

The Information Technology Revolution

Edited and introduced by

TOM FORESTER

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The Information Technology Revolution

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The Labour Party and the Working Class (1976)

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Part One: The Computer Revolution

1 Introduction to Information Technology

The Anatomy of Computing

John Halton

In order to understand the information technology revolution, you need to know something about how computers work. In this introduction to computing, the author first describes the importance of information processing and then takes us through the hardware and software of the modern microcomputer. Halton, an Englishman who settled in the US in 1962, was formerly Professor of Computing Sciences at the University of Wisconsin, Madison. He is at present Principal Engineer, Advanced Technology Department, Harris Corporation, Melbourne, Florida. Taken from a series of articles in the Wisconsin Medical Journal, April 1982–April 1983.

The Second Industrial Revolution

The world is undergoing a major social and economic change, a Second Industrial Revolution, through the new information-processing technology of communications and computers. While mankind has developed a myriad ways of applying and controlling power to dominate and shape our environment, through the use of tools, weapons, machines, fuels, vehicles, instruments, clothing, buildings and roads, metals, plastics and drugs, agriculture, and electricity, the handling of information has lagged considerably, perhaps because the human brain is itself so remarkably powerful. Until recently, there have been only three major developments in this area: the invention of written (or painted or carved) language, some five or six thousand years ago; that of simple arithmetic operations, using what would now be called a digital representation of numbers, about a thousand years later; and that of printing, about five hundred years ago.

With written language, we get the capacity to make a permanent record of information and also to convey messages across space and time: *storage*, *retrieval*, and *communication*. With digital arithmetic, we get the ability to perform accurate, repeatable *manipulations* of *quantitative data*. With printing, we can make many identical copies of the same record and so *broadcast* a

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single message to a wide and continuing audience. Beyond these outstanding advances, until the last hundred years or so, the only progress has been in the engineering and increasingly plentiful production of more powerful and reliable and efficient, faster and cheaper devices to implement these concepts (such as styli, chalks, brushes, and pens; slates, wax tablets, papyrus, parchment, and paper; typewriters; abaci, cash registers, and calculating machines; movable type and typesetting machines; and printing presses of increasing speed and complexity).

In the last hundred years, we see the rapidly accelerating advent of a technology so powerful, novel, widespread, and influential that we may indeed call it the Second Industrial Revolution. Its basis is electromagnetic, in many interconnected forms: photography, photocopying, cinematography, and holography; telegraphy, telephony, radio communication, radar, sonar, and telemetry; sound and video recording and reproduction; vacuum tubes, transistors, printed circuits, masers, lasers, fiber optics, and (in rapid succession) integrated circuits (IC), large-scale integration (LSI), and very large-scale integration (VLSI) of circuitry on a tiny semi-conducting 'chip'; and, finally, the bewildering variety of electronic digital computers. All these devices are intimately interrelated, and any advance in one tends to generate advances in all of them.

The progress has been truly amazing. In only about 40 years, electronic communications and news media have become commonplace and indispensable; computers have proliferated, becoming increasingly fast, powerful, small, and cheap, so that now there is scarcely a human activity in which they are not to be found, bearing an increasing share of the burden of repetitive information processing, just as the machines of the First Industrial Revolution have taken over the majority of heavy and unpleasant physical labor (we may say, energy processing).

Now, information can not only be stored, retrieved, communicated, and broadcast in enormous quantities and at phenomenal speeds; but it can also be *rearranged*, *selected*, *marshalled*, and *transformed*. Until recently, these activities were the sole province of the human brain. While creative, judicious, moral, and esthetic choices are still best left to people, all the tedious and mechanical mental processes can now be relegated to the accurate, fast, and tireless machines. Any sequence of operations on information that can be precisely specified can be carried out without further human intervention or supervision.

