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From timesharing to the sixth generation: the development of human–computer interaction. Part I

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The human-computer interface is increasingly the major determinant of the success or failure of computer systems. It is time that we provided foundations of engineering human-computer interaction (HCI) as explicit and well-founded as those for hardware and software engineering. Computing technology has progressed through a repeated pattern of breakthroughs in one technology, leading to its playing a key role in initiating a new generation. The basic technologies of electronics, virtual machines, and software have gone through cycles of breakthrough, replication, empiricism, theory, automation and maturity. HCI entered its period of theoretical consolidation at the beginning of the fifth generation in 1980. The lists of pragmatic dialog rules for HCI in the fourth generation have served their purpose, and effort should now be directed to the underlying foundations. The recently announced sixth-generation computer system (SGCS) development program is targeted on these foundations and the formulation of *knowledge science*. This paper surveys the development of HCI and related topics in artificial intelligence; their history, foundations, and relations to other computing disciplines. The companion paper surveys topics relating to future developments in HCI.

Introduction

In the 1980s the state of the art of human-computer interaction (HCI) has given many indications of reaching new levels of knowledge, capabilities and importance. This heightened significance may be judged by the frequency of reference to HCI in the press and general computing literature, the volume of specialist papers and books on HCI, the commercial research and development expenditure on HCI, the number of researchers in HCI, the increasing attendance at specialist HCI conferences, the number of HCI sessions at non-specialist conferences, and so on. We have been in an era of transition from a period in which HCI concerns were the province of a few specialist researchers to one in which HCI science and technology are widely regarded as basic concerns in computer-based system design and application.

However, although the attention given to HCI may be pleasing to those concerned with human-computer studies, it does not in itself indicate that the problems of the poor HCI have become less, or that our knowledge of good HCI is now an adequate basis for computer-based system design. There are many examples of attractive HCI

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designs that appear to work very well in particular applications, notably the Xerox Star and Apple Macintosh. However, there are many examples also of widely used HCI designs from highly reputable organizations that are difficult and frustrating to use by both experienced and novice users.

This paper assesses the state of the art in HCI research and development using an analysis of past trends to indicate future directions. It reviews the development of HCI and related topics in artificial intelligence from the early generations of computers through the present fifth generation and projects future trends into the future. It analyses the place of HCI research, science and technology within the infrastructure of the computing industry, its role in fifth-generation research and commercial product innovation, and the significance of human factors knowledge in the proposed sixth-generation research program.

HCI in an information age: problems and responsibilities

Electronic computing is one of the phenomena of our age. Many writers have speculated upon the impact of computers on our society, culture and value systems (Wiener, 1950; Marschak, 1968; Mowshowitz, 1976; Weizenbaum, 1976; Porat, 1977; Gershuny, 1978; Dertouzos & Moses, 1979). The impact is now being felt and many commentators are attempting to analyse its nature and project its trends (Machlup, 1980, 1982, 1984; Wojciechowski, 1983; Stonier, 1983; Brod, 1984; Turkle, 1984; Pagels, 1984; Traub, 1985). 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."

These remarks will be heart-felt for many HCI specialists responsible for designing, evaluating, rectifying, or explaining, the human factors aspects of modern computer-based systems. Perhaps, like physicians, human factors specialists only get called in when there are problems. They see many sick systems and are prejudiced by their 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. It is also apparent that the information age is not an act of nature, like a plague, fortuitously 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.

COMPUTING AS A PHENOMENON OF THE LIFE WORLD

Much of the speculation about, and analysis of, the impact of computing neglects its positive social role and offers one-sided perspectives relative to two key distinctions. One perspective assumes that the major impact is of computing on society rather than society on computing. This takes for granted Ellul's (1964) view of technology as autonomous, and fails to question why the technology itself has arisen out of the processes of society. Another perspective assumes that the future may be projected as an extrapolation of processes begun in the past. This takes for granted the causal models fundamental to physical science and fails to recognize the higher level goals that lie behind computing developments seen as part of the teleology of society.

These one-sided perspectives have limited validity in that they lead to meaningful conclusions relative to their presuppositions. They are appropriate to the analysis of technological dependencies for purposes of industrial and government planning, e.g. that we must have adequate capabilities for semiconductor-device manufacture or purchase before we can develop a computer industry. However, they are not appropriate perspectives from which to evaluate many aspects of HCI, such as the relations between computing, society, values, culture and creativity. These last four are phenomena of the *life world* (Schutz & Luckman, 1973) and embedded in its processes. To understand their relations to computing we must view it also as a phenomenon of the life world embedded in its processes, both generated by them and generating them (Kohak, 1984; Blum & McHugh, 1984). Computing technology is directed by the processes of society at least as much as it impacts them. Up to its present fairly primitive stage its development has been governed by existing social processes and the dominant value system. It is only just beginning to become an agent for social change. The perspective that views only the impact of computing on society misses the major dynamics of computing technology during the past forty-five years.

In his book *Trust and Power*, Luhmann (1979) has expressed the systemic principles that underly human civilization and the development of our society in such a way that the role of information technology can be placed in a social context:

> "The world is overwhelmingly complex for every kind of real system ... Its possibilities exceed those to which the system has the capacity to respond. A system locates itself in a selectively constituted 'environment' and will disintegrate in the case of disjunction between environment and 'world'. Human beings, however, and they alone, are conscious of the world's complexity and therefore of the possibility of selecting their environment—something which poses fundamental questions of self-preservation. Man has the capacity to comprehend the world, can see alternatives, possibilities, can realize his own ignorance, and can perceive himself as one who must make decisions."

The increase in world population to its present level could not have been sustained without the development of technology to support the complex socio-economic infrastructure required. DeBono (1979) expresses the role of computers in a complex world in his book *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 organization 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 the reality and responsibility of those currently concerned with HCI. Fourth-generation computing systems are already making demands on human-factors specialists that stretch their 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. In considering the foundations of HCI it is worth remembering Luhmann's (1979) additional caveats about human–human interaction:

> "We invoke a whole new dimension of complexity: the subjective 'I-ness' of other human beings which we experience (perceive) and understand. Since other people have their own first-hand access to the world and can experience things differently they may consequently be a source of profound insecurity for me."

It is often assumed that HCI can be modeled on our knowledge of human–human interaction but Luhmann's remark reminds us that there are complexities in relations between people that go far beyond the complexities of those between people and the inanimate world. The problems of understanding HCI should be simpler than those of understanding interpersonal interaction.

THE CHALLENGE OF FIFTH GENERATION SYSTEMS

We are now in the fifth-generation computing era with its emphasis on complex, knowledge-based systems involving close human–computer interaction. 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 the fourth and fifth generations go beyond human factors knowledge based on the textual display and keyboard technology of yesterday. If we continue to rely on empirical knowledge based on studies of the past, we shall never be equipped to deal with the systems of the present let alone those of the future. This is the dilemma of current HCI research and one that can be resolved only through the development of foundational models of HCI that can be projected to novel situations.

