An Introduction to

Computer Applications in Medicine

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Edward Arnold

First published 1982
by Edward Arnold (Publishers) Ltd
41 Bedford Square, London WC1B 3DQ

British Library Cataloguing in Publication Data

Kember, N. F.
An introduction to computer applications in medicine.
1. Medicine—Data processing
I. Title
510'.28'54 R858

ISBN 0-7131-4144-9

Filmset in 10/11pt Compugraphic Plantin by
Reproduction Drawings Ltd., Sutton, Surrey.
Printed in Great Britain by
Spottiswoode Ballantyne Ltd,
Colchester and London.

Preface

For a number of years, as part of a statistics course, I have lectured briefly to medical students on applications of computers in medicine. As increasing numbers of students come up to medical college with some computing experience, it would be useful to point them to a background book which would stimulate their interest to read further. Being aware of no recent text I therefore decided to embark on my own. It soon became obvious why others with greater knowledge and more practical experience had not ventured on this path. The field is advancing so rapidly that no book can be up to date while no one person is able to keep abreast of developments in all the different aspects of computer applications in medicine. However, once begun, the task was considered worthy of the attempt and this book is offered as a personal survey of the medical computing scene. It has all the faults of a single-author text on a subject which calls for a multi-author encyclopaedia but the level is set at 'introductory'.

Many people deserve credit for the better parts of the book. I am grateful to Dr David Ingram who kindly agreed to read the penultimate draft. He pointed out the mistakes in that draft and tried to dissuade me from some of my idiosyncratic methods of writing about computers. In some instances he was successful. I also thank Messrs Ewart Shaw, Peter Browne and Gary Inglis of the Charterhouse Square computer unit of St Bartholomew's Hospital Medical College for answering so many of my naive questions. I am also aware that a number of other computer experts in the London area—for example, the staff of the BUPA Medical Centre and at Northwick Park Hospital (Middlesex)—were unwitting contributors to this volume as they kindly spared the time to show me their systems.

My thanks also go to Miss Marguerite Snell who patiently typed the final draft. I am grateful to my wife for her encouragement and hope that the returns on the book will pay for a little of the home repairs and decorating neglected in 1980.

London 1981 N.F.K.

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Introduction

At the time of writing it is evident that we are in a transitional phase in the application of computers to medicine. For the past 20 years their use has been largely confined to specialized units manned by enthusiasts who have advanced the application of computers in their own field of practice. Now that prices have come down, computers will become commonplace—they are already built into many laboratory instruments and imaging devices (e.g. the computerized tomograph or CT scanner). There will be an increasing utilization of computers for processing and analysing physiological signals such as the electrocardiogram but the main expansion is likely to be in medical record keeping and secretarial work both in the hospital and in the GP surgery. We have the technology. There are, however, some fields where computer techniques have proved unfruitful. For example, in spite of all the effort which has been devoted to automated recognition of chromosomes there is little return in the form of reliable routine systems. It is also probable that computer-assisted interviews and diagnosis will remain controversial and the endeavours of their proponents will not be accepted generally for a decade or more.

In the light of possible changes in medical practice it is important that the present generation of medical students be introduced to these mysteries—their elders often show a reluctance to learn but an eagerness to quote anecdotes of computer shortcomings. It is certain that the next generation of students that has become familiar with computers at school will wonder why more extensive use of the power of the silicon chip is not made in medical practice and research.

Guide to reading the book

The text has been written in the anticipation that the average reader will not read through from cover to cover but will dip into it according to interest. The aim has been to give some cover to all aspects of computer usage in medicine—clinical, research, administrative with the important exception of finance and salaries. The material in each chapter should stand independently although readers without background knowledge of computing may have to refer occasionally to the glossary since it is unreasonable to explain the specialist terms each time they arise.

The opening two chapters introduce computer technology: in the chapter on computing apparatus (hardware), the emphasis is on what it does rather than how it does it—there is no need (fortunately) to understand how computers work in order to use them successfully. The next chapter is an introduction to software (the commands which control the computer). The concepts behind computer programming will be discussed to give some insight into the instructions which the computer obeys to tackle the work you have planned for it. Again, provided that you have confidence in the programmer there is no need to understand the languages in which the programs are written. This book does not attempt to teach computer programming but to discuss the range of programs available. The best way to learn how to program is to attend a short intensive course or simply to sit down at an interactive computer terminal with a book such as *Basic BASIC* and to try typing in and running a few of the sample programs. All the discussion in these and other chapters is limited to digital computers because there are few applications of analogue computers in current practice.

