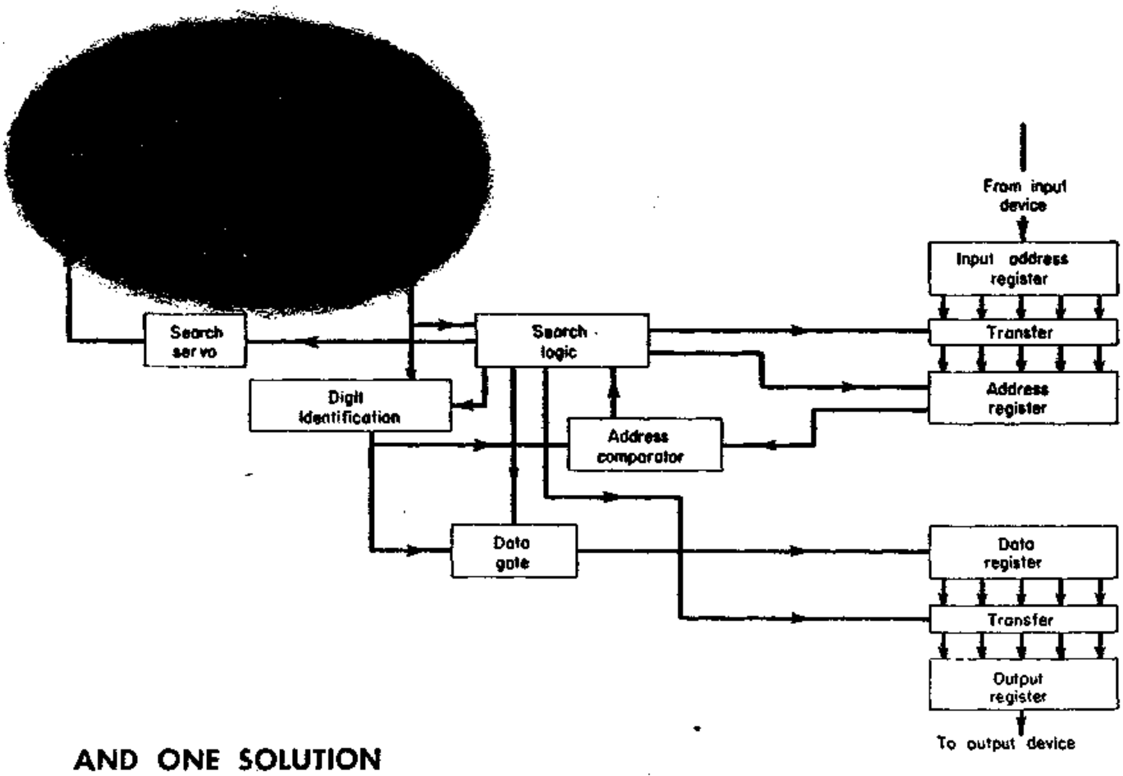
A NEW APPROACH TO INFORMATION

THE PROBLEM

. . . To store large quantities of information commonly of the order of a billion bits. For example, a table of trigonometric functions for a gun director requires 10^6 bits, the New York telephone directory 10^7 bits, a mail-order catalog 10^8 bits, and the Library of Congress 10^{14} bits. This information must be available for fast and frequent reference for computing and billing and must be adaptable to change or discard. FIG. 1



AND ONE SOLUTION

. . . A photoscopic information storage unit that records coded information using the exposure or nonexposure of areas on a photographic emulsion. High resolution emulsions permit information to be stored at a density of a million bits per square millimeter. Thus a 3 by 5 in. plate of this density would have the capacity of the human mind and a cubic foot could more than handle the Library of Congress. FIG. 2

STORAGE

COMPARISON OF INFORMATION STORAGE DEVICES

	Capacity	Access	Cost per Bit	Size of Equipment
MAGNETIC CORES	[illegible]	Very good	Very high	Large
MAGNETIC DRUMS	[illegible]	Good	High	Small
MAGNETIC TAPE	[illegible]	[illegible]	Low	Small
PUNCHED PAPER TAPE	Very high	Poor	Low	Small
PUNCHED CARDS	Very high	Poor	Low	Large
PHOTOGRAPHIC	Very high	Good	Very low	Small

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The control of many contemporary operations in computing, logistics, libraries, and commerce involves storing large quantities of information. These can be held in an automatic memory on punched cards, or on rolls of punched-paper or magnetic tape. But, paralleling the demand for large stores is one for access time of less than a second. Mechanical form of punched cards and required rolling and unrolling of tape limit capacity and accessibility.

