Chapter 25: External Storage

Author's Note: *This chapter is copied almost verbatim from the material in Chapter 17 of the textbook by Peter Abel. It is used by permission.*

A file, or data set, is a collection of related data records. Most data processing applications involve data files of such volume that they require large external magnetic tape and disk storage devices. Tape and disk provide mass external permanent storage, extremely fast input/output, reusability, and records of almost any reasonable length.

This chapter introduces the various file organization methods and describes the architecture for magnetic tape and disk drives. The next three chapters cover the processing of files.

File Organization Methods

In any system, a set of related records is arranged into a file and organized according to the way in which programs are intended to process them. Once you create a file under a particular organization method, all programs that subsequently process the file must do so according to the requirements of the method. Most commonly, this is done by using macros and subroutine calls associated with the method that wrote the data: VSAM out, VSAM in. Let's take a brief look at the most common organization methods.

Sequential File Organization

Under sequential organization, records are stored one after another. Almost all commercial data sets comprise records with an identifying element called the key. For example, consider a data set holding student information. Each record would probably have a key value used to associate that record with the student, most likely a student ID number.

The records in a commercial data set would normally be in ascending sequence (the usual) or descending sequence by a particular key or keys (control word), such as customer number or employee number within department, or, contrary to what the name "sequential organization" implies, records need not be in any particular sequence.

In some data sets used to support scientific research, records do not have associated keys. The record may be a list of measurements, such as temperatures or particle energies that have been observed. All of these data are input to a program that processes them.

In commercial usage, we have the "old master/new master" scenario. A typical instance of this would be inventory processing. The program that does such processing would have two inputs, each a sequential data set.

1) An "old master" data set containing inventory information, with records sorted by part number in ascending sequence.
2) A data set containing transaction records for the sales activity that day.

At the end of the day, the transaction records would be read into the computer and sorted by part number in the same way as those records in the old master data set. The processing would then apply the transactions to the old master data set, producing a "new master" data set that represented the inventory at the end of the day (accounting for all sales in the transaction records); this becomes the old master for the next day. Other processing may produce a data set containing orders to be made in order to replenish the inventory.

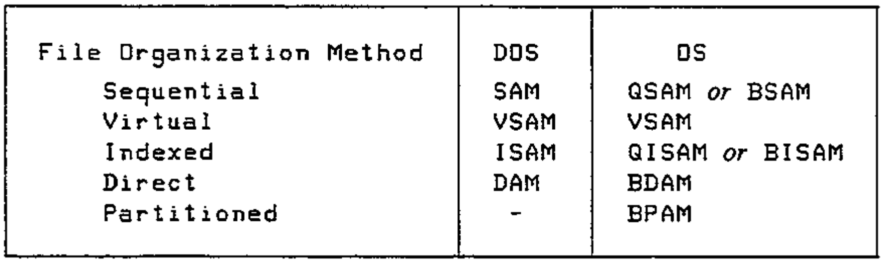
You can store a sequentially organized file on any type of device and for any type of file, such as master, transaction, and archival. Such a file can even be stored on punch cards, such as the 80–column punch cards that were once used to store programs and data. While punch cards have not been much used to store data since about 1990 (due to the storage space required), a data set on punched cards may be considered as being in unblocked form (see below) on a magnetic tape (also little used since about 2000).

Indexed Sequential (ISAM) File Organization
Indexed sequential organization for master files lets one access records in ascending sequence and also support indices that enable access of any record randomly by key. The ISAM organization is very efficient, but not flexible when records are inserted and deleted at random. The newer VSAM method is more flexible and provides equivalent services; for this reason we mention ISAM only as an item of historical interest.

Direct File Organization
Direct file organization facilitates direct access for any record in a master file. The main advantage is that this method provides fast access for records and is thus particularly useful for online systems.

Virtual Storage Access Method (VSAM)
Virtual storage access method (VSAM) supports three organization types. Entry–sequenced is equivalent to sequential organization, key–sequenced is equivalent to ISAM, and relative–record is equivalent to direct. Disk storage devices, but not tape, support indexed sequential, VSAM, and direct organization. Chapters 26, 27, and 28 cover sequential, ISAM, and VSAM, respectively.

ACCESS METHODS
An access method is the means by which the system performs input/output requests. The methods depend on the file organizations and the file type of accessing required.
DOS supports four methods and OS supports seven. The latest implementation of z/OS, which is the Operating System for the z/10 and z/11, probably support more.



File Organization Method	DOS	OS
Sequential	SAM	QSAM *or* BSAM
Virtual	VSAM	VSAM
Indexed	ISAM	QISAM *or* BISAM
Direct	DAM	BDAM
Partitioned	-	BPAM

Processing of External Storage Devices
Major similarities between tape and disk are that records may be of virtually any length, of fixed or variable length, and clustered together into one or more records per block. It should be mentioned that disk records are not partitioned into fixed length sectors, as is the case for computers running MS–DOS or its equivalent, MS–Windows. When we discuss the logical disk architecture as implemented by modern IBM Mainframe (Enterprise Server) computers, we shall have occasion to mention again this logical record architecture.

There are, however, two major differences in processing tape and disk. First, each time you read or write, the tape drive starts, transfers the data, and then stops, whereas a disk drive rotates continuously. The sole exception to this is the now obsolete external “floppy disk” in which the disk rotation is discontinued after a period of inactivity in order to avoid wear on the motor. The second difference is that update of records on tape involves rewriting of the entire changed file on another reel of tape. Disk records can be updated in place, but the mechanical problems of tape movement mean that in–place replacement of records is likely to be error prone and should be avoided.

Identification of External Devices

Both disk and tape have unique ways of identifying their contents to help in locating files and in protecting them from accidental erasure.

Tape file identification. At the beginning of the tape reel is a volume label, which is a record that identifies the reel being used. Immediately preceding each file on the tape is a ***header label***, which describes the file that follows. This record contains the name of the file (for example, INVENTORY FILE) and the date the file was created. Following the header label are the records that comprise the data file.

The last record following the file is a ***trailer label***, which is similar to the header label but also contains the number of blocks written on the reel. The operating system automatically handles the header and trailer labels.

Disk file identification. To keep track of all the files it contains, a disk device uses a special directory *(**volume table of contents***, VTOC) at the beginning of its storage area. The directory includes the names of the files, their locations on disk, and their present status.

Packed and Binary Data

Tape and disk records can contain numeric fields defined as zoned, binary, or packed. Packed format involves two digits per byte plus a half-byte for the sign, such as

```
PAYMENT DS PL4
```

In this case, the field length is 4 bytes, stored as **dd** | **dd** | **dd** | **ds**, where **d** is a digit and **s** is the sign. If the field is defined as binary, watch out for erroneous alignment of the field when you read it into main storage. The following binary fields are both 4 bytes long:

Aligned on a fulIword boundary:	`PAYMENT1 DS F`
Not aligned on a boundary:	`PAYMENT2 DS FLA`

The assembler automatically aligns **PAYMENT1** on a fullword boundary, whereas the assembler defines **PAYMENT2** at its proper (unaligned) location.

Unblocked and Blocked Records

Disk and tape devices recognize ***blocks*** of data, which consist of one or more records. A blank space, known as an ***interblock gap*** (IBG), separates one block from another. The length of an IBG on tape is 0.3 to 0.6 inches depending on the device, and the length of an IBG on disk varies by device and by track location. The IBG has two purposes: (I) to define the start and end of each block of data and (2) to provide space for the tape when the drive stops and restarts for each read or write of a block.

