CREATIVITY, VALUES AND THE INFRASTRUCTURE OF COMPUTING

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Abstract

Computing technology may be viewed as autonomously impacting society. However, it may also be viewed as a product of society, created through its needs and molded by its values. This paper adopts the second point of view and models the development of computing as succession of social learning processes arising out of the need to cope with an increasingly complex world. The role of computing in the socio-economic infrastructure supporting the human hierarchy of needs is examined. The end-product of computing developments is modeled as a logical completion of existing media for communicating human experience and shown to have the characteristics of a prosthetic brain. It is suggested that advances in computing technology are symptomatic of deeper changes in civilization that will result from the understanding and control of knowledge processes.

Introduction

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, Bell 1973, Mowshowitz 1976, Weizenbaum 1976). The impact is now being felt and many commentators are attempting to analyse its nature and project its trends (Toffler 1980, Dizard 1982, Brod 1984, Turkle 1984). However, the majority of such speculation and analysis offers one-sided perspectives relative to two key distinctions. The first 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. The second 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 are valid and lead to meaningful conclusions relative to their presuppositions. They are appropriate to the analysis of technological dependencies for purposes of industrial and government planning, for example, 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 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.

Viewed as a causal chain the development of computing technology is highly indeterminate. Technological forecasts for computing are notoriously inaccurate (Withington 1974, Gaines 1984a). 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 Infrastructure of Computing as a Recursive Learning Process

In coming to understand computing technology, it is important to realise that the electronic computer itself 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 development of the infrastructure of computing can be modeled using the most significant seminal concept underlying computing itself, that of recursion. This consists of the formation of complex processes through the interaction of a few primitive functions that generate complexity from simplicity by referencing themselves. From a mathematical point of view, computing science is founded upon the theory of recursive functions. The notions of recursion, self-reference and analysing complex systems as generated by the recursive application of self-referential functions, have proved very powerful in the analysis of many significant systems, including the physical world, biological organisms, societies and human consciousness.

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 1984b). 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 (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.

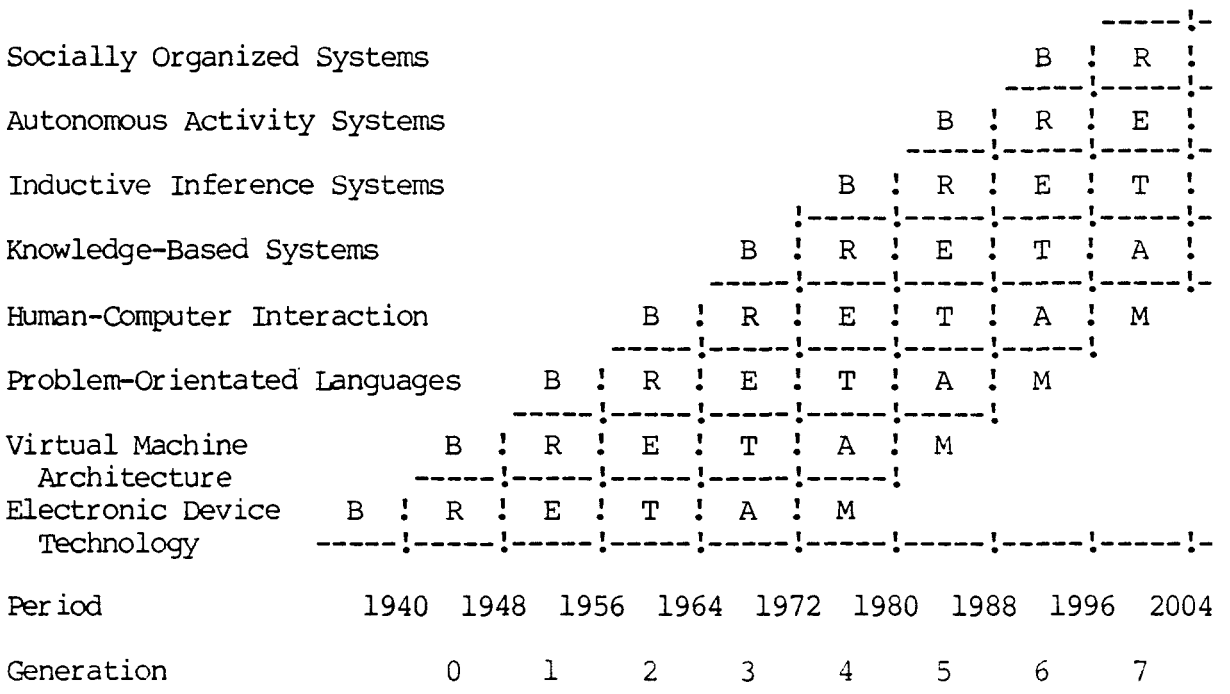
It has been noted in many disciplines that the qualitative phenomena during the growth of the logistic curve vary from stage to stage (Crane 1972). If we take the amount of knowledge necessary for a mature technology to be 100%, then the 10%, 25%, 50% and 75% points are equally spaced in time along the logistic curve. These points mark significant phases in knowledge acquisition. When less than 10% of the knowledge is available little can be achieved and we are in a breakthrough period where most projects attempted will fail through lack of some critical information or skill. However, 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 mimices widely with little understanding. This 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.