We believe that such foundational models are feasible given the advances in neurology, psychology, linguistics, cognitive science and system science during the past twenty years. However, the tradition in HCI studies is still one of empiricism in research and evolutionary design in product development. The remainder of this paper gives a number of different perspectives on HCI which show how this situation has come about and why it is reasonable to expect it to change. The companion paper (Gaines & Shaw, 1986) analyses what trends are leading to that change and what types of study may be expected to bring it about.

Generations of computers: the background to HCI

Interest in HCI has existed since the early days of computing became of high significance in applications as interactive computing came into widespread use in the 1960s, and is fundamental to the fifth- and sixth-generation computing system (FGCS and SGCS) development programs. Users and commentators have been ambivalent towards the state of the art in HCI, oscillating between the euphoric prospects of person–computer symbiosis and the frustratingly poor person–computer interfaces provided with many

systems (Gaines, 1978; Shackel, 1979; Guedj, tenHagen, Hopgood, Tucker & Duce, 1980; Smith & Green, 1980; Shackel, 1981; Coombs & Alty, 1981; Badre & Shneiderman, 1982; Sime & Coombs, 1983; Degano & Sandewall, 1983; Green, Payne & van der Veer, 1983; Salvendy, 1984). While researchers now treat HCI as a distinct discipline with its own rationale, methodologies, techniques and foundations, its focus of attention and dynamics of change are best explained as part of the larger scenario of the total development of computer systems.

For the reasons already noted, viewed as a causal chain, the development of computing is highly indeterminate. Technological forecasts for computing are notoriously inaccurate (Withington, 1974; Gaines, 1984*b*). 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 subgoals 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 & Shaw, 1985*a*, *b*). The generations show an eight-year cyclic pattern that corresponds to the medium-term Juglar business cycle (Rau, 1974; Van Dujin, 1983). At the beginning of each generation a new systems technology comes into existence. The technology depends upon correlated advances in a number of subsystems' technologies with variation in which one is innovative at each stage. The first generation commenced in 1948 and we are now in the fifth generation spanning 1980–1987.

THE LEARNING CURVES OF COMPUTING TECHNOLOGIES

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*. 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 an initial need to have knowledge in order to acquire more and a finally slowing down in the acquisition as there is less and less left to acquire.

The base learning curve shows that the electronic-device technology underlying computing has shown a fairly steady exponential climb from one device on a chip in 1959 to several million in 1985 (Robinson, 1984). This corresponds to an increase of two orders of magnitude for each computer generation of eight years, a rate of improvement typically achieved in the technologies of other industries, for example aircraft speeds, only over 50–100 years. This magnitude of quantitative change, although

in itself continuous, leads to discontinuous qualitative changes as new possibilities become cost-effective. Taking these qualitative changes into account, the growth of the infrastructure of computing technology may be seen as an *envelope* (Ayres, 1968) of logistic learning curves as shown in Fig. 1.

An interesting pattern can now be seen in the introduction of new technologies at the transitions between generations. The zeroth generation resulted from the breakthrough in *electronic device technology* (EDT) with vacuum tubes replacing electromechanical relays (Shurkin, 1984). In the first generation the digital computer as we know it today came into being through Mauchly and Von Neumann's breakthroughs to the concept of programmability (Goldstine, 1972; Wulforst, 1982), leading to the *virtual machine architecture* (VMA) principle at the heart of computing and the detachment of computing science as a separate discipline from electronic engineering. The second generation corresponded to breakthroughs in *problem-orientated languages* (POLs) that made programming easier (Wexelblat, 1981). The third generation corresponded to breakthroughs in operating systems giving timesharing and *human-computer interaction* (HCI) through conversational computing (Orr, 1968). The fourth generation corresponded to breakthroughs in expert systems (Michie, 1979; Buchanan & Shortliffe, 1984) allowing the development of *knowledge-based systems* (KBSs). The fifth generation corresponded to breakthroughs in machine learning (Michalski & Chilausky, 1980; Davis & Lenat, 1982) giving *inductive inference systems* (IISs) and promoting the current research thrust on learning systems (Michalski & Carbonnel, 1983).

The projection of the sixth generation from Fig. 1 is clearly speculative and prone to error. It will probably involve new subsystem technologies for high-density information storage and processing which are under investigation now, such as optical logic and organic processing elements (Tucker, 1984). AI and HCI activities will have completely converged and the research focus will move down from the cortical knowledge-processing level of the brain to the limbic attention-directing level. This is only now beginning to be studied in cognitive science (Norman, 1980) and manifests itself in human emotions and awareness (Gaines & Shaw, 1984).

It seems likely that the "breakthrough" into the sixth generation era will come from work on robotics relating to *autonomous activity systems.* Such systems will be goal-directed and their activities will be generated by internal planning taking into account both their goals and their interaction with the environment. In these circumstances their activities may be incomprehensible to their designers and users, and they will appear autonomous. Such a development is consistent with the developmental sequence whereby computer behavior has been programmed initially at a low level, then at high levels, and now through non-procedure specification of goals as in PLANNER (Hewitt, 1969) and Prolog (Clark & Tarnlund, 1982). Goal-specification in an indeterminate environment, particularly when coupled with learning, generates a high degree of autonomy. Currently we have few techniques for understanding autonomy and representing it formally (Varela, 1979; Zeleny, 1981), and the breakthrough will come in being able to handle it logically and computationally.

There are significant changes in the nature of work, and workers, in a technology as it proceeds along its learning curve (Crane, 1972; De Mey, 1982). Each technology in the sequence EDT-VMA-POL-HCI-KBS-IIS-AAS seems to follow a course in which a *breakthrough* leads to successive eras: first *replications* in which the break-

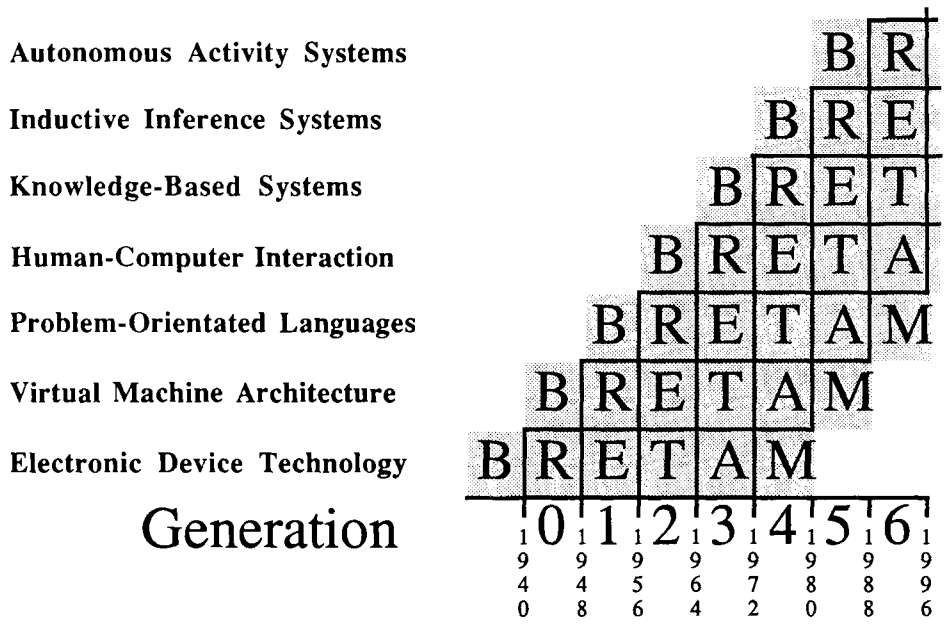

FIG. 1. The infrastructure of seven generations of computing based on the learning curves of the underlying technologies.

