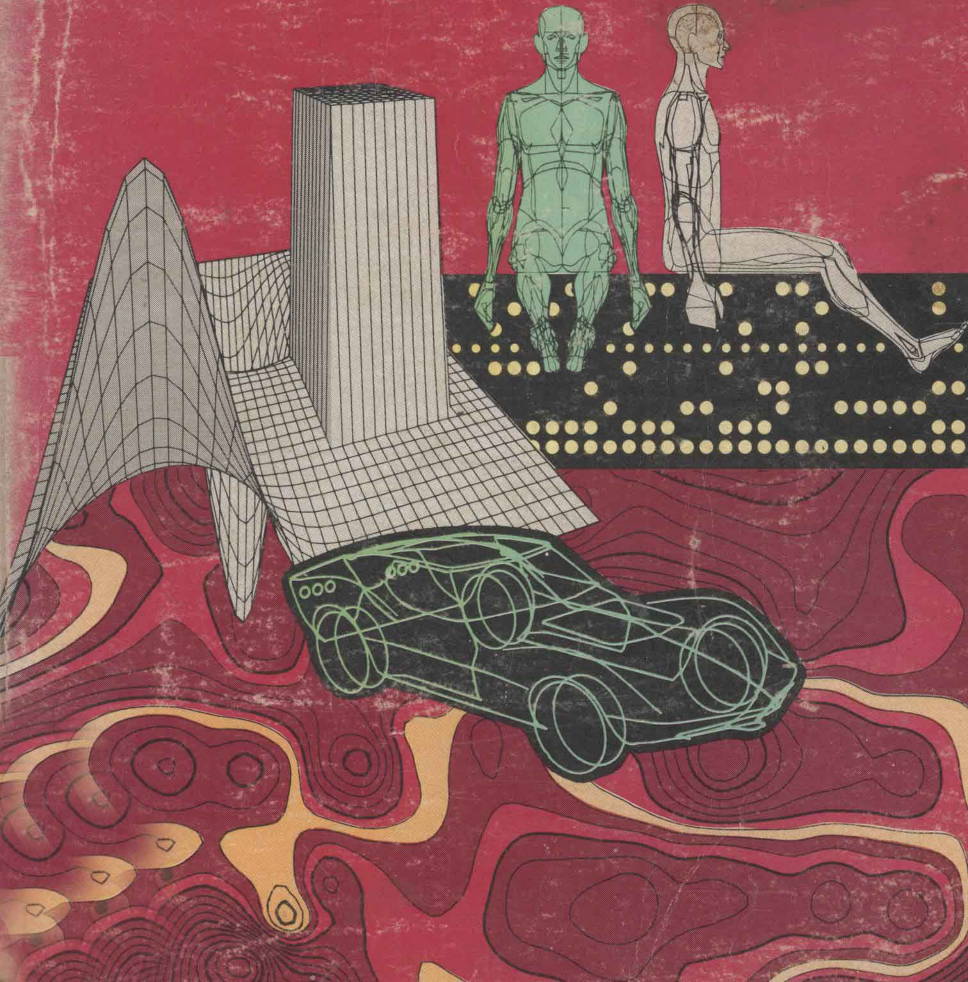
COMPUTERS AND PROGRAMMING GUIDE FOR SCIENTISTS AND ENGINEERS

by Donald D. Spencer



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A Revision of

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Preface

Computers are being woven more and more into the lives of virtually everyone. Although much of this growth is in data processing and personal computing (microcomputers being used in the home), computers have also become essential tools for scientists and engineers. A knowledge of what computers can do and an ability to make them do it has become a necessary part of a technical education.

Computers have had a tremendous impact in science and engineering. Aeronautical engineers design supersonic aircraft with the aid of computers. Architectural firms have used computers for over a decade to help them design and plan building projects. Civil engineers use computers to aid them in designing and constructing dams, buildings, tunnels, highways, airports, transportation systems, and stadiums. Computer-aided design is an ever-increasing activity with electrical engineers. Mechanical engineers use computers to help them design automobiles, tools, and power plants. Naval architects have streamlined the art of shipbuilding by using computers. Scientists have used computers to help them make new discoveries in physics, chemistry, medicine, and other technical fields.