The learning curve model for the substitution of different electronic device technolgoies (EDTs) as a basis for computing distinguishes the first three generations of computers. 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 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 very large-scale integration 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 and the seventh generation in 1996 with grand-scale integration and 1,000 million on a chip.

This definition of generations in terms of EDT, however, 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. 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 1 shows this infrastructure with the phases on the learning curve of EDT at the base and successive computing technologies above it as the infrastructure.



B -- Breakthrough period - 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. 1 Eight generations of computers and their underlying technologies

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 as a virtual machine. The second generation breakthrough was to bridge the gap between machine and task through the development of problem-orientated languages 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. The fourth generation breakthrough was to in the early 1970s with developments in expert systems based on knowledge-processing, the capability to store information through its inter-relations and make inferences about its consequences. The fifth generation breakthrough was in 1980 with developments in machine learning and inductive inference systems. We 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 autonomous activity systems. The interaction between these systems will become increasingly important in enabling them to cooperate to achieve goals and that the seventh generation era commencing in 1996 will be one of socially organized systems.

The Upper Level Social Goals in the Development of Computing

The model of the development of computing described above 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. 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 and the theoretical foundations 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.

In the current fifth generation (1980-1987): (BR) recognition of the goal-seeking possibilities of inductive inference systems will lead to the breakthrough to autonomous-activity systems in robotics; (RE) research is focused on learning in knowledge-based systems; (ET) the advantages of the non-procedural representation of knowledge at the human-computer interface led to the innovative designs of the Visicalc

spread-sheet business product and the LISP machine scientific product; (TA) the ease of human-computer through a direct manipulation problem-orientated language led to the Apple Lisa/Macintosh product line for personal computers.

Note that the potential of computers to influence human creativity was very low through the first three generations. The capabilities for effective human-computer interaction in fourth generation products and those for knowledge processing appearing in fifth generation products are both necessary to support the creative process. The inductive inference capabilities now being researched will enable sixth generation produts to suggest new hypotheses and views of the world. The autonomous activity capabilities expected to be the next breakthrough will enable seventh generation products to suggest alternative sub-goals in order to achieve an overall objective.

Thus, it is reasonable to view the current stage of computer development as still being fairly primitive and not having achieved the critical capabilities necessary to be an agent of change in society. Drucker (1978) compares the development of the electricity industry with that of the information industry, making the analogy that "information is energy for mind work". He remarks that if it had been fashionable to speak of generations of generators then there "would have been a 'fifth-generation' or 'sixth-generation' generator before there was any widespread use of electric power". It was the invention of the light bulb that led to the use of electricity as a universal form of energy. It is emulation of human knowledge-processing capabilities that will lead to the use of computing as a universal extension of the mind.

We suggest that the social needs leading to the development of computing technology will only begin to be satisfied in the sixth and seventh generations. These needs result from increasing world population and integration leading to an increasingly complex society. In Trust and Power Luhmann (1979) postulates complexity-reduction as the fundamental motivation for all our social institutions. We assume roles to simplify our interactions with one another. We use technology to simplify the natural world, creating man-made environments that we can undersand and control. In Future Positive De Bono (1979) suggests that computer technology was developed to aid us in coping with the increasing complexity of society. The computer is to the organisation revolution what steam power was to the industrial revolution. The computer extends our organizing power in the same way as steam engines extended muscle power.