through results are copied widely; second *empiricism* in which pragmatic rules for good design are generated from experience; third *theory* in which the increasing number of pragmatic rules leads to the development of deeper principles that generate them; fourth *automation* in design based on the theory; finally leading to an era of *maturity* and mass production based on the automation and resulting in a rapid cost decline.

At the end of the fourth generation in 1980, we had electronics in mass production; computer design automated; a solid foundation of theory underlying software, pragmatic rules for interaction; and the breakthroughs in knowledge-based systems that triggered off FGCS.

The current fifth generation is one of: low-cost mass production of electronics and computers, where we have the achievements, experience, rules, theory and automation; automation of software development based on achievements, experience, rules and theory; theoretical foundations for HCI based on achievements, experience and rules and pragmatic rules for knowledge-based systems based on achievements and experience.

In the sixth generation, hardware will be freely available, software development should no longer present problems, the design of the human–computer interface should become automated, firm theoretical foundations should be developed for knowledge engineering, and breakthroughs in machine learning at the beginning of the fifth generation should be consolidated through further experience into pragmatic rules.

THE PIVOTAL ROLE OF HCI

The infrastructure of Fig. 1 shows that HCI techniques have not just evolved in a vacuum but are an integral part of developments in computer technology and applications. The context of developments in HCI has been: the preceding developments in the three levels below, EDT, VMA and POL, which may be summarized as hardware and software engineering; and the succeeding developments in the three levels above, KBS, IIS and AAS, which may be summarized as artificial intelligence. HCI is at the pivot point between one form of computing based on algorithms programmed in every detail, and another form of computing based on encoding of knowledge, learning and expression of goals.

This pivotal role shows up in HCI studies and objectives where on the one hand the focus may be interfacing the person effectively to a complex information processing system, whereas, on the other, it may be achieving a form of symbiosis with a partner whose knowledge-processing capability is comparable to that of the person. The first type of study is concerned with the ergonomics of the interface and interaction, and can separate out the human and computer components. The second type of study is concerned with the total knowledge system and, to the extent that separation is possible, sees the processes of the person mirrored in the computer (artificial intelligence) and the processes of the computer mirrored in the person (cognitive science).

The next sections present major landmarks in the development of AI and HCI in the context of the generational sequence shown in Fig. 1, relating them to the underlying trends in hardware and software engineering.

The historical development of AI

Figure 2 shows the history of developments in the generations of computers based on an extensive list of significant events in computing (Gaines, 1984*a*). The table was initially based on that by Withington in 1974 and his names have been retained for all but the fourth generation.

HARDWARE AND SOFTWARE THROUGH THE GENERATIONS

The first column of Fig. 2 shows developments in the underlying technologies of EDT, VMA and POL through the generations. There was a zeroth generation of pre-commercial machines such as COLOSSUS and ENIAC and this was certainly *up and down*, mainly down. The first generation was an era of *gee whiz—computers can do anything.* This was necessary to support the act of faith by their users that one day they might become cost-effective. It took at least one more generation for this to happen but many families of commercial machines began in this era and so did applications to numeric control and navigational aids. The second generation was an era of *paper pushers* in banks and insurance companies. It was also that of developments in software such as operating systems and problem-oriented languages.

	Hardware/Software EDT/VMA/POL	State of AI KBS/IIS/AAS	State of HCI HCI
0 1940-47	**Up and Down** Relays to vacuum tubes COLOSSUS, ENIAC	**Mind as Mechanism** Logic of neural networks *Behavior, purpose & teleology*	**Designer as User** Judge by ease of use
1 1948-55	**Gee Whiz** Tubes, delay lines, drums BINAC, EDSAC, UNIVAC, WHIRLWIND, EDVAC, ACE IBM 701, 702, 650 Numeric control, navaids	**Cybernetics** Turing test Ashby's homeostat Grey Walter's tortoise Samuel's checkers player *Design for a Brain*	**Machine Dominates** Person adapts to machine *Human Use of Human Beings*
2 1956-63	**Paper Pushers** Transistors & core stores I/O control programs IBM 704,7090,1401, NCR 315 UNIVAC 1103, PDP 1,3,4,5 FORTRAN, ALGOL, COBOL Batch, execs, supervisors Petrinets *Communications of ACM*	**Generality/Simplicity The Oversell** Perceptron, GPS, EPAM Learning machines Self-Organizing systems IPL V, LISP 1.5 Dartmouth AI Conference *Mechanization of Thought Processes*	**Ergonomics** Console ergonomics Job control languages Simulators, graphics CTSS, MAC JOSS, BASIC ***Breakthrough to HCI***
3 1964-71	**Communicators** Large-scale ic's Interactive terminals IBM 360,370 CDC 6600, 7600 PDP 6, 7, 8, 9, 10 DBMS, relational model Intel 1103, 4004	**Perform by Any Means** Semantic nets, ATNs, ELIZA PLANNER, fuzzy sets DENDRAL, scene analysis Resolution principle, 1st IJCAI *Machine Intelligence 1* *Artificial Intelligence* ***Breakthrough to KBS***	**Man-Machine Studies Interactive Experience** Time-sharing services Interactive terminals Speech synthesis TSS360, APL\360 Unix, shell *Int. J. Man-Machine Studies*
4 1972-79	**Personal Resources** Personal computers Supercomputers, VLSI Very large file stores Databanks, videotex IBM 370/168—MOS memory & virtual memory Intel 8080, NS PACE 16-bit	**Encoded Expertise & Over-Reaction** PROLOG, Smalltalk, frames, Scripts, systemic grammars SHRDLU, MARGIE MYCIN, TEIRESIAS Dreyfus, Lighthill & Weizenbaum attacks on AI *Cognitive Science*	**HCI Design Rules** Personal computing Dialog rules LUNAR, ROBOT, LIFER Videotex services Altair & Apple PC's Visicalc *J. Assn. Comput. Linguistics* *Byte*
5 1980-87	**Action Aids** PC's with power & storage of mainframes plus graphics & speech processing Networks, utilities OSI, NAPLPS standards IBM 370 chip, HP-9000 chip with 450,000 transistors	**Commercialization** LISP and PROLOG machines Expert system shells EMYCIN, AL/X, OPS5, APES Fifth generation project ICOT PSIM & PIM Knowledge bases *Handbook of AI*	**User-Natural Systemic Principles** Xerox Star, IBM PC Apple Macintosh Videodisk Human protocol KLONE-ED, INDIS, KLAUS ARGOT, HAM-ANS
6 1988-93	**Partners** Optical logic and storage Organic processor elements AI in routine use	**Learning & Emotion** Parallel knowledge systems Audio and visual sensors Multi-modal modeling	**User-Similar Automated Design** Integrated multi-modal systems Emotion detection

FIG. 2. Developments in computing, artificial intelligence and human-computer interaction through seven generations.

