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THE LINGUISTIC APPROACH TO PATTERN ANALYSIS: A LITERATURE SURVEY

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ABSTRACT

This report gives the results of a literature survey of linguistic approaches to pattern analysis. Since the linguistic aspects of patterns have received very little attention to date, the literature on the subject is scant. In this report this literature is augmented by pertinent material from the fields of language theory, pattern analysis and artificial intelligence to provide a more comprehensive foundation from which research in the area can be initiated.

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I. INTRODUCTION

Patterns are a form of language. It should be possible to exploit this relationship and use the large body of theory developed for natural and artificial language to analyze and classify patterns. This report gives the results of a survey of the literature related to pattern linguistics. Since it is only recently that attention has been given to the linguistic aspects of patterns, not much literature exists on the subject. Much of material reviewed here has been taken from related areas including language theory, pattern analysis, artificial intelligence, information retrieval, list processing and graph theory. The objective of this survey has been to provide a base from which research in pattern linguistics might begin. Interesting problems and possible extensions of some of the work reviewed here have been suggested.

The body of this report is in four sections. Section II contains reviews of material describing and relating to pattern description and processing languages. In some cases, such as SKETCHPAD, the pattern description language is implied. Section III contains reviews of works on natural and artificial languages, compiler theory and mathematical linguistics. Also included in this section is material on parameterized compilers, that is, compilers able to process statements in a language whose formal grammatical description has been supplied beforehand. Section IV reviews material relating to possible machine representation and manipulation of pattern structures. Included is material on list processing and information retrieval using structural procedures. Section V reviews related material on pattern analysis, artificial intelligence and graph theory.

Within each section the works are listed chronologically to provide an indication of the overall development of the field. Author and subject indexes are included, for convenience at the end of this report.

Because of lack of time or unavailability, some of the works listed have not been read or reviewed. They are indicated by an asterisk (*) following their designation number. Excepting these, the length of a review can serve as a rough indication of the estimated relative importance of the work to the overall objectives of this literature survey. Occasionally, where a work was found not to be pertinent at all, a short comment is included to this effect.

Although no attempt was made to give exhaustive coverage to all related fields, it is hoped that no significant works pertaining to linguistic pattern recognition have been omitted. If inadvertently some have been omitted, the author would very much appreciate it if these would be called to his attention.

II. PATTERN LANGUAGES

Included in this section are works directly relating to pattern linguistics. Items 2.1*, 2.2, 2.3, 2.9, 2.10, 2.14, 2.16, 2.17, 2.18, 2.19 and 2.20 give a linguistic approach to the description and analysis of pictures. Items 2.5, 2.6, 2.7, 2.8, 2.12, 2.13, 2.15 and 2.16 describe computer programs built around a linguistic picture description. In 2.5 and 2.6 the linguistic description is implied. Items 2.3, 2.4, 2.5, 2.6, 2.11, 2.16 and 2.17 give pattern manipulation formalisms. Item 2.22 gives a language for the serial analysis of patterns coded into a mosaic of black, white and grey squares.

2.1* Eden, M., "On the Formalization of Handwriting," AMS Applied Math. Symposia, Vol. 12, ("Structure of A Language and Its Mathematical Aspects"), 1961.

A linguistic approach to handwriting analysis is presented, leading to the development of a generative grammar for cursive hand-written English letters.

2.2 Narasimhan, R., "A Linguistic Approach to Pattern Recognition," Report No. 121, Digital Computer Laboratory, University of Illinois, Urbana, Illinois, July 1962.

Narasimhan is probably the most important contributer to the field of linguistic pattern recognition and this is one of his most important papers. Described is a language for the analysis and description of a class of line patterns. The language uses as its lowest level units neighborhoods of a pattern with specific topological properties such as terminals, crossings, junctions, bends and corners. Narasimhan calls these the "basic sets." The pattern consists of the basic sets, connected by horizontal, vertical and 45° diagonal lines. A basic description of the pattern is formed by listing statements, each consisting of a pair of basic sets with their line connector, in a table called the "table of primary connections." Strings of primary connections are then formed. By the application of grammar rules, phrases and sentences are formed. Some flexibility is included to permit a choice of grammar rules for use in a particular application.

The approach is a good one with considerable power. Not too much use is made of language theory, however, and no attempt is made to classify patterns using the principles of mathematical linguistics. A more formal linguistic analysis and classification of the grammar would be desirable. Also included in the report are some parallel processing techniques for noise elimination, gap filling and line thinning of patterns. (See also 2.4, 2.7, 2.8, 2.9, 2.15 and 5.19.)

2.3 Ledley, R.S., Programming and Utilizing Digital Computers, McGraw-Hill, New York, 1963, Chapters 6-8.

Chapter 6 contains a good and interesting introduction to computer linguistics. The chapter begins with a discussion of languages in general and a classification of these is made based on the way in which an object is represented by the elementary characters in the language. The reader is then introduced to the Backus Normal Form (BNF) for the expression of the syntax of a language. ALGOL is used as an example to illustrate some of the aspects of computer languages and their representation in BNF. The exposition of ALGOL is exceptionally clear. Chapter 7 contains a similar, clear BNF exposition of COBOL.

Chapter 8 gives an introduction to some of the more important concepts in the area of artificial intelligence. Many of the ideas contained are original to Ledley and have not been published elsewhere. Ledley gives an algorithm, which he has developed, for compiling languages expressed in BNF. One of Ledley's examples is a unique pattern language (See also 2.10, 2.16, 2.17.) in which he expresses a simple sketch of a house. By means of various string transformations he is able to show the equivalency of a number of different representations of this house. He suggests the use of General Problem Solving (GPS) techniques for demonstrating pattern equivalency in this language. The ideas expressed in this chapter, especially the BNF picture language, are definitely worth careful study in the linguistic approach to pattern recognition.

