officials said the probe, for all its depth, is not intended as a 'definitive piece of research'. But after the 3 years, they aim to know if voice identification is feasible for law enforcement—and if more study will be worthwhile." (Electronic News **13,** June 24, 1968).

5.100b "Fingerprint identification is a very real possibility with the computer-controlled CRT reader. The technique might well produce a more complete method of cataloguing and comparing fingerprints automatically and at very high speeds." (Fulton, 1963, p. 40).

5.100c "Trauring and Cuadra have suggested matching of minutiae patterns as a basic for automatic print identification, such as for a personal identification system. In his preliminary studies, Cuadra uses manual detection of minutiae. Trauring assumed idealized feature detectors." (Hankley and Tou, 1968, p. 417).

5.100d "Van Emden has suggested a single print classification scheme using multiple ridge counts between selected minutiae, but also assumes idealized feature detectors." (Hankley and Tou, 1968, p. 417).

"Scientists and technicians at Litton Industries Advance Data Systems have been conducting a series of experiments and studies in the field of automatic fingerprinting processing for approximately three years . . .

"Consider now the key problem in the field. What information is to be extracted from the finger ridge pattern? If the FACT [Fingerprint Automatic Classification Technique] technique is employed, the finger ridge pattern is scanned and the location of all minutiae that has ridge endings and ridge bifurcations or branches is temporarily entered into storage . . . The data extraction device then returns to each of these locations and counts the number of ridges intervening between all combinations of minutiae . . .

"Using the Fingerprint Automatic Classification Technique, the minutiae table is processed using a proprietary technique evolved by the staff of Litton Industries. In actuality, four different processing techniques have been evolved using the minutiae table. They all reduce to a binary descriptor word whose length is a function of the number of minutiae encountered in the original print. This descriptor typically runs somewhere in the vicinity of forty bits but could go as high as 120 bits in some remote cases. This descriptor is well ordered and preliminary tests have indicated it to be unique." (Van Emden, 1967, pp. 493, 496, 498).

5.100e "After elementary spatial filtering, an interpretation program systematically searches along ridges, correcting for gaps, contiguous ridges, etc., to detect the print core and topological features. A topological coding program generates a sequential code sentence which describes the topological structure of the center region of the print. Ordering of code sentences is used to classify fingerprints." (Hankley and Tou, 1968, p. 413).

"All lines are directed downward from locally uppermost points, labelled T_i and called top nodes. The choice of ridge tops as nodes may be justified by their use in topological coding and by the fact that humans place comparatively heavy emphasis on such points of locally maximum curvative." (Hankley and Tou, 1968, p. 423).

"The proposed automatic fingerprint interpretation and topological coding schemes were simulated on an IBM 7094. The Ohio State University SCATRAN language was used, which allowed bit manipulating operations and logics to be expressed in essentially FORTRAN-like notation." (Hankley and Tou, 1968, p. 444).

Additional features are as follows:

"(1) The proposed scheme is a single-print system. Sufficient information is extracted from each print to allow a fine classification.
(2) The interpretation program learns print structure and performs contextual filtering to correct for imperfections such as ridge gaps and contiguous ridges.
(3) The interpretation logic is evolved via a learning mode using training data and interaction with human programmer.
(4) The coding system is topological . . . The topological structure of a fingerprint is invariant to distortions due to rolling or stretching of the skin or to changes in the size of the finger. It is also invariant to translation and rotation of the prints.
(5) The classification technique is highly compatible with the manual mode. The rules are easily learned, and classifications may be verified by inspection." (Hankley and Tou, 1968, p. 413).

Hankley (1968) reports further as follows: "This paper presents a new scheme for topological classification of single fingerprints. As a basis for a fingerprint file system, it allows a fine ordering of individual prints using a concise coding of only a small core area of each print. Moreover, the classification is highly compatible with the way in which humans naturally describe prints. These properties make practical today an automated file system with remote manual input of print code. Alternately, the scheme lends itself to automatic photointerpretation, which is described elsewhere in the literature." (Hankley, 1968, p. 1).

5.100f "Under the control of the computer, the scanner scans selected areas of 35 mm film, either in the horizontal or vertical direction. The line scanning density may be varied. The scanner sends to the computer the x and y coordinates of boundary crossings between light and dark areas. It also identifies whether a light or dark area is being entered . . .

"In the experiment we conducted, 128 small squares per print were scanned. The square size was approximately $4\frac{1}{2}$ ridges on a side. Proper positioning of the boundary was checked for each area. This was accomplished in the following manner. First an area was scanned. Then the amount of dark area was calculated. A ratio was formed between the amount of dark area and the total area. If this ratio was between the limits of one-third and two-thirds, the sample was accepted for additional processing. If it was outside these limits, the boundary was changed, the print was rescanned and the ratio test repeated . . .

"There are two types of information that a machine can extract, namely ridge endings and ridge slopes. Ridge endings can be used for secondary classification and positive identification of an unknown print. Ridge slopes can be used for primary classification. If a fingerprint is segmented into a number of small areas, the slope of the ridges passing through each area allows one to recreate, using only the slope data, a rough approximation of the print. Having this rough approximation of the print allows one to divide the total fingerprint population into a number of groups, thus allowing one to determine into which group an unknown print belongs without searching the entire file." (Shelman, 1967, pp. 467–469).

"If complete automation is to be accomplished, the scanner should have provisions for translating and rotating a print to establish a reference system. If a translational and rotational invariant descriptor can be developed, this constraint may be relieved." (Shelman, 1967, p. 477).

5.100g "It is the purpose of this paper to consider optical processing of two-dimensional images or patterns and to stress its usefulness for fingerprint processing . . . An angular averaging method, which provides rotational invariance of the spectra, in addition to their inherent translational invariance, is shown to be suitable as a coarse classification method. In addition, the use of cross-correlation techniques for identification of a fingerprint against a limited set is discussed, and some other possible schemes of optical processing are briefly mentioned." (Marom, 1967, p. 481).

5.100h "A very special hologram, called a spatial filter, has the capability of comparing two patterns and producing a signal which is a function of the correlation or similarity of the patterns. Experimentally, it has been found that complicated, natural objects with irregular patterns can be recognized with greater confidence than can man-made objects which tend to be geometrically symmatrical. Fingerprints, because of their randomness, appear to be ideal objects for the spatial filtering method of recognition . . .

"Eight fingerprints . . . were obtained from the New York State Identification and Intelligence System . . . All of the prints were very similar and would have the same general classification. The prints were copied on 35 millimeter film and a spatial filter was produced from the print designated 'E'. The strip containing the eight similar prints was then passed through the recognition system with the spatial filter in position and the recognition plane was photographed. The only print that produced an intense recognition spot was fingerprint 'E', the correct print. Several of the other prints produced some light scattering in the recognition plane due to partial correlation with the filter, but the light was not focused to a small spot and measurement showed that the intensity of the spot produced by fingerprint 'E' was 175 times greater than any of the noise produced by the other prints. There is absolutely no doubt that fingerprint 'E' was the only print which correlated with the filter. Other experiments supported the conclusion that the spatial filtering process is very selective and is not confused by two very similar prints. In fact, attempts were made to generate a filter which would recognize all prints of one particular classification and in this way the spatial filtering process could be used to classify prints automatically. So far we have been unsuccessful, largely because the spatial filters are too selective and tend to recognize prints by their fine details and ridge spacing rather than simply by their general patterns. This is advantageous when you are attempting to recognize one particular print, but disadvantageous when you are attempting to classify it." (Horvath et al., 1967, pp. 485, 489–490).

5.100i "In September 1965, the FBI submitted to members of industry who had displayed an interest, a request for proposal stated in very broad terms. This proposal solicited ideas for the development of a device that would accurately read and classify inked fingerprints. By the end of the year, we have received a number of responses . . . It appeared that the greatest consideration had been given to the use of general purpose scanners; however, it became apparent that a number of organizations were giving serious consideration to the use of coherent light and a system of optics to do the reading . . .

"An indication of the industry's interest in this area can be garnered from the fact that a preproposal conference held at FBI Headquarters on January 12, 1967, was attended by representatives of more than 30 interested companies." (Voelker, 1967, pp. 446–447).

5.100j "With the current state of the art, it is not possible to tell whether an automatic coding technique can be developed and put into practical operation over a period of the next five to ten years or so. This depends as much upon interest in the problem and financial support as it does upon technological development. With this somewhat uncertain prognosis, it seems desirable to examine alternate coding procedures while still maintaining the computerized efficiency of the rest of the system. An obvious appraoch to such an alternate technique was a hybrid system where a human would perform some of the more critical pattern recognition functions and a machine would perform the remaining functions. This hybrid system can be called a semi-automated system. If a fully automated coding technique were eventually to be developed, it seems highly probable that there would still exist many situations in which it could not perform satisfactorily. This is particularly true with respect to the coding of many latent fingerprints found at crime scenes." (Kingston, 1967, p. 450).

"Thus we have two major reasons for developing a semi-automated technique: (1) it could serve to get a computerized fingerprint processing system operational sooner than would be possible if we were to wait for fully automatic procedures, and (2) it could serve as an ancillary input to a fully automated system when this is developed." (Kingston, 1967, p. 450).

