Introduction to COMPUTER CONCEPTS Hardware and Software

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IN MEMORY OF
OUR SON ALAN
1967–1973

The exuberance of this boy has left us with a message, which Rev. Dr. Atkinson has paraphrased, "The life of our years is more precious than the years of our life."

Preface

As a result of teaching computer technology courses for Bell Telephone Laboratories' employees, I became aware that careful consideration is needed in presenting complex information. My pursuance of these aims has led to this introductory textbook, specifically written for community college students studying data processing or technical aspects of computers. The textbook is applicable to a wide range of other courses, including enrichment courses for programmers studying in universities or working in government or industry. My objective is a book that is logically organized and clearly presented for an audience that is believed to be interested in an up-to-date and accurate coverage of this timely subject.

Computers have become part of our lives and we should understand them. They are used to process customer billings, bank records, payrolls, and even college enrollments. We generally appreciate the labor savings offered by computers. We are amazed at their speed and flexibility and want to understand them. To take advantage of the capabilities of computers, we need to understand them.

Computers are based on simple concepts. I have tried to approach them as machines being supplied with electrical pulses in the particular sequence that represents the problem to be solved. The logic circuits in the computer function to produce the solution as another pulse sequence.

The course level does not require prior knowledge of computers, circuits, or mathematics beyond high school algebra. I have tried to keep prerequisites at a minimum and to include all important aspects of an introductory course. In dealing with those topics that are normally complex but important, I use a straightforward approach and rely on logical organization to achieve simplicity. Further, example problems are used to illustrate the simplicity of mathematical manipulations. To avoid confusion in the figures showing circuits, I use the same format in all circuit drawings in hopes that the new item being illustrated will be evident.

To motivate student interest and learning inclination, I have included questions and problems. Computer hardware courses are a natural source for homework. For example, the problems for Chapter 5 on Karnaugh maps are as entertaining as crossword puzzles. Students studying logic design tend to come to class with circuits for timing household appliances, lighting fixtures, etc.

The ten basic chapters are intended to provide an understanding of digital computer designs. In Chapter 10, computer units from the preceding chapters are organized into a control system to execute the programmer's instructions.

In using this book as a data processing text, the instructor may concentrate on the software in Chapters 11 through 17 more than the hardware in Chapters 2 through 10. It is my opinion that most instructors prefer to cover hardware concepts in introducing data processing. Several sections in Chapters 2 through 10 are marked with a star, signifying that the material is of lesser importance to data processing students. These sections are, by no means, beyond the student's grasp; however, they can be skipped without loss of continuity.

The textbook is organized to provide flexibility to the data processing instructor. The old argument persists of whether the chicken or the egg came first. Another argument, almost as unresolvable, is whether the student's first exposure should be to computer hardware or software. Instructors can be their own judge in this matter because the material is purposefully written to accommodate either option. After covering Chapter 1 (and perhaps Chapter 2), the class may proceed with programimng in Chapters 11 through 17 and then return to hardware in Chapters 2 (or 3) through 10.

In introductory computer science courses, the instructor will probably follow an outline quite close to the order of presentation in the text. The starred sections should be of interest to the student; however, Chapters 13 and 14 may be skipped.

I want to express my appreciation to three people who helped prepare this book. Nancy, my wife, typed the manuscript; John J. Duerr prepared the illustrations; and Maureen Wilson of Prentice-Hall did a superb job of production editing. My contribution was a stack of papers with handwritten scribble and messy sketches, which these talented people composed into a textbook for your enjoyment.

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1 Introduction

1.1 HISTORICAL DEVELOPMENTS

The electronic digital computer first appeared on the scene in 1946. Then it was a specialized tool of scientists. Today, they are used for many things by many people. As a result, the term "computer" is a word that is familiar to almost everyone. Computers are used by institutions and businesses for a variety of purposes, including accounting, inventory records, and payroll processing. They also perform calculations in finding solutions to complex scientific problems. The first electronic computer was specially built to calculate the trajectory of rounds fired from artillery weapons. The trajectory could be expected to be shortened or shifted by unfavorable winds. The scientists computed data for trajectory charts by calculating the effects of wind velocity. These charts were used by the artillery men to correct their aim and improve the weapon's effectiveness.