The main part of the book contains the medical applications of computers and here I have ordered the material leaving the more controversial topics until the later chapters. While the aim has been to describe the range of computer applications in medicine, the selection of examples for more detailed consideration has followed my own bias. I am aware that when I have chosen to illustrate one particular technique for computation there are generally many other available techniques which computer users more expert than I would consider superior to the method given in the text. But computers are like that—there are many routes to the same end and the protagonists will argue fiercely for their own favourite computer system, or language or algorithm.

I have tried to read widely enough in the many unfamiliar fields to include informed critical views of the various applications of computers. It is not always easy to find criticisms in the literature—most complaints are verbal rather than written.

Further reading

Under 'Further reading' (page 149) a few books and articles are suggested for each topic. In general I found the literature scattered and obscure; that is, many of the specialist journals are taken by few libraries, and when articles were searched out they were often written with too much jargon. Most introductory books to the subject were written 5–10 years ago, and although they give an adequate discussion of general principles the applications are described in terms of the last generation of computers when memory size and hardware costs were often a limiting factor.

There are also many volumes of conference proceedings but the papers in them, like those contained in the specialist journals, are invariably terse and written for fellow experts. Articles prepared for the general medical journals are more readable but they do not encompass the majority of computer applications. The reader must take his chances with the literature.

Future advances in computing

This book makes no attempt to provide an up-to-date account of computer technology. That's impossible. However comprehensive a review of computer hardware might be at the time of writing it would be out of date well before it reached print. The general principles of computer applications, however, do not change so rapidly. It is worth noting that some 'new' techniques are not innovations. The 'Fast Fourier Transform', which is a mathematical method used widely in signal and image processing, was discovered for computing in 1965, but the principle was described in 1903 and then rediscovered in 1937, 1939, 1942, 1958 and 1963!

Some advances in computer applications are heavily dependent on the latest technology but, as systems become progressively smaller and faster with larger storage facilities, the main effects will be the spread of relatively straightforward computer uses. This spread will also be facilitated by the expected improvements in the ways in which computers and humans can talk to each other.

In writing this book I have not taken the view that computers are either the villans or the heroes of the future of medicine but simply that computers are tools which may be used efficiently or badly. Most doctors cannot hope to keep up with every advance in computer technology and they will have to trust the experts for advice. But if disastrous errors are not to be made, the doctor must be able to recognize the limitations of computers and to communicate with programmers and manufacturers. The design of new projects should be based on collaboration between doctors and computer analysts, and one aim of this book is to assist the dialogue between them.

Part 1 An outline of computers

2

Hardware

Introduction

The digital computer has descended from two lines of development. The first line is that of aids to arithmetic—machines which make calculations easier. From this viewpoint we can look on the computer as just one further device in the progression from abacus to slide rule to electromechanical calculator and difference engine—all systems which have been developed in the past to tackle everything from addition to complex numerical integration. The computer is here to make sums easy.

The second line of ancestors is that of data handling devices. Man has been keeping records for a long time, first on mud tablets and tally sticks, then in hand-written accounts. As civilization has advanced so the complexity of record keeping has increased—unnecessarily so some might think. As in the UK, the USA has a regular population census every 10 years. When the results of the 1880 census were still being processed—and not yet finished in 1886—the Records Office realized that a mere increase in the number of clerks would not cope with the flood of data due to arrive in 1890. Hollerith suggested that the data could be coded on punched cards and that the encoded data could then be sorted for analysis by an electromechanical sorter which sensed the positions of the holes. (The idea of holes in cards had been used by Jacquard much earlier in the century to program patterns for weaving machines.) By 1970 the US census contained 2.6×10^{11} bits of information—far too much to be handled by Hollerith systems since it would require something over 100 000 000 punched cards to hold all this information. The computer provides the next step in data handling.

The computer, then, is a device which makes it possible to process vast amounts of data and to perform calculations on the stored data at very high speed—over 1 million multiplications a second in advanced machines.

The basic computer

Most computers include certain basic features and these can be seen in Fig. 2.1.

