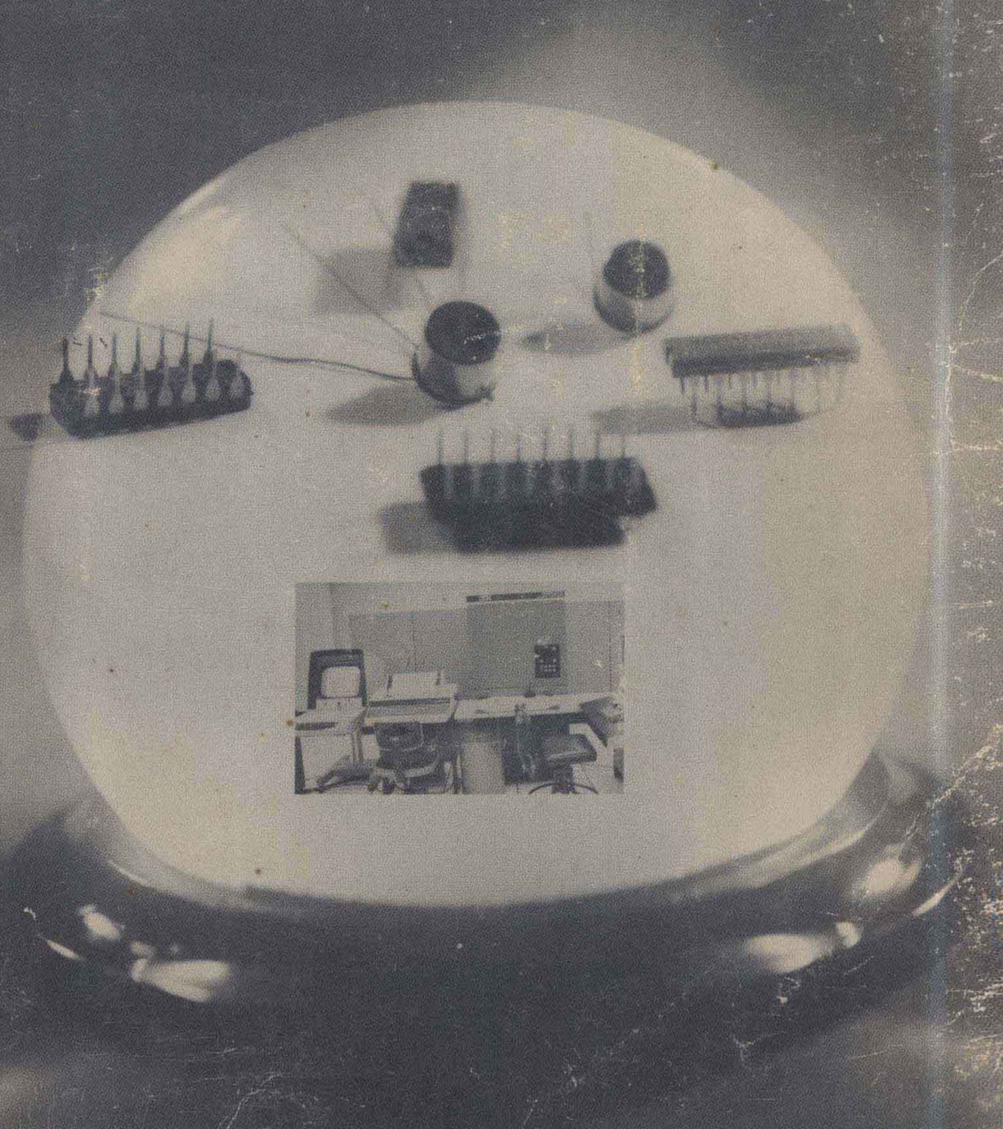
# COMPUTERS IN THE 1980s

rein turn



REIN TURN

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*Rein Turn is a senior systems analyst for The Rand Corporation.*

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# COMPUTERS IN THE 1980s

TO IRENE, INDRA, AND MIKE

# PREFACE

THIS BOOK is not *about* technological forecasting, it *is* a technological forecast. It takes the mid-1971 state-of-the-art digital computer *hardware technology* as a base line and projects improvements in this technology over the next fifteen to twenty years. Projected are future trends in such computer characteristics as speed (in terms of millions of instructions per second) and physical properties (volume, weight, and power consumption). These are obtained from the projections of relevant characteristics of components, the semiconductor logic circuits in particular.

