AFCRL-67-0485

NATURAL COMMUNICATION WITH COMPUTERS

Daniel G. Bobrow

Bolt Beranek and Newman Inc
50 Moulton Street
Cambridge, Massachusetts

Contract No. AF19(628)-5065

Project No. 8668

Final Report
Period Covered: 15 March 1965 through 31 August 1967

This research was sponsored by the Advanced Research Projects Agency under ARPA Order No. 627, Amendment No. 2

31 August 1967

Contract Monitor: Stanley R. Petrick
Data Sciences Laboratory

Prepared for:

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS

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SECTION I

INTRODUCTION

For two years, Bolt Beranek and Newman has been engaged in a number of research activities relating to problems affecting computer communications with people, other computers and real-time devices, under Contract Number AF19(628)-5065. This work will continue under a new contract sponsored by the Advanced Research Projects Agency. In accordance with our responsibility to report the results of our investigations, we have distributed a number of scientific reports and have in preparation a number of others. Many of these have been, or will be, published in journals. Following a brief summary of our research, we give a list of publications supported under this contract. Then we provide a copy of the abstracts of the scientific reports prepared or in preparation for this contract.

SECTION II

SUMMARY OF RESEARCH

1. Natural Language Studies

A. Construction of a Semantic Memory

The research under this task has been devoted toward building a structured data base which will allow representation of the meaning of English sentences. Facts, implicitly or explicitly, stored in this "semantic memory", can be accessed through questions input in English.

B. Syntactic Analysis of English

Because understanding of English may be strongly related to the techniques one uses for syntactic analysis of English sentences, we are devoting some effort to the development of a general system which will allow investigation of different grammars of English in an easy, on-line, interactive fashion. In addition, we are working on some theoretical transformational linguistics.

2. Programming Aids

Our principal work in this area has been devoted to development of a good on-line interactive LISP list processing system. We have extended LISP to make it useful when utilizing secondary storage, and have embedded in the LISP system a number of very useful sublanguages, such as FLIP which does format-directed list processing.

3. Input/Output Devices and Systems

We have been developing visual input and output systems for our computer. An image dissector system for visual input has been connected to the SDS 94Ø and used for some pilot experiments in character recognition. A special display processor for the SDS 94Ø for output of visual information has been designed and will be installed in the near future. In addition, we have made some preliminary explorations of the usefulness of a voice insertion system. We are beginning to investigate hardware and software necessary for input and output to a network of computers.

4. Hybrid and Real-Time Computation

We have been investigating software and hardware techniques to allow hybrid and real-time computation in a time-sharing system without great penalty in central processor time. We have designed and built a special hybrid processor as an interface to real-time processes.

5. Models and Evaluation of Man-Computer Systems

A. Computer Operator Models

We have been developing a detailed man-computer interaction model from a control and decision theory point of view. We expect to perform on-line experiments to test details of this model.

B. Information Retrieval Evaluation

The objective here is to validate empirically a recently proposed measure of information retrieval systems. Specifically, a plot of the proportion of relevant items retrieved (hits) versus the proportion of irrelevant items retrieved (false drops), under various acceptance criteria proved to be a linear function on double probability scales. Thus this line provides a goodness measure for retrieval system.

6. A Program for Man-Computer Communication

In this area, we have developed a software system for an IBM 360/30 computer to facilitate man-computer interaction utilizing graphic displays. This system is currently operational. Its capabilities are being investigated and extended.

SECTION III

PUBLICATIONS SUPPORTED UNDER CONTRACT AF19(628)-5065

Reports and Articles Available:

Bobrow, D. G., Darley, D. L., Murphy, D. L., Solomon, C., and Teitelman, W., "The BBN-LISP System." AFCRL-66-180, (BBN Report #1346) February, 1966. (Revised October, 1966.)

