THE INFRASTRUCTURE OF FIFTH GENERATION COMPUTING

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A model of the development of the computing industry is described and used to account for past events and predict future trends. The industry came into being as electronic device technology enabled the social need to cope with an increasingly complex world to be satisfied. 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.

1. Introduction

Computer technology changes rapidly and we have become used to being surprised. In a world of change and surprise how much, and how far into the future, can we predict? This paper arises from a study of key events in the the computing industry and their relationship to business cycles. It provides a framework for the computer industry that shows a logical progression of developments. It links this empirically to key events in the development of computing. It relates 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.

2. Systemic Foundations of Computer Development

There is a simple systemic model of the development of the computer industry. The precursors necessary to the birth of a new industry are a social need and a technology capable of satisfying it. The need allows a market to be generated. The technology allows products to be created for that market. For computers the enabling technology was electronics. The key operational concepts of a digital computer date back at least to Babbage, Lovelace and Boole in the nineteenth century [1]. However, the mechanical technology of their time could not support a digital computer with adequate operations, storage capacity and speed.

The social need for computation in Babbage's time was navigation and its support through astronomical calculations themselves supported by the calculation of tables of logarithms. The enabling technology of electronic devices dates to the early 1900s with De Forest's development of the triode vacuum tube [2]. However, it was not until the outbreak of World War 2 in 1940 generated the need for rapid calculation of ballistic trajectories that the social requirement for computation became sufficiently urgent. Mechanical device technology in the ball and disk differential analyser had been taken to its limit and was inadequate. The pressures created by the urgent need to find an alternative technology supporting computation led to the use of vacuum tubes in the design of ENIAC by Mauchly and Eckert [3].

3. The Learning Curves for New Technologies

The introduction of any new knowledge, technology or product follows a "learning curve" in which growth takes off slowly, begins to climb rapidly and then slows down as all the information has been assimilated. Such **logistic** curves arise in many different disciplines such as education, ecology, economics, marketing and technological forecasting [4]. They are the outcome of any systemic process in which the rate of growth is proportional to the amount: a) already accumulated; and b) remaining to accumulate.

It has been noted in many disciplines that the qualitative phenomena during the growth of of the logistic curve vary from stage to stage [5]. 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 mimiced 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

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The next level of breakthrough was to bridge the gap between machine and task through the development of **problem-orientated languages** (POLs). Their foundations in the first generation were subroutine libraries providing VMAs closer to the problem requirements, notably floating point arithmetic and mathematical functions. Work on the design of FORTRAN in 1954 and its issue in 1957 marks the beginning of the second generation era with languages targeted to specific problem areas of business data processing, text processing, database access, machine tool control, and so on. A 1968 paper on the coming fourth generation notes that "programming today has no theoretical basis" and calls for a scientific basis in the next generation [16]. Sure enough the theory linking POLs to the underlying VMAs developed during the fourth generation era, for example, that of abstract data types and initial algebras [17]. In the fifth generation era the application of experience, design rules and theory to the automation of software production has become the top priority [18].

The binary VMA-POL relationship bridges the gap between the computer and its application. However, the computer industry is based on the triadic relationship between computer, application and person, for example, programmer, system analyst or user. The next level of breakthrough was to bridge the gap between the computer and the person with the development of **interactive** computers. The move from baten-processing to direct **human-computer interaction** (HCI) was made in 1963/1964 with the implementation of MIT MAC, RAND JOSS and Dartmouth BASIC systems [19]. The study of such systems led to design rules for HCI in the 1970s [20] and theoretical foundations have started to emerge in the 1980s [21]. The improvement of HCI is a major priority in the Japanese fifth generation development program [22].

The third element in the triadic relationship between computer, application and person is that between the application and the person. It is one of **knowledge-processsing**, the human capability to store information through its inter-relations and make inferences about its consequences. The breakthrough in **knowledge-based systems** (KBS) dates from the development of DENDRAL [23] for inferring chemical structures from mass-spectrometry data and MYCIN [24] for the diagnosis of microbial infections in the early 1970s. It led to a spate of expert system development in the fourth generation era of the 1970s [25], and pragmatic design rules for knowledge engineering in the current fifth generation era [26]. The utilization of their massive VLSI production capability [27,28] for the support of KBS through LISP [29] and PROLOG [30] machines is the other major priority in the Japanese fifth generation development program [31].

Defining the upper levels of the infrastructure becomes more and more speculative as we move into the immediate past of our own era and look for evidence of learning curves that are at their early stages. It is reasonable to suppose that the level above the representation and processing of knowledge in the computer will be that of its acquisition, breakthroughs in machine learning and inductive inference systems (IIS). Two breakthroughs in this area have been Lenat's **AM** learning mathematics by discovery [32] and Michalski's inductive inference of expert rules for plant disease diagnosis [33]. In the current fifth generation era machine learning has become a highly active research area still in its replication phase (Michalski & Carbonell 1983). 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** (AAS). We speculate further that 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** (SOS).

5. Conclusions

The computer industry came into being as electronic device technology enabled the social need to cope with an increasingly complex world to be satisfied. Underlying all developments in computing is a succession of learning curves which make up the infrastructure of the computer industry. The base curve is that for electronic device technology and above it in succession are those for: virtual machine architectures; problem-orientated languages; human-computer interaction; knowledge-based systems; inductive inference systems; autonomous activity systems; and socially organized systems. In each generation the types of breakthrough, research focus, product innovation, and established product lines, may be predicted from the levels of technologies in particular phases. This gives a satisfactory account of past surprises in invention, fashions in research, innovations in products and launches of product lines. It also gives a reasonable basis for forecasting future trends in the fifth, sixth and seventh generations.

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7. References

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