2.4 Narasimhan, R., "A Programming Language for the Parallel Processing of Pictures," Report No. 132, Digital Computer Laboratory, University of Illinois, Urbana, Illinois, January 1963.

Narasimhan has found that parallel processing can accomplish labeling and other linguistic classification operations for pictures (see 2.8). The relation between parallel processing and pattern languages appears to be worth investigating. (See also 2.12, 2.18, 5.12, 5.19, 5.20, 5.23.)

2.5 Sutherland, I.E., "SKETCHPAD: A Man-Machine Graphical Communication System," Technical Report No. 296, Lincoln Laboratory, MIT, Cambridge, Massachusetts, January 1963.

This interesting report describes a program for synthesizing, analyzing and manipulating drawings inputted by light pen. The basic vocabulary consists of points, lines and arcs. From these basic elements complex drawings are constructed or approximated. Provision is made for change in size, movement, copying and modification according to constraints, of input drawings. Of primary interest is the use of a hierarchial, ring-type data structure, composed of n-component elements, which is responsible for some of the peculiar advantages of the system. This type of data structure might have application in a more general linguistic pattern recognition program. It would be of interest to examine some of the peculiarities obtained due to the use of this data structure such as the properties of dependent and independent elements, the recursive merging and deletion of portions of a pattern, and the results of the use of instances (Chapter 6), in the light of a pattern linguistic theory. (See also 2.6, 2.20.)

2.6 Roberts, L. G., "Machine Perception of Three-Demensional Solids," Technical Report No. 315, Lincoln Laboratory, MIT, Cambridge, Massachusetts, May 1963.

A computer program which can transform a photograph into a line drawing, the line drawing into a three-dimensional representation, and finally display the three-dimensional structure with hidden lines removed, is described. Restriction is made to the class of compound convex figures composed from a number of selected simple convex polygons called models. Of special interest in this work is the conversion between a two-dimensional line drawing and a three-dimensional representation. It is suspected that this procedure can be formalized by considering the search for models in the line pattern as being analogous to the search that takes place during the compiling of a source statement.

The approach taken by Roberts is basically structural and for this reason his report may provide ideas pertinent to three-dimensional pattern linguistics. (See also 2.5, 5.4, 5.17.)

2.7 Narasimhan, R., "A Programming System for Scanning Digitized Bubble-Chamber Negatives," Report No. 139, Digital Computer Laboratory, University of Illinois, Urbana, Illinois, June 1963.

A brief non-detailed general description of the automated bubble-track analysis system at the University of Illinois as of June 1963 is given. (See also 2.2, 2.4, 2.8, 2.9, 2.12, 2.15, 5.12, 5.16, 5.19.)

2.8 Rice, K. R.; Narasimhan, R., "Bubble Chamber Scanning Program: 1. LABEL 2. SEARCH (Stage 2)," File No. 542, Digital Computer Laboratory, University of Illinois, Urbana, Illinois, June 1963.

The use of parallel processing operations to accomplish the direction labeling, finding of the basic sets, and other procedures necessary for the analysis of a line drawing described in 2.2 is examined. (See also 2.7, 5.16, 5.19.)

2.9 Narasimhan, R., "Syntactic Description of Pictures and Gestalt Phenomena of Visual Perception," Report No. 142, Digital Computer Laboratory, University of Illinois, Urbana, Illinois, July 1963.

This interesting and important report attempts to relate pattern linguistics to the way patterns are perceived by humans. Narasimhan gives a somewhat more general language model (the "Syntactic Model") than used in 2.2, which consists of a set of hierarchical classifications applied to each point of a picture, leading to an ultimate structural analysis of the picture. A number of characteristics of human visual perception are discussed, including various types of perceived ambiguity. Each of these is related to Narasimhan's Syntactic Model.

Narasimhan does not attempt to make any mathematical linguistic classification of the Syntactic Model. It is felt that such a classification would shed light on the representation capabilities and compiling properties of this grammar. Narasimhan's grammar could lead to a three-dimensional phrase structure diagram for two-dimensional patterns (see 2.14).

The Syntactic Model allows for some degree of freedom in pattern phrase specification which adds considerably to its generality. Narasimhan points out that, in general, classification rules need not be fixed and that classification can be a dynamic procedure in which there is feedback between the results of classification and the grammar rules. Grammar rules can also be changed to suit different situations. When humans search for a particular item or figure, it is not at all implausible that the selectivity takes the form of an adjustment in an internal language specification.

Narasimhan uses transformational analysis to explain certain perceived ambiguities. Unfortunately, however, transformational analysis (see 3.2) is not examined further to determine ways in which it could make the Syntactic Model more powerful. This report describes some fine work and it is unfortunate that Narasimhan did not pursue the similarities between language and patterns in his later research.

2.10 Ledley, R. S., "Thousand-Gate Computer Simulation of A Billion-Gate Computer," (Tou, J. T.; Wilcox, R. H., Computer and Information Sciences, Spartan Books Inc., Washington, D.C., 1964, pp. 457-480.

Ledley proposes the construction of a billion-gate computer out of a large number of million-gate gate computers, called dipsomes, each with its own function, and each having a separate memory and ability for motion and interaction with the others. An analogy to people in a department store is made. As an example of the use of such a model, Ledley proposes a two-step pattern recognition process. The first step is the recognition of the parts of the pattern and their spacial relationships - local operations, performable simultaneously by the dipsomes. The second step involves the straightfoward application of a set of recursive reduction formulas (see 2.3). Ledley gives some possible applications of his model in concept recognition and learning. Many of the approaches in Ledley's paper are vague and undeveloped, but the paper is full of ideas, some of which are quite innovational. (See also 2.16, 2.17.)