Quillian, M. R., "Semantic Memory." AFCRL-66-189, (BBN Report #1352) October, 1966. (Also M. R. Quillian's Ph.D. Thesis, Psychology Department, Carnegie Institute of Technology, accepted December 1, 1966.)

Bobrow, D. G. and Teitelman, W., "Format-Directed List Processing in LISP." AFCRL-66-302, (BBN Report #1366) April, 1966. (Also, paper presented at ACM SICSAM Symposium on Symbolic and Algebraic Manipulation, held March 29-31, 1966. Abstract in August, 1966 issue of the Communications of the ACM, Vol. 9, No. 8.)

Bobrow, D. G., "Storage Management in LISP." AFCRL-66-426, (BBN Report #1423) June, 1966. (To appear in Proc. of IFIP Conf. on Symbol Manipulation Languages, North Holland Press.)

Teitelman, W., "PILOT: A Step Toward Man-Computer Symbiosis." Project MAC, Report TR-32, Ph.D. Thesis, Mathematics Department, Massachusetts Institute of Technology, accepted September, 1966.

Bobrow, D. G., "Problems in Natural Language Communication with Computers." AFCRL-66-620, (BBN Report #1439) August, 1966. (In Man-Computer Input-Output Issue of the IEEE Trans. in Electronics, March, 1967.)

Bobrow, D. G. and Murphy, D. L., "The Structure of a LISP System Using Two-Level Storage." AFCRL-66-774, (BBN Report #1467) November, 1966. (In Comm. of the ACM, March, 1967.)

Bobrow, D. G., Fraser, J. B. and Quillian, M. R., "Survey of Automated Language Processing." AFCRL-67-0269, (BBN Report #1490) April, 1967. (To appear in Annual Review of Information Science and Technology, American Documentation Institute, Annual Review series, 1967.)

Quillian, M. R., "Word Concepts. A Theory and Simulation of Some Basic Semantic Capabilities." (To appear in Behavioral Science)

Raphael, B., Bobrow, D. G., Fein, L. and Young, J. W., "A Survey of Computer Languages for Symbolic and Algebraic Manipulation." (To appear in Proc. of IFIP Working Conf. on Symbol Manipulation Languages, North Holland Press.)

Bobrow, D. G. (Editor), Proc. of IFIP Working Conf. on Symbol Manipulation Languages, North Holland Press. (In press)

Swets, J. A., "Effectiveness of Information Retrieval Methods." AFCRL-67-0412, (BBN Report #1499) June, 1967.

Bobrow, D. G., Darley, D. L., Deutsch, L. P., Murphy, D. L. and Teitelman, W., "The BBN 940 LISP System." AFCRL-67-0458, (BBN Report #1539) July, 1967.

Reports in Preparation:

Teitelman, W., "Design and Implementation of Flip, A LISP Format Directed List Processor."

Clark, W. E., Kenyon, C. N. and Wallace, D. C., "Enhancement of a Moderately Small Computing System for Man/Computer Communication."

Myer, T. R. and Sutherland, I., "Development of a Research Display System."

Cooper, G., "The Semantics of English Locative Prepositions."

Elkind, J. I. and Strollo, F., "A Hybrid Processor for a Time-Shared System."

Carbonell, J. R., "On Man-Computer Interaction: A Model and Some Related Issues."

Carbonell, J. R., Elkind, J. I. and Nickerson, R. S., "The Dynamics of Time-Sharing Systems from a Human Factors Point of View."

Carbonell, J. R., Elkind, J. I. and Nickerson, R. S., "Human Factors and the Design of Time-Sharing Computer Systems."

SECTION IV

ABSTRACTS OF SCIENTIFIC REPORTS AVAILABLE

THE BBN-LISP SYSTEM *

Daniel G. Bobrow
D. Lucille Darley
Daniel L. Murphy
Cynthia Solomon
Warren Teitelman

This report describes in detail the BBN-LISP system on the DEC PDP-1. This LISP system has a number of unique features; most notably, it has a small core memory, and utilizes a drum for storage of list structure. The paging techniques described here allow utilization of this large, but slow, drum memory with a surprisingly small time penalty. These techniques are applicable to the design of efficient list processing systems embedded in time-sharing systems using paging for memory allocation.

