EPISTEMOLOGICAL FOUNDATIONS OF INFORMATION TECHNOLOGY

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ABSTRACT

Abstract: System-theoretic accounts of the epistemological processes underlying knowledge acquisition have been shown to apply to individual human behavior and to enable algorithms to be developed for computer-based systems modeling. Such accounts are also applicable to the upper levels of the hierarchy of autonomous systems as models of socio-economic behavior. In this paper they are applied to the development of information technology and used to account for past events and predict future trends. Underlying all developments in computing is a tiered succession of learning curves which make up the infrastructure of the computing industry. The paper provides a framework for the industry based on this logical progression of developments. It links this empirically to key events in the development of computing. It links it theoretically to a model of economic, social, scientific and individual development as related learning processes with a simple phenomenological model. It uses this model to account for past developments in computing and extrapolates it to predict future trends.

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 one must have adequate capabilities for semiconductor device manufacture or purchase before one can develop a computer industry. However, they are not appropriate perspectives from which to evaluate the future development of computing which involves 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.

In this paper we extend the notion of a **personal scientist** modeling the world (Shaw 1980) to that of a society learning a technology. This enables us to use Marchetti's (1981) concept of society as a learning process in order to model the development of information technology.

THE EPISTEMOLOGICAL HIERARCHY

In analysing the architecture of modeling systems, Klir (1976) proposed an **epistemological hierarchy** accounting for the main components of any modeling systems and their inter-relations. Gaines (1977) gave a mathematical formulation of the general problem of modeling as a relation between order relations at different levels of the hierarchy. Gaines & Shaw (1981) gave a general interpretation of this hierarchy as generated by **levels of distinction** and showed how it was instantiated in psychological terms. The hierarchy has proved a valuable conceptual tool in analysing a wide variety of modeling systems.

Distinctions are not just static partitions of experience. They may be operations: actions in psychological terms; processes in computational terms. The role of distinctions is evident in Klir's hierarchy shown in Fig. 1. The loop from events through distinctions up through the modeling hierarchy and then down again to predictions and actions characterizes what Shaw (1980) has termed the **personal scientist.** Note that the upper levels of modeling are totally dependent on the system of distinctions, or personal constructs, used to express experience through the source system.

We have noted previously that Fig. 1 presents a general modeling schema and applies as much to groups of people, companies and societies as it does to the individual. The epistemological hierarchy of a person is a cross-section of the epistemological hierarchy of the society generating their life-world. Pask's (1975) concept of **P-Individuals** as the basic units

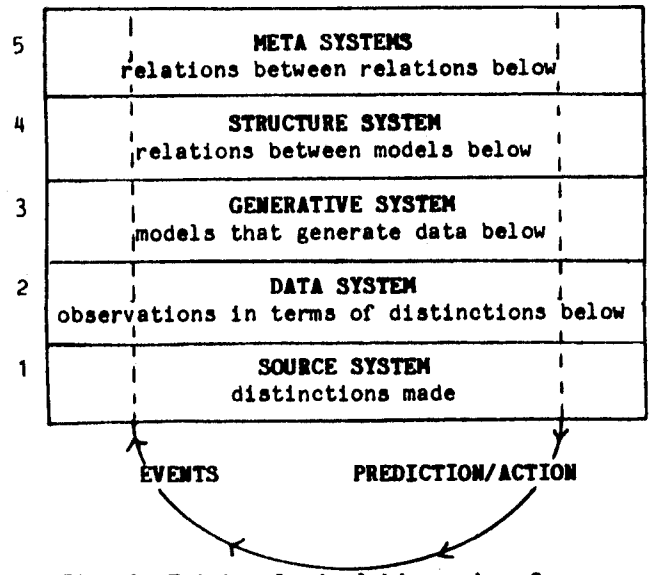


Fig. 1 Epistemological hierarchy of a personal scientist

of psycho-socio-processes allows roles, people, groups, organizations and societies to be treated in a uniform framework (Shaw & Gaines 1981). In this paper we use the hierarchy to model the process of technological development in the computing industry.