Records that are stored one to a block are called ***unblocked***. As shown in Fig. 25-1(a), following each block is an IBG.

To reduce the amount of tape and disk storage and to speed up input/output, you may specify a ***blocking factor***, such as three records per block, as shown in Fig. 25-1(b). In this format, the system writes an entire block of three records from main storage onto the device. Subsequently, when the system reads the file,it reads the entire block of three records from the device into storage. All programs that subsequently read the file must specify the same record length and block length. Blocking records makes better use of disk and tape storage but requires a larger buffer area in main storage to hold the block.

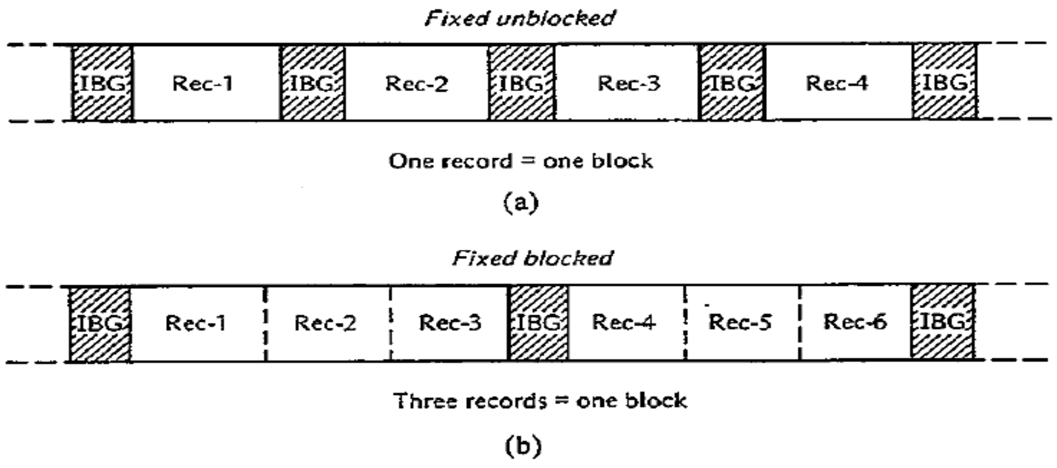
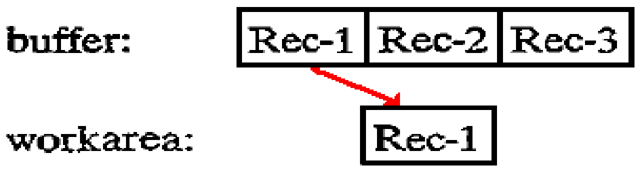


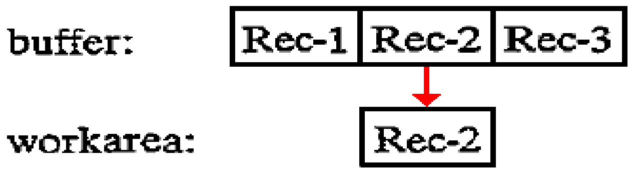
Figure 25–1 (a) Unblocked records. (b) Blocked records

Input Buffers

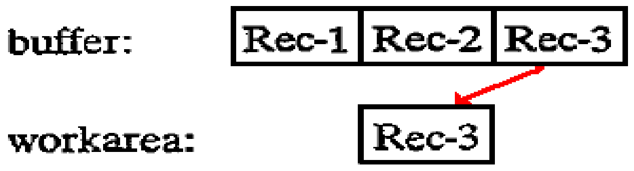
The action of an input operation depends on whether records are unblocked or blocked. If unblocked, the operation transfers one record (block) at a time from the device into the input/output buffer in your program. The following example of blocked records assumes three records per block. Initially, the input operation transfers the first block from the device into the buffer (I/O area) in your program and delivers the first record to your program's work area:



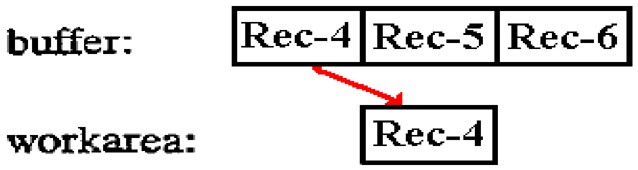
For the second input executed, the operation does not have to access the device. Instead, it simply delivers the second record from the buffer into your program’s work area:



And for the third input executed, the operation delivers the third record from the buffer to your program's work area:

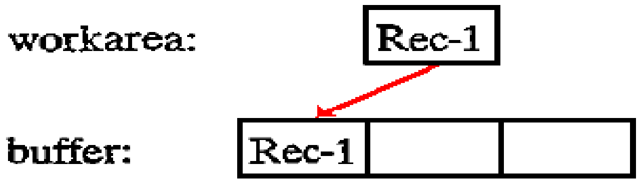


While the program processes the third record in the work area, the system can read ahead and transfer the second block (containing records 4, 5, and 6) from the device into the buffer in your program. For the fourth input executed, the operation delivers the first record from the buffer into your program's work area:

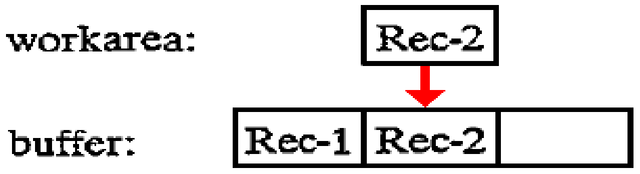


Output Buffers

The action of an output operation depends on whether records are unblocked or blocked. If unblocked, the output operation transfers one record (block) at a time from your work area to the buffer in your program and then to the output device. The following example of blocked records assumes three records per block. The first output operation writes the record in the work area to the first record location in the output buffer, but not to the output device:



No actual physical writing to the output device occurs at this time. The second output operation writes the record in the work area to the second record location in the buffer:



Similarly, the third output operation writes its record from the work area to the third record location in the buffer. Now the buffer is full, the system can physically write the contents of the buffer, this block of three records, to the external device.

The CLOSE operation automatically writes the last block of data to the output device. This last block may validly contain fewer records than the blocking factor specifies; consider a program that writes ten records with a blocking factor of three. When the CLOSE operation is called, the buffer will contain one valid record (record 10) and two empty slots.

NOTE ADDED BY Ed Bosworth

There is some security advantage to having each physical write, including the last CLOSE, completely clear the buffer before any additional logical writes take place.

Fixed-Length and Variable-Length Records
Records and blocks may be fixed in length, where each has the same length throughout the entire file, or variable in length, where the length of each record and the blocking factor are not predetermined. There are five formats:

1.	***Fixed, unblocked:***	one record of fixed length per block
2.	***Fixed, blocked:***	more than one fixed-length record per block
3.	***Variable, unblocked:***	one variable-length record per block
4.	***Variable, blocked:***	more than one variable-length record per block
5.	***Undefined:***	contents of no defined format (Not all systems support this format.)

MAGNETIC TAPE STORAGE

The magnetic tape used in a computer system is similar to the tape used by conventional audiotape recorders; both use a similar coating of metallic oxide on flexible plastic, and both can be recorded and erased. Its large capacity and its reusability make tape an economical storage medium.

Data records on tape are usually, but not necessarily, stored sequentially, and a program that processes the records stints with the first record and reads or writes each record consecutively.