5.101 "During the past several years, various organizations have been investigating the possibility of identifying a fingerprint by automated means. A system to perform this function would encode a fingerprint pattern to be identified so that it could be compared at high speed with similar patterns, available in a computer type storage facility. An approach to encoding a fingerprint, using data about bifurcations, or ridge splits, is described. Some relationships between a suggested approach to matching fingerprint pattern and correlation detection procedures used in various modern communication systems are cited." (Gaffney, 1967, abstract).

5.102 "The system concept that was examined in our research . . . attempts to capitalize on the information represented by the ridge characteristics. Unlike the other approaches, which aim at complete automation, it proposes a man-machine operation, with the man locating the ridge characteristics and the machine (computer) performing computation and matching of the locations . . . The computer would transform the locations into a standard frame of reference and perform a variety of calculations on the relationships among core, delta, and characteristics, to provide 'index' handles for later comparison." (Cuadra, 1966, p. 9).

5.102a "One advantage of neighborhood logic over other pattern recognition schemes is its invariance to orientation . . . The PLUS instruction is a symmetrical operation and as such it does not depend upon the orientation of the bifurcations. Thus, a single sequence of instructions extracts all the bifurcations which are in the fingerprint. Since in the inverted image (negative), a ridge ending resembles a bifurcation, the algorithm can be applied to the inverted image to extract ridge ending locations." (Freedman and Hietnanen, 1967, p. 508).

"At present, work is continuing at Bendix Research Laboratories to develop an electro-optical computing system which will be capable of processing fingerprints in parallel using neighborhood logic. It is felt that such a system will have a great deal of potential to solve many other pattern recognition problems including some in the area of surveillance and detection. Thus, the system will be extremely flexible, just as the biological pattern recognition system is, and it would, therefore, fill the gap left by existing equipment." (Freedman and Hietnanen, 1967, p. 509).

5.102b "Several approaches have been made to automatic fingerprint identification including holographic techniques. The techniques that use details of a fingerprint such as cores, deltas, ridge counts, ridge endings, and ridge bifurcations tend to be specialized according to the method by which the information is taken from the fingerprint. Thiebault has described a technique using the directions of minutiae (ridge endings and bifurcations) where the data are obtained by a special camera that photographs the finger. Where a human operator identifies the core and delta as a reference axis, a matching technique has been developed that utilizes only the positions of the minutiae. The technique described in this paper is intended primarily for use with an automatic reader that reads minutiae directly from a fingerprint card without identifying cores and deltas.

"This paper describes a procedure for matching fingerprint impressions by computer using only two types of minutiae: *ridge endings* and bifurcations . . . [The] matching procedure is based on matching a constellation or group of minutiae formed about a particular minutia called the mucleus from one impression with a corresponding configuration from another impression . . . Although a particular constellation flexes and stretches, it retains a certain pattern identity in impressions taken from the same figure over a period of years. Matching just one constellation from one impression with a corresponding impression appears to be sufficient for concluding that both impressions were made by the same finger.

"Both relative distances and relative angles are used to match a constellation in one fingerprint impression with a similar constellation from another impression . . ." (Wegstein et al., 1968, pp. 1–2).

"It is interesting to note that the variation in the angle between minutiae directions tends to be quite different than the variation in the distances. This suggests that differential emphasis might be placed on angular information versus positional information in the development of a descriptor. It is clear that any descriptor must be tolerant of these variations and would, therefore, be redundant. It would not be used with the expectation of a perfect fit but rather in the sense of 'best match'. Its development would represent another challenging bench mark along the route to a possible automated fingerprint identification system." (Wegstein and Rafferty, 1967, p. 464).

"Various minute details in a fingerprint might be utilized in a descriptor. For example, the characteristics of sweat pores are as individual as the minute details of ridges. Unfortunately, special processes are required for making impressions that show sweat pores. On the other hand, ridge endings, bifurcations, islands, enclosures, incipient ridges, and breaks in ridges readily appear in inked fingerprint impressions. Furthermore, if just a few of these minutiae are the same in two different fingerprint impressions, then there is a very high probability that both impressions are from the same person." (Wegstein and Rafferty, 1967, p. 461).

5.102c It is similarly pointed out that: "Although simple and economical, the familiar process of recording inked fingerprints is liable to a variety of errors and inconsistencies. There is wide tolerance in positioning the finger. Variations in inking cause marked differences in contrast between fingerprints as well as in different parts of the same fingerprint. Ridge details are lost through over- and under-inking. The flexibility of the finger makes the image depend on the way the finger is pressed and rolled. The extent to which the sides of the finger are recorded is highly variable." (Schwartz, 1967, p. 511).

5.103 "*Recognition of Plant Species from Leaf-Vein Patterns.* We begin this study under the assumption that an algorithm can be developed which will generate a venation pattern in which certain stochastic features perturb an essentially deterministic process. The parameters of the algorithm could then be regarded as the features serving to classify the leaf types according to species." (Quarterly Progress Report No. 80, Research Laboratory for Electronics, M.I.T., 221 (1966).)

5.103a "Seven types of patterns were considered. Four of these were features of the lunar terrain: craters with flat floors, craters with central peaks, rima, and wrinkle ridges . . . The remaining three classes of patterns were types of cloud cover appearing in NIMBUS imagery: noncumulous, cumulous polygonal cells, and cumulous solid cells." (Darling and Joseph, 1968, pp. 457–458).

Another approach to cloud pattern recognition, at Astropower Laboratory, has involved the computer simulation of a Perceptron-type approach. (Joseph et al., 1964).

5.104 "A group is conducting research on respiratory ailments at Southwestern Medical School in Dallas, Texas. One parameter of interest is the number of times that a patient coughs during a given interval. Microphones are placed in selected hospital rooms and audio recordings are made . . . In addition to the requirement to classify the audio signal as cough or non-cough, the physiological model of the cough indicates that decision theory may profitably be applied to the waveform to identify the cough as having emanated from individuals suffering from different broad classifications of respiratory diseases." (Welch et al., 1967, p. 260).

5.105 "The recognition of sheet music is being studied as an example of pattern recognition in partially structured pictures. 'Partially structured' refers to a picture composed of well-defined forms or 'characters' and of forms that are only partially defined. The need to handle both types of forms and to deal with the relations between a number of forms simultaneously makes this problem more pictorial in nature than character recognition alone. The scheme that is being utilized includes nonlinear background elimination, contour tracing, and feature extraction. . . .

"With the aid of the scanner and ancillary equipment . . . it is possible to program a computer to determine note value, duration, phrasing, and certain other music indicators from ordinary printed sheet music. . . .

"At present, the program successfully processes and recognizes one general class of patterns, namely the timing-bar complexes attached to notes containing the time information for the notes. Progress continues along these lines with work now being directed toward recognition of general note clusters. . . .

"By using this scanner, pictures of music were scanned into the TX–0 and written on magnetic tape in a format compatible with FORTRAN. Nonlinear vertical and horizontal defocusing (background elimination) were effected on these pictures by using the IBM 7094 computer. Tapes were then generated containing pictures obtained by various logical combinations of picture arrays, such as complementation and logical 'anding'. The results of using these processes were various types of modified pictures, such as those with horizontal and vertical lines erased, those with nothing present except horizontal lines, and so forth." (D. H. Pruslin, Quarterly Progress Report No. 80, Research Laboratory for Electronics, M.I.T., 221, 225–226 (1966).)

5.105a "I have already been approached by persons interested in tracking baboons in their migrations across Africa. The problem is: Can the rump prints of baboons be taken by a machine such as the FACT finger scanner, processed and held in file for future comparisons when these same animals are again captured? While this seems very comical, this and other side benefits could accrue from the work done in the name of automatic fingerprint processing." (Van Emden, 1967, p. 504).

5.105b "It is wise to remember that many problems in music are complex. The extent to which data-processing technology will render solutions more accessible than do traditional procedures remains an open question. For example, it now appears that computer-generated graphic displays offer new resources for the editing procedures that are central to much work in musicology. Yet, a great deal of work must be done before machine-implemented editing can cope with the notational systems of various historical periods or with such a complex representation of the human creative process as a page from a Beethoven sketchbook. In attempting to cope with such problems, however, we can expect that traditional music scholarship will obtain insights that may determine extensive critical revisions of conventional methods and criteria." (Forte, 1967, p. 329).

5.105c "Before processing, scores are encoded by hand in a language designed by Stefan Bauer-Mengelbery in connection with a computer-implemented project to print scores automatically. This input language has unique attributes:

(1) It is isomorphic to standard music notation.
(2) It is highly mnemonic, hence easy to learn.
(3) The responsibilities of the encoder are minimal. The encoding rules are unambiguous and do not require the encoder to make arbitrary decisions.
(4) It is economical. The amount of code for a complete representation is remarkably small." (Forte, 1967, p. 4).

5.106 "As an aid to the physician, to release his time for other types of patient care, the Instrumentation Field Station of the United States Public Health Service has developed programs for automatic analysis of waveforms such as the electrocardiogram, phonocardiogram, forced respiratory spirogram, electroencephalogram, and other medical signals." (Weihrer et al., 1967, p. 289).