Computers are electronic devices that are capable of manipulating pulses that represent digits of numbers. The history of computers is normally approached by discussing *earlier machines* for performing numerical calculations. We will also pursue this approach; however, it is also important that we discuss *earlier electronic devices,* mainly the radio. *Vacuum tubes* were used in the amplifier circuits of radios in the 1946 period when the first electronic computer called the ENIAC (Electronic Numerical Integrator and Calculator) was built for the U.S. Army. This machine, developed at the Moore School of Electrical Engineering, University of Pennsylvania, contained 18,000 vacuum tubes. As time progressed, *transistors* were used in radios and then later in computers. Thus, the early computers were built of existing devices from radio circuits; however, the present immense size of the computer market is certainly sufficient to warrant special devices. Efforts to develop smaller, faster, and less expensive devices for making computer circuits may lead to a vestpocket-sized computer with capabilities equal to the 25-ton ENIAC.

By the term "digital computer" we imply the use of digits or numbers. It is usually assumed that man developed the concept of numbers and counting before he developed an effective written language. His first countings were with sticks, pebbles, or whatever.

The Abacus—500 B.C.

The abacus was the first counting tool. It has been used for the last 2000 years and is still used in parts of Asia.

Ex. 1–1

How is the number 827 represented on an abacus?

The abacus is a rectangular frame with several parallel wires. Each wire is threaded with seven beads, two above the horizontal bar and five below. Numbers are represented by pushing the free-sliding beads against the bar. Each bead above the bar is worth 5 and the beads below are 1; *thus, 827 is represented* as shown in Fig. 1–1. The existing tally in Fig.

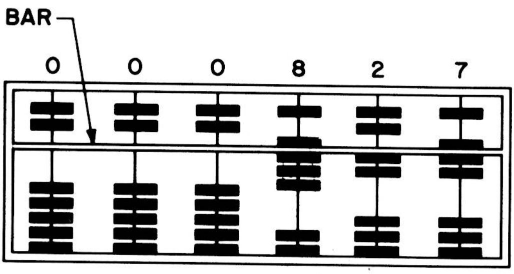

FIG. 1–1 Abacus Registering 827.

1–1 can be increased. For example, to add *521,* we start with the right group of beads and push *one* more unit's bead toward the bar. We push *two* beads in the next column. In the third column we want to add *five* to the existing 8, which means a carry to the next column.

$$\begin{array}{r} 827 \\ +521 \\ \hline 1348 \end{array}$$

The final answer is illustrated in Fig. 1-2.

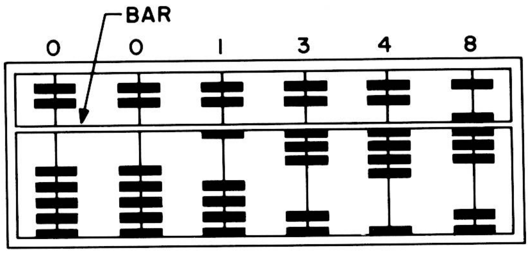

FIG. 1–2 Abacus Registering 1348, the Sum of 827 and 521.

A skillful abacus operator can add, subtract, multiply, and divide with amazing speed. In contests the *abacus has been shown to be faster* than modern calculating machines.

Figures 1–1 and 1–2 represent the Chinese abacus. The Japanese abacus has one bead above the bar and four below.

Pascal Arithmetic Machine—1643

Pascal at the age of 19 devised the *first mechanism for calculations.* The principles of this machine are still used today in automobile odometers and pocket-sized calculators. It was operated by dialing a series of wheels bearing the numbers 0 to 9 around their circumference. Figure 1–3 shows

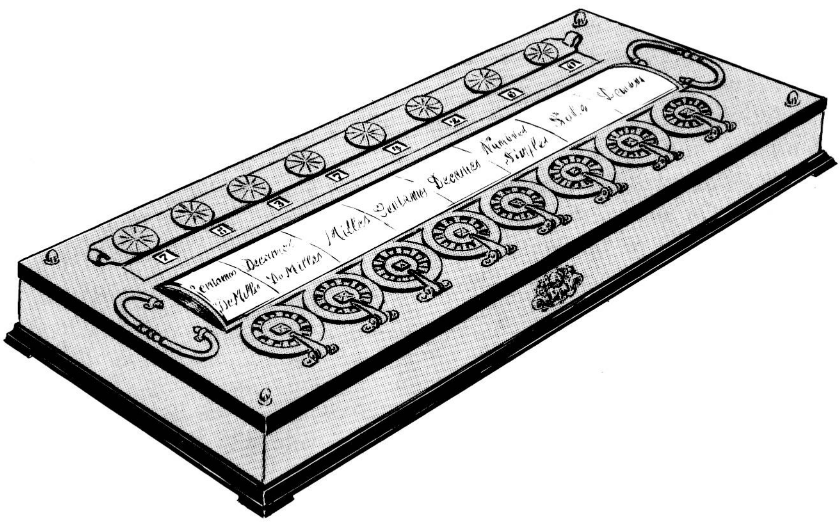

FIG. 1–3 French Mathematician Blaise Pascal's Arithmetic Machine. (Courtesy of Elias M. Awad, *Automatic Data Processing: Principles and Procedures,* 2nd Ed., © 1970, Prentice-Hall, Inc.)

the top face. The wheel on the right represents the value of the least significant digit, which would be units place for whole numbers. To "carry" a number to the next column after 9 was reached, the next wheel was geared to advance one digit when the wheel to the right made a complete revolution. Answers appeared on the face above the dials.

