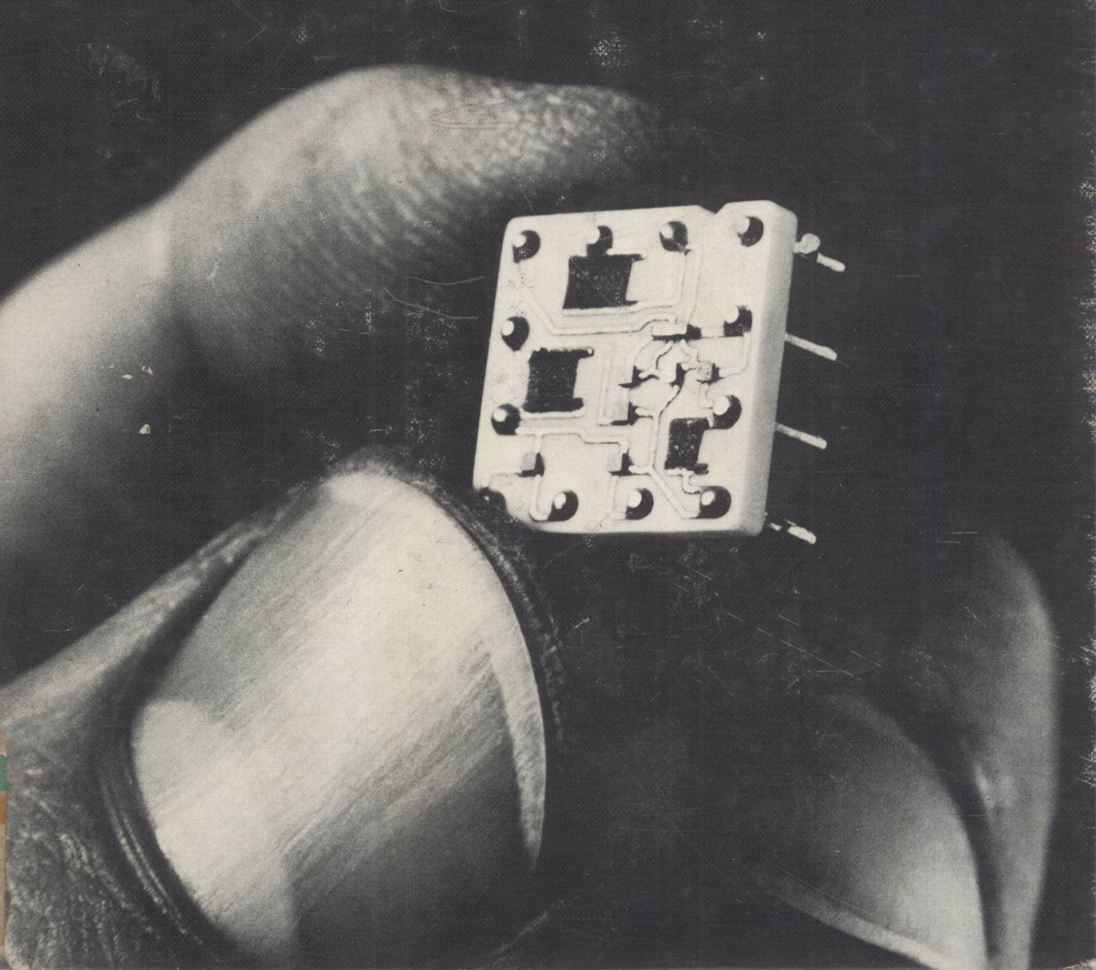
DIGITAL COMPUTER FUNDAMENTALS

JEFFERSON C. BOYCE



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Digital Computer Fundamentals

To my mother,
whose life has been dedicated
to helping others

Preface

Electronic digital computers, the subject of this book, show promise of providing solutions to many of today's problems. Man's muscles were extended by machines as a result of the industrial revolution. Now man's intellect is being extended by computers in an "intellectual" revolution. Computer techniques, for example, provide the mechanism for storage of untold billions of pieces of information. Consider how an attorney might be able to use computer-stored libraries of rulings, laws, regulations, procedures, and the like. The time formerly spent scanning such voluminous data could be more effectively spent in creative thinking, advancing the legal profession. The engineer, whose design activity typically consists of short periods of creative thought followed by long periods of systematic analysis, can relegate the analysis tasks to the computer. Similarly the doctor, airline pilot, teacher, almost anyone, can benefit from a computer's abilities to store large amounts of information and process such information in very short periods of time. All of these possibilities hinge on the electronic digital computer and man's developing capability to use it. The doorway to the future is via the electronic digital computer; this book attempts to open that door for the reader.

