Proceedings of the Annual Conference of the Human Factors Association of Canada
Comptes-rendus du congrès annuel de l'Association candienne d'ergonomie

HUMAN-COMPUTER INTERACTION IN FIFTH GENERATION COMPUTING: PROBLEMS AND OPPORTUNITIES

Brian R. Gaines

Department of Computer Science, University of Calgary,
Calgary, Alberta, Canada T2N 1N4

We are in the fifth generation computing era with its emphasis on complex systems involving close human-computer interaction. If we were able to use today's technology to instrument, model and understand the interfaces of yesterday life would be easy. However, system design always seems to be one step ahead. Multi-task, multi-user, multi-modal systems test our human factors skills to the utmost. Today the engineering of complex human-computer systems may seem as difficult as did the problems of software engineering ten years ago. However, it is suggested that we are beginning to see the signs of breakthroughs in our understanding of the human computer interface which will provide solid foundations for engineering interaction in the future.

INTRODUCTION

For many years we have been told that we are on the brink of an **information** age (Dizard 1982), a **post-industrial society** (Bell 1973), in which we shall establish different relationships to one another, and to our environment, based on computer technology. Toffler (1980) advances the concept of a **third wave** civilization following previous agricultural and industrial waves:

> "Without clearly recognizing it, we are engaged in building a remarkable new civilization from the ground up... It is, at one and the same time, highly technological and anti-industrial."

He rationalizes much of the turmoil around the world as "agonies of transition" between two civilizations and notes:

> "Caught in the crack-up of the old, with the new system not yet in place, millions find the higher level of diversity bewildering rather than helpful. Instead of being liberated, they suffer from overchoice and are wounded, embittered, plunged into sorrow and loneliness intensified by the very multiplicity of their options." (Toffler 1980 p.224)

These remarks will be heart-felt for many of us responsible for designing, evaluating, rectifying, or explaining, the human factors aspects of modern computer-based systems. Being wounded, embittered and plunged into sorrow are becoming expectations based on the experience of one exciting, state-of-the-art, advanced system after another -

- o The marketing blurb extols the diversity of the system's capabilities.
- \- We infer that operational procedures are necessary that reduce the capabilities to those relevant to the system's functions.
- \- It may then be comprehensible to its users.
- o The user manual extols a multiplicity of options.
- \- We infer that training procedures are necessary that activate a minimal subset of consistent procedures essential to the system's functions.
- \- It's configuration and operation by one user may then be comprehensible to another.

Perhaps, like physicians, human factors specialists only get called in when there are problems. We see many sick systems and are predjudiced by our experience with them. There are many healthy systems where the designer's exuberance at the technological capabilities available has been tempered with knowledge and intuitions about the needs and capabilities of users. We know also that the information age is not an act of nature, like a plague, fortuitiously undermining our civilization, although it is often presented as such. Information technology was developed by man to solve the problems of increasing complexity in the control and management of our society. DeBono (1979) expresses this in **Future Positive:**

> "By great good fortune, and just in time, we have to hand a device that can rescue us from the mass of complexity. That device is the computer. The computer will be to the organisation revolution what steam power was to the industrial revolution. The computer can extend our organizing power in the same way as steam extended muscle power..... Of course we have to ensure that the result is more human rather than less human. Similarly we have to use the computer to reduce complexity rather than to increase complexity, by making it possible to cope with increased complexity."

DeBono's caveats are our reality and our responsibility. Fourth generation computing systems are already making demands on human factors specialists that stretch our capabilities to their current limits. The fifth, sixth and beyond, generations will make substantially greater demands and require conceptual advances in human factors science of which we are at present only dimly aware.

The problems we face are truly foundational. The complexity of our man-made civilization has to be balanced by the complexity of information technology. Any imbalance has the potential to destroy not only the individual but our entire civilization. We have developed a system that enables this planet to sustain a human population that vastly exceeds that possible on any natural basis. The infrastructure of our civilization is necessarily complex and intrinsically unstable. It will become more so and the pressures upon to relax to its natural state will continue to increase. We have learned to control the explosive forces of steam, gas and nuclear energy and to reduce the probability of disaster to acceptable levels. We are becoming more aware of the analogous forces in our physical, economic and social environments. This is an era of increasing brinkmanship in every aspect of our lives.

Hopefully, politicians, planners, economists, sociologists, ecologists, and so on, are developing the strategic tools to control the long-terms risks to our civilization. Hopefully, industry, engineers and computer scientists are developing the technologies needed to support our civilization. Unless we are willing to hand over complete control of our destiny to technology alone, there will always be an interface at which people exert control over the operation of our society. Any weaknesses at that interface have the potential to undermine both the planning and the technology. The design of that interface requires interdisciplinary human factors skills, knowledge of both the people and the technology. This is our problem and our opportunity.

