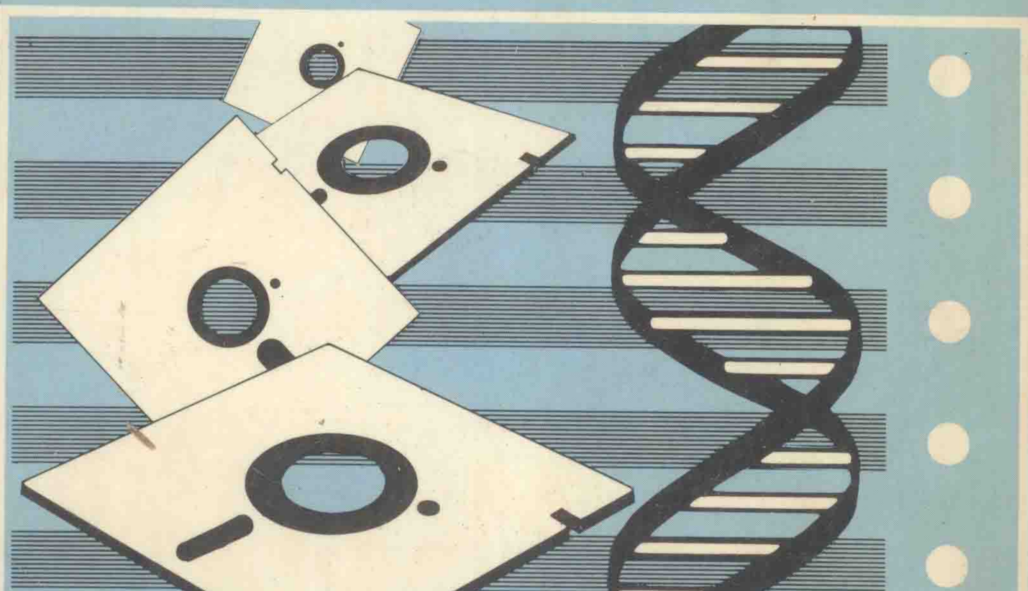
Microcomputers in biology

a practical approach

Edited by
C R Ireland & S P Long



Published in the
Practical Approach Series
Series editors: D.Rickwood and B.D.Hames

IRL PRESS
Oxford · Washington DC

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IRL Press Limited
P.O. Box 1,
Eynsham,
Oxford OX8 1JJ,
England

British Library Cataloguing in Publication Data

Microcomputers in biology : a practical approach.
—(Practical approach series)
1. Biology—Data processing
I. Ireland,C.R. II. Long,S.P. III. Series
574′.028′5404 QH313

ISBN 0-904147-57-6

ISBN 0-904147-98-3
(book plus software)

Printed in England by Information Printing, Oxford.

Preface

Computers have, since their introduction into universities and research establishments in the early 1960s, been widely employed by biologists. However, the mainframe computer was always an entity isolated from the laboratory and its use was commonly restricted to post-experimental analysis of data and computer modelling of biological systems. Users of these systems had to master not only unhelpful high-level languages, but also often complex control and operating systems. The advent of the inexpensive microcomputer, providing interactive conversational languages, has completely altered this concept and has allowed the transfer of instant computer power directly into the laboratory. The danger inherent in this is of course that it is very simple to leap upon the bandwagon without first examining exactly what the microcomputer may or may not be able to achieve for the user, and without establishing whether any real advantage is to be conferred by becoming 'computerised'.

The major objective of this book is to introduce the concept of the microcomputer as a piece of laboratory equipment and to demonstrate not only what advantages may be acquired, but also what pitfalls may be met. The first pitfall is always likely to be the jargon. As is stated in the introductory chapter, overcoming the jargon is half the battle and an attempt is made to explain, in a clear and concise way, the most common terminology that the user is likely to meet. The subsequent three chapters describe the problems and provide some of the solutions to communicating between laboratory equipment and the microcomputer, the graphical display of biological data and the use of microcomputers as data-loggers. These will be common requirements of nearly all users who are research biologists. The rest of the book deals with more specialist topics. The use of microcomputers in the analysis of enzyme-catalysed reactions and of nucleic acid sequences are described in two following chapters. The next three chapters describe the employment of microcomputers in chromatography, spectrophotometry and centrifugation and the final chapter outlines the use of the microcomputer in the control of the biological environment. In each case the chapter authors, who have been carefully selected for their expertise, provide a practical guide to the use of the microcomputer in their field.