The main users of tape are installations such as department stores and utilities that require large files that they process sequentially. Many installations use disk for most general processing and use tape for backing up the contents of the disk master files at the end of each workday. Consequently, if it is necessary to rerun a job because of errors or damage, backup tapes are always available.

Characteristics of Tape

The most common width of a reel of magnetic tape is 1/2 inch, and its length ranges from 200 feet to the common 2,400 feet, with lengths as long as 3,600 feet. A tape drive records data as magnetic bits on the oxide side of the tape.

Storage format. Data is stored on tape according to tracks. The tape in Fig. 25–3 shows the arrangement of a nine–track tape; it has nine horizontal tracks, each of which represents a particular bit position. Each vertical set of 9 bits constitutes a byte, of which 8 bits are for data and 1 bit is for parity. In the 1950's and 1960's, the seven–track format was also popular, having six bits for data and 1 bit for parity. By the mid–1970's, this format was becoming unpopular, and seven–track tape readers were hard to find.

The picture at left (**Fig. 25–2**) shows the first magnetic tape drive produced by IBM. This was the IBM 729, a 7–track device, first released in 1952. The novelty of the design is reflected by an actual incident at the IBM receiving dock. The designers were expecting a shipment of magnetic tape when they were called by the foreman of the dock with the news that "We just received a shipment of tape from 3M, but are going to send it back … It does not have any glue on it"

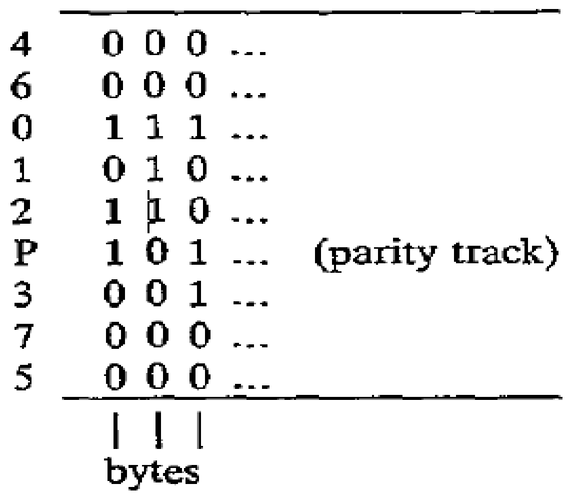


Figure 25–3 Data on Tape, with Bytes in Vertical Stripes

As you can see, the tracks for each of the bits are not in the expected sequence. The tracks for bits 4 and 5, the least used, are in the outer area where the tape is more easily damaged. The first byte, on the left, would appear in main storage as follows:

Bit Number	0	1	2	3	4	5	6	7	P
Bit Value	1	0	1	0	0	0	0	0	1

The data value stored in the byte is “1010 0000” or hexadecimal “A0”. The parity bit is set for odd parity, in which each byte will be represented with an odd number of 1 bits in its vertical stripe. Here, the data byte contains an even number of 1 bits, so P is set to 1.

Storage density. Tape density is measured by the number of stored characters, or bytes, per inch (bpi), such as 800, 1,600, or 6,250 bpi. Therefore, a 2,400-foot reel with a recording density of 1,600 bpi could contain 46 million bytes, which is equal to over a half-million 80-byte records. Double-density tape stores data on 18 tracks, representing 2 bytes for each set of 18 vertical bits. This however is an unusual format.

Tape speed. Tape read/write speeds vary from 36 to 200 or more inches per second. Thus a tape drive that reads 1,600 bpi records at 200 inches per second would be capable of reading 320,000 bytes per second. Other high-speed cartridge drives transfer data **at** up to 3 million bytes per second.

Tape markers. A reflective strip, called a load point marker, located about 15 feet from the beginning of a tape reel, indicates where the system may begin reading and writing data. Another reflective strip, an end-of-tape marker, located about 14 feet from the end of the reel, warns the system that the end of the reel is near and that the system should finish writing data. Both the load point marker and the end-of-tape marker are on the side of the tape opposite the recording oxide.

Tape File Organization

A file or data set on magnetic tape is typically stored in sequence by control field or key, such as inventory number. For compatibility with disks, a reel of tape is know as a ***volume***. The simplest case is a one-volume file, in which one file is entirely and exclusively stored on one reel (volume).

An extremely large file, known as a ***multivolume file***, requires more than one reel. Many small files may be stored on a ***multifile volume***, one after the other. The primary problem here is that you may have to rewrite the entire reel just to update one of the files.

Unblocked and Blocked Tape Records
As an example of the effect of blocking records on tape, consider a file of 1,000 records each 800 bytes long. Tape density is 1,600 bytes per inch, and each IBG is 0.6 inches. How much space does the file require given (a) unblocked records and (b) a blocking factor of 5? Calculate the size of a record of 800 bytes as 800 / 1,600 = 0.5 inches.

(a) Unblocked records
One block = one record = 800 bytes

Length of one block = 800 bytes/1,600 bpi	= 0.5”
Length of one mG	= 0.6”
Space required for one block	= 1.1"

Space required for file = 1,000 blocks x 1.1" = 1,100"

(b) Blocked records
One block = five records = 4;000 bytes

Length of one block = 4,000 bytes/1,600 bpi	= 2.5"
Length of one IBG	= 0.6”
Space required for one block	= 3.1"

Space required for file = 200 blocks x 3.1" = 620"

As can be seen, the blocked records require considerably less space because there are fewer Interblock Gaps.

Standard Labels
Under the various operating systems, tape reels require unique identification. Each reel, and each file on a reel, usually contains descriptive standard labels supported by the operating systems (1) to uniquely identify the reel and the file for each program that processes it and (2) to provide compatibility with other IBM systems and (to some degree) with systems of other manufacturers.

Installations typically use standard labels. Nonstandard labels and unlabeled tapes are permitted but are not covered in this text. The two types of standard labels are volume and file labels. Figure 25–4 illustrates standard labels for one file on a volume, a multivolume file, and a multifile volume. In the figure, striped lines indicate IBGs, and TM (for tape mark) is a special marker that the system writes to indicate the end of a file or the end of the reel.

Volume Labels
The volume label is the first record after the load point marker and describes the volume (reel). The first 3 bytes contain the identification VOL. Although some systems support more than one volume label, this text describes only the common situation of one label.

On receipt of a new tape reel, an operator uses an IBM utility program to write a volume label with a serial number and a temporary header file label. When subsequently processing the reel, the system expects the volume label to be the first record. it checks the tape serial number against the number supplied by the job control command, TLBL under DOS or DD under OS.