At first, computers were the experimental toys of university researchers; then they became the tools of government establishments and giant corporations, huge, expensive, individually designed and manufactured, and beyond the reach of any but the wealthiest organizations. People thought of the future in terms of machines of ever-greater speed and capacity; centralized behemoths would hold all the world's information in gigantic data banks, whence major decisions would issue to be imposed upon the populations at their mercy. With the emergence of powerful, cheap, mass-

produced computers-on-a-chip, the picture has changed radically. Now we see tiny computers everywhere: in wrist-watches, microwave ovens, electronic games, pocket calculators, cameras, typewriters, musical instruments, etc. What used to be done, with few options, by intricate mechanical devices is now performed, with great flexibility and convenience and at much less expense, by the ubiquitous preprogrammed microcomputer. The probable future has become one of millions of small yet powerful computers, controlling virtually every machine and appliance, distributed in every home, on every desk, in every workshop; many of them connected in a maze of small and large networks, much like the present telephone network (and perhaps replacing it), so that individual computers could communicate, sharing information in a gigantic distributed data-base, and gaining, through distributed processing, computational power whose extent is yet difficult to gauge; all this following the individual requirements and choices of the owner or operator of each machine.

Increasingly, we are confronted, not only with the results of the use of computers throughout industry, commerce, banking, advertising, science, the communications industry, newspapers, airlines, and hospitals; but with the realistic possibility of purchasing computer power for our own small enterprises, offices, and homes. This may be done in a variety of ways; but in all of them, the real cost of computation is constantly diminishing. It is probably fair to say that the question of computerization is not “whether,” but “when” and “how.” We must choose whether to lease equipment or to buy it; whether to install terminals, connected to a computerized “service bureau,” or a complete local computer system; whether to get a package of standard programs directed towards our kind of work, to commission new programs tailored to our special needs, or to learn programming and write our own; whether to go it alone or to share a system with a number of similar users (especially if they are in the same building); how far to take our first efforts at computerization; what to include and what to continue doing by hand. Then, having made the broad choices, we must select, from the wide range of available products, those that will suit our situation best.

Computer programming is likely to become the literacy of the third millennium AD. Elementary schools may well be teaching it before long, and we might be well advised to gain at least a smattering of knowledge of computers and of programming competence, especially since computer languages and programming environments are becoming increasingly helpful and friendly to the uninitiated user.

The anatomy of a computer

A computer is a machine for the automatic processing of *information*. Historically, this information was numerical, and computers were machines for doing arithmetic. Unlike the simpler *calculating machines*, which can perform only one elementary arithmetic operation at a time, then need to be

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told what to do next (usually, by suitable button-pushes); computers can be given a list of operations to perform (often with branching and repetitions, depending on tests of sign or value included among the operations), and will then execute these in proper sequence without further intervention. This sequence of instructions is called a *program*.

A *digital computer* stores its information in the form of *words*, finite ordered sets of *digits*, each of which can have only one of a finite set of values. (This is analogous to the *decimal* representation of numbers, in which each digit takes one of the values 0, 1, 2, 3, 4, 5, 6, 7, 8, 9; or the written representation of English words, in which the “digits” are the 26 letters of the alphabet.) Considerations of simplicity, reliability, and economy dictate that electrical engineers should design computers to consist of a great number of similar pieces of circuitry, each of which can only be in one of two states, usually denoted by 0 and 1. Such *binary digits* (or *bits*) are the elements of which computer digital representation is built. A row of eight bits is called a *byte*, and the majority of computers have their storage of information organized in words of one, two, four, or eight bytes (8, 16, 32, or 64 bits). The number of bits in a word is termed its *length*; if this is k , then the number of possible distinct pieces of information that can be stored in such a word is 2^k . In particular, four bits together can have 16 different contents, and these are standard *binary representations* of the numbers 0–15:

0000 = 0 0001 = 1 0010 = 2 0011 = 3
0100 = 4 0101 = 5 0110 = 6 0111 = 7
1000 = 8 1001 = 9 1010 = A 1011 = B
1100 = C 1101 = D 1110 = E 1111 = F

with A = 10, B = 11, C = 12, D = 13, E = 14, and F = 15. These may now be viewed as the 16 possible digits of a representation (the *hexadecimal*, or *hex*), which is much more compact and humanly intelligible than a long string of zeros and ones. For example, the byte 10110010 becomes “B2,” and the four-byte computer word 01001100011100101101000110001110 becomes the eight-digit hex word “4C72D18E.”