The remainder of this paper presents some perspectives on the problems and opportunities for human factors developments in future generation computing applications.

FIFTH GENERATION COMPUTING

The Japanese initiative in 1981 of scheduling a development program for a **fifth generation** of computers (Moto-oka 1982, Gaines 1984a) shocked a drowsy West into realizing that computer technology had reached a new maturity. Fifth generation computing systems (FGCS) would integrate advances in very large scale integration (VLSI), database management systems (DBMS), artificial intelligence (AI), and the human computer interface (HCI) into a new range of computers that were closer to people in their communication and knowledge processing capabilities. It may be difficult to recapture the shock of this announcement: it was unforeseen, from an unexpected source, gave a status to HCI and AI research that was yet unrecognized in the West, and proposed an integration of technologies that were still seen as distinct.

Human factors considerations are fundamental to FGCS objectives. As Mota-oka (1982), Chairman of the Managing Committee of the ICOT centre in Tokyo, notes:

> "In these systems, intelligence will be greatly improved to match that of a human being, and, when compared with conventional systems, man-machine interface will become closer to the human system."

and Karatsu (1982), Chairman of the Social Needs Committee of ICOT, reiterates the HCI theme:

> "Until today, man had to walk toward the machine with effort to fit precisely. On the contrary, tomorrow, the machine itself will come to follow the order issued by man."

Figure 1 shows the **conceptual diagram** of fifth generation computers, and it is notable that the user interface is one of **speech, natural language, pictures and images** to a system processing **knowledge** rather than information. Fuchi, the Director of the ICOT Research Center, writes of **The Culture of the Fifth Generation Computer** (Hirose & Fuchi 1984), and we can see it as being **user natural** in its human factors. The next generation of computers is intended to operate comfortably within the culture of person-person interaction; the HCI should no longer be different.

We may see the Japanese proposal as a natural response to advances in computer technology that have given us massive power in hardware and software at low cost (Gaines 1984b). The technology which limited us for so long has now outstripped our demands and we can expect a shift from technology-push economics in computer systems to those of market-pull. The HCI is what the customer sees and is where the market requirements are being expressed. It is expected that we will increasingly build systems top-down from user needs rather than bottom-up from technology availability.

However, the development of computing systems has generally been pragmatic with attempts to engineer systems whose activities go well beyond the science of their time. Our creative imaginations are usually well in advance of our scientific knowledge and skills. This applies with force to the fifth generation conceptual diagram. The hardware and software rings are full of structure which is expanded in detail in the accompanying

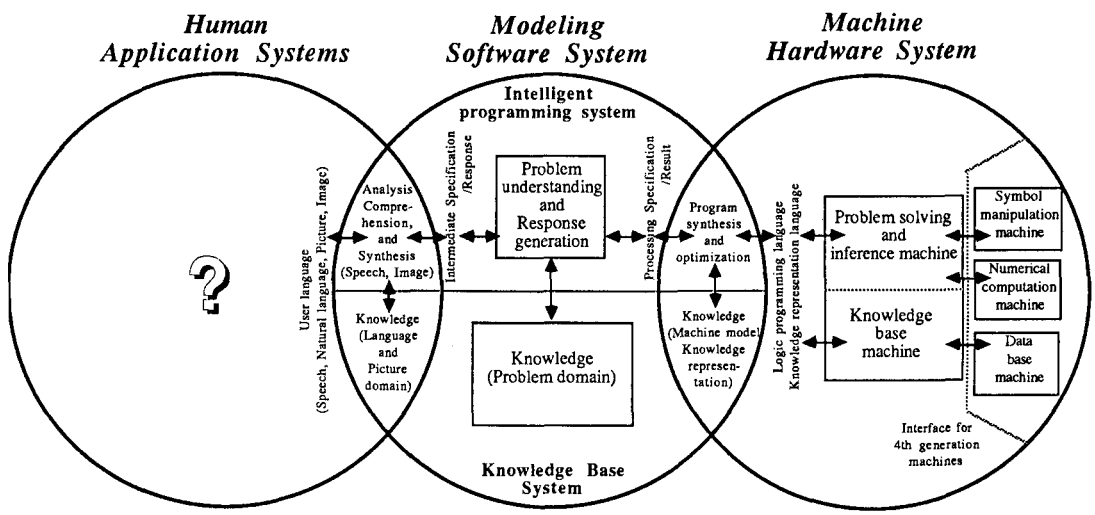


Fig. 1 Conceptual diagram of fifth generation computing (Moto-oka 1982)

text. The human ring is empty and the ICOT research program has no activities designed to fill it. Logic tells us that the third ring should contain the psychological structure of the user but it does not yet tell us what this is.