One perspective on the social needs for, and social impact of, computing comes from examining its role in the hierarchy of human needs. Maslow's (1971) hierarchy of personal needs gives the dynamics of individual motivations and priorities. The logic of his hierarchy is that upper level needs are of low priority until lower level ones are satisfied. We need to satisfy basic biological needs before we are concerned with safety, and only when we are safe are we concerned with belonging and so on. The theory is subject to debate (Lederer 1980) but it gives a logic for the social infrastructures that support individual needs. The left column of Figure 2 shows Maslow's hierarchy of needs, and the centre column shows those social systems that have been set up to aid the individual in satisfying his needs. The right column shows the

roles that computers have played in supporting these social systems. The two lowest levels account for the impetus behind the first three generations of computers. They have been used commercially to support the industries necessary to basic biological needs and militarily to support safety. The levels above are all new applications that have opened up only with the fourth generation and personal computers.

The hierarchy of needs model has some interesting consequences. It suggests a divergence between developed world and third world priorities in the use of computers. For countries where food and energy crises still exist the use of computers in agriculture, energy, communications, and so on, will be the main priority. For the developed nations the use at the lowest levels is taken for granted and the levels of belonging and esteem are where the fifth generation makets lie. The logic at these levels is also significant in the analysis of job displacement. Esteem is enhanced if computers provide the capability to do a task more effectively but not if the perceived role is undermined, e.g. to that of servant to a machine. This is the conflict between those who see the computer as a tool to enhance life and those who see it as destroying the social fabric. The impact of computers on our value systems depends on the way in which they are used.

INDIVIDUALS	SOCIO-ECONOMIC INFRASTRUCTURE	COMPUTERS
Self-actualization	Realizing personal potential. Facing life as it is. Aesthetics. Peak experiences.	Tools in hands of individuals to give new perspectives.
Esteem	Role in family, work and community. Other recognized achievements (artistic, horticultural).	Tools in hands of individuals to perform role better.
Belonging	Family, work, religion, politics, entertainment.	Networking, bulletin boards, games.
Safety	Social norms, police, military, medecine, insurance.	Command and control crisis decision-making.
Basic biological needs	Agriculture, energy, housing, ecology, finance, and physical communications.	Planning, management and control.

Fig. 2 Maslow's hierarchy of personal needs, its social support and the role of the computer

Media, Creativity and the Prosthetic Brain

The higher levels of Maslow's hierarchy are those of human creativity. It is not yet clear what impact fifth through seventh generation computing developments will have on creativity. However, we can give a model on which to base speculation by considering computing as providing a new medium of communication extending those previously available (Shaw & Gaines 1984, Gaines & Shaw 1984a).

Two of the most important capabilities of computers are those of simulating other systems and of providing expert systems (ESs) encoding human knowledge. Simulation and ESs may be seen as providing complementary approaches to providing aids to the person in coping with the world. Simulation provides models of the world which can be used to test ideas before they are tried in the real world. EDs provide models of people which can be used to discuss ideas before they are tried in the real world. This distinction is one that predates computers and occurs in human knowledge acquisition and the media to support it. We may gain knowledge of the world by direct action or by conversation with others as shown in Figure 3.

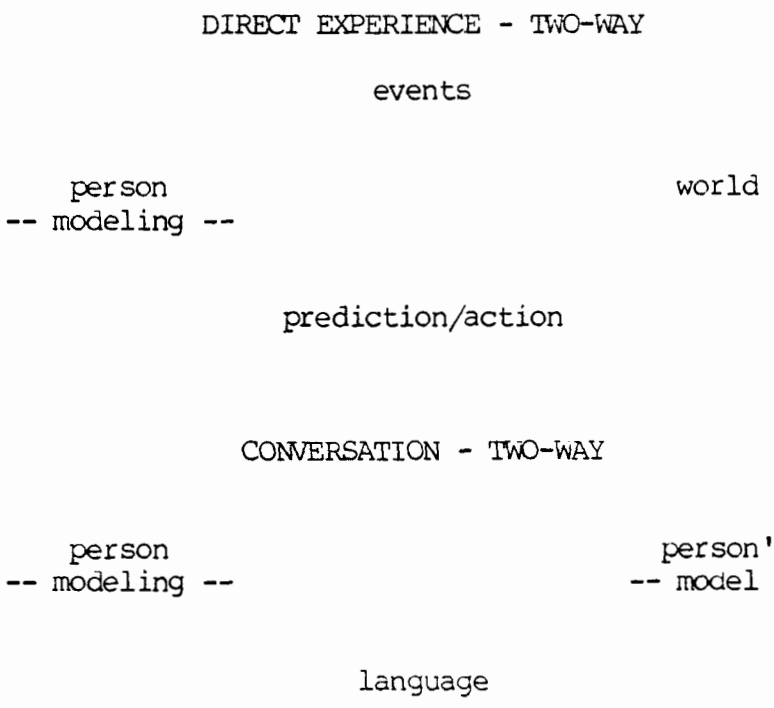


Fig. 3 Two modes of human knowledge acquisition

As shown in Figure 4, representational media such as photographs and television provide an alternative channel for experience of the world. Symbolic media such as letters and books provide an alternative channel for conversation about the world.