Certain deviations from conventional approaches to the digital computer are used in *Digital Computer Fundamentals*. Although Chapter 1 follows common introductory processes to orient the reader toward the world of the digital computer, Chapter 2 deviates from traditional presentation sequences. The author feels that it is highly desirable to establish a "talking knowledge" of digital computers very early in the reader's experience. Therefore Chapter 2 contains considerable detail concerning each conventional functional section of the computer. The reader should not feel overwhelmed at this detail. Consider that it is presented so that information in subsequent chapters can be more adequately assimilated, and so that communication with others interested in digital computers can be established very early.

Chapter 3 develops the basic circuits and shows how to describe them in preparation for detailed discussion of each of the functional units of the computer. The mathematics of the computer—Boolean algebra—is presented in Chapter 5 by use of basic logic circuits and logic simplification (both algebraic and map methods). The basic circuits of Chapter 3 and the Boolean algebra of Chapter 4 are combined in Chapter 5 to explain many complex computer functions such as counting, decoding, multiplexing, etc. and the like. Chapter 6 discusses information coding and how it is applied to the digital computer.

The Control function introduces a detailed coverage of the computer's functional sections in Chapter 7. Basic timing and data flow for the remainder of the computer is also discussed in this chapter. Computer memories constitute the contents of Chapter 8, where the complete range of memory devices from high-speed semiconductor memories to high-volume magnetic tape memories is developed. Chapter 9 presents simple computer arithmetic operations and the logic circuits that are used to implement them. Input functions and devices are the subject of Chapter 10, and Chapter 11 discusses output functions and devices.

In Chapter 12 the very basic fundamentals of computer programming are shown. Machine language, assembly language, high-level language, and operating system terminology are developed, and simple examples are covered. Chapter 13 integrates the operation of the five basic functional units, and explains their applicability to the increasingly-popular bus-organized concepts. Finally, for those readers desiring details concerning the internal operation of logic circuits, Appendix C discusses diodes and transistors, and Appendix D covers implementation of logic functions with various logic families.

As a result of understanding and applying the concepts presented in this book, the reader should be adequately prepared to discuss computer operation at the functional level. He or she should be able to follow the flow of data in digital computers, explain the operation of the five functional sections of the computer, and recognize the requirements for various levels of programming. As computer technology advances, the reader should be adequately prepared to advance with it, and apply related concepts as they appear.

Preparation of this book would have been impossible without the aid of many people. First has been the cooperation of the many manufacturers in the computer and digital fields. Their unselfish sharing of technical information has made possible the inclusion of much of the detailed coverage presented here. Credit lines accompanying illustrations throughout this text identify the manufacturers whose assistance has contributed so much to the

technical detail. Secondly, the experience gained from so many people at Prentice-Hall, Inc. during publication of the predecessor to this book, *Digital Logic and Switching Circuits*, was invaluable. Margaret McAbee, perhaps, was most influential in motivating this author during some rather trying times. Without her encouragement, perhaps this book might have never reached publication. Finally, and not at all last in order of importance, has been the cooperation of my wife and family. Without their unselfish dedication to the details of day-to-day operations of a household, the many thousands of hours required to prepare this book would not have been available.

JEFFERSON C. BOYCE

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1

Introduction to Digital Computers

1–1 INTRODUCTION

What is a Digital Computer?

An answer to the question what is a digital computer is not very difficult if one is willing to accept the broad dictionary type of definition. The class of machines called *computers* are devices that accept information, apply predetermined processes to the information, and supply the results of the processes. When more strictly classified, *digital computers* perform these functions by representing information in a discrete or discontinuous form and operate with symbols expressible as digits in some number system.

Dictionary definitions are complete and accurate but do not really reflect the manner in which different people view digital computers. Today's students often see computers as a tool that can extend their abilities and save large amounts of time when routine tasks must be accomplished. Many have been introduced to computers early in life by using computer-operated learning devices. In school computers prepared report cards, scheduled classes, cut calculating tasks and allowed more time for creative thinking, and even made large libraries of educational materials available at the touch of the "inquiry" button. Colleges and universities are even more progressive in their applications of computers, and most modern college graduates are well versed in computer usage. Today's students, and tomorrow's leaders, are being prepared for the computer-assisted world.