Fuchi, the Director of ICOT, recognizes this problem in his reply to the interview question:

> "Are you saying that the design of the fifth-generation may be modeled by learning more about the human thinking process?"

answering:

> "Yes, we should have more research on human thinking processes, but we already have some basic structures. For more than 2000 years man has tried to find the basic operation of thinking and has established logic. The result is not necessarily sufficent; it's just the one that mankind found. At present we have only one solution - a system like predicate calculus. It is rather similar to the way man thinks. But we need more research. What, really, is going on in our brain? It's a rather difficult problem." (Fuchi, Sato & Miller 1984)

This can be regarded as a courageous or foolhardy statement according to ones views and mood. It is both. We know that standard logic bears only a remote resemblance to human thought processes. Modern formal logic was developed as a foundation for mathematics just because mathematical rigor is so foreign to everyday human activity. We know that understanding what is going on in the brain is not just a difficult problem but one that may be insuperable within our present scientific paradigms. The causal models of physical science may be totally incapable of encompassing the processes of biological systems and currently we have no formalism in which to express the anticipatory cynamics of living systems (Rosen 1985).

However, human civilization progresses largely from acting to knowing. Technology precedes science and the pioneers of new technology are strengthened in their resolve by unrealistic optimism, unfounded gut-feel and sublime disregard for the many reasons why their efforts may be doomed to failure. Ignorance is not bliss but it is better than false knowledge. It is easy to prove that man cannot fly. It required courage and sacrifice to be an aircraft pioneer. The inevitable and necessary early failures in new technologies provide ample support for the pessimists. It is easy to prove that we can never emulate human intelligence. Until the Japanese fifth generation initiative it required courage and sacrifice to be an AI pioneer. Now the status is high and the funding lucrative. This may not be a good recipe for the next breakthrough!

We cannot wait for an adequate model of the brain, a complete human psychology, or even comprehensive empirical studies of human factors in HCI, to build complex human-computer systems. They are needed now. They are funded now. They are being built now. What we can do is take advantage of the applications of HCI to advance human factors science. We can learn from both failure and success and improve the knowledge-base on which our discipline is founded. To utilize this knowledge effectively requires some understanding of the role of human factors in computing, and this in its turn requires a perspective on the overall development of computing technology. The following section sketches in such a perspective.

GENERATIONS OF COMPUTERS

Viewed as a causal chain the development of computing is highly indeterminate. Technological forecasts for computing are notoriously inaccurate (Withington 1974, Gaines 1984b). Projections of the technology over more than a few years are meaningless. Each month the technical press contains a number of major surprises. The causal model is not appropriate to a phenomenon governed by social needs and hence directed by the goals of society. The past is not an adequate determiner of the future in these circumstances. A teleological model that views society as moving towards some future situation is more appropriate to the processes of the life world. The cascade of sub-goals generated in order to create that future situation accounts for the activities of the past, generates those of the present and determines those of the future. The determinacy, however, is that of a goal-seeking, adaptive system. It predicts the necessary achievements but not the means by which they will be achieved.

The computer is only one component in an elaborate and highly differentiated infrastructure. This infrastructure has grown through a succession of **generations** of computers, each of which represents a major change in computing technology (Gaines 1984b). During the eight year span of each computing generation, revolutionary changes have taken place that correspond in magnitude to those taking place over some seventy years or more in the aircraft industry. The first generation commenced in 1948 and we are now in the fifth generation spanning 1980 through 1987.

The growth of the infrastructure of computing technology may be seen as the recursive application of the basic process underlying social and individual development, that of **learning** (Gaines & Shaw 1985). Marchetti (1981) has shown that treating society as a learning process leads to simple explanations of socio-economic processes such as business cycles and technology substitution. The introduction of any new knowledge, technology or product follows a logistic **learning curve** in which growth takes off slowly, begins to climb rapidly and then slows down as all the information has been assimilated (van Dujin 1983). The shape of the curve corresponds to: initially needing to have knowledge in order to acquire more; and finally slowing down in the acquisition as there is less and less left to acquire.

It has been noted in many disciplines that the qualitative phenomena during the growth of the logistic curve vary from stage to stage (Crane 1972). If we take the amount of knowledge necessary for a mature technology to be 100%, then the 10%, 25%, 50% and 75% points are equally spaced in time along the logistic curve. These points mark significant phases in knowledge acquisition.