Leibniz Calculating Machine—1694

The principles of Pascal's machine were used by Leibniz, who developed the first machine to multiply and divide directly. Addition and substraction were accomplished exactly as in Pascal's machine. Gears were added to enable multiplication and division. Leibniz believed that scientists should be free from laboring with manual calculations and hoped that his machine would help in this respect. Throughout the years, mechanical calculator designs continued to exhibit most of the principles of the original Leibniz calculator.

Babbage Analytic Engine—1834

Leibniz's design is still used after nearly 300 years, but Charles Babbage's contribution to the computer is even more remarkable. Babbage was 100 years ahead of his time with his ideas for a really powerful tool to handle any sort of mathematical computation automatically. He planned an *analytic engine* that had all the major features of a modern computer. It would process instructions from a program on punched cards. It would include a memory and output devices for printing results. However, the components just weren't available to build the analytic engine. The inventor was determined to see his design work, and petitioned officials in his native England for funds to build the machine using steam power and all mechanical parts. His plan became known as Babbage's Folly and was never completed. There was no technological base for his ideas. In fact, Babbage's forerunner to the computer was forgotten until Howard Aiken of Harvard University rediscovered his writings in 1937.

Hollerith Punched Cards—1890

Although Babbage had already conceived of punched cards, Herman Hollerith used electromechanical devices developed after Babbage to assemble a practical punched-card reader. Holes in the cards represented numbers and letters of the alphabet. Figure 1–4 shows the code used for the *80-column Hollerith card*—the universal standard of today. The card reader consisted of a series of metal pins with a wire attached to one end. The pin could descend and touch mercury in a pan below if there happened

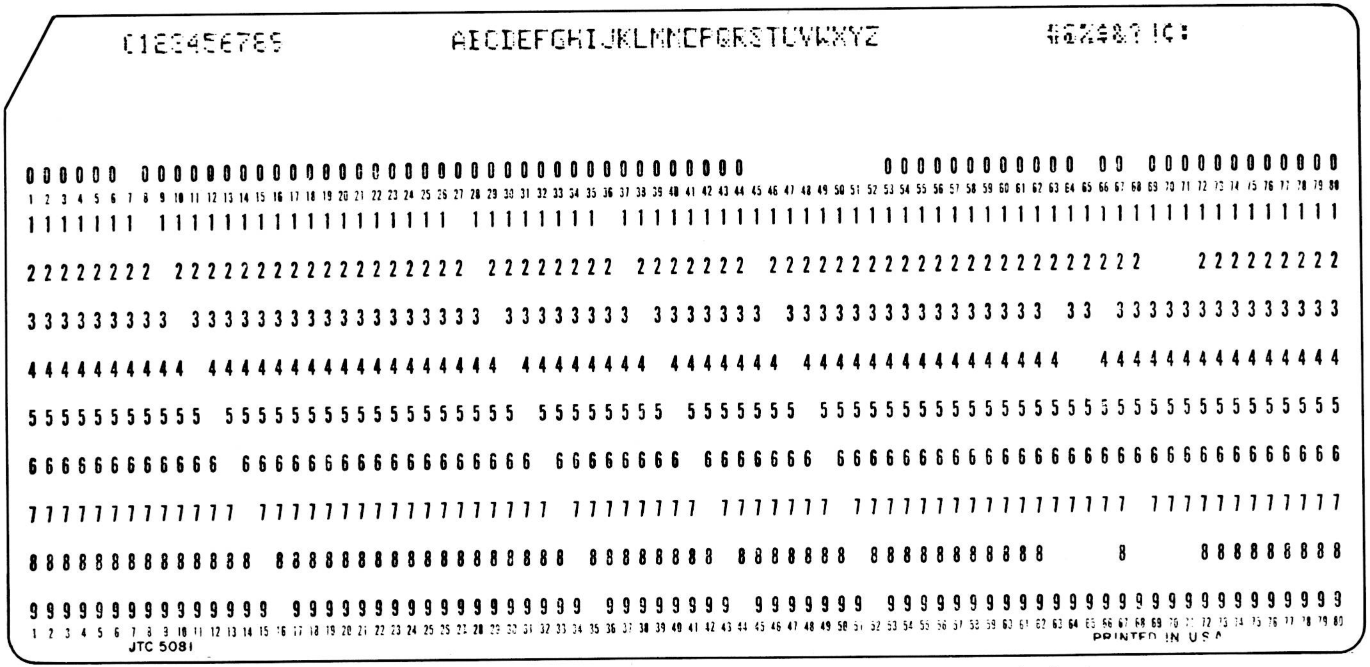

FIG. 1–4 Hollerith Code of Punches for Numerals and Alphabetic Characters (3¼ by 7¾ inches).