2.11 Knowlton, K. C., "A Computer Technique for Producing Animated Movies," Proceedings - Spring Joint Computer Conference, 1964.

A picture processing language to be used for the production of animated movies is described. An interesting idea incorporated into the program is the use of a set of scanner or "bugs" which are imagined to be sitting on different squares of a raster that can be given orders to read or write in the square, or to move in any direction. The idea of scanners is easily adapted to chain coded line patterns (see 5.8, 5.9, 5.14, 5.18) and may be useful in the construction of a picture processing language around a descritpion language for two or three-dimensional line patterns.

2.12 Narasimhan, R., "Labeling Schemata and Syntactic Description of Pictures," Inf. and Cont. 7, September 1964, pp. 151-179.

A description of some of the work on the University of Illinois Bubble Track project that is of general interest is given. The paper is a well-written summary but contains little or no material not contained in earlier reports. (See also 2.2, 2.4, 2.7, 2.8, 5.12, 5.16.)

2.13 Narasimhan, R.; Witsken, J. R.; Johnson, H., "BUBBLE TALK: The Structure of A Program for On-Line Communication with ILLIAC III," File No. 604, Digital Computer Laboratory, University of Illinois, Urbana, Illinois, July 1964.

BUBBLE TALK is the most extensive system yet devised for the structural analysis of patterns. Although designed primarily for the analysis of bubble-track data, the approach is applicable to a much wider class of patterns. Pattern input to the computer takes place by means of a photographic negative scanner-digitizer. The operator may communicate verbally to the program by means of a typwriter, or graphically by means of a light pen. A command language has been developed for the system including statements to define objects and attributes, to locate and name objects in a given pattern, to compute the attributes of a selected object, to display portions of a pattern, and to perform searches. New objects are defined using propositional expressions involving attributes of known objects. This is an interesting idea and permits objects to be defined, in a sense, conceptually. No basically new objects can be defined, however, which limits considerably the use of the system for other than bubble-track data. The system is built around Narasimhan's pattern description language (see 2.2) and hence it can be no more powerful than this scheme. Despite its limitations, BUBBLE TALK is a big step foward in pattern processing.

2.14 Kirsch, R. A. "Computer Interpretation of English Text and Picture Patterns," IEEE Trans. Electron. Comp., August 1964.

Kirsch suggests that because of the degree of overlap between the text and pictures in printed matter, both can be treated by uniform methods. He believes that patterns have a syntactic structure much the same as natural language. An English sentence can be considered to be a one-dimensional concatenation of symbols of which a two-dimensional structural description can be made. Kirsch suggests that a pattern is a two-dimensional juxtaposition of symbols of which a three-dimensional structural description can be made. Although Kirsch does not mention how to do this, Narasimhans labeling scheme indicates a very good way. Kirsch does suggest, however, a method of constructing a two-dimensional grammar for two-dimensional sources. Unfortunately, only very limited success is obtained with the method.

2.15 Narasimhan, R., "BUBBLE SCAN I Program," Report No. 167, Digital Computer Laboratory, University of Illinos, Urbana, Illinois, August 1964.

BUBBLE SCAN I is a program which scans one view of a bubble-chamber stereo-triad and outputs various information about the tracks and vertices contained. A post-editing program (not described) then considers the three views of the stereo-triad and assembles and analyzes the bubble-chamber occurences. This report may contain some useful ideas on data structures and track classification, but contains little basic information that is not contained in earlier reports. (See 2.2, 2.4, 2.8, 5.16.)

2.16 Ledley, R., "High Speed Automatic Analysis of Biomedical Pictures," Science, Vol. 146, October 1964.

A system and some techniques that are being used for the analysis of biomedical pictures is described. The example included contains a description of the way in which Ledley's technique for the syntactic analysis and description of pictures has been applied to the computer classification of chromosomes. (See also 2.3, 2.10, 2.17, 2.22.)

2.17 Ledley, R.; Wilson, J., "Concept Analysis By Syntax Processing," Proc. of Amer. Doc. Inst. Annual Meeting, Vol. 1, October 1964.

This paper contains probably the most comprehensive exposition of Ledley's linguistic pattern description and analysis techniques available. The techniques are explained from the point of view of concept analysis and recognition. An exceptionally clear comparison of inductive (GPS) and deductive techniques for pattern recognition using the techniques is included. (See also 2.3, 2.10, 2.16.)

2.18 Breeding, K. J.; McCormick, B. H.; Witsken, J. R., "Order Code for the Film Scanners of ILLIAC III," Report No. 176, Department of Computer Science, University of Illinois, Urbana, Illinois, March 1965.

Some aspects of the ILLIAC III computer are described. The only item of interest is a string representation of line patterns (on page 11) which relates intuitively and is easily interpretable using a pushdown stack. (See also 2.19)

2.19 Breeding, K. J., "Grammar for a Pattern Description Language," Report No. 177, Department of Computer Science, University of Illinois, Urbana, Illinois, May 1965.

A language for string representation of the class of line patterns formed by the vertical and horizontal connection of nodes on a rectangular grid is described. A formal procedure for reducing the drawings to string form is developed. Contained in this formalism are pattern equivalents of words, phrases, sentences and paragraphs; and rules specifying the hierarchical relations between these. Some use is made of definitions and elementary principles of graph theory. Algorithms are developed for two simple transformations - 90° rotation, and horizontal reflection. A description of the language is given in Backus Normal Form. Unfortunately, as the author recognizes, the BNF grammar does not completely describe the language.

This work appears to have led to a deadend. The description format is not at all intuitive or elegant, and transformation of a pattern by operation on its string representation has proven to be complex and difficult except in the simplest cases. The class of patterns describable in the language can be expanded somewhat, but the awkwardness of the pattern description and transformations will be difficult to overcome.