The appendices to eight of the ten chapters contain a number of complete program listings. These are programs constructed by the chapter authors and which are explained in the text. The programs are written, with few exceptions, in BASIC language, this being the almost universal language for microcomputers. However, a large number of forms of BASIC exist and to avoid the dependence of the book on any one brand of microcomputer the programs are listed as written by the author for their particular machines. Fortunately, the various forms of BASIC are not vastly different and are readily intertranslatable so readers with some programming experience should be able to modify any of the programs for their own use without great difficulty. The programs have, however, been translated into software packages on floppy disc for four common microcomputer systems and further translations may follow. Initially discs are available for the Apple, IBM (Personal Computer), BBC and Commodore PET to enable immediate use of the programs with these brands of machine. While the editors have done their utmost to ensure that the program listings appearing in this book and upon the accompanying floppy discs are without fault they can take no responsibility if a few minor 'bugs' are still retained.

Possibly the major use of the microcomputer within biology will remain as a powerful calculator in the quantitative and statistical analysis of biological data. There are on the market a vast number of publications describing the employment of the microcomputer in this role and the authors have no desire to add to this particular glut, however a package of statistical programs in BASIC is included on the accompanying floppy disc. This book is thus meant essentially as a practical guide to the use of the microcomputer as a piece of laboratory equipment, a concept which is rapidly becoming commonplace.

C.R. Ireland and S.P. Long

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Contents

CHAPTER 1

An Introduction to Microcomputers

S.P. LONG and C.R. IRELAND

1. OBJECTIVES

It may seem that no field of study is more prone to the use of jargon than Microcomputer Technology. Yet understanding this jargon is basic to any understanding of microcomputers. This chapter examines the basic structure of microcomputers and in so doing will explain some of the key terminology, in so far as this is important to those interested in computers as a means rather than an end; a more extensive explanation of microcomputer terms may be found in reference (1).

2. FUNDAMENTALS OF MICROCOMPUTERS

The **microcomputer** has come to be regarded as a small stand-alone desk-top computer. The word is derived from **microprocessor**, the term commonly used to describe a digital electronic processor of **CPU** (central processor unit) contained on a single **IC** (integrated circuit) chip (2). Strictly, a microcomputer is a computer system built around a microprocessor. The centre of the microcomputer consists of three basic parts (*Figure 1*).

(i) The **CPU**, including the Control Logic – which co-ordinates the whole system and manipulates data according to a pre-programmed set of instructions.

(ii) The memory – which is both the working space or volatile memory termed **Random Access Memory (RAM)** and the permanent memory termed **Read Only Memory (ROM)**.

(iii) The **buses** and **I/O** (input and output interfaces) – which connect the CPU to the other parts of the microcomputer and to the outside world.

In modern microcomputers these parts are reduced to microscopic circuits on one or a few individual chips. Thus, the basic part of the computer may be housed in a small box which will fit comfortably onto a desk or bench. Three other pieces of **hardware** (the physical parts of the system) will complete a basic microcomputer system.

(i) The keyboard – normally **QWERTY** (i.e., typewriter style board), but more rarely a calculator or finger ball keypad.

(ii) The screen – a **CRT** (Cathode Ray Tube) monitor or, built-in to some of the more recent portables, an 80 column x 8 or 16 line **LCD** (liquid crystal display).

(iii) The back-up store – tape cassette and/or discs.