Nowadays, the subject of computer science, with lectures on computer principles and programming, and laboratory sessions using a computer terminal or microcomputer, is a feature of many undergraduate courses. For the many undergraduates in science and engineering who will subsequently be required to use computers effectively, a book is needed which explains the general principles on which computers operate and the means by which one communicates with them. Illustrations of the use of a computer should be within the kind of context in which students may be expected to work subsequently, so that they see it in a satisfactory relationship to the whole of their studies. Engineers and scientists should use the computer as a tool to aid them in solving problems. I attempted to keep this theme in mind while writing this book. The book is based on experience I have gained in designing scientific and real-time computer systems over the past 20 years.

The major purpose of *Computers and Programming Guide for Scientists and Engineers* is to help science and engineering students develop an understanding and appreciation of the computer, its capabilities and limitations, the concept of computer problem solving, the concepts of programming languages, and the techniques used in designing computer software systems.

A second purpose of the book is to help readers develop programming skills that will enable them to use a computer in the context of science and engineering rather than business.

The BASIC and FORTRAN programming languages are widely used in scientific and engineering applications. FORTRAN has been used by scientists and engineers for the past two decades. BASIC, a similar but easier-to-use language, is more widely used with microcomputers. Both of these languages are fully discussed in this book.

All scientists and engineers should have some knowledge of real-time systems, simulation, problem-oriented programming languages, systems design, operating systems, and teleprocessing. These subjects are all covered in this book.

Questions and exercises appear at the end of each chapter. These exercises serve to illustrate the material of the chapter, to help the reader gain computational programming skill, and to extend the material to closely related topics not covered in the chapter. A comprehensive glossary of computer-related terms is provided at the back of the book.

The future use of computers in scientific and engineering practice is limited only by the imagination of our scientists and engineers. These technical people should not lag behind in adopting the use of computers in future scientific and engineering applications.

I wish to thank the many computer manufacturers and computer users who supplied me with photographs of equipment and applications where computers are used. I also thank my wife, Rae, for typing the manuscript.