5.107 See Swanson, 1966, p. 4.

5.108 "At the Royal Institute of Technology, Stockholm, S. Karlsson of the Institute for Telecommunication Theory is engaged in the study of problems of pattern recognition with respect to electrocardiographic recordings. Karlsson and Arvidsson have developed a programming system for EKG measurements, using an approach somewhat similar to that of Pipberger (1965) at the U.S. Veteran's Administration. Karlsson starts with a procedure to formulate initial clusters such that a member of a cluster has its nearest neighbor in the same cluster (e.g., in the peaks of the recording), and repeats for the next nearest neighbors and so on. The purpose is to derive a measure for each pattern category by extracting features common to all members of the same cluster." (Stevens, 1968, p. 33)

5.108a See, for example, Pizer and Vetter, 1968, on the perception and processing of medical radioisotope scans and the work of Butler (1968) on automatic analysis of bone autoradiographs.

5.109 "The general approach is also being applied to problems of medical diagnosis and data interpretation such as are encountered in electrocardiographic, phonocardiographic, and x-ray interpretation." (Teager, H. M., Quarterly Progress Report, No. 80, Research Laboratory for Electronics, M.I.T., 269 (1966).)

5.110 For example, projects at the University of Pisa are concerned with automation of the analysis of radiocardiograms. "This involves a non-linear programming problem to determine transfer functions of interest, requiring detections of the first three moments, average dispersion, symmetry, as characteristic of desired curves. Similarly, there is a project to extract time sequences of nerve pulses and to determine coding in the optical system. For this purpose, a special-purpose analog-to-digital converter has been designed. A more generalized converter is under development for a variety of biomedical investigations including EEG, EKG, and other problems involving pattern recognition with respect to clinical data." (Stevens, 1968, p. 32).

5.110a "The automatic computer analysis for the determination of the mitotic index involves scanning with the FIDAC . . . Since a mitotic cell is in the process of fragmenting, it has a much more irregular boundary than has a nonmitotic cell. To distinguish between mitotic and non-mitotic cells, then, the computer is programmed to count the number of concavities smaller than a given segment length in the silhouette of each object or cell, and compare this number with the total number of such segments on the boundary. The greater the proportion of concavities, the more irregular the boundary and the more likely it is that the cell is mitotic." (Ledley et al., 1968, p. 100).

5.111 "The CYCLOPS 1 appears to be among the most sophisticated and powerful pattern-recognition devices yet reported; its capability to do quite elaborate scene analysis is perhaps unique." (Hart, 1966, p. 16).

For example, "the program may be commanded from the typewriter to analyze a complex scene. Such a scene may consist of *known items,* i.e., shapes which have been defined as being significant (the alphanumeric characters); and of other items, some of which may be significant to the viewer but not to the system, and some of which may be merely background 'noise'. An arbitrary number of known items may be present simultaneously; they may be of different sizes and orientations; they may overlap, or be inside each other; they may be superimposed on an arbitrary background." (Marill et al., 1963, p. 28).

The CYCLOPS–I scheme involves a series of *finding* operations by looking for what might be there and by progressive eliminations of possibilities. Thus, "a negating *tree* system has been used by Marill et al. in which the possibility of an unknown being a particular character is examined sequentially (i.e., if the unknown alphanumeric does not consist of essentially one segment whose length is little more than the distance across the end points, and is approximately vertical, it is not a *one*)." (Minneman, 1966, p. 86).

5.112 ". . . We are now able to begin serious study of the most difficult problem facing the project: The analysis of real-world three-dimensional scenes." (Minsky, 1966, p. 12).

"Programs have been developed to read selected parts of the visual scene, analyse them for parts of polygonal objects, and then transform them to real-world coordinates. The present programs are still rudimentary, and their extension is vital to the project." (Minsky, 1966, p. 16).

"Our goal is to develop techniques of machine perception, motor control, and coordination that are applicable to performing real-world tasks of object-recognition and manipulation." (Minsky, 1966, p. 11).

"The sensory equipment includes two visual-input devices: TVA, a vidicon television camera, and the more precise TVB, an image-dissector device for controlled-scan analysis." (Minsky, 1966, p. 13).

Further, "processes for recognizing visual objects by computer programs are being studied. These processes involve analysis of the visual field into objects and background. Objects are to be recognized by generating hypotheses and confirming them or modifying them by the results of selective attention to parts of the field and of the proposed objects. These processes will entail use of stereopsis and color, as well as the construction of abstract symbolic three-dimensional representations of the scene within computer memory." (Quarterly Progress Report, No. 80, Research Laboratory for Electronics, M.I.T., 195 (1966).)

"A picture, scene or view is read with the help of an optical device and stored as an array of light intensities in the memory of the computer. The ultimate goal will be to understand this information, that is, to identify, separate and position the different objects or bodies belonging to the scene(s). The demands of information will vary: sometimes we will be interested in knowing if an object is seen in the scene or not, while at other times we may require a complete description of the scene, including information on relative support and (3-dim) position of the different components." (Guzmán-Arenas, 1967, p. 1).

"For planning and control of the overall activity of the machine, we are taking into account texture and color, as well as object boundaries and the like. The system will be able to partition a scene into objective regions, combine these regions into proposed objects, and finally present this collection of pseudo-objects as an abstract model of the objects and background in real space." (Minsky, 1966, p. 16).

5.113 Cf., for example, Dreher as follows: "As a matter of survival and social interaction, it is necessary for living systems constantly and concurrently to perform two types of event classification, termed by anthropologists 'etic' and 'emic' distinctions. Under etic classification, similarities among events are cancelled out and attention is focussed upon differences; in the emic classification, differences are disregarded and any possible similarities are focussed upon." Dreher (1966, p. 9).

5.113a "Pattern recognition is only one aspect of the much more fundamental problem of analysis and description of *classes* of patterns (or equivalently, *classes* of pictures)." (Narasimhan, 1966, p. 167).

"The problem of designing logics to recognize characters can be considered as requiring two main efforts. The common starting point of all recognition techniques is 'feature extraction' operations on the character to determine the significant characteristics of the character. The second investigation involves the problem of identification, that is, the problem of classifying a character as a member of one of several classes." (Liu, 1964, p. 586).

"The essential problem of character recognition is to find which of two patterns is the more similar to a third. When this problem has been solved, an unknown pattern can simply be 'recognized' as belonging to the recognition class to whose members it is most similar." (Ullmann, 1966, p. 584).

5.113b "Since pattern recognition is actually the operation of classification, the concept of classes of patterns plays a central role . . . Each class is represented by a region, or more generally by a distribution function in some kind of pattern space." (Richardson, 1966, p. 10).

"Very popular in decision techniques and in pattern recognition is the minimum Hamming distance (MHD) method using binary feature set $\{x_i\}$. Here the categorizing is accomplished by determination of the MHD between the applied binary sets and all those ideal feature sets stored." (Kazmierczak and Steinbuch, 1963, p. 826).

"A more general adaptive procedure for determining linear or piecewise linear discriminant functions for multiclass pattern classification is proposed. The adaptive procedure is a many-pattern or group-pattern adaptation. The training sequence consists of groups of vectors in matrix form instead of single vectors. The convergence proof shows that this procedure terminates in a finite number of adaptations if a solution exists. A necessary and sufficient condition is developed for testing the linear separability of each subset of (d & 1) samples. Furthermore, the proposed procedure can be implemented with the addition of only a little complexity to existing systems. Computer simulations indicate satisfactory results." (Wee and Fu, 1968, p. 178, *abstract*).

5.114 "There are many purely hardware considerations that dictate the particular choice of measurement, transformation, or decision function to be used; certain measurement spaces may require much more digital storage than others." (King and Tunis, 1966, p. 66).

5.115 "Among the challenging problems in the design of pattern recognition systems, two problems are of utmost importance: (1) the extraction of pattern features, and (2) the optimum classification of pattern classes. The first is concerned with the problem of what to measure, and the second deals with the problems of making optimum decisions in classification." (Tou and Heydorn, 1967, p. 57).

"The essential point underlying the validity of the separation of the system into two parts, is the requirement that the quantities $[b_i]$ produced by the property filter define a pattern space of modest dimensionality in which the classes overlap to only a minor degree." (Richardson, 1966, p. 75).

"To avoid inaccuracies in prediction caused by too many measurements, a method is given for selecting from the available measurements a subset that will usually give a more accurate prediction. Essentially, this technique consists in estimating the mean square error associated with various numbers of measurements in a particular ordering. This selective approach to prediction is most profitably applied to problems involving a relatively large number of measurements and a limited number of learning samples. Two experiments having these properties were presented to show the power of the selective predictor." (Allais, 1966, p. 128).

5.116 "The theorem of the ugly duckling shows that if all the predicates which are logical functions of the observable attributes of objects are considered as having equal importance, or weight, there cannot exist any recognizable classes of similar objects. This is because, according to the theorem, any pair of non-identical objects shares the same number of predicates as any other pair of non-identical objects. This means that if there are recognizable classes of similar objects in our world of experience, some predicates are tacitly given more weight than some others. This is the basic mathematical fact underlying the technical knowledge shared by everybody that the essence of pattern recognition lies in weighting or evaluation of variables and in eventual selection of a 'few' 'good' ones . . . For this reason, the process of pattern recognition can be considered also as a sort of information compression, because its purpose is to ignore that information which is irrelevant to class features." (Watanbe et al., 1967, p. 192).

