Devices for Transporting the Recording Mediums

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The large-scale digital computers now in use have demonstrated that efficient operation of their internal elements can be maintained in a manner satisfactory to the users. They have also shown great versatility in the problems to which they can be applied. As a result, a demand for such devices has been spread from among scientific laboratories through industry, commerce, and government, for their application to a myriad of purposes. In most cases, the requirements of the problems can be accommodated by any of the general-purpose machines and in many instances more specialized, less elaborate units can be used. Almost all installations require that a means be provided for keeping information in a latent form which can be recorded and reproduced by automatic mechanisms, under the control of the machine, for introducing input and absorbing output information, and for storing data too voluminous to be kept in the machine's high-speed internal memory.

Many factors enter into the choice of the latent information storage mediums and of the type of mechanisms used in manipulating it. The purpose for which the installation is used is, of course, of primary importance. This will determine whether high handling speeds are necessary in the input, output, or intermediate equipment. Usually, the input data are relatively small, so that speed at this point is not essential. The output data may only amount to a yes-or-no answer, in which case a simple indicator is all that is needed, but usually the output is very extensive and high speeds are needed. If intermediate storage is necessary, it is because the information in the problems is too abundant to be contained in the machine's internal memory. Therefore, it may be assumed that fast operation should be provided. Frequently, when intermediate storage of information is required, the same type of equipment and often the identical devices are used for all three functions. Occasionally, a computing system is used in an establishment where much of the data processed by the machine have been accumulated in the past and are kept in such a form that they can be automatically interpreted. In this circumstance, it may be advantageous to have an input device of a type which will accommodate existing records. A second input device which can handle a more desirable type of record may be included in the system and the first input unit discarded after the old records have been processed or transcribed.

Other considerations determining the choice of record material and transport devices are the necessity for visual inspection of the records, the ability to reinscribe automatically an old record with new information, the type of computer to be served, the availability of devices already in use which may fulfill the requirement, and the time schedule which must be kept in completing the system, and, not the least important, the ingenuity of the designers.

In all designs, the method of handling latent information must be reliable and accurate. Reliability is necessary because frequent breakdowns cause lost computing time and require the provision of a greater number of maintenance people than would otherwise be needed. High frequency of failure also makes the maintenance of other parts of the system difficult. The degree of accuracy in operation required of these devices is such as to discourage a designer at the outset. If confusion of information occurs more often than once in 100,000 operations, the system will be practically useless. Satisfactory performance requires an error no more frequently than one in $10^8$ to $10^9$ operations.

Simplicity and convenience in operation are highly desirable to reduce the effort of mathematicians or other personnel using the system. It should be remembered that the efficiency of operation of an installation suffers as much if a computer is improperly operated for a day because of misunderstanding as it does if the machine is out of order for a day. Indeed, time wasted in this way is more costly than computer breakdown because it wastes the effort of the mathematicians and users as well as that of the technical personnel. Simplicity of operation is also desirable because the personnel, particularly where scientific computations are involved, usually changes frequently, and ease of instruction in itself saves time at the outset and enables an infrequent user to operate efficiently without instruction after a long absence.

Philosophy of Recording

In all systems of mechanized record keeping, wherein information is extracted from the recording mediums without human interpretation, it is recorded in a yes-or-no form. For example, if numbers are to be represented in decimal form, it is done by providing a particular character position with space for ten choices. Then to record, one of these spaces is marked or punched. The reading device then scans the position and finds that all but one of the choices are not marked and are therefore 'no,' the one choice which is marked indicating "yes." This system is common among card-handling devices where each position is provided with a column of characters ranging from zero to nine, and a hole is punched through one of the characters. Such a system provides a record that is easily interpreted by humans, but is somewhat wasteful of recording space and time.

Most efficient use of the recording medium can be made if the less familiar binary notation is used. In this system,
the numbers are the summation of combinations of different powers of two, whereas decimal numbers are the summation of constants, each of which is multiplied by a different power of ten. Binary notation, therefore, requires, only an indication as to whether or not a particular power of two or digit-position is to be counted in the summation. An example of the convenience of binary notation is found in the magnetic recording of digital information on wire. The information is stored in adjacent segments of the wire which form very small permanent magnets whose poles are displaced from one another longitudinally. Each elemental magnet following a characteristic marker, designating the beginning of a word (usually an unmagnetized section of the wire), represents a power of two or digit-position in the number. Whether or not a digit is to be counted in the summation is determined by the order in which the poles occur. If north precedes south, the element may represent one and if south precedes north, the element then represents a zero.

