HUMAN–COMPUTER INTERACTION – INTERACT '87

HUMAN–COMPUTER INTERACTION – INTERACT '87

Proceedings of the Second IFIP Conference on Human–Computer Interaction
held at the University of Stuttgart, Federal Republic of Germany, 1-4 September, 1987

edited by

H.-J. BULLINGER

University of Stuttgart and
Fraunhofer-Institute for Industrial Engineering
Stuttgart, Federal Republic of Germany

B. SHACKEL

HUSAT Research Centre
University of Technology
Loughborough, United Kingdom

associate editor

K. KORNWACHS

Fraunhofer-Institute for Industrial Engeneering
Stuttgart, Federal Republic of Germany

1987

NORTH-HOLLAND – AMSTERDAM · NEW YORK · OXFORD · TOKYO

ISBN: 0 444 70304 7

Published by:
ELSEVIER SCIENCE PUBLISHERS B.V.
P.O. Box 1991
1000 BZ Amsterdam
The Netherlands

Sole distributors for the U.S.A. and Canada:
ELSEVIER SCIENCE PUBLISHING COMPANY, INC.
52 Vanderbilt Avenue
New York, N.Y. 10017
U.S.A.

Library of Congress Cataloging-in-Publication Data

IFIP Conference on Human-Computer Interaction (2nd :
1987 : University of Stuttgart)
Human-Computer interaction.

Includes bibliographies and indexes
1. System design--Congresses. 2. Human engineering--
Congresses. I. Bullinger, H.-J. (Ha-
II. Shackel, B. (Brian), 1927-
Klaus, 1947- . IV. Title.
QA76.9.S88I325 1987 004'.019
ISBN 0-444-70304-7 (U.S.)

PRINTED IN THE NETHERLANDS

PREFACE

Since the first INTERACT conference, which was held in London in September 1984, the field of Human–Computer Interaction has received increasing attention from researchers and industrial practitioners, and the importance of the topic is now widely recognized. There are two major reasons for this increasing interest. Firstly, technological developments over the last few years have enabled us to seek new solutions to the problem of supporting work processes by information technology and for designing the interface between the user and the machine. Secondly, computers have become an everyday and common tool in the work of a great number of people. These two observations have motivated the development of an interdisciplinary field of research which, today, appears much more established than it was a few years ago.

Against this background, a broad international forum on the subject of Human–Computer Interaction is required. It is particularly important, that this international forum has the opportunity for a regular presentation and discussion of new results from both research and application. The International Federation for Information Processing (IFIP), by its Task Group on Human–Computer Interaction, has therefore proposed and organized the INTERACT '87 conference, to be held in Stuttgart, as a successor to the first successful conference in London.

It was the Programme Committee's intention, that this book should serve the purpose of conference proceedings as well as a publication on the state-of-the-art in this field of Human–Computer Interaction. It contains the text of all the papers presented at the conference. A total of 375 abstracts was received in response to the call for papers, which gives a good indication of the considerable interest in this subject and conference. On the basis of a thorough evaluation, 231 authors were invited to submit full papers. Finally, 163 papers were accepted for presentation at the conference and thus are published here. As in INTERACT '84, in the final editing of papers for this conference book, changes have only been made in cases where it was felt to be essential to clarify meaning.

The arrangement of the papers reflects their presentation at the conference. Firstly, all papers have been classified according to the five broad areas, which constituted the basis for inviting these contributions, i.e.:

1. Human Factors in System Development	(13 blocks)
2. Design and Evaluation Methods	(6 blocks)
3. Human Computer Interface Design	(11 blocks)
4. Impact of Computers on Human Behaviour	(6 blocks)
5. Forefront Systems and Techniques	(6 blocks)

Each area was subdivided into named sections containing blocks of four papers, which correspond to the paper sessions of the conference and represent the special subfield of research and application within the field of Human–Computer Interaction.

A subset of eight blocks of papers was selected to cover all areas, which will be presented under the general heading 'Main Issues in Human–Computer Interaction'. The rationale for this selection was to highlight the current state-of-the-art, which will be interesting for both researchers and practitioners.

This series of INTERACT conferences should aim to bring together the various disciplines and research approaches on a worldwide basis. Momentarily two major views can be distinguished: the designer-oriented view and the customer-oriented view. In the designer-oriented view, research is conducted to produce guidelines as well as research results to be of practical help for designers of IT products. In the customer-oriented view, research is conducted to assist in evaluating and implementing IT technology into increasingly more complex application systems. Both approaches are indispensable and the INTERACT conferences should serve to bring both approaches together.

These conference proceedings are the result of a combined effort by a great number of people, to whom we would like to express our sincere thanks. To begin with, IFIP acknowledges its debts to the members of the Programme Committee, who have contributed so much to the arrangement of the final conference programme. In particular, the composition of a well-balanced lecture programme has been made possible by their careful and knowledgeable selection of papers. Furthermore, the members of the Organizing Committee, especially those responsible for the various special activities during the conference, deserve much appreciation for their assistance while preparing and running the conference. Above all however, thanks must be recorded to the authors, who actually did the writing of this book.