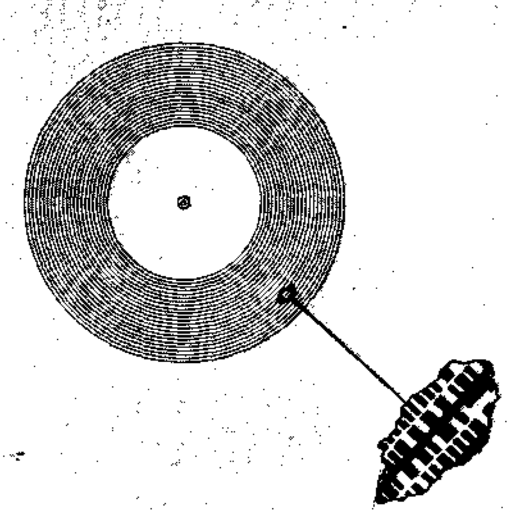
In contrast, photographic techniques offer interesting possibilities because of the storage density capabilities of the new high-resolution silver-halide emulsions and the fast access to the reduced physical storage area. The table above compares characteristics of six information storage devices.

The photographic emulsion is two-dimensional, requiring an area search, and is read with a light beam. There are two ways of finding a given bit of information: movement of the emulsion past a stationary spot of light, or scanning the emulsion with a moving spot of light. A combination of the two gives the lowest access time.

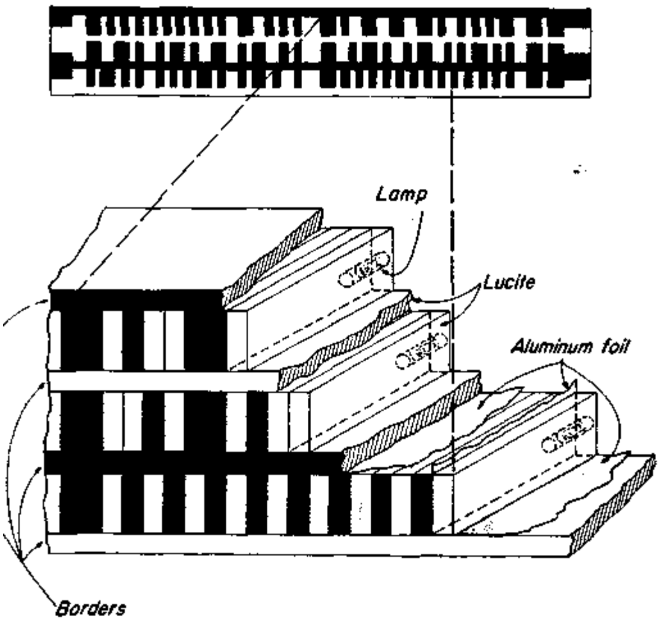
Photographic recordings are hard to erase. But the information in the storage problems considered here is relatively permanent because of its large volume. Nevertheless, even in the largest stores, changes and additions do occur. These can usually be handled by a combination of photoscopic units, or by adding small temporary erasable storage devices of conventional design.

THE STORAGE DEVICE

In photoscopic stores requiring rapid access, the information is held on a transparent disc coated with a photographic emulsion. It can appear on this disc in a coded form that is wholly or partly digital. The digital store consists of a code of microscopic black and white rectangles arranged in concentric tracks. To read information, the disc is rotated while a light beam shines through the information tracks. A



Typical disc showing tracks on outer annulus and detail of black and white coded emulsion. Photo shows lens, disc, and phototube. FIG. 3



These plastic slabs build up a display. Foil prevents light transmission between slabs while lucite sheets form borders. FIG. 4

phototube picks up the light that gets through the disc and converts the sequence of light and dark to electrical signals. Figure 3 shows a 16 in. disc with storage tracks on the outer four in. annulus. The rectangles are only 0.001 by 0.003 in.

The reading station consists of a cathode-ray tube, a lens that projects an image of the spot on the tube onto the information track, and a photomultiplier tube behind the disc. Deflection of the electron beam in the cathode-ray tube moves the spot radially and illuminates any one of the thousand tracks in the four in. annulus. The low switching inertia permits a two-dimensional search of the annulus area, so there is random access in a revolution.

This size disc can store 20 million bits, equivalent to four million characters or several books. At a speed of 2,400 rpm, information is read at a rate of one million bits per sec. The maximum access time to an item chosen at random is the time of one revolution, or 25 millisec. This can be reduced by using several reading heads.

