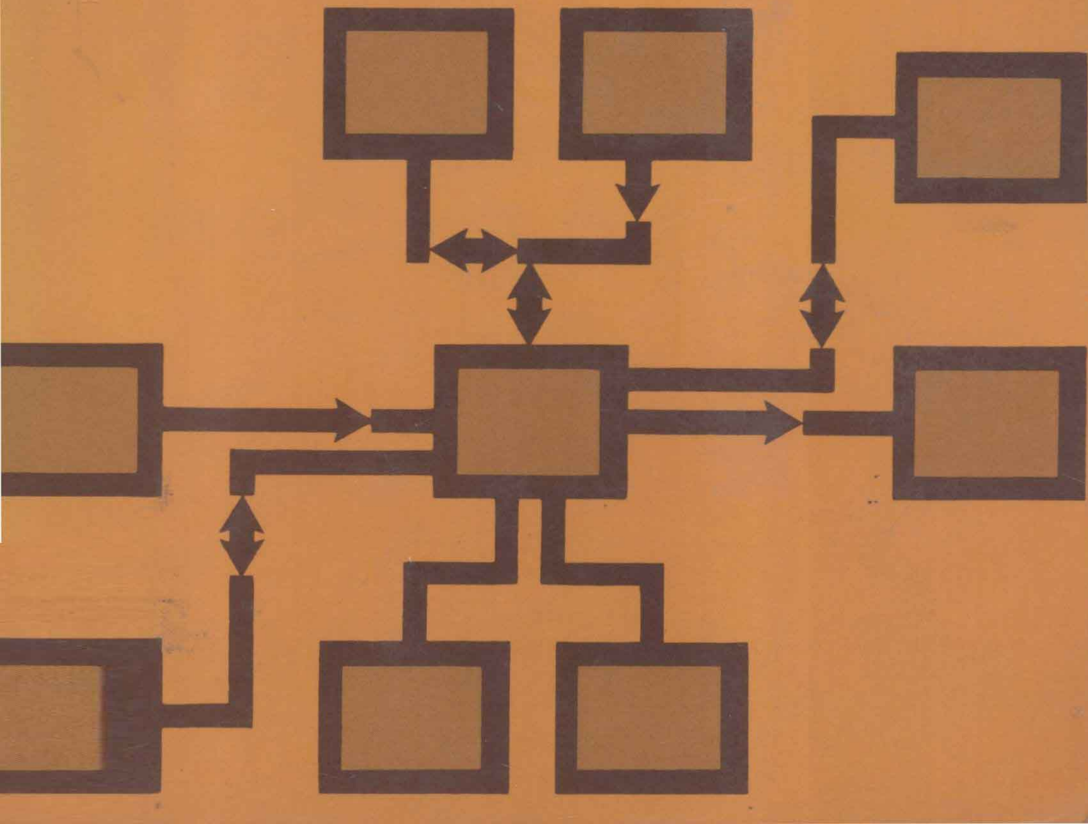
Michael G. Hartley and Martin Healey

A First Course in Computer Technology



A First Course in Computer Technology

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A First Course in Computer Technology

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Richard G. Meadows
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To Mike and Sue and friends in JHB
and
To Janet

PREFACE

This book has been written specifically for students commencing the study of computers and computing. It is an introductory text aimed at providing a broad understanding of how a computer works and is, thus, of importance to disciplines which range from electronic engineering to mathematics. The intention has been to cover the subject broadly rather than in depth; during a student's career each chapter may well be expanded into a full course in its own right. It is the authors' opinion that, in their first exposure to the subject, students should acquire an overall picture of hardware and software so that future detailed studies will have relevance and not appear as unrelated entities. While the book is seen especially as an undergraduate text, it should appeal to a wider readership. On the one hand it should be of interest to many final-year high-school pupils, while on the other hand it will be helpful to students on specialized Masters' degree courses who have not studied the subject at undergraduate level and for whom computer technology will be important.

The authors have lectured in the field of computers and computer systems for a number of years. They have been aware of a continuing lack of a book which bridges the gap between the rather elementary volumes and the professional works. It is anticipated that this book will fulfil the need.

