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# ELECTRONIC DATA PROCESSING*

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## INTRODUCTORY NOTE

Directors of health services, senior medical administrators and others who make major policy decisions cannot, as a rule, have personal knowledge of the technicalities upon which their decisions in part depend. This is especially true of subjects such as, for instance, radiation medicine, population genetics and electronic data processing (EDP) which are virtually new subjects based on rapidly expanding technologies.

In such fields, the policy maker's function is to assess critically, the advice given by specialists and to relate their proposals to the total situation in a country, region or medical institution, to health and medical needs and to the existing organization of services. To do this effectively, they need a sufficient understanding of the principles upon which a particular specialist relies and need to be familiar with his specialist terminology so as to be able to discuss the position with him.

On these grounds, the present paper has two parts which can be read independently of each other.

Part I has been designed to introduce a discussion on computer applications in public health and medical care services and to refer to the question of when and where EDP systems might be introduced advantageously.

Part II refers to the logical basis of computer operations, to the physical structure of digital machines and to the principles of computer programming, i.e. to the so-called hardware and software of EDP systems. Its purpose is to provide convenient background information and terminology for readers who need to refresh their minds on the subject.

## PART I

> "No other technical innovation has changed so many human activities in so short a time. An extension of man's brain power, it is transforming science, medicine, government, education, defence, business. It may transform man himself."
>
> Gilbert Burch (Writing in 'Fortune')

Calculating devices have a history that goes back to the ancient Greeks. Mechanical digital calculators have been in use since the 17th century. The first electronic computer (ENIAC - electronic numerical integrator and calculator) began operating only as recently as 1946.

In the intervening twenty years, computer technology has grown with such rapidity that it is not fanciful to speak of a computer revolution in many industrial societies.

In 1950, for instance, there were only ten to fifteen computers in the United States, whereas today, there are over 35 000, including over 2 000 large systems costing over one million dollars each. By 1975, there will be 85 000 installations including 4 000 large systems. The current outlay of the United States Government on computer installations is of the order of 1 000 million a year. Over 200 000 professional workers (systems analysts and programmers) are now employed in the United States in this field and computer operation is now the fastest growing occupation in the United States labour force. Comparable developments have taken place in other highly developed industrial countries, though generally at a slower pace. There are, for example, some 1 000 computers in the United Kingdom and some 20 000 professional computer personnel.

In the last twenty years, moreover, the early valve and wire machines have been superseded first by machines with transistors and printed circuits and more recently by machines using micro-modules or chip transistors, i.e. the 'third generation' of computers. In these machines, the micro-circuit printed on a silicon disk the size of a dot, replaces the old fashioned circuit measuring 14" by 18". This makes the modern computer faster and cheaper as well as smaller. For a scientific problem, for instance, a running time of an hour in 1950 has been reduced to a few seconds in a fast contemporary machine.

It is no exaggeration to say that the electronic computer has advanced our capacity to process information in a manner commensurate with the thousand-fold increase in our capacity to process materials brought about by the industrial revolution. Consequently, the actual and potential range of EDP in almost every aspect of organized human activity is a fact beyond dispute.

Electronic machines are already undertaking a variety of time-consuming tasks in industry and commerce, banking and accountancy, communications and air travel. They are employed in medical data systems, clinical practice and medical research. They are testing new drugs, helping to refine medical nomenclature, diagnosis and prognosis and they have already increased the availability of archives of bio-medical information.

Although it is true that electronic storage and retrieval of information and the processes of electronic computation are still under review in many areas of clinical-pathological medicine and public health, the EDP machine is already on the way to becoming routine equipment in large hospitals and in public health practice for a wide range of purposes. These include not only accountancy, statistics, and medical recording but also such operations as patient-monitoring, the assessment of X-ray pictures and ECG tracings and the application of automated biochemical analysis.

Computers now undertake the routine aspects of programming themselves; they communicate with each other (i.e. the output of one machine is used as the input of another); they are being used to design and control the production of more sophisticated machines.

It is indeed, evident that the electronic computer is a prodigious new tool in our technological civilization and a powerful new device in medicine whose potentialities have hardly begun to be exploited.

The Unique Character of EDP

The features of electronic data processing which distinguish it from the most highly sophistical mechanical methods are its universality, flexibility, capacity and vastly greater speed; of these characteristics, the speed of EDP is perhaps, at first sight, the most impressive.

The electronic computer does in seconds what previously took hours. It can solve in hours or days problems which a mathematician cannot solve in a lifetime because of the volume of routine calculations involved. If man's actions are measured in seconds, punched card machine operations in tenths of a second, the modern computers work in micro-seconds (millionths of a second) or in nano-seconds (seconds x $10^{-9}$). Indeed, so inconceivably fast is the powerful computer that without the organization of output devices and simultaneous discourse with a number of users (time-sharing) the 'on-line'* use of a modern machine would be prohibitory costly.

No less significant than the speed of computer operations is the wide range of computer uses. The electronic computer is a universal data processing machine. By this is meant that the electronic computer can store and process not only numerical data but also ordinary words no matter what the language, length or form of the texts. It can also handle graphs and two-dimensional visual patterns in almost any form. Or to generalize, any data which can be recorded on a typewriter can be computerized. These, it should be noted, include pictures and graphs. A radiograph, for instance, can be digitalized by representing it as dots of differing densities, or tracings of ECG and EEG by sequences of number-pairs. Whether the computer is the most

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*'on-line' describes a system in which signals from the user pass directly into the computer and the results are presented directly to the user.

effective device for the routine storing of these patterns is another matter. The radiograph, for instance, requires 200 x 200 dots to the sq. inch, and ten grades of density per dot. A film 10" x 10" would, therefore, require $400 \times 10^6$ digits for its representation, and the micro-film is consequently a preferred device except for certain research purposes.

It should be stressed that the electronic computer is a data engine which, though a calculating machine without precedent, is far more widely used for storing, retracing and processing, editing, selecting, classifying and counting information in the form of the printed word.

The flexibility of the machine is unique in several respects. Firstly, the machine contains a structural unit for storing instructions (programme of operations) for processing data as well as a unit for storing the data to be processed, i.e. operations and operands can both be fed into the machine and the entire sequence can then be carried out without human intervention. Secondly, the sequence of operations at a given point can be varied according to the results of earlier operations, a capacity which enables the system to simulate intermediate discretion or decision. Thirdly, and by no means least important, a sequence of operations can be repeated at will on successive batches of data and any programme can be stored in permanent form, repeated at will or can be copied for use on machines elsewhere, with enormous economy of human effort in the long run.

The combination of flexibility and a <u>capacity</u> to store prodigious amounts of information with great accuracy in small space, and to recall or process the information (select, classify, count, edit) at great speed, make the computer a valuable device in contributing to the managerial process.

Automation of data processing is not synonymous with mechanization and much more than a labour saving device. Automation is mechanization in which provision is made for a flexible strategy or alternative operations which can be selected according to the current course of events. It possesses, therefore, many of the characteristics of management, i.e. adjustments or modifications of processes according to circumstances.

Automation, like management, depends on a sequence of activities beginning with observations which are quantified and ending with a directive. Between the two are processes such as the recording of data to indicate trends or departures from a norm, data transmission from many sources, compilation, assessment, decision, and the retransmission of information in the form of a directive.

Current managerial practice is, as a rule, based on inadequate data (i.e. human eye-brain information) and related to past situations by a managerial group convened to pool their resources. The process has obvious limitations. Individual experience is restricted, deficiencies in memory or recall are common and consultation committee procedures are often so lengthy that decisions do not keep pace with events. Automation has no such limitations and can be regarded in one sense as the instrumentation and processing of information to facilitate decisions about changing situations, such as arise in disease control programmes, hospital management, patient-monitoring and the administration of health services.

It is now common knowledge that the electronic computer can receive information and transmit results by land, line or radio to and from geographically remote input and output devices, such as the teleprinter. The use of remote computers by means of 'on-line' connexions is already commonplace and growing rapidly, e.g. M.I.T. computable time sharing system and the proposed G.P.O.* national computer network in the United Kingdom.

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*The G.P.O. is to set up a £ 12 000 000 data processing service for the use of private firms based on an inter-linked network of 20 computers in major cities. The service will deal with post office jobs and research, but will also be hired to businesses and local authorities throughout Britain. It is expected that the hire charge will be something less than the previously standard rate of £ 200 per computer hour.

The importance of this kind of development for those who have to make decisions about the establishment of EDP systems is obvious.

Before leaving this aspect of the subject, it is well to refer to a self-evident feature of computers which they share with all man-made devices. The computer has been called the electronic brain. This is a misnomer. The question, "Can computers think", which has been much discussed, is seen for what it is alongside such questions as "Can a pencil write" or "Can an aeroplane fly". Of course, the computer cannot think. It cannot understand, feel, will, establish human priorities or make decisions. The computer can only process data which has been fed into it and perform only operations embodied in instructions compiled proximately or remotely by a man. The computer can solve only problems which someone already knows how to solve; it can solve a mathematic problem only when a method of solution has already been propounded.