The third generation was one of *communicators* as increased reliability and timesharing operating systems allowed online interaction. Large-scale integrated circuits began to be used and database management systems were developed. The fourth generation has been retitled *personal resources* from Withington's "information custodians" to subsume both database access and the personal computer. Withington's name of over a decade ago for the projected fifth generation is surprisingly apt as expert systems (ES) are certainly *action aids.* The sixth generation is seen as approaching the partnership of Licklider's (1960) *man–machine symbiosis.*

THE EARLY AGES OF AI: CYBERNETICS, GENERALITY AND SIMPLICITY IN GENERATIONS 1 AND 2

AI developments are shown separately in the second column of Fig. 2 because of their significance to HCI. AI research existed in each generation but its tactics changed markedly from one to another. The concepts underlying AI of mind as mechanism were already present in the zeroth generation era of the 1940s with McCulloch & Pitts' (1943) work on the logic of neural networks and Rosenblueth, Wiener & Bigelow's (1943) analysis of behavior, purpose and teleology. This led in the first generation era to Wiener's (1948) development of *cybernetics* and von Bertalannfy's (1950) development of *general systems theory*, and to the fabrication of cybernetic machines emulating feedback in animal behavior such as Ashby's (1952) homeostat and Walter's (1953) tortoise. In this era also Turing (1950) raised the question of how we might test for the emulation of human intelligence in computers.

However, the generally accepted starting period for research on AI is in the second generation era of the late 1950s with work by: Newell, Shaw and Simon (1958) on the *General Problem Solver*; Samuels (1959) on a *checkers player*; McCarthy (1959) on *programs with common sense*; Selfridge (1959) on *Pandemonium*; Rosenblatt (1958) *Perceptrons*; Widrow (1959) on *Adalines*; Solomonoff (1957) on *mechanized induction*; and Farley and Clark (1954) on *neural nets.* Minsky's (1961) survey gives a comprehensive account for this era world-wide. The logic behind much of the work was that new forms of computer organized as aggregates of simple, self-organizing elements, could be induced to perform a task by mechanisms of learning through mimicking, reward and punishment similar to those of animal learning (Gaines & Andreae, 1966).

These objectives and this type of work characterized the goals and approaches being taken worldwide at that time. They should be placed in the context of the early development of digital computers where slow, expensive, unreliable machines with mercury-delay line memories were still in use programmed in various forms of assembler or autocode. The JOSS, Culler-Fried, PLATO and Project MAC experiments on timesharing were peak achievements at the end of the same era (Orr, 1968). The atmosphere was one of immense excitement at the potential for computer systems to lead to the *augmentation of human reasoning* and *man–machine symbiosis* to use the terms of books and papers of that era (Sass & Wilkinson, 1965).

THE MIDDLE AGES OF AI: CRITICAL APPRAISAL AND PERFORMANCE PARADIGM IN GENERATIONS 3 AND 4

The excitement and the funding died down during the third generation era of the 1960s as a result of two main factors. Firstly, the work did not fulfil the promises made on

its behalf: neural nets did not self-organize into brains; learning machines did not learn; perceptron-like elements did not recognize patterns. Secondly, the conventional digital computer became more reliable, smaller, faster, and cheaper, and the advantages of its sheer generality became widely realized. In the third-generation era, effort out of designing brain-like machines to emulating human-like activities on general-purpose computers (Goldstein & Papert, 1977). The focus of attention also became human performance, not human learning or human simulation. The initial rationale for this shift was that: if we could not program a computer to perform a task then it was unlikely that we could program it to learn to perform that task; and if we could not program it somehow then we certainly could not in a way that simulated a person. This became the definition of legitimate artificial intelligence research at the end of the third generation: the performance of tasks that required intelligence when performed by people.

While the AI community regrouped around the revised goals in the third generation era, the time scale between research and widespread publication is such that even by the start of the fourth generation era of the early 1970s, many outside that community felt the necessity to express disenchantment with the whole endeavor. Dreyfus (1972) in his book, *What Computers Can't Do*, detailed many of the over-optimistic claims for AI research and the ensuing under-achievement. He points to weaknesses in the philosophical and methodological foundations of work in AI. His 1979 revised edition at the end of the fourth generation era reports some of the intervening debate resulting from his book and the changing priorities in AI research. His original book was a well-balanced report that can be criticized primarily because it was out of date by the time it was published. Those in the AI community had already learnt the lessons he expressed and changed their strategy.

Lighthill's (1973) negative report on behalf of the SRC on the status of AI research and the appropriate level of its funding in the UK reflected the disenchantment at the end of second-generation work with its over-sell and lack of achievement. However, there was another motivation behind the commissioning of that report and that was the fear of some of those responsible for developing computer science departments in the UK that AI research would be funded most strongly outside those departments. At a mundane level, the misgivings came from the realization that the expensive and powerful computers then necessary for AI research might not be used to improve the research facilities of recently formed computer science departments. More fundamentally, it was sensed that developments in AI might prove to be a major part of the future foundations of computer science. Whatever the motivation, the outcome of the report was very negative for AI research funds in the UK during the fourth generation era (Fleck, 1982).

Weizenbaum's (1976) book, *Computer Power and Human Reason* was a far more personal statement than that of Dreyfus by someone who had been responsible for one of the early achievements of AI research. His ELIZA program (Weizenbaum, 1966) was widely acclaimed in the late 1960s as an early breakthrough in advanced HCI and the first successful attempt at passing the Turing test for AI. It could carry out *cocktail party conversation* with a person at a terminal that was remarkably human-like. However, the acclaim became embarrassment as it was realized the simple mechanisms of ELIZA illustrated the weakness of the Turing test rather than a major advance in HCI and AI. People were all too ready to discern intelligence in machines

and men, and commonsense human judgment in the matter was not an adequate criterion. The AI community was forced to reconsider what was meant by intelligence.

The shift of attention of AI work in the third generation era de-emphasized requirements for power and generality, consideration of computer architecture, and the simulation of human operation. It instead emphasized requirements to encode human expert knowledge and performance, by whatever means, for emulation by the computer. These targets resulted in practical achievements in the development of systems that could perform in diagnostic inference tasks as well as human experts, and the fourth-generation era became that of *expert systems* research (Michie, 1979).