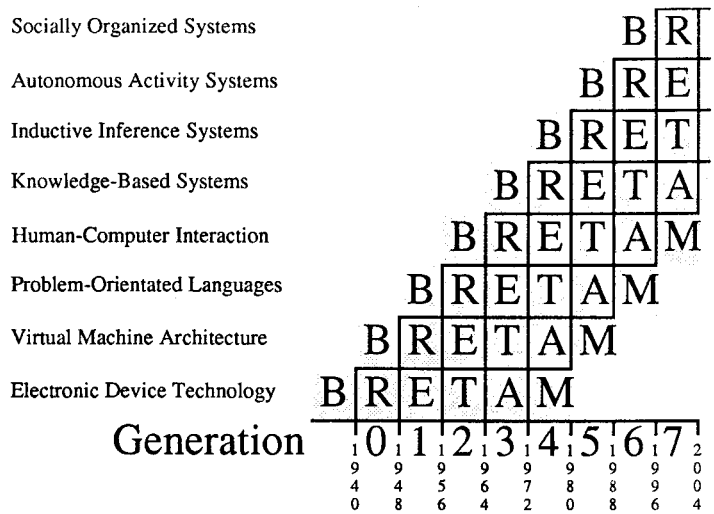
- When less than 10% of the knowledge is available, little can be achieved. We are in a **pre-breakthrough** period where most projects

attempted will fail through lack of some critical information or skill.
- At around the 10% level some form of recognizable breakthrough becomes possible and we move into a phase of **replication** in which the breakthrough activity is noted and mimiced widely with little understanding.
- Replication leads to increasing experience and knowledge based upon it and when the 25% level is reached sufficient information is available for a phase of **empiricism** in which design rules are formulated based on experience.
- At the 50% level sufficient information has been accumulated for deeper patterns to be discerned, and a phase of **theory** commences in which causal rules are derived that allow further experience to be predicted and design rules to be derived.
- At the 75% level the theories have become accepted as the normative basis for further progress and an **automation** phase starts in which they are used for design and to search out the residual knowledge.
- Above the 90% level a **phase of maturity** is entered when the knowledge is expected to be available and used routinely.

This **learning curve model** may be applied to the substitution of different electronic device technologies (EDTs) as a basis for computing. It then distinguishes the generations of computers in terms of the technology in use.
- The zeroth generation started in 1940 with the relay-based Bell Complex Number Computer followed in 1941 by the Zuse Z3.
- The first generation started in 1948 with the vacuum tube-based BINAC in the USA and EDSAC in the UK.
- The second generation started in 1956 with the transistor-based Bell Leprachaun followed in 1959 by the RCA 501.
- The third generation started in 1964 with the IBM 360 family using some integrated circuits.
- The fourth generation started in 1972 with the use of large-scale integration in the main memory of the IBM 370/158 and in the Intel 8008 8-bit microprocessor.
- The fifth generation started in 1980 with the use of vlsi by IBM to put the 370 processor on a chip followed by the HP-9000 in 1981 with 450,000 transistors on a chip.
- Projecting the 8-year cycle of generations has the sixth generation starting in 1988 with ultra large-scale integration and some 10 million transistors on a chip.
- Projecting further has the seventh generation starting in 1996 with grand-scale integration and 1,000 million on a chip.

QUALITATIVE CHANGES IN THE NATURE OF COMPUTING

The definition of generations in terms of EDT captures some important aspects of computing technology such as cost decreases, size decreases, power increases, and so on. However, it fails to account for the **qualitative** changes that have given computing its distinct character in each generation. The change from mechanical to electronic devices made it possible to store programs as data and enabled the use of computers as a general-purpose tool and then the development of programming language compilers. The transistor made reliable operation possible and enabled routine electronic data processing and then interactive timesharing. Integrated circuits reduced costs to the level where computers became commonplace and made possible the personal computer dedicated to a single user. Human factors considerations became important when direct human-computer interaction became a significant mode of operation.



B • Breakthrough: creative advance made

R • Replication period: experience gained by mimicing breakthrough

E • Empirical period: design rules formulated from experience

T • Theoretical period: underlying theories formulated and tested

A • Automation period: theories predict experience & generate rules

M • Maturity: theories become assimilated and used routinely

Fig. 2 Eight generations of computers and their underlying technologies

What is missing from the model of computing developing through successive generations of EDT is the infrastructure that has been built above this. A complete account of the development of the computing industry must be two-dimensional with breakthroughs in key system technologies also represented. Figure 2 shows this infrastructure with the phases on the learning curve of EDT at the base and successive computing technologies above it as the infrastructure. Now the generations may be defined in terms of major qualitative changes.
- The initial breakthrough in EDT leading to the zeroth generation is placed at 1940 about the time of the Atanasoff and Berry experiments with tube-based digital calculations.
- The first generation breakthrough was the introduction by Mauchly and Von Neumann of stored program and subroutine concepts around 1947 which led to the transition from the ENIAC to the EDVAC designs. This detached computing as a separate discipline from electronics by substituting software for hardware in a **virtual machine architecture** (VMA).
- The second generation breakthrough was to bridge the gap between machine and task through the development of **problem-orientated languages** (POLs) such as FORTRAN around 1956.