In the foreseeable future, we shall have smaller, cheaper and faster machines, special purposes computers, mini-computers, machines with large capacity memories constructed from bulk materials without fabrication, and machines which are logically closer to the user. The use of "mark-sensing" to avoid the need for transferring original data to tape will increase, and we can expect computers ultimately which will accept data in handwriting or the spoken word. Modular installations will be the rule, programme libraries widespread and transmissions over distances, a commonplace. It is by no means unlikely that within a decade or two, computer services in many countries will be provided as a public utility system on a scale comparable with the existing supply of electric power. It is already foreseeable that EDP will ultimately provide an extension to human sensory-brain reactions of the same order as the extension of muscle power which chemical and electric power have brought about.

Computer Applications in Health Services and Bio-Medical Service

Enough has been said to indicate that the time has passed for pleading the case of EDP in medical care and other health services. During the last few years, there have been many conferences and symposia on medical computing whose proceedings make clear that the time has also passed for presenting a catalogue of computer applications in the bio-medical science and medical practice. To take an instance in the clinical field, the papers presented at a Symposium on Progress in Medical Computing (see reference, Appendix IV), held in London 1965, included the use of computers in: diabetic screening analysis; psychiatric research; health management; analysis in the bio-medical sciences; analysis of radio-isotope investigation; radiation treatment planning; dietary analysis; diagnosis of non-toxic goitre; routine tracer tests; processing of biochemical test data; statistical use of laboratory data; preparation of laboratory reports; cardiovascular analysis; cardio-respiratory diagnosis.

The Report of the WHO (European Region) Conference on the Application of EDP Systems in Health Administration* (Copenhagen 1964) covers a wider field, including medical documentation, epidemiology and integrated medical information systems in hospitals.

To ask about the range of EDP applications in health services is indeed rather like asking about the uses of paper and pencil, mechanical tabulation, filing systems and instrumentation in medicine. As everyone knows, they are tools which are used in every field of medical science, medical practice and public health. The right question to ask, where and how they can be used to the best advantage. It will be sufficient here to cite certain areas in which EDP is used, and to distinguish broadly:

a. applications to replace established procedures formerly undertaken by other means, and

b. new applications to undertake tasks which were not feasible before EDP was developed.

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*EURO - 309.

Applications under the first heading include:

A. Management

For example, finance, accountancy, staff records and duty rotas; management in paramedical fields such as dietetics, hospital catering and bed allocations. An increasing volume of clinical and administrative work formerly done by hand or electro-mechanical methods is now computerized.

B. Health Statistics

The advantages of using computers for statistical processing as compared with conventional punch-card machines, include:

i. Increased processing speed. The value of statistics declines with the delay in obtaining the results of the analysis of data. Voluminous data of vital statistics, disease notifications, hospital records, morbidity surveys and health insurance returns can be processed on a computer much more quickly than on conventional punch-card machines.

ii. Wider scope in processing. Linkage of separate records is difficult and can be done only on a limited scale on the conventional punch-card machinery. Computer applications have definite advantages in this domain. Complicated tabulations and calculations (totals, averages, standard rates, etc.) can also be done easily on a computer.

iii. Credibility tests. Frequently credibility testing of some of the information contained on the original source documents may be incorporated in the processing programme on the computer. In addition to the detection of errors, it is sometimes possible to programme for their automatic identification and correction.

C. Medical Records

For storage of medical records, magnetic tape and discs have the advantages of compactness (i.e. they occupy much less space) coupled with rapid and accurate retrieval. This permits a more complete and effective utilization of records than is usual at present.

Generally, computer information storage and retrieval has many advantages over paper filing systems and human memory. The volume of information storable is much greater (capacity). There is greater speed of retrieval (accessibility). There is no attenuation factor with the passage of time (accuracy of retrieval).

D. Publications and Medical Archives

MEDLARS (Medical Literature Analysis and Retrieval System) is perhaps the best known example of the storage and retrieval of published material which has been computerized for some years. MEDLARS uses a Honeywell 800 computer employing a permanent magnetic tape store. The input is by perforated tape and the output by a GRACE printer (Graphic Arts Composer Equipment). It is unnecessary to stress that the rapid development of medical and allied sciences and the mountainous volume of medical communications make the extension of electronic storage and retrieval essential for speedy and convenient access. In this context, EDP is an instrument of the technology of communications made necessary by the volume and complexity of technical communications and the need for comprehensive or speedy access.

The WHO Information Service (WHO Headquarters) described in later pages (see page 35) is an example of computer storage and retrieval of research data.

Examples of new applications are:

1. The standardization of medical records, i.e. the conversion of soft data into hard or quantifiable data. This applies especially to medical opinions requiring corrections for inter-observer differences, patterns of body events such as ECG and EEG, and disease descriptions.

2. Classification analysis as an aspect of nosology and the statistical classification of disease.

3. Medical diagnosis and prognosis.

Computer systems for diagnosis are already in regular use in many places. For instance, a computer is now being used at the Vishnevsky Institute of Surgery in Moscow for diagnosing infectious diseases, diseases of the liver, kidney and stomach and heart diseases. It is reported to be far more exact than most skilled specialists.

As computers become smaller and cheaper, this development may prove to be of great practical significance in countries where medical auxiliaries are used extensively because of the relative scarcity of doctors.

4. The compilation of individual health records for whole populations or their component groups, thus preparing the way for national systems of such records.

5. For processing and printing out results of mechanized and automated laboratory procedures. The results of these procedures are usually available primarily as continuous records in the form of graphs. The graph is digitalized for feeding into a computer. Laboratory results can be transmitted to and from a central computer, to hospital wards or operating theatres without storage, i.e. 'on-line'.

6. The indication of trends of disease incidence, congenital abnormalities, birth rates, etc. which may require investigation or measures of control.

7. Patient-monitoring, e.g. the continuous recording of pulse rate, blood pressures and ECG and the detection of variations which exceed prescribed limits.

8. The construction of experimental models and simulation of genetic processes, and the construction of mathematical models which simulate medical events in populations and thus enable data to be manipulated experimentally. The flexible models which have thus been made available

by the computer simulations can often replace experimental physical models as used in the past. They are especially useful for the manipulation of data relating to large populations.

In a word, the electronic computer has proved itself as an instrument of quantification and interpretation, and thus a means of introducing greater precision in medical science and practice as it does in many other fields.

The Introduction of EDP into Health and other Departments

A decision to introduce EDP into a Central Department of Government or Health Service for the first time depends on many highly technical considerations and usually requires a great deal of specialist advice. Among the questions which have to be settled are:

1. The area to be computerized and the timetable for progressive transfer to EDP.

2. The system to be employed.

3. Capital and running costs related to estimated savings.

Such questions cannot be discussed exhaustively in a short paper, but the following notes indicate some of the points which have to be taken into account.

The Opportune Moment for Introducing EDP

It is far from easy to decide when the time is ripe for the introduction of EDP because of the rapid technical progress of machine design and EDP systems, and because computers can be expected to become progressively cheaper, more efficient and easier to use with every year that passes. The advantage of waiting has to be balanced against the fact that transfer to EDP on a big scale takes a fairly long time after a start has been made. A compromise solution is to make a modest beginning in a limited area and to extend in the light of circumstances and experience.

Separate Smaller Installations or Large Time-Sharing Systems

A general answer cannot be given to this question. In highly computerized countries both independent, small computers and giant systems have been found necessary to meet the needs. With the growing efficiency of telelinks and interrogating systems, the present trend favours increasingly the use of large machines. Leaving aside the question of cost, the establishment, in the first place, of one or more intermediate size installations (e.g. in a central department of Government or a hospital) would, as a rule, appear to be the prudent course.

Certain Practical Considerations

Though for some purposes computers are purchased outright, a more usual arrangement is to hire a computer at a yearly rental which includes installation and maintenance costs. Another arrangement which is likely to become increasingly common is to buy computer time. Under this arrangement, the customer has a contractual claim on a computer installation for a stated number of hours of computer service.

The staff of a computer installation of intermediate size, consists as a rule of a director, two or more experts in systems analysis, two or more professional programmers, and a number of punch-card operators. In some instances, the programmers are attached to the departments using the computer's services and the programmers then work in close association with the experts in systems analysis. In other cases, programmers work in the computer unit exclusively. The services of a computer engineer for maintenance and checking the installation is usually provided on a contractual basis by the suppliers.

It is reckoned that about half the cost (in man hours) of operating is for machine running and maintenance and about half for programming and interpretation, i.e. 50 per cent for hardware and 50 per cent for software.