The strength of this paradigm shift cannot be over-emphasized. It defined the boundaries of an AI community that established parameters for funding and publication. The focusing of effort on performance led to achievements recognized outside this community and hence established the legitimacy of AI research. As the fourth-generation era ended the community had become strong enough to re-absorb some of the earlier objectives and concepts. Human simulation rather than just emulation is an objective of cognitive science (Lindsay & Norman, 1977; Johnson-Laird & Wason, 1977). Certain aspects of knowledge acquisition processes subsumed under learning have been successfully programmed (Michalski & Chilauski, 1980). New computer architectures have been developed targeted on AI requirements (Bawden, Greenblatt, Holloway, Knight, Moon & Weinreb, 1979).

THE CURRENT AGE OF AI: COMMERCIALIZATION AND KNOWLEDGE SCIENCE IN GENERATIONS 5 AND 6

We are now in the fifth-generation era where the commercialization of expert system developments derived from AI research has generated a major new industry. The understanding and development of FGCS are being treated as a national priority by many nations (Moto-oka, 1982; HMSO, 1982; Steier, 1983). The defence and commercial implications of achieving even part of the FGCS objectives are a more compelling argument for massive resources than any the AI community had been able to muster. The socio-cultural implications might also be overwhelming (Machlup, 1984). The close AI community of earlier eras no longer exists and AI research is regarded as the cutting edge of mainstream computer science. The financial pull of industry has fragmented effort (Business Week, 1984) and it will be some time before new patterns of activity are clarified.

The recently announced sixth-generation development program (STA, 1985) recognizes some of the fundamental topics of early AI research, such as the physiology of knowledge-processing in the brain, which were significant themes in second generation AI studies but became neglected in the third generation switch to a performance paradigm. The significance of this program is discussed in a later section.

The historical development of HCI

HCI research and development parallels that of AI but has not given rise to the similar strong emotions, probably for three reasons. First, through the perceived thrust of the differing objectives: AI to emulate and possibly excel or replace people; HCI to support interaction with the computer and enhance human capabilities. Second, due to the

differing resource requirements: AI research has needed a high proportion of the time of large expensive matches; HCI research has been possible ethologically by observing users of existing systems and through behavioral experiments on small laboratory machines (Gaines, 1979). Third, due to the dual roles already noted for HCI as the pivot between information-processing and knowledge-processing technologies: most HCI research through the fourth generation has been concerned with improving the interface rather than promoting person-computer symbiosis. In recent years, there has been a strong convergence between the two areas as AI techniques have come to be applied in HCI development. AI research has come to concentrate on the combination of person and computer in joint problem-solving, and AI techniques have become usable in low-cost systems.

THE EARLY AGES OF HCI: ERGONOMICS AND TIMESHARING IN GENERATIONS 1 AND 2

Computers as tools to enhance the capabilities of people has been a recognised theme from the early days of computing system design. In 1879 the Merrifield committee was concerned that Babbage's analytical engine might be abused by people who used it for *Sisyphean* tasks. They take logarithms as a comparison and note:

> "Much work has been done with them which could more easily have been done without them... more work has been spent on making tables than has been saved by their use" (Merrifield, 1973).

Probably, a proper starting point for concern with human factors lies with Mauchly who, in discussing EDVAC programming in 1947 at the end of the zeroth generation notes the importance of ease of use of subroutine facilities, remarking:

> "Any machine coding system should be judged quite largely from the point of view of how easy it is for the operator to obtain results" (Mauchly, 1973).

Replace "machine" by "virtual machine" and you have an aphorism which lies at the heart of HCI design today. However, in the early years the problems of making any form of operational computer far outweighed such ease of use considerations, and we have to move on some 20 years to see the beginnings of human factors studies of HCI as we know them today.

The third column of Fig. 2 shows the state of HCI developments through the generations. In the first generation, the operator was part of the design team and adapted his behavior to that required by the machine. Computers were awkward to use, although Mauchly's remark shows that human factors considerations were in evidence. Early computers were slow, expensive and unreliable, so that interactive use was rare in all but a few military and control applications. Those interacting with the machines were a few skilled operators accepting the problems of the interface as minor compared with all the other difficulties of using computers.

Professional ergonomic considerations of computer consoles commenced in the second generation (Shackel, 1959). However it was the breakthrough into timesharing systems at the end of the second generation making interactive access widely available that focused attention on human factors. The MIT MAC system (Fano, 1965) in 1963, the RAND JOSS system in 1963/64 (Shaw, 1968) and the Dartmouth College BASIC system in 1964 (Danver & Nevison, 1969), pioneered a new style of computing where the problems of HCI became significant.

THE MIDDLE AGES OF HCI: MAN-MACHINE STUDIES AND DIALOG ENGINEERING RULES IN GENERATIONS 3 AND 4

The significance for HCI of developments in timesharing was recognized at the start of the third generation by what appears to be the first conference on HCI, the *IBM Scientific Computing Symposium on Man-Machine Communication*, held at Yorktown Heights in May 1965 (IBM, 1966). The sessions covered: *Scientific Problem-Solving, Man-Computer Interface, Languages and Communication, New Areas of Application* and *Man-Computer Interaction in the Laboratory.* The fifteen papers included those by Fano on computer utilities, Oettinger on linguistic problems of man-computer interaction and Coons on computer graphics and innovative engineering design.

Timesharing systems opened computer use to a wider community less tolerant of technical problems. In 1967, Mills remarked:

> "the future is rapidly approaching when 'professional' programmers will be among the least numerous and least significant system users" (Mills, 1967).

In the same year, White considered the problems of on-line software and noted:

> "A complex set of problems exists in the area of intelligible communications between the system and the user. Effective solutions to this problem have been few and far between. The user of many systems soon gets the feeling that either the messages he receives were hung onto the system as an afterthought or that they were designed for the convenience of the system rather than the user" (White, 1967).

This remark appears as relevant today as it was nearly twenty years ago and is echoed in the reviews of many current software packages.

In the latter part of the third generation, Nickerson (1969) surveyed work on man-machine interaction, remarked on its paucity, and quoted Turoff to the effect that, although 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" (Nickerson, 1969).

However 1969 was also a landmark year in the recognition of the significance of HCI: *Ergonomics* had a special issue based on papers to be given at an *International Symposium on Man-Machine Systems*; the *IEEE Transactions on Man-Machine Systems* reprinted the same papers to give them wider circulation; and the *International Journal of Man-Machine Studies* (IJMMS) started publication.

While such publications provided a forum for HCI research it was not easy to obtain true human factors material for publication in those days. As a scientific discipline, the field did not yet exist, but what could be communicated was a wide variety of user experience of interactive systems applied to many tasks. The 1969 issues of IJMMS contain papers on teaching systems, learning machines, natural-language processing, speech recognition, radiological reporting, automated psychological testing, and air traffic control. Computers are stimulating and the world was alive with imaginative computer applications from the earliest days onwards. It took a long time for our scientific knowledge and professional skills as psychologists to begin to catch up with our creative imaginations as computer users.