- The third generation breakthrough was to bridge the gap between the computer and the person with the development of **interactive** time-shared computers in 1964 allowing close **human-computer interaction** (HCI).
- The fourth generation breakthrough was in the early 1970s with developments in **expert systems** based on **knowledge-processing.** Such **knowledge-based systems** (KBSs) have the capability to store information through its inter-relations and make inferences about its consequence.
- The fifth generation breakthrough was in 1980 with developments in machine learning and **inductive inference systems** (IISs).
- One may speculate that the growth of robotics will provide the next breakthroughs in which goal-directed, mobile computational systems will act autonomously to achieve their objectives. The breakthrough into the sixth generation era commencing in 1988 will be one of **automomous activity systems** (AASs).
- The interaction between these systems will become increasingly important in enabling them to cooperate to achieve goals and the seventh generation era commencing in 1996 will be one of **socially organized systems** (SOSs).

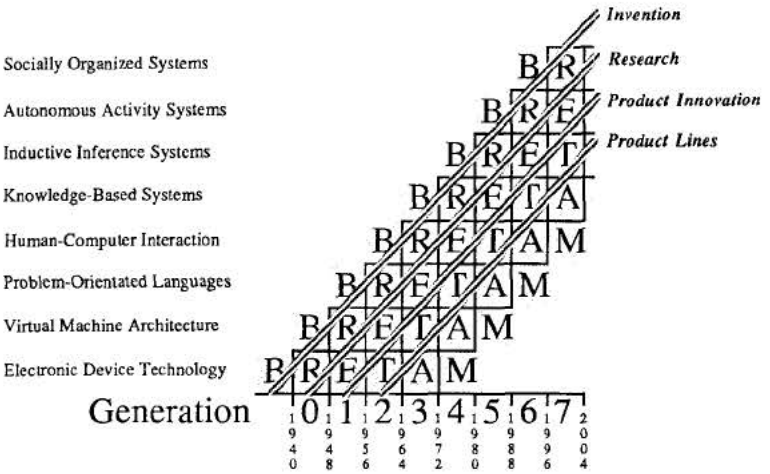


Fig. 3 Invention, research & products through generations of computers

This model of the development of computing is important in any evaluation of the impact of computing. Each generation represents a revolution in technology with a qualitatively different impact. Each generation subsumes the capabilities of that proceeding it, providing very much better facilities at very much lower cost, and adding new capabilities not possessed by the previous generations. The availability of these new capabilities in a generation is linked to the stage of the learning curve for each technology in that generation as shown in Figure 3.

- **Invention** is focused at the **BR** interface where new breakthrough attempts are being made based on experience with the replicated breakthroughs of the technology below.
- **Research** is focused at the **RE** interface where new recognized breakthroughs are being investigated using the empirical design rules of the technology below.
- **Product Innovation** is focused at the **ET** interface where new products are being developed based on the empirical design rules of one technology and the theoretical foundations of the technology below.
- **Established Products** are focused at the **TA** interface where product lines can rest on the solid theoretical foundations of one technology and the automation of the technology below.

For example, in the fourth generation (1972-79): **BR**: recognition of the knowledge acquisition possibilities of KBS led to the breakthrough to inductive-infererence systems; **RE**: research focused on the natural representation of knowledge through the development of HCI, e.g. the Xerox Star direct manipulation of objects; **ET**: experience with the HCI using the POL BASIC led to the innovative product of the Apple II personal computer; **TA**: the simplicity of the POL RPG II led to the design of the IBM System/3 product line of small business computers.

In the current fifth generation (1980-87): **BR**: recognition of the goal-seeking possibilities of IIS is leading to the breakthrough to automomous-activity systems in robotics; **RE**: research is focused on learning in KBS; **ET**: the advantages of the non-procedural representation of knowledge for HCI led to the innovative designs of the Visicalc spread-sheet business product and the LISP machine scientific product; **TA**: the ease of HCI through a direct manipulation POL led to the Apple Macintosh product line of personal computers.

HUMAN FACTORS THROUGH THE GENERATIONS

Figures 2 and 3, and their rationale, give a framework within which to analyse the role of human factors studies in computing. The horizontal BRETAM sequence for HCI has the breakthrough in 1963-64 with the development of interactive timesharing systems such as MIT MAC (Fano 1965), RAND JOSS (Shaw 1968) and Dartmouth BASIC (Danver & Nevison 1969). Such systems came into widespread use well before the human factors principles underlying their design were understood. Even towards the end of the third generation era in surveying work on man-computer interaction, Nickerson (1969) remarks on its paucity and quotes Turoff to the effect that psychology should be able to contribute greatly to the design of interactive systems:

> "When one looks at some of the current systems of this nature, it becomes quite evident that the evolution of these systems has not been influenced by this field."