* Scientific Report #1, AFCRL-66-180, BBN Report #1346, February, 1966

SEMANTIC MEMORY *

M. Ross Quillian

This report describes a model for the general structure of human long term memory. In this model, information about such things as the meanings of words is stored in a complex network, which then displays some of the desirable properties of a human's semantic memory. Most important of these properties is the capability of the memory to be used inferentially; i.e., to allow for the answering of questions besides those specifically anticipated at the time the information is stored in the memory. A computer program is described which illustrates this property by using the memory model inferentially to simulate human performance on a basic semantic task.

When the meaning of some segment of natural language text is represented in the format of the model, relationships and features of this meaning must be made explicit which were not explicit in the text itself. This becomes a methodological advantage in an experiment in which a person reads text and represents its meaning in the model's format, for then certain parts of his otherwise covert "understanding" of the text become externalized, and available for study. A verbal protocol recorded in such an experiment is analyzed. From this analysis a theoretical picture is developed of how text understanding may proceed on the basis

* Scientific Report #2, AFCRL-66-189, BBN Report #1352, October, 1966 (Also M. R. Quillian's Ph.D. Thesis, Psychology Department, Carnegie Institute of Technology. Accepted December 1, 1966)

of selective interaction between the text and the reader's overall store of prior information.

FORMAT-DIRECTED LIST PROCESSING IN LISP *

Daniel G. Bobrow
Warren Teitelman

This report describes a notation and a programming language for expressing, from within a LISP system, string transformations such as those performed in COMIT or SNOBOL. A simple transformation (or transformation rule) is specified by providing a pattern which must match the structure to be transformed and a format which specifies how to construct a new structure according to the segmentation specified by the pattern. The patterns and formats are greatly generalized versions of the left-half and right-half rules of COMIT and SNOBOL. For example, elementary patterns and formats can be variable names, results of computations, disjunctive sets, or repeating subpatterns; predicates can be associated with elementary patterns which check relationships among separated elements of the match; it is no longer necessary to restrict the operations to linear strings since elementary patterns can themselves match structures. The FLIP language has been implemented in LISP 1.5 and has been successfully used in such disparate tasks as editing LISP functions and parsing Kleene regular expressions.

* Scientific Report #3, AFCRL-66-302, BBN Report #1366, April, 1966 (Also, paper presented at ACM SICSAM Symposium on Symbolic and Algebraic Manipulation, held March 29-31, 1966. Abstract in August, 1966 issue of the Communications of the ACM, Vol. 9, No. 8.)

STORAGE MANAGEMENT IN LISP *

Daniel G. Bobrow

Storage allocation, maintenance, and reclamation are handled automatically in LISP systems. Storage is allocated as needed, and a garbage collection process periodically reclaims storage no longer in use. A number of different garbage collection algorithms are described. A common property of most of these algorithms is that during garbage collection all other computation ceases. This is an untenable situation for programs which must respond to real-time interrupts. The paper concludes with a proposal for an incremental garbage collection scheme which allows simultaneous computation and storage reclamation.

* Scientific Report #4, AFCRL-66-426, BBN Report #1423, June, 1966 (To be published in Proc. of IFIP Conf. on Symbol Manipulation Languages, North Holland Press, in press - D. G. Bobrow, Editor)

PROBLEMS IN NATURAL LANGUAGE COMMUNICATION WITH COMPUTERS *

Daniel G. Bobrow

This paper gives an overview of the problems involved in the construction of a computer-based question-answering system designed to interact with the user in English. The system is viewed as containing five distinct parts -- a parser, a semantic interpreter, an information storer, an information retriever, and an English output generator. There is a need for extensive interaction among these subsystems, and between the subsystems and the user. Examples are given of the type of processing done by each subsystem, and the nature of the possible interactions. The syntactic analysis described is based on a Chomsky type of transformational grammar. The semantic store is characterized by a form of the predicate calculus, with additional algorithms for computation, and structures designed for fast access to relevant data.

*Scientific Report #5, AFCRL-66-620, BBN Report #1439, August, 1966 (Also in Man-Computer Input-Output Issue of the IEEE Trans. in in Electronics, March, 1967)

THE STRUCTURE OF A LISP SYSTEM * USING TWO-LEVEL STORAGE

Daniel G. Bobrow
Daniel L. Murphy

In an ideal list-processing system there would be enough core memory to contain all the data and programs. This paper describes a number of techniques used to build a LISP system which utilizes a drum for its principal storage medium, with a surprisingly low time-penalty for use of this slow storage device. The techniques include careful segmentation of system programs, allocation of virtual memory to allow address arithmetic for type determination, and a special algorithm for building reasonably linearized lists. A scheme is described for binding variables which is good in this environment and allows for complete compatibility between compiled and interpreted programs with no special declarations.

*Scientific Report #6, AFCRL-66-774, BBN Report #1467, November, 1966 (Also in Comm. of the ACM, March, 1967)

SURVEY OF AUTOMATED LANGUAGE PROCESSING *

D. G. Bobrow
J. B. Fraser
M. R. Quillian

This report is a survey of Automated Language Processing done in 1966. It is limited in scope to analytical processing of natural language, excluding work in programming languages, speech recognition, and statistical processing of text. It focuses on work aimed at generating and analyzing sentences of a natural language. This survey has four major sections:

The first, on syntactic theory, contains a summary of the principal assumptions underlying work in generative grammar and a report of the most significant developments in theoretical and descriptive work in syntax. The second section, on semantic theory, attempts to provide some dimensions along which we can judge various theories that have been proposed and developed in the literature in 1966. A number of empirical studies related to semantics and psycholinguistics are reported in a third section. Finally, a fourth section discusses various computer systems for manipulation of natural language. These range from systems that support linguistic studies to systems that are attempting to utilize natural language as a communication medium.

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* Scientific Report #7, AFCRL-67-0269, BBN Report #1490, April, 1967 (To appear in Annual Review of Information Science and Technology, American Documentation Institute. Annual Review series, 1967)

EFFECTIVENESS OF INFORMATION RETRIEVAL METHODS

John A. Swets

Results of some fifty different retrieval methods applied in three experimental retrieval systems were subjected to the analysis suggested by statistical decision theory. The analysis validates a previously-proposed measure of effectiveness and demonstrates its several desirable properties. The examination of a wide range of data in relation to this one metric provides a clear and general assessment of the current state of the retrieval art, and shows that the art is still far from what might be considered a desirable state.

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*Scientific Report #8, AFCRL-67-0412, BBN Report #1499, June, 1967

THE BBN 940 LISP SYSTEM *

Daniel G. Bobrow
D. Lucille Darley
L. Peter Deutsch
Daniel L. Murphy
Warren Teitelman

This report describes the LISP system implemented at BBN on the SDS 940 Computer. This LISP is an upward compatible extension of LISP 1.5 for the IBM 7090, with a number of new features which make it work well as an on-line language. These new features include tracing and conditional breakpoints in functions for debugging, and a sophisticated LISP oriented editor. The BBN 940 LISP System has a large memory store (approximately 50,000 free words) utilizing special paging techniques for a drum to provide reasonable computation times. The system includes both an interpreter, a fully compatible compiler, and an assembly language facility for inserting machine code subroutines.