The relative efficiency of use of storage space of the binary notation over decimal notation used in mechanized record-keeping devices can be demonstrated by comparing the number of choice spaces required to hold a number which can have any one of a thousand values. A decimal number will require three sets of ten choice spaces, whereas a binary number with a slightly greater range of values can be accommodated in ten spaces.

The simplicity and efficiency of binary notation is, however, offset to a considerable degree by its unfamiliarity and an inherent ocular difficulty in reading of binary numbers by humans. Furthermore, the mechanization of conversion of decimal notation to binary, and conversely, requires arithmetic operations which involve expensive equipment, if a converter is used, or appreciable computing time and memory space in the computer if the conversion is carried out by a program in the computer.

There are, however, several kinds of notations which effect a compromise between the two extremes of efficiency and ease of interpretation. These can be exemplified by a discussion of binary coded decimal notation. It may be mentioned that a choice of two combinations can be had from one binary yes-or-no element, sometimes called a bit, four combinations from two such elements, eight from three, and 16 from four bits. Therefore, a decimal character having only ten possible values can be represented by four binary digits. So, to store any one of a thousand combinations, this system would require 12 elements. Although this notation is not as easy for humans to read as decimal numbers, it is much less difficult than is binary. Conversion between decimal and binary coded decimal information is quite easy technically, requiring only a simple matrix device. These systems are used extensively with tape records. For example, paper tapes may be arranged to have holes perforated in rows which are perpendicular to the length of the tape.

The holes are made by a group of four or more electrically driven punches operating in concert so that all of the information in each row is punched and may be read simultaneously. Such records are not difficult to interpret visually because each character lies in one position along the length of the tape.

It should be noted that most tapes accommodate more than four holes because most perforated-tape-handling equipment has been designed for communication service in which it is necessary to process alphameric information. Usually, if only numbers are to be recorded, such spare hole spaces are used for redundant checking. This is done when five hole spaces are available by punching the fifth space if, and only if, an even number of holes is
present in the four binary coded decimal spaces. When such a symbol is later read from the tape, a special circuit indicates an error if there is not an odd number of holes. Usually, there is also a circuit which will produce an error alarm if the binary value of a character is outside the decimal range.

In addition, a count may be made to ensure that each word or group of symbols has the correct number of characters. In some instances, particularly when magnetic tape is used as the recording medium the complement as well as the number is recorded and must be correctly reproduced, otherwise an error halt is effected. It has been proposed that triple recording be used and the system arranged to accept a number if two of the three records agree, so that fewer error halts will be experienced.

The method and degree of checking are of considerable importance in the design of latent-information-handling devices because the equipment, information storage capacity, time of operation, and maintenance requirements are all increased by these measures. These considerations are of particular moment in the development of magnetic-tape equipment because the reliability of these systems decreases with increases in the density of recording. So much checking may be required by dense recording that even more tape will be needed for closely packed information than for more conservative signal spacing.

The two exceptions to the use of yes-or-no notation in recording computer information are in the keyboarding or preparation of input information and the presentation of the printed output. In keyboarding, conventional symbols are present on the keyboard for the operator to see. The depression of a key causes a binary coded symbol corresponding to the character to be registered on the input medium. In the printing operation, ordinary symbols are recorded on paper by some form of automatic typewriter. Such devices are controlled from yes-or-no binary coded signals, either directly from the computer or from transcribing equipment extracting information from the recording medium used in the other operations described.

To provide a clearer understanding of how the principles discussed in the foregoing may be applied, some examples of each of those now in use are presented in the following.
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can read at the rate of 1,200 symbols per second. The reader is designed for automatic operation, having servo-controlled reels and an automatic capstan; however, it is seldom used with automatic control because it is easier to pull the tape by hand than to set up the reels. The internal memory is sufficiently large to hold an extensive program and the speed of the reader is so great that the time for pulling the tape is negligible. These shortcomings are noted because they emphasize the necessity for simplicity of operation. A tape transport mechanism which is much easier to use is shown in Figure 10. The serious unbalance of the speeds between the input and output of this system and others like it has brought about programs for the development of better recording devices.