5.117 Some of the results that have been reported deal with the likelihood functions of separable stochastic functions (Brick and Owen, 1967), with measures to select variables so that the probability of misclassification is systematically decreased (Rao, 1966), and on algorithmic approaches to the determination of decision boundaries based on learning samples. (Henrichon, 1967).

5.118 "The mathematical model used is the classic one of which so many of the statistical pattern recognition studies have been based, whereby an n-dimensional sample space is partitioned into category regions with decision boundaries . . . Assuming there exists a probability distribution associated with each category describing the distribution of its members in n-space, the object is to partition the space in an optimal fashion. An unknown vector is then assigned to the category in whose region it falls." (Cooper, 1966, pp. 1–2).

"Adaptive pattern recognizers incorporate approximations to the class probability distributions that improve as a result of cumulative information derived from known inputs." (Barus, 1966, p. 385).

5.118a "The reliability of a particular recognition procedure can be described quantitatively by means of certain misclassification probabilities and cost functions. These, in turn, define a loss function which usually forms the base for choosing the classification regions. For example, the Bayes procedure chooses $R_1, \ldots R_m$ so as to minimize the expected loss, while the minimax procedure minimizes the maximum expected loss." (Capon, 1965, p. 247).

A specific example is given by Allais as follows: "Data for the first experiment were obtained from a handwritten character reader, built by IBM (Greanias, et al.). The problem treated is that of discriminating between the handwritten numerals one and zero. One hundred measurements were chosen at random from 160 which were available, and of these only 78 were nontrivial. Thus these experiments were performed with $q=78$ candidate measurements. Each measurement was an integer-valued number less than 20, and predictand y was a binary indicator. Hence, the data are nonnormal. Measurements were ordered by partial correlation with the class indicator y, using 100 learning samples. Recognition using various numbers of measurements was then tested on 284 independent data samples. Minimum estimated error ϵp occurred with $p=29$, which in this case resulted in zero recognition errors." (Allais, 1966, p. 128).

"The main result of the foregoing analysis is the practical interpretation of an expression for the mean square error of the maximum-likelihood predictor. Here, the fractional increase in error due to using a learning sample was found to be approximately $p/(N\text{-}p\text{-}2)$, where p is the number of measurements. This result explains why a prediction is sometimes more accurate if it is based on fewer than the total number of available measurements." (Allais, 1966, p. 128).

5.118b "The notion of effectiveness of a recognition logic may be interpreted from an information-theoretic point of view. Intuitively, one hopes to obtain effective recognition logics so that the accuracy of recognition may be enhanced, or the number of logics required to achieve a given accuracy may be reduced." (Liu, 1964, p. 586).

5.118c "Since the shapes of the Arabic numerals and English alphabet were not designed to make the most efficient use of common features, it is not possible to code the numerals and alphabet with six or seven features bits, as in the case of an ideal code. Prior studies have shown that substantially more than seven features will be required—perhaps as many as twenty or thirty." (Greanias, 1962, p. 145).

5.118d "Considering pattern recognition as a statistical decision problem, the structure of a recognition system can be derived from the functional form of the probability distributions. Successive approximations to the distribution functions lead to a hierarchy of recognition structures." (Chow and Liu, 1966, pp. 73–74).

5.118e "In general, the measurements are not statistically independent; there exists a certain, though usually unknown, dependence among the measurements. The central problem is to determine which dependence relations are worth examining and how to weigh them." (Chow and Liu, 1966, p. 74).

"For certain types of measurements, the chain ordering or the dependence tree may be inferred from the physical or geometrical properties of the measurements. For example, when these are the direct video image of the pattern, then the assumption of neighbor dependence such as described by Chow [1962] is a reasonable choice." (Chow, 1966, p. 108).

5.119 "It has been recognized that the pattern recognition problem can be discussed within the framework of statistical classification theory." (Capon, 1965, p. 247).

"We turn now to a second way of describing classes, namely in terms of statistical distributions . . . The only reasonable way to describe overlapping classes is statistical. In this kind of description, whether the pattern space be complete or incomplete, a given pattern is assigned a probability of lying in a given small region of pattern space and this probability is further decomposed into a sum of terms each giving the probability of membership in a given class. . . .

"Another way, perhaps intuitively appealing, of looking at the statistical prescription is to regard each class as a pile of dust resting on a multidimensional floor corresponding to the pattern space. Each pile contains a particular kind of dust and different piles may overlap, one layer over another. The total amount of dust of all kinds over a given area of the 'floor' represents the probability that a pattern lies in the area regardless of its class membership. The relative thickness of the various layers of dust then gives the probability of membership in each class." (Richardson, 1966, pp. 11–12).

"The use of statistical decision functions is one of the many possible approaches to the problem of character recognition by computer." (Chu, 1965, p. 213). Cf., also, Dressler and Werner as follows:

"Of the many different pattern recognition systems and devices utilizing various principles of operation, this analysis is confined to those which employ a 'forced-learning' preliminary procedure, and which base decisions upon application of the maximum-likelihood principle of statistical decision theory. In this type of system, the statistical data compiled from the forced-learning process are stored in the memory of some associated computing circuits and used as the basis for calculations of posterior probabilities, and probability calculations are made directly from Bayes' Rule. Within this particular procedural framework, there are, among other conceivable possibilities, two basic alternatives regarding the nature of the data utilized.

(a) The simpler method, now in common use, employs some fixed *threshold*, a single quantity, for each *mask*. If the excitation resulting from the application of an unknown pattern to a mask exceeds this threshold, then the mask is said to be excited or to *fire*. The probability scores necessary for the calculations are then only the relative frequencies of excitation and nonexcitation for each pattern class of interest . . .

(b) Contrasted with this, a somewhat more complicated procedure which could be used would employ the complete probability density curves resulting when one entire class of patterns is presented to each mask, instead of just a fixed threshold procedure. The statistical decision in this case is then based not merely upon the probability of a firing or a nonfiring, but rather upon a quantitative measure of the mask's response to an unknown, in terms of the known probability density curve." (Dressler and Werner, 1964, pp. 471–472).

5.120 Similarly, in the area of speech recognition, "one approach of interest assumes the existence of a perfect measurement X_j for each class of utterance. It also assumes that the variety of measurements is the result of the perfect measurements being corrupted by additive noise. . . .

"If an operation on the measurements, $X^1 = g(X)$, could be discovered that would eliminate the effects of variation in speed of talking, volume, and expression between speakers, the problem of recognition of human speech might still be approached from the perfect signal point of view." (King and Tunis, 1966, pp. 66–67).

"Talbert, et al., and Dammann have reported on the use of adaptive linear decision functions in speech recognition studies . . ." (King and Tunis, 1966, p. 65).

"Research in pattern recognition may be characterized as a search for invariants. The problem is to find attributes that all instances of a given pattern have in common that instances of other patterns do not. The particular class of invariants selected will ultimately determine the performance of the pattern recognition system. However, performance is not the sole factor influencing the choice of invariants. Associated with any research project are certain objectives and goals. In pattern recognition, achievement of these goals is not only a function of what the system recognizes, but also how it performs the recognition. Thus the selection of invariants may be more influenced by the purposes and philosophy of the research than by a desire for a high rate of recognition. To illustrate this point, let us examine briefly two character recognition schemes which are at opposite ends of a spectrum with respect to the aims of their research. Both perform very well in that their recognition accuracy is high. Their basic difference in purpose and philosophy is reflected in two very diverse sets of invariants. These two schemes will provide a frame of reference for the research described in this paper." (Teitelman, 1964, pp. 559–560).

"What is needed, then, is a concise description, invariant to size and position of the pattern which presents, in a direct manner, the segment interrelationships. One would like, further, that any such description while not being rotationally invariant, be readily amenable to rotational manipulations. This last because many line patterns and letter sets, while not wholly rotationally invariant, are largely so, and it would be desirable to be able to conveniently probe this aspect of the recognition problem. Clearly, in order to avoid reference to an arbitrary external point, a point in the pattern itself should be chosen as a reference. The pattern's centroid is a good choice." (Spinrad, 1965, p. 128).

5.121 "Only this kind of identification of the problem [defining the objectives of associative retrieval in mathematical terms] is likely to yield productive results and we may find . . . that distinctly different association matrices are required, depending upon the problem which requires solution. . . .

Bryant also expresses ". . . surprise that so much attention has been given to derivation of measures of association and correlation in the absence of mathematical work which specifies that, under certain reasonable assumptions, these are the measures needed." (Bryant, 1964, pp. 503–504).

"It is clear that carefully controlled experiments to evaluate the efficacy and usefulness of the statistical association techniques have not yet been undertaken except in a few isolated instances. . . .

"Adherents of the statistical approach spend much time arguing among themselves as to whether this or that statistical technique is more appropriate, but those who have a chance to compare them often find that the difference in output between one technique and another is not appreciable." (Doyle, 1965, p. 18).