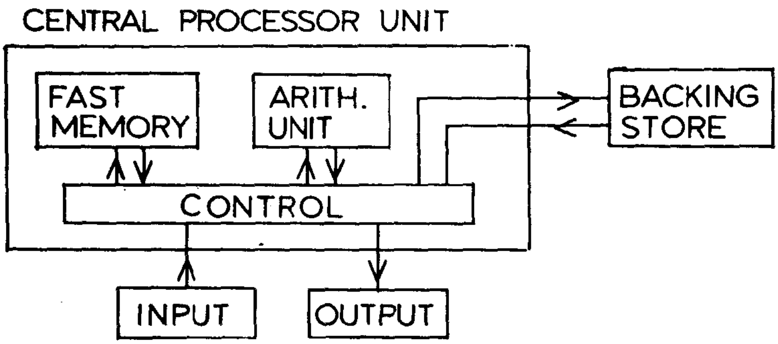

Fig. 2.1 Block diagram of the basic computer with its component parts. The arrows represent major directions of data flow.

Input

There must be a method of feeding instructions and data into the device. For a simple system the input will be a typewriter-style keyboard.

Output

Again, this is an obvious necessity if we are to have a two-way conversation with the system. The basic methods of presenting numbers and words to the user are by printout on a teletype device or by display on a cathode ray oscilloscope—the Visual Display Unit (VDU).

Central Processor Unit (CPU)

This is the 'works' of the computer and contains the necessary electronic components for storing instructions and data, for carrying out arithmetic and for routing the data from place to place within the system (e.g. from input to store to arithmetic unit, back to store and then to output).

As the instructions and data arrive at the CPU from the input they are stored in the fast access memory. This can be looked at as a large bank of pigeon holes. The instructions are sorted, one into each pigeon hole in one area of the store, and the data are similarly sorted into holes in another storage area. On the command 'RUN' the first instruction is removed from its 'hole', read and acted on—perhaps taking a datum from its store and passing it on to an action store or register in the arithmetic unit where, following further instructions, it will be compared with, added to, multiplied by, divided by or subtracted from another datum. The next instruction in sequence may send the answer back to a further storage site or through to an output for display. The instructions are followed through sequentially unless the user's list of instructions (program) commands a jump in the sequence under some circumstances.

For many years the fast access store of a computer was based on small magnetic rings or cores that could be magnetized clockwise or anticlockwise to represent a 0 or a 1. These ferrite core stores have been replaced for practically all purposes by semiconductor microcircuits based on a variety of high technology methods of construction.

The CPU also holds in its fast memory the master program, called the operating system, which organizes the efficient running of the computer, oversees the correct functioning of the program and adapts the data to a form suitable for acceptance by each of the peripheral devices; that is, backing stores, inputs and outputs.

Backing stores

If the amount of data for a problem or the accumulation of answers is too large to be stored in the fast memory (access time 50 nanoseconds to microseconds) then there is a need for a large capacity backing store from whence stored data may be retrieved at a slower rate. Examples are magnetic disk stores which can hold millions of characters with fetch or access times from 10 to 100 milliseconds or magnetic tapes where the access times for items of stored data may run up to hundreds of seconds.

The human brain has often been compared to a computer: input by ear or eye; output by hand or mouth; fast memory, operating system and arithmetic unit in the brain; and slow backing store a piece of scrap paper. Try calculating 73 × 12 + 56 × 8 without writing down an intermediate answer for later retrieval by your twin visual input devices.

Types of computers

Computers can be classified in a number of ways—by physical size, by data storage capacity, by the tasks they perform or simply by cost. Recently the divisions between types of computer have become more and more arbitrary, since the most powerful computers may be built up of hundreds of small processors.

Currently interest is focused on the microprocessor—the 'silicon chip'. In this device all the circuits for a CPU with some memory are prepared on a single slice of silicon. The microprocessor may be built into a scientific instrument such as an autoanalyser but it does not constitute a microcomputer until further memory, interfaces for input/output and other peripherals are added. The overall size of the CPU and memory may be so small that a complete computer can be carried in the pocket although the keyboard of the pocket computer calls for microfingers and the output is limited to one line of characters on a liquid crystal display. A microcomputer which might be useful, say, for word processing or statistics, will have a visual display, a typewriter-size keyboard, one or two floppy disk drives for large store memories and perhaps a printer. The