Punched Cards

One of the means employed to obtain greater output speeds has been the installation of standard card-handling equipment. In these installations, information can be handled at rates of about 100 characters per second. These speeds are obtained by using many relatively slow electromechanical punches to perforate each card. One standard commercial card punch uses cards accommodating 80 characters perforated by 80 separate punches. This speed can be, in effect, increased by clever manipulation of the logic relating to the arrangements of the perforation patterns. Figure 3 is a picture of the Ordvac at the Ballistic Research Laboratories at Aberdeen where the original perforated-tape equipment is shown in the central background and the card-handling devices manufactured by the International Business Machines Corporation at the extreme right. This computer is shown to the left. In this installation, the perforated information patterns in the cards are made to correspond to a similar pattern in the high-speed internal electrostatic memory, so that the meaning of the patterns can be made to conform to any logic desired. At this writing, each card is used to store 24 40-binary-digit words, wherein each word is equivalent to about 12 decimal characters. The card-handling devices operate at the speed of about 80 to 100 cards per minute so that the system is capable of transferring the equivalent of approximately 400 decimal characters per second. Cards which have been keyboarded to record input information and cards which have subroutines which may have been generated by the computer, are assembled in stacks which are placed in the reader. New cards are stacked in a hopper in the punch to receive output or intermediate information. The output cards are then run through a tabulating machine for final printing. These devices cannot be reversed to permit searching for information as can the tape equipment.

Figure 4 shows the older installation of the card-handling equipment in the Eniac system at Aberdeen Proving Ground. This is somewhat slower because the cards are used with the standard commercial notation. The card systems are very satisfactory because long development and years of experience have brought about great reliability in card mechanisms and in tabulation equipment. Furthermore, the information is at all times easily re-arranged to fit into various routines.

Photographic Recording

Another means of automatically handling information in a way that can be

Figure 11. A magnetic memory drum associated with Mark IV computer, Harvard University

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visually interpreted and at the same time handled automatically at high speeds involves photographic processes. Such a system developed at Eastman Kodak Company for “Project Whirlwind” is shown in Figure 5. This equipment uses motion picture film which is automatically exposed to patterns on the face of a cathode-ray tube for recording, and which is scanned photoelectrically for reproduction. The information is recorded in a redundant binary code which provides facilities for checking. The patterns consist of rows of dots which represent binary numbers and their complements. About 2,500 bits per square inch are accommodated. Several of these mechanisms have been made and, in themselves, performed satisfactorily. However, the time and the difficulties involved in the development of the film, and the high cost of the medium, have made it appear likely that they will not be widely used in the near future for handling coded information. Nevertheless, it appears that the development of film-handling equipment is necessary to produce mechanisms which will be required to handle information that must be stored in pictorial form.

Magnetic Tapes

From the standpoint of mechanization, probably the most versatile means of storing latent information for computers is that involving magnetic recording and reproduction. In devices of this type, the surface of the storage medium, which is composed of magnetizable material, is placed near to, or in contact with, a small electromagnet called a head, which may be energized by a pulse of electric current that causes a strong magnetic field to pass in and out of an elemental area of the magnetic surface so that this area thereafter remains magnetized. The magnetized area may then be transported to some other place for storage and can later be brought under the poles of the head where the motion of the magnetized area past the poles causes a slight amount of flux to build up and subside in the core structure of the head and generate a voltage across its coil. The polarity of the field from the magnetic region is determined by the direction of the current in the recording head which is so chosen that in one direction it will represent a binary one, and in the other direction a binary zero. Usually, the poles are arranged on the magnetic surface in such a way that they succeed one another in the direction of motion, in which case the recording is said to be longitudinal. They may be oriented at right angles to the direction of travel, in which case the recording is said to be transverse. In some instances, where thin magnetic recording mediums are employed, magnetization is through the medium with a pole on either side of the record. Magnetic records can be made extremely rapidly. A good recording can be made by a pulse the duration of which is less than a microsecond. The magnetized regions can be exceedingly small. In contact recording, some areas are of the order of 0.01 inch wide and 0.005 inch long. With such high densities of information, very conservative mechanical speeds can be used to transfer information rapidly enough to fulfill all the requirements of electronic devices. Magnetic records may be reproduced a very large number of times without destruction, will last indefinitely, and may, in many types of equipment, be modified with no more trouble than the simple operation of recording over the previous record. In some instances, erasure by high-frequency magnetic fields may be required before a new record can be superimposed over an old one.