The output of the phototube is fed to computer-type circuits that convert the signal into conventional characters. These are temporarily stored in a shifting register. The required address or index in another register is compared with what is momentarily being read. If it matches, the subsequent information is sent to an output register and temporarily stored until delivered to the output unit.

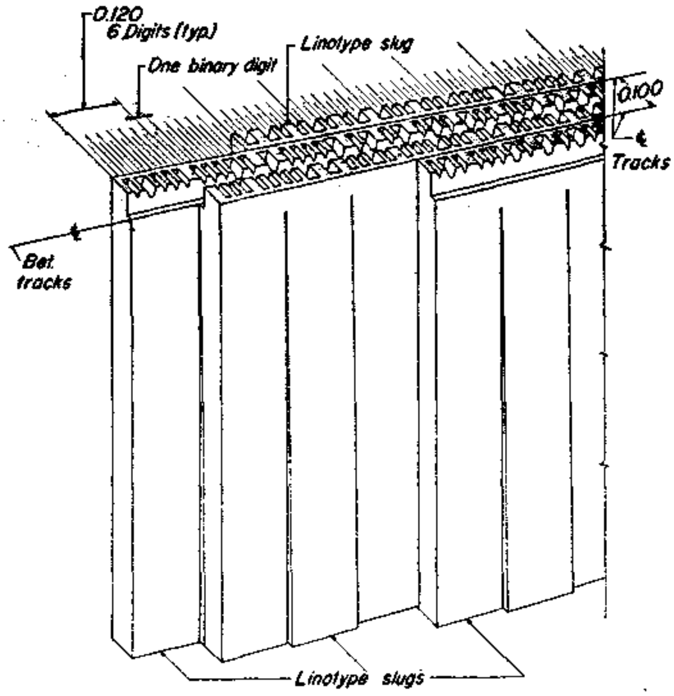
THE RECORDING UNIT

Some applications permit the simplest display of a single light source, and record information bit by bit by flashing a light or opening a shutter and exposing the emulsion on the rotating disc. But the concept of recording 20 megabits serially is not attractive. One reason is that an error or an insertion requires that the whole series be done again. Then too, information is normally supplied at least as characters and usually as words. This suggests that the groups be accumulated in a temporary store, called a display, prior to permanent storage. Proofing then can be done at this stage.

Each display can consist of one or more decks of light boxes, Figure 4. A bulb is inserted in the rear of each plastic slab, and a white or black mark, depending on whether or not the bulb is illuminated, is made on the emulsion. During packing, the slabs are separated by sheets of aluminum foil.

The decks of boxes, corresponding to the several tracks, are separated by dark or illuminated strips that photograph as the guiding borders. Also, punctuation marks that indicate the beginning of new words can be built in. The beginnings and ends of the tracks have "half tracks" that allow each recording to be aligned without registry problems.

The operation of the device depends on the source of information. If the source is a manually operated typewriter, the typewriter's keys actuate appropriate switches so that the proper bulbs light up. If the information is received on punched cards or tape, conventional reading equipment is used, and the electrical signals from the reading heads automatically operate the switches. For example, fully loaded cards can be read at 600 per min. After each word has been set up on the display and photographed, the emulsion is advanced the correct



Special Linotype slugs with digital representation. FIG. 5

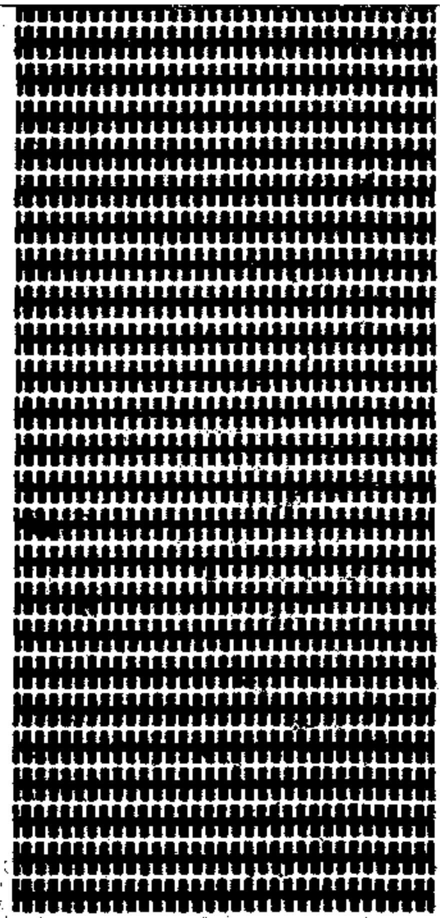
amount and new information read in.