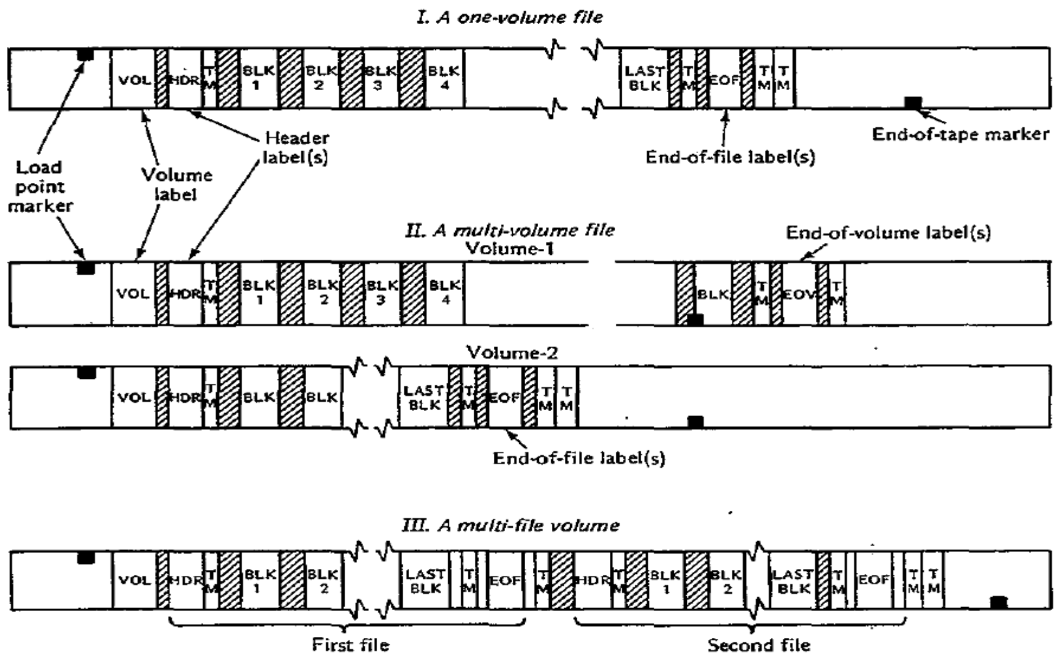


Figure 25–4 Magnetic Tape Standard Labels

The following describes each field in the 80–byte standard volume label:

Positions	Name	Description
01 – 03	Label identifier	Contains the three characters “VOL” to identify the label.
04	Volume label number	Some systems permit more than one volume label; this field contains their numeric sequence.
05 – 10	Volume serial number	The permanent unique number assigned when the reel is received. This number also becomes the file serial number in the header label.
11	Volume security code	A special security code supported by the OS
12 – 41	Unused	Reserved for use by IBM.
42 – 51	Owner’s identification	May be used under OS to identify the owner’s name and address.
52 – 80	Unused	Reserved/

File Labels

A tape volume contains a file of data, part of a file, or more tban one file. Each file has a unique identification to ensure, for example, that the system is processing the correct file and that the tape being used to write on is validly obsolete [presumably meaning that its contents can be overwritten – ELB]. Two file labels for each file, a header label and a trailer label, provide this identification.

The following describes each field in the standard file label for both header and trailer labels. (This table, accurate for the late 1970's, must now be obsolete; note the two digit "**yy**" format for the year number in the Creation Date and Expiration Date fields. – ELB)

Position	Name	Description
01 – 03	Label identifier	HDR if a header label, EOF if the end of a file, EOV if the end of a volume. Three EBCDIC characters.
04	File label number	Specifies the sequence of file labels for systems that support more than one. OS supports 2 labels each for HDR, EOF, and EOV.
05 – 21	File identifier	A unique name that identifies the file.
22 – 27	File serial number	The same identification as the volume serial number for the first or only volume of the file.
28 – 31	Volume sequence number	Sequence of volume numbers for multivolume files. The first volume for a file contains 0001, the second 0002, etc.
32 – 35	File sequence number	The sequence of file numbers for multifile volumes. The first file in a volume contains 0001, the second 0002, etc.
36 – 39	Generation number	Each time the system rewrites a file, it increments this number by 1 to identify the edition of the file.
40 – 41	Version number of generation	Specifies the version of the generation number of the file. (Whatever that means – ELB)
42 – 47	Creation Date	The year and day when the file was written. Format is " yyddd", with two digit year and 3 digit day number. Note the leading blank, to make six characters.
48 – 53	Expiration Date	The year and day when the file may be overwritten. The format is identical to that for the creation date.
54	File security code	A special security code used by OS.
55 – 60	Block count	Used in trailer labels for the number of blocks since the previous header label.
61 – 73	System code	An identification for the operating system.
74 – 80	Unused	Reserved, but probably now used to expand the year numbers for Creation & Expiration date. Corrections for the Y2K problem cannot invalidate older file formats.

Header label. A header label precedes each file. If the file requires more than one reel, each reel contains a header label, numbered from 001. If a reel contains more than one file, a header label precedes each file.

The header label contains HDR in the first 3 bytes; the file identification (such as CUSTOMER RECORDS), the date the file may be deleted, and so forth. The system expects a header label to follow the volume label immediately and checks the file identification, date, and other details against information supplied by job control.

OS supports two header labels, HDRI and HDR2, with the second label, also 80 bytes, immediately following the first. Its contents include the record format (fixed, variable, or undefined), block length, record length, and density of writing on the tape.

Trailer label. A trailer label is the last record of every file. (OS supports two trailer labels.) The first 3 bytes contain EOV if the file requires more than one reel and the trailer label is the end of a reel but not end of the file. The first 3 bytes contain EOF if the trailer label is the end of the file.

The trai1er label is otherwise identical to the header label except for a block count field. The system counts the blocks as it writes them and stores the total in the trailer label. Subsequently, when reading the reel, the system counts the blocks and checks its count against the number stored in the trailer label.

IOCS FOR MAGNETIC TAPE

The system (IOCS for DOS and Data Management for OS) performs the following functions for input and for output.

Reading a Tape File

The processing for reading a tape file is as follows:

*1. **Processing the Volume Label**.* On OPEN, IOCS reads the volume label and compares its serial number to that on the TLBL or DD job control entry.

*2. **Processing the Header Label**.* IOCS next reads the header label and checks that the file identification agrees with that on the job control entry to ensure that it is reading the correct file. For a multivolume file, the volume sequence numbers are normally in consecutive, ascending. sequence.

*3. **Reading Records.*** The GET macro reads records, specifying either a work area or IOREG. If the tape records are unblocked, each GET reads one record (a block) from tape into storage. If records are blocked, IOCS performs the required deblocking.

*4. **End-of-Volume**.* If IOCS encounters the end-of-volume label before the end–of–file (meaning that the file continues on another reel), IOCS checks that the block count is correct. It rewinds the reel, opens a reel on an alternate tape drive, checks the labels, and resumes reading this new reel.

5. End-of-File. Each GET operation causes IOCS to transfer a record to the work area. Once every record has been transferred and processed and you attempt to perform another GET, IOCS recognizes an end-of-file condition. It then checks the block count, (usually) rewinds the reel, and transfers control to your end-of-file address designated in the DTFMT or DCB macro. You should now CLOSE the tape file. To attempt further reading of a rewound tape file, you must perform another OPEN.

Writing a Tape File

The processing for writing a tape file is as follows:

***1. Processing the Volume Label**.* On OPEN, IOCS checks the volume label (VOL) and compares its serial number to the serial number (if any) on the job control entry.

*2. **Processing the Header Label**.* IOCS next checks the header label for the expiration date. If this date has passed, IOCS backspaces the tape and writes a new header (HDR) over the old one, based on data in job control. If this is a multivolume file, IOCS records the volume sequence number for the volume. It then writes a tape mark.

3. ***Writing Records***. If the tape records are unblocked, each PUT writes one record (a block) from tape into storage. If records are blocked, IOCS performs the required blocking.

4. *End-of-Volume*. If10CS detects the end-of-tape marker near the end of the reel, it writes an EOV trailer label, which includes a count of all blocks written, followed by a tape mark. Since the reflective marker is on the opposite side of the tape, data may be recorded through its area. If an alternate tape drive is assigned, IOCS opens the alternate volume, processes its labels, and resumes writing this new reel.