Donald D. Spencer

To my wife
Rae

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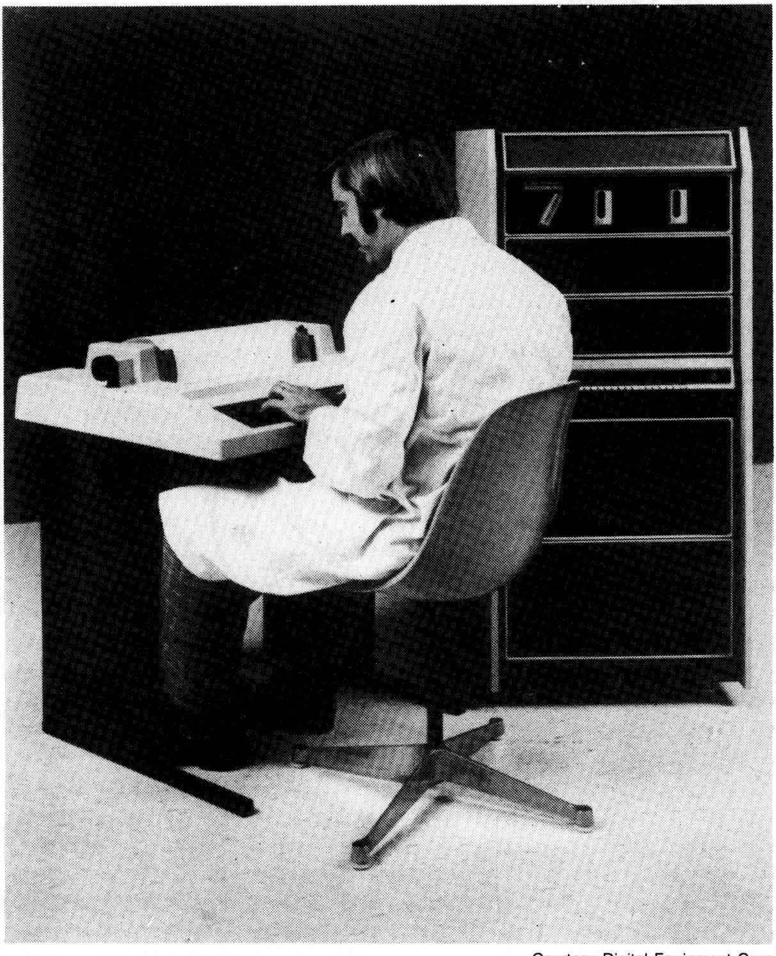
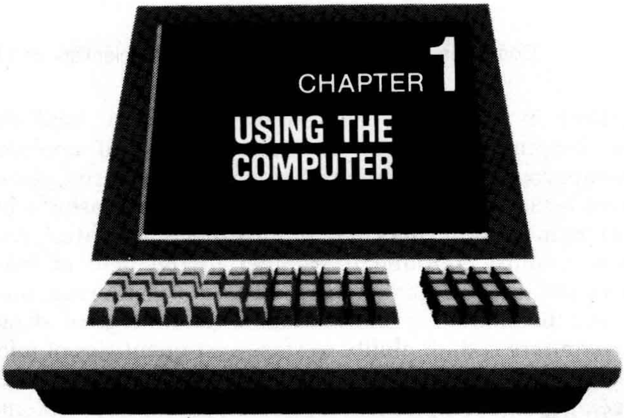


Courtesy Digital Equipment Corp.

A scientist using a minicomputer system designed to collect, record, and process data from laboratory instruments.



This is the era of automation. A variety of machines (large-scale computer systems, supercomputers, medium-scale computers, minicomputers, and low-cost microcomputers) are now available that can, by means of programmed instructions, solve difficult engineering problems, shape and machine intricate parts, control industrial systems, plot contour maps, design electronic circuits, simplify air-traffic control, land astronauts on faraway planets, and perform countless other tedious and time-consuming tasks that would have been impossible just a short time ago.

WHAT BENEFITS DO COMPUTERS OFFER SCIENTISTS AND ENGINEERS?

Most of the development concerning computers has occurred within the last two decades. The scientist and engineer, from the beginning, have been closely associated with this development. In fact, the engineer originally created much of the demand for a computing machine to aid in solving problems encountered in military applications. As soon as it became possible to solve problems previously considered impractical to solve because of time, many new computer applications became apparent in all phases of industry. The engineer and scientist now have computers available that can perform more calculations in an hour than they could do in 40 lifetimes using desk calculators.

Engineers are primarily concerned with the application of science to industrial progress. It is their objective to plan, design, develop, and construct usable devices that employ scientific principles. One of the many problems facing engineers today is the increasing complexity of their profession. Only a few years ago they were accustomed to resolving many aspects of their work with little effort; now these aspects have become complex enough to require other specialists who are as qualified in their fields as engineers are in their field.

Engineers and scientists operate at the forefront of technological development in chemistry, cryogenics, metallurgy, and the other sciences, keeping abreast of new discoveries and applying them wherever appropriate. With each passing year, successful pioneering in these areas becomes more difficult and requires increasingly improved means of communicating information and exercising control. As a result, the engineer must continue to pioneer in the field of information processing and in developing better systems for gathering, processing, storing, and disseminating information. One of the great attractions of digital computers is their ability to store vast quantities of information and to retrieve it almost instantaneously when required to do so.

By placing greater emphasis on the development and implementation of advanced information processing techniques, engineers will be better able to cope with pressing problems that are common to the entire engineering field—problems such as short time schedules, growing complexity of products, meeting stringent reporting requirements of customers, faster design and construction processes, and higher standards of product design.