LEARNING IN THE HIERARCHY

The hierarchy of Fig. 1 accounts for learning processes as the modeling of events enabling adequate prediction and action. A modeling schema results from distinctions about distinctions at each level in the hierarchy. In prediction the key distinction is to what degree a level accounts for the information flowing through it and hence we have termed this distinction one of **surprise** (Gaines 1977), borrowing the term from the economist Shackle (1955). Surprise goes in opposition to the degree of membership (Zadeh 1965, Gaines 1983) of a predicted event to an actual event and the expected surprise is a form of entropy. Surprise at the lowest level of the hierarchy corresponds to distinctions being inadequate to capture events; surprise at the next level to inadequate variety to experience events; at the next level to inadequate approximation to predict events; at the next level to inadequate simplicity to explain events; at the next level to inadequate comprehensiveness to account for events.

The formal theory of modeling is one in which models are selected at each level down the hierarchy to minimize the rate at which

surprise is passing up the hierarchy. The criteria for model selection independent of the data are generally thought of as being ones of **simplicity/complexity**: of two models which fit the data equally well choose the simplest. However, notions of simplicity/complexity are not well-defined nor intrinsic to the class of models. The simplicity/complexity ordering is arbitrary and in its most general form is just one of **preference**. Hence the general modeling schema is one in which surprise flows up the hierarchy and preference flows down. In situations that are mathematically well-defined, such as determining the structure of a stochastic automaton from its behavior, such a model schema gives the correct results (Gaines 1977). Conversely, the success of the schema in stabilizing with regard to a given universe defines the characteristics of that universe.

Thus the basic modeling schema for learning from experience is one in which surprise flows up the hierarchy and preferences flow down. Surprise is generated from experience so that it is easy to see its origins. However, where does preference come from? To some extent it may be preset, genetically encoded. However, this does not seem to account for the origins of novel models. Language is a way of by-passing the normal modeling procedures and interacting directly with the system at any level. In particular it can directly affect the preference system. Language is essential to much of human learning, and our interaction with the knowledge construct (Wojciechowski 1983, Gaines & Shaw 1983) is just as important as our interaction with the world (Shaw & Gaines 1983, Gaines & Shaw 1984a).

CREATIVE LEARNING IN THE HIERARCHY

Linguistic transfer of knowledge is the most important process for the dissemination of information, for example in technology transfer. However, the creation of new knowledge takes place through the surprise/preference flows through the hierarchy and it is these processes that determine the rate of technological invention and product innovation. In modeling creative learning we have to account for the growth of knowledge structures at each level of the hierarchy. Figure 2 is a psychological interpretation of Fig.1 to show the different forms of knowledge associated with each level of the hierarchy.

The lowest level is one of **constructs**, distinctions made in interacting with the world. The next level is one of **experiences**,

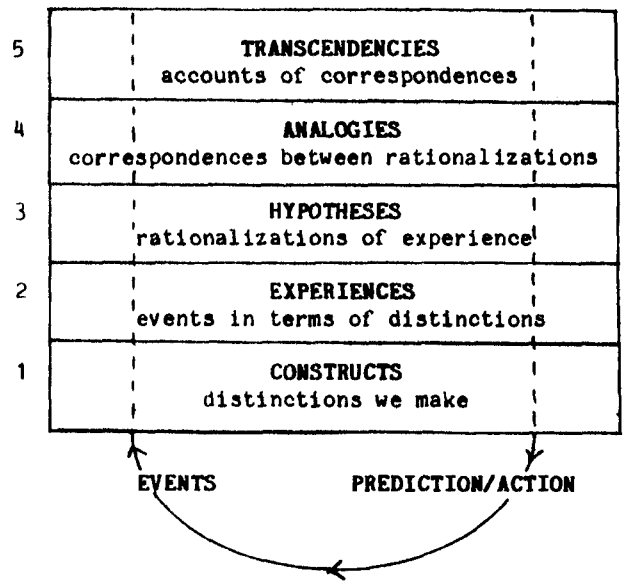


Fig. 2 Knowledge hierarchy of a personal scientist

events which happen to us, and we make happen, in terms of the distinctions already made. Levels above these are **hypotheses** which are rationalizations of experience, **analogies** between these rationalizations and **transcendencies** which are preconceptions underlying rationality.