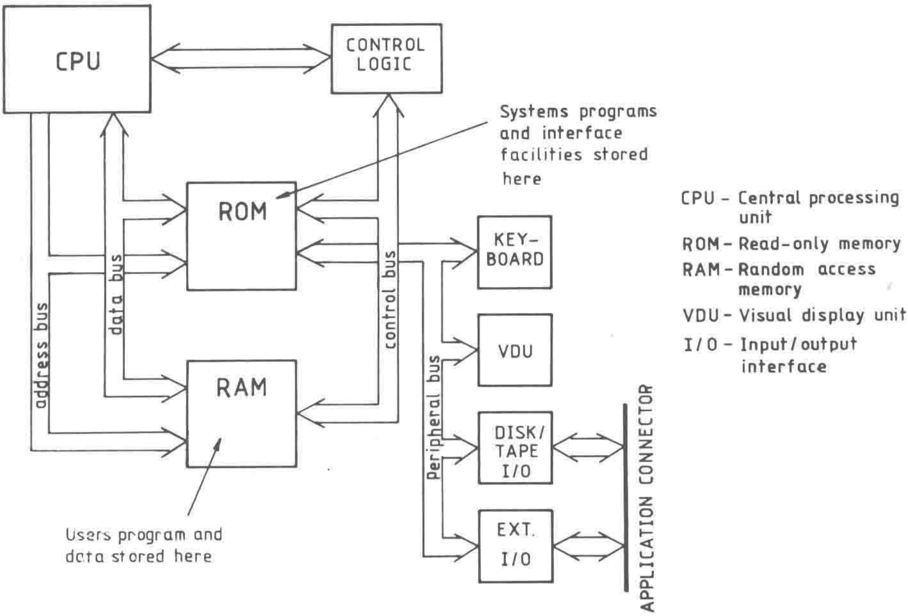

Figure 1. Block diagram illustrating the essential architecture of a typical microcomputer. Note that the control logic circuitary will often be included with the CPU. The address, data and control buses may also feed to an expansion port allowing the user to add further RAM chips.

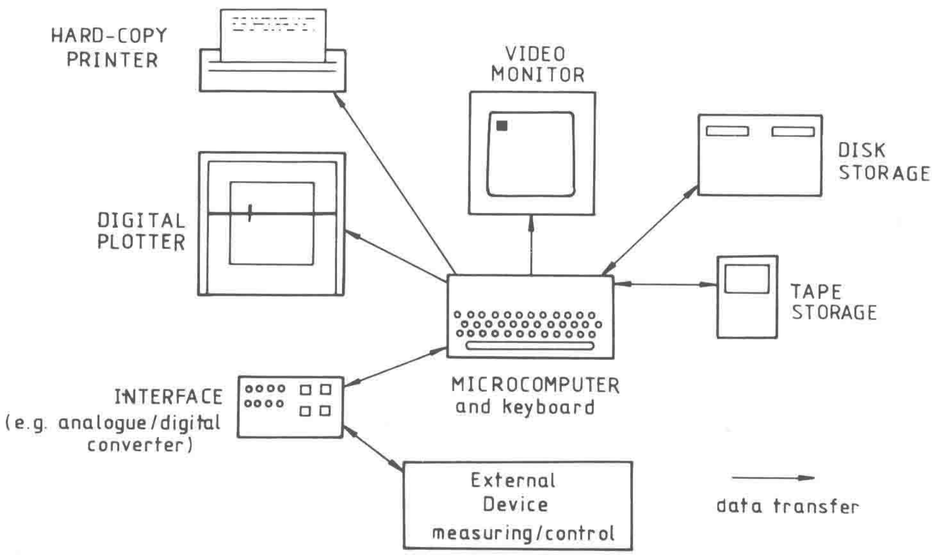

Figure 2. A microcomputer system.

Microcomputer systems in biological research laboratories will commonly include other peripherals – typically a printer, an x/y plotter and possibly a graphics tablet. A typical microcomputer system is diagramatically illustrated in

Figure 2. Items of laboratory equipment with a compatible digital interface may be connected directly to the system (Chapter 2) or *via* an interposed data-logger (Chapter 3). Alternatively, equipment with an analogue output may be connected *via* an analogue to digital converter (discussed in Chapter 2), such as those described in Chapters 3 and 10, to allow data acquisition and the control of a wide range of laboratory equipment.