"All such methods involve two considerations. First, there is defined a measure of group-density or of inter-group likeness. Examples of the latter type of measure (the so-called 'similarity coefficients') are legion; the best-known have been reviewed by Goodman and Kruskal (1954, 1959), Dagnelie (1960) and Sokal and Sneath (1963), but it is doubtful whether even these extensive collections are complete. For general consideration, suppose that two groups (i) and (j) fuse to form a group (k); then, extending (and slightly altering) the symbolism of Williams, Lambert and Lance (1966), we shall need to distinguish between three types of measure: (i)-measures, which define a property of a group, (i, j)-measures, which define a resemblance or difference between two groups, and (i, j, k)-measures, which define some difference between the original two groups, considered jointly, and that formed by their fusion. Of these, (i)-measures are confined to clustering techniques except in so far as they may be incidentally required in the course of calculation of (i, j, k)-measures." (Lance and Williams, 1967, p. 373).

5.122 "Goodman and Kruskal (1959) have identified over 50 different formulas for measuring associations. Each such formula has its own advantages as well as its drawbacks, and, given our present incomplete understanding of the problem of semantic association, it would be premature to suggest any one as ideal." (Guiliano, 1965, p. 27).

5.123 An optical relization of "PAPA" (Italian acronym for 'Automatic Programmer and Analyzer of Probabilities') (1962) provided a filter for each of the two classes *a* and *b* to select only those optical fibers that give a preferential 'yes' answer for the appropriate class with weights proportional to their 'goodness' as discriminating criteria.

"The first dichotomic separation is based on 'the most widely fluctuating property', which is also in most cases the most evident or simple property for the sense organs of the machine." (Gamba, 1961, p. 147).

"The inductive ability of PAPA is related to an 'intelligence' term, proportional to the average correlation factor of *different* patterns of the same class." (Gamba, 1962, p. 176).

"After PAPA No. 2 has been instructed by presenting to it an equal number of example patterns of both classes, the tape is run backwards. The read-out amplifiers pick up the "yes" (and "no") pulses for each A-unit and check their values. If they are the same within a preassigned percentage, this means that the A-unit is inefficient. In this case the corresponding noise . . . is automatically erased and replaced by fresh noise. This might give rise to another inefficient A-unit, but since the process is such that the efficient A-units are maintained, by repeating the process several times the average efficiency of the A-units for the given classes is considerably increased." (Palmieri and Sanna, 1962, pp. 8–9).

In the presently demonstrable model of Gamba's 'PAPA', Figure 18, 4,096 associational 'cells' are used with 8-bit discriminatory capacity for each, so that 64,000 bits of storage are required for this purpose, and up to 8 categories or classes can be distinguished. It should be noted, of course, that size normalizations are not required in the system and that depending upon the training sequence, considerable tolerance to location in the input field and to rotation can be accommodated.

"The present demonstration equipment and programming allow a 32-sample training sequence per class. Output consists of the lighting up of an indicator signal for the machine-selected class and/or the printout of the numerical values of the machine-calculated probabilities that a given input pattern belongs to class 1, 2, . . . 8.

"Potential application investigations have included studies of knight vs. rook moves in chess, and the question of whether the Paschal lines for random interconnections of lines drawn from 6 points on the circumference of a circle are vertical or horizontal. Perhaps more practically, the system has been applied to meteorological chart discriminations with respect to isobar or isotherm curve patterns, that are symptomatic, respectively, of good or bad succeeding weather in a specific location. Here, given training sequences of 50 samples each for the two classes, the 'PAPA' machine system has achieved 80% valid recognitions," (Stevens, 1968, p. 29).

To date, the same randomly-generated intersection-detection patterns have been used for the various tests. There is no reason, however, that other randomly-generated filtering patterns could not also be used, but this question has not been investigated in detail. On the other hand, at least preliminary consideration has been given to problems of speech recognition, without alteration of the basic approach.

5.124 The objective is, "given a set of patterns, [to] determine a set of features, minimal in number, such that each pattern can be formed by the superposition of a subset of these features." These authors conclude, however: "Unfortunately, we have not yet been able to find a reasonably brief algorithm to solve the problem in this degree of generality. However, we shall present two useful algorithms for the case in which the features are large compared to their mutual overlap. Results of experiments by digital-computer simulation will be used to show that these algorithms can lead to valuable results, even when this restriction is not met." (Block et al., 1964, p. 84).

5.125 "A 'conditioned-reflex' machine which can learn to recognize photos of aircraft or even people has been developed for the Air Force Systems Command's Aeronautical Systems Division at Wright-Patterson Air Force Base, Ohio.

"Called Conflex 1, the pattern-recognition system was built by Scope, Inc., of Falls Church, Va., in a 30-month program for the Air Force Avionics Laboratory at ASD.

"Decision-making by machine is becoming a critical requirement in aerospace operations where vast quantities of data must be collected, studied, and a conclusion reached almost instantaneously.

"The device is capable of recognizing 4,800 different previously learned patterns, including pictorial displays, letters, numbers, and geometric designs, with 99.6 per cent accuracy." (Ordnance Electronics, 212, Sept.–Oct. 1963).

"CONFLEX I was designed to serve as an experimental CR ['conditioned-reflex'] system. For this reason, it was decided that the design should provide for several thousand D-cells [discrimination] and multiple M-fields (classes)." (Uffelman, 1962, p. 137).

"What is required, is a system that does not merely discriminate between one pattern and another, but rather analyzes classes of patterns and is capable of extracting the properties of a class that is common to all its members. . . .

"Handwritten characters were used to train the device. The letters A, D, and C were considered. Thirty examples of each were used for training. After training, all ninety of these examples were rerun through the system for recognition. There were eight system errors using probabilistic sorting. Using unknowns (or letters not used in the training sequence) the probabilistic scoring technique was compared to the Perceptron technique. The error rates were 14% for Perceptron and 20% for Probabilistic scoring." (Hoffman, 1962, pp. 153, 156).

5.126 "The GPO approach of Coombs and Milne has been applied to badly mutilated examples of a 10-character multifont vacabulary. A technique of 'shuggling' (shuffling or jittering) is used to determine maximum and minimum correlata of the input image with the same and other patterns in the vocabulary. From these determinations, a somewhat irregular 20 × 10 matrix of criterial points provided successful character discrimination of 198 of 200 patterns of the training set." (Stevens, 1968, p. 5).

5.127 "Much more substantial is the nonlinear nature of transformations realized by the *A*-units with many inputs. Such transformations, as has been shown by Barus' work, given a great number of *A*-units, make it possible to store more detailed information about the variety of patterns utilized during the teaching." (Kovalevsky, 1965, pp. 41–42).

"The test alphabets were chosen on purpose to be difficult to classify. Early success with an alphabet of 'squares' and 'circles' ('O's') led to further tests with a more difficult alphabet, consisting of the hand-printed letters 'O', 'Q' and 'C'. Although these letters are distinguished by simple features, it must be remembered that we are assuming no *a priori*