2.20 Lang, C. A.; Polansky, R. B.; Ross, O. T., "Some Experiments with An Algorithmic Graphical Language," Technical Memorandum ESL-TM-200, Electronic Systems Laboratory, MIT, Cambridge, Mass., August 1965.

AED-Jr. (see 3.18) is applied to the processing of a simple graphical language. All figures are expressed in terms of points, lines and arcs. Statements are inputted in the form of light pen movements. Line intersections are detected upon input and immediately incorporated into the First Pass Structure (see 3.11), which when completed is the output of the program.

Even though the vocabulary has been restricted to only three basic pattern elements, the AED-Jr. formal description and the First Pass Structure (FPS) representation of simple patterns is fairly complex. It is evident that each addition to the pattern vocabulary will result in a sizable increase in the complexity of the language. Much of this complexity has resulted because of inherent limitations of the basic AED-Jr. meta-language (see 3.7). Additional complications occur because the FPS is not especially well suited for pattern representation. It does not model the structure of the pattern.

In short, although AED-Jr. is able to process picture statements, its basic framework is not suitable for picture processing and a high price has been paid in the form of increased complexity. Nevertheless, AED-Jr. is an important step in the development of parameterized picture processing systems.

2.21* Londe, D. L.; Simmons, R. F., "NAMER, A Pattern Recognition System for Generating Sentences About Line Drawings," Proc. ACM 20th Nat. Conf.

2.22 Ledley, R.; Jacobsen, J.; Belson, M., "BUGSYS: A Programming System for Picture Processing - Not for Debugging," Comm. ACM, Vol. 9, No. 2, February 1966.

A pattern analysis and processing program and language based on Knowlton's idea of "bugs" (2.11) is described. This system could be programmed to convert from a black and white mosaic to a chain code representation of patterns (see 5.8, 5.9).

III. LANGUAGE THEORY

This section contains reviews of works pertaining to natural and artificial languages in which the emphasis is not on pattern analysis. Items 3.1, 3.2, 3.9, 3.9A, 3.9B, 3.9C, 3.9E, 3.9F, 3.9H and 3.10* deal with the analysis of natural languages. Items 3.9D, 3.12*, 3.13 and 3.17* describe artificial languages. Items 3.3 and 3.8* are papers in mathematical linguistics. Items 3.4, 3.5, 3.6 and 3.14 pertain to compiler theory. Items 3.7, 3.11, 3.15 and 3.18 describe parameterized compilers or processing schemes. Items 3.9G and 3.16 pertain to the use of mathematical logic for representing natural language semantics. Items 3.19* and 3.21 take a General Problem Solver (GPS) approach to linguistic translation. It 3.20 is a state of the art survey of the processing of natural and artificial languages.

3.1 Wykoff, G. S.; Shaw, H., The Harper Handbook, Second Ed., Harper and Brothers Publishers, New York, 1955.

Chapter 5 contains a fairly comprehensive and well-written exposition of classical English grammar of which a knowledge is helpful if one is to understand the papers in the field of language theory relating to natural languages in general.

3.2 Chomsky, N., Syntactic Structures, Mouten and Company, The Hague, Netherlands, 1957.

This is one of the classic works of language theory. The book is very clearly written and can serve as an introduction to Chomsky's other writings (2.3, 2.7). First Chomsky presents an argument against the use of semantics for determining "grammaticalness." Then the class of finite-state languages is examined and it is shown why finite-state grammars are not powerful enough to be suitable for English. The phrase structure model is shown to be better, but it still leaves much to be desired for natural language description. Finally phrase structure analysis is combined with a new type called transformational analysis to form a model deemed suitable for the construction of a formal English grammar. This book is an excellent introduction to the finite state, phrase structure and transformational models of language.

3.3 Chomsky, N., "On Certain Formal Properties of Grammars," Inform. and Cont., 2, 1959, pp. 137-167.

A classic in the field, this paper gives a scheme for classifying grammars into four types, each capable of generating more complex languages than its successor. Each of these four grammar types is related to well-known mathematical constructs. Much of mathematical linguistics has been built around the results contained in this paper. Since the paper is not easy to read, it will probably be desirable to read Chomsky's book (3.2) first. (See also 3.8.)

3.4 Comm. ACM, January 1961.

Entire issue is devoted to compilers.

3.5 Floyd, R. W., "A Descriptive Language for Symbol Manipulation," Journ. ACM, October 1961.

A formalism for expressing the operations involved in the compilation of a given artificial language or the translation of a given artificial language into another is described. A formalism of this type may provide the basis for a parameterized pattern analysis scheme. (See also 3.15.)

3.6 Ledley, R. S., "Automatic Programming Language Translation Through Syntactical Analysis," Comm. ACM, Vol. 5, No. 3, March 1962.

Ledley's algorithm for the translation of languages whose syntax is expressed in Backus Normal Form (BNF) is described. The description is slightly more comprehensive than that given in 2.3.

3.7 Ross, D. T., "An Algorithmic Theory of Language," Technical Memorandum ESL-TM-156, Electronic Systems Laboratory, MIT, Cambridge, Massachusetts, November 1962.

This is the first of a series of reports describing work on a processor-oriented computer meta-language developed by Ross. The theory provides for a language to be specified as a series of words and symbols in conjunction with connective properties called "wordlikes." An algorithm, called the "First Pass Algorithm," is developed for processing statements in the prespecified language. The output of the algorithm is a plex (see 4.3), called the "First Pass Structure" (FPS), which indicates both the syntactic and semantic structure of the input statement. Actually the claim that the FPS shows semantic structure is misleading since all that is really shown is a precedence string indicating the order in which branches on the FPS are to be processed.

Ross's language specification formalism lacks hierarchical levels. Since such levels are desirable in a pattern language, the Algorithmic Theory of Language does not appear to be the best choice for use in pattern analysis. It does, however, have the advantage of allowing for a degree of context dependency and of using semantics in its processing, and these characteristics may offset its disadvantages for some uses.