To understand how the basic components of the microcomputer system, i.e., the CPU, Memory and I/O interfaces, function it will be first necessary to consider the digital data fundamental to their operation.

2.1 Digital Data

The CPU, like the CPU of a mainframe computer, can only handle **binary logic**, i.e., the two numbers 0, for off or false, and 1, for on or true. Within the computer these correspond to particular voltage levels. For example, in **TTL** (Transistor-Transistor-Logic) circuits, binary 0 and 1 correspond in theory to 0 V and 3.5 V, respectively. In practice most manufacturers allow some flexibility in these values such that any voltage of less than or equal to 0.7 V will be interpreted as binary 0 and any voltage of 2.4 V or more will be interpreted as binary 1. Other types of IC will use different voltage levels. Digital electronics concerns the manipulation of this 0/1 logic system according to the set of rules known as **Boolean algebra**, which is closely related to normal arithmetic using a binary number system (2,3). Thus, the alphabet, numbers and symbols of the keyboard must all be represented by permutations of just two numbers, i.e., 0 and 1 and all data, programs and internal manipulations are translated into and back from binary.

Each binary digit is stored at a single on/off or 0/1 position known as a **bit**. These bits are arranged in sets of eight, termed **bytes**. Most microcomputers manufactured in the 1970s and most of the cheaper (<£1000) microcomputers today are 8-bit, that is, they can only handle one byte at a time. Increasingly, new microcomputers are **16-bit**, i.e., they handle two bytes simultaneously, these two bytes being known as a **word**. The IBM Personal Computer and Olivetti M20 are examples of 16-bit microcomputers, while even 32-bit, i.e., 4-byte word, microcomputers have become established in the mass-market, for example, the Apple Macintosh and the Sinclair QL. However, determining the bit size of processors is not as simple as it may seem from manufacturers' descriptions. Not all operations will use the same bit size. For example, the processor used in current versions of the IBM-PC (the Intel 8088) may manipulate 16-bits simultaneously in calculations, but has only an 8-bit interface (4). A useful definition is that a processor may be described as *n*-bit if the largest operand handled by the majority of data operations is *n*-bit (5). Regretably, some manufacturers have shown a tendency in their advertisements to interpret 'majority' as 'any one'.

The organisation of bits into bytes is relevant to the internal representation of the keyboard characters. The most common code for the conversion of keyboard characters and commands into binary is **ASCII** (American Standard Code for Information Interchange). Representation of a single character or decimal number requires a whole byte, or strictly the last seven bits out of the byte. For

Table 1.

Binary (base 2)	Hexadecimal (base 16)	Decimal (base 10)	Binary (base 2)	Hexadecimal (base 16)	Decimal (base 10)
0000	0	0	1000	8	8
0001	1	1	1001	9	9
0010	2	2	1010	A	10
0011	3	3	1011	B	11
0100	4	4	1100	C	12
0101	5	5	1101	D	13
0110	6	6	1110	E	14
0111	7	7	1111	F	15

Thus the eight digit binary number of a byte, e.g.

7 6 5 4 3 2 1 0 (bit number)
Byte: **1 0 0 0 1 1 0 0**

Would be represented in hexadecimal as: **&8C**

Where: '&' is used to indicate that the number is hexadecimal; C represents the values of bits 0 – 3; 8 represents the value of bits 4 – 7.

example the English letter 'H' is represented in a byte as '1001000', whilst the lower case 'h' is slightly different '1101000' (2). Despite the implication in the name that this is a standard, there are in fact many forms of ASCII, whilst some computers may use a completely different code.

Programming at the level of bits is only required for Machine Code operations. Although the computer can only operate with Machine Code, programs may and are usually written in higher level languages, i.e., languages which use a limited English vocabulary. These are translated into Machine Code by a compiler or interpreter (discussed further in Section 8.2). Representation of Machine Code in strings of eight binary digits is cumbersome and more conveniently represented in the **hexadecimal** system (base 16) where each byte may be represented by exactly two digits. The hexadecimal system needs 16 single characters to specify the decimal numbers 0 – 15. The characters 0 – 9 are naturally used to specify decimal 0 – 9, and the letters A – F are used to specify decimal 10 – 15 (*Table 1*).