5. ***End-of-File***. When a program closes the tape file, 10CS writes the last block of data, if any. The last block may contain fewer records than the blocking factor specifies. IOCS then writes a tape mark and an EOF trailer label with a block count. Finally, IOCS writes two tape marks and deactivates the file from further processing.

DISK STORAGE

A **d**irect **a**ccess **s**torage **d**evice (DASD), which includes magnetic disk storage and the less common drum storage, is a device that can access any record on a file directly. Diskettes, a common and familiar storage medium on micro- and minicomputers, store data in a similar manner. This section describes the details of the larger magnetic disk devices used in data processing installations. (**ELB:** Basically, a DASD is any device that can be addressed and used as if it were a disk. Today, this might include USB Drives, which are formatted as disks in order to facilitate their portability among computer systems. A CD–ROM, though called a disk, is formatted and accessed more like a magnetic tape; it is not a DASD.

Historically, the first DASD built was a magnetic drum memory, which was invented in 1932 for use in early calculating machines. A drum is a large metal cylinder that is coated on the outside surface with a ferromagnetic recording material. This surface is divided into parallel tracks, each of which would resemble a circle, or line that encircles the cylinder. A row or read–write heads runs along the axis of the drum, one for each track.

The figure below shows magnetic drums from two commercial firms, IBM and UNIVAC. The magnetic drum on the left is one for the IBM 650, from about 1954. This drum was four inches in diameter, 16 inches long, and stored 2,000 10–digit numbers (possibly 20 KB). The drum rotated at 12,500 rpm. The drums on the right are probably variants of the Model 1124, made by UNIVAC beginning in about 1953. These would store between 18 KB and 36 KB on 133 to 270 parallel tracks. The picture on the right probably dates to 1958.

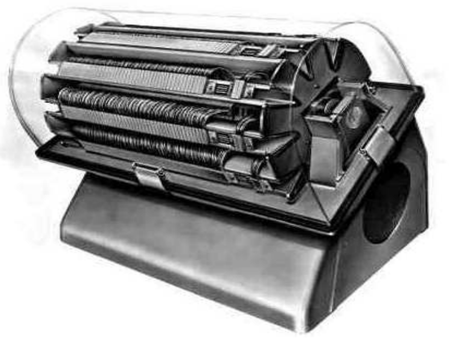
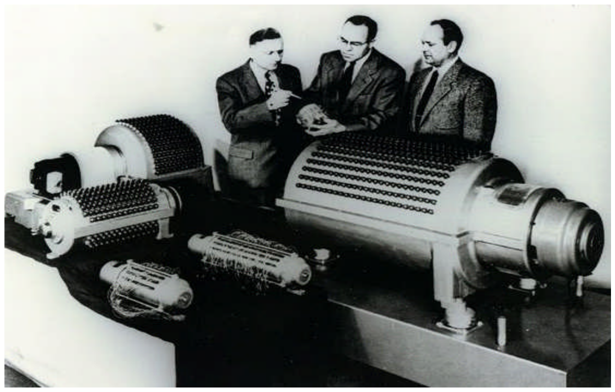



Figure 25–5 Magnetic Drum Memories

The "golden era" of magnetic drum memories seems to have begun in the early 1950's, when they replaced the smaller and much more fragile Williams–Kilburn tubes, to the middle of the 1960's, when magnetic disk technology as we know it became more cost effective. The technology persisted because it was useful; as late as 1980, PDP–11/45 computers that used drums for swapping (management of virtual memory) were still in use.

The first commercial disk drive seems to have been the IBM 350, an integral part of the IBM RAMAC 305 System (Random Access Method for Accounting and Control) introduced in 1956. The figure below shows two views, one showing the mechanism of the disk drive itself and one showing the IBM 350 as a part of the RAMAC 305. The RAMAC disk had fifty aluminum disks, each twenty–four inches in diameter. Its total storage capacity was variously quoted at either 4.4 MB or five million characters. The disks spun at 1200 rpm, yielding an average latency of 1/20 second), and transferred data at 8,800 characters per second. According to IBM, the disk would store the equivalent of 64,000 punched cards. The standard punched card of the time was the IBM 5081, which was usually 0.007 inches thick. Thus the system would store about the same amount of data as 37 feet of cards, as 64,000 • 0.007 = 64,000 • 7/1000 = 64 • 7 = 448 inches = 37 feet, 4 inches.

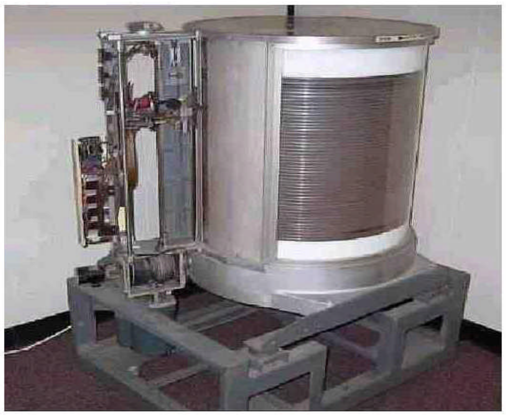


Figure 25–6 Two Views of the IBM RAMAC: IBM 305 and IBM 350

Each disk storage device contains a number of thin circular plates (or disks) stacked one on top of the other. Both sides of each plate (except the outer top and bottom on some devices) have a coat of ferrous oxide material to permit recording. (ELB: Before the introduction of the IBM "Winchester technology" in 1973, disk packs were often removed from the disk drives. This resulted in possible damage to the outer top and outer bottom recording surface, which were not used in order to avoid data corruption. A disk pack with six platters, as shown in the figure below, would have either ten or twelve recording surfaces.

I have decided to include more on the history of this disk drive. This was officially named the IBM 3340 Direct Access Storage Facility, but unofficially named "Winchester". The early design focused on two removable 30 megabyte disk modules; the name was selected after the famous Winchester 30–30 rifle. The design was changed, but the code name stuck. The significance of this technology was it was the first to package the disk packs, read heads, and read arm assembly in a sealed unit that could be removed as a single module. With reduced possibility of contamination of the recording surfaces of the disk, it became possible to increase recording densities and use all of the available surfaces. The IBM 3340 was introduced in March 1973 for use with the IBM System/370.)

As Fig. 25–7 shows, each disk contains circular tracks for storing data records as magnetized bits. Each track contains the same number of bits (and bytes) because the bits are spaced more closely together on the innermost tracks. (ELB: Modern designs partition the surface into a number of zones. Within each zone, each track contains the same number of bytes, but tracks in an outer zone contain more bytes than those in an inner zone.)

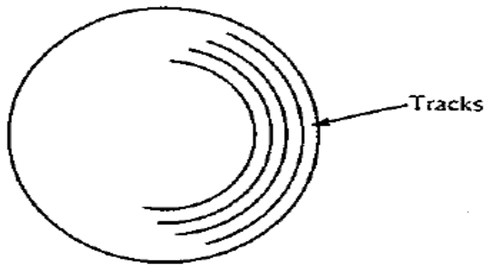


Figure 25–7 Disk Surface and Tracks

The disks are constantly rotating on a vertical shaft. As Fig. 25–8 shows, the disk device has a set of access arms that move read/write heads from track to track. The heads read data blocks from a disk track into main storage and write data blocks from main storage onto a disk track. Because the disks spin continually, the system has to wait for a required data block to reach the read/write heads. (ELB: Note that this configuration does not use the top surface of the top platter or the bottom surface of the bottom platter; it has six platters and ten recording surfaces. A Winchester unit would use all twelve surfaces.)