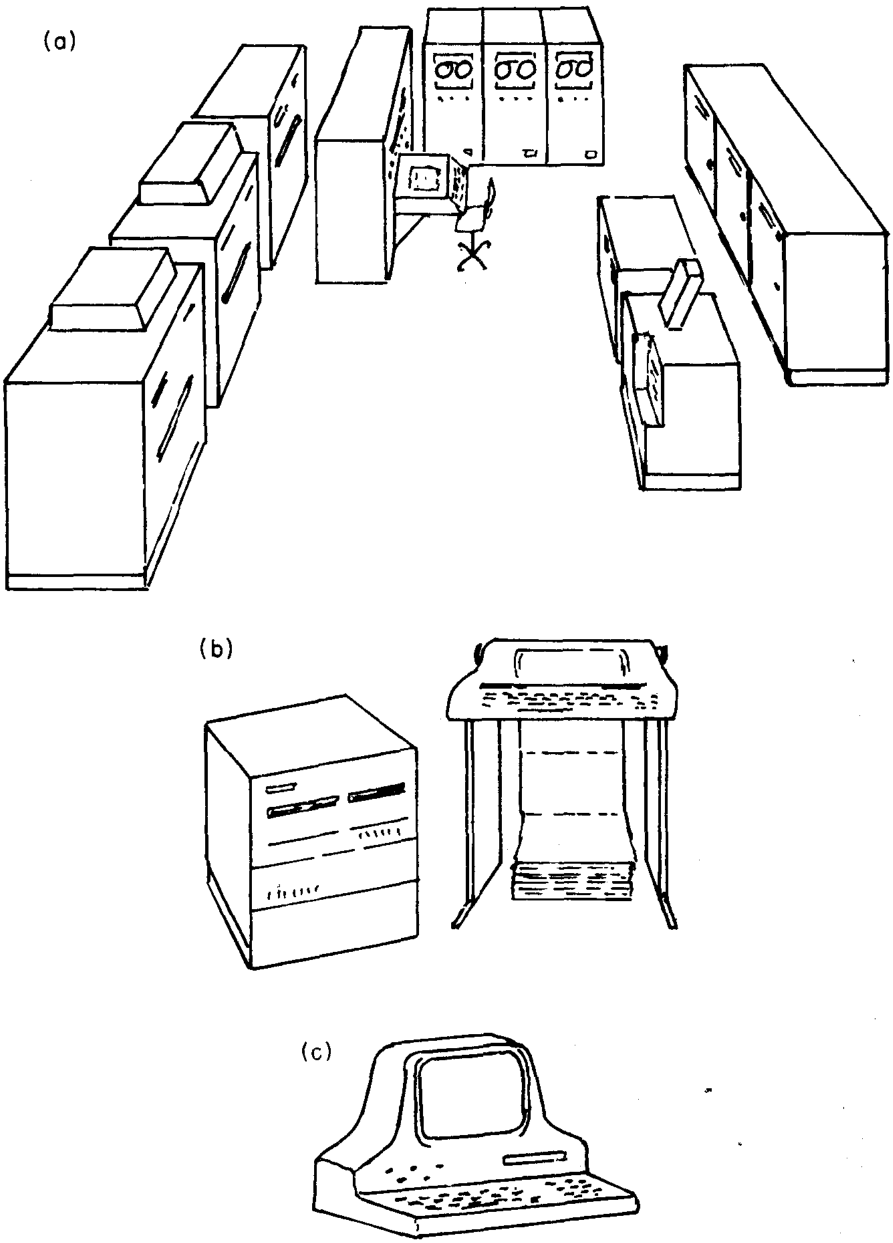

Fig. 2.2 Sketches to illustrate the features of the three main classifications of computers. (a) A Mainframe computer with (from left) line printers, central processor with control console, magnetic tape units, card reader and punch, disk drives. (b) Minicomputer with central processor plus disk unit and control teletype. (c) Desk-top microcomputer which includes processor, display screen and keyboard with integral floppy disk unit.

whole system will sit on a desk top (Fig. 2.2c). A small microcomputer will normally be capable of running programs written in one high level language such as BASIC.