How is the computer regarded by the average citizen? Many different opinions exist, of course, based on individual experience. Consider the factory production line worker's image of the computer. New machines are moved into the factory, and attached to the new machines are electronic devices called computers. The worker sees the new machine performing routine production jobs and is told that the computer is directing the machines. Thus the computer becomes a threat to the factory worker and his job.

The person who has been harassed by an improperly programmed computer billing system obviously has negative opinions and considers the computer as an impersonal, unyielding, "stupid" machine. When that same computer makes and confirms airline and hotel reservations almost instantaneously, the negative opinions are forgotten. Suddenly the computer becomes a warm, obedient, and wise helper. Fortunately the "good" aspects of the computer overshadow the "bad," and the general populace is beginning to become aware of the computer's great positive impact on society.

The true effect of the computer on society is of such great magnitude that it cannot accurately be measured. Past contributions are well documented, and are discussed in this chapter. Present contributions are easily observed all around us. Manned trips to the moon, automatic computer-controlled spaceships to the planets, instantaneous credit-card verification in department stores, roadway traffic signals operating according to computer direction, election results being accurately forecast by computer, and so forth. There should be no doubt that future computer uses will be limited only by the imagination of society.

The communications media are largely responsible for the avid interest of the average citizen in computers. Newspapers, magazines, radio, and television all publicize the computer and its attributes. One can hardly live in today's world without being reminded that computers exist. When a criminal is apprehended, credit is given to the computer-stored information that helped identify and locate the culprit.

Pictures of planets taken by spacecraft yield highly usable photographs by computer techniques. Data gathered from both manned and unmanned spacecraft is stored in computer memories and reduced by computer techniques to provide the scientific community with the latest information. Practically all manned and unmanned space explorations are computer controlled. Human intervention is available as backup and is used only if necessary. It is highly doubtful that the objectives of many of the space exploration activities could be accomplished *without* the computer.

Thus the definition of "digital computers" is both technical and non-technical. For the technical individual, a technical definition is most meaningful, while for the general populus a less stringent definition (one which describes what it does) may be more useful. In this book the technical definition, tempered by the many application definitions, is used to guide the readers' progress from general to specific knowledge about the computer.

What Does the Digital Computer Do?

Implicit in all of the digital computer's applications is the *processing of information*. Whether controlling a space vehicle or verifying a credit card number, the computer is performing some kind of operation on information. It is constantly accepting new information, storing that information, performing mathematical operations determined by the information, routing the information to the required parts of the computer, or making processed information available to the user. Each of these functions is discussed in detail in this and succeeding chapters.

1–2 THE PAST

Pre-1940

One of the earliest devices built to aid man in his intellectual pursuits was the *abacus*. This digital device finds mention in history prior to the birth of Christ. The example of the abacus shown in Figure 1–1 is a modified

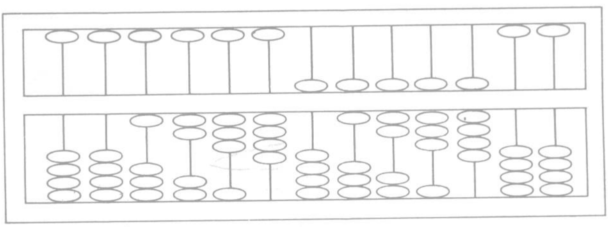

Figure 1–1 Japanese abacus, or soroban

form of the early abacus and was used extensively in the Japanese and Chinese civilizations. A skilled abacus operator can still successfully compete with mechanical desk-top calculators, although the electronic calculator easily outstrips either the abacus or the mechanical calculator. There was very little additional progress in the field of mechanical aids to mathematics until the appearance of Blaise Pascal's desk calculator in 1642. Pascal's device used simple gears to add and subtract. Other mathematicians improved Pascal's early machine by achieving multiplication, but the lack of mechanical precision hampered progress.

The next major milestone associated with the development of digital machines occurred in the early 1800s. Charles Babbage envisioned a mechanical device which incorporated many of the principles of the modern digital computer. His "Difference Engine" was developed to calculate and print mathematical tables. Again, imperfect materials, a shortage of precision tools, withdrawal of government support (after 1843), and a lack of understanding among his associates resulted in abandonment of his project after several incomplete models had been constructed.