For computer memories, both high-speed random-access memories and mass memories, access times, data-transmission rates, and physical characteristics are projected. Also discussed are future characteristics of input-output terminals and, rather briefly, data-communication systems. Presented in less quantitative terms are computer and memory systems' viability (reliability, maintainability, ruggedness against environmental factors) and problems associated with their programming. Many future innovations in computer system architecture, functional capabilities, and use are pointed out.

Throughout the preparation of the book an effort was made to show as explicitly as possible the calculations and considerations which were used to make the projections. The purpose was not only to make it easier for the reader to understand and check on the reasonableness of the projections, but also to provide a mechanism for the reader to update, or correct, the projections by using more current data on component capabilities which he may have or which can be expected to become available as time passes. If the book, indeed, has this property, and it was the author's objective to achieve it, then it will not lose its value with time, but will remain as a framework for continuous updating of the projections.

To enhance further the value of the book as a "do-it-yourself" forecasting guide in computer technology, Part 1 contains an abbreviated tutorial presentation of various technological forecasting techniques, their suitability, considerations in assessing a forecast's validity, and the pitfalls and errors which prey on the forecaster. However, not much of this discussion is original with the author, as the excellent books and articles on technological forecasting by Joseph Martino, Marvin Cetron, James Bright, and Robert Ayres were extensively consulted. Inclusion of this material can be justified on the grounds of providing a compact overview of what is involved in technical forecasting and providing check lists for assessing the credibility of the trend projections that follow in Parts 2 and 3.

Part 2 contains the trend projections for several architectural configurations of general-application computers—the standard "commercial" computers seen in the computer centers of industry, business, government agencies, and research laboratories—and command-control system computers. The latter are used in special, demanding environments for tasks that require special features, such as ultrahigh reliability, small physical size, and resistance to natural or man-made nuclear radiation effects. Command-control computers and their applications are discussed in Chapter I.

Part 3 presents the detailed analyses that underlie the forecasts made in Part 2. Treated here are the specifics of logic-circuit components, arithmetic algorithms and their implementations, high-speed memory and mass-memory technologies, input-output devices and displays, and communication systems. The detailed discussions and relationships form the basis for the hoped-for capability of the reader to use the book to make updated projections of technological trends. The relationships developed are further outlined in Chapter XIII (in Part 4) to show as clearly as possible their effects on the relevant characteristics of processors and memory systems.

Another chapter in Part 4 presents the innovations in computer system design and applications which become feasible with the developments of the computer hardware technology as projected in Part 3. Numerous recent references are included to direct the reader to more detailed discussions in the literature of the innovations and their implications to the users of the computer system.

The trend in computer hardware technology is unmistakably toward greatly improved computing speeds, reduced physical size, and reduced cost (although the latter characteristic proved most difficult to forecast in quantitative terms). Indeed, the question is not *whether* these improvements take place, but *when* and to what degree. Nevertheless, technology does not advance by itself but requires continuous research and development. Therefore the conclusions reached in this book should be regarded as an indication of what *could* be achieved if the current trends in research and development of computer systems continue, rather than as a flat assertion of what *will* be achieved.

On the other hand, the disclaimer just stated could be countered by observing that the approach taken in this book is what might be called a "surprise-free" trend projection in which it is assumed that present component, interconnection, and manufacturing technologies will be improved in an evolutionary way, at a deliberate rather than an explosive rate. Consequently, any technological breakthroughs that might occur would tend to make the projections in this book conservative in terms of both the time and the level of achievement. The "do-it-yourself" forecasting capability of this book should be especially useful for these situations.

The technology projections and supporting analyses in Parts 2 and 3 are based on The Rand Corporation report R-1011, "Air Force Command and Control Information Processing in the 1980s: Trends in Hardware Technology," October 1972. This report, in turn, stemmed from the author's participation in a U.S. Air Force Systems Command study (the CCIP-85 study) of the information-processing research and development required to meet the command-control requirements in the 1980s. This, then, accounts for the slightly military flavor of some of the discussion, especially in the area of command-control computer systems. However, as repeatedly pointed out in the text, command and control is a functional activity which transcends military requirements and appears everywhere that man makes decisions to control dynamic systems and processes. The reference to military computer systems and command-control requirements, therefore, should not detract from the value, or applicability, of projections of future command-control computer system characteristics.

Many people helped to compile data for Parts 2 and 3 of the book when they were being prepared for the CCIP-85 study, made useful suggestions during their writing, and commented on the content. In particular, Barry W. Sine, a consultant for the U.S. Air Force during the

CCIP-85 study, contributed material for the subsections on programming, and Albert A. Jamberdino of the Rome Air Development Center, Griffiss Air Force Base, contributed material on wideband recorders. Ronald S. Entner of the Naval Air Systems Command provided information on the AADC computer development.