This terminology emphasizes the predictive aspects of modeling, but the analysis of technological change places equal emphasis on the action side of modeling. In terms of constructs, or distinctions, it makes no difference to the theory whether they are instantiated through sensation or action. We can make a distinction passively or actively. We can sense some condition already in the world or we can act to establish some condition in the world.

In terms of modeling technology it is the capability to act to achieve a goal which is critical. Figure 3 shows the basis for action at different levels in the epistemological hierarchy:

(1) At level one, the activation of a construct may be linked directly to a primitive act, another construct. This corresponds to reflex actions and stimulus-response connections. Knowledge at this level has no verbal component and comes directly from experience, often mimicing the behavior of others. We have termed level 1 **informal** to correspond to Hall's (1959) definition of cultural transmission of behavior of this type. In a

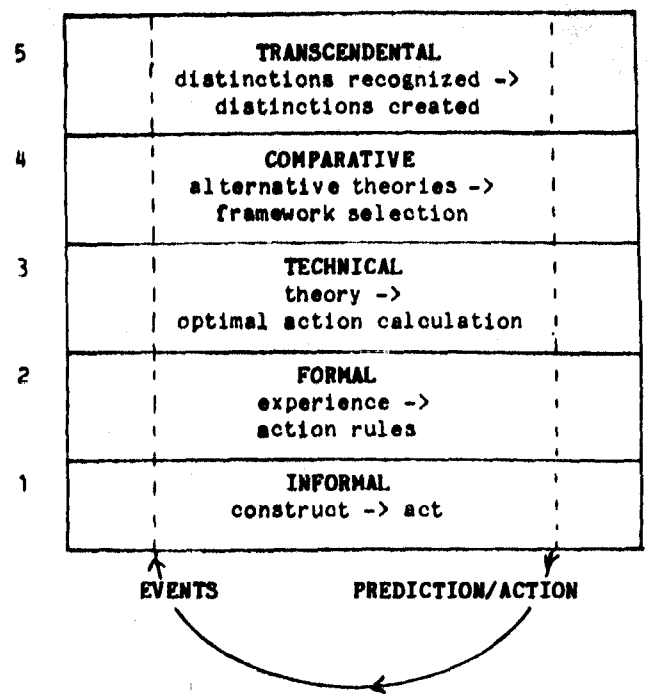


Fig. 3 Cultural transmission hierarchy of a personal scientist

computational system this level might be implemented by conditional probability calculations giving confirmation-theoretic inductive inference.

(2) At level two, constellations of experience may be linked to complete action sequences through rules derived from similar experience. Knowledge at this level is usually transmitted by verbal rules, or is induced from the patterns of knowledge at level 1. We have termed level 2 **formal** to correspond to Hall's definition of cultural transmission of behavior of this type. In a computational system this level might be implemented by fuzzy production rules giving generalization-based inductive inference.

(3) At level three, a generative model of experience, or theory, may be used to calculate the optimal action sequence. Knowledge at this level is usually transmitted by technical explanation, or is induced from the patterns of knowledge at level 2. We have termed level 3 **technical** to correspond to Hall's definition of cultural transmission of behavior of this type. In a computational system this level might be implemented by a state-based modeling scheme giving model-based inductive inference.

(4) At level four, a variety of alternative theories may be used as a basis for selecting one appropriate to the required goals. Knowledge at this level is usually transmitted by philosophical analysis, or is induced from the patterns of knowledge at level 3. We have termed level 4 **comparative** to correspond to Hall's own activities in comparing cultural transmission in different societies. In a computational system this level might be implemented by a category-theoretic functional analysis scheme giving analogical inductive inference.

(5) At level five, the entire process described may be transcended through a recognition that it is based on distinctions being made at various level, and an attempt to rationalize these distinctions and create new ones. Knowledge at this level is usually transmitted by general system-theoretic analysis, or is induced from the patterns of knowledge at level 4. We have termed level 5 **transcendental** to emphasize that it results from moving outside the framework established at the lower levels. Pope (1984) has given examples of this process in a wide range of cultures. In a computational system this level might be implemented by a distinction-based analysis scheme giving what might be termed transcendental inductive inference.