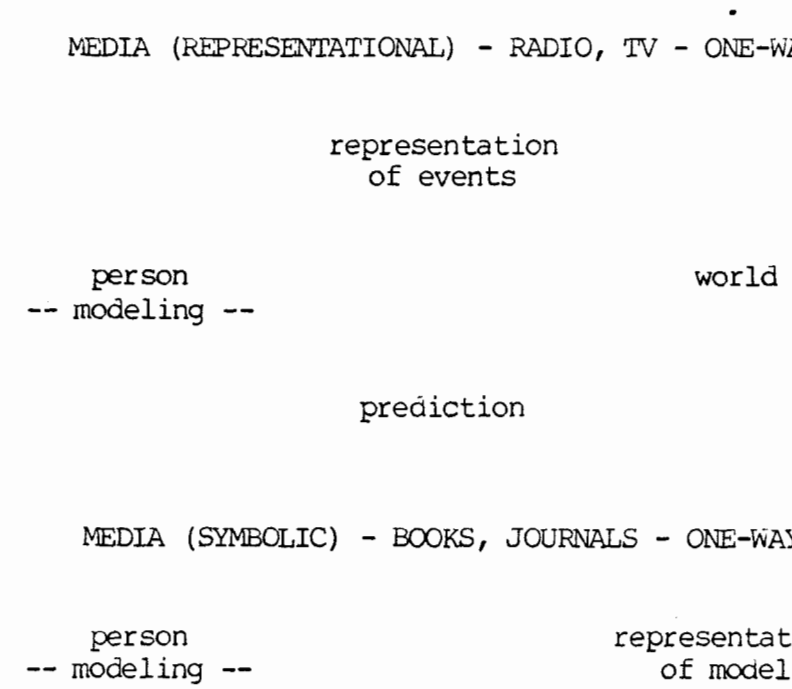


Fig. 4 Two modes of operation of media

A major disadvantage of past media has been that they are one-way. We can experience remote events through television but cannot interact with them. We can access the thoughts of an absent person through his writing but cannot discuss them with him. As shown in Figure 5, computing can be regarded as providing a new medium which is two-way and hence interactive (Gaines & Shaw 1984b). Simulation corresponds to mediating direct experience of the world. ESs correspond to mediating conversations with people.