to be a hole under the pin. Contact with the mercury (a liquid, but an excellent electrical conductor) completed the electrical circuit to that pin. This record of the absence or presence of holes was the electromechanical process of reading the punched cards.

Using punched cards in this manner, Hollerith devised a way to speed the classification and counting of data from the U.S. Census of 1890. The data included the person's name, age, sex, address, and other statistics. With census data entered on machine-readable cards, it was possible to process the 1890 census data in one third the time it had taken for the manual procedure in 1880. This is only an indication of the time savings available in the computer field. Computers can perform lengthy calculations that would require years by hand. The company organized by Hollerith merged in 1911 with the company that was eventually to become International Business Machines (IBM).

Ex. 1–2

What salary would you ask if you were to substitute yourself for a modern computer doing mathematical calculations?

Large-scale computers are normally rented at a typical monthly rental of $200,000. They can perform 1 million simple additions while an average man is doing one. Thus, to be economically competitive, a man must be willing to work for $200,000 ÷ 1 million = $0.20 per month or $2.40 per year. Time must be allowed for eating and sleeping, which would *bring down the salary to less than $2 per year.*

Despite its great speed and electronic sophistication, the computer is unable to think for itself, which people do with ease. We want to remember throughout our discussion that *computers can't think any more than radios can sing.* Our definition of thinking implies the entrance of an idea into one's mind with or without deliberate consideration or reflection. Both thinking and singing are human functions.

Aiken and Stibitz Electromechanical Calculator—1944

A host of mechanical calculators made their appearance near the turn of the century. The *Burrough's adding machine* appeared in 1885. The acceptance of this machine was widespread and was followed in 1917 by the *desk calculator* which did multiplication and division as well as addition and subtraction. The calculators became electromechanical in 1944 when Howard Aiken of Harvard University developed the *MARK I,* the first large-scale digital calculator. Once the steps in a solution were programmed by code on paper tape, the device would sequence through the calculations without human intervention. It weighed 5 tons and contained

3304 electromechanical relays. Consequently, it was faster than previous calculators. *Relays* are switches that can be opened or closed by an electrical current passing through a magnetic coil. Figure 1–5 is a sketch of a

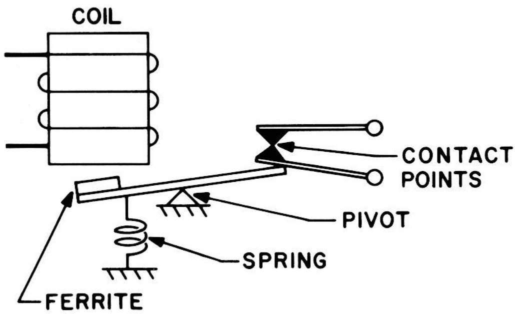

FIG. 1–5 Arrangement of Components in a Normally Closed Relay.

relay that is normally closed, but is switched open by the coil current. The magnetism induced in the armature of the coil attracts a ferrite piece on the end of the relay spring and causes the mechanical opening or closing of the switch contact points. The spring returns the switch to its original state when the signal is absent. Thus, the absence or presence of a signal to an array of relays coils can influence the current paths through the array of associated switches. We will see in Chapter 3 that the characteristics of switching networks are useful for designing computers. The MARK I remained in use for over 15 years before being retired in 1959. Parts of the original machine are on display at the Smithsonian Institution and at Harvard University.

Another man working independently of Aiken envisioned such a calculator at about the same time. He was George R. Stibitz, a research mathematician at Bell Telephone Laboratories. The Stibitz machine, known as the complex number calculator and later as the *Bell Model I,* was placed in formal operation on January 8, 1940. The Bell System could be expected to be in the forefront in developments using relays because a new relay system for switching telephone calls appeared in 1937. Figure 1–6 shows the external resemblance between the Bell Model I and the first crossbar switching system. The Bell computer represented a landmark in reliability in that it could be left running overnight with no one in attendance.

Eckert and Mauchly Electronic Computer—1946

A real breakthrough came in 1946 when *high-speed bistable devices* were used to make the first electronic computer, the ENIAC. We mentioned