It is an interesting comment on the state of the art in computer science that information technology has been primarily concerned with level three activities, and is only now beginning through expert system developments to emulate level two activities. The primitive sensation-action modes of learning at level one require the large-scale parallel processing essential to the emulation of human vision and locomotion, and will be developed as part of the next generation of robotic systems.

PHASES OF LEARNING

Learning from experience requires increasing information flows to build up each level of knowledge in the hierarchy. The inductive process at level n is dependent on the results of the inductive process at level n-1 and hence the rate of development of knowledge at the higher levels of the hierarchy is initially extremely slow. However, were it not for the higher-level inductive processes the lower levels would become overloaded with excessive detail very rapidly. The epistemological hierarchy represents an evolutionary adaptation to a

world in which a small number of generative principles can account for an extremely wide range of experience.

As learning accumulates at the higher levels it makes information acquisition at the lower levels decreasingly necessary. When a level is able to account for all the information it receives then no surprise flows up from it and any information flow from it can be discarded. Our civilization is itself a learning system with this overall structure and the societies, organizations and people within it form linked substructures. Viewed in this way, the flow of information through language may be seen as a way of passing knowledge between the substructures, and the accumulation of knowledge in libraries and databanks may be seen as a way of preserving it across time. Language and the knowledge construct are the side-effects of a learning civilization based on a diversity of autonomous learning units, i.e. people.

If we examine sub-structures of knowledge that are somehow complete in that they give an adequate basis for a certain class of actions, then the same considerations apply. At the beginning the learning process is very slow because it has no foundation other than creative action, i.e. search procedures and experimentation directed by curiosity, the drive for novelty. When one person makes a creative breakthrough their knowledge is at level one and can be communicated to others only informally by aiding them in mimicing the breakthrough procedure. The originators have little basis for communicating through language except by saying what they do as if they were observing themselves. The communication of knowledge in this way after breakthrough leads to a phase of **replication.**

When more experience is gathered of breakthrough-like situations, inductive inference at level two enables rules to be stated which generalize the experience. Natural language plays an important role here because it facilitates the expression of generalizations as apparently vague statements using fuzzy quantifiers. The explanations that can be given based on rules appeal to past experience, and this phase is one of **empiricism.**

As further experience leads to the accumulation of the rules, the numbers become excessive in terms of memory and application and they also make possible inductive inference of generating principles underlying the rules. These principles are usually remote from experience and require the development of technical languages for their expression. As these languages are not directly related to experience it becomes important to be very precise in their use in order to communicate correctly. The explanations that can be given based on technical languages appeal to abstract models and this phase is one of **theory.**

The next phase is complex because it has multiple branches. An adequate theory solves the problem within a given domain and one effect is to reduce research interest in that domain as noted by Crane (1972). However, as a variety of theories develop, the learning process at level four becomes significant leading to interest in foundations, reductionism, and the use of one theory as a metaphor to speed up the development of another. This metaphorical process has occurred many times in extending human knowledge and is embedded in the structure of language (Lakoff & Johnson 1980). In technology terms, as the use of the models enables more and more action to be subsumed under a small set of principles it becomes feasible to incorporate these principles in mechanisms and hence to enter a phase of **automation.**

5	**MATURITY** Theories have been assimilated and are used routinely without question
4	**AUTOMATION** Theories become accepted and made operational as a basis for automation
3	**THEORY** Hypotheses are formed about the causal systems underlying experience
2	**EMPIRICISM** Lessons are drawn from experience and formulated as empirical rules
1	**REPLICATION** Breakthrough process is recognized and mimiced leading to experience
0	**BREAKTHROUGH** Problem-solving attempts but failure eventually leading to creative advance

Fig. 4 The phases of learning hierarchy of a personal scientist

Finally, the technology enters a **mature** phase where the theory is well-established and well-founded in relation to other areas. The learning process continues at level 5 where the complete process of knowledge acquisition can now be examined to draw out systemic principles that are applicable to wide domains of human processes. Figure 4 shows the different phases of the learning process as it proceeds up the levels of the hierarchy.