We now turn to Figure 1.1, which is a diagram of the various parts of which any computer is composed. These are, essentially,

- 1 a *central processing unit* (CPU), which is the controlling and computing center of the machine;
- 2 a *memory*, possibly of different levels, in which both *data* and *instructions* are stored;
- 3 a variety of *input* and *output* (I/O) *devices*, through which the machine communicates with the world outside it.

The CPU consists of an *operation control unit* (OCU), an *arithmetic/logical unit* (ALU), and a relatively small, very-fast accessible *local memory* (LM). The OCU keeps track of the memory location of the next instruction to be executed, and analyzes the current instruction, so as to activate the proper operation of

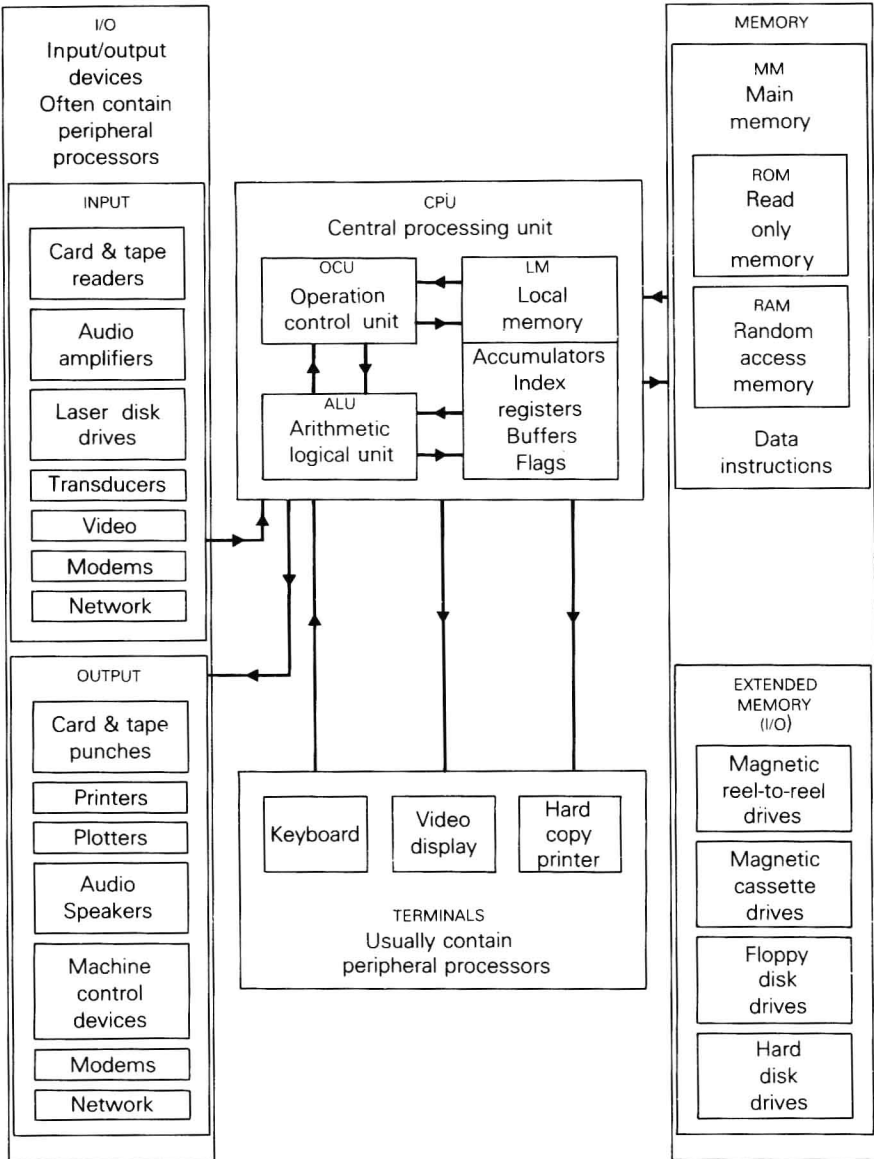


Figure 1.1 The anatomy of a computer.