Hans-Jörg Bullinger
Fraunhofer Gesellschaft
Universität Stuttgart

Brian Shackel
University of Technology
Loughborough, U.K.

June 1987

COMITE D'HONNEUR – LIST OF MEMBERS

Prof. Dr. H. Bouma
Institute for Perception Research
University of Eindhoven
The Netherlands

Prof. Dr. E. Grandjean
Institute for Hygiene and Physiology of Work
ETH Zurich
Switzerland

Prof. J. Kuorinka
Int. Ergonomics Association
Institute for Occupational Health
Helsinki
Finland

Prof. Dr. F. Novara
Ing. C. Olivetti & C. S.p.A.
Ivrea
Italy

Prof. Dr. U. Oshima
The Medical Information System Development Center
Tokyo
Japan

Dr. J. Rasmussen
Risø National Laboratory
Roskilde
Denmark

Dr. D.H. Roberts
The General Elecfric Co.
Wembley, Middlesex
United Kingdom

Dr. F. Salle
Bull S.A.
Massy
France

Prof. Dr. Ing. H.J. Warnecke
Fraunhofer Institute for Manufacturing Engineering
and Automatisation
University of Stuttgart
Federal Republic of Germany

Mr. J.M. Watson
International Computers Limited
London
United Kingdom

Prof. Dr. A. Wisner
Laboratoire d'Ergonomie et Neurophysiologie du Travail
Paris
France

INVITED LECTURES

Human–Computer Interaction – INTERACT '87
H.-J. Bullinger and B. Shackel (Editors)
Elsevier Science Publishers B.V. (North-Holland)
IFIP, 1987

COGNITIVE ENGINEERING

Jens Rasmussen

Risø National Laboratory, DK 4000, Roskilde Denmark

Different approaches to the study of cognitive systems can be identified. The AI related 'cognitive science' is based on the information processing metaphor of human cognition in an attempt to reach 'computational' models for behaviour in well-formed micro worlds. Within the field of 'human-computer interaction' studies have been focused on analysis of the communication across the interface between computers and their users. Both these approaches have, quite naturally, been guided by the architecture of present computers. Application of advanced information technology in large scale systems, however, also calls for a more system oriented approach. The paper briefly characterises such a 'cognitive engineering' approach and discusses an approach to analysis and modelling of large scale systems.

1. INTRODUCTION

The evolution of advanced information technology has had an immense influence on the studies of cognitive processes of humans and artefacts. Such studies have been approached from different point of view. First of all, the capacity of computers for symbolic information processing has offered new tools for the study of human mental processes and, in consequence, a cognitive science has evolved which includes the interaction between computer science and a number of basic human sciences, such as psychology, neuro-physiology, and linguistics.

Other approaches to cognitive studies have been caused by the wide-spread introduction of computer-based tools for human work and leisure. Computer systems are becoming intermediaries between humans and their activities and, quite naturally, studies of the interaction have been approached from two sides. With the outset from computer and software sciences, large efforts are spent in attempts to match computer systems to users under the label of HCI, human computer interaction. This branch of cognitive studies is focusing on the user-computer interface design. Another branch has grown from industrial engineering studies of human work, and is dealing with the influence of information technology on work conditions. This point of view leads to the consideration of the proper design of the total human-computer-work system and the term cognitive engineering has been suggested.

2. COGNITIVE SCIENCE.

The basic cognitive science is, in a way, developed by merging artificial intelligence research with different sciences such as cognitive psychology, neurophysiology, and linguistics. The cognitive science approach is based on the information processing metaphor of cognition, and a general requirement is that models and theories should be 'computational', i.e., they can be tested by computer simulation. For this purpose, AI research has provided many very useful tools.

To enable explicit, computational formulation, cognitive science necessarily has to consider well defined and separate cognitive functions. Furthermore, theories and models will be strongly influenced by the available computer technology. Until recently, the sequential computer has been very influential, but clear trends toward parallel distributed processing metaphors are now visible. The approach of this cognitive science is, also by necessity, a bottom-up approach aiming at modelling separate components of the human cognitive system and their performance in well defined 'micro Worlds'. The results are important for understanding human cognition and to identify properties and limitations of basic mechanisms, but transfer to complex, real world context will be difficult because human behaviour during actual work depends heavily on the interaction among the various basic mechanisms.

3. HCI, HUMAN-COMPUTER INTERACTION.

HCI, as a discipline, typically deals with the interaction of users with computers in terms of general aspects of communication languages, irrespective of the context of the work in which the systems are used. Clearly, this approach is important for the development and ergonomic optimisation of the interfaces of separate tools such as word-processors, graphic packages, spread-sheets, etc., which are in general use and which can be optimised individually, just like a ball point pen or a typewriter can be optimised ergonomically without considering what the topic of the writing is. Users' interaction with such tools will typically develop into interface manipulation skills, and the focus of research will be on human perceptual-motor abilities. Consequently, studies are well suited for laboratory experiments by behaviouristic methods, isolated from the complexity of the actual work domain (not without reason, the word processor has been called the Skinner-box of HCI).