TIERS OF LEARNING

The BRETAM learning sequence shown in Fig.4 represents the phases of knowledge acquisition involved in a specific technology as a linear sequence. However, it does not make apparent the impact of developments in one technology on those in another or the changes in people, locations and applications involved in the technology. The development of one technology is often the prerequisite for a breakthrough in another so that the BRETAM sequences of related technologies tend to be linked together. These linkages become strongly emphasized because of the personalities and roles of the people involved at different stages of the sequence and the socio-economic effects of a developing technology.

We have noted previously (Gaines & Shaw 1984c) that major differences in people result from different emphasis on the levels of the epistemological hierarchy. The core constructs (Kelly 1955) that determine the dynamics of the individual and manifest as "drive" and "motivation" may be predominantly at one level of the hierarchy. Some individuals are concerned primarily with experience not assimilable at level one, with extreme novelty where appropriate constructs do not yet exist. They are inventors of modes of experience. Their emphasis on novelty may make it difficult for them to operate in tight organizational structures and it is difficult to manage the promotion of breakthroughs. They tend to occur unexpectedly by their very nature.

Some individuals are primarily concerned with the assimilation of novel constructs at level one. They are the generators of new experience and gravitate towards research positions where facilities are available to replicate breakthroughs and refine them. Some individuals are primarily concerned with the assimilation of experience at level two. They are innovative designers who formulate rules for product development and gravitate towards companies willing to undertake the risk of product innovation. Some individuals are primarily concerned with the assimilation of theory at level three. They design products ranges that are well-founded on principles enabling integrated systems to be developed and supported as long-term products line. They tend to gravitate towards industry majors who take a strategic position towards supporting a large customer base requiring product continuity.

These personal and industry phenomena lead to the successive stages of the BRETAM sequence being associated with different individuals, functions within companies, and types of company. For those concerned with any phase of the BRETAM sequence there is the equivalent of a switch of attention when a particular technology enters the next phase. The breakthrough person will look for other breakthroughs but probably never find another. The research team will switch to alternative projects as will product innovation teams and product line teams. Thus social dynamics are superimposed on the basic learning sequence.

The overall effect is that BRETAM sequences for a sequence of technologies, each of which is a prerequisite for the breakthrough of the next, tend to get stacked in a regular formation as shown in Fig.5. Technology 0 is a prerequisite to technology 1, which is a prerequisite to technology 2, and so on. The focus of attention in research, product innovation, and so on, shifts from one technology to another in each successive phase of the learning sequence. The generic technology from which all the others derive tends to define an **industry**, and the phases of the learning curves define **generations** of technology within that industry.

Note how the horizontal BRETAM sequence becomes replicated in a vertical BRETAM structure representing the stages of development of all the differing technologies in a given generation. This happens in the fifth generation which is often seen as the one in which the industry itself reaches maturity. For example, 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.

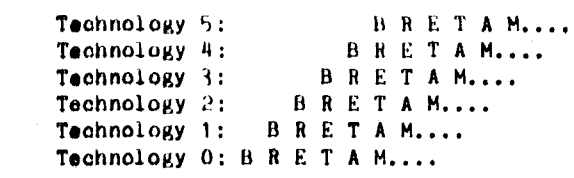


Fig.5 Tiered learning sequences for related technologies in an industry

APPLICATION TO INFORMATION TECHNOLOGY GROWTH

Information technology is interesting in provide an example of a well-documented learning process that exhibits the phenomena of Fig.5 (Gaines & Shaw 1984b). 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 initial breakthrough for computing was in electronic device technology (EDT). This was the base technology that was a prerequisite to all others. Figure 6 shows the BRETAM tiers for the computing industry:

(0) The start of the zeroth generation is placed at 1940 about the time of the Atanasoff and Berry experiments with tube-based digital calculations.

(1) 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.**

(2) 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.

(3) 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.

(4) The fourth generation breakthrough was 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.

(5) The fifth generation breakthrough was in 1980 with developments in machine learning and inductive inference systems.