3.8* Chomsky, N., "Formal Properties of Grammars," [Bush, R. R.; Galanter, E. H.; Luce, R. D. (Eds.) Handbook of Mathematical Psychology, Vol. 2, Wiley, New York, 1963.]

This is one of the most often referenced papers in the field of mathematical linguistics.

3.9 Garvin, P. (Ed.), Natural Language and the Computer, McGraw-Hill, 1963.

Garvin has collected a number of papers by different authors in the field of natural language data processing, including works on language theory, machine translation and information retrieval. The work is rather loosely tied together and often the relation and relative importance of different approaches to a problem are not made clear. The papers differ greatly in the level of audience for which they are intended. The book offers a good overall view of the field of natural language data processing and can serve to acquaint and orient a beginner interested in the field. Some of the papers contained are reviewed separately below.

3.9A Garvin, P., "The Definitional Model of Language."

A structural description of language on the word and subword level is given. The relationships between phonemes, morphemes, graphemes, symbols and words is discussed. The models described may have application in pattern description.

3.9B Stockwell, R.P., "The Transformational Model of a Generative or Predictive Grammar."

Some of the different grammars and types of grammars that have been proposed for the analysis of natural language are reviewed. Much of this article deals with the transformational analysis of Chomsky. Some of the recent research related to this type of analysis is surveyed. It is recommended that Chomsky's Syntactic Structures (3.2) be read first.

3.9C Sebeok, T.A., "The Informational Model of Language: Analog and Digital Coding in Animal and Human Communication."

A study of language from the point of view of communication among animals and humans is made, with emphasis on the relationship between its analog and digital aspects. This approach does not appear suitable for pattern analysis.

3.9D Melkanoff, M.A., "Computer Languages."

Some of the relations between computer languages are discussed, including criteria for deciding relative strength. The article is written for a beginner and does not contain much information.

3.9E Ray, L.C., "Programming for Natural Language."

An introduction to computer data processing is given. This article is written for a beginner and is of no use to anyone moderately acquainted with computers.

3.9F Garvin, P., "A Linguists View of Language Data Processing."

An introduction to the field of language data processing is given. The main areas into which effort has been funneled are listed and a description is given for each: speech recognition, character recognition, linguistic analysis, machine translation, content processing, semantic classification and semantic coding.

3.9G Maron, M.E., "A Logicians View of Language Data Processing."

An introduction to the use of mathematical logic in language data processing is given. The author feels that existing logics are not sufficiently complex to represent all the properties and relationships which are described in natural language and is rather pessimistic about the ultimate use of logic expressions to represent the meaning of linguistic statements.

3.9H Edmundson, H.P., "A Statisticians View of Linguistic Models and Language Data Processing."

The author describes four different information theoretic and statistical approaches which have been taken in the study of natural language. None of these appear to be useful in linguistic pattern analysis.

3.10* Malmberg, B., Structural Linguistics and Human Communication, Academic Press, New York 1963.

An analysis of some of the basic properties of language in general is made. Some of the chapter headings of this book are: The Linguistic Sign, Communication Processes, Preliminary Expression Analysis, Paradigmatic Structure, Segmentation, Redundancy and Relevancy, Levels of Abstraction, Distinctive Features and Primitive Structures.

3.11 Ross, D.T., "Theoretical Foundations for the Computer Aided Design System," Proc. Spring Joint Comp. Conf., AFIPS, Vol. 23, May, 1963, pp. 305-322.

Ross's Algorithmic Theory of Language (see 3.7) and his concept of plex processing (see 4.3) are presented as the framework of the M.I.T. Computer Aided Design System. The basic principles of the Algorithmic Theory of Language are clearly presented and some illustrations of how they are applied to Computer Aided Design are given. This paper is well written and is the best place to start in understanding Ross's work. (See also 3.7, 3.18.)

3.12* National Academy of Sciences, Washington, D.C., Survey of Chemical Notation Systems, 1964.

Chemical notation systems are languages for the representation of chemical structures. An examination of these systems may give ideas for pattern languages and linguistic structures.

3.13 Farber, D.J.; Griswold, R.E.; Polonsky, I.P., "SNOBOL, A String Manipulation Language," Journ. ACM, Vol. II, No. 1, January, 1964.

A computer language for string manipulation is described. Not pertinent.

3.14* Ross, D.T., "On Context and Ambiguity in Parsing," Comm. ACM, Vol. 7, No. 2, February, 1964.

3.15 Feldman, J.A., "A Formal Semantics for Computer Oriented Languages," Doctoral Thesis, Carnegie Institute of Technology, Pittsburgh, Pennsylvania, May, 1964.

An attempt to formalize the meaning of statements in a wide variety of computer languages is made. This involves the formulation of a metalanguage in which the meaning of statements in a given language can be expressed. Once this has been accomplished it becomes possible to state in fixed terms both the syntax and the semantics of a given computer language. A compiler can then be built that is capable of compiling statements in any language suitably described to it beforehand. A possible application of this idea would be the formation of a formal semantic meta-language for picture processing. This could lead to a generalized compiler capable of translating and processing statements in a wide variety of picture processing languages. A probable prerequisite for the construction of such a processing meta-language would be a meta-grammar capable of describing in a formal way the grammar of a given pattern description language.

Feldman's thesis contains a good introduction to production languages and the relation between syntax and semantics in processing languages. The bibliography of the thesis contains most of the important papers in mathematical linguistics and compiler theory.

3.16 Raphael, B., "SIR: A Computer Program for Semantic Information Retrieval," Doctoral Thesis, M.I.T., Cambridge, Massachusetts, June, 1964.