In many respects, user studies within the present paradigm of HCI can be considered a development from the established 'ergonomics' or 'human factors' professions into a kind of 'cognitive ergonomics'. This approach is, basically, a 'bottom-up' approach from the point of view that proper design of the individual building blocks of a system will make it possible to assemble from these larger, effective systems.

Such a technology-driven approach is necessary for proper design and optimisation of the rapid stream of new technological media such as mice, windows, equipment for speech synthesis and understanding, etc., and quantitative models like the Card-Moran Key-stroke model are very important in this context.

4. COGNITIVE ENGINEERING.

There are, certainly, a number of implications of modern information technology for human affairs, work conditions and society in general, for which neither of these 'bottom-up approaches' are adequate. There is a general trend toward large centralised installations, not only for process systems like chemical plants, but also for production and distribution of consumer goods, for information distribution and storage, for control of the circulation of monetary values, etc. For such systems, the potential consequences of human mistakes and errors may be very large, and low probability of such events may be required. Therefore, design cannot be based on direct empirical evidence from accidents but has to be judged by predictive models of the human-system interaction. Furthermore, automation tends to transfer humans from all tasks that can be formally described, to higher level tasks of supervision, problem solving and decision making for which behaviouristic studies are inadequate. Instead, models of cognitive functions in complex environments are needed.

This is typically the case when advanced computer systems are introduced in support of the dynamic decision making required for control of process plants, manufacturing systems, etc. However, the general trend toward 'integrated work stations' for many professions makes this problem very important in a wider context in the future. Since the quality of human computer interaction in these cases can only be judged with reference to the ultimate system goals and constraints such as productivity and safety, a top-down approach to the analysis, design, and evaluation of the entire system is mandatory. In addition, an analysis of integrated systems requires knowledge and methods from cognitive psychology, control theory, and branches of engineering. On this background, quite naturally, the problem driven and system oriented approach to human-machine research which here is called cognitive engineering, has also been taken. The cognitive engineering approach is important not only to be able in advance to judge the potential for unacceptable consequences of system failure. Equally important is the development of methods to analyse functionality and user acceptance of large-scale systems before expensive prototypes are produced.

5. RESEARCH PROBLEMS OF COGNITIVE ENGINEERING.

A number of basic research topics has been identified as a consequence of the present rapid technological development. In order to illustrate how close the problems in application of information technology are to the present topics of basic research, a few representative examples will be given (for details and references, see Rasmussen (1) and (2)).

Several major industrial accidents have demonstrated the difficulty of the operating personnel in controlling disturbances in large complex systems. Consequently, the use of modern information technology for more effective coding and presentation of plant information in support of operator diagnosis and intervention has been widely considered, but has immediately revealed a lack of knowledge and models concerning basic human cognitive abilities and limitations. We need to know more about the mental models which will be effective for various tasks and, therefore, should be taken as a basis for display design. Likewise are the differences important between mental models supporting routine work and performance during rare, risky events, and between the models kept by experts and novices, as well as between those of designers and operators.

Furthermore, models are needed of the basic psychological mechanisms behind human errors, together with identification of features of work interfaces required for error detection and recovery during routine work as well as during unusual and rare work conditions. Operator mistakes made during diagnosis, evaluation and planning for control of disturbed systems are typically involved in most major accidents, and systems for support of operators decision making during such situations are needed. For the design of systems leading to a co-operative human-computer activity in problem solving tasks, models of human problem solving strategies and limitations are badly needed. In addition, we need to know much more about the information necessary for operators to understand and accept advice. When 'expert-systems' are introduced to support operation during high-risk situations, what are then the requirements to the systems in order to gain the trust of users?

Expert systems are, in general, widely discussed as a means for making available the know-how of experts for less proficient decision makers. One of the hallmarks of experts is that they have a vast repertoire of procedural rules which makes it possible to go directly from observed cues to heuristic rules of action without painstaking analysis. However, in contrast to expert systems, human experts tend to know the limits of their rules-of-thumb and, furthermore, computers have no problems with getting lost during complex information processes or becoming bored when repeating them during frequent routines. It is, therefore, a question whether decision makers (e.g., process operators) should be supported by the heuristics of similar, but more skilled decision makers, or whether support in stead should be given in the form of computer based tools for actually performing model-based, consistent analysis rapidly and effortless for the user. We need research on the proper combination of heuristic know-how and formal, conceptual analysis and their allocation to humans and computers in co-operative decision making in actual work when errors are costly.

The trend toward diversification of work as a result of the automation of work routines, in factories as well as offices, lead to a situation when a number of users or decision makers are co-operating and communicating from 'integrated work stations', sharing databases and information sources. Several basic cognitive model problems appear for advanced systems. Decision making in social groups has so far been studied either from the economic, management theoretic (i.e., normative) point of view, or from the social science (i.e., quality of working life) perspective. What is urgently needed is a cognitive approach to models of distributed decision making in actual, complex work settings. Such models should represent the information and communication needs together with the information processing models and strategies of the different decision makers cooperating in the control of an otherwise loosely coupled work domain. Also, models are needed of the cognitive processes as influenced by different organisational structures and their typical communication conventions and 'protocols'. AI tools are readily available for experimental studies. However, field studies and theoretical development are also needed.