As programming is a lengthy business and as only little computer time is required for completing even elaborate and lengthy programmes, machines are almost invariably under-used for some time after installation. If under-use is to be avoided, a fairly lengthy period, i.e. one or two years is required for preparatory steps before the computer is installed. These include systems analytical work, the training of operating staff, and no less important, instruction of senior staff members on the proposed installation and a review of the administrative and technical fields which can usefully be computerized (i.e. statisticians, hospital administrators, finance officers, laboratory directors, senior administrators, university academic staff, research workers).

Technical officers such as administrators and statisticians need to work closely with the professional programmers. The contribution to programming processes made by these officers depends in large measure on the type of programme to be prepared. Broadly speaking, there are two types of programme in this sense:

a. programmes with a large input and output and relatively little processing, e.g. record storage and retrieval;

b. programmes with small input and output and a large volume of processing or compilation, e.g. statistical and mathematical problems.

Programmes of the first type can usually be undertaken by the professional programmer with a small amount of assistance from administrative and technical staff. A programme of the second type usually requires a great deal more collaboration between statisticians and scientists and professional programmers.

In the areas of finance and administration, unless speed is of paramount importance, EDP is not usually economical for non-repetitive procedures. Generally, computerization for the sake of filling computer time should be resisted although the risk of overloading a machine for the first two or three years is small. Under-use is far more likely to be a problem than misuse.

Note on Costs

Because of the wide range of machines and systems now on the market and range of circumstances in which they are employed, a lengthy reference to capital and running costs would have little value. The following examples are an indication of the order of expenditure involved in installing and running EDP systems.

Example 1. The International Computing Centre of the United Nations

The United Nations system comprises a 7044 system, a 1401 system and certain auxiliary and tabulating equipment. Estimated costs for 1968 are given below:

Rental Charges $ 666 000

a. $ 486 660 for a first shift of 176 hours for the 7044, plus extra shift time of 100 hours per month.

b. $ 147 545 for the full year first shift rental of the 360/30, plus an extra full shift.

c. $ 15 000 for the rental of a data plotter
$ 16 000 for the rental of key punchers and verifiers and a sorter.

A staff establishment of 47 is provided for - 18 professional and above and 29 general service.

Example 2. The WHO Data Processing System at Headquarters, Geneva

This is an IBM System /360 with CPU (model 30). It is an instance of an intermediate sized installation with a printer output of 240 lines per minute, i.e. approximately a quarto sheet of typescript every eight seconds.

Budgetary provision for 1969 is as follows:

| | |
|---|---|
| Hardware (rental including maintenance) | $ 260 000 |
| Staff (31 posts) | $ 218 000 |
| Supplies | $ 30 000 |
| Estimated total annual cost | $ 508 000 |

It should be noted that an initial capital outlay is required for the housing and site preparation of installations which might be expected to lie between $ 100 000 - $ 500 000 according to local circumstances.

Example 3. Small Electronic Office Computer

The Olivetti P203 office computer is an example of a small modern machine. The current price is $ 5 600, which includes programming and training support. The Olivetti P203 is in effect a multi-purpose calculating machine with internal programme storage and permanent off-machine storage on magnetic cards. It can be used for commercial, financial, statistical, mathematical, scientific and technical operations.

The programming support provided comprises access to standard programmes and a programme library. Regular programming courses are held which users can attend free of charge.

Cost per Job

Clients who use computer time on contract without owing or running an installation themselves are clearly interested in the cost per job rather than capital and maintenance costs.

The WHO computer installation might be expected to have an overall running cost of some $ 100 per hour. This approximate estimate is based on 100 hours running time per week for 50 weeks per year. With longer operational periods, the hourly cost would clearly be reduced.

There is insufficient information to make even an approximate estimate of the running costs of the United Nations installation. It is, however, likely to be between $ 100 to $ 150.

Time hiring on large EDP time-sharing systems runs at $ 50 per hour upwards, but may well be only half this figure in the not distant future.

# PART II

## Data Processing Systems in General

Data processing comprises an enormously wide range of activities, such as the performance of mental arithmetic, every-day figuring with paper and pencil, the employment of the desk calculator, the use of mechanical counter-sorters and tabulators, the preparation of a dictionary or bibliography and the use of a conventional library for systematic documentary searches.

These, and all other data processing systems have three essential elements in common, namely:

1. AN INPUT of information (meaningful data) entering the system, i.e. information in conventional symbolic form in an appropriate medium (e.g. numerals on paper, punched cards, a library of books with its catalogues and indexes).

2. PROCESSING - within the system, i.e. the performance of a sequence of operations on the data, the operations being so designed and ordered as to achieve a predetermined objective.

3. AN OUTPUT - from the system, i.e. making the result available in suitable form, (e.g. the written result of a paper calculation; the printed output from a mechanical tabulator in the form of statistical tables, invoices, payrolls and the like; the results of calculations from a computer).

However complex the operations of processing, they are either -

a. Calculations, which can be performed only on numerical data, or

b. Discriminatory Procedures such as selection, sorting, classifying and editing, which can be performed on non-numerical as well as numerical data.

Data Processing in the Binary Code and the Internal Operations of the Computer

To understand how the computer performs elaborate calculations, it is useful first of all to recall that every mathematical operation, no matter how complex, can always be reduced to an arithmetical sequence.

Thus, for instance, a system of linear equations can be solved by performing arithmetical operations on the numerical coefficients of the variables, and the value of any exponential or trigonometrical function can be obtained from an arithmetical series.

e.g. $$\sin \sigma = \sigma - \frac{\sigma^3}{3} + \frac{\sigma^5}{5} \quad \ldots\ldots \ (\sigma \text{ in radians})$$

Or again, to take a familiar example which we shall later use to illustrate computer programming, the value of $\chi$ in the equation

$$a\chi^2 + b\chi + c = 0$$

is given by the expression

$$\chi = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

i.e. in terms of the numerical coefficients.

Next, though at first glance less obvious, the arithmetical operations of addition, subtraction, multiplication and division can all be reduced to addition (including counting, which itself is a simple additive process).

Multiplication can clearly be done by repeated additions, e.g. 24 x 4 = 24 added to itself four times.

Likewise, division can be done by repeated subtractions and counting. Thus to divide 24 by 4, four is subtracted from 24, and again from the remainder and so on. The number of times this can be done (counting) without leaving a negative remainder, i.e. a remainder 0 is the required quotient.

The way in which subtraction can be replaced by addition is somewhat more involved. This operation is explained in Appendix I.

Finally, the operation of addition is, in the last analysis an elaboration of the proposition that 1 + 1 = 2, or more precisely of the equations

$$0 + 0 = 0$$
$$1 + 0 = 1$$
$$0 + 1 = 1$$
$$1 + 1 = 2$$

Given these facts, it follows that a machine in which sequences of 1s and 0s can be represented and added according to the above equations can perform any mathematical operation which is humanly possible. There are, of course, short cuts and elaborations but a fundamental fact about the digital computer is that it works exclusively in 1s and 0s, or as we say, it is a binary machine.

Computers have been built which use the familiar decimal system, but modern machines use the binary code exclusively because it is logically simpler and because machines using this code are easier to design and construct.

To understand the internal operations of the computer and its so-called machine language, it is, therefore, necessary to refer to the basis of binary notation.

## Binary Notation

It will be recalled that in the familiar decimal system of counting and number representation a digit may have one of 10 values, i.e. 0 - 9; and the place value of a digit signifies units, tens, hundreds, thousands and so on in ascending powers of 10 from right to left. Thus, for example, the decimal number 4382 stands for $(4 \times 10^3) + (3 \times 10^2) + (8 \times 10^1) + (2 \times 10^0)$ or 4000 + 300 + 80 + 2.

In the binary system of notation, the base is the number two, instead of the number 10 in the decimal system. The binary system uses, therefore, only two digits, 0 and 1. The place value of a digit signifies powers of two. Thus, for example, the binary number 1010 stands for $(1 \times 2^3) + (0 \times 2^2) + (1 \times 2^1) + (0 \times 2^0)$, or 8 + 0 + 2 + 0 = decimal 10.

The binary representation of the decimal numbers 0 - 15 is as given below:

| Equivalent decimal number | Place value 8 | 4 | 2 | 1 |
|---|---|---|---|---|
| | (binary digits) | | | |
| 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 1 |
| 2 | 0 | 0 | 1 | 0 |
| 3 | 0 | 0 | 1 | 1 |
| 4 | 0 | 1 | 0 | 0 |
| 5 | 0 | 1 | 0 | 1 |
| 6 | 0 | 1 | 1 | 0 |
| 7 | 0 | 1 | 1 | 1 |
| 8 | 1 | 0 | 0 | 0 |
| 9 | 1 | 0 | 0 | 1 |
| 10 | 1 | 0 | 1 | 0 |
| 11 | 1 | 0 | 1 | 1 |
| 12 | 1 | 1 | 0 | 0 |
| 13 | 1 | 1 | 0 | 1 |
| 14 | 1 | 1 | 1 | 0 |
| 15 | 1 | 1 | 1 | 1 |

4 digit binary numbers

It will be noted that four binary digits (places) are needed to represent the decimal number 0 -15. Likewise, five digits would be needed to represent the decimal numbers 0 - 31, six to represent 0 - 63 and so on. The binary digits 0 and 1 are called "bits" ("bit" being an abbreviation of binary digit). The 0 is described as a no-bit, and the 1 is usually called a bit.