The computer can relieve the engineer and scientist of many tiring and time-consuming processes, thus enabling them to spend more time on more important aspects of their profession. In addition to being able to store and retrieve vast quantities of information, the computer is also

"THE COMPUTER WILL NEVER REPLACE PEOPLE COMPLETELY — SOMEONE'S GOT TO PLUG IT IN!"

able to analyze and simulate an almost infinite number of problems. The scientist or engineer can, therefore, perform a far more rigorous analysis of design factors by using a computer than would be possible in the same period of time by using manual methods.

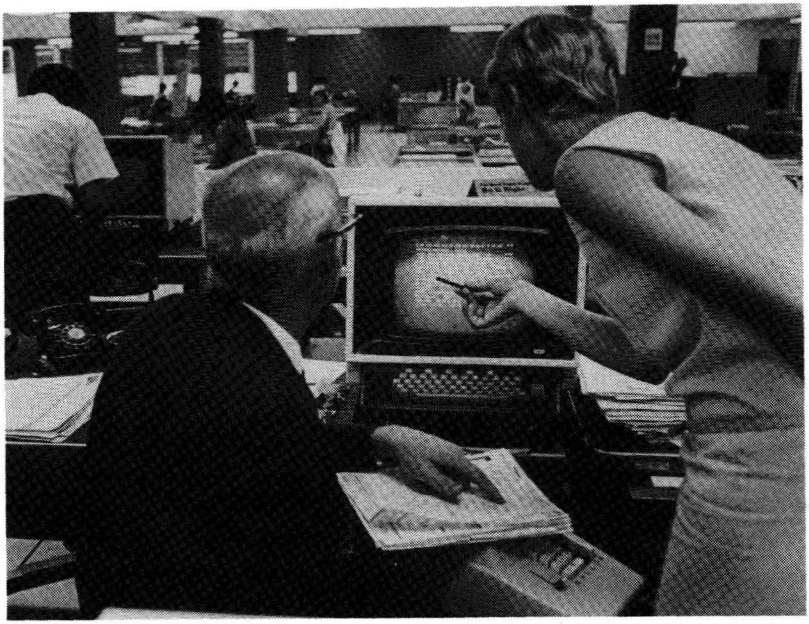
Unfamiliarity with computers and programming techniques in general has limited the use of this powerful tool in many technical areas. Many scientists and engineers are, in fact, openly skeptical of using a computer to carry out processes that they have done for many years by manual methods. If engineers and scientists are to obtain any benefit from using computers, they must be prepared to understand them. But before they can be persuaded to make the effort to understand and master the use of computers, they must first learn of the potential uses of computers. Let us now look at some of the tasks that computers can already undertake for the scientist and engineer, along with some possibilities for future uses.

THE APPLICATION OF COMPUTERS TO MANAGEMENT

In recent years, management has been faced with a persistent and ever-mounting pressure to keep pace with the scientific, technical, and productive capabilities of its laboratories and plants. The ability to secure new business depends to a great extent on management's proficiency. Customers weigh management performance very heavily in assessing a company's ability to meet future requirements. Even after a contract has been won, the amount of profit will frequently depend on management's ability to meet preset standards of cost, time, and reliability.

To meet this challenge, management requires an information and control system that relates each part to the other parts, with changes in one function immediately reflected in the others. It must be dynamic and capable of keeping all levels of management fully informed about activities that are of concern to them. A computerized management system can fill this role. It can produce the specific, tailor-made reports management needs. It can provide information in a form that gives management the key facts necessary for making decisions, noting especially the exceptions or critical areas requiring immediate action (Fig. 1-1). The use of such a system will assist management by contributing to:

- Improved planning of manpower, facilities, and technical abilities to meet the future market.
- Better selection of contracts that utilize existing or planned resources and capabilities.
- Better analysis of contract cost, permitting more precise bidding to meet management's profit objectives.



Courtesy Control Data Corp.