SIR is a more "intelligent" question answering system than any yet devised. Of special interest is the use of formal logic to deal with semantic properties and relationships. A recourse to a formal logical system may prove useful in linguistic pattern analysis and recognition, especially when combined with a GPS approach (see 2.3, 3.21, 5.5).

3.17* Floyd, R.W., "The Syntax of Programming Languages - A Survey," <u>IEEE Trans. on Electron. Comp.</u>, EC-13, August, 1964, pp. 346-353.

3.18 Ross, D.T., "AED-Jr.: An Experimental Language Processor," Technical Memorandum ESL-TM-211, Electronic Systems Laboratory, M.I.T., Cambridge, Massachusetts, September, 1964.

AED-Jr. is a generalized compiler built around the principles of Ross's Algorithmic Theory of Language (see 3.7). This theory describes a meta-language in which the grammar of arbitrary languages can be expressed. AED-Jr. accepts the specification of an arbitrary language and then processes statements in the language, providing as output a plex representation of the First Pass Structure. The use of the system in pattern linguistics is limited by deficiencies inherent in the Algorithmic Theory of Language (see 2.6). The basic idea of the program, however, that of a generalized compiler based upon a grammar specification formalism, may have application in pattern analysis. A pattern linguistic compiler of this sort would be capable of handling a wide variety of pattern languages. (See also 2.20, 3.15.)

3.19* Faulk, R.D., "An Inductive Approach to Language Translation," Comm. ACM, Vol. 7, No. II, November, 1964.

3.20 Oettinger, A.E., "Automatic Processing of Natural and Formal Languages," Information Processing 1965, (Proceedings of the IFIP Congress 65) Vol. I, Spartan Books, Inc., Washington, D.C., 1965, pp. 9-16.

A brief survey of the state of the art of processing natural and formal languages is given. The paper is too sketchy to be used for tutorial purposes but it contains a good set of references and can be used as a point of departure for gaining an acquaintance with the field.

3.21 Amarel, S., "Problem Solving Procedures for Efficient Syntactic Analysis," RCA Laboratories, Princeton, New Jersey, August, 1965.

The use of the General Problem Solving (GPS) techniques of Newell and Simon (see 5.15) for the computer analysis of statements in a context-free grammar is examined. The benefit of using these procedures is increased efficiency in the form of reduced average computer time required to process statements. Ledley (see 2.3) has given examples of the use of these procedures to reduce and show equivalence between statements in his pattern language. It is possible that a way might be found to demonstrate pattern equivalence when representation is in other than string form. (See also 2.20.)

IV. MACHINE REPRESENTATION

The material reveiwed in this section pertains to the internal representation and manipulation of pattern structures. Items 4.2, 4.5, 4.6 and 4.9 are about list processing and list processing languages. Item 4.7 gives a comparison of four popular list processing languages. Items 4.1 and 4.8* describe techniques for information retrieval. Item 4.3 describes a generalization of list and tree structures. Item 4.4 gives a method for representing concepts in the form of list structures.

4.1 Mooers, C.N., "Ciphering Chemical Formulas - The Zatopleg System," Zator Technical Bulletin Number 59, Zator Co., 79 Milk Street, Boston 9, Massachusetts, 1961.

A technique of encoding chemical structures for information retrieval purposes is described. The code permits unique reconstruction of a chemical compound. The method is a specialized, ad-hoc one, and does not relate to the discovery of good data structures for pattern languages.

4.2 Newell, A. (Ed.), Information Processing Language-V Manual, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1961.

Besides being an excellent instruction manual for IPL-V this work is also a superb introduction to list processing. The language is led-into gradually and illustrative examples are abundant and well chosen. The manual is divided into two sections. Section I is an introduction to the various concepts of IPL-V programming, written in a way that gives the reader a feel for the language. At the end of this section is an example of how an adaptive organism could be programmed in IPL-V. Section II is a more formal statement of the rules of IPL-V. This manual is highly recommended to those who want to learn IPL-V or list processing. (See also 4.7.)

4.3 Ross, D. T., "A Generalized Technique for Symbol Manipulation and Numerical Calculation," Comm. ACM, Vol. 4, No. 3, March 1961.

An argument is presented that simple list and tree structures are inadequate for generalized data representation inside the computer. The author proposes n-component elements as data structure units and suggests that there be a number of different possible types of connections between them. The resultant structure, called a "plex," appears to be excellent for the representation of pattern structures in memory. (See also 2.5, 3.11.)

4.4 Banerji, R. B., "The Description List of Concepts," Comm. ACM, Vol. 5, No. 8, August 1962.

An interesting method of representing a concept in the form of a list structure is described.

4.5 Sherman, P. M., Programming and Coding Digital Computers, Wiley, 1963.

A good but elementary introduction to list processing is contained.

4.6 Berkeley, E. C.; Bobrow, D. G. (Eds.), The Programming Language LISP: Its Operation and Applications, Information International Inc., 200 Sixth Street, Cambridge, Massachusetts, March 1964.

A collection of contributions of a number of different authors to LISP programming is presented. Part I contains an introduction written for persons with little or no prior knowledge of LISP. Since the LISP 1.5 Programmer's Manual (4.9) is relatively difficult reading it is recommended that this work be used in conjunction for people desiring to learn LISP. Part II of this work contains some interesting programs and techniques using LISP. (See also 4.7.)

4.7 Bobrow, D. G.; Raphael, B., "A Comparison of List-Processing Computer Languages," Comm. ACM, April 1954.

The four most popular list processing languages, IPL-V, LISP, COMIT and SLIP, are compared with respect to types of problems to which each is best applicable, important features, availability, ease of use, processing speed and documentation.

4.8* Salton, G.; Sussengath, E., "Some Flexible Information Retrieval Systems Using Structure Matching Procedures," Proc. AFIPS 1964 Spring Joint Comp. Conf., Washington, D.C., April 1964.