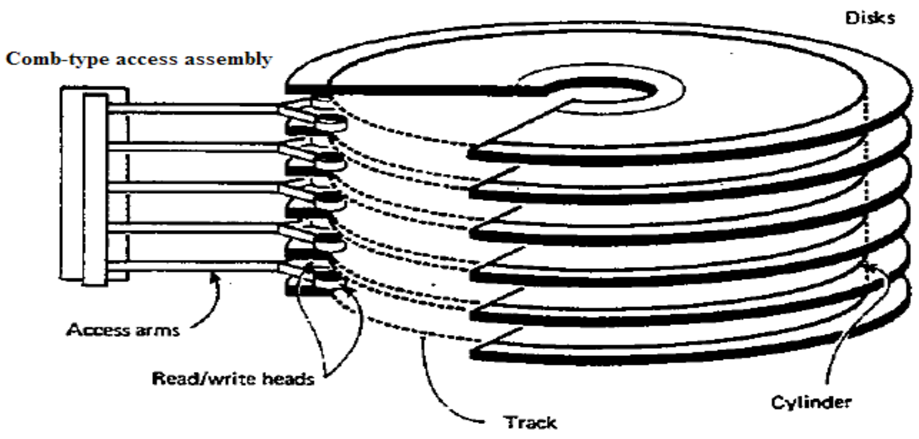


Figure 25–8 Disk read/write mechanism (Non Winchester)

Disk storage devices permit processing of records both sequentially and randomly (directly). As a result, programs can read unsorted records from a transaction file and use them to randomly update matching master records on disk. Disk storage therefore facilitates online processing where users can at any time make inquiries into a file and can enter transactions for updating as they occur.

(ELB: There are two factors of importance when considering a disk: maximum transfer rate and disk access times. The maximum transfer rate is computed simply: it is the number of bytes on a disk track divided by the time to read the entire track. Consider a disk rotating at 15,000 rpm, or one revolution every 1/250 = 0.004 second. If the track holds 4 MB of data, the transfer rate is 4MB /0.004 second = 1 GB/second.

Times of importance when assessing disk speed, the **average latency** and the **track access time,** commonly called **"seek time"**. The latency is computed as the time for the disk to spin one half of a turn; if the read/write heads are on the correct track, this is the average wait time for the desired sector to rotate under the heads. For example, a disk rotating at 12,000 rpm would make 200 revolutions per second. This corresponds to 5 milliseconds per revolution or an average latency of 2.5 milliseconds.

The track access time is that time to move the heads from one track to another. Remember that each disk surface is divided into a number of concentric circles, called **tracks**. There are two times routinely quoted: move to next track, and move to average track. The first is the time to move the read/write heads to an adjacent track; the second is the average time to move from any one track to any other track. The two measures typically yield similar values, with 2 milliseconds being seen in high–end servers, and 15 milliseconds being common for standard servers. Common systems quote an average seek time of 9 milliseconds.

The final topic in this aside is the concept of a **cylinder**. It is best defined by illustration. Consider Figure 25–8 above, in which the disk drive is shown as having ten usable recording surfaces. The read/write heads move as a unit, so that a single move places each of the ten heads on a specific track on its recording surface. The collection of these tracks is called a **cylinder**. The cylinder, comprising one track per recording surface, is the set of all disk sectors that can be read without physically moving the read/write heads.)

Disk Format

The amount of data that a disk device can store varies considerably by model, ranging from small disks with a few million bytes to large disks with more than one billion bytes. Some disk models use fixed-length sectors on each track to store one or more records; the system addresses a record by disk number, track number, and sector number. On other disk models, tracks are not sectored, and records may be of almost any length; the system addresses records by disk surface number and track number.

Like magnetic tape, disk storage contains gaps between one block of data and the next, but the size of the gap is greater on the outermost tracks and smaller on innermost tracks. You may also store records on disk as unblocked or blocked. However, because of the fixed capacity of a disk track, the optimum blocking factor depends on the record length and track capacity. Special formulas are available for calculating optimum blocking factors for different disk devices.

(ELB: The design suggested in Figure 25–7 calls for each track to hold the same number of bits. More specifically, every track holds the same number of sectors, and each sector holds the same number of bits. The sectors, hence bits, are more densely packed on the inner tracks than the outer tracks, which have greater linear circumference. Thus, the linear density is specified by the maximum density allowable on the innermost track; the outer tracks may be viewed as being "under–populated". Having a fixed number of sectors per track greatly simplifies the design of the disk controller, but leads to excess unused capacity.

A more modern design divides the tracks into a number of zones, each holding a number of tracks with the same number of sectors per track. However, an outer zone will have more sectors per track than an inner zone. This allows more efficient use of the linear density of each of the zones, while allowing for a relatively simple disk controller.)

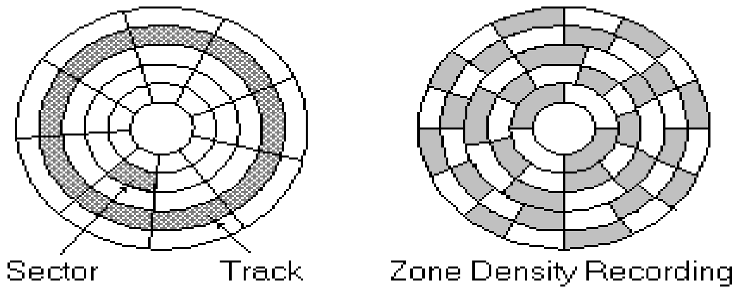


Figure 25–9 Multiple Zones Increase Disk Density

In the above figure, the disk surface is divided into three zones, each zone having a constant number of sectors per track contained. This allows a better use of linear track density, while maintaining a reasonably simple disk controller.)

As a simplified example, consider a file containing 1,000–byte records and a disk track with a capacity of 10,000 bytes. If the blocking factor is 5, one block is 5,000 bytes and you can store two blocks (ten records) on a track. If the blocking factor is 6, one block is 6,000 bytes and a track has space for only one block (six records).

The storage of data on disk begins with the top outermost track (track 0) and continues consecutively down, surface by surface, through to the bottom outermost track. Storage of data then continues with the next inner set of tracks (track 1), starting with the top track through to the bottom track. The set of vertical tracks is known as a ***cylinder***. As a result, for sequential processing the system reduces access motion of the read/write heads: It reads and writes blocks, for example, on track 5 of every surface (cylinder 5) before moving the arm.

DISK ARCHITECTURE

The two main types of IBM disk devices are count–key–data (CKD) architecture and fixed–block architecture (FBA). (ELB: There is an interesting design compromise that appears on later disks, such as more recent implementations of the IBM 3390 that continue to use the CKD architecture. The newer devices implementing the 3390 architecture are actually large RAID (Redundant Array of Independent Disks) arrays, each of which implements the FBA architecture that is common among disks for commodity computers, such as the Intel x86 and Intel Pentium servers that are quite common.

The 3390 controller has an interface that allows it to appear to the Mainframe Computer (such as a z/11) as a CKD architecture while actually using FBA devices, which are very reliable, but commodity market, and therefore less expensive. This design choice shows how IBM has evolved to maintain its architecture while using commodity items.)