With the increasing use of integrated circuits, coupled with an almost miraculous fall in the price of components, the earlier emphasis on logic design is now no longer so important. This change of emphasis is reflected in the book, which strives to preserve a balance between computer hardware, architecture, and software and, as a result, finds only a limited space for Boolean algebra and logic design. A systematic treatment has been adopted throughout, with an initial statement of the objectives of each chapter, the material relating to the chapter itself, a summary, and, in appropriate cases, references and problems. The references have been kept to reasonable proportions, since it is unrealistic to expect students at undergraduate level to have sufficient time to read a substantial number of books and papers ancillary to the main course material.

The book is divided into nine chapters. Chapter 1 is a reasonably detailed history of computers which, while not essential to an understanding, gives some feel of the exciting field in which we are working. Chapter 2 gives an introduction to the operating principles of a computer and a review of the applications areas. Chapter 3 gives an introduction to the representation of information, both numerical and non-numerical, with particular emphasis on binary techniques. Chapter 4 defines the basic 'building blocks' used in logic systems with a brief review of Boolean algebra. Chapter 5 is devoted to a detailed description of the hardware and machine-level programming of a minimal four-bit computer. While the machine is impractical in terms of computing power, it displays many of the characteristics of a real computer and yet is so simple that the decode logic, etc., can be explained in detail. Having thus established the principle of instruction decoding and execution, more practical machine architectures are explained in Chapter 6. Both a 24-bit machine with a straightforward instruction set and a rather more sophisticated 16-bit machine are discussed. Chapter 7 is devoted to details of memory systems, concentrating on magnetic-core and semiconductor random-access memory, but putting other types of memory into perspective. Chapter 8 contains a review of the elements that go to make up a complete software system. Finally, Chapter 9 covers the basics of pocket calculators and microprocessors.

The authors wish to acknowledge the assistance of a wide variety of people in producing this present volume. A word of thanks is due to the students who have attended their courses over the years. Through interaction with the students, the need for this book has been identified and points which are likely to prove particularly difficult have been highlighted. The authors' immediate colleagues are especially thanked for their discussions and in some cases for help in reading manuscripts with considerable diligence. These include fellow members of our departments at UMIST and University College, Cardiff and also within the University of the Witwatersrand, Johannesburg, where Michael Hartley spent a year as visiting Professor while the book was in preparation. A particular word of thanks is due to Mrs Thomas in Johannesburg and Janet Healey in Cardiff, who assisted with the preparation of the text.

CONTENTS

1

INTRODUCTION

Objectives

This chapter is intended to fulfil a variety of objectives. The first is to serve as a brief historical introduction, stressing the antiquity of aids to calculation and to distinguish between analogue and digital techniques. The work of Charles Babbage, who pioneered digital computers in the early part of the 19th Century, will be contrasted against the analogue approach of Lord Kelvin later in that century. Even at this early stage, computers were developed with commercial, military, and scientific applications in mind.

The chapter continues by contrasting the development of analogue and digital computers in the 1940's and 1950's against the earlier work in the 19th Century. It concludes with a brief mention of the situation in the USA and Britain in the late 1940's and early 1950's; a period when many of the most important features of modern computers were established. This part of the chapter is suitable for re-reading after studying the main body of the text. Such a re-reading will serve to reinforce basic ideas and set them into context.

1.1 INTRODUCTION

In this chapter, the background to computers is discussed. Early aids to computation are considered and, from the examples chosen, the essential differences between analogue and digital equipment emerge. Long before the end of the 19th Century, the two main types of computer had evolved and much of the basic scientific and mathematical groundwork essential to modern computing machines had been discovered.

Before discussing the work of the two 19th Century pioneers of computing, whose activities serve to distinguish between analogue and digital methods, it is instructive to consider, briefly, earlier aids to calculation and notice how, even at that stage, these exhibited either analogue or digital characteristics.

The abacus, or counting frame, is an excellent example of a digital calculating aid. It is first mentioned by Herodotus (*c.* 450 BC) as an aid used in ancient Egypt. Samples used by the Greeks and Romans have been discovered. It was particularly useful to the Romans, since with them there was no emphasis on degree of significance, as indicated by place in alphanumeric representation of quantities; thus, XIII for 13 and XIV for 14, but XIX for 19 and XXI for 21. There was no representation of zero in the Roman number system.