It will be evident that just as alphabetic characters and therefore, of course, descriptive matter in ordinary words can be coded as decimal numerals, they can equally be represented by combinations of noughts and ones, i.e. by binary numbers, - or by dots and dashes as in the familiar morse code. Five binary places, giving $2^5$ or 32 permutations are sufficient to represent the letters of the alphabet with a few to spare for punctuation marks. Thus, 00000 can stand for a, 00001 for b and so on in a manner analogous to the number representation shown above.

The complementary physical fact to the computer's reliance on binary operations is that essential computer components are bi-stable devices. That is to say, they have only two alternative states, one of which can represent "0" and the other "1" - or Yes and No in answer to a question. Examples are a hole or no-hole in a punched card or in paper tape, a switch which is either open or closed, a light on or off, an electric pulse or no-pulse, or a magnetic field which is either clockwise or anti-clockwise.

The following example of binary addition illustrates the simplicity of binary arithmetic compared with operations in the decimal system.

```
  1010   (decimal 10)
  1010   (decimal 10)
 -----
 10100   (decimal 20)
```

N.B. 1 + 1 = 0 and carry 1.

Similarly, the multiplication of two binary numbers is done by a sequence of shifts to the left followed by additions. Thus -

```
  1011   (decimal 11)
   101   (decimal  5)
 ------
  1011
 00000
101100 (1011 shifted two places to left)
------
110111   (decimal 55)
```

The steps by which the computer undertakes discriminatory operations such as sorting, ordering and selecting from medical and other records is illustrated by the following simple examples. Their elaboration for more complex procedures can readily be envisaged.

<u>Example 1</u>. To select from a batch of records those of patients 50 years and over.

a. Programme to enter chronological ages in computer register one after the other.

b. In each case subtract 49.

c. Print out when result is 0. i.e. a positive number.

<u>Example 2</u>. To identify records of patients with a given disease (numerically coded disease category). Programme machine to subtract the code number from each patients disease code number in turn and disregard results other than zero. If, for example, the number 745 represents cerebral haemorrhage, then the subtraction of 745 from recorded code numbers in turn would give zero uniquely for cerebral haemorrhage.

<u>Example 3</u>. To find the largest of three given numbers, a, b and c. The problem is first broken down as follows: find (a-b), and if the result is positive then a>b. It is then only necessary to find (a-c) to decide whether a is also > c; if so, then a is the largest number, and if not, c. If, on the other hand (a-b) is negative, then b>a, and the next step is to find (c-b) which shows c to be the largest of the three numbers if positive and b to be the largest if negative. By extension, any number of records stored in the computer memory can be sorted into alphabetical order, order of chronological age, period of in-patient stay in hospital and so forth.

It is convenient to mention here another important way in which a change of sign is used to vary the sequence of machine operation. A computer generally proceeds in sequence from one programmed instruction to the next. When the machine is instructed to make a conditional transfer (so-called "branching"), it takes the next instruction in sequence only if a number it has computed is positive. If the number is negative the machine takes instead an instruction out of sequence as specified in the programme. This operation enables the computer to vary its sequence of operations at one point or another in the course of a computation and accounts for much of its flexibility. The basis of machine recognition of a change of sign is explained in Appendix II.

Fundamentals of Computer Construction

The structural requirements which a digital electronic machine has to meet are easily related to the foregoing account of basic logical operations. The digital computer clearly consists of four basic components:

1. An input mechanism for getting data and instructions into the machine in binary form.

2. An output mechanism for ejecting processed data after translating it back into alpha-numerical form.

3. A mechanism for storing data and instructions in binary form (the machines memory).

4. A processing unit in which arithmetical and logical operations can be performed on data (the central processing unit, CPU). The CPU also controls the working of the machine as a whole.

A unit called the console provides for external control enabling the operator to monitor and supervise machine operations. (See diagram in next Section).

The arithmetic-logic unit of the machine is designed to perform the elementary operations into which, we have seen calculations and discriminatory operations, however complex, can be broken down and incorporated in the computer programme, namely:

1. Binary addition (including counting).

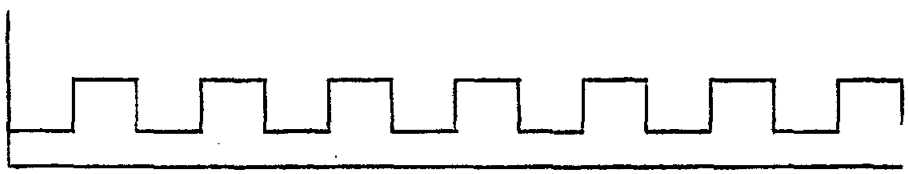
2. Moving data from one location to another (internal move operations).

3. Comparing the identity of two items of information and if necessary initiating alternative operations according to a previous result. Or what is the same thing, responding to a zero result (or change of sign from + to -) in an internal register.

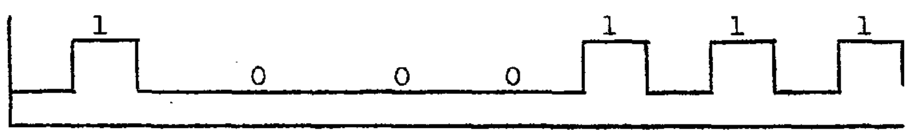
Before considering the lay-out of a modern computer, it remains to enquire into the character of events which enable the machine to store information in code and perform on it the required logical and arithmetical operations.

In the electronic computer, data are represented by sequences of electric pulses of extremely short duration, i.e. of the order of a millionth of a second. The machine embodies a pulse-generating equipment which produces pulses at a standard rate and related to a standard time base provided by the machine's electronic "clock". Pulse trains are tapped off to represent numbers or instructions, which are thus uniquely symbolized in binary form according to the pulses which are present or absent. The basic operation of the electronic computer is to count pulses. A standard interval of time for the machine, known as the machine cycle, fixes the number of pulses in a basic machine operation.

The diagram(b) illustrates the representation of the binary number 1000111 by the suppression of pulses in the virgin train(a).



(a) Series of pulses

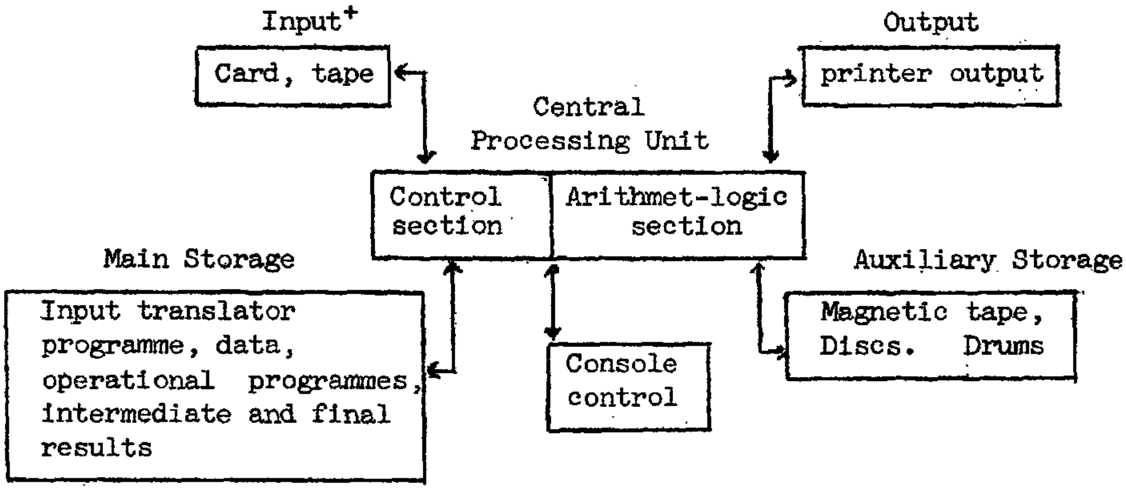



(b) Pulses and absence of pulses representing a binary number (see later)

Lay-Out and Functional Units of the Computer

The general lay-out of the units of a digital computer* is shown diagrammatically below and the general appearance of a data processing system is shown in the accompanying illustration (A). A brief description of the units follows. Further particulars can be obtained from the manufacturer's information manuals.

Computer Lay-Out




+Also serves as output on tape or cards.

*Digital and analogue machines

The present paper refers only to the digital computer but there are in fact two types of electronic computers, the digital and analogue.

The basic operation of the digital computer, we have seen, is to count. In other words, it works directly with numbers and is essentially a machine for performing arithmetical operations.