Post-1940

As scientists developed techniques for application of electrical and electronic principles to the record storing, account handling, and bookkeeping processes, new and versatile machines appeared. The early 1940s saw the development of an electromechanical computer. Pulse techniques which evolved in connection with World War II radar development were wedded with increased use of applied mathematics. Automation requirements to meet wartime production needs resulted in machines which could perform routine tasks without human intervention. Electronics took over, and soon the production machines were programmed to make decisions concerning quality, quantity, and so forth. The general development of vacuum tube electronic computers in World War II was soon followed by increased activity in design and application of "intelligent machines."

While the application of vacuum tubes resulted in a tremendous increase in computer speed of operation over the electromechanical computer, the instructions to the machine still tended to be stored external to the actual computer and fed in sequentially as needed. In addition, the high electrical power requirements of the vacuum tube computer began to restrict its capability. Two important events occurred in the mid-1940s that were to shape the future of the digital computer. In 1946, Dr. John von Neumann made a now-classic proposal for computer design. He proposed placing the program of instructions for the computer in storage internally with the data being processed. This was to shape the entire future architecture of digital computers. In 1947 the work of Drs. William Shockley, John Bardeen, and Walter H. Brattain culminated in the demonstration of a solid-state amplifying device—the transistor. In a very small fraction of the space and requiring an even smaller fraction of the operating power, the transistor removed the barrier of physical size and power requirements. Soon computers which formerly required *rooms* to house their components shrank to desk size, and computers which were beyond comprehension during vacuum-days began to appear.

Knowledge gained by developing and using the smaller and more powerful computers further expanded the field. Requirements for larger capacity memories soon resulted in improved technology to meet the requirement, and physical size once again shrank. Techniques which were used to develop and manufacture transistors were applied to other solid-state achievements, and multifunction solid-state devices appeared. Soon complex computer functions were built into packages no larger than a common transistor.

Perhaps one of the easiest ways to demonstrate the development of the digital computer is to show examples of the evolution of these powerful machines. Figure 1–2 shows an early electromechanical computer. It had a storage capacity of 132 words, and it took three seconds to add two num-

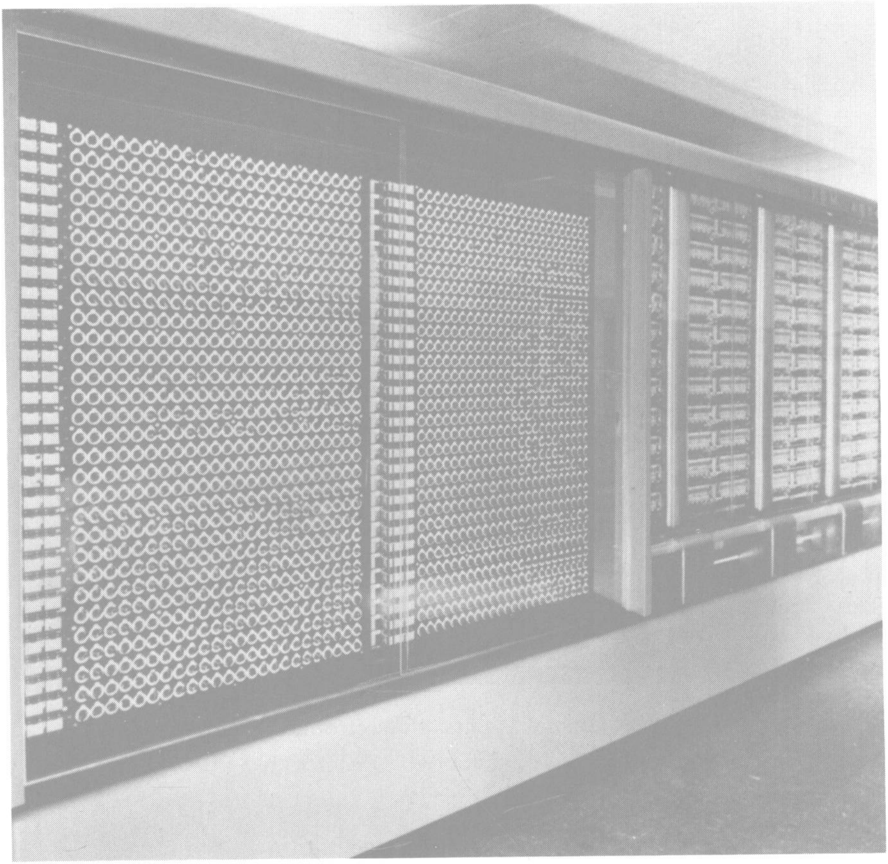

Figure 1–2 Automatic sequence controlled calculator, Mark I, circa 1940s (courtesy of International Business Machines Corporation)