Another type of display is a printed sheet pulled from a galley of Linotype slugs. The information is delivered to the Linotype machine a character at a time, either by manual depression of a key or from punched tape. At each stroke a piece of brass on which a raised rectangle is engraved with binary code is brought down to the line being composed. When a line has been composed, a lead casting is made from it. In this application, a line corresponds to a unit record or word of 250 bits, Figure 5.

The galleys are then inked and a proof is pulled on white paper to form the Linotype displays to be photographed, Figure 6. A true proofing operation can be carried out at this step by making a negative of the same size and scanning with a simplified photoscopic device. The sheets pulled from the galleys can also be arranged in a larger display, say a quandrant of a circle. This then can be photographed directly onto the disc.

Note that the slugs are similar to cards and comprise the "unit record" of commercial filing. They can be changed and reordered if desired. Ordinary characters at the beginning or end of the slugs aid in manual arrangement. And the sheets can be rearranged or replaced.

The displays can be photographed directly on the disc, or on an intermediate strippable type film. In the latter procedure, the emulsion can be soaked off the backing and pasted on the disc. The pieces of film attached in this way can be as large as a quadrant of the annulus or as small as a postage stamp. Thus, small accumulations of new material can be added to the disc.



Proof pulled from galley made of Linotype slugs. Character shown is an eight-bit symbol, repeated sixteen times in a row. There are 50 rows, each sharing a black and white border. FIG. 6

RECORDING PATTERNS

Since the exposure of the film is inherently binary, it is possible to record binary information with black representing zero and white representing one. But this creates the analog problem of determining electronically whether a long black mark is n or n plus or minus one zero digits. To make sure that the detection of digits imposes the minimum requirement on the electronics, a redundant symbol is used for recording binary bits. Two bits of storage are used to record one binary character. With this notation, no message has combinations of digits that result in more than double whites or blacks. Thus, the electronics need only discriminate between singles and doubles, Figure 7.

There is this advantage in the above notation: since the average light intensity over a short string of digits is grey, it is unnecessary to project the spot of light exactly in the track of information. Each track is bordered by a black and white strip, so that wandering from the track changes the dc level from the phototube. These changes actuate a servo to control the deflection of the electron beam.

The borders may be shared to save space, but this means that the sense of the servo is reversed in successive tracks. While complicating the servo loop, this simplifies the circuitry for switching from track to track. If the spot is given a small push in the direction of switching, and the sense of the servo is simultaneously reversed, it automatically settles down in the next track and will not skip a track.

It is necessary that no recording be made in certain sections of the track. For example, if the length of track assigned to each word is uniform but the words are of different length, the sections of track not used must be filled with blanks. These blanks can be recorded as "half tracks", Figure 8.

In addition to the basic binary characters, a search routine requires punctuation marks to indicate the beginning of various kinds of information, such as the address and the desired information for output. Since the redundant code used to record binary digits makes it impossible to have odd numbers of singles between doubles of the same type, these arrangements can be used as punctuation marks when combined with the no information symbol.

COMBINED ERASABLE AND PERMANENT STORAGE

Where changes occur frequently, photographing of intermittently received new information is cumbersome. Here it is convenient to have an associated storage device for quickly inserting new information. A magnetic storage element with a capacity of a small percent of the photoscopic unit usually can accommodate several days' accumulation of new and changed information. When full, its contents are transferred to a photoscopic disc. This can be done independently of the main disc, or the two can read out to produce a new disc.

Using this technique, both the photoscopic and erasable stores must be searched simultaneously. Three conditions arise:

1—Address found only in photostore. Associated information read out.

2—Address found only in erasable store. Associated information read out.

3—Address found in both stores. Information in erasable store is used and the other discarded.

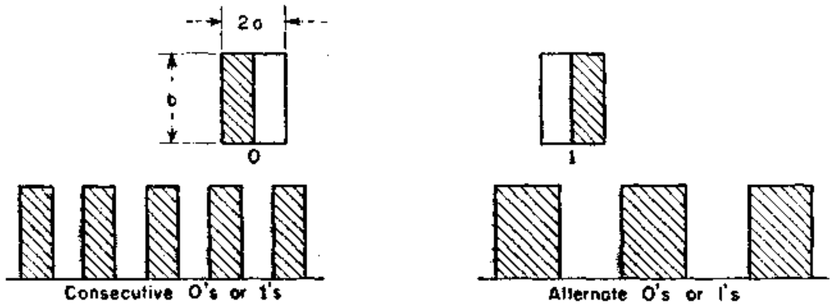
USING THE STORAGE

The simplest scheme is the same as a conventional file. Each item or word has a unique index or address. To find information, the address is set in the machine and the spot scans the disc until this particular address is found. By means of a matching signal the needed information associated with the address is passed to a register and then read out to a printer or visual display.

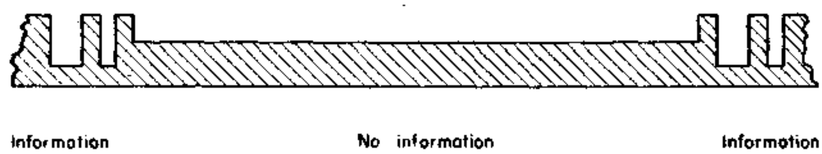
Filling the orders in a mail-order house is typical. Each item in an order must be checked in a catalog for price, size, etc. The number of items in a catalog times the number of bits required per item is about a billion. Over a hundred thousand orders arrive a day, averaging two items per order. Very fast access is required. This relatively permanent information is arranged according to catalog number.

In some files, the information only has value for a specific time. For example, in a credit or liability file, information older than four or five years is ignored. Two expensive operations are made on each entry: in-filing, or putting a new entry in its place in an ordered file, and purging, or removal of the card after the expiration date. The latter requires periodic reading of every card in the file. Access is simple; names are in alphabetical order.

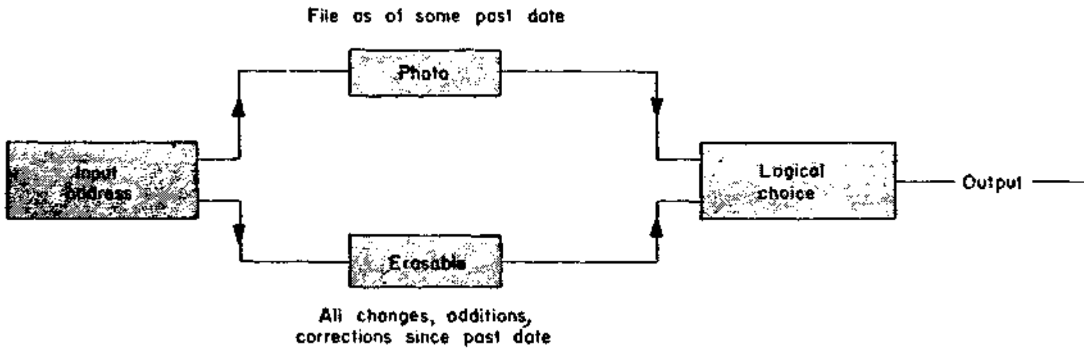
On the other hand, the file can be divided into coarse categories. Assume, for example, that it consists of only the first letters of the name, with a separate drawer for each letter. New cards are sorted only by the first letter and inserted in the front of the corresponding drawer. In-filing is reduced to a minimum and in any drawer the cards are arranged by the date of accession. In purging,