Many thanks are due to Barry W. Boehm, former head of the Information Sciences Department of The Rand Corporation, who, as director of the CCIP-85 Study, provided guidance and later encouraged the author to undertake the writing of this book.

Detailed reviews of Parts 2 and 3 by Malcolm R. Davis and Roderic Fredrickson of The Rand Corporation and Thomas O. Ellis of the University of Southern California Information Sciences Institute are gratefully acknowledged. The responsibility for the conclusions reached in the book, and for errors which may have evaded careful scrutiny, rests, of course, with the author.

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*January 1974* REIN TURN

*Santa Monica, California*

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# TECHNOLOGICAL FORECASTING

## PART ONE

# I

# INTRODUCTION

## PROPHECIES AND FORECASTS

THROUGHOUT THE AGES, man has striven to learn about the results of his actions planned for the future. In the days of antiquity it was believed that beneficially inclined gods were willing to reveal the future to qualified petitioners for appropriate sacrifices. The mode for such revelations ranged from the utterings of prophets and oracles under trance to patterns in birds' flight or in the entrails of sacrificial animals. The mythical Greek god Apollo, in particular, was consulted by the oracles at Delphi whose prophecies, vague and ambiguous as they were, were famous throughout the Mediterranean area.

Indeed, during the days of Alexander the Great (356–323 B.C.), the demand for Delphi prophecies was so great that several oracles were used simultaneously and their "staffs" were busy assigning priorities to requests, taking them to the oracles (there was no direct contact between an inquirer and the oracle), and returning to the person the prophecies, which were often "edited" to suit the inquiry. Alexander himself frequently consulted the Delphi oracles. In one instance, so the legend goes, Phyria, the oracle, refused to prophesy. Angered, Alexander started to drag her to the tripod used as the seat for prophesying. "My lad, you are invincible!" shouted Phyria in distress. Alexander readily accepted this as a prophecy and confidently departed on his next round of conquests.

The ancient methods of foretelling the future are still with us in the form of palmistry, astrology, laying the cards, and the like. But now, fortunately, they are regarded by very few gullible individuals as serious predictions of things to come. However, the *need* for reasonably credible information about the future is greater than ever. No business or industry can expect to remain successful and profitable for long without making plans about future products, marketing, investments, or capital expenditures. The success of these plans depends largely on the ability of the planners to anticipate changes in the availability of resources; the size and nature of the potential market; the tastes and fads of the buyers; the costs of materials, labor, capital, distribution, advertising; the general economic climate of the market area; technologies of materials, manufacturing, distribution, communication, and so forth.

Some of these variables, such as the demographic makeup of a potential market, are slowly changing and can be predicted for relatively long time periods in the future. Others may be rapidly changing and partly "irrational" in nature, such as the tastes and fads of the buyers. Still others are very complex and require a great deal of understanding and study for credible forecasting of their future trends. Among the latter are the rapidly changing branches of modern electronics technology: materials, microelectronics, packaging, and all facets of information processing and communication.

Indeed, *technological forecasting*—the prediction of the future characteristics of useful machines, procedures, or techniques—as defined by Martino [1], is involved in all plans and decisions which affect or are affected by technological changes. As Martino points out in a discussion of alternatives to technological forecasting, even the decision by planners to make no technological forecast at all is, if made deliberately and rationally, really a forecast of "no change" in the involved technologies.

Although for certain technologies and short-term plans it may be possible to do without explicit technological forecasts, this is highly unlikely for large systems which often require more than five years of development and testing before achieving operational status. The large military command and control systems, modern weapons systems, and space flight and exploration systems are typical. For example, eight and a half years elapsed between President Kennedy's announcement in January 1961 of the plans for manned exploration of the moon and the first landing on the moon by American astronauts in 1969.

During the long development periods of large systems the technologies to be used in system implementation or those affecting the environment of its operation constantly change at various rates and, for effective use and interfacing with these technologies, it is important to forecast the changes and take them into account as early in the system design as possible. Eventually, of course, the system design must be "frozen," and the subsequent advances in the involved technologies cannot be employed. The earlier in the system design process this decision must be made, the more will the system planners and designers benefit from high-quality technological forecasts.

*Computer technology,* the topic of this book, is a relatively young, rapidly developing field which has already profoundly affected other technologies, industries, business, government, and the society at large. Assessing the state of the art and forecasting future developments in computer technology have therefore become important in the planning, developing, and implementing of nearly every modern system.