The analogue machine, on the other hand, performs mathematical operations by measuring. In this machine all quantities at all stages - input, output and intermediate stages - are represented by physical magnitudes; usually these are voltages which represent the size of the variables which the machine is handling. It is essentially a calculus machine or an integrating machine.

The analogue machine is especially suitable for handling continuous variables and is used particularly for solving problems in dynamics and kinematics which are concerned with quantities varying continuously with time. For the right problem the analogue machine, though less accurate than a digital machine, has the advantages of cheapness and speed.

There are few medical problems outside the laboratory, for which the analogue computer is the machine of choice and in any event, problems with continuous variables can always be digitalized, i.e. represented in digital form.

Input-Output Devices

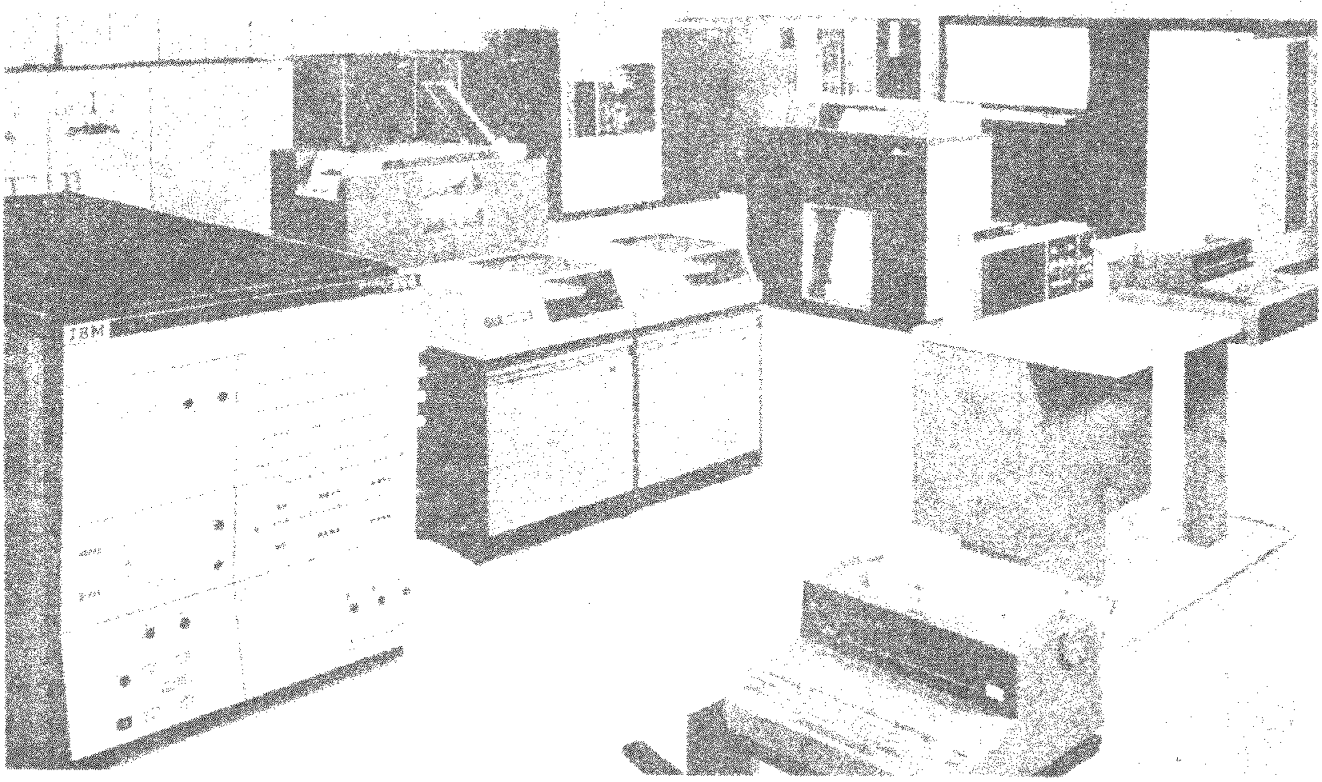
Information for feeding into the computer system is commonly in the form of punch-cards, magnetic tape or paper tape. For some purposes magnetic ink characters (e.g. on banker's cheques) and optically recognizable characters (e.g. graphs and tracings) are also used. The input device reads information from one of these recording media and converts it into coded patterns which the machine translates into patterns of electrical pulses. Most input devices are automatic in operation and are controlled by a translator input programme which is permanently stored in the central processing unit. The process of converting data coded in decimal by the translator input unit into binary form is described in Appendix III.

The output devices in common use include the chain printer in which characters are assembled on a moving chain and printed a line at a time by magnetically-activated hammers; the wheel printer equipped with 120 rotary printing wheels; and the typewriter which is activated in accordance with a stored programme. (See illustrations C and D.)

The output from wheel printers is about 600 lines per minute and from chain printers about 1 100 lines per minute, i.e. approximately the content of 20 printed octavo pages. The typing speed of the output typewriter under automatic control is about 120 words per minute or about a foolscap sheet, double spacing every two minutes.

Magnetic tape is less expensive, less bulky and speedier than punch-cards as an input medium. The information on 100 000 punch-cards which cost about £ 70 and occupy a volume of three cubic metres can be recorded on 720 metres of magnetic tape, costing about £ 16 and occupying a volume of only 25 cubic centimetres. This length of tape would take only two to three minutes to run through as compared with some two hours for 100 000 cards. Magnetic tape is especially useful for assembling programmes from punch-cards and for storing data which may need up-dating. Paper tape, on the other hand, is used

A



System 360 computer, models 70 and 40 interconnected, with magnetic tape units, teleprocessing unit, disk storage, drums and magnetic cells, card reader/punch, printer and additional core storage.

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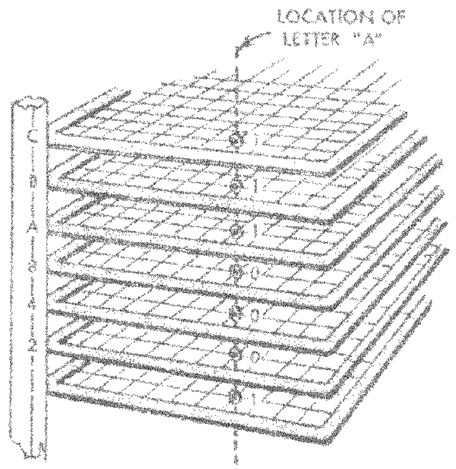
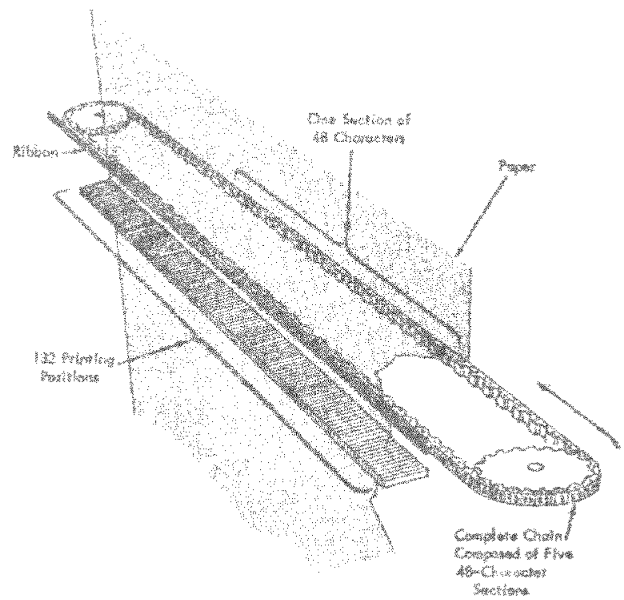
B



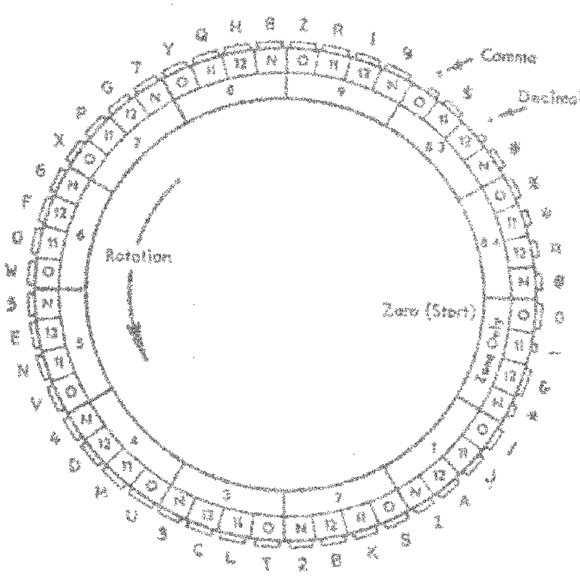

BCD Character Location    Storage Devices

C




Print Chain

D




Print Wheel

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particularly for recording data for dispatch to a computer installation some distance away.