a memory transfer, non-sequential jump (by appropriately changing the address of the next instruction), input or output of information, or computation (performed by the ALU), as is indicated by the instruction code. The ALU actually carries out the elementary arithmetic operations (addition, subtraction or negation, multiplication, division or reciprocation) and logical

operations (these being bit-by-bit operations, without carry, such as **not**, **and**, and **xor**; eg., **not** 1010 = 0010, 1100 **and** 0101 = 0100, 0110 **xor** 1010 = 1100) on the data given to it by the OCU. The LM receives the operands called for by the OCU and also the results of the ALU's operations upon them. For example, the OCU may retrieve the factors of a multiplication from the main memory into a pair of LM registers and instruct the ALU to multiply them and place their product in another LM register. Such registers are usually called *accumulators*, and they are normally double-length (since the product of two k -bit numbers is a $2k$ -bit number). Other LM registers are used for counting (eg. repetitions) and are called *index registers*; others hold intermediate values and are called *buffers*; and, finally, there are one-bit or two-bit registers which reflect the information on which tests are made by the OCU (for example, the occurrence of a carry, the vanishing or positivity of an answer, or the occurrence of an arithmetic overflow): these are termed *flags*.

Originally, the CPU was a sizable piece of electronics, hand-assembled and highly complex. With the advent of micro-miniaturization of circuitry, printing, and photographic techniques, and the mass production of components only the largest computers (*mainframes*) are built in the old way. Smaller systems generally have the entire CPU on a single chip. Among these, the name *microcomputer* is now applied to those with less than a million words of memory and a word length of one or two bytes; the name *minicomputer* applies to the larger machines, with two- to four-byte words and one to a hundred million words of memory. (The smallest micro is probably more powerful than the big computers used by universities and industry in the 1950s.)

The *main memory* (MM) consists of magnetic or electronic components which store the information (both data and instructions) needed by the computer. The individual words are directly *addressable* from the CPU by number (rather like houses in a street), and their contents are retrievable in very short times, of the order of the operation time of the CPU (ranging from fractions of a *nanosecond*, 10^{-9} or one billionth of a second, for the fastest main-frames to several *microseconds*, 10^{-6} or millionths of a second, for the slower micros). This is often referred to as *high-speed storage* or *random-access memory* (RAM). While most of the MM is erasable and may be changed at will, some memory is used to store constants and often-used utility programs and is not erasable by the CPU: such memory is called *read-only memory* (ROM). Sometimes this is optional and can be plugged into the computer: this is called *firmware*.

Note that a computer with one-byte-long addresses can have at most $2^8 = 256$ words of MM; a two-byte address can reach $256^2 = 65536$ words; a three-byte address can select any of 16777216 words of MM; and so on. In practice, most micros and minis have MM ranging in size from $2^{14} = 16384$ to $2^{18} = 262144$ words. It should be noted that $10^3 = 1000$ and $2^{10} = 1024$. Because computers are so heavily slanted towards base-2 representation, it has become almost universal computer parlance to use the prefix *kilo* or K

(which usually denotes a thousand units) to denote 1024 and the prefix *mega* or M (which usually denotes a million units) to denote $2^{20} = 1024^2 = 1048576$. Thus, we write 16K for 2^{14} and $\frac{1}{4}$ M for 2^{18} . Perhaps the commonest size of MM consists of $64K = 65536$ words.

Almost all computer instructions comprise an *operation code* (usually one byte long, allowing 256 possible operations to be specified), followed by an *operand reference* (number, index, or address) of variable length (since some operations require more data than others; for instance, the STOP instruction needs no operand, so it is one byte long).

The *extended memory* (EM) is sometimes considered under I/O devices, both because it is often physically located outside the computer (while the CPU and the MM are usually in the same enclosure), and because its speed of access is much slower than the speed of operation of the CPU and is comparable with the range of speeds of I/O devices. Most read/write memory is magnetic (optical memory is read-only, and fast RAM is either magnetic or electronic), either in the form of *tape*, *drum*, or *disk*, coated with magnetic material, much like sound-recording equipment; it is similarly erased, read, and recorded upon by "heads" which contain electromagnetic sensors/polarizers. The cheapest (and most limited, in both speed and capacity) device is a common portable cassette recorder, with $\frac{1}{4}$ " tape cassettes. From this, one moves to specially engineered cassettes and recorders, and thence to high-speed $\frac{1}{2}$ " or 1" reel-to-reel drives carrying thousands of feet of tape at very high speeds. Access times can be quite good for *sequential* access, along the tape, but *random access* time is poor at best, running to seconds or even minutes. Economy and a virtually unlimited total storage capacity (on numerous cassettes or reels; but only as many units as one has on-line tape-drives are actually accessible without human intervention) are the only advantages.