Fig. 1-1. Information being displayed on a cathode-ray tube (crt) display device that is connected to a computer located elsewhere in the building.

- Improved planning of project schedules and distribution of funds and technology.
- Faster response to deviations from the schedule or budget.

Information is the basis for management action. Only through proper use of informational resources can management establish better control and provide adequate guidance to every aspect of a company's operation.

Forecasting and Planning

Long-range planning is the process of supplying a guide for action to bring about a desired future business position. It involves setting objectives and goals, establishing guides to facilitate the accomplishment of the objectives, and following through to see that the plans are carried out to a successful conclusion.

Long-range planning involves the entire organization. The capability profile of the firm is shaped by the activities of the research and engineering organizations in developing proficiency in new areas of technology, and by the personnel and facilities groups in the development and acquisition of manpower skills, facilities, and equipment. The function of the plan is to provide for the expenditure of company resources in a manner that will provide for continuing progress of the firm. The continuing appraisal of corporate goals and strategy in the face of new market demands and opportunities is a requisite for survival. The major steps involved in long-range planning are:

- Formulation of long-term company objectives.
- Identification of alternative courses of action available to the firm.
- Statement of constraints imposed by the available and attainable company resources and capabilities.
- Balancing required capabilities with potential.
- Selection of market opportunities that promise the greatest potential return.
- Determination of the nature and timing of required decisions.
- Assignment of responsibility for the actions required to implement the plan.
- Establishment of measurement criteria to gauge the effectiveness of the plan.

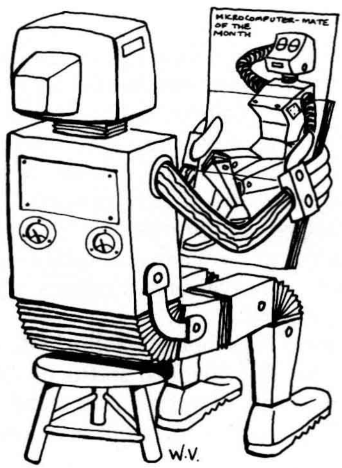
The planning procedure begins with an analysis of data from a variety of sources, including information concerned with customer requirements and the action of competitors. A determination is made of the required resources in each major business area. Then, on the basis of the business dollar potential, an evaluation is made of anticipated returns versus investment requirements. This process is dynamic. Profit potential under alternative assumptions is evaluated since certain combinations of programs may reveal undesirable peaks or valleys in resource utilization. Thus, after various iterations, a plan is evolved that is satisfactory to management.

After marketing strategy has been established, a financial plan is prepared to set targets for the financial status of the company. These targets are expressed in terms of anticipated status of profit and loss, balance sheet, cash flow, and return on investment by the major business area.

Data processing offers the capability to evaluate promptly the changing internal and external conditions. It provides the facility for simulating the effect of common planning assumptions through the various operating organization levels in the company. Management will receive reports that reflect the most current information in the form of a statement of consequences based on the alternative assumptions. The ease with which data-processing equipment prepares the information needed for the planning function is an important added management capability.

Estimating and Pricing

The actual process of seeking business takes place after the business environment is determined. The estimating and pricing group has the primary responsibility for preparing sales proposals for a company. Two significant developments have occurred within engineering that increase the need and value of data-processing systems in the estimating and pricing function. First, products have become considerably more complex and diversified. Electronics, missiles, and spacecraft have increased the time and skills needed to estimate these products. Second, recent trends in proposal requirements have called for more details to be submitted to support cost estimates. This has resulted in an increased effort to control the cost elements, to prepare all proposal schedules and reports, and to make necessary revisions when the elements change. There is also an increase in the number of reestimates that require changes in rates and schedules. The result of these developments is an increase in the cost and the time pressure of preparing proposals.



Data-processing techniques for preparing proposals and cost estimates reduce the work load of the estimating and pricing department by performing much of the clerical effort and helping to control and calculate all cost elements. The necessary data is sorted, summarized, and printed into proposal reports. Adjustments and reestimates are easily prepared. As a result, the cost and time required to prepare proposals is significantly reduced.