Another important aspect of distributed decision making is the communication of intentional information and value structures which is not only necessary for goal setting and planning, but for understanding ambiguous messages and for error correction in co-operative work. At present, information system development is focused on the collection, communication and storage of factual information on the work domain. Work on representation and communication of implicit or tacit knowledge of intentions, values, and motives is also necessary. Early attempts to explore the potential of computers for integrated management information systems failed, probably because designers mistakenly assumed that executive managers made their decision based on factual information in reports and statistics, whereas they in fact spend most of their time exploring values and intentions of other executives in direct contact by phone, meetings, and cocktail parties.

From these examples it appears that cognitive engineering is a truly cross-disciplinary activity, involved in studies of the interaction between humans and a complex environment. Because the approach is basically problem driven, a typical feature is the aim to represent possible, effective functions and relationships of advanced human-machine interaction and to define their limits. Cognitive engineering is, in Herbert Simon's term (3), the science of the artificial, and the objects of study are under continuous change - as a result of the science itself. It is, therefore, characteristic of this field that basic research and application are very intimately connected.

6. A FRAMEWORK FOR SYSTEMS ANALYSIS.

Several different approaches has been taken to analysis of complex systems. Early attempts have been based on cybernetic system theory and aimed at an identification of the network of feedback control loops involved in system functioning together with an analysis of the information flow necessary for system control and stability. This approach has not had particularly visible influence on recent system design, probably because the cybernetic view did not adequately consider the creativity and the goal directed nature of the behaviour of people and, consequently, of their organisations. Social systems are intentional, not causal, by nature and the structure of the information carrying network will be in unceasing change.

Decision making means change and is depending on alternatives for action and freedom to choose. Decision makers are actually constantly redesigning the system, and the role of the initial system designer will be to supply an envelop of resources and opportunities within which decision makers can act without undue constraint from system limitations.

System design will, consequently, not be directed toward a normative formulation of system functions and preplanned work procedures. It will, in stead, involve a careful analysis of the means and ends of the work domain, the required roles of human decision and control, and the human resources called upon. As a basis for such an approach to system design and evaluation, we have suggested the following domains of analysis. The dimensions of this conceptual framework presented in the following sections appear to be relevant for several application domains:

The Problem Domain. This dimension represents the environment of a human actor. Two distinct types of representation of environments are considered. One representation is in terms of a network of means-end relations used for problem-solving. Three important conclusions for interface design can immediately be recognized from the problem space perspective:

* System design should not only be focussed on familiar tasks with procedural support. Also problem solving and improvisation in higher level functions should be supported effectively. Means-end relations, therefore, should be explicitly represented, not only implicitly in terms of general practice.

* For such decision support, it is important that the information of the subject matter of work can be retrieved from different points of view, defined by the mapping in the means-end space, i.e., seen as means, ends, or function.
* Furthermore, this information has two different sources. Information on functional resources and the actual state of affairs can be collected and represented by means of rational analysis of the work domain. On the other hand, information on goals, ends, and intent will have to include, in addition to institutional goals and constraints, the subjective goals and preferences of individuals. This kind of information will be difficult to collect and to formalize. Generally speaking, such information is propagated through social contacts in all kinds of meetings and get-togethers, a mechanism which is very difficult to replace by computer-based communication.

The Decision Task. This dimension represents the different decisions and choices to be made in terms of diagnosis, evaluation, goal setting, and planning. Analysis in the domain of the decision task is necessary for resolution of important issues related to the user-system interaction:

* Which set of decision functions are needed to serve the overall task content of the user? What is the appropriate role allocation between designer, user, and computer, considering the different resource profiles with respect to basic knowledge, state data, and processing capacity?

* Proper selection and grouping of the information to be available in the various display formats depends on a careful analysis of the actual decision task.

* When should messages communicated between partners be interpreted as neutral messages, as a piece of advice, as a recommendation, or as a direct order? In systems with drastic consequences of mistakes, this raises some questions regarding responsibility of ethical as well as legal kind.

* What is required from this communication in order to assure the understanding and acceptance by the user? Such understanding is not only needed for the user to be motivated to use the system, but is a prerequisite for the ability of a user to detect his or her own errors, erroneous messages caused by cooperators' mistakes, as well as violations of the basic conditions of the system operation.

The Information Processing Strategies. These strategies specify the possible, effective information processes which can be chosen by the decision maker according to subjective performance criteria. Analysis of the users' repertoire of strategies is important for the following interface design issues:

* Each strategy has a particular requirement with respect to support in terms of level of generalization of data and the mental model as reflected in the structure of display formats, selection among displays to match strategies, etc.

* It is important to support novices without frustrating the expert. Therefore, different display formats may be needed for the same task by different users.

* This may result in a great repertoire of display formats, and support of the user's easy retrieval of information in her or his preferred form should be considered. In 'intelligent' support systems, it should be possible to have the computer recognize the user's 'cognitive style', given the relevant strategies and the ways in which they can be communicated.