It is said that the abacus was introduced into Europe by Pope Sylvester II about 1000 years ago, although its popularity waned after the introduction in the 12th Century of the Hindu–Arabic number system, incorporating the notion of place to indicate degree of significance and representation of zero, and used to the present day. The abacus is still widely used in the Orient.

One of the authors was able to purchase an abacus at the campus bookshop of a major American university as recently as 1962; the shop had a variety for sale, the simpler ones with ten rods, constraining the beads and permitting calculations up to ten significant decimal digits, while the more expensive ones incorporated up to twenty rods, with a corresponding improvement in precision. The Chinese abacus has five beads on the rod below the bar, each of unit value in the appropriate degree of significance, with two beads, each of value five units, above the bar. The Japanese abacus, illustrated in Fig. 1.1, has four beads below the bar, each of unit value, and a single bead of value five units above the bar. With the abacus it is convenient to adopt the normal convention that the most significant digit column is on the extreme left and the least significant digit column is on the right. The representation of decimal 3.141 592 7, i.e., π to eight significant digits, is shown in Fig. 1.1. It is clear that with a larger abacus greater precision may be achieved. With the abacus, correct answers to the four basic mathematical operations of addition, subtraction, multiplication, and division may be attained, provided that the scale of the problem lies within the number of significant digits available with the machine. Good results may be obtained

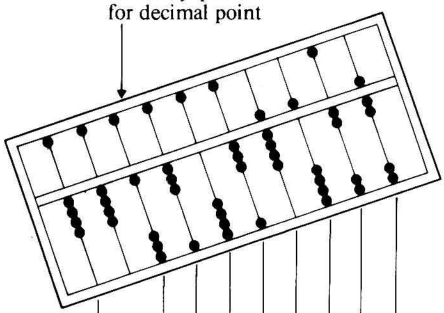

Fig. 1.1 An abacus displaying the value of π to eight significant digits

also when appropriate arithmetic algorithms are used, to determine a square root, for example.

In 1642 came the first simple mechanical calculating machine, invented by Blaise Pascal. The stepped-wheel calculator, invented by Leibnitz, was completed in 1673 and exhibited to the Royal Society in London. Such machines came into their own with the work of the Swedish engineer Odhner, who invented the pin-wheel method of mechanical addition in 1878. From his work stemmed the decimal hand or electric calculating machines so widely used throughout the world until the advent of the electronic pocket calculator rather less than a century later. With the exception of the electronic pocket calculator, the other machines concentrated on the four basic arithmetic operations and, like the earlier abacus, provided precise answers to arithmetic calculations, under the constraint that the numbers involved were within their range.

The above aids operate in arithmetic fashion and, hence, are classed as *digital* devices. Mechanical calculating aids reached their zenith with the work of Charles Babbage (1792–1871), of whom more shortly. With the digital devices came others adopting an alternative approach. Here, machines represented the magnitude of numbers by a set of physical quantities, say lengths or shaft rotation, with respect to a datum position. The slide rule exploiting the properties of logarithms is a good example of this approach. Logarithms were invented by John Napier of Merchiston in Scotland, who wrote a treatise on the subject in 1614. In 1632, William Oughtred, an English clergyman, arranged two log scales, which had been invented about 12 years earlier by Edmund Gunter, side by side to form the first slide rule. As a result, multiplication of two quantities was possible by adding the lengths on the log scales, and division occurred on subtraction. The fixed-stock slide rule was invented by Robert Bissaker in 1654, while the modern form was developed by a French artillery officer, Amédée Mannheim, in 1850. This slide rule incorporated ABCD scales and a cursor, and is similar to the version shown in Fig. 1.2, as used today.

Clearly, precision of result is a function of a number of variables. The accuracy with which the scales are engraved, the fit of the moving scale in the fixed stock, the quality of the cursor used to assist in reading the scales all play a part in the precision of the final result. Good eyesight and minimization of parallax error are also important. An increase in the total length of the slide rule, an improvement in the engraving of the scales, the use of a cursor incorporating a magnifying glass, all play their part in improving accuracy, but precise results must not be expected.