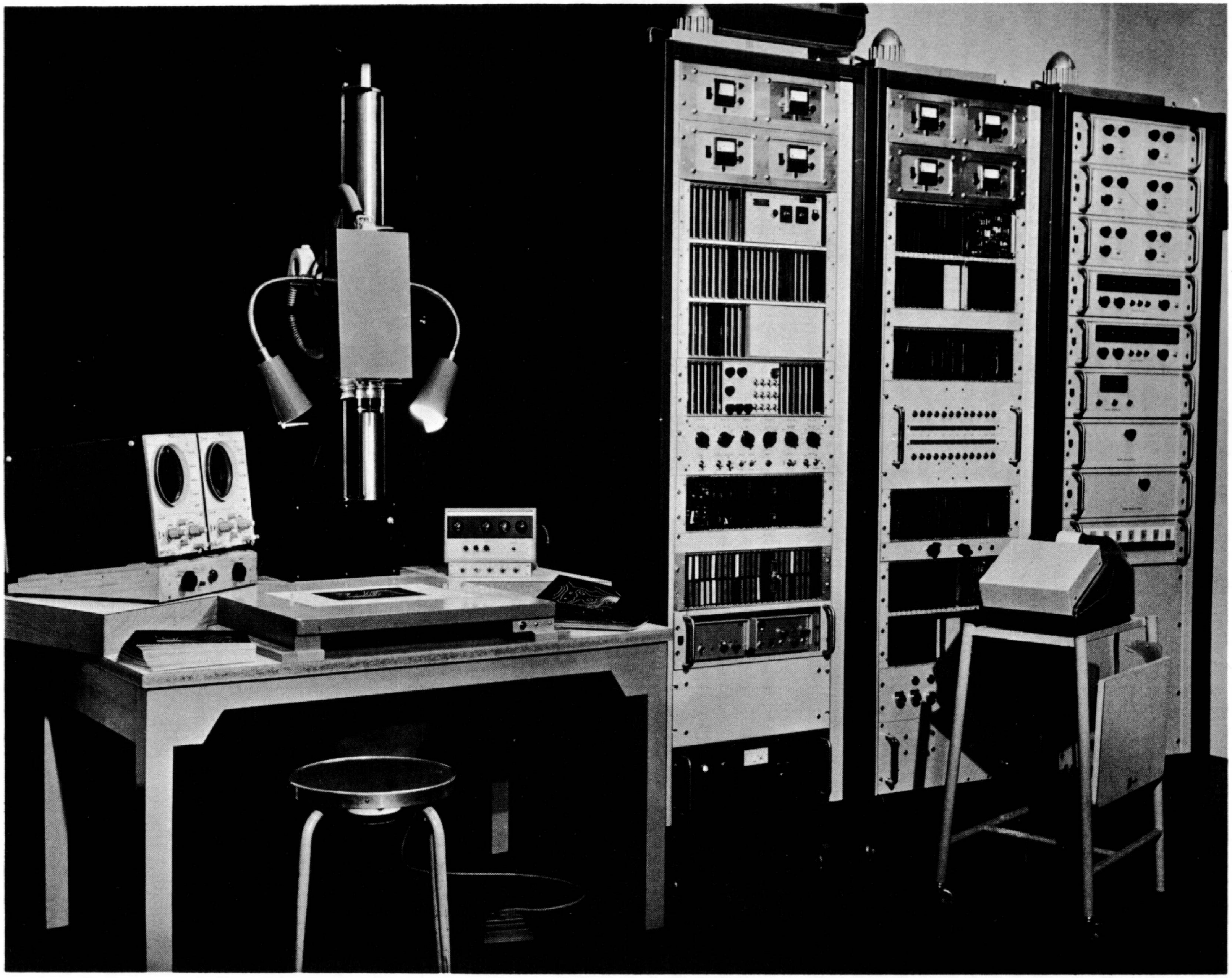

FIGURE 18. *PAPA machine assembly.*

knowledge of the alphabet on the part of the machine or the designer." (Barus, 1962, p. 241).

"Members of a stored sample can also be used to *define* subclasses, each sample member being treated as a subclass centroid. Newly encountered pattern members, instead of being averaged into an evolving subclass . . . are used to evaluate the representativeness of the stored sample, to assign weights to each subclass, and to adjust parameters of the assumed subclass distribution. With this method, subclasses (each represented by a member of the stored sample) can easily be discarded or new ones added as part of a learning program." (Barus, 1966, p. 386).

5.128 "The Multivac has been trained to recognize and discriminate alphanumeric symbols, play simple games, differentiate between sounds (such as between those of a whale and a dolphin), and even to run a maze . . . The Multivac's ability to search photographs for evidence of structures of a particular kind is being applied under a contract to NASA which calls for a 'study of the feasibility of extra-terrestrial landmarks', which may lead to an automatic method of classifying the visual appearance of other planets. The contract includes design of a system that will be trained to recognize a number of categories of landscapes by processing a library of representative slides to be furnished by NASA. In actual spaceflight missions, the system will observe the surface of a planet being explored and classify the landscape into one of the known categories." ("Machines That Think?", 1966, pp. 6–7). See also Asendorf (1968).

5.129 "MINOS II has been successfully trained on patterns, converted by preprocessors into digital form, that represent such diverse subject areas as handwritten graphical symbols, weather information, visual or photographic objects, time-varying wave-forms, statistical data, and switching functions." (Munson et al., 1966, p. 360).

"In the meteorological application, ISODATA is being used to aid in the analysis of 646 weather records related to ceiling height at Washington, D.C. The goal in this case is the design of preprocessing for short-time (5 hours ahead) predictions of ceiling height." (Ball and Hall, 1965, p. 330).

5.130 "The input to CHILD consists of n analog values, which can be thought of as an n-dimensional analog vector. This input vector can be derived either directly from the sensors or from some pre-processing technique utilized to extract characteristics (or features) from the sensory pattern . . . It is CHILD's primary purpose, then, to determine (1) which components of the input vector are important, (2) the range of acceptable values each component may assume, and (3) the degree of importance to be assigned to each component." (Choisser and Sammon, 1963, p. 1).

5.131 In Bonner's method (1962), samples of members of the recognition vocabulary are represented as binary words for the presence-absence of pre-specified properties. The problem is then simplified by breaking the total number of samples into subsets of similar samples, where similarity is defined as the number of identical bits in the words equalling or exceeding a given threshold. Categories are formed by taking, any sample, and 'remembering' it as 'Mask i', taking another sample and either ignoring it if similar to Mask i or remembering it as Mask ii, continuing until all samples have been processed. A "signature" is then developed for each sample consisting of binary indications as to which of the categories it does or does not belong to. (p. 355).

Further, Bonner's property-finding algorithm "looks for bits and logical combinations of bits which are valuable in distinguishing the various types of samples in the category. It does this mostly in a nonexhaustive manner by proposing hypotheses of possibly valuable properties, then evaluating and classifying these properties and creating new hypotheses from the result." (p. 355).

5.132 "By a procedure using these principles, the program builds up properties of such complexity as: a thirty way AND OR-ed to a forty-way AND; a four-way OR AND-ed to another, and other properties of lesser complexity down to and including individual bits." (Bonner, 1962, p. 356).

5.132a "The problem of designing discriminant functions for nonseparable pattern sets is a practical one because in many practical problems the overlapping probability densities of the different pattern categories will make nonseparable pattern sets inevitable. Current practice for pattern sets which are not completely separable is to use the adaptive methods anyway, because they tend to yield adequate classifiers even though they cannot eliminate all classification errors.

"Using linear programming in the design is easier than using adaptive methods." (Smith, 1968, p. 367).

"In general, the feature sets of different pattern classes are not linearly separable. It is doubtful whether in this case an approximation by complete linear-decision functions is practical with regard to the required expense." (Kazmierczak and Steinbuch, 1963, pp. 831–833).

5.133 For a comprehensive discussion of threshold logic techniques, see the text by Hu (1965). We note also the following:

"Many pattern classification systems use linear threshold elements to perform linear discriminations on the patterns of interest. In such an approach, n properties of patterns are measured and each property is assigned a real number, X_i. The n values (X_i . . ., X_n) are used as a descriptor of the pattern. . . .

"A linear threshold element (LTE) is a device which has n inputs (X_i, . . ., X_n) and a single output, f. Each X_i is a real number and the value of f is determined by forming a weighted sum of the input quantities and comparing this sum S to a threshold T." (Mattson and Dammann, 1965, p. 294).

"A linear logic unit may be provided with a threshold varying in time over the entire range of possible input levels. A logic unit then turns on at a time directly determined by the input level. Depending on the nature of the weights assigned to the input connections, a unit with n binary inputs may have from nt 1 to 2^n distinct input levels. In the latter case—achieved by assigning weights proportional to powers of 2 to the connections—each possible binary input state has a unique weighted signal level. Thus the time of response of a logic unit may be made to specify exactly the input subpattern to the unit.

"The proper utilization of this unit in a large system requires that the output weight associated with a logic unit vary synchronously with the threshold. To accomplish this, a system clock may be used to control the threshold and to specify the output weight." (Astropower Lab., 1964, p. 192).

"The input weights and hence the logic unit hyperplanes were determined by the use of the discriminant analysis technique . . . For computational reasons, each logic unit is permitted only a small number of input connections (corresponding to nonzero coefficients of the hyperplanes). More units are generated than are used in the machine.

"The selection of logic units to be incorporated in the machine is done sequentially in order to maximize the separation of pattern classes in the recognition space . . . each unit being added to the machine being selected from a population of possible units by the criterion of maximum improvement over existing interclass separations. This is accomplished by means of a loss function . . . The procedure . . . concentrates on those patterns near the boundaries, assigning large weights to logic units active for these patterns, thus effectively increasing the separation of pattern classes.

"The use of linear logic threshold elements in current pattern recognition devices involves two major difficulties: such devices are capable of only two outputs, and the assignment of outputs to particular inputs is subject to the restraints of linear separability." (Astropower Lab., 1964, pp. 192, 194).

"Threshold logic, a new and active area of switching theory, has been primarily motivated by an interest in certain computer devices called 'threshold gates'. The logical functions performed by such gates—called threshold functions, linear-input functions, majority functions, etc.,—have been given a great deal of mathematical attention. A switching function f of n arguments is a *threshold function* when there exist *weights* $a_1, a_2, \ldots a_n$ and a *threshold* T (all real numbers) so that

$$f(x_1, \ldots, x_n = \begin{cases} 1 \text{ if } \sum_{i=1}^{n} a_i x_i \geq T, \\ 0 \text{ if } \sum_{i=1}^{n} a_i x_i < T." \end{cases}$$

(Winder, 1963, p. 108.).

5.134 ". . . Iterative routines which operate on a sequence of measurements, $X_1, X_2, \ldots, X_n$ where the class associations are known *a priori* and the number of measurements from each class is large enough to be representative. After a suitable number of iterations, the process either converges, or else the performance of the systems ceases to improve . . . Nonconvergence indicates either overlap of the distributions associated with certain or all pairs of classes or else linear inseparability." (King and Tunis, 1966, p. 67).

"Two classes are said to be linearly separable if a hyperplane can be placed between them. Many self-organizing machine concepts assume the linear separability of classes. It is obvious that if two classes are convex and nonoverlapping they are linearly separable. However, if the classes are not convex the question of linear separability is harder to answer. However, in the case of certain specific models of classes, linear separability can be shown to be impossible." (Richardson, 1966, p. 11).