One of the most commonly used kinds of magnetic record is made on flexible tape having a ferromagnetic surface. Usually the magnetization is longitudinal and the tape is run in contact with the recording and reproducing heads. The density of recording on tape varies over wide limits. In a longitudinal direction, it ranges from 25 to 400 per inch and in a transverse direction from 4 to 32 tracks per inch.

In Figure 6 is shown a magnetic tape drive developed by the Raytheon Manufacturing Company and used in a number of installations. The unit in the illustration is installed in the Raydac.

Figure 12. Magnetic head assembly for Mark IV drum, Harvard University

This tape carries six channels, is equipped with bidirectional servos, and has the unique feature of having visible photoelectrically read address markers on the back of the tape to facilitate rapid search operations. Also to be noted is the rather elaborate tape-tensioning system. The density of recording is not standard on these units, being chosen to fit the particular installation. Another commercially available tape transport system is shown in Figure 7. This unit is called the Uniservo and is manufactured by the Eckert-Mauchly division of the Remington Rand Corporation. It employs metallic tapes with multiple channel recording. The picture shows a battery of eight units. Figure 8 shows the magnetic tape installation on the Mark IV computer built at the computation laboratory at Harvard University. These transports utilize a very fast vacuum-type accelerator and brake. Another commercial unit is shown in Figure 9 which is made by the Computer Research Corporation and utilizes a principle developed at the National Bureau of Standards. This principle is better illustrated in Figure 10, which shows a similar device built at Aberdeen Proving Ground to handle both magnetic and perforated tapes. In this transport mechanism, tape is laid in a slot under which are placed magnetic heads or photoelectric cells, depending on the type of tape to be used. The cover carries two magnetically moved idler rolls and when it is closed, the tape lies between the idlers and two capstans which rotate in

Figure 13. Small commercial drum

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opposite directions. The tape is then drawn from the reel by manually controlled electrically driven rollers into a basket-like receptacle. The tape can be moved in either direction by actuation of one idler roll magnet which causes the tape to be squeezed between the actuated roll and one capstan. This action causes the tape to be pulled toward the actuated side. Braking is constantly applied by a spring-loaded shoe.

It may be noted that in all magnetic-tape transport mechanisms considerable effort has been made to achieve rapid acceleration and deceleration. This characteristic is necessary because the amplitude of the signal generated in the output system is proportional to the speed with which the elemental magnets pass the reading head. Slow starting and stopping cause the first few and the last few characters to be so poorly read that their information is unreliable. This condition is particularly important when the space between words is very small.

Magnetic tape, as the medium of recording of digital information, is very attractive because the recording and the reproducing speeds may be as great or as small as desired; bidirectional operation can be provided; many tracks may be used; and the information can be erased and recorded without difficulty. Though the users of magnetic tape have found many serious difficulties they have, it is pleasant to state, to a great extent surmounted them. Outstanding among these have been the difficulties caused by particles of foreign matter which lift the tape from the head at a critical instant, irregularities in magnetic and physical properties of the tape, and in making the tape track through the guides and rollers.

**Wire**

In an effort to achieve a denser storage of information, and possibly alleviate some of the dust and irregularity troubles encountered with tape, the National Bureau of Standards and the Institute for Advanced Study have conducted research to produce magnetized-wire-handling equipment. To date, such a system has not been satisfactorily used. It is also beset with mechanical difficulties, the principal one being that of manipulating the wire so that no snarls or kinks result. The trend seems to be toward using wire held in special capsules from which it is never removed except for a very short section that passes between rolls in the capsules to contact the head.