CKD Architecture

In this design, records and blocks may be of almost any length, subject to limitations of the disk device. A count (C) area contains the block size and an optional key (K) area contains the key of the last record in the block, both of which precede the actual data (D) area; hence CKD. If a disk contains 20 surfaces, the outer set of tracks (all track 0) is called cylinder 0, the next inner vertical set of tracks is cylinder **1,** the next is cylinder 2, and so forth. If the device contains 200 sets of tracks, there are 200 cylinders numbered 0 through 199, each with 20 tracks. If a disk contains 20 surfaces, each cylinder contains 20 tracks. If the disk contains 200 cylinders, then each surface contains 200 sets of tracks.

Examples of disk devices using CKD architecture include IBM models 3330, 3340, 3350, and 3380. The basic format for a track on a CKD device is

Index Point	Home Address	Track Descriptor Record	Data Record (R1)	Data Record (R2)
(a)	(b)	(c)	(d)	

(a) ***Index Point.*** The index point tells the read/write device that this point is the physical beginning of the track.

(b) ***Home Address***. The home address tells the system the address of the track (the cylinder, head, or surface number) and whether the track is primary, alternate, or defective.

(c) ***Track Descriptor Record (R0)***. This record stores information about the track and consists of two separate fields: a count area and a data area. The count area contains 0 for record number and 8 for data length and is otherwise similar to the count area described next for data record under item (d). The data area contains 8 bytes of information used by the system. The track descriptor record is not normally accessed by user programs.

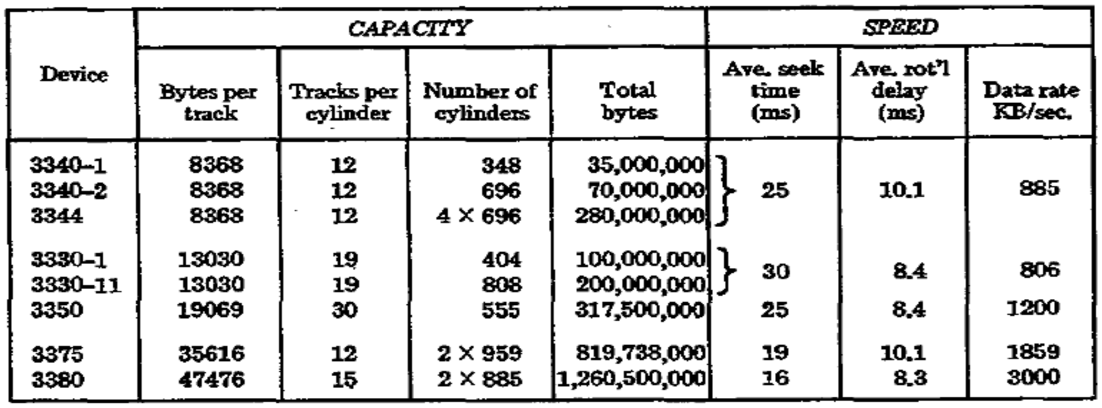
(d) ***Data Record Formats (Rl through Rn)***. The users' data records, or technically, blocks, consist of the following:

Address Marker	Count Area	Key Area (optional)	Data Area

The I/O control unit stores the 2-byte address marker before each block of data, which it uses subsequently to locate the beginning of data. The count area includes the following:

- An identifier field that provides the cylinder and head number (like that in the home address) and the sequential block number (0-255) in binary, representing R0 through R255. (The track descriptor record, R0, contains 0 for record number.)
- The key length (to be explained shortly).
- The data length, a binary value 0 through 65,535 that specifies the number of bytes in the data area field (the length of your data block). For end–of–file, the system generates a last dummy record containing a length of 0 in this field. When the system reads the file, the zero length indicates that there are no more records.
- The optional key area contains the key, or control field, for the records in the file, such as part number or customer number. The system uses the key area to locate records randomly. If the key area is omitted, the file is said to be formatted without keys and is stored as count-data format. The key length in the count area contains O. If the file is formatted with keys, it is stored as count-data format. The key length in the count area contains the length of the key area.
- The data area contains the users' data blocks, in any format, such as unblocked or blocked and fixed or variable length. The system stores as many blocks on a track as possible, usually complete and intact on a track. A record overflow feature permits the overlapping of a record from one track to the next. Figure 25–10 provides the capacities and speeds of a number of IBM CKD devices.
  Figure 25–11, added in 2009, shows more modern disks.

Under normal circumstances, you won't be concerned with the home address, the track descriptor record, or the address marker, count area, and key area portions of the data record field. You simply provide appropriate entries in your file definition macros and job control commands.



Device	CAPACITY				SPEED		
	Bytes per track	Tracks per cylinder	Number of cylinders	Total bytes	Ave. seek time (ms)	Ave. rot'l delay (ms)	Data rate KB/sec.
3340–1	8368	12	348	35,000,000			
3340–2	8368	12	696	70,000,000	25	10.1	885
3344	8368	12	4 × 696	280,000,000			
3330–1	13030	19	404	100,000,000	30	8.4	806
3330–11	13030	19	808	200,000,000			
3350	19069	30	555	317,500,000	25	8.4	1200
3375	35616	12	2 × 959	819,738,000	19	10.1	1859
3380	47476	15	2 × 885	1,260,500,000	16	8.3	3000

Figure 25–10 Capacity Tables for CKD Devices

Model	Average Seek Time	Average Latency	Data Rate
2314	75 milliseconds (ms)	12.5ms	291 KB/second
3330	30ms	8.4ms	806 KB/second
3350	25ms	8.4ms	1.2 MB/second
3380	17ms	8.3ms	3 MB/second
3390	12ms	7.1ms	4.2 MB/second
DS8000™ (with 15K RPM disks)	3.5ms	2ms	2-3.7 GB/second

Figure 25–11 DASD Speeds and Data Rates, November 2009

Fixed–Block Architecture

In this design, the recording tracks contain equal–length blocks of 512 bytes, although your records and blocks need not fit a sector exactly. (ELB: This is the format commonly used by MS–DOS and MS–Windows file systems).

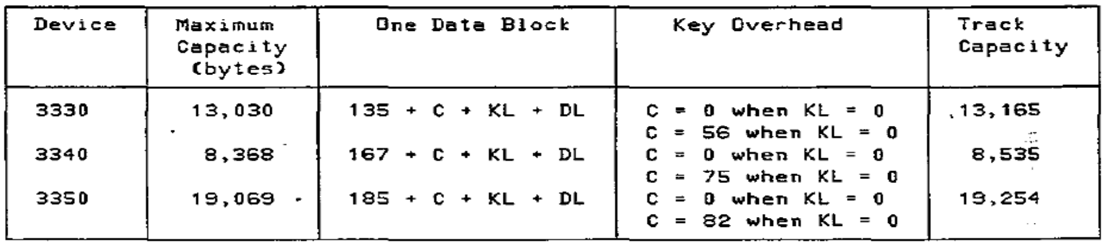
Device	Bytes/block	Blocks/track	Number of Cylinders	Tracks per Cylinder	Total Bytes
3310	512	32	358	11	64, 520, 192
3370	512	64	2 of 750	12	571, 392, 000

Disk Capacity

Knowing the length of records and the blocking factor, you can calculate the number of records on a track and on a cylinder. Knowing the number of records, you can also calculate the number of cylinders for the entire file. Based on the values in Figure 25–12, the formula for the number of blocks of data per track is

$$\text{Blocks per track} = \frac{\text{track capacity}}{\text{overhead} + C + KL + DL}$$

In the formula, C is a constant overhead value for keyed records, KL means Key Length, and DL is Data (Block) Length. These values vary by disk device, as shown below.