The Domains of Cognitive Control. Characterization of the cognitive control applied by humans involves a framework for describing the cognitive resources and information requirements in different types of human-work interaction, which depend on the level of training and familiarity of tasks. The analysis of the users' cognitive style is important for consideration in the interface design:

* The configuration of a display is generally designed to support the structure of the mental activity. This means that the configuration in familiar tasks should be related to the rules of users' know-how. For support in problem solving situations, the configuration should reflect the structure of the problem domain.

* The information given will be interpreted as stereotypical signs during familiar situations. The display surface will be manipulated according to empirical rules. When problems arise, information is to be interpreted symbolically with reference to a mental model. This switch should be supported explicitly in system design.

* 'Direct manipulation' is typically discussed with reference to manipulation of computer functions directly from the display surface, i.e., the goal is a proper mapping between the configuration of display and computer functions. Direct manipulation of the task content should be considered by proper 'externalization' of the proper mental model for direct manipulation from the display configuration.

<u>The Role and Organization of Decision Makers.</u> Different aspects of the organization of the members of distributed decision making are discussed, and a framework for systematic analysis of the architecture of such systems is outlined. This domain of analysis is very important for the analysis of role allocation and communication needs in different organizational structures.

7. ENGINEERING; A PROFESSION OF DESIGN OR ANALYSIS?

The conclusion of this discussion could be that complex information systems should be designed top-down from a thorough cognitive task analysis. The view that design can be a well structured process of creating a suitable implementation of a formulated goal in reality appears to be wishful academic dreaming. In general, design involves either up-dating of a previous product, a creative invention from some individual insight, or purely technology driven development.

Basically, engineering professions are supposed to be concerned with design of new tools or systems and, therefore, research would be expected on the problems of synthesis rather than analysis. However, most part of engineering curricula are spent on analysis, not synthesis; for obvious reasons. In general, a new artefact is a result of an invention, and the subsequent artful engineering. Afterwards, research adopts it as a topic for investigation in order to formulate the underlying laws of nature and to identify the limits of refinement. Watt's steam engine was followed by extensive research in thermodynamics to understand the process and to optimise its efficiency, and the 'governor' of the engine gave rise to Maxwell's study of stability of control loops. The field of study and source of data have, of course, been the actually existing worlds but the result has, in both cases, been abstractions representing possible worlds and their limits rather than the actually existing worlds.

In the same way, the invention of flexible information processing tools has given rise to different system engineering sciences, the aim of which is to explore the laws underlying complex information processing systems and to identify the limits of the possible worlds from analysis of the actually operating systems. In such systems, human agents will be in control of a work environment through an intermediary, a computer, which will serve to collect, preprocess and integrate information for the ultimate human decision. As it was the case with Watt's rotating weight 'govenor', the actual performance and its theoretic limits in terms of stability and accuracy can only be studied by taking the properties of the entire system into consideration.

Human abilities and limitations with respect to information processing behaviour are closely related to the way in which the individual adapts to the symbolic information features of the environment and cognitive engineering analysis will, therefore, have to be akin to Brunswikian ecological psychology (4), focusing equally and concurrently on human properties and the causal texture of the environment, as it has also been suggested in the framework discussed in the previous section.

On this background it appears to be more realistic to spend effort on a formalization of the analysis and evaluation of a new system concept than to aim for a formalization and control of the design process itself. Mathematicians, according to Hadamard (5), work by intuition and afterward rationalize and prove the result. Very likely, this is the natural way, also for designers and, therefore, guidelines should be focused on systematic evaluation to be a part of the design process, not on the creative part of the process.

Evaluation of the quality of a new system concept can be done by analytical and by empirical methods. Very often, proposal of a new complex system is met with the question whether a cost-benefit judgement can be supported by hard facts in terms of empirical data. This is a difficult question to resolve. The features to evaluated by empirical, respective analytical methods should be very carefully selected.

Empirical evaluation is, generally speaking, only suited for separate functions or tasks for which a reasonable level of operational skill can be developed by the experimental subjects and compared with alternative system designs. For systems intended for decision support in complex tasks, empirical evaluation is much more difficult to perform in a convincing way, because the experimental situation, to be realistic, will have many uncontrolled variables. There will, therefore, be no stop rule for considering whether adjustment of the experimental conditions is necessary, if the result is not in accordance with the intuition of the experimenter. Consequently, the danger exists that conditions are readjusted until the results correspond to the experimenter's predictions. This is a general problem in research, compare for instance with Kuhn's discussion (6) of the fact that chemical research found broken numbers for atomic weights, but only up to the day when theoretical considerations showed they ought to be whole numbers. This trend will be very pronounced for experiments with complex information systems.

Analytical evaluation requires an analysis of the actual work domain and of the cognitive task elements, as described in the previous section, in order to be able to judge the match between system requirements and users' resources and preferences. Such an analysis will be resource demanding, and it will be unrealistic to request a full scale cognitive task analysis from scratch for every system evaluation. It should, however, be possibly to analyse a number of representative application domains and to formulate a set of prototypical worksettings as 'default-frames' which can be up-dated by specific analysis for a particular system evaluation. In addition, such prototypical domain descriptions could serve to give designers a more well-founded intuition for the creation of new systems.