Hansen (1971) seems to have made the first attempt to tabulate some user engineering principles for the design of interactive systems. Sackman's (1970) **Man-Computer Problem Solving** and Weinberg's (1971) **Psychology of Computer Programming** did much to stimulate interest in the possible applications of human factors principles in computing science.

This work marks the transition from the Replication to the Empirical periods in the BRETAM sequence. Sime, Green and Guest (1973) aroused experimental psychological interest in HCI with the publication of their paper on the **Psychological evaluation of two conditional constructions used in computer languages.** Martin's (1973) **Design of Man-Computer Dialogues** began to formalize the guidelines for HCI design and the problems of the naive user were highlighted in Wasserman's (1973) paper at the NCC on **the design of 'idiot-proof' interactive programs.** During the 1970s papers giving pragmatic HCI guidelines proliferated (Kennedy 1974, Gaines and Facey 1975, Pew and Rollins 1975, Cheriton 1976, Gilb and Weinberg 1977, Gebhardt and Stellmacher 1978, Turoff, Whitescarver and Hiltz 1978).

The transition from Empiricism to Theory at the beginning of the 1980s was marked by a growth in the books on HCI (Shackel 1979, Shneiderman 1980, Guedj, tenHagen, Hopgood, Tucker and Duce 1980, Smith and Green 1980, Shackel 1981, Coombs and Alty 1981). These combined pragmatic papers from the empirical period with a new generation of papers developing theoretical foundations for HCI based on cognitive science and system theory. The need for theoretical foundations for HCI is nowhere better illustrated than in the most recent exhaustive compendia of the pragmatic rules of the previous generation. Williges and Williges (1984) list over 550 rules which, while they are significant for reference, are far too many to be remembered explicitly in day to day design.

What we might reasonably ask for in the Theory phase of fifth generation HCI is a set of **principles** that systematically **generates** rules for dialog engineering (Gaines & Shaw 1984b). The principles should be **grounded** in **system theory, computer science** and **cognitive psychology.** The principles should be **applicable** to the entire range of possible dialog **styles and technologies,** now and in the future. The principles should be **operational** so that they can be embedded in standard procedures, **dialog shells** widely available for all interactive systems.

There have been a number of developments that satisfy some of these objectives. Thimbleby (1980) explores a number of generative principles for dialog design such as **dialog determination.** Nelson (1980) proposes **virtuality** as an analytic principle, noting that we project to the user a virtual world from within the computer. In his development of Pygmalion, Smith (1977) propounds the creation of visual worlds of **virtual objects** and this became the design principle of the Xerox Star (Smith et al 1983). Shneiderman (1983) subsumes a range of such recent developments in display-orientated systems as examples of **direct manipulation.** Gaines and Shaw (1984a) analyse computing as a **new medium** in relation to past media. Shaw and Gaines (1985) extend the **virtual machine hierarchy** to provide a model of the roles of people in human-computer systems. Taylor extends the OSI **virtual circuit** concept to provide a model of human-computer communication (Taylor, McCann & Tuori 1984). Each of these concepts gives a logic for HCI design that is supported psychologically and operationally, and hence satisfies some of the objectives expressed above.

At this stage it might seem unreasonably optimistic and foolhardy to project the BRETAM sequence for HCI and predict that the theory will be substantially in place by the end of the fifth generation era in 1987, and that it will give foundations for a period of Automation from 1988 onwards. However, the analogy with software engineering is a strong one. The problems of software development a decade ago, of massive budget over-runs, meaningless schedules, and system failures are thankfully now largely behind us. Fourth generation program generators and the associated software tools and software workbenches have brought software into the engineering domain. Fifth generation dialog generators, associated interaction tools and HCI workbenches will do the same for human-computer interaction; or, if these do not, then something remarkably similar will.

HUMAN FACTORS IN THE FIFTH GENERATION

The vertical BRETAM sequence for the current fifth generation era shows the interplay between HCI and the other strata of computing. This shows up particularly well in Figure 3.

- Fifth generation product lines are built upon the solid foundations of electronics, machine architecture and problem-orientated languages. The most recent developments to impact them are in HCI and these are the most critical to product differentiation. This is why human afctors research has become such a major priority for IBM.
- Fifth generation product innovation is based on the same technologies with the critical one being that of knowledge-based systems. Good human factors is implicitly taken to be essential in the same way as sound software engineering, adequate machine facilities and reliable, low-cost electronics.
- Fifth generation research concentrates on the inductive aspects of knowledge acquisition, systems learning from people and from experience. Knowledge-based processing, good interaction, and so on, are assumed essential but it is the structuring of information into knowledge that is the key problem.