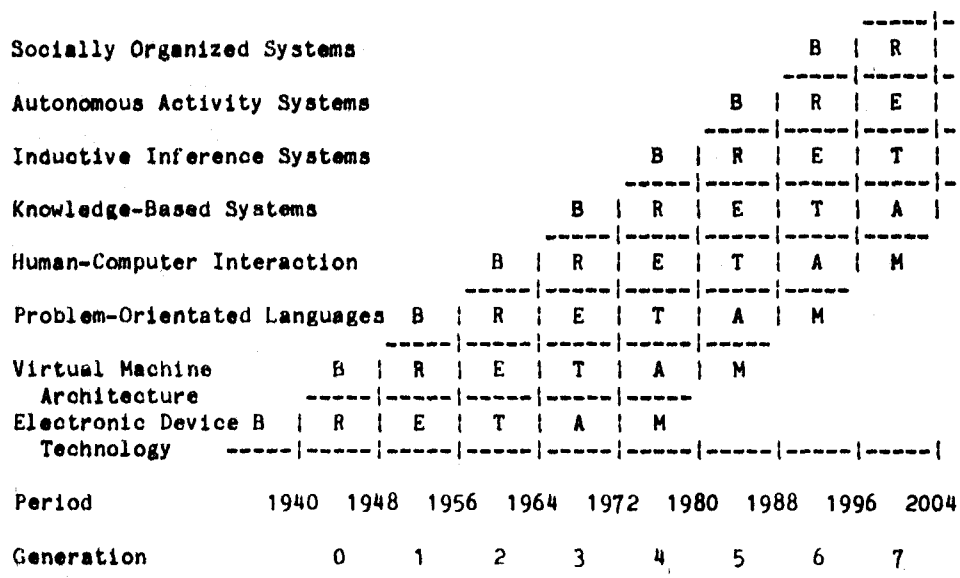
(6) We speculate that the growth of robotics will provide the next breakthroughs in which goal-directed, mobile computational systems will act autonomously to achieve their objectives. The breakthrough into the sixth generation era commencing in 1988 will be one of **automomous activity systems.**

(7) 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 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 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 zeroth generation (1940-47): (BR) recognition of the potential of EDT led to the breakthrough to the stored program and virtual machine architecture.



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. 6 Eight generations of computers and their underlying technologies

In the first generation (1948-55): (BR) recognition of the capabilities of subroutines to extend the VMA led to the breakthrough to the problem-orientated language; (RE) research focused on increasing the capabilities of the VMA to take advantage of advances in hardware development, e.g. index registers in the Manchester University Mark I.

In the second generation (1956-63): (BR) recognition of the advantage of making the POL directly control the machine led to the breakthrough to direct human-computer interaction; (RE) research focused on increasing the capability of POLs to take advantage of advances in VMAs, e.g. the block structure of ALGOL60; (ET) experience with the potential of the VMA led to the product design innovation of virtual memory hardware in the ATLAS computer.

In the third generation (1964-71): (BR) recognition of the knowledge engineering possibilities of HCI led to the breakthrough to knowledge-based systems; (RE) research focused on the improvement of the HCI through the development of interactive languages, e.g. Dartmouth BASIC; (ET) experience with the POL ALGOL60 led to the innovative VMA of the Burroughs B6500 computer; (TA) the emulation capability of the VMA led to the design of the IBM360 product line of mainframes.

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

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

In the sixth generation (1988-95): (BR) the recognition of cooperative goal-seeking possibilities of AAS will lead to the breakthrough to socially-organized systems in robotics; (RE) research will focus on goal-seeking in robots learning about their environment; (ET) innovative products will use inductive inference to set up KBSs; (TA) expert systems will become established product lines.

In the seventh generation (1996-2003): (RE) research will be focused on the social interaction of autonomous robots; (ET) innovative products will be based on goal-directed autonomous robots; (TA) learning systems will become established products, e.g. an encyclopaedia that generates new knowledge from inferences based on combining entries.

CONCLUSIONS

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 moulded by its values. From this second point of view, the development of computing may be modeled as a 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 is yet to come.

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. 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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REFERENCES

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

Blum, A. & McHugh, P.
1984 **Self-Reflection in the Arts and Sciences.** Atlantic Highlands, New Jersey: Humanities Press.