5.135 Greenberg and Konheim ask "*how well will the separating hyperplane separate patterns which are not included in the training set but which are to be separated into the same classes?* This is a question involving the error rate on new patterns and one that can be answered only by subsequent testing of the new data. On the other hand, since the linear functionals are continuous it is reasonable to assume that new patterns that are close to old patterns will be similarly classified. The limits of such a form of 'generalization' depend upon how well the linear functionals separate the classes. There is a well-defined and obvious sense by which we may rank the functionals which separate the two classes A and B. However, the algorithm given . . . yields only one such separating functional and the problem of finding the 'best' separation is a difficult unsolved problem." (1964, p. 306).

5.136 "Rabinow Electronics, Inc., . . . has received a patent for an optical character recognition system featuring dictionary lookup . . . The system checks doubtful words (indistinctly written) by comparing characters against words in storage, then selects the most likely word." (Commun. ACM **9**, 707 (1966).

"Successful machines of which we are aware, recognize individual characters and produce outputs (usually clerical) identifying the characters. There have been a smaller number of attempts to recognize words, as opposed to the individual characters of which the word is composed. The S. F. Reed Patent No. 2,905,927 discloses a method and apparatus for recognizing words as such, and not the individual characters of the word. The V. K. Zworykin et al. Patent No. 2,616,983 and L. E. Flory et al., Patent No. 2,615,992 disclose machines which are in the nature of word recognizers. The Zworykin and Flory disclosures relate to equipment for translating written data into sound to aid the blind. On the other hand, the Read patent is directly concerned with word recognition in data processing pursuits.

"An object of our invention is to provide a recognition system for identifying the individual characters of a word, but which relies on a dictionary look-up to ascertain the identity of the word if the reading machine is incapable of identifying one or more of its characters. In principle, we recognize a word (and hence obtain knowledge of all of the characters thereof) by identifying all of the characters of the word which the reading machine is capable of identifying, and then systematically interrogating a dictionary until we find a word or words which have all of the machine-read characters plus another character (or characters) in the place of the unknown character (or characters). The dictionary word (or words) are then fed to a utilization device such as a buffer, printer, computer, etc. . . .

"Another object of our invention is to provide automatically operative means for correcting an erroneously read character, or character reading machine failure of any other type, where the intelligence criteria to determine the identity of the unknown character are based on the characters which are correctly read by the machine.

"A broader objective of our invention is to provide an error correction system for a character or characters of a word, regardless of the originating source, i.e., whether or not a reading machine is used.

"A novel aspect of our invention is the technique for finding the word in the dictionary. One technique involves inserting 'trial' characters into the proper position or positions of a group of identified characters for a dictionary look-up which continues until a word having the known characters plus a trial character is found . . . We have means to remember the characters which are properly identified and also the positions of the character or characters which are not identified. With this remembered information we insert 'trial' characters one after the other into the position of the improperly identified character to form 'trial' words. A 'trial' character as used herein, is a character inserted in the space which would be occupied by an unknown character of a word. A 'trial word' is a word formed of known characters, i.e., those read by the machine plus one or more trial characters. The trial words are compared to the words in a dictionary for a dictionary look-up. The entire dictionary may be interrogated and all words made with trial characters printed out, or we can stop the dictionary look-up when the correct word is found in the dictionary. The dictionary is preferably a high-speed magnetic storage device, for example a magnetic drum, because it is fast and offers versatility not found (or at least as easily used) in other storage devices. It is entirely possible and practical to have a drum store the entire English language in the practice of our invention." (Rabinow and Holt, 1966, p. 1).

5.136a "The experience gained in developing a recognition method independent of the particular geometrical configuration of the characters in the text has also been applied to other tasks. Portions of the clustering algorithm were used to group Chinese characters, to design ternary references for a commerical multifont reader, to derive Boolean recognition logic, and to classify the entries, on the basis of a philological questionnaire, in a dictionary designed for automatic translation." (Casey and Nagy, 1968, pp. 502–503).

5.137 ". . . Recognition performance can be improved by using context. Most obviously, letters and sounds make words, but even knowing digram letter or syllable frequencies can improve decisions about letters or phonemes." (David and Selfridge, 1962, p. 1094).

5.137a "The machine's recognition accuracy is improved by using simple contextual constraints; letter digram frequencies are employed." (Harmon, 1962, p. 152).

5.138 "A good example illustrating the use of context in a decision theoretically correct manner is the improvement achieved in the performance of a faulty character recognizer through the utilization of letter digram or trigram frequencies." (Sebestyen and Edie, 1964, p. 9).

5.138a "When recognizing handwritten or highly disturbed characters human beings make use of the redundancy of the words and sentences, i.e., of the context. This process can be simulated by layering learning matrices and thus used for increasing the recognizing ability of an automatic system." (Steinbuch and Piske, 1963, p. 858).

5.138b "As a preparatory step, a trigram of the Japanese phoneme sequence was examined, which gave us the data to design the recognition system . . . From the result about 1000 cases of three phoneme sequences cover 90 per cent of the data appearing in the conversational speech . . . The basic principle of recognition is the matching of the analyzed pattern of input unknown speech sound with the stored standard patterns corresponding to the three phoneme sequences." (Sakai and Doshita, 1963, p. 843).

5.139 "The specific effect on error reduction is impressive. If a scanner given a 5% character error rate, the trigram replacement technique can correct approximately 95% of these errors. The remaining error is thus . . . 0.25% overall." (Carlson, 1966, p. 191).

5.139a. "One stores the $(27)^2$ digram frequencies of the English language (space is a character here) and, in the case that a letter sequence is not found in the dictionary (indicating that an incorrectly spelled word has been detected), uses this table to examine the left and right neighbors of each letter in an effort to find the letter *least* likely to be correct . . . The *most* likely change is then made, based on the same digram data, and the dictionary searched again with this change. This process is repeated . . . until a match is found." (Cornew, 1968, pp. 79–80).

5.139b "In a sample of text several thousand words long, the observed letter transition frequencies may be expected to match the stored values quite closely. For printed text in such quantity, it seems reasonable to base recognition on the relatively invariant transition frequencies, rather than on preconceptions of the structure of characters." (Casey and Nagy, 1968, p. 492).

"Tentative identities are assigned to groups of similar characters. These identities are then permuted until the text reads sensibly; good sense in this case means an admissible set of transition frequencies. Letter pair frequencies are actually used . . .

"In solving a cryptogram, each type of character is labeled with the same (though incorrect) symbol to start with. The processor described here, however, must first perform the nontrivial task of determining which samples should be classed together by the same symbol. The system achieves this by means of a series of cluster-seeking algorithms operating in the sample space." (Casey and Nagy, 1968, p. 492).

5.139c "We have been concerned . . . with the recognition of the *identity* of a word or of letter sequences by making use of the fact that only certain letter sequences occur in English with any appreciable probability. . . .

"Since certain forms occur in certain contexts while others do not, all the available information is not being used by current pattern recognizers." (Vossler and Branston, 1964, p. D2.4–1).

"The dictionary method has the disadvantage of requiring that any word to be recognized must be included in the dictionary. This requires a large amount of storage space, as well as a fair amount of time for calculation in a sequential computer, since the joint probability must be calculated for each word of the given length. . . .

"A system combining the dictionary method [3737 words] with use of the digram method for words detected as not occurring in the dictionary, was tested on text from newspaper articles and from a psychology book. With this combined system a reduction of about 45% in the number of letter errors was obtained, with an original garbling of 20%.

"A character recognizer performing at the 80% recognition level might be expected to improve to a recognition performance of 95% or 96% or slightly higher through the use of an extensive word dictionary." (Vossler and Branston, 1964, pp. D 2.4–1, 7, 8).

5.140 "Closely related to the use of molecular formula in the recognition process is the use of chemical context to assist in recognition . . . For example, hydrogen links with only one other atom, whereas nitrogen links with three, four, or five other atoms. Thus, 'H' is not likely to be mistaken for 'N'." (Cossum et al., 1964, p. 271).

5.140a "Classification problems may be divided into two categories: pattern recognition and clustering. In pattern recognition, the classifier knows the names of classes and some samples (called hereafter, paradigms) of each class. After the training period is over, during which the paradigms are shown, the classifier is required to place new objects of unknown class affiliation into the classes by a sort of inductive generalization based on the known paradigms. In clustering, the classifier is given a collection of objects with known properties, and is required to generate classes in such a way that objects within each class are strongly similar to one another, while objects of different classes are appreciably less similar. Obviously, there is no place for paradigms in clustering problems." (Watanbe et al., 1967, p. 92).

5.140b "The purpose of Taxometric Analysis is to separate a population into distinct groups or *clusters*, each cluster being defined in terms of the qualities or *attributes* which the members of the cluster have in common. This is achieved by first computing a measure of association, a *similarity coefficient* between each and every member of the population or *operational taxonomic unit* (O.T.U.). The simplest coefficient might be defined as:

$$S = \frac{\text{number of attributes shared}}{\text{total number of attributes.''}}$$

(Shepherd and Willmott, 1968, p. 57).

5.141 "Early work in clustering techniques assumed that the clusters were known *a priori*. Fisher in 1938 made contributions in this area." (Mattson and Dammann, 1965, p. 296).