At output, binary results are translated by a teleprinter-interpreter combination which translates them into alpha-numeric form and prints or types them automatically. The lay-out of typescript, form of tabulation or design of graphs are also taken care of by the machine in accordance with directions in the programme. Both input and output devices are said to be "off line" as they are not directly controlled by the computer.

Storage Devices

Storage is classified as "main" or "auxiliary".

Main Storage

A cardinal feature of internal computer operations is that all data has to pass into main storage before it is available for processing, and all results of processing have first to be recorded in main storage before they can be put out. The main storage unit of a computer therefore, records data from the input unit and furnishes data to the output unit. It also supplies data and instructions to the central processing unit and records processed data from this unit. A second basic fact is that storage consists of elements referred to as locations or cells, each of which holds a specific unit of data (usually a computer 'word') each of which has an assigned 'address' represented by a number. An instruction always consists of an operation and an operand or codified item of information specified by an address. It can also include a control function such as a left or right shift of the primary number in a register, the rewinding of a reel of tape or a lay-out instruction. The time required to locate and transfer information to or from storage is called access time. For modern storage units, it is a few millionths of a second.

The usual form of main storage is the so-called core storage. This is, in effect, a stack of frames each bearing a lattice of fine wires on which large numbers (hundreds of thousands) of tiny rings of ferro-magnetic material are strung. The ring, or magnetic core, is a fraction of a millimetre in diametre. The passage of an electric current magnetizes the core giving it a polarity, depending on the direction of the current. Reversing the direction of the current reverses the polarity of the core. The core is, therefore, a two-state element appropriate for binary representation. (See illustrations E, F and G).

Central Processing Unit

The central processing unit activates and controls the entire computer system, in accordance with the programmed instructions. Its functions include the control of input-output devices, entry or removal of information from storage, and the activation of the arithmetic-logical section. This section contains the circuitry for performing arithmetical calculations and such operations as selection and discrimination.

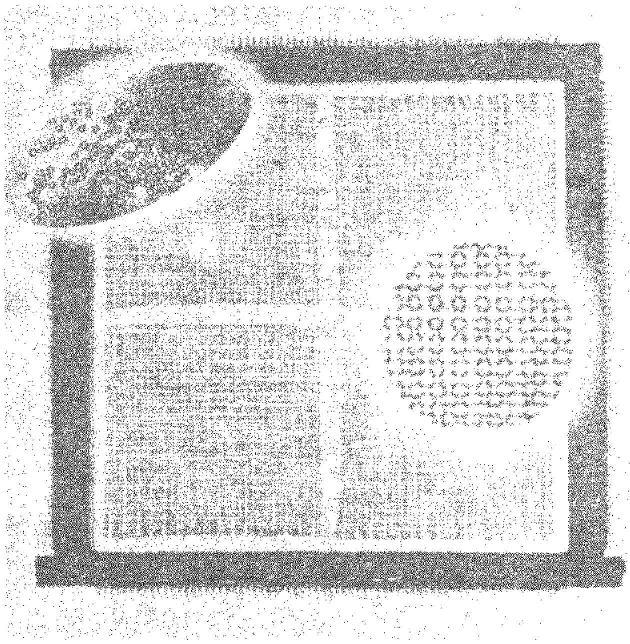
The unit also embodies stores called registers which hold information received from storage for processing, and pending transfer to storage after processing. The registers are named according to their function. An accumulator, for instance, accumulates results; a storage register holds addresses or instructions taken from storage, or on their way to storage. Small neon lights on the console indicate the contents of registers and the stage of machine operations.

Auxiliary storage

For the storage of large quantities of information such as, for instance, are contained in tens of thousands of medical records or medical publications, auxiliary storage devices are used. An obvious advantage is its permanence compared with the transient character of main storage employed in the course of processing data.

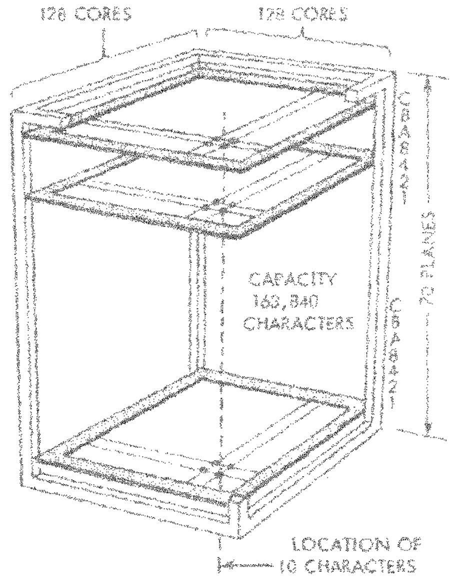
A valuable type of auxiliary storage is magnetic disc storage. In this device data are stored on a thin metal disc about the size of a 14" gramophone

E



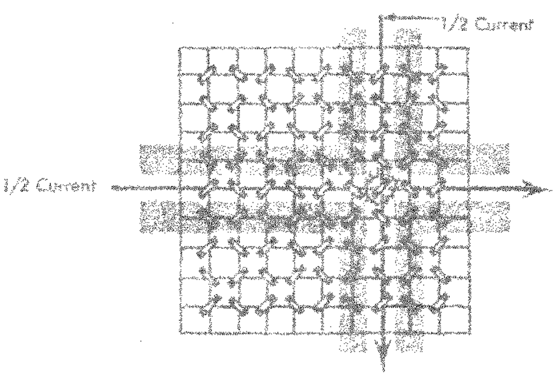
Magnetic Core Plane

F

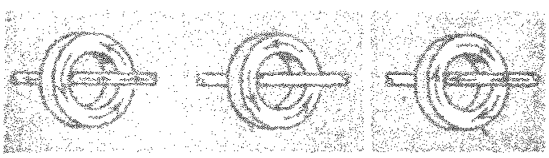



Schematic, 163,840 Position Storage

G




Magnetic Core Plane




Reversing a Core

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record and coated on both sides with a magnetic recording material. Each item of information is stored as magnetized spots in concentric tracks on both upper and lower surfaces of the discs. The discs are mounted in packs or modules. The items of information have an address or location defined by the position of the disc in the module, the disc track and the position of the information on the particular track. The tracks are accessible for entering or retrieving information by spinning the discs and positioning read-write heads between them. The particular advantage of this storage is that it enables data to be recorded or retrieved randomly, i.e. item by item as required from specific addresses. In this respect the process differs from retrieval of data recorded on magnetic tape which can only be retrieved sequentially, i.e. by running the tape through the machine and searching through all the records in the order in which they were recorded, and from retrieval from drums at each rotation of the drum (periodic access).

Information in auxiliary storage must be routed through main storage to become accessible to the central processing unit, or to input or output devices.

Computer Circuitry

A knowledge of circuitry is not required by the computer user or for that matter by the programmer. For the present purpose, it is sufficient to recall that circuits in the machine are designed to carry out logical sequences of elementary operations on information coded in binary form which has been fed into the machine. Circuits also control the internal working of the machine according to input instructions in binary by moving data from one place to another within the machine, activating output mechanism and so forth. In other words, the circuitry of the system embodies the logic of the computer's operations.

The old-fashioned electronic circuit measures 14" x 18". It is made up of various components linked by wires. Its purpose is to receive weak signals, to make them clear and strong, and interpret them in terms of sounds and pictures.

Micro-circuits are the same circuits reduced to the size of this dot*, and about five thousandths of an inch thick. A micro-circuit is built up in layers which make up the transistors and other components. A metallic layer links them up to make a complex electronic unit.

The computer programme

The programme which activates the computer (machine programme) consists of a sequence of elementary instructions in binary code, each of which corresponds to a basic machine operation. Likewise, alpha-numeric data must also be entered in the machine in binary code.

Writing a machine programme for the electronic computer would, therefore, be a lengthy and tedious business because of the large number of elementary operations involved. It is greatly simplified by a provision which enables the machine itself to convert a decimal input to binary form. The steps in the conversion are given in Appendix III. Even so there is still a wide gap between machine instructions and the ordinary language of human intercourse.

One way of bridging the gap is to employ a trained programmer to act as an intermediary between the user, i.e. the man with the problem, and the computer itself. A way of simplifying the programmer's task, as is now done on all present day computers, is to use programme languages which consist of ordinary words and phrases or of stylized conventions which the machine translates into machine instructions. For this purpose, computer manufacturers supply 'auto-code' manuals and translator programmes.

Two widely used computer languages are FORTRAN (formula translation) and COBOL (common business oriented language). Fortran is designed particularly for scientific and engineering use. It is a highly compact and somewhat abstract language which is far less time-consuming than conventional programming. Each Fortran phrase conveys as many as a score of machine language instructions. Cobol, on the other hand, is designed especially for commercial and accountancy routines such as, for instance, processing pay-rolls and stock lists. Both are examples of computer languages or auto-codes which enable the user to do most of his own programming without taking up a prohibitive amount of time and effort.