At the end of the third generation 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. Hansen (1971) seems to have been the first to develop some *user engineering principles for interactive systems.* He compares the system designer with a composer:

> "The 'feel' of an interactive system can be compared to the impressions generated by a piece of music. Both can only be experienced over a period of time. With either, the user must abstract the structure of the system from a sequence of details. Each may have a quality of 'naturalness' because successive actions follow a logically consistent pattern."

It is a great pity that Hansen's terminology did not get into wider use since *user-natural* seems a more accurate description of HCI objectives than does the commonly used term *user-friendly.* At the beginning of the fourth generation Martin's (1973) *Design of Man-Computer Dialogues* was the first book devoted to HCI. He emphasizes the critical role of human factors in the utility of computer systems:

> "Man must become the prime focus of system design. The computer is there to serve him, to obtain information for him and to help him do his job. The ease with which he communicates with it will determine the extent to which he uses it. Whether or not he uses it powerfully will depend upon the man-machine language available to him and how well he is able to understand it."

Experimental psychological interest in HCI was also evident in 1973 with the publication of Sime, Green and Guest's paper on the *Psychological evaluation of two conditional constructions used in computer languages.* The same year saw the publication of Wasserman's paper at the NCC on *The design of 'idiot-proof' interactive programs.* The choice of a less insulting term for *naive, non-professional, non-specialist* or *casual* users has been a continuing problem.

The increasing problems created by poor HCI for the growing casual and non-specialist user populations were highlighted by Walther and O'Neill at the NCC in 1974:

> "The lowered cost of computer access and the proliferation of on-line systems produced a new breed of users, people whose expertise was in some area other than computer technology. As their initial fascination with conversational computing wore off, users reported experiencing feelings of intense frustration and of being 'manipulated' by a seemingly unyielding, rigid, intolerant dialogue partner, and these users began disconnecting from time-sharing services at a rate which was very alarming to the industry." (Walther & O'Neill, 1974).

THE CURRENT AGE OF HCI: COMMERCIALIZATION AND KNOWLEDGE SCIENCE IN GENERATIONS 5 AND 6

Concerns about poor HCI have continued into the current fifth generation. Nickerson (1981) analysed the continuing defects of HCI in his paper, *Why interactive computer systems are sometimes not used by people who might benefit from them.* Ledgard, Singer & Whiteside (1981) give an extensive list of basic faults in many interactive systems in their book *Directions in Human Factors for Interactive Systems.* Chapanis (1984) quotes these faults in a paper on *Taming Computers* and illustrates them with examples of his own experience in using IBM's PROFS office administration system, supposedly designed for "those who have little or no experience with computing systems".

However, the personal computer came into being in the latter part of the fourth generation and by the fifth generation the availability of low-cost computers with graphic displays led to their increasing use in psychological studies, and a boom in the associated literature. The decline in computer costs and the decreasing differences in hardware and software capabilities from different manufacturers led to increasing

commercial interest in good human factors as a marketing feature. *Ease-of-use* and *user-friendliness* began to be seen as saleable aspects of computer systems, and human engineers as product generators. Labor organizations intensified commercial interest as they promoted legislation relating to worker interaction with computer-based systems. This has stimulated studies of human factors of computer systems in the workplace (Christie, 1985), particularly the ergonomics of displays (Granjean & Viglianni, 1980; Ericsson, 1983; Pearce, 1984).

The papers from commercial sources further expanded an already swelling fifth-generation HCI literature, and conferences on almost any computing topic felt it was timely to have a session on the human factors associated with it. More and more sessions at human factors meetings were devoted to HCI topics. The 1980s saw many books on HCI, the monthly publication of *IJMMS* and two new journals on human factors in computing, *Behaviour and Information Technology* and *Human-Computer Interaction.*

THE FIFTH-GENERATION COMPUTING SYSTEMS DEVELOPMENT PROGRAM

The culmination of this growing emphasis on the need for improved HCI may be seen in the Japanese announcement in 1981 of a program of development for a *Fifth Generation Computing Systems* (FGCSs), and the funding of the ICOT research center in Tokyo in 1982. ICOT, the Institute for New Generation Computer Technology, has 40 research staff seconded from industry and close links with a number of university projects on AI, its technology and applications, both in Japan and abroad. The objective:

> "knowledge processing systems" using "latest research results in VLSI technology, as well as technology of distributed processing, software engineering, knowledge engineering, artificial intelligence, and pattern information processing" and contributing "to the benefit of all humankind" (ICOT, 1983).

The emphasis on HCI is apparent in the remarks of Moto-oka (1982), Chairman of the Managing Committee:

> "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" (Moto-oka, 1982),

and Karatsu (1982), Chairman of the Social Needs Committee, who 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" (Karatsu, 1982).

Figure 3 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; 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