**Drums**

Probably the most successful magnetic recording devices so far used in conjunction with computing machines are rotating drums. Unfortunately these devices can only be used for intermediate storage because the medium of recording is the surface of a heavy cylinder which turns in precise bearings and, therefore, cannot be removed from the equipment and placed in a filing cabinet. The capacity of such drums varies from 500,000 to about 3,000,000 bits of binary information. The surface of the drum is coated with magnetic material and exposed to heads which record circumferential tracks that are displaced in an axial direction from one another by their own widths plus a slight space necessary to provide sufficient isolation to prevent crosstalk. The heads clear the surface of the drum by about 0.002 inch. The density of recording along the circumference of the drum may lie between 10 and 150 bits per inch. The speed of rotation of the drum ranges from 1,200 to 7,200 rpm.

A typical installation is shown in Figure 11 which is the drum associated with the Mark IV computer at Harvard University. A head assembly for this drum is shown in Figure 12. A small commercially available drum made by the Electronic Computer Corporation is shown in Figure 13. Another commercially built drum which was manufactured by Engineering Research Associates is shown...
in Figure 14. This company records on
its drum in what is called a nonreturn-to-
zero system. In this type of recording,
only the changes in the polarity of the
bits are noted; that is, only those signals
are used which are generated when a
binary digit is succeeded by another
binary digit of opposite sign. This type
of recording is advantageous because it
has been found that the signal developed
in this fashion is much greater and less
ambiguous than those reproduced from
conventional pulse recordings where each
pulse is resolved in the output circuit.
This system requires slightly more com-
plex circuits to reproduce the signal, but
by its use the storage capacity of the drum
is considerably increased.

Preparation Devices
Most of the manually encoded data for
large-scale computers are prepared on
standard tape- or card-punching key-
boards, modified only to the extent neces-
sary to provide the symbols peculiar to
the particular work. Such equipment
has long been available and little im-
provement can be desired because this is
the one instance in which all of the speed
requirements have been fulfilled.

Printing Devices
The output of computing machines,
which must be in a form to be read by
humans, is generally presented by auto-
matic typewriters. These typewriters
may be controlled by the computer
directly or by transcribing equipment
which interprets information from the
computer's input-output medium. The
transcribing procedure is more commonly
used because most of the automatic type-
writers are so slow that valuable comput-
ing time would be wasted if the machine
had to be stopped while the printers per-
formed their tasks. Figure 17 shows the
electric typewriter complement for Mark
IV.

An installation using the conventional
Teleprinters at Aberdeen Proving Ground
is shown in Figure 16. Also shown is
equipment used to prepare perforated
tapes. A more advanced development is
shown to the left in Figure 17. It is a
very-high-speed rotary printer manu-
factured by Shepard Laboratories for
Aberdeen. This is one of the class of
printers which are also made in different
designs by Potter Instrument Company
and Wheaton Engineering Corporation.
In it a number of sets of all of the
characters to be used are arranged around
the circumference of a rotor. Directly
beneath the rotor is a typewriter ribbon
underneath which is the paper from a roll
on which the printing is to be done. Beneath the paper is a row of electrically
operated hammers. The drum rotates at
some speed between 5 to 30 revolutions
per second. The hammers are then
energized by a decoding apparatus at such
a time that they will strike the paper
against the inked ribbon and the rotor
when the desired character is in the
proper position. Such a printer is fast
enough to keep pace with the fastest com-
puter and no intermediate storage is
needed to conserve time.

Conclusion
At the moment of writing, it appears
that magnetic recording devices are the
most flexible units for handling the
mediums used for manipulation of latent
digital information. However, the me-
chanical difficulties which now beset their
use indicate that much more research and
development will be necessary before
completely satisfactory systems are avail-
able. For certain applications, per-
forated cards and tapes will probably be
more satisfactory than any other medium,
particularly where the amount of data to
be handled is small, visual inspection is
desirable, and redundancy is to be avoided.
Photographic storage of pictorial infor-
mation, and possibly printed output mat-
ter, needs considerable development but
will undoubtedly perform valuable
functions which cannot be otherwise ac-
complished. Simpler and less expensive
automatic printers must be developed.
When it is remembered that serious work
on these devices commenced little more
than 5 years ago, the progress in their
development must certainly be the source
of considerable satisfaction to those work-
ing in this field.