With calculating devices such as the slide rule, one set of physical variables represent another. Hence, such devices are categorized as *analog* (analogue) calculating aids and later as *analogue computers.* Other examples include the planimeter, used to estimate areas. The highlight of the early mechanical analogue machines was reached with the work of Lord Kelvin (W. Thomson) when, together with his brother James Thomson, he invented the first differential analyser in 1876.[1,2,3] Here, mechanical adders and integrators were connected together in closed-loop fashion, so as to solve continuously second-order differential equations. For such a machine, the independent variable was shaft rotation. No further machines embodying the principles of Lord Kelvin were made until the first of a class of much more ambitious mechanical differential analysers was constructed by Bush at MIT in 1931.[4] Such machines became popular in the later 1930's and especially in the early 1940's, when they were used for a variety of military applications in World War II.

Up to this time, the analogue quantity remained shaft rotation, but, with the advent of more reliable electronic valves (vacuum tubes) and the invention of the electronic integrator and adder, voltage was used as the

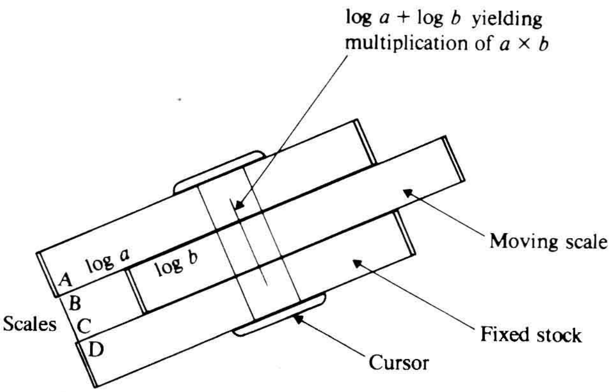

Fig. 1.2 A simple slide-rule illustrating multiplication

analogue quantity. Integration was with respect to time and, as a result, computations were related to time. In some cases there was a 1:1 time correspondence between the computation and the actual events, permitting *real-time* working. On occasions, the rates differed, permitting working faster or slower than real-time. The relation to real-time has proved very advantageous in many cases, permitting an enhanced 'feel' to the solution of problems.[5] Such an approach has continued to the present day, when general purpose analogue computers based on high-performance transistor *operational amplifiers* solve continuously sets of simultaneous differential equations which represent the behaviour of physical systems large or small.[6] The differential equations act as a link between the real system and the model, as shown in Fig. 1.3. Naturally, the differential equations, frequently linear equations, may not represent performance completely.

Accordingly, in these cases, the solution is not precise. Nevertheless, with care, results achieved with such analogue computers can be both accurate and extremely useful. It is true, however, that analogue computers have been eclipsed in recent years by digital machines. As a result, it is appropriate at this point to return to the field of digital machines for a brief consideration of the work of Charles Babbage, the 'father of digital computers'.

1.2 CHARLES BABBAGE – THE FATHER OF DIGITAL COMPUTERS

Charles Babbage[7,8] was one of the most remarkable figures to have emerged during the Victorian age; an age which was so prolific in men and women of tremendous imagination and invention. Born in Devonshire in 1792 he went as a young man to Cambridge, only to discover that he knew more algebra

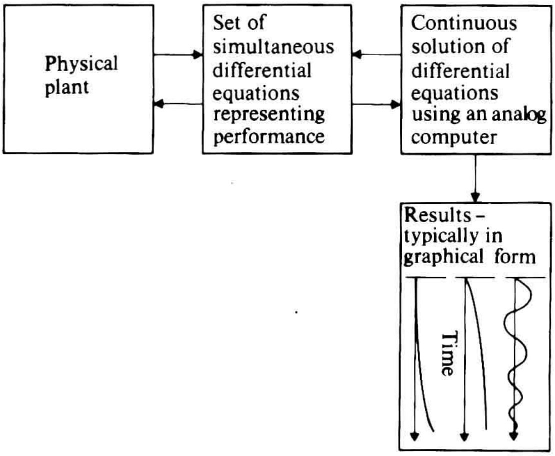

Fig. 1.3 Schematic diagram illustrating operation of an analogue computer