bers. The next generation machines were constructed with vacuum tubes. The example shown in Figure 1–3 could add two 10-digit numbers in 1/5000 of a second, quite a jump from the earlier three-second add time (storage capacity was still limited, however). Occupying 15,000 square feet of floor space, weighing 30 tons, and containing approximately 18,000 vacuum tubes, this behemoth ushered in the era of electronic computers.

Transistor-based digital computers greatly reduced space and power requirements, and the early transistorized computer of Figure 1–4 could easily perform additions in mere microseconds.* Storage capacity was in the general range of 1000 to 4000 words internally. Peripheral (external) storage devices, such as the magnetic tape units shown in Figure 1–4, greatly

*A microsecond is a millionth of a second.

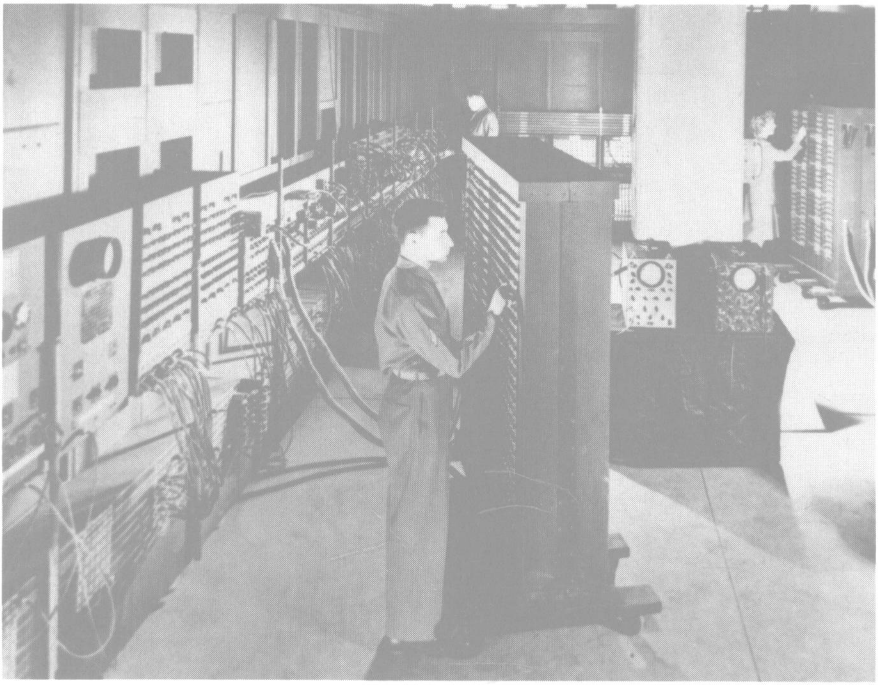

Figure 1–3 ENIAC, one of the first all-electronic computers, circa late 1940s (courtesy UNIVAC Division, Sperry Rand Corporation)

extended the storage capacity of second generation and all later digital computers. The development of integrated circuit techniques again reduced the size and power requirements, and the digital computer in Figure 1–5 is representative of today's so-called minicomputer. Mini describes size only, because this machine possesses the following characteristics: (a) operating times in nanoseconds,* (b) storage capacity up to 31,000 words internally, and (c) a full system weight of only 110 pounds.

Finally, the modern large-scale computer of Figure 1–6, with a capability of nanosecond operating times, a storage capacity limited only by the imagination, and a multi-million dollar price tag, shows the results of less than half a century of technological advances in the digital computer field. As new techniques and devices appear, speed of operation is decreasing, price is decreasing, and storage capacity is increasing. Is it any wonder that even professionals in the field are sometimes awed by such progress?

*A nanosecond is a billionth of a second.