Operational Planning

The planning, estimating, and pricing functions have one aim—to secure business that satisfies the company's profit and growth objectives. Then, having secured a contract, management is concerned with the functions of scheduling, budgeting, evaluation, and control. The following paragraphs deal with data-processing systems that supply information to assist management in improving operational effectiveness.

A schedule is a plan that specifies the objectives, the sequence of activities required to meet them, and the dates by which key events or milestones must be completed in order to ensure that the project is completed on time. A total project schedule is submitted as part of the proposal for the contract. Therefore, preliminary schedules must be determined as part of the process of preparing the proposal. A firm, final schedule is established through negotiation with the customer at the time of contract award. This must be broken down into controllable elements beginning with the management of the major segments of work, down to the various supervisory levels. Changes in project schedules may subsequently be required because of changes in customer delivery requests, product specifications changes, or schedule slippages in elements of the work.

Progress reporting starts after work begins on the contract. Actual times are compared against schedule times. Progress information is initiated on the working level and then summarized for management. This information is a basis for management evaluation of project status. The rapid rate of growth and increased size of research and development projects make it imperative that they be carefully scheduled and controlled. These same increases in growth and size, however, make scheduling and controlling by manual methods almost impossible, since it is necessary to integrate and correlate the efforts of many different departments and groups working on large, complex projects. Processing the large volumes of data for scheduling, and analyzing the completed operations against the schedules, is readily performed by data processing; thus, more time is allowed for corrective action by management. A data-processing system for scheduling may also be used to evaluate the effect of proposed changes before they are made, by executing them in the computer system for analysis only.

A budget is a financial plan of action for a specific period of time. Its purpose is to coordinate and control the activities of the various divisions of the business and to find the most profitable courses of action. To achieve this end, the budget reflects not only a plan but also a standard by which the performance and accomplishments of all levels of the organization can be measured. Since the budget is management's declaration of a plan of action, it serves as a formal means of stating corporate policy and advising all management echelons of their goals and targets. One objective of a budget system is to produce a forecasted balance sheet, profit-and-loss statement, and cash-flow statement for management. These are the summary budgets. Before they can be prepared, each element going into them must be forecast, and individual departmental or functional budgets must be prepared. Functional budgets cover sales, operations (including labor, material, and factory overhead), and the general and administrative areas.

Forecasting the future financial position of a company on the basis of estimated operations can be considered a typical simulation problem and ideally lends itself to data-processing techniques. Opening account balances are entered into the computer along with estimated operations, which are converted to appropriate journal entries. These are added to or subtracted from the affected accounts, and the projected statements are printed. The effects of changing conditions, such as the rate of progress payments on government contracts, the rate of profit, or whether a contract will be received, can be readily observed. Since many large engineering companies have a great many contracts in-house, summarizing them is a time-consuming manual task. Data-processing systems can save large amounts of time and effort in the computing and printing of the necessary reports.

In science and engineering, the trend is toward using a stand-alone microcomputer or using a remote terminal (such as the one shown in Fig. 1-2) that feeds directly to a central computer. Such a system eliminates the delays inherent in a manual entry system. After raw data is gathered for the data-processing system, it can be processed for preparation of management reports. These can be historical accounting records or evaluation reports where the data has been:

1. Summarized.
2. Compared with budget and schedule.
3. Computed for budget and schedule variance.
4. Tested against tolerance limits.
5. Printed on exception reports if called for by decision rules stored in the system.

The input data is collected from all departments via automatic data acquisition terminals and may include attendance data, requisitions, purchase orders, work orders, receiving reports, job completion notices, etc.

The success of a company is reflected in the ability of its management to plan adequately for the potential market and to control the operations. Long-range planning, estimating and pricing, and operational planning, including scheduling and budgeting, are important management functions. Effective performance of these functions results in survival and growth.