Both the memory and CPU bytes are contained on miniaturised ICs or chips. There are several types of these chips, according to the way in which they are constructed and operate (2,3). One common group of chips are the **MOS** (metal oxide semiconductors). Most frequently these are NMOS (MOS using currents of negative charge); these circuits being faster in operation than their PMOS (MOS using currents of positive charge) counterparts. Recently CMOS (complementary MOS), which is a hybrid using both negative and positive charges on the same silicon substrate, has started to be employed. The major advantage of CMOS is its far lower power consumption, roughly 1/20th of NMOS. CMOS also has better tolerance of supply voltage fluctuations and better noise immunity, whilst its lower power consumption and heat dissipation means that a more compact arrangement of electronic components is possible (6). This development has important implications for environmental biology since it allows the development of truly portable, battery operated systems as powerful as many of today's common microcomputers, which could be used in the field or at remote field stations.

2.2 The Central Processing Unit (CPU)

This is essentially the unit around which the computer is built. The CPU of a mainframe computer system may occupy the space of several large filing cabinets and require precise air-conditioning. In contrast, the CPU of a microcomputer is contained on a single chip and may operate under most ambient conditions. Two components with distinct functions in a computer system have traditionally been combined into the CPU. First, the **ALU** (Arithmetic Logic Unit) which, using the rules of Boolean algebra, will change the data presented at its inputs according to a specified plan of action. Secondly, the **Control Logic** under the aegies of which all other components act. This part of the CPU decodes instructions to determine which byte transfers are to be performed, in which order and to where. The methods used vary considerably between processor types and have been described in detail elsewhere (2,3,5). Associated with the CPU is the **clock,** a device with no inputs but an output which changes at a fixed frequency between logic levels. During the execution of a program, events within the microprocessor (e.g., fetching and sending of data, accumulation and examination of a given byte) occur at discrete intervals which are synchronised by the clock. The clock speed therefore determines the rate of execution of instructions by the processor. Clock speeds are measured in **Hz** (Hertz) i.e., the number of cycles per second. Microprocessor clock speeds vary from 500 kHz to 10 MHz. For example, the Acorn BBC model B operates its 6502 processor at 4 MHz, i.e., 4 million events per second.

The tremendous diversity of microcomputer models is in fact based on a relatively narrow range of CPUs or microprocessor chips. The most commonly used microprocessor chips have been the **6502**, Zilog **Z80** and Intel **8080**. The 6502 was one of the first cheap CPU chips to be produced in volume and has been used in the Commodore PET, the APPLE II, and the Acorn BBC model B. The development of a CMOS version of this processor, the Rockwell R65C02, may revive interest in the 6502 (6). The Z80 has been used in many business machines, e.g., the Cromenco Sys. 0, Radio Shack TRS-80 Model 16 and DEC Rainbow 100, but may also be found in some microcomputers manufactured for the home-computer market, most notably the Timex/Sinclair SPECTRUM and ZX81. A particular advantage of Z80 processors is that they may use the operating system **CP/M** (Control Program for Microprocessors). **Operating systems** supervise and control the running of user programs and input to or output from peripherals, such as disc drives and printers. Many manufacturers have incorporated CP/M into their design and thus a large body of software for use under CP/M has been written and is interchangeable between different models and brands. Many other operating systems have been developed in competition with CP/M, most notably **MS-DOS** (MicroSoft Disc Operating System).

The processors considered above are all 8-bit. Increasingly, 16-bit or 32-bit microprocessor chips are being incorporated into microcomputers. Most notably the Motorola **68 000** series, Zilog **Z8000** and Intel **8086**. These processors are not only faster but can also handle considerably more RAM, and where 32k or 64k has become standard on 8-bit machines, 124k or 256k is standard for current 16-bit machines. A temporary disadvantage of these machines is a lack of soft-