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preface

The cost and size of computers providing the same performance have been steadily decreasing for more than two decades, greatly expanding the market for computers. The lower cost has made it economically feasible for smaller and smaller businesses to automate and has made many new applications possible. The increased use of computers has not been without problems, however. Although most applications have been reasonably successful, many have failed and many others have not been as successful as they could have been. The major contributor to failure has been poor system design.

Many small businesses either did not recognize the need for thorough design or they did not know how to go about it. The designers of a computer system must have a thorough understanding of the application being put on the computer and must also understand computer systems and the principles of data processing. They also need to use a design approach that will result in successful, cost-effective systems. The intent of this book is to provide the student with a basic understanding of computer systems and a design methodology.

Chapter 1 is a brief introduction that defines a few terms relative to small computers and describes some common uses of small computers.

Chapter 2 discusses both computer architecture and operation. Architecture refers to the basic hardware components and how they are organized. Operation has to do with the way the hardware is used to perform useful work. Designers must understand both the architecture and operation of computers.

Chapter 3 describes peripheral devices commonly used in computer systems. Peripheral devices perform two major functions in a computer system: they provide permanent storage of large quantities of data, and they link the computer to the outside world. There is a wide variety of peripheral devices available for small computer systems, and designers must know what is available and how to use it.

Chapter 4 deals with software. Software controls the operation of the hardware (system software) and performs the functions required by the application (applications software). Designers must know what software is available, understand how to use it, and know how to develop software.

Many small computers are used in networks. Chapter 5 briefly describes networks and the use of small computers in networks.

Chapter 6 describes a procedure for designing and selecting small computer systems. This is a general design discipline that has been tailored to the design of small computer systems.

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1 introduction

history

Electronic elements

Since the first electronic computer was developed in the mid-forties, rapid technological developments in electronics have had great impact on computers. Early (first-generation) computers used large, power-consuming vacuum tubes for the processor. Development of the transistor in the fifties resulted in the second-generation computers, which used small, low-power transistors in place of vacuum tubes. Continued developments in semiconductor or solid-state technology produced the integrated circuit (IC) in the early sixties. An integrated circuit can contain thousands of electronic elements (transistors, diodes, resistors, capacitors, etc.) on a rectangular chip a few millimeters on a side. Third-generation computers use integrated circuits in place of discrete components; in fact, the entire processor may be one integrated circuit.

Integrated circuits made the small computer possible. The complexity, and thus capacity, of integrated circuits has almost doubled each year since they became available. Early integrated circuits contained only a few electronic elements and are referred to as small-scale integration (SSI). Continued development first produced medium-scale integration (MSI), with up to 100 elements, and then large-scale integration (LSI), with over 100 elements. By 1978, some integrated circuits contained more than 250,000 elements, and this rate of development is expected to continue for some time.

Costs and performance

Integrated circuits

Although integrated circuits have become more complex, their cost has decreased. For each doubling of complexity, costs have declined by more than 25 percent. The cost of a given function has declined even faster than the cost of integrated circuits because of the simultaneous increase in capacity. For example, semiconductor memory has declined in cost per unit of storage by an average of 35 percent per year since it became operational in 1970. These cost declines were achieved by experience, as well as by increasing the storage density per integrated circuit from 256 bits (binary digits) in 1970 to 16,384 in 1977.

Computer hardware

Integrated circuits have greatly reduced the cost of computer hardware in several ways. First, the cost of a computer made from integrated circuits will be less than one percent of the cost of the same computer made from discrete components. Second, the smaller size of the computer requires less floor space and support structures, such as cabinets, further reducing costs. A third factor is lower power consumption, and proportionately less heat dissipation. With heat dissipation reduced, there is less need for cooling fans and air conditioning, decreasing not only the cost of this equipment but also the power required to run it.

Finally, the very complexity of integrated circuits leads to additional savings. Connections within an integrated circuit are more reliable than solder joints or connectors, increasing reliability and lessening costs associated with maintenance and computer failures. And as integrated circuits grow more complex, less material and labor are needed to build a computer, and computer hardware costs decline.

The declining cost of computing produced by technological developments in electronics has led to such widespread use of computers that they now affect almost everyone's life. A comparison of the first electronic computer, the ENIAC, with a microcomputer of 1978 points up the effects of these developments in Table 1–1.