Some topological structure matching procedures for information retrieval are given. These techniques may have application in pattern linguistics when patter structures are represented internally in the form of a plex. (See 4.3.)

4.9 McCarthy, J., et.al., LISP 1.5 Programmer's Manual, MIT Press, MIT, Cambridge, Massachusetts, February 1965.

This is a programming manual for the LISP 1.5 list processing language. Since it is not simply written it should be used in conjunction with 4.6. (See also 4.7.)

V. PATTERN ANALYSIS, ARTIFICIAL INTELLIGENCE AND RELATED FIELDS

This section contains reviews of material drawn from the related areas of pattern analysis, artificial intelligence and graph theory. Items 5.1, 5.2, 5.3, 5.4 and 5.17 describe pattern analysis or recognition techniques involving structuring. Items 5.8, 5.9, 5.13, 5.14, 5.17 and 5.24 give information about techniques for quantizing and coding two and three-dimensional line drawings. Items 5.12, 5.19, 5.20 and 5.23 are about the parallel processing of patterns. Items 5.11, 5.16 and 5.18 give other pattern recognition and processing techniques. Item 5.6 is a survey of the area of artificial intelligence. Item 5.5 describes General Problem Solving (GPS). Item 5.10 is a text on graph theory. Items 5.7, 5.15 and 5.21 are literature surveys in pattern recognition and artificial intelligence.

5.1 Grimsdale, R. L., et.al., "A System for the Automatic Recognition of Patterns," Proc. IRE, 106B, March 1959.

A structural approach to the recognition of alphanumeric characters is given. The pattern is broken into simple parts and pattern recognition takes place by means of comparison of matrix representations. Only a fixed and very simple set of structural parts and relationships can be considered, greatly restricting the use of the system.

5.2* Sherman, H., "A Quasi-Topological Method for the Recognition of Line Patterns," Proc. Int. Conf. on Inf. Proc., UNESCO, Paris, France, June 1959.

5.3 Uhr, L., "Machine Perception of Forms By Means of Assessment and Recognition of Gestalts, Preprint No. 34, University of Michigan, Ann Arbor, Michigan, October 1959.

An argument and some techniques for a "gestalt" or structural approach to pattern analysis and recognition is presented. The structural techniques are described too vaguely and are not very interesting.

5.4 Smith, A. F., "A Method for Computer Visualization," Technical Memorandum 8436-TM-2, Electronic Systems Laboratory, MIT, Cambridge, Massachusetts, September 1960.

A program which constructs a three-dimensional description of an object from a three-view orthographic projection of the object is described. Restriction is made to objects bounded by plane surfaces. Some rules are developed which may be of interest in two to three-dimensional transformations in linguistic pattern recognition.

5.5 Newell, A.; Simon, H. A., "GPS, A Program that Simulates Human Thought," (Feigenbaum, E. A.; Feldman, J. A., Computers and Thought, McGraw-Hill, 1963) pp. 279-293, (Orig. art. apprd. in 1961).

A description of General Problem Solving (GPS) technigues and a program which incorporates them is given. GPS techniques have been found to have application in compilers, linguistic translation, theorem proving and other areas, and will probably prove useful in pattern recognition once a good formal description scheme for patterns has been developed. (See also 2.3, 2.17, 3.19, 3.21.)

5.6 Minsky, M., "Steps Towards Artificial Intelligence," (Feigenbaum, E. A.; Feldman, J. A., Computers and Thought, McGraw-Hill, 1963) pp. 406-450, (Orig. art. apprd. in January 1961).

An excellent survey of work in the general area of artificial intelligence before 1961 is given. Contained is a section on pattern recognition which classifies and places in perspective the various approaches which have been taken. The section on pattern recognition is required reading for anyone interested in the area.

5.7 Minsky, M., "A Selected, Descriptor-Indexed Bibliography to the Literature on Artificial Intelligence," (Feigenbaum, E. A.; Feldman, J. A., Computers and Thought, McGraw-Hill, 1963), pp. 453-523, (Orig. art. apprd. in January 1961).

Approximately 1,100 papers related to artificial intelligence are listed. An extensive list of subjects and pertinent papers is provided. The subject classification scheme appears to have been carefully worked out and papers of interest are quickly located. Unfortunately, coverage does not extend beyond 1961.

5.8 Freeman, H., "On the Encoding of Arbitrary Geometric Configurations," IRE Trans. Electron. Comp., June 1961.

Some ways of encoding arbitrary geometric curves are discussed. A rectangular array coding scheme called chain coding which may prove to be useful for representing patterns for linguistic analysis is introduced. Some processing algorithms are given. Chain coding has the advantage of leading to relatively simple algorithms for pattern manipulation and analysis. (See also 5.9, 5.13, 5.14, 5.24.)

5.9 Freeman, H. "Techniques for the Computer Analysis of Chain-Encoded Arbitrary Plane Curves," Proc. National Electron. Conf., Chicago, Illinois, Vol. 17, October 1961, pp. 421-432.

Some algorithms for the manipulation and analysis of chain encoded curves are given. (See also 5.8, 5.13, 5.14, 5.24.)

5.10 Berge, C., Theory of Graphs and Its Applications, Translated by Alison Doig, Wiley, New York, 1962.

A standard treatment of graph theory is given. Although some of the definitions and principles of this branch of mathematics may conceivably be of use toward pattern linguistic objectives, at present this approach should be deprecated.

5.11 Sebestyen, G. S., Decision Making Processes in Pattern Recognition, Macmillan Co., New York, 1962.

A statistical decision theoretic approach to pattern recognition is presented. Not pertinent.