The broad scope of computer technology—processors, memory units, peripherals, data-communication equipment, and software are involved—makes technical forecasting a difficult task requiring detailed knowledge of the design and operation of these subsystems, as well as an understanding of the underlying physical principles, design, and manufacturing processes of their components.

Only a few decisionmakers in business, industry, or government have staffs that can handle a detailed computer technology forecast. For others there are available several consulting firms which can produce specialized forecasts, and a few forecasts that have been published in the literature. As a rule, the published forecasts address specific subsystems only, apply to different time frames, provide different levels of detail, and are scattered among a variety of books, journals, reports, and conference papers [2–6]. A few forecasts of the developments in the entire computer technology field have also been published [7–9]. They are relatively long-range forecasts which utilize the Delphi technique: they provide systematically gathered opinions of groups of experts on the time when selected technological innovations and capabilities in the computer field are likely to become available. Typically, such forecasts do not provide technical details on how the capabilities forecast will be achieved. While it may be true, as practitioners of technical forecasting argue [1], that technological forecasts do not need to specify the technical details, there are instances where an understanding of the details involved is useful for planning purposes as well as for checking the credibility of the forecasts themselves.

After a discussion of the various types of computers, their uses in large systems, and a brief review of technological forecasting methodology, this book presents for a time span of nearly twenty years an explicit and detailed forecast of the relevant computer system characteristics such as processing speed, memory-access time, data-transfer rates for various peripheral devices, instruction execution times for various computer system architectures, logic-circuit speeds and size. Discussed are the prominent types of contemporary computer architectures—uniprocessors, multiprocessors, array processors, associative processors, and federated systems, both in general-purpose applications and in specialized, so-called "command and control" applications in military and commercial systems. The relationships and reasoning used to derive the forecasts are shown in detail.

Detailed presentation of the premises and data used in forecasting is of great importance, as it allows the users of the forecasts to check on the reasoning and computations used and, subsequently, to revise the forecasts as time goes by because, as must be expected, the real-world developments differ from those assumed in the forecasts. An important objective in writing this book was to provide this capability.

## COMPUTER TECHNOLOGY

Computer technology is the totality of means, devices, processes, and techniques employed in the construction and operation of digital computers. The basic components may be electronic, magnetic, optical, mechanical, acoustic, or chemical. Principles of electromagnetics, thermodynamics, electroacoustics, quantum mechanics, nuclear radiation, communications and information theories, logic, and modern mathematics are involved. Indeed, there is hardly a branch of science that is not included. The application of each of these disciplines in the manufacture of components or subsystems for computers is a technology in its own right.

Whether or not it is necessary to involve all the associated technologies when discussing computer technology depends on the context and on the level of detail. In the conventional use of the term "computer technology" the discussion is in terms of performance characteristics that represent the computer as seen by the users and system designers:

△ *Computing speed* in terms of number of instructions processed per second, when a particular instruction mix is specified.
△ *Memory capacity* in terms of number of words that can be stored in random-access memory (or bulk memories).
△ *Access time* of the memory in terms of time required to fetch a word.
△ *Reliability* in terms of average number of failures over a time interval.
△ *Architecture* of the system in terms of operating capability, such as multiprocessing, time sharing, real-time response, remotely accessible terminals.

In different contexts the system is described in terms of more detailed characteristics: instruction execution times, logic-circuit switching time, power consumption, packing density, wiring delays, signal-to-noise ratios, and other engineering descriptors.

On the component level the discussion is in terms of physical and electrical (or optical, magnetic, chemical) characteristics of the components and their manufacture: current and voltage levels, noise characteristics, speed-power products, thicknesses of deposited metallization or dielectric layers, line widths, frequency-response characteristics, and others.

There exists, however, a causal chain from the microcharacteristics of basic circuit elements to the macrocharacteristics which describe the computer system behavior. Any one of these functional characteristics, at any level, can be selected for investigation and technical forecasting. Thus a forecast may be made about the maximum density of emitter-coupled logic (ECL) gates when silicon-on-sapphire manufacturing technology is used. Or a forecast may be requested on the maximum available addition rate when, for example, a parallel 36-bit adder is used.

A technological forecast of computer technology can be a very complex undertaking when all the associated component and subsystem manufacturing techniques are brought into the picture or it may be a simple trend extrapolation of the maximum instruction execution rate without any regard for the developments in component and subsystem levels. Both approaches can produce credible results, but the level of work and the expertise required differ vastly. The former requires knowledge of computer engineering; subsystem design, manufacturing, and engineering; and component design and manufacturing. An understanding