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*Scientific Report #9, AFCRL-67-0458, BBN Report #1539, July, 1967

DESIGN AND IMPLEMENTATION OF FLIP
A LISP FORMAT DIRECTED LIST PROCESSOR *

Warren Teitelman

This paper discusses some of the considerations involved in designing and implementing a pattern matching or "COMIT" feature inside of LISP.[1],[2] The programming language FLIP is presented here as a paradigm for such a feature. The design and implementation of FLIP discussed below emphasizes compact notation and efficiency of operation. In addition, FLIP is a modular language and can be readily extended and generalized to include features found in other pattern driven languages such as CONVERT and SNOBOL. This makes it extremely versatile.

The development of this paper proceeds from abstract considerations to specific details. The syntax and semantics of FLIP are presented first, followed by a discussion of the implementation with especial attention devoted to techniques used for reducing the number of conses required as well as improving search strategy. Finally, FLIP is treated as a working system and viewed from the user's standpoint. Here we present some of the additions and extensions to FLIP that have evolved out of almost two years of experimentation. These transform it from a notational system into a practical and useful programming system.

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* Scientific Report #10, AFCRL-67- , BBN Report #1495, 1967

SECTION V

ABSTRACTS OF SCIENTIFIC REPORTS IN PREPARATION

ENHANCEMENT OF A MODERATELY SMALL COMPUTING SYSTEM FOR MAN/COMPUTER COMMUNICATION

Welden E. Clark
Clifford N. Kenyon
Donald C. Wallace

This report describes work undertaken to enhance the man/computer communication capabilities of a moderately small computing system (64K IBM System/360, Model 30). The objective was to combine important large-system features (list processing, dynamic allocation, multi-programming) and user-oriented features (Fortran and other common languages, subroutine packages), with more exotic features (multi-user partitioning, graphic input and display, satellite computer services). The resulting system is believed to be a significant alternative to batch-process computing centers and keyboard-only time-sharing services. It will be used in research concepts and techniques for computer aid in design, planning, and operations-analysis problems.

The system described is based on the IBM Disk Operating System (DOS), a medium-scale monitor system that provides supervisory and I/O services, language and library facilities, and, most important, the expectation of wide usage and long-term software support. Extensions have been developed in three major areas: system control, data structure, and problem and data management. Although much of the work is directed toward graphical data handling and console interaction the augmented facilities are useful for other computer applications.

System control extensions allow handling of asynchronous interrupts within the framework of the IBM LIOCS software, for support of display, graphic input, and satellite devices. Communications and files service for a satellite PDP-1 computer are described, as are provisions for an IBM 2250 display and a Grafacon 1010A (RAND) tablet.

A HYBRID PROCESSOR FOR A TIME-SHARED SYSTEM

J. Elkind
T. Strollo

The synchronization of a digital computer to the demands of the real world can use a large percentage of a digital computer's capacity. In a system where time-sharing of several real-time processes is involved, the real-time demands may saturate the digital computer. We have designed a special purpose time-shared hybrid processor which relieves the CPU of the burden of synchronization to real-world demands. This processor accurately synchronizes all I/O transfers between the core memory of the digital computer and real-world devices such as A/D converters, D/A converters, digital inputs and digital outputs. Up to four real-time processes can be controlled simultaneously by the Hybrid Processor. These processes may be operating at independent rates so long as the aggregate input/output rate does not exceed 50KC.

A software system is under development which permits use of the Hybrid Processor while both real-time and non-real-time processes are using the computer system. This software will permit up to four real-time processes to operate independently. They will each refer to the hardware in their programs by invariant numbers (e.g. channel numbers on the A/D converter); but they may be physical assigned different channels. Users will have time-shared access to a number of devices including a visual input device, a hybrid/analog computer, a display, and a number of miscellaneous devices such as relays and shaft encoders.

DEVELOPMENT OF A RESEARCH DISPLAY SYSTEM

T. H. Myer
Ivan Sutherland

The work covered in this report falls into three areas. In the first area we explored techniques for generating displays, and reached some conclusions about the facilities that should be included in a display generator, their quality, and their speed. The result of this effort was a detailed specification for a display generator.