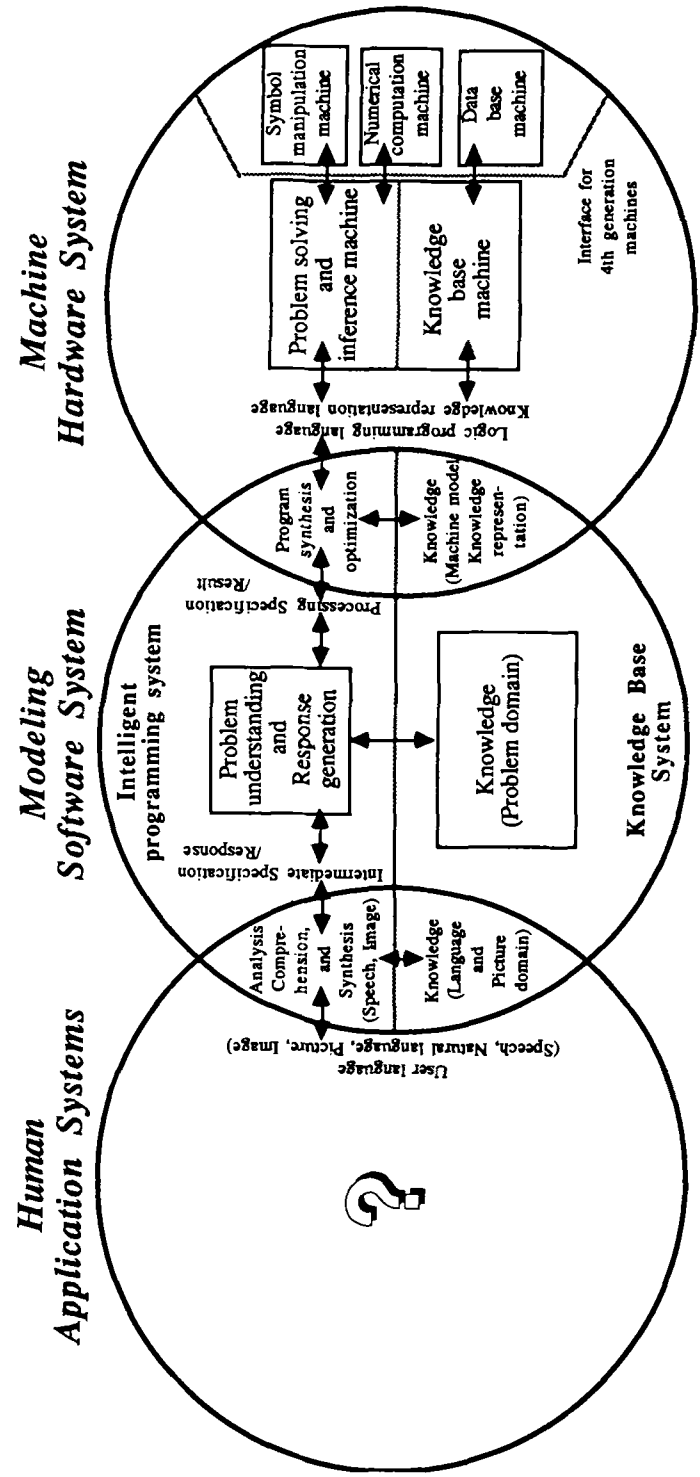

FIG. 3. The conceptual diagram of fifth generation computing (Moto-oka, 1982).

(Gaines, 1984*a*). The technology which limited applications for so long has now outstripped demands and one could expect a shift from technology-push economics in computer systems to those of market-pull. The HCI is what the customer sees as a computer and is where the market requirements are being expressed. Systems will increasingly be built top-down from user needs rather than bottom-up from technology availability. However, the remarks above about our creative imaginations being well in advance of our scientific knowledge and skills applies with force to the fifth generation conceptual diagram of Fig. 3. The hardware and software rings are full of structure which is expanded in detail in the accompanying text. The human ring is empty and the Japanese fifth generation 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 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 sufficient; 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).

The ICOT project has concentrated on the development of high-speed logic programming computers as its initial objective, a Sequential Inference Machine (SIM) working at 30 KLIPS (thousands of logical inferences per second) operating in December 1983, and a Parallel Inference Machine (PIM) using dataflow techniques completed in late 1984 and ultimately capable of working at 1 GLIPS (Kawanobe, 1984). However, from a human factors point of view, it is known that standard logic bears only a remote resemblance to human thought processes (Wason & Johnson-Laird, 1972). Modern formal logic was developed as a foundation for mathematics just because mathematical rigor is so foreign to everyday human activity (Mohanty, 1982). Understanding what is going on in the brain is not just a difficult problem, but one that is foreign to scientific paradigms based on the physical sciences. Causal models may be incapable of encompassing the processes of biological systems and currently we have no formalism in which to express the anticipatory dynamics of living systems (Rosen, 1985).

It is unlikely that a bottom-up approach based on a particular computing architecture will bridge the gap between our requirements for advanced HCI and our fundamental knowledge of how to achieve it. However, the significance of logic programming and Prolog machines for HCI should not be underestimated. The implementation of interfaces enforcing uniform application of dialog rules for HCI has proved very effective in Prolog. Natural language processing using logic programming is also attractive in making very direct links between the grammatical and semantic rules and their implementation (Dahl & Saint-Dizier, 1985).

As we approach the end of the fifth generation era, the limitations of the fifth-generation program have been addressed recently in the proposal for a sixth-generation computing systems (SGCS) program in Japan issued in mid 1985.

THE SIXTH GENERATION COMPUTING SYSTEMS DEVELOPMENT PROGRAM

Sixth generation computing is the name used in the Japanese press for the proposals put forward in the report, *Promotion of R&D on Electronics and Information Systems That May Complement or Substitute for Human Intelligence*, from the Subcommittee on Artificial Intelligence of The Council on Aerospace and Electronics Technology in Tokyo (STA, 1985). The Council was asked by the Ministry of Science and Technology in January 1983 to report on AI in these terms. It formed an AI subcommittee that met twelve times in preparation of this report, using the term *knowledge science* for its subject matter and reporting in March 1985. The English translation comprises some 18 000 words. The AI subcommittee included major figures from the FGCS program such as Moto-oka and Fuchi, as well as those whose names have been predominantly associated with the sixth generation initiative such as Eiichi Goto.

The report is divided into three major sections: *Basic considerations in the promotion of knowledge science*; *Present state and future development of science and technology related to computer science*; and *Methodology for promoting knowledge science.* The first section argues that computers were invented as devices to enhance human intelligence, but conventional computers may be inadequate as social and economic structures change, and as non-specialists become extensive users. For an information society, computers must be developed with intelligent abilities: intuitive recognition of situations; inductive inference; accumulation of knowledge; and learning. The man-machine interface must also be improved. To develop integrated AI systems with human capabilities it is necessary to clarify the brain's thought processes, construct a basic model for the technical development of intelligent functions and establish theories of the model. Implementation can take advantage of major hardware advances in VLSI.

Knowledge Science (KS) is defined as science and technology for clarifying advanced intelligent functions of human beings, that is, recognition, learning, inference, and so on, while developing these functions technically for the construction of various systems. KS will revolutionize many science and technology fields and contribute to progressive global change. Four objectives are given for promoting knowledge science: innovations in frontier high technologies; contributions to societal, economic and cultural advancements; contributions to the expansion of human potential; and establishing a foundation for creative sciences. The need for interdisciplinary research is emphasized and physiology, psychology, linguistics and logic are identified as the key sciences relevant to the objectives of the program.

The second section analyses the state of the art in these four relevant sciences, eight technologies based on them and four major application areas. Figure 4 summarizes the coverage of this section. It is particularly interesting to note the operationalism of the section on brain physiology which calls for:

> "a model of the information processing function of the brain ... a reasonable facsimile of the human cognitive process ... modified throughout the investigation by using computer simulation and a mathematical method."

This operationalism continues through the sections on psychology and linguistics and corresponds to the emphasis in the fifth-generation program on logic programming and relational databases. The Japanese require mathematically well-founded structures as the basis for their AI and HCI developments, a contrast to the heuristic approaches common to both in the West.