Other computing system components

The price/performance ratio for computer hardware has improved, based on direct cost, by a factor of about 200,000. If costs for space and power were included, this factor would be even larger. This price/performance ratio does not include peripheral devices or software. Peripheral devices are generally electromechanical and have not enjoyed the tremendous cost reduction

Table 1–1
Comparison of ENIAC and microcomputer

Factor	*ENIAC (1948)*	*Microcomputer (1978)*
Physical size		
Weight (pounds)	60,000	10
Volume (cubic feet)	15,000	1
Power required (watts)	150,000,000	500
Speed (additions per second)	5,000	500,000
Cost	$400,000	$400

of electronic devices, although their price has declined somewhat. Increased performance and reliability of most peripheral devices have significantly improved their price/performance ratio. The cost of software, however, has increased relative to hardware costs and is the major cost in computing at this time. This is especially true with large, complex software systems. Computer networks and distributed processing also include the cost of data communication, which is relatively expensive and may account for as much as half the total system cost.

Advances in integrated circuit technology are reducing the cost of data communication, but at a much lower rate than computer hardware costs. Because peripherals, software, and data communications remain expensive, the total cost of computing has not declined as much as have its hardware costs, but it has declined substantially.

small computer terminology

The lower cost of computing has greatly expanded the market for all computers, but especially for small computers, making it economically feasible for smaller businesses to automate and permitting new applications. Rapid expansion of the market has caused small computer suppliers to proliferate. In 1978 there were more than 100 companies marketing several hundred models of small computers in a wide range of capabilities, sizes, and prices. Such computers are given various ill-defined names. The term "small computer" is itself ambiguous—when does a computer cease being small, and is it small in size, price, or performance? Other terms in general use, but equally ambiguous, include "minicomputer," "microcomputer," "calculator," "small business computer," and "programmable controller." These will be defined here in order to clarify the terminology used in the rest of the book. The definitions, though somewhat arbitrary, are also used to categorize small computers.

A *small computer* is a computer costing less than $100,000 for a minimal system that can perform useful work. Small computers include both general- and special-purpose computers and can be used for all kinds of applications. This category includes all the others.

The term *minicomputer* was coined in 1969 to refer to small, general-purpose computers used in scientific, control, and data communications applications. Since then, almost all small computers have been called minicomputers by someone. Within this text, a minicomputer is defined as a small computer with the following characteristics:

1. It costs less than $25,000 for a minimum configuration that includes at least 4,096 words of memory and some type of input/output device.
2. It is programmable in assembly or a high-level language and operates under stored program control.
3. It is general-purpose.

By the early seventies, integrated circuit technology had progressed to the extent that the entire central processing unit (CPU) of a computer could be contained on a single chip. These CPU chips are referred to as *microprocessors*. The first microprocessors were quite limited, but as LSI technology continued to advance they became more sophisticated. A *microcomputer* is a microprocessor with additional integrated circuits to provide memory and the capability of the CPU to communicate with other devices. Some current microprocessors include the memory and logic to allow communication on the same chip. These chips are also referred to as microcomputers. Microcomputers can be purchased as a computer on a chip, a computer on a printed circuit board, or a complete computer system. Most microcomputers are built into products such as test instruments, TV games, terminals, and appliances to replace hardwired logic. They are also widely used as low-cost, low-performance computer systems.

There are several categories of calculators, including hand-held calculators, printing calculators, and desk-top programmable calculators. *Hand-held calculators* typically provide key-activated arithmetic functions and have very limited input/output capabilities. Many hand-held calculators are more sophisticated and provide complex mathematical functions for specific applications (e.g., electronic slide rule, accounting, and statistics). Some of them can be programmed by using the keys to "write" the program into memory within the calculator, or in some cases onto a magnetic strip or card. A few of the most sophisticated hand-held calculators can be connected to a printer or other external devices.

Printing calculators are essentially hand-held calculators with a printer replacing the output display. This produces a physically larger calculator that is generally not battery-powered because of the increased power requirement of the printer.

Most *desk-top programmable calculators* are actually microcomputer systems called calculators for marketing purposes. They differ from the other categories of calculators in that they are programmed using a programming language rather than keystrokes.

A *small business computer* is a minicomputer, microcomputer, or calculator that has been configured and programmed for business applications. Similarly, a *programmable controller* is a microcomputer, minicomputer, or calculator configured and programmed to perform control functions, such as elevator controllers or machine tool controllers.

uses of small computers

In the sixties, small computers were primarily used for industrial control and scientific problem solving. Early users were an expert group that could configure and implement small computer systems with little help from vendors. User expertise was generally necessary in these early years, since most vendors offered few peripheral devices, minimal systems software, and very little applications software. As might be expected, this limited the expansion of small computers into new markets, especially into business applications.