In the second part of the work we considered the control or processor portion of the display system, and developed a specification for a display processor. Significant conclusions about the processor are: 1) It should take its information direct from the memory of the host computer; 2) For compatibility with the time-shared system of our particular computer (the SDS-940) it should access memory through a map system identical to that of the 940; 3) It should utilize a rather elaborate push-down stack system for data storage and subroutine linkage; and 4) It should have a general purpose input-output system to handle the separate consoles in a multiple console system and to allow for addition of various experimental equipment; 5) The processor should include general computing power only insofar as useful to generate display from a read-only representation in core; it should not be given the task of generating such a representation from a higher level structure.

The third portion of the work concerned expansion of the display system both in the sense of adding additional consoles and in the sense of adding experimental display equipment. We examined a number of devices from the standpoint of their intergration into the system. They include: 1) Curve generation, rotation, and perspective projection devices. 2) Provision for driving storage tube displays from the main display generator. 3) Provision for driving color displays. 4) Special modes of display generation such as a scan node to generate television-like pictures.

THE SEMANTICS OF ENGLISH LOCATIVE PREPOSITIONS

Gloria Cooper

A formal theory is presented which specifies readings for 38 English locative prepositions.

A reading for a locative preposition consists of an ordered string of semantic markers. Markers are of two types, property markers and relational markers. The former represent visual properties of concrete objects, and the latter represent singular relations between specified objects.

In all phrases such as:

1) The book on the table
2) The man in the room

The nouns such as "book" and "man" are labelled X's and the nouns such as "table" and "room" are labelled Y's.

Thus a reading for a preposition specifies a relation R between the properties

$$(P_i)_{i=1\ldots n} \text{ of X and}$$

the properties

$$(P_j)_{j=1\ldots m} \text{ of Y.}$$

The preposition selects, as salient, some properties of X and Y from the domain of possibilities.

Included in this report are the complete definitions of 38 prepositions.

ON MAN-COMPUTER INTERACTION:
A MODEL AND SOME RELATED ISSUES

Jaime R. Carbonell

A survey of the literature related to man-computer interaction reveals the many aspects of this problem, which appears to be in the crossroads among such diverse fields as computer languages, computer systems operational characteristics, control theory, decision theory, information theory, applied psychology, computer display and interface engineering, etc. In this paper, we have chosen to present the on-line interaction from an information and decision point of view. After a brief discussion of classes of on-line situations and tasks, we propose a model of the case in which a human operator is engaged on-line in the solution of a problem like debugging a program, testing a model in a scientific application, or performing a library search. In this model the human operator is considered to seek to maximize the information he possesses about his problem at a minimum overall cost. This cost is obtained by adding the operational cost of both man and computer to a remnant terminal cost originated by the remaining uncertainty. This analysis, performed for each of a set of possible alternatives for action, may lead to select and execute one of them, to terminate the process, or to re-evaluate the possible alternatives and/or hypotheses in a search for new ones. Some practical applications in terms of response time and other characteristics of a computer utility will be discussed, as well as some theoretical implications from an informational point of view.

THE DYNAMICS OF TIME-SHARING SYSTEMS FROM A HUMAN FACTORS POINT OF VIEW

Jaime R. Carbonell
Jerome I. Elkind
Raymond S. Nickerson

One of the most important aspects in the design and/or operation of a computer utility is to obtain dynamical characteristics acceptable and convenient to the on-line user. In this paper we are concerned with the problems of access to the computer utility and general availability of it, response time and its effect upon conversational use of the computer, and the effects of the load on the system (and its fluctuations) upon the other aspects.

Primary attention is placed upon response time. Some of the difficulties in its definition are pointed out through examination of the typical interaction process. It is concluded that rather than a single measure a set of response times should be measured in a given computer utility, in correspondance to the different types of operations requested. Next, it is tentatively assumed that the psychological value of short response times stems from a subjective cost measure of the user's own time, largely influenced by the value of concurrent tasks being postponed. A measure of cost (to the individual and/or his organization) of

the time-on-line required to perform a task might thus be derived.