5.142 Parker-Rhodes says: "Broadly, members of a clump must be more like each other, and less like non-members, than elements of the universe picked at random. We can put this more rigorously in terms of inconnections (i.e., similarities between members of one proffered clump), and outconnections (similarities between members of the clumps and those of its complement); the former must be above average, relative to the number of pairs of elements involved, while the latter must be below average."

"The analogue of error, or uncertainty of the data [in statistical theory], is that [in classification theory] we do not really know with certainty whethr we do not really know with certainty whether or not a given element of the universe belongs to a given class or to its complement. . . . the statistical expression of this is to assign a probability to its class membership, assigning thus a vector of real numbers to each element. . . . Instead, we conceive of our classes as marked off by partitions of the universe; the uncertainties attaching to them are then represented as partitions of the universe into three parts, the 'in', the 'out', and the 'doubtful'." (Parker-Rhodes, 1961, pp. 7–9).

Needham adds: "We suppose that the data are presented as a series of objects, to each of which is attached a string of properties. We then have two problems:

(1) to find a suitable definition of a 'class' or group which is stated in terms of something computable from the data;
(2) to find a practicable algorithm for discovering the classes in a given body of data." (Needham, 1963, pp. 4–5).

5.142a See also: "Automatic clustering techniques for subclass determination reported by Bonner and Firschein and Fischler may be adopted to subdivide some classes of characters that have large variations among the fonts in consideration." (Liu, 1964, p. 593).

5.143 "Dee F. Green, a research associate at the University of Arkansas Museum . . . [has developed a code] for reducing the individual attributes of some 4,000-odd pottery vessels to a numerical system for computer handling. Once the material is classified, the various attributes will be sorted into discrete categories and then statistical techniques applied to lump the attributes into statistically meaningful groups, or ceramic types." (Bowles, 1965, p. 271).

". . . The computer is of use in studies of shards or fragments of artifacts . . . In this connection, Jesse D. Jennings of the University of Utah suggests constructing a matrix of coefficients of similarity of one artifact to another, and thus to all others within a given corpus of objects." (Bowles, 1965, p. 270).

5.144 "Four measures of connection (similarity) between pairs of objects may be computed . . . The first three assume a binary incidence matrix . . . The fourth connection definition is used in cases where definition is used in cases where the initial incidence data consists of nonbinary attribute values . . .

"Each connection matrix is compacted, in the sense that only nonzero elements of the full n x n matrix are recorded." (Dale et al., 1964, p. 9).

We note further that ". . . An alternate technique is suggested in which the properties rather than the objects of the incidence matrix are classified. The properties are regarded as a second universe set 'U', and the connections formalize similarity between properties through reference to their coincidence among objects. Clumping in 'U' will accordingly associate properties that are similar in their properties of incidence among the objects of U." (Dale et al., 1964, p. 5).

5.144a "Rabinow has recently obtained a patent covering the general concept of an autonomous reading machine. He envisages combining an elementary clustering procedure with dictionary look-up techniques." (Casey and Nagy, 1968, p. 493).

5.145 "Word and document associations have been used variously for the alteration or extension of a set of index terms attached to a given document, by addition of associated terms; for the generation of word or document clusters related according to some given criterion; for the ranking of documents, obtained in answer to a search request, in order of relevance; and for the detection of synonyms by comparing association lists attached to the index terms." (Salton, 1963, p. 53).

5.146 Further ". . . the requirement that algorithms for automatic classification should be potentially capable of application to very large object universes prompts investigation of new procedures that may prove more efficient when applied on a large scale or may prove more efficient under certain conditions." (Senechalle, 1964, p. 1–1).

5.147 "A few examples of pattern recognition problems that might be handled by a machine of the type envisioned will now be mentioned. The first class of patterns that comes to mind is an alphabet of hand-printed characters drawn on a binary grid, the components of the primary measurement vector ω corresponding to the cells of the grid. Another problem is the classification of organisms into species, where the components of ω might represent the presence of strength of certain attributes. The problem of medical diagnosis is closely related, the attributes becoming symptoms and results of certain diagnostic tests. Library classification can be considered a pattern recognition problem, in which the components of ω might denote the presence or absence of certain key words in titles, subheadings, abstracts, and so forth. A set of waveforms, corrupted by noise and distortion, but normalized in time and band-limited, can be considered a set of patterns. Sampling at the Nyquist intervals would provide the ω-components. Other possible examples include recognition of spoken syllables, identification of languages from spoken samples, identification of musical instruments from their tone qualities, and prediction of weather, economic trends and the like." (Barus, 1962, pp. 228–229).

"Pattern recognition should ultimately provide powerful techniques for use in such research areas as form perception, target recognition, language translation, theorem proving, game playing, and the testing of psychological models." (Prather and Uhr, 1964, p. D2.2–1).

6. Conclusions

6.1 For example, " 'Recognize' is used to connote the act of identifying an incoming pattern with one of a known set of patterns. 'Classify', is meant to describe the separation of the incoming patterns into several sets according to similarities between the patterns which are inferred by the device." (Meyer et al., 1962, p. 181).

6.2 "Another area which would bear investigation is that of higher level interaction between the control computer and the operator to permit even greater variability in the input documents and flexibility in the output. The scanner could proceed autonomously until it encounters 'unreadable' material, which it then displays on a screen for the operator's attention (a far smaller display than that necessary for an entire page would be sufficient here). The operator then simply indicates to the scanner what action to take: to scan the material, as before, in a facsimile mode; to resort to curve following; to summon its arsenal for italics, boldface, or superscripts; or to let the operator key in the offending word or letter. Aside from the intrinsic economies which may be realized on some classes of character recognition applications, the experience gained here may be useful in other man-machine interaction situations." (Nagy, 1968, p. 487).

6.3 "In the case of Russion language materials, in which we have a great deal of interest, we have found that an optical character reading device which would be able to accept just the Russian scientific material, would require the unambiguous identification of about 800 characters and symbols. This would give us an acceptable input capability for automatic translation. These 800 characters and symbols are found in four fonts of the Cyrillic alphabet, upper and lower case; the Greek alphabet; the Latin alphabet; the digits; subscripts and superscripts; the mathematical symbols; and all of the normal symbols that are used in the expression of scientific discourse." (Howerton, 1962, p. 349).

"On the machine print reader, a technical requirement will probably exist to read scientific Chinese publications. The RADC technical approach is based on evolutionary research and development." (Shiner, 1962, p. 337).

"The first step involves research and development on a semiautomatic technique to determine optimum coding and logic characteristics. The second step then involves the development of an optical character recognition technique which will completely mechanize the digital coding of the Chinese ideographs for rapid processing with automatic language translation equipment such as the USAF AN/GSQ–16 language translation machine." (Shiner, 1962, p. 337).

6.4 "In foreign language materials we find that there is a tendency to avoid the use of such things as italics or underlining for emphasis, but rather the foreigners spread the letters of a word apart to draw attention. If you teach a machine to recognize a white space between two characters as being the boundary between the two words, how do you also make that machine recognize that when it sees white barriers between letters, it may be the case of a word having been expanded for emphasis?" (Howerton, 1962, p. 349).

6.5 This is an approach suggested by Kirŝch et al. (1964), and earlier.

Work on picture-language-equivalence inference systems has also proceeded elsewhere, notably in experimental investigations reported by Schwartz et al. (1965) and by Narasimhan (1966).

We note further that "such picture processing techniques may also be able to handle the problem of assigning descriptors to schematic representations of electrical circuits." (Wooster, 1963, p. 156), but that "much less work has been done on good programming systems for 'picture languages', than has been done on the techniques and media for picture production." (Wigington, 1966, p. 87), and that "a picture language is two-dimensional, and as yet we have no general method of formalizing its syntax. A number of investigators are working on the problem, but to date useful results are not available." (Sutherland, 1967, p. 29).

6.6 "It has been pointed out that there are theoretical problems; phonemic theory does not make it possible to set up unique rules according to which the acoustic patterns of an utterance may yet be correlated with the phonetic elements of the message conveyed by the utterance (Fant and Risberg, 1962). One of the most serious problems is deciding how to use the information that a human listener obtains from the context (Garvin and Bertram, 1964). Current work is concerned with analysis in greater detail of the various formants involved in the speech signal, and with investigating what elements of the signal are significant for speech production and recognition." (Spolsky, 1966, p. 494).

6.7 "In the area of pattern description, there is as yet no general theory, and few properties of measurement design algorithms can be adequately generalized from one application to another. The problem of deriving efficient sets of measurements needs a proper formulation. . . ." (Chow, 1966, p. 102).

6.8 In addition to patents and patent drawings as such, we note the following suggestion: "The large volume of trademarks registered with the patent office has prevented any systematic search prior to adopting one's own mark . . . The computer here presents an excellent method for prescreening . . . Advanced input devices to computers will accept an overlay composed of a halftone of the trademark in question . . . The computer will then search its memory for a trademark of similar pattern quality. If one is found, it will be reprinted on a return screen immediately. Once the basic composition of a trademark is found to be similar to another, differentiating colors may then be checked out." (Sims, 1966, p. 26).

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- **Economic Development Administration**
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JULY 1969

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