It follows from this discussion that system evaluation should be planned as a careful combination of empirical and analytical methods. Several levels of evaluation will be necessary and, in general, empirical approaches will be useful mostly at the lower levels. Separate experiments are useful for verification of compatibility with anthropometric features and with the capacity of sensory mechanisms. For this evaluation, empirical data are, to a large extent, available in the form of check lists and human factors handbooks, Other features, such as the consistency and understandability of interface features, will require specific empirical evaluation by methods currently developed by HCI research. Finally, features related to evaluation of the semantic information content supplied by a system and the decision processes they are intended to support vil have to be evaluated analytically, as discussed above.

A major problem in system evaluation is, at present, the prediction of user acceptance and of the the propagation of changes through the organization when a new major system is introduced. To be successful, a new system has to motivate its users to explore its capabilities. This acceptance depends on the subjective criteria adopted by users for judging a number of informal properties of a system and its effect on social relations. We have, at present, neither theories suited to support analytical evaluation, nor methods for empirical studies in the conceptual phase of system development. Research is needed in this area inbetween cognitive engineering and social sciences.

8. CONCLUSION.

The conclusions of the arguments offered in the paper is that a system oriented research effort is required in addition to the present research within the paradigms of cognitive sciencs and human-computer interaction. Research in representation of knowledge about complex, open domains, in human cognitive mechanisms and strategies for control of actions in such complex worlds, and the cognitive architecture of collaborative decision making are among typical topics which will have important implications for proper use of information technology. For this research, it is important to consider that a special tradition in Europe for phenomenology, semiotic analysis, and for task analysis in complex settings exists, which can have very important contributions to offer.

9. REFERENCES.

(1) Rasmussen, J. (1986): Information Processing and Human Machine Interaction: An Approach to Cognitive Engineering. New York: Elsevier Science Publishing Co.

(2) Rasmussen, J. (1987): A Cognitive Engineering Approach to Modelling Decision Making and Its Organization. In: W. B. Rouse: Advances in Man-Machine System Research, Vol. 4. Greenwich: J.A.I. Press. ~~In press.~~

(3) Simon, H. A. (1969). The Sciences of the Artificial. Cambridge, Ma: M.I.T. Press.

(4) Brehmer, B. (1984). Brunswikian psychology for the 1990s, in K. M. J. Lagerspetz and P. Niemi, eds. Psychology in the 1990s, New york: Elsevier Science Publishing Co.

(5) Hadamard, J. L. (1945). The Psychology of Invention in the Mathematical Field. Princeton: Princeton University Press.

(6) Kuhn, T. (1962). The Structure of Scientific Revolutions. Chicago: University of Chicago Press.

Human–Computer Interaction – INTERACT '87
H.-J. Bullinger and B. Shackel (Editors)
Elsevier Science Publishers B.V. (North-Holland)

ON HUMAN PARSING

Friedhart KLIX

Humboldt University of Berlin
Department of Psychology, Oranienburger Strasse 18
1020 Berlin, GDR

A model of sentence processing is outlined. It reflects to some extend human strategies in text comprehension. The main differences in comparison with AI approaches are (1) in the immediate access of words (or word groups) to their conceptual representation in memory and (2) in how conceptually organized background knowledge interacts with the text inputs.

1. INTRODUCTION: Approaches to the translation problem

The present paradigm of language comprehension is mainly the result of interaction between computer science and linguistics. The development of this interaction can be observed in different approaches to the translation problem. At first it was assumed this task could be solved by substituting given words or utterances with equivalents of the target language. As the ALPAC report (1966) indicates, this approach fell through very soon. Language, it was said, was a highly structured entity with interaction also going on between non-connected words. A much more sophisticated approach was developed on the basis of Chomsky's paradigm. So-called ATN parsers were developed (Wilks (1), Simmons (2)). They had a high potential in recognizing structural dependence and interaction. Language families like LISP or (to some extent) PROLOG are well-equipped to manipulate tree structures or transformations within or between symbol concatenations. Yet the translation problem is still unsolved. Why?
Even though we do not have an answer either, we can offer our knowledge of a system that could give an answer: the cognitive machinery of the human brain.
In what way is Chomsky's approach different from what we can learn by investigating the strategies of man?
Chomsky's assumption that grammar includes semantics (and, as a result, the understanding of meaning) might be wrong as a general claim. We saw in our experiments (Kempe, 1987, unpublished) that subjects (1) first try to identify the conceptual background of an utterance; and (2) if the result is ambiguous, a process of using grammatical rules begins to operate (e.g. case markers for differentiating the agent vs. the recipient in a sentence like Den Vater pflegt die Mutter). Another implicitly given presupposition in AI models is that comprehension is restricted to words and their possible transformations and concatenations. The memory store in artificial parsing is subdivided into files of word classes and rules for word transformation. Experiments on concept identification (Hoffmann, Ziessler and Grosser (3); Hoffmann and Ziessler (4); Preuss (5); Wolf (6)) show that there are "sub-symbolic processes", which allow comparing, activating or inhibiting conceptual properties after their activation by words. It is obvious that similarities between words (like TANNE and WANNE) are quite different from those between the conceptual background (like TANNE and EIBE). There is knowledge behind the words, which governs a good deal of the understanding of meaning. Language comprehension also happens beyond language representation in human memory.