Brod, C.
1984 **Techo Stress: The Human Cost of the Computer Revolution.** Reading, Massachusetts: Addison-Wesley.

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

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

Drucker, P.F.
1978 **The Age of Discontinuity.** New York: Harper & Row.

Ellul, J.
1964 **The Technological Society.** New York: Vintage Books.

Gaines, B.R.
1977 "System identification, approximation and complexity." **International Journal of General Systems** 3: 145-174.
1983 "Precise past - fuzzy future." **International Journal of Man-Machine Studies 19**: 117-134. No. 1.
1984a "A framework for the fifth generation." **Proceedings of National Computer Conference 53**: 453-459. Arlington, Virginia: AFIPS Press.
1984b "Perspectives on fifth generation computing." **Oxford Surveys in Information Technology 1**: 1-53.

Gaines, B.R. & Shaw, M.L.G.
1981 "A programme for the development of a systems methodology of knowledge and action." In Reckmeyer, W.J.(ed.) **General Systems Research and Design: Precursors and Futures.** pp. 255-264. Louisville, Kentucky: Society for General Systems Research.
1983 "Is there a knowledge environment?." In Lasker, G.(ed.) **The Relation Between Major World Problems and Systems Learning.** pp. 27-34. Society for General Systems Research .
1984a **The Art of Computer Conversation: A New Medium for Communication.** Englewood Cliffs, New Jersey: Prentice Hall.
1984b **Generations of computers: modeling and forecasting. Possible Worlds 1**: 3-16. No. 4.

1984c "Emotion: a systemic development of the personal construct model." **Proceedings of Personal Construct Network Conference.** Cincinnati.

Hall, E.T.
1959 **The Silent Language.** New York: Doubleday.

Kelly, G.A.
1955 **The Psychology of Personal Constructs.** New York: Norton.

Klir, G.J.
1976 "Identification of generative structures in empirical data." **International Journal of General Systems** 3: 89-104.

Kohak, E.
1984 **The Embers and the Stars: A Philosophical Enquiry into the Moral Sense of Nature.** Chicago, Illinois: University of Chicago Press.

Lakoff, G. & Johnson, M.
1980 **Metaphors We Live By.** Chicago: University of Chicago Press.

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

Mowshowitz, A.
1976 **The Conquest of Will: Information Processing in Human Affairs.** Reading, Massachusetts: Addison-Wesley.

Pask, G.
1975 **Conversation, Cognition and Learning.** Amsterdam: Elsevier.

Pope, S.
1984 "Conceptual synthesis: beating at the ivory gate?." In Smith, W.(ed.) **Systems Methodologies and Isomorphies.** pp. 31-40. California: Intersystems.

Schutz, A. & Luckmann, T.
1973 **The Structures of the Life-World.** London: Heinemann.

Shackle, G.L.S.
1955 **Uncertainty in Economics.** Cambridge University Press.

Shaw, M.L.G.
1980 **On Becoming a Personal Scientist: Interactive Computer Elicitation of Personal Models of the World.** London: Academic Press.

Shaw, M.L.G. & Gaines, B.R.
1981 "The personal scientist in the community of science." In Reckmeyer, W.J.(ed.) **General Systems Research and Design: Precursors and Futures.** pp. 59-68. Society for General Systems Research.
1983 "Computer systems in the knowledge environment: a new medium." In Lasker, G.(ed.) **The Relation Between Major World Problems and Systems Learning.** pp. 35-41. Society for General Systems Research .

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

Turkle, S.
1984 **The Second Self: Computers and the Human Spirit.** New York: Simon & Schuster.

Weizenbaum, J.
1976 **Computer Power and Human Reason: From Judgement to Calculation.** San Francisco: W.H.Freeman.

Wiener, N.
1950 **The Human Use of Human Beings.** Cambridge, Massachusetts: Riverside Press.

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

Wojciechowski, J.
1983 "The impact of knowledge on man: the ecology of knowledge." In **Hommage a Francois Meyer.** pp. 161-175. Marseille: Laffitte.

Zadeh, L.A.
1965 "Fuzzy sets." **Information and Control 8:** 338-353.