Another way of sparing programmer labour is to have ready-made programmes for commonly occurring sections or sub-routines of complete programmes. By using a programme library of such routines, a great deal of the programmer's work is reduced by breaking down the programme for a large problem into the sub-routines and then linking a sequence of sub-routines by means of a "master" routine. Translator input programmes known as "compilers", which in effect transfer to the machine the task of writing a master programme, are also prepared by the manufacturers professional programmers for inclusion in the users' programme library.

The computer programmer charged with the task of preparing a programme is presented with a set of input data and instructed about the form of output required. His task is usually undertaken in two stages.

1. Identifying the sequence of logical operations linking input with output in what is called a FLOW CHART

2. Translating into the auto-code of the particular machine to be used, the flow chart items. The sequence of auto-code instructions constitutes the programme which is fed into the machine on cards or tape.

As a skill, computer programming is more difficult than arithmetic or driving a car but less difficult than algebra or learning a foreign language. The professional programmer has usually pursued a systemic training lasting some months.

A higher level of skill is demanded of another grade of specialist in the use of EDP who is known as a systems analyst. His job is to examine the feasibility of transferring complex operations to EDP and to specify in detail the way in which data must be recorded so as to be suitable for electronic processing, e.g. patient records, staff records, systems of accounts.

It will be clear that the form assumed by a programme depends not only on the character of the operation involved but also on the computer language or auto-code employed. Consequently, the following examples are intended only as illustrations of the format of programmes and flow charts. Programmes for the same operations on other machines using other auto-codes might be quite different.

Example 1.

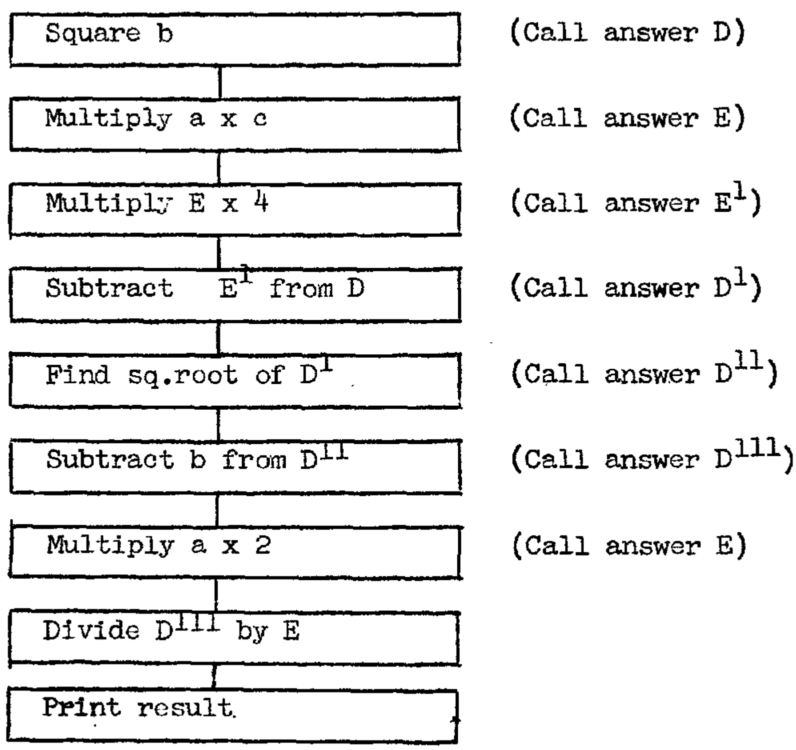
To calculate one root of $3x^2 + 5x - 2 = 0$ (where $a = 3$, $b = 5$, $c = -2$)

Recalling that

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

The FLOW CHART has the following form (for one solution):

FLOW CHART



A sub-routine stored in the machine would be brought into use for calculating the sq. root.

The programme itself have the following form.

```
Start: 1)  READ A
           READ B
           READ C                                   (A = 3
           D = B * B                                 B = 5
           E = A * C                                 C = -2
           E = 4E                                    D} Used as
           D = D - E                                 E} working locations)
           D = SQ RT D
           D = D - B
           E = 2 * A
           D = D/E

           PRINT D
           STOP - (indicates that programme is complete)
           START 1)  -  (instructs machine to start operation programme
                         from point (1) ).
```

**Example 2.** WHO Biomedical Research Information Service**

Illustration of a Computer Application for the Storage and Retrival of Medical Research Data

The World Health Organization has established a medical research information service to provide precise, comprehensive and up-to-date information about current activities in certain fields, for the use of biomedical scientists. For this purpose, information relating to research institutions, departments, scientists and their current research projects has been collected. Data about the institutions, departments and scientists is coded from master lists, transferred to punched cards and stored on large-capacity

---

* Note 1: The comments in brackets are explanatory, not part of the programme proper.

Note 2: D = B * B means square number in B and store result at D.

D = D - E means subtract number in E from number in D and return result to D for storage.

For additional examples see other course documentation.

** see also DP/67.1

random access disk files connected to the IBM system /360 computer in Headquarters. Each research project is allocated a 14 digit code number. The first six digits of this code number indicate the research institution, three digits indicate the department, three indicate the scientist, while the remaining two provide the serial number of the project itself. The projects are stored in code number sequence in open language on magnetic tape. In addition, each project is indexed under one or more keywords. These keywords are stored on random access disk files, so that all projects containing a specific keyword will be recorded by their code numbers after that keyword.

When a request is received for particulars of current research projects in a specified field of activity, the processes which would be followed to retrieve the required information are illustrated on the subjoined flow chart (illustration H).

The procedure is briefly as follows:

1. A request for the retrieval of stored information is passed to a classifier who indicates which keywords should be searched in order to furnish the required information. (Assume that keyword A, P and X are indicated).

2. Query cards are punched for keywords A, P and X. These cards provide the search criteria which are inserted in a specially prepared computer programme.

3. The following items are mounted on the computer:

   a. a random access storage unit (Disk No. 1) containing the dictionary of keywords with their listing of all associated project numbers;

   b. a second random access storage unit (Disk No.2) containing the names and addresses of research institutions, departments and bibliographical data concerning scientists;

   c. a magnetic tape containing (in sequential order according to project number) a full narrative description of all research projects;

   d. the programme to be processed, including the query cards especially prepared for the search.

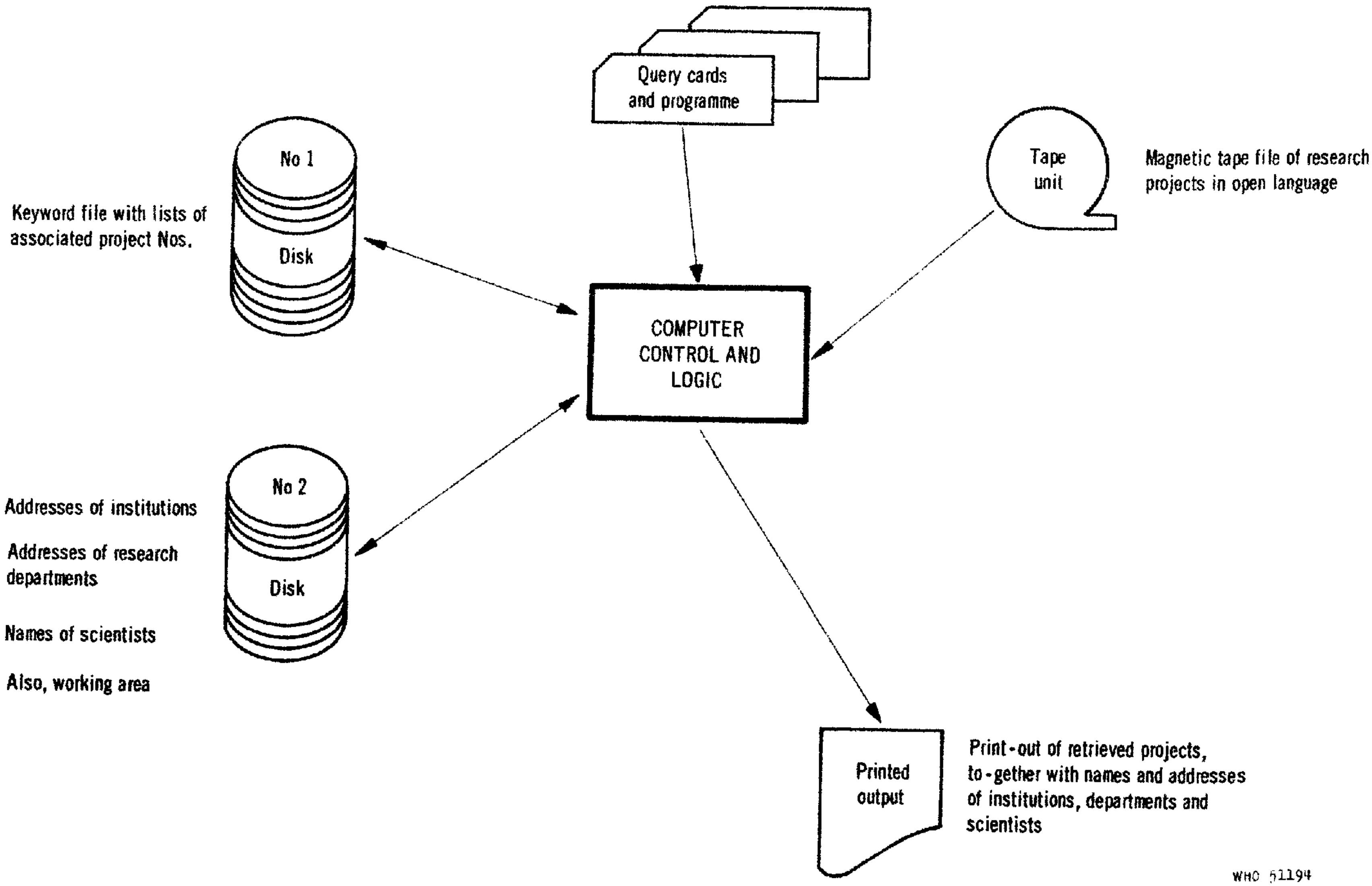
4. The computer transfers the project numbers listed after keywords A, P and X on disk No.1 to a working area on disk No.2, and proceeds to prepare in the working area a sequential list of project numbers, which are associated in all three of the specified keywords.