Discussion

L. Difford (National Bureau of Stan-
dards): Will you please give more detail on
the Shepard printer?
Mr. Snyder: I shall describe it as com-
pletely as I can. The print roll consists of
a cylinder about 16 inches long, having 56
cylinder wheels on it. It has a typewriter
ribbon, about an inch wide and slightly
skewed, underneath the roll and clearing it
by some 0.005 to 0.01 inch. The paper, I
believe, is about 16 inches wide. There is
a row of hammers aligned beneath the
paper at intervals of about 3/16 inch. The
printing does not extend over the full width
of the paper.

The time of flight of a hammer striking
the paper appears to be about 2.7 milli-
seconds, and the dwell time has been guessed
at being about 8 microseconds. The
hammers are actuated by thyratrons.
Mr. Difford: You said 15 lines per
second. Is there any way of speeding this
up?
Mr. Snyder: That is most conservative,
because the print roll is rotating at 30 revo-
olutions per second, and one revolution is
assumed to be allowed for paper shift.

Actually, a quarter of a revolution is suf-
fi cient, and these printers have been operated
with 60 revolutions per second. The
problem appears to be one of moving the paper
rapidly rather than of getting the hammers
to strike accurately.

W. P. Byrnes (Teletype Corporation):
What is the maximum number of channels
or rows across the width of the tape en-
visaged at the time for either magnetic or
perforated tape?
Mr. Snyder: That is a very hard ques-
tion to answer. I have heard of some mag-
netic tapes as wide as 6 inches, involving
something like 30–50 tracks. I have also
seen some installations where there is a
single track on magnetic tape 1/4 inch wide.
In the perforated tapes, the standard 5-hole
Teletype tape is, of course, quite useful.
The 6-hole tape was used in the relay type
of computers, but some tapes, if one may
call them that, have been as wide as the
standard punched card, that is, 80-column
tapes. I believe they have been used in the
selective sequence calculator at the Inter-
national Business Machines Corporation in
New York City. I do not think there is
any limit in either case, except for magnetic
tapes, where the dust problem may cause
serious difficulty.

Mr. Byrnes: In some cases, it may be
desirable to represent more than one decimal
digit across the roll of tape.
Mr. Snyder: It may also be desirable for
checking.
Mr. Byrnes: What speed of reading and
perforating paper tape is considered ade-
quate at present?
Mr. Snyder: At present, the best per-
formation speed that I happen to be aware of
is in the Orvanc card-punching system,
which punches the equivalent of about 400
characters per second. I think that is more
rapid than is absolutely necessary for a
device to be very useful to the computing
industry. I think, from 100 characters per
second up would be very useful for many
applications.

Mr. Byrnes: That also goes for reading
tape?
Mr. Snyder: Yes, but reading perforat-
tape is easy with photoelectric devices—
perhaps not easy, but it is quite amenable
to a little effort, shall we say? There is no
limitation to reading photoelectrically.

Mr. Byrnes: Is it true that reading
mechanically requires less associated equip-
ment?
Mr. Snyder: I think that was true some
time ago, but with the introduction of
Buffering Between Input-Output and the Computer

A. L. LEINER

This paper will discuss some of the basic methods or general principles which have been applied for carrying out the transfer of words between input-output equipment and the high-speed memory of computers. Since general principles can best be demonstrated by showing them exemplified in particular cases, specific selected systems which accomplish this buffering will be discussed. In doing so, however, an attempt will be made to avoid detailed descriptions of specific pieces of equipment. The particular selection chosen represents, of necessity, a quite incomplete sample from the total of available methods. Omission of some of the many alternative methods for accomplishing similar objectives in no way implies that the methods omitted are inferior to the methods presented.

Nature of the Buffering Problem

Before proceeding further, it will be well to consider for a moment the special nature of the relationship between the internal circuitry of present-day high-speed digital computers and the external input-output equipment through which they communicate with the outside world. The first and most obvious difference between these unequal partners is the much slower operating rates of the external input-output equipment, but the main distinction between the two is the fact that the external devices (whether high-speed magnetic recording equipment or mechanical typewriters) are bound by mechanical inertia or friction

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