Device	Maximum Capacity (bytes)	One Data Block	Key Overhead	Track Capacity

3330	13,030	135 + C + KL + DL	C = 0 when KL = 0
			C = 56 when KL = 0
				13,165

3340	8,368	167 + C + KL + DL	C = 0 when KL = 0
			C = 75 when KL = 0
				8,535

3350	19,069	185 + C + KL + DL	C = 0 when KL = 0
			C = 82 when KL = 0
				19,254

Figure 25-12 Track Capacity Table

The following two examples illustrate.

Example 1: Device is a 3350, records are 242 bytes, five records per block, (block size = 1,210), and formatted without keys.

$$\text{Blocks per track} = \frac{19{,}254}{185 + (5 \times 242)} = \frac{19{,}254}{1{,}395} = 13.8$$

$$\text{Records per track} = \text{blocks per track} \times \text{blocking factor}$$

$$= 5 \times 13 = 65$$

Example 2: Same as Example 1, but formatted with keys (key length is 12).

$$\text{Blocks per track} = \frac{19{,}254}{185 + 82 + 12 + 1{,}210} = \frac{19{,}254}{1{,}489} = 12.93$$

$$\text{Records per track} = 5 \times 12 = 60$$

Note that a disk stores a full block, not a fraction of one. Therefore, even if you calculate 13.8 or 12.9 blocks per track, the disk stores only 13 or 12 blocks, respectively.

To determine the number of records on a cylinder, refer to Fig. 25–10, which discloses that a 3350 has 30 tracks per cylinder. Based on Example 1 where the number of records per track is 65, a cylinder on the 3350 could contain 65 x 30 = 1,950 records.

Using these figures, you can now calculate how much disk storage a file of, say, 100,000 of these records would require. Based on the figure of 1,950 records per cylinder, the file would require 100,000 ÷ 1,950 = 51.28 cylinders.

DISK LABELS

Disks, like magnetic tape, also use labels to identify a volume and a file. The system reserves cylinder 0, track 0 for standard labels, as Fig. 25–13 shows.

The following describes the contents of track 0:

Record 0: The track descriptor, R(0) record.

Records 1 and 2: If the disk is SYSRES, which contains the operating system, certain devices reserve R(l) and R(2) for the Initial Program Load (IPL) routine.
For all other cases, R(l) and R(2) contain zeros.

Record 3: The VOL1 label. OS supports more than one volume label, from R(3) through R(10).

Record 4 through the end of the track: The standard location for the volume table of contents (VTOC). The VTOC contains the file labels for the files on the device. Although you may place a VTOC in any cylinder, its standard location is cylinder 0, track 0.

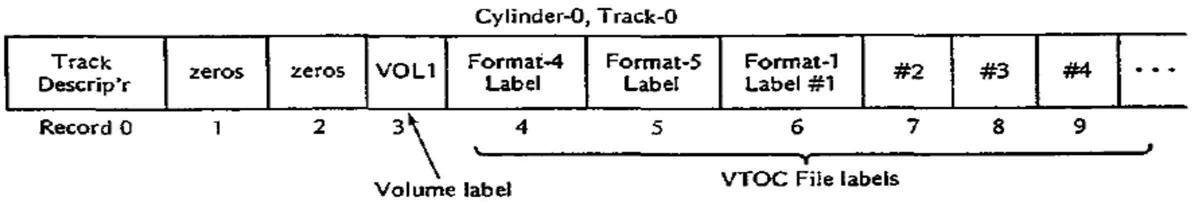


Figure 25–13 Disk Volume Layout

Volume Labels
The standard volume label uniquely identifies a disk volume. A 4–byte key area immediately precedes the 80–byte volume data area. The volume label is the fourth record (R3) on cylinder 0. The 80 bytes are arranged like a tape volume label, with one exception: Positions 12-21 are the "data file directory," containing the starting address of the VTOC.

File Labels
File labels identify and describe a file, or data set, on a volume. The file label is 140 bytes long, consisting of a 44–byte key area and a 96–byte file data area. Each file on a volume requires a file label for identification. In Fig. 25–13, all file labels for a volume are stored together in the VTOC. There are four types of file labels:

1. The format 1 label is equivalent to a file label on tape. The format 1 label differs, however, in that it defines the actual cylinder and track addresses of each file's beginning and end (its extent). Further, a file may be stored intact in an extent or in several extents in the same volume. Format 3 is used if a file is scattered over more than three extents.

2. The format 2 label is used for indexed sequential files.

3. The format 3 label is stored if a file occupies more than three extents.

4. The format 4 label is the first record in the VTOC and defines the VTOC for the system.

The format 1 file label contains the following information:

Position	Name	Description
01 – 44	File Identification	Unique identifier consisting of the file ID, optional generation number, and version number. These fields are separated by periods.
45	Format Identifier	‘1’ for format 1
46 – 51	File Serial Number	Volume serial number from the volume label.
52 – 53	Volume sequence number	Sequence number if the file is stored on more than one volume.
54 – 56	Creation date	Three bytes: **ydd**. y = year (0 – 99) and dd = day (1 – 366). Not Y2K compliant
57 – 59	Expiration date	Same as format for creation date.
60	Extent count number	Number of extents for this file on this volume.
61	Bytes in last block of directory	Used by OS.
62	Unused	Reserved
63 – 75	System code	Name of the operating system (OS)
76 – 82	Unused	Reserved
83 – 84	File Type	Code to identify is SD (sequential), DA (direct), or IS (indexed) file organization.
85	Record Format	Used by OS
86	Option Codes	ISAM – indicates if master index is present and type of overflow area.
87 – 88	Block Length	ISAM – length of each block.
89 – 90	Record Length	ISAM – length of each record.
91	Key Length	ISAM – length of key area.
92 – 93	Key Location	ISAM – position of key within the record
94	Data Set Indicators	SD – indicates if last volume
95 – 98	Used by OS	None of your business.
99 – 103	Last record pointer	Used by OS
104 – 105	Unused	Reserved
106	Extent type	Descriptors for the first or only extent for the file. Ten bytes.
107	Extent sequence number	
108 – 111	Extent lower limit	
112 – 115	Extent upper limit	
116 – 125		Descriptors for a second extent. Same format as the firs extent, described in positions 106 – 115.
126 – 135		Descriptors for a third extent. Same format as above.
136 – 140	Pointer	Address of the next label.

KEY POINTS

- Sequential file organization provides only for sequential processing of records. Indexed and direct organization provides for both sequential and random processing of records.
- At the beginning of the tape reel is a volume label, which identifies the reel being used. Immediately preceding each file on the tape is a header label, which contains the name of the file and the date the file was created. Following the header label are the records that comprise the data file. The last record is a trailer label, which is similar to the header label but also contains the number of blocks written on the reel.
- To keep track of all the files it contains, a disk device uses a special directory (volume table of contents, VTOC) at the beginning of its storage area. The directory includes the names of the files, their locations on disk, and their present status.
- If you define a tape or disk field as packed on an IBM system, the field contains two digits per byte plus a half-byte for the sign.
- The set of vertical tracks on a disk device is known as a cylinder.
- An interblock gap (IBG) separates each block of data from the next on tape and disk. The length of an IBG on tape is 0.3 to 0.6 inches depending on the device, and the length of an IBG on disk varies by device and by track location. The IBG defines the start and end of each block of data and provides space for the tape when the drive stops and restarts for each read or write.
- Blocking of records helps conserve space on storage devices and reduces the number of input/output operations. The number of records in