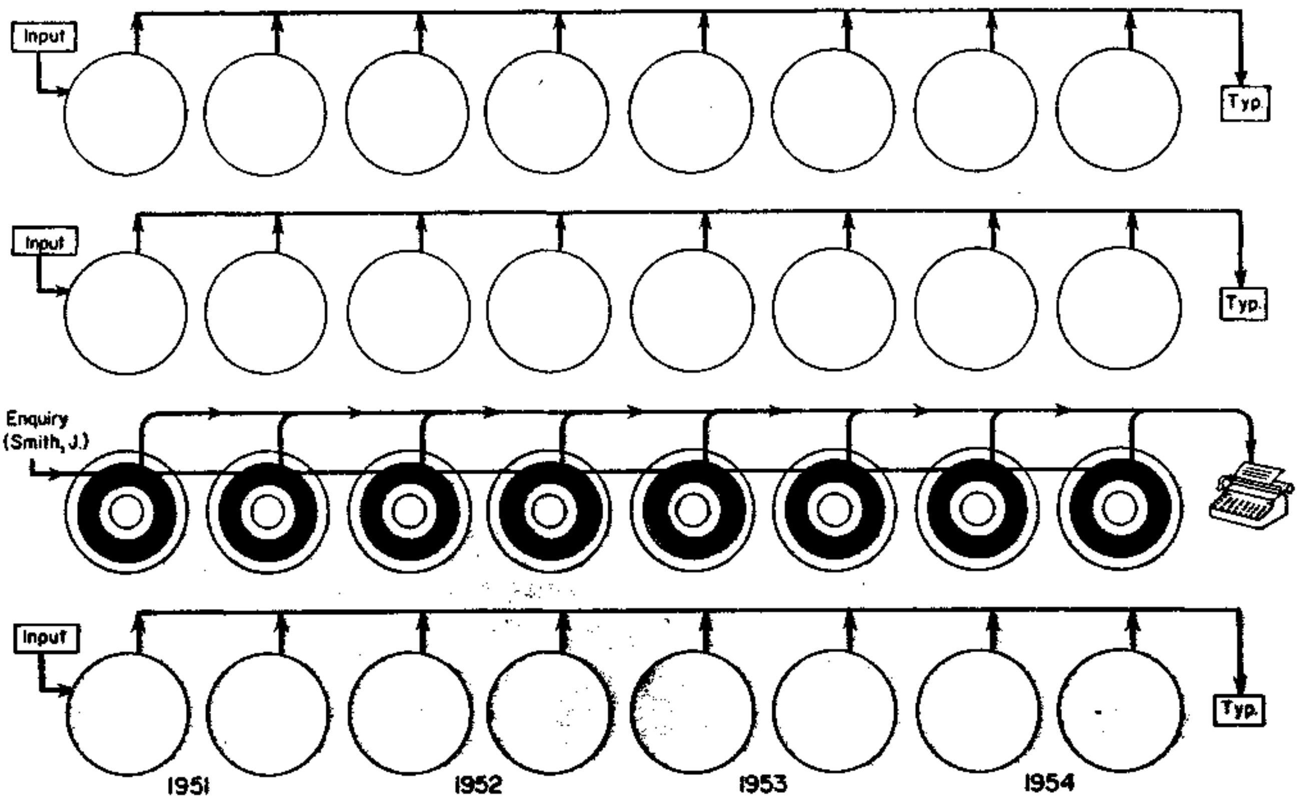
Redundant coding uses two bits of storage to record one binary character. FIG 7



"Half track" symbol records blanks in information. FIG. 8



Combining permanent and erasable storage techniques. FIG. 9



Schematic of photoscopic storage system for four-year credit file. FIG. 10

cards are removed from the rear of the drawer. This is difficult to accomplish manually, since every card must be examined to find an address in a given drawer, but with a photoscopic unit, the high reading rate is exchanged for collation. In a typical commercial file, the information under a particular coarse grouping can be searched in a second or two. If faster access is required, the information can be grouped into more catagories.

Assume that six million names in a typical credit file are held for four years. At this rate of change, four discs must be assigned to each six-month period. Four years' accumulation takes 32 discs. Each disc is divided into eight annuli, so there are 32 areas, each assigned to a letter of the alphabet. To find a particular name the search is carried out simultaneously in the appropriate annulus on each of the eight semi-annual discs, Figure 10. All matching entries are delivered to the output equipment. If necessary, discriminating circuits can reject all but the latest entry.

After a period of four years, the information on four of the discs assigned to the eighth semi-annual period is obsolete, and the discs can be cleaned off and used again.

New information is put on the last bank of four discs. However, the material only has to be sorted by the first letter, and the daily intake for each letter merely has to be put in the appropriate zone. Strippable type film can be used. Precise alignment is not required because of the servo devices built in the reading head.

An inventory machine is a reference file in which each item in inventory is described and a record is kept of the number of items in stock. The list of items, with identification by description, supplier, etc., is relatively permanent. The item count changes frequently, and good control of inventory demands that changes be noted instantaneously. Usually the permanent part of the information is several hundred bits in size, while the item count requires only a few tens of bits. Even in moderate operation, the total volume of information to be stored is several tens or hundreds of millions of bits.

Since about 95 per cent of this information is permanent, this part can be recorded in a photoscopic storage unit while the remaining changeable information is recorded on an erasable medium. When the inventory of an item is to be changed, its description is sent to the permanent storage unit as an address. When the address is located, the photoscopic unit delivers the location in the erasable store where the count of this item can be found. This count is read out of the erasable store, changed by the amount withdrawn or deposited, and the new count is reinserted. No permanent information is recorded in the erasable store. It is only used to store information that can and does change.