When we wish for practically useful EM, combining large capacity with relative economy and speed of random access, we must turn to *drum* or *disk memory*; and, nowadays, the former have been practically replaced by the latter. Disk memory is of two types: *floppy disk* and *hard disk*, the first being the cheaper, slower, smaller-capacity option. Floppy disks are flexible, have diameters of $5\frac{1}{4}$ " or 8", generally, and are removable from the disk-drive, so allowing one to build up an unlimited *library* of stored data. The information is stored on concentric circular *tracks* (not on a single spiral track, as on a sound record), on one or both sides of the disk. The number of tracks and the number of bytes per track vary (the density increasing with precision of engineering, and so with cost of the drive), but the total capacity of a floppy disk is in the range of 50KB to 1MB. The disks rotate at, typically, 300 rpm, and access time is governed by the time required to place the *movable head* on the right track, a fraction of a second, plus the fifth of a second taken by the head to traverse the circumference of the track, in search of a record; thereafter, consecutive bytes are accessed at some thousands per second.

Hard disks are rigid and have larger diameters. There are drives with anything from one to a dozen disks, rotating at about ten times the speed of

floppy-disk drives (and so diminishing the access time of records in a track), with one or several heads. *Fixed-head* drives naturally must have a head for each track (which costs more), but save head-movement time in random access. *Winchester* disks are movable-head drives with sealed-in disks, in which the heads ride very close to the disk, cushioned by the layer of air between. In floppy-disk drives, the head actually rides on the disk, eventually wearing it out. The capacity of hard-disk drive ranges from 10 MB to 100 MB in a single drive. Some movable-head hard-disk drives have removable disks or disk-packs, allowing for greater library storage.

The *I/O devices* are the computer's link with the outside world. In large mainframe computers, we see *paper card* (as in Hollerith or "IBM" cards) and *paper tape* readers and punches: the perforations in the paper carry the information. Increasingly in large computers, and almost universally in small ones, the main input is from the *keyboard* of a *terminal*. This is much like a typewriter keyboard, and depressing any key sends an 8-bit code to the computer. When the computer is waiting for input from this terminal, it reads the code and interprets it as a datum; when it is busy, either the message is lost or it is held in a "buffer" for subsequent input (this depends on how the connection is made and what the computer is made to do). It is quite common for the computer to be connected to several terminals, all competing for its attention. This is called *time-sharing*. The computer cycles around the terminals, looking for their several inputs and dividing its CPU time among them. The main output of the computer is to the display devices of the terminals; these are either *video displays* (cathode ray tubes, CRT, just like the screens of black-and-white or color TV sets; indeed, simple micros sometimes use ordinary television sets as display devices) or *printers* (in so-called *hard-copy terminals*). Of course, the computer may be connected to additional video displays and printers, of different qualities, as well as to *plotters*, a kind of printer for drawing graphs and diagrams. Many types and speeds of printers exist.

Other input devices, such as audio amplifiers (receiving signals from radio tuners, record players, etc), video receivers and recorders, laser disk drives, and a variety of scientific instruments, can all be classified as *transducers* (devices that transform physical quantities, such as position, conductivity, pressure, temperature, vibration frequency, or amplitude, into electromagnetic impulses) linked to *digitizers* (which convert such impulses into sequences of zero/one pulses). Output from the computer can similarly follow the reverse process, yielding visible or audible results, or the control of mechanical or electrical equipment. Thus computers can draw pictures (often, moving pictures), make music and other sounds, and can control appliances, machinery, and whole manufacturing processes.

In order to connect *remote terminals* to a computer, use is often made of telephone lines; and, for this purpose one employs a device called a *modem* (for "Modulator/DEModulator"), which converts the computer's digital signals