Thus HCI has become a support technology in the fifth generation. It is no longer remarkable that people interact with computers. Nearly everyone in Western society does so from an early age. HCI research is expected to concentrate on strengthening its foundations as a support technology. The wounds, bitterness and sorrow depicted at the beginning of this paper belong to a passing era. This does not mean that our profession is becoming easier. On the contrary. The final phase of the learning curve in any discipline is when research becomes harder, standards of refereeing become harsh and many researchers drop out (Crane 1972). Obtaining results in the final 10% of the curve requires a thorough understanding of the known 90%. It requires careful experimental design, precise theoretical formulations, meticulous engineering practice in system development. In short, it is a phase of **professionalism.**

CONCLUSIONS

If we were able to use today's technology to instrument, model and understand the human-computer interfaces of yesterday life would be easy. However, the system designer always seems to be one step ahead. The multi-task, multi-user, multi-modal systems of today test our human factors skills to the utmost. It is technically easy to combine multi-screen text and graphics, keyboards, gesture and speech interaction in low-cost knowledge-based interactive systems. It is very difficult to design effective interactive procedures for such systems, evaluate them and their users, and predict the merits and problems of their use. Today the human factors engineering of complex human-computer systems may seem impossible as did the equivalent problems in software engineering ten years ago. However, it is suggested that we are beginning to see the signs of breakthroughs in our understanding of the human factors of HCI which will provide solid foundations for engineering interaction in the future. To achieve this is our greatest challenge and our greatest opportunity.

ACKNOWLEDGEMENTS

Financial assistance for this work has been made available by the National Sciences and Engineering Research Council of Canada.

REFERENCES

Bell, D. (1973). **The Coming of Post-Industrial Society.** New York: Basic Books.

Cheriton, D.R. (1976). Man-machine interface design for time-sharing systems. **Proceedings of the ACM National Conference,** 362-380.

Coombs, M.J. & Alty, J.L., Eds. (1981). **Computing Skills and the User Interface.** London: Academic Press.

Crane, D. (1972). **Invisible Colleges: Diffusion of Knowledge in Scientific Communities.** Chicago, Illinois: University of Chicago Press.

DeBono, E. (1979). **Future Positive.** London: Maurice Temple Smith.

Danver, J.H. & Nevison, J.M. (1969). Secondary school use of the time-shared computer at Dartmouth College. **AFIPS Spring Joint Computer Conference, 34,** 681-689. New Jersey, USA: AFIPS Press.

Dizard, W.P. (1982). **The Coming Information Age: An Overview of Technology, Economics and Politics.** New York: Longman.

van Dujin, J.J. (1983). **The Long Wave in Economic Life.** London: George Allen & Unwin.

Fano, R.M. (1965). The MAC system: a progress report. Sass, M.A. & Wilkinson, W.D., Eds. **Computer Augmentation of Human Reasoning.** pp. 131-150. Washington D.C., USA: Spartan Books.

Fuchi, K., Sato, S. & Miller, E. (1984). Japanese approaches to high-technology R&D. **Computer, 17**(3), 14-18 (March).

Gaines, B.R. (1984a). A framework for the fifth generation. **Proceedings of National Computer Conference, 53,** 453-459. Arlington, Virginia: AFIPS Press.

Gaines, B.R. (1984b). Perspectives on fifth generation computing. **Oxford Surveys in Information Technology, 1,** 1-53.

Gaines, B.R. & Facey, P.V. (1975). Some experience in interactive system development and application. **Proceedings IEEE, 63,** 155-169 (June).

Gaines, B.R. & Shaw, M.L.G. (1984a). **The Art of Computer Conversation: A New Medium for Communication.** Englewood Cliffs, New Jersey: Prentice Hall.

Gaines, B.R. & Shaw, M.L.G. (1984b). Dialog shell design. **Proceedings of INTERACT'84: 1st IFIP Conference on Human-Computer Interaction,** 344-349. Amsterdam: North-Holland.

Gebhardt, F. & Stellmacher, I. (1978). Design criteria for documentation retrieval languages. Banathy, B.H., Ed. **Systems Inquiring: Theory, Philosophy, Methodology. Journal of the American Society for Information Science, 29**(4), 191-199 (July). Seaside, California: Intersystems Publications.

Gilb, T. & Weinberg, G.M. (1977). **Humanized Input.** Cambridge, Mass., USA: Winthrop Publishers.