2. ON KNOWLEDGE REPRESENTATION: Computer oriented vs. human oriented representation

A most promising new look at computer oriented text comprehension was provided by the storage of a somehow conceptually oriented knowledge base. Several prototypes have been developed: Collins & Quillian's model (7), Simmons' approach (8), and the Schank group's approaches (Schank (9); Riesbeck (10); Goldman (11)). Collins & Quillian's approach, which is suitable for some kinds of disambiguation of word meaning, uses three kinds of relations between words: pointers between sub-superordinated concepts, AND and OR connections, and MODIFIERS like adjectives that are attached to words. Simmons' approach (like Norman & Rumelhart's (12)) mainly uses three other classes of connections between the type nodes of a semantic net: agent connections (related e.g. to GOAL and LOCATION), attribute attachments (like PART, POSS, SHAPE, SIZE etc.), and quantity specifications.
Sentence comprehension ends in a set of lists with a node code, the words, and addresses that point to another node. So, the sentence can be mapped in a graph structure. The idea of Schank's approach is to view conceptual knowledge in a more sophisticated way. It differentiates between (1) ACTIONS, (2) STATES,

and (3) TRANSITIONS between states. The main idea is to resolve actions into elementary units, whose composition allows reconstructing any compound action. Among the states are emotional shifts, POSS(ession), LOC relation, etc. The case world of the grammatical approach is widely used.
Like others in this field, all three approaches have in common that the knowledge base for language comprehension is a composition of words and relations between them. The question is: can this be a model of what happens in man? The unmentioned procedures of the parsers are highly sophisticated; expensive backtracking procedures after misleading steps are partially automated, inference rules are sometimes integrated in, and sometimes separated from, the knowledge base. It might be advantageous to neglect the human touch of sentence (or text) understanding since human parsing is more painstaking and does not encourage AI researchers to look for that aspect, but - as long as this has not been proved, the opposite may also be true, at least in some respect. And it is the purpose of our investigations to find out precisely in what respect this may be true.

3. CONCEPTS, CONCEPT RELATIONS AND INFERENCES

The following claims and statements are supported by a large number of experiments carried out by Van Der Meer (13a, 13b), Preuss (5), Wolf (6), Karzek (14), Ricken (15) and Beyer (16). Summaries were given by J. Hoffmann (17a, 17b) and F. Klix (18a, 18b).
Beside the ability of human mental activity to produce images of perceived or perceivable objects, the knowledge base of human memory consists of concepts and concept relations (some of them are named), of operational rules as to how to use that stationary architecture to find answers in view of problems, and of rules for expressing the results of such processes in verbal form, written or inserted into a communicative act. The interaction between the stationarily structured knowledge base and suitable operations is - in the area of phenomena - called thinking. In this connection, we are trying to explain how these two components also interact in language comprehension processes.
There is sufficient evidence to show that we have to distinguish between three families of concepts:

(1) Concepts representing classes of objects like BIRD, SHARK, ROSE, BIRCH, PIANO, etc. Words that denominate these concepts are attached to a (non-closed) set of properties that allows describing these concepts and that results from (averaged) sensory inputs like the COLOUR, SIZE, and FORM of a given class. As memory entries, properties depend on a person's age, his interests or special training effects in a given area of knowledge.

(2) Concepts that describe events and classes of situations in their coherence in space and time, and possibly including the speaker as an agent or recipient. Event concepts are defined by a semantic core, often a verb (like TEACH, SELL, EAT, or PLAY), but not exclusively so (like TREATMENT, CHESS or VICTORY). The semantic core is the source of a set of semantic (case) relations like AGENT, RECIPIENT, OBJECT, INSTRUMENT, and PURPOSE, which stress properties of concepts, possibly be linkable by the relation: respective the relevant OBJECT properties of 'piano' are stressed differently by events like 'CONCERT' or 'MOVE'. General object properties, which are emphasized by the particular relation, place constraints on the selection of appropriate words for an utterance. Event concepts also include transitions between object properties, like 'CUT' or 'BREAK'.

(3) The third class comprises sequences or concatenations of events like 'VACANCY', 'ADVENTURE', 'SHOPPING', etc. Conceptual links between events are, in general, mappings of goal-oriented activities that involve physical or social conditions, causality, changes in life-space, and temporal perspective. When being described, concepts of this kind often require compound sentences or sentence concatenations that are linked by words expressing time or condition, like 'while', 'since', 'although', and 'afterwards'.