5. The project tape is searched sequentially until the first project listed in the working area has been reached. At this point, the computer by reading the separate code numbers incorporated in the project number, prints out from disk No.2 the name and address of the institute, the department and the scientist in charge of the project. Then by reading from the tape it also prints out the full narrative description of the project.

This process is repeated until all retrieved projects have been listed.

# H

## WHOBRIS - FLOWCHART OF SEARCHES BY KEYWORD



# APPENDIX I

## Subtraction by Complement Addition and the Representation of Negative Numbers

Suppose we have a decimal desk calculator handling, say for the purposes of illustration, four digit decimal numbers. And let us say we operate the machine so as to subtract 1 from 0. The machine will do this by borrowing 10 from the tens digit and so on until the number 9999 appears in the register of the machine. This result is produced in effect by the machine continuing to borrow one from a single place beyond its range, i.e.

$$\begin{array}{r} 0000 \\ \underline{1} \\ 9999 \end{array}$$

Thus the -1 is represented in the calculator by 9999. This number is called the complement of -1.

The addition of number's complement in the machine produces the same result as subtracting the number itself. For example, if 1 is subtracted from 4965 the result is 4964. This is the same as adding to 4965 the complement 9999, since the most significant digit of the sum is not registered in the four digit machine.

$$\begin{array}{lr} & 4965 \\ \text{subtract} & \underline{1} \\ & 4964 \\ & \\ & 4965 \\ \text{add} & \underline{9999} \\ \text{(not registered)} & 1\ 4964 \end{array}$$

This result follows from the fact that the number of digits registerable is fixed - in our illustration 4. In effect we borrowed $10^4$ in the initial subtraction to form the complement and then rejected $10^4$ in the complement addition, i.e.

$$(4965-1) = (4965 + (10\ 000-1) - 10\ 000)$$

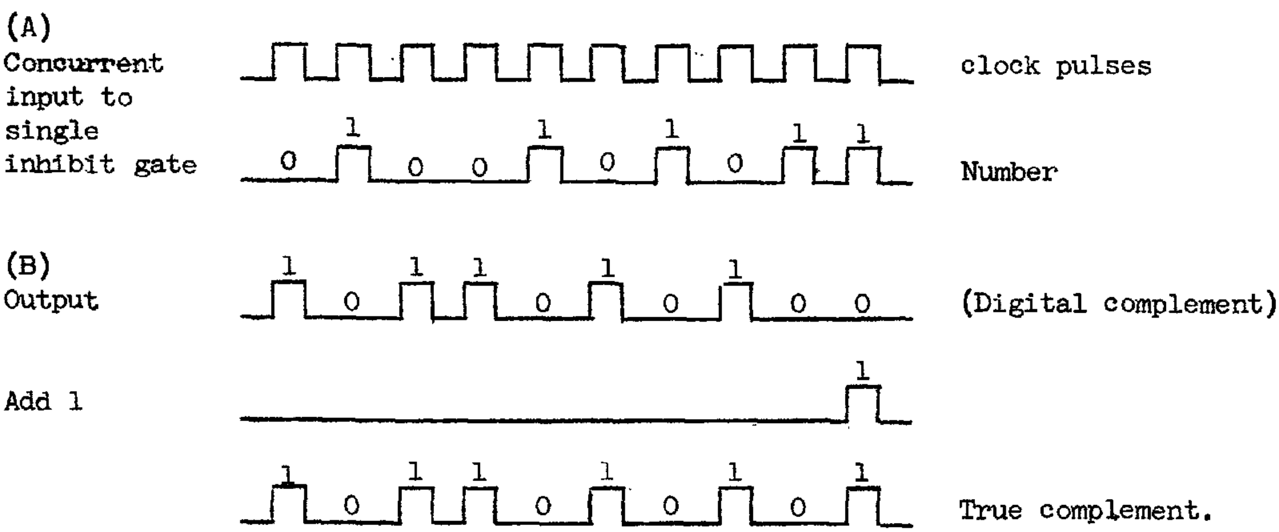
It is advantageous to substitute complement addition for subtraction because in binary notation the positive complement of a negative number is easily derived. It is done by representing every 0 in the negative number by 1, and every 1 by 0 (giving what is called the digital complement) and then adding 1.

In a 10 digit machine, for example, if one is subtracted from 0 the result is as follows:

```
  0000000000
- 0000000001
  ----------
  1111111111
```

and it is easy to confirm that this result can be generalized into the rule above quoted.

Thus, to produce the digital complement of a number, it is only necessary to apply concurrently the number and clock pulses to a gate whose output is a pulse when only one pulse is applied in the input, and is no pulse when two pulses are applied. (Single inhibit gate). The production of a digital complement in this way is illustrated below.




It will be seen also that the addition of the complement of a number gives the same result as subtracting the number. Thus -

```
  | 0000000000
+ 1 | 1111111111   (complement of -1)
  | ----------     i.e. -1
  | 1111111111
```

# APPENDIX II

## Machine Recognition of Number $>0$ and $<0$

When it is said that the machine distinguishes between a plus and a minus number, this means in effect that it is activated in one specific way when a positive number result from an operation appears in the appropriate place, and is activated in another way when a negative number appears. The machine is enabled to make the distinction between plus and minus by reducing its capacity by one digit, so that the largest positive number which is acceptable in a 10 digit machine is -

0 111111111

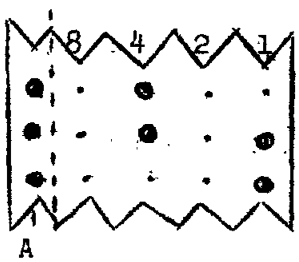
In other words, a number which has one for its most significant digit is the complement of a negative number. The explanation of the convention of sign digit resides in these facts.

## APPENDIX III

## Decimal to Binary Translation

The steps by which data coded in decimal numbers are converted into binary form affords a good example of binary arithmetic. For a five-hole punched tape, they are as follows:

1. A programme tape is prepared by typing a sequence of decimal digits on a teleprinter keyboard so designed that each digit in turn is punched on the tape in binary form. The decimal digit 451, for instance, would be punched on the paper tape as:

| Tape | | Decimal digit | Binary equivalent |
| --- | --- | --- | --- |
|  | - | 4 | 0100 |
| | - | 5 | 0101 |
| | - | 1 | 0001 |

(disregard, see note)

Shaded circles indicate punches.

**Note:** The position A is always punched when decimal digits are represented, so that the digit 0 can be represented by a hole instead of a blank, i.e. a hole at A represents 0, not 1.

2. The tape is then placed in the input device and processed according to a translator input programme already in store in the machine. By this means, the binary coded decimal (BCD) on the tape is converted into binary form for entry into the computer store. Taking a 12-digit binary machine for purposes of illustration, the BCD number 451 is processed as follows:

   a. the first digit is placed in the accumulator and multipled by 10, i.e. by 1010 in the binary code. This multiplication is done by successively shifting the digits one place to the left (x) then three places to the left (y), and then adding the two results, i.e.

```
000000000100
        1010
------------
000000001000   (x)
000000100000   (y)
------------
000000101000
```

The decimal number now represented in the accumulator is 40;

b. to the binary number in the accumulator the second digit of the number 451, i.e. 5, in binary form is added, with the result that the accumulator now contains 45 in binary form;

c. this number is next multipled by 10 (i.e. by binary 1010) and the digit 1 is finally added. The accumulator now contains the number 451 in binary form, i.e. 111000011 and this "word" is transferred to store.

# APPENDIX IV

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