Guedj, R.A., tenHagen, P.J.W., Hopgood, F.R.A., Tucker, H.A. & Duce, D.A., Eds. (1980). **Methodology of Interaction.** Amsterdam: North-Holland.

Hansen, W.J. (1971). User engineering principles for interactive systems. **Proceedings of the Fall Joint Computer Conference, 39,** 523-532. New Jersey: AFIPS Press.

Hirose, K. & Fuchi, K. (1984). **The Culture of the Fifth Generation Computer.** No. In Japanese. Tokyo: Kaimeisha.

Karatsu, H. (1982). What is required of the fifth generation computer - social needs and impact. Moto-oka, T., Ed. **Fifth Generation Computer Systems.** pp. 93-106. Amsterdam: North-Holland.

Kennedy, T.C.S. (1974). The design of interactive procedures for man-machine communication. **International Journal of Man-Machine Studies, 6,** 309-334.

Marchetti, C. (1981). Society as a learning system: discovery, invention and innovation cycles revisited. **Report RR-81-29** (November). Laxenburg, Austria: International Institute for Applied Systems Analysis.

Martin, J. (1973). **Design of Man-Computer Dialogues.** New Jersey, USA: Prentice-Hall.

Moto-oka, T., Ed. (1982). **Fifth Generation Computer Systems.** Amsterdam: North-Holland.

Nelson, T. (1980). Interactive systems and the design of virtuality. **Creative Computing, 6**(11), 56-62 (November).

Nickerson, R.S. (1969). Man-computer interaction: a challenge for human factors research. **IEEE Transactions on Man-Machine Systems, MMS-10**(4), 164-180 (December).

Pew, R.W. & Rollins, A.M. (1975). Dialog specification procedure. **Report No.3129.** Cambridge, Massachusetts: Bolt, Beranek & Newman.

Rosen, R. (1985). **Anticipatory Systems.** Oxford: Pergamon Pres.

Sackman, H. (1970). **Man-Computer Problem Solving.** Princeton: Auerbach.

Shackel, B., Ed. (1979). **Man/Computer Communication.** Maidenhead, UK: Infotech International.

Shackel, B., Ed. (1981). **Man-Computer Interaction: Human Factors Aspects of Computers and People.** The Netherlands: Sijthoff & Noordhoff.

Shaw, J.C. (1968). JOSS: experience with an experimental computing service for users at remote consoles. Orr, W.D., Ed. **Conversational Computers.** pp. 15-22. New York, USA: John Wiley.

Shneiderman, B. (1980). Systemic principles for human-computer interaction. Banathy, B.H., Ed. **Softare Psychology.** pp. 377-386. Cambridge, Massachusetts: Winthrop.

Shneiderman, B. (1983). Direct manipulation: a step beyond programming languages. **Computer, 16**(8), 57-69 (August).

Sime, M.E., Green, T.R.G. & Guest, D.J. (1973). Psychological evaluation of two conditional constructions used in computer languages. **International Journal of Man-Machine Studies,** 5(1), 105-113 (January).

Smith, D.C. (1977). **Pygmalion.** Basel: Birkhauser.

Smith, D.C., Irby, C., Kimball, R., Verplank, B. & Harslem, E. (1983). Designing the Star user interface. Degano, P. & Sandewall, E., Eds. **Integrated Interactive Computing Systems.** pp. 297-313. Amsterdam: North-Holland.

Smith, H.T. & Green, T.R., Eds. (1980). **Human Interaction with Computers.** London: Academic Press.

Taylor, M.M., McCann, C.A. & Tuori, M.I. (1984). The interactive spatial information system. **DCIEM Report 84-R-22.** Toronto: DCIEM.

Thimbleby, H. (1980). Dialogue determination. **International Journal of Man-Machine Studies, 13**(3), 295-304 (October).

Toffler, A. (1980). **The Third Wave.** New York: Bantam.

Turoff, M., Whitescarver, J. & Hiltz, S.R. (1978). The human machine interface in a computerized conferencing environment. **Proceedings of the IEE Conference on Interactive Systems, Man and Cybernetics,** 145-157.

Wasserman, T. (1973). The design of idiot-proof interactive systems. **Proceedings of the National Computer Conference, 42,** M34-M38. New Jersey: AFIPS Press.

Weinberg, G.M. (1971). **The Psychology of Computer Programming.** New York: Van Nostrand Reinhold.

Williges, B.H. & Williges, R.C. (1984). Dialogue design considerations for interactive computer systems. Muckler, F.A., Ed. **Human Factors Review: 1984.** pp. 167-208. Santa Monica, California: Human Factors Society.

Withington, F.G. (1974). Five generations of computers. **Harvard Business Review,** 99-108.