The second main part of human memory is the operative machinery: the set of procedural modules, operators and rules that allow manipulating stationarily stored entities like concepts or properties.
Operations concerning conceptual properties are: suppression (or inhibition) of properties (which allow producing superordinated concepts); unfolding of properties (which allow producing subordinated concepts); comparison procedures (which allow detecting coordinated concepts by tracing and comparing joint and different properties (like 'carp' vs. 'shark', or 'mushroom' vs. 'rose'), and also allow detecting synonyms); and, finally, there is the possibility of emphasizing specific properties (which, beside other phenomena, allows detecting or producing antonyms, comparatives, or additional properties).
Event concepts allow detecting truth values (TO DRINK demands 'ANIMATE' as a property for all agents; STONE or BUILDING would be unacceptable). Semantic relations allow forward inferences by concatenation via PURPOSE: to BUY in order to GIVE. And conceptual event sequences allow inferring backward conditions, causal relations or violations of space and time dependence. Other kinds of cognitive capabilities, like derivation of metaphors or analogical reasoning, are derivable as compound inferences. (Meta-level rules like deduction or induction, the role of complete vs. incomplete information, or differences between

areas of physical and social knowledge go beyond the scope of our discussion.)

After having outlined stationarily as well as procedurally realized parts of human memory, we use this means to construct a model of sentence comprehension and (finally also) of text comprehension. Several times the idea has been mentioned in eye behaviour investigations (Groner (20); Klix et al. (19)) and is now being spelled out in detail; human language understanding is a process that changes between parts of the text input and the conceptually structured knowledge base of the user.

4. OUTLINE OF AN APPROXIMATIVE MODEL OF HUMAN TEXT (SENTENCE) COMPREHENSION

The model that is to be outlined here is partly supported by data about human text processing and partly derived from hypotheses on what we know about the organization of conceptual memory, and realized in an AT computer. The deviations from what we know about the AI parser are important: the usual procedure in AI sentence comprehension is the processing of the simultaneously represented word chain from left to right: Having checked the first noun, article and adjective loop, we apply the rule: "The first noun is the subject" (unreliable in German): then we go on to the verb phrase, checking whether it is transitive or not, opening the next slot for an object or a prepositional phrase: then checking the inflection properties; etc.

Human parsing usually takes some other course. There is (in general) direct access from words to concepts. The first step (now in the model) is looking for the first event concept, usually a verb, either complete or auxiliary (from 'TO BE'). This is followed by an internal activation of the possible semantic relations in this sequence: MAIN AGENT (linked with its most generally allowed properties), RECIPIENT, OBJECT, INSTRUMENT and, eventually, FINALITY - all with their general properties, and FIN refers to possible goals or motives of the agent. These relations open a particular file and here point to (the just mentioned) most general properties (which are assigned to the particular superordinated concept): these properties function as a restricting condition (e.g. if the event is COOKING, the AGENT PROPERTIES demand an adult agent, the restriction for EAT is human being; the OBJ for COOKING is a marked subset of food (excluding e.g. bisquits);LOC is a subset of rooms (excluding bath or toilet); FIN (or PURPOSE) is goal related to 'for eating', whatever the special kind of eating may be). This procedure is a latent activation process, after which the words of the input sentence are conceptually recognized as members of the file in question, e.g. in terms of their semantic role. The activated most general properties allow realizing whether there are violations of the selection restriction thus defined. In case of COOKING, concepts like Doctor, Teacher, Mother, Aunt, Psychiatrist, Murderer, Thief ... all are accepted since they represent adults, but Baby or an animal are not accepted as agents. On the other hand, Baby is accepted as Recipient, but rejected as Object, where a specified subset of animals or plants is accepted. In short, the unfolded semantic core allows identifying (in principle) the (possible) semantic truth value of a written statement. Since all input words are mapped onto the restriction grid it is also possible to recognize restrictions that depend on more than the "most general set of properties": a doctor is allowed to teach at a hospital and to teach how to sail, he is allowed to teach therapy at a hospital, but is not allowed to teach how to sail there.

The next step in the (human) model procedure is a refinement of this crude semantic structure: adjectives are identified as (possible) emphasized properties of object concepts, and adverbs are of event specifications. They are attached to their particular reference concept. This refining procedure ends the first phase of the model procedure. The next steps are optional. Which of them is carried out depends on the self-controlled or induced 'comprehension instruction' of the reader. The background to these optional devices is the simulation of some kind of metarule: what step of comprehension is needed to realize the given recognition requirement: for being vaguely informed, answering a question, or translating a sentence. Below, we will indicate several possible paths that can be followed:

A: If the sentence is divided by a comma or "UND", a referential analysis starts (after the identification of the first structure around the event concept). The procedure is forked:
(1) a possible forward inference is due to a purpose (FIN) reference: "um ... zu", which allows relating a subject-free sentence to the first event concept: "Er schlachtete ..., um das Fleisch zu verkaufen ...".
(2) A backward inference due to the identification of conjunctions like "bevor", "obgleich", "während", "weil", "so ... daß" etc. allows realizing time dependence, conditions or causal relations. The procedure interacts with the referential attachment of pronouns.

B: If the self-instruction for comprehension demands a time analysis (e.g. in answering "WHEN" questions), a subprogram is started that asks for grammatical cues that allow finding out (1) whether the time is past, present or future, and (2) if so desired, which of the linguistic pasts or futures are expressed (e.g. the cues "HATT" & "GE" identify past perfects).