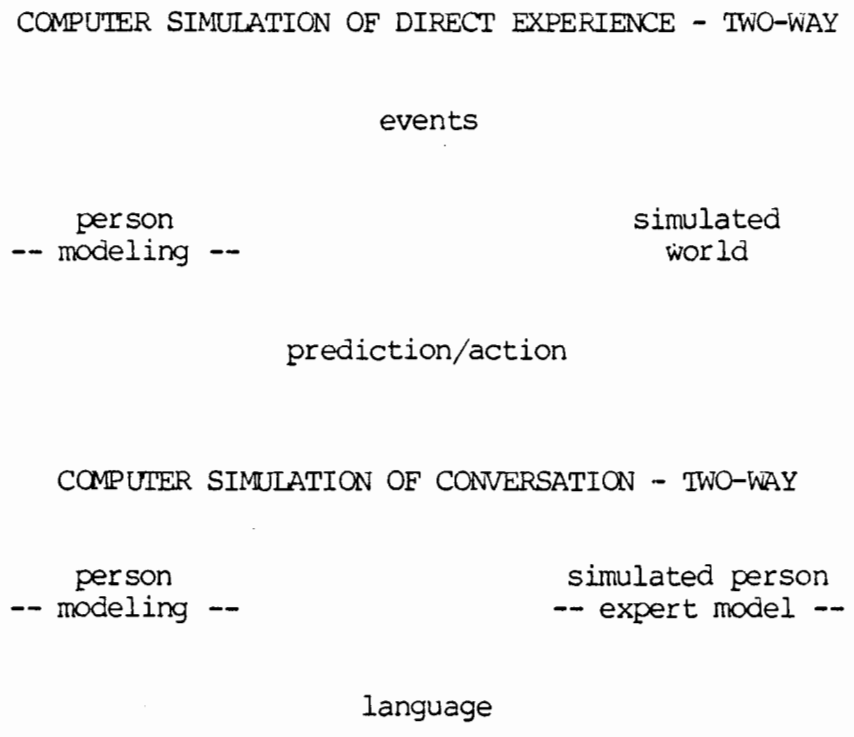


Fig. 5 Computing in the evolution of media: an interactive medium for encoding simulated worlds and people

However, once we view simulation and ES in this way, and when we realize the capability of ES to acquire knowledge both from people and through experience, it is apparent that the two complementary uses of computers shown in Fig. 5 may be combined in a variety of ways. Figure 6 shows a system in which simulation and ES provide mutually supportive capabilities to a person in a decision support system that might well be termed a computer-based prosthetic brain.

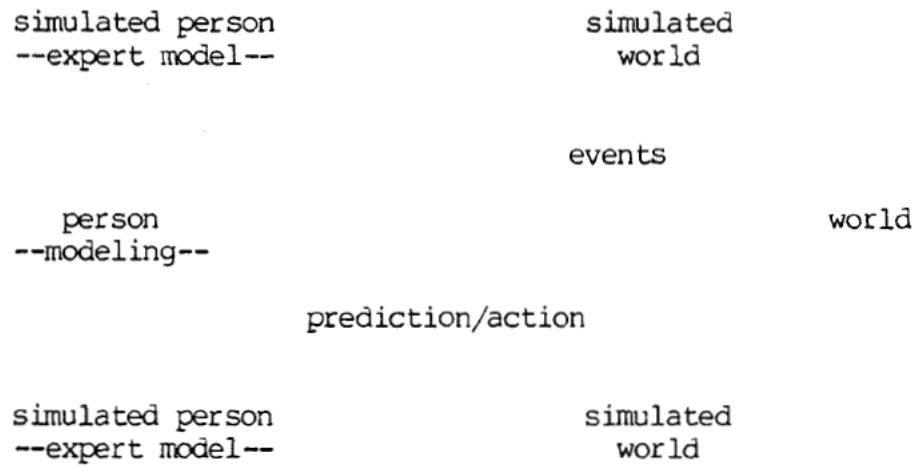


Fig. 6 Combination of simulation of the world and simulation of the expertise of people in a prosthetic brain

In this example, the person interacts with the world. He may test predictions and actions in simulated worlds. He may ask advice from simulated experts. He may turn control over to simulated experts. The simulated experts may use the simulated worlds as part of their knowledge processing. The simulated experts may have access to real-world experience for knowledge acquisition. The simulated worlds may be updated from real-world experience, by the person or by simulated experts. Such systems are now in development and will form the next generation of expert systems (Gaines & Shaw 1985, Shaw & Gaines 1985).

Conclutions

Computing technology may be viewed as autonomously impacting society. However, it may also be viewed as a product of society, created through its needs and molded by its values. From this second point of view, the development of computing may be modeled as succession of social learning processes arising out of the need to cope with an increasingly

complex world. This gives rise to successive generations of computers with qualitatively different capabilities. Only now in the fifth generation and beyond are computing systems becoming able to interact with people at the levels of the higher processes of the mind. Thus, their major impact on values and creativity is yet to come.

To evaluate this future impact, computing developments may be modeled as a logical completion of existing media for communicating human experience. The use of computer-based simulation and expert systems to provide decision-support systems for people has the characteristics of a prosthetic brain. The significance of this prosthesis depends on the development of inductive inference capabilities to enable sixth generation computing systems to suggest new hypotheses and views of the world, and autonomous activity capabilities to enable seventh generation systems to suggest alternative sub-goals in order to achieve an overall objective.

As a parting remark, let us note that the understanding of the processes of knowledge, induction and problem-solving that are necessary to the development of future generations of computers is equally applicable to human development. The tools of humanity change the world and humanity itself. The prosthetic brain will be a only one component in the re-structured life world of the future. If we view the development of computing as a symptom of a changing basis for civilization then we can begin to gain some glimpses of the future. If we view it as autonomous technology causing problematic and unwanted change then the future will continue to be opaque.

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