More subtle is the problem of the user's acceptability of given response times. This acceptability is a function of the service requested (e.g., length of computations), and variability with respect to expectations due both to uncertainty in the user's estimation and to variations in the response time originated by variable loads on the system.

This paper concludes with a strong advocation that an effort be made by computer-utility designers to include dynamic characteristics (such as prediction of loads and their effects) among their design specifications. To achieve this goal, more research both on the human factors and systems aspects of this problem is urgently needed.

HUMAN FACTORS AND THE DESIGN OF TIME-SHARING COMPUTER SYSTEMS

J. R. Carbonell
J. I. Elkind
R. S. Nickerson

Although the growth in the number of computers at work in this county has been phenomenal (from less than 20 in 1950 to over 35,000 in 1966), the community of "hands on" users of computers has been a relatively select group. For the most part it has been composed of skilled specialists in one or another of the areas of computer technology who have been willing and able to live with consoles, languages, services and operating procedures that were anything but optimal from a human engineering point of view. Moreover, the high cost of the computer's time relative to that of the people using it served to place a premium on economizing the former even at the expense of the latter, and to de-emphasize the importance of human factors considerations in computer systems design. Recent developments that allow the time of a central processor to be shared among several independent and simultaneous users are rapidly changing this situation. It appears now to be economically feasible to make the computer directly accessible to a much larger and less homogeneous segment of the general population. It is our contention that this development presents a unique and exciting challenge to human factors

specialists, and constitutes one of the most promising areas for human factors research during the next decade - and beyond. Clearly, as the community of computer users expands to include an increasingly large percentage of people whose training or interest is in some area other than computer technology, human engineering considerations will play an increasingly critical role in determining the efficiency and fruitfulness of the man-computer interaction.

In addition to calling attention to the need for the involvement of human factors specialists in this general area of man-computer interaction, our objectives in this paper are to indicate what appear to us to be some of the specific questions and problems with which they should be concerned, and to offer some tentative suggestions concerning user-oriented criteria against which interactive computer systems can be evaluated for selection and design.

Among the questions and problems needing the attention of human factors specialists, we note and briefly discuss the following. What are the features and characteristics that an interactive computer system must have if it is to be truly useful to individuals who are not trained in any area of computer technology? What are the factors that in combination will determine the effectiveness of any particular system, or the productivity of the man's interaction with it? What psychological principles are relevant to the design and evaluation of computer languages, and editing and debugging aids? How important are the dynamical aspects of the system such as continuity of user access and the temporal characteristics of the system response? How does one determine users' needs in such a way as to anticipate the load that will be imposed on any particular system? What sorts of models will be useful for predicting growth in the demand for computer services by a user population?

Concerning criteria for the evaluation of interactive systems, an effort is made to rate various facilities, services and system characteristics in terms of their importance from the user's point of view. At the grossest level a distinction is made between features that are expendable niceties and those without which the system would be highly likely to be rejected as inadequate. For example, whereas a long term program storage facility is considered a necessity, a facility allowing inter-user communication, however, desirable, cannot (for the present at least) be considered absolutely essential. Some consideration is given to the problem of establishing acceptable trade-offs when all desiderata cannot be simultaneously realized.

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13. ABSTRACT

For two years, Bolt Beranek and Newman has been engaged in a number of research activities relating to problems affecting computer communications with people, other computers and real-time devices, under Contract Number AF19(628)-5065. This work will continue under a new contract sponsored by the Advanced Research Projects Agency. In accordance with our responsibility to report the results of our investigations, we have distributed a number of scientific reports and have in preparation a number of others. Many of these have been, or will be, published in journals. Following a brief summary of our research, we give a list of publications supported under this contract. Then we provide a copy of the abstracts of the scientific reports prepared or in preparation for this contract.

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