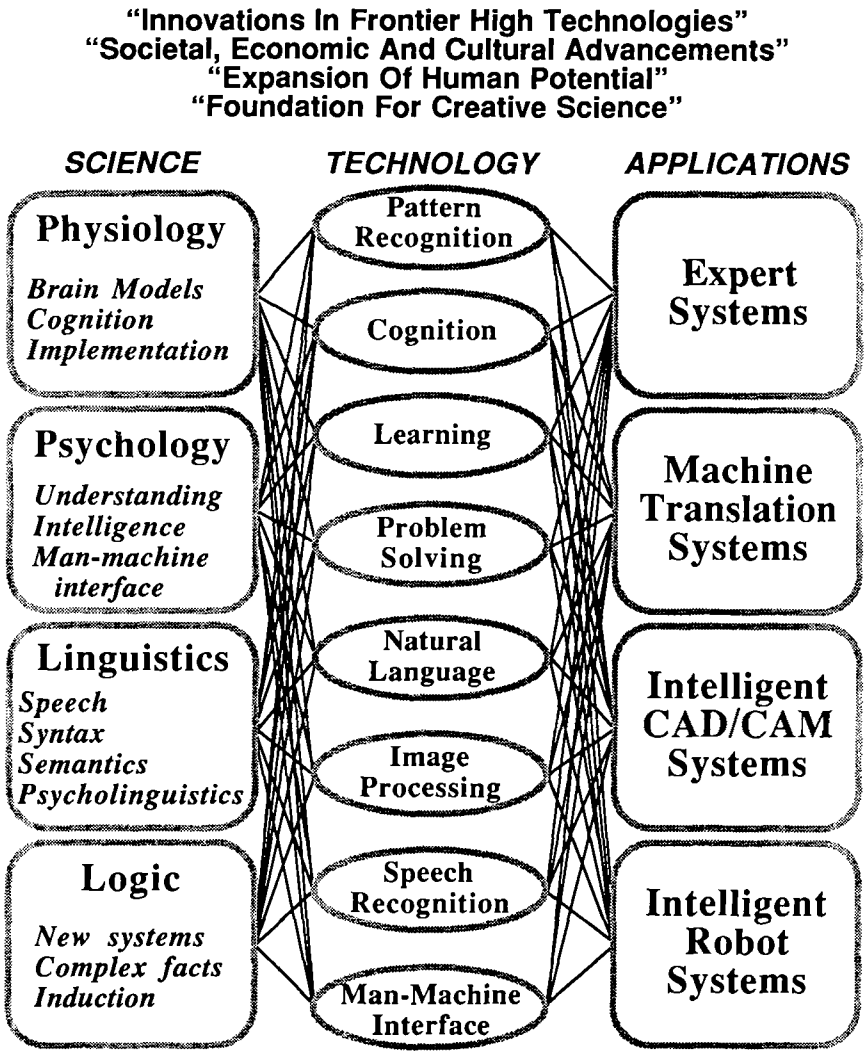

FIG. 4. A synopsis of the sixth-generation computing proposal.

The psychology of HCI is analysed in the science part of the second section in these terms:

> "The man-machine system has been considered thus far in terms of human engineering in which the configurational characteristics of man are discussed. However, it is also important to reconsider it in terms of cognitive science, in which knowledge gained by analysing human cognitive processes is used for technical design, so as to develop a system for human beings not only physically but also cognitively."

The man-machine interface is also analysed in the technology part in terms of the requirements of non-specialist users, the assignment of intelligent functions and the understanding of human factors.

The applications envisioned to expert systems, machine translation, intelligent CAD/CAM and intelligent robot systems, do not go beyond those of the FGCS proposal and are the least innovative part of the SGCS document. However, it is interesting to note that major advances in the understanding of human cognitive processes are now seen as necessary to success in these applications.

The third and final section outlines how the program might be established based on the development of the necessary manpower, international cooperation, and a multi-disciplinary approach combining research on: the clarification of human intelligence; systems for the acquisition, utilization and control of knowledge; and intelligent man-machine communication systems. It is noted that:

> "the life cycle of R&D in knowledge science is much longer than that of other scientific topics... we must exert effort to train researchers, expand research institutes which have already been established, build more institutes where research can be integrated, gather researchers from related fields, and arrange R&D systems continuously from a long-term point of view with industry-university government cooperation."

It is reported that MITI has agreed to fund at least part of the SGCS program with US$32 million over ten years as an extension to ICOT's activities commencing mid 1986 (Chapman, 1985). The SGCS proposals counter-balance much of the bottom-up, machine architecture content of the FGCS program, and the emphasis on a need for major investments in the development of knowledge science may have substantial effects on Japanese government, industry and educational policies.

Summary and conclusions

The human-computer interface is increasingly the major determinant of the success or failure of computer systems. Its improvement is a major objective of the fifth-generation computing development program. A variety of quotations from the literature from the early days of computing to the present shows that the problems of HCI have been recognized but still adversely affect the use of computers. It is suggested that it is time that we provided foundations for engineering the human-computer interface as explicit and well founded as those for hardware and software engineering.

An analysis of the pattern of development of computing technology shows that it follows a definite sequence of breakthroughs in one technology leading to its playing a key role in initiating a new generation. The basic technologies have been identified as: electronic device technology; virtual machine architectures; problem-orientated languages; human-computer interaction; knowledge-based systems; inductive inference systems; and autonomous activity systems. The cycle of development within each technology is one of replication in the generation after breakthrough, followed by empiricism and pragmatic rules in the next generation, theoretical foundations in the next, automated design in the next, and maturity with mass production and declining costs thereafter. HCI went through its period of pragmatic rules in the fourth-generation era of the 1970s, and entered its period of theoretical consolidation at the beginning of the fifth generation in 1980.

We believe that the cutting edge of HCI research studies must now move to the provision of deep theories. We see a danger that too much effort will go into optimizing the interface to the detriment of overall systems. We also see the danger of the field fragmenting so that problems of the psychology of programming languages, for

example, are treated quite separately from problems of user interaction. This would be out of step with trends in computer system design, such as those in knowledge-based systems, where programming and interaction are becoming inseparable user activities. Some specialization of HCI according to roles is necessary but it is desirable that this be derived from overall principles.

We emphasize the need for models of computer systems to be developed that are well-suited to the analysis of HCI. The computer and the person are both essential subsystems of the HCI situation, but there is a tendency to assume that the missing formalization is only that for the person. This is not so. We are equally in need of formalizations of computer systems that can be used in conjunction with those of the person for overall system design. It is necessary to have models of both subsystems that can be used together in a way that accounts naturally for their interaction, for the reflection of the user model needed in the computer and for the reflection of the computer that is the user's model.

These considerations are consistent with the objectives of the sixth-generation computing system development program based on inter-disciplinary collaboration between brain physiologists, psychologists, linguists, logicians and computer scientists to develop foundations for knowledge science and technology. One objective of HCI studies is closely related to those of hardware and software engineering and is concerned with the problems of interfacing people to information-processing technology. Another objective of HCI studies is closely related to those of artificial intelligence and is concerned with the problems of establishing symbiotic partnerships of people and knowledge-processing technology. Achieving the first is a goal in its own right and an essential prerequisite to achieving the second. We need effective human-computer communication before we can achieve effective amplification of intelligence. Our companion paper considers the first objective in more detail, analysing the foundations of dialog engineering from historical and interdisciplinary perspectives, and surveying topics relating to future developments in HCI.

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