5.12 McCormick, B. H.; Narasimhan, R., "Design of a Pattern Recognition Digital Computer with Application to the Automatic Scanning of Bubble Chamber Negatives," File No. 463, Digital Computer Laboratory, University of Illinois, Urbana, Illinois, July 1962.

A partial description of a parallel processing pattern recognition computer is given.

5.13 Freeman, H., "On the Digital Computer Classification of Geometric Line Patterns," Proc. National Electron. Conf., Chicago, Illinois, Vol. 18, October 1962, pp. 312-314.

Some techniques for the analysis and correlation of chain encoded line patterns are given.

5.14 Ruttenberg, K., "Digital Computer Analysis of Arbitrary Three-Dimensional Geometric Configurations," NYU Technical Report 400-69, Department of Electrical Engineering, NYU, University Heights, Bronx, New York, October 1962.

The work of Freeman on chain coded curves (see 5.8, 5.9) is extended to three dimensions. Algorithms for manipulation and analysis include means of finding the two-dimensional projections of a three-dimensional chain and a means of synthesizing a three dimensional chain from its two-dimensional projections. This work may be combined with a linguistic approach to yield simple techniques for the analysis of bubble track and other three-dimensional data. (See also 5.18.)

5.15 Fenton, R., "Survey of Research on Automatic Pattern Recognition," Report 1222-16, Department of Electrical Engineering, Ohio State University Research Foundation, Columbus, Ohio, December 1962.

A description and classification of various techniques used for pattern recognition is given along with a set of abstracts of selected papers in the field. Literature coverage does not extend beyond 1962. The linguistic approach is not dealt with.

5.16 Narasimhan, R.; Mayoh, B. H., "The Structure of A Program for Scanning Bubble Chamber Negatives," File No. 507, Digital Computer Laboratory, University of Illinois, Urbana, Illinois, February 1963.

Part of the structure of a program, which can scan a view of a bubble track stereo-triad and output information to be used for three-dimensional analysis by another program, is described. The descriptions of the programs for labelling and in-window searching are not included. The techniques for breaking a picture into sections for analysis may be of interest. (See also 2.2, 2.7, 2.8.)

5.17 Johnson, T. E., "SKETCHPAD III, Three Dimensional Graphical Communication with A Digital Computer," Technical Memorandum ESL-TM-173, Electronic Systems Laboratory, MIT, Cambridge, Massachusetts, May 1963.

A three-dimensional version of SKETCHPAD (see 2.5) limited to straight line, wire-frame figures, is described. (See also 2.6.)

5.18 Ruttenberg, K., "Algorithms for the Encoding of Three-Dimensional Geometric Figures," NYU Technical Report 400-86, Department of Electrical Engineering, NYU, University Heights, Bronx, New York, June 1963.

The work in 5.14 is continued and extended to the representation of surfaces. Possibilities may exist for combination of this work with a linguistic approach.

5.19 Narasimhan, R.; Fornago, J. P., "A Preprocessing Routine for Digitized Bubble Chamber Pictures," File No. 558, Digital Computer Laboratory, University of Illinois, Urbana, Illinois, July 1963.

Some routines for line thinning and gap filling of raw bubble track data are contained. (See also 2.4.)

5.20 Stein, J. H., "Users Manual for PAX - An IBM 7090 Program to Simulate the Pattern Articulation Unit of ILLIAC III," Report No. 147, Digital Computer Laboratory, University of Illinois, Urbana, Illinois, July 1963.

An IBM 7090 program which simulates the operation of a parallel processing pattern analysis computer is described. (See 2.2, 2.4.)

5.21 Krause, R. H., "Interpretation of Complex Images: Literature Survey," GER-10830 REV A, Goodyear Aerospace Corporation, Akron, Ohio, February 1965, (AD614703).

The abstracts of 245 papers related to perception theory are given with emphasis on photographic interpretation and target identification. Most of the papers listed contain experimental studies concerned with the determination or description of various aspects of human visual behavior. There does not appear to have been much emphasis on hierarchical structuring or recognition levels in picture interpretation. As a result few if any of the papers listed are of more than casual interest in pattern linguistic objectives.

5.22 Fralick, S. C., "Learning to Recognize Patterns Without A Teacher," Technical Report No. 6103-10, Systems Theory Laboratory, Stanford Electronic Laboratories, Stanford University, Stanford, California, March 1965.

Since the learning is done without any structuring of the visual field, this paper is not of interest.

5.23 Yamada, S.; Fornago, J. P., "Experimental Results for Local Filtering of Digitized Pictures," Report No. 184, Department of Computer Science, University of Illinois, Urbana, Illinois, June 1965.

The results of experiments in the use of parallel processing for filtering and noise are given. (See also 5.19.)

5.24 Feder, J. and Freeman, H., "Digital Curve Matching Using A Contour Correlation Algorithm," Proc. IEEE International Conv., March 1966.

Some experimental results for segment fitting with the chain correlation method of comparing chain encoded curves are given. A noise analysis is included.

VI. CONCLUSION

Linguistic pattern analysis is in its infancy. Possibly this is a result of the fact that the field of language theory itself has come into full bloom only within the past decade. Whatever the reason, it is evident that the large body of linguistic theory which now exists could be profitably applied to pattern analysis. The biggest bottleneck appears to be the lack of a formal linguistic structuring and classification scheme for patterns. A formal theory would pave the way for the construction of parameterized picture processing systems and for the use of GPS techniques in the analysis and recognition of two- and three-dimensional patterns.

AUTHOR INDEX

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Wykoff, G. S.	3.1
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13. ABSTRACT
This report gives the results of a literature survey of linguistic approaches to pattern analysis. Since the linguistic aspects of patterns have received very little attention to date, the literature on the subject is scant. In this report this literature is augmented by pertinent material from the fields of language theory, pattern analysis and artificial intelligence to provide a more comprehensive foundation from which research in the area can be initiated.

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