Virtually all small computers prior to 1970 were minicomputers. Minicomputer manufacturers included Digital Equipment Corporation (DEC), Hewlett-Packard, Varian Data Machines, Honeywell, Interdata, and many others. These companies primarily catered to sophisticated users and left the business market open to others. These "others," among them IBM, Burroughs, and National Cash Register (NCR), introduced small computers developed specifically for business applications. Burroughs introduced its L Series of small, low-cost business computers in 1968. IBM entered the market in 1969 at the upper end of the small business computer market with its System 3. NCR followed with its NCR 299 electronic accounting system and Century 100 and 50 small business computers. Since 1970, many of the minicomputer manufacturers have recognized the great potential of small business computers and have offered systems configured for business. By the end of 1977, there were approximately 70 vendors marketing over 150 models of small business computers.

Small computers now operate throughout business and industry. A few common applications will be briefly described to illustrate the versatility of small computers.

Industrial and process control

This applications area uses small computer systems to monitor and control industrial processing and manufacturing operations. Industrial control application varies from such simple systems as monitoring a single test stand, to complex systems that monitor and control many processes simultaneously. The control function itself varies from messages and alarms output to operators who initiate control action (no automatic control), to complex feedback and adaptive control systems. The process under control may be either continuous or discrete. The manufacture of glass, paper, cement, and plastic, and the operation of an oil refinery, are examples of continuous processes. Parts manufacturing is the most common discrete process using computer control.

Benefits of industrial and process control include lower production costs, shorter production times, better and more consistent product quality, reduced power consumption, and less waste of raw materials. Computer-aided manufacturing (CAM) can improve parts quality and consistency and can increase the flexibility of the manufacturing operation. A few examples of computer-aided manufacturing will illustrate the benefits of this kind of application.

Carburetor testing

Several automotive components are automatically tested, but one of the most successful and well known processes is carburetor testing. Government regulations concerning exhaust gas emissions made it necessary to improve carburetor testing methods to meet the requirements. Testing a carburetor essentially means testing its ability to mix air and fuel at desired ratios under the full range of carburetor operation from idle to full throttle. At each condition, the computer compares the actual value with the desired value stored in the computer. Depending on the comparison results, the metering screw on the carburetor is turned backward or forward until the test value is within tolerance. A stepping motor controlled by the computer is used to position the metering screw. If the carburetor cannot be adjusted to meet the specifications, it is automatically rejected.

The Rochester Products Division (RPD) of General Motors pioneered computer-automated carburetor testing in the late sixties. Their original system included 104 test stands capable of testing and adjusting 20,000 carburetors per day. About 102 different carburetor models could be tested. The operator would load a carburetor, input the model number, and initiate the test. If a carburetor failed the tests, the computer would notify the operator, who attached a reject tag to the carburetor.

All of the test stands in this early system were controlled by a single computer, an arrangement in which all test stands were inoperative if the computer failed. RPD later built another carburetor test facility in which each of the test stands included a minicomputer to control carburetor testing and adjustment at the test stand. This approach enhanced reliability, since a computer failure took down only its associated test stand rather than affecting all stands. Benefits derived from computer-controlled carburetor testing include faster and more accurate testing and adjustments, reports on accept/reject status, reduced labor costs, and consistent testing of all carburetors.

Energy consumption control

Electrical power and gas utility companies usually establish rates based on a total energy consumption charge and a peak demand charge. Peak power demand is determined by measuring cumulative energy consumption over a demand interval of time. If a fixed limit is exceeded in any demand interval, the customer will pay a higher rate over an extended period of time. Demand intervals and rate structures vary among utilities, but in most cases there is a penalty for exceeding the peak limit for a demand interval.

A typical industrial user of gas or electricity can avoid exceeding the peak limit by using a small computer system to control energy use. Such a computerized system monitors energy consumption, projects demand period totals, and shuts down noncritical equipment if a demand violation is predicted. Though its primary purpose is to save money, rather than to conserve energy, such an energy management system does result in real energy conservation as well as cost reductions.

Computerized systems have been developed primarily to save energy. These systems may optimize a manufacturing operation by prescheduling start/stop control of equipment, and monitoring and controlling processes to minimize energy consumption.

Computer- controlled elevators

Computer-controlled elevators provide a final example of industrial control. Sensors are used to indicate such parameters as the number of passengers in a car and the position of each car. The computer is programmed to use this information, as well as elevator characteristics like car acceleration, maximum allowed weight, door opening and closing times, and travel time between floors to optimize routing of the cars. The computer could also keep activity records of each car to allow adaptive routing, positioning cars where