The distinction between a micro and a minicomputer is now blurred. Many 'mini' computers have a microprocessor at the heart—as the CPU. The term 'minicomputer' would, however, by common usage imply a system which takes up a few cubic feet (1 cubic metre) of space. Typically it would have a teletype or VDU as the console for controlling the system and one or two cartridge disks as backing stores. If dedicated to scientific work, a mini may run a graphics facility or have special interfaces such as an Analogue to Digital Convertor (ADC) so that it can accept physiological signals as input. At the larger range, a minicomputer could have a central memory of 1–10 megabytes (bytes are discussed in the next section), support a multiple disk memory and be capable of running a hospital records system with 30 or 40 interactive terminals for wards and clinics.

By the traditional classification the largest systems are the 'mainframe' computers. These are large installations, generally kept in an air-conditioned environment and requiring a staff of operators, programmers, systems engineers and analysts to run them. They have a variety of input and output devices with a fast memory of at least 1 megabyte capacity. Both disk and magnetic tape backing stores increase the data handling capacity. The mainframe computer may also support many other users at distant sites who have simultaneous access to the machine through their own input/output terminals linked to the central CPU by telephone lines. The system might need a separate 'front end' computer to handle all these various inputs and to allocate space and priorities in the main machine. The large capacity will be needed for complex scientific programs and statistical work on extensive quantities of data. A university might need such a computer.

The next step in the scale is not generally to build larger and larger single systems but to link a number of computers together in a network such that data can be passed rapidly from site to site. The advantage of a network lies in efficiency. Small tasks can be tackled by small machines in the network, leaving the large systems to cope with very big jobs. It may also be that only one machine in the network need keep certain scientific program packages up to date while another unit might specialize in graphical output. Workers needing these particular facilities can input data to their local computer which will then pass it through the network to the specified system. Results can then be routed back to the user's site and output on a line printer or VDU.

Batch and interactive modes

A further classification which affects the average user is the mode in which the computer is run. In 'batch' mode the instructions and data for a particular 'job' are submitted as punched cards and they wait in a queue of jobs, probably all stored in order on a magnetic tape. When the computer is ready the jobs are processed, and when each is finished the results are fed back onto another magnetic tape until an output device is ready to print them out or until the user asks to collect them, perhaps at a local terminal in the user's department. Batch mode makes efficient use of the computer's time because it always has work waiting to be done; however, the user may prefer to work in 'interactive' mode where the computer waits for his commands and carries them out promptly, printing or displaying the answers on teletype or VDU as they are computed. In interactive mode the user can change his instructions or rearrange data as required if the first results are not satisfactory.

Larger computers may be able to support many interactive users simultaneously and to carry out batch mode working at the same time. A powerful operating system is needed to run with this degree of flexibility and the system will have the task of partitioning or dividing the available memory, giving each job as much space as it requires. In a good multi-access system each user thinks he has sole use of the machine.

Bits, bytes and words

In order to discuss a little further the workings of computers, it is necessary to obtain some insight into the binary notation because all internal computer transactions are carried out in binary code.

Binary numbers are numbers to base 2 and the conversion from base 10 decimal numbers is straightforward:

1	0001	5	0101
2	0010	6	0110
3	0011	7	0111
4	0100	8	1000

Each binary digit is known as a 'bit'; that is, either an 0 or a 1. As can be seen above, 3 bits are sufficient to code all base 10 numbers up to 7 whilst 4 bits enumerate up to 15 (1111). Computers are generally designed to work in multiples of 8 bits; that is, 8, 16, 24 or 32 bits. By convention a unit of 8 bits is known as a byte (occasionally more than 8 bits). An 8-bit number can enumerate decimal numbers up to 255. In a small computer all information is transmitted in units of 1 byte, this being sufficient to code all the characters, letters, numbers and symbols (e.g. +, ", *) used in computing. Normally an input device translates a character on the keyboard into binary form and passes it as a sequence of voltage pulses down a wire to the central processor unit (Fig. 2.3).

Within the computer the byte is transferred from a series of pulses into parallel form so that eight parallel wires are needed to pass data between each component of the CPU. Parallel working speeds the process. The convenience of binary numbers lies, in the first place, in the ease with which binary numbers can be stored. Any system which exists in two states can be used to store a bit (e.g. 0 is off, 1 is on; 0 is up, 1 is down; 0 is left, 1 is right; and so on). But a command expressed in binary form can be used directly to control the flow of data within the computer as the 0 and 1 pulses switch gates open or shut along the computer's eight-lane highways.

The *word* size, measured in terms of bits, is fundamental to the design of a given computer. Word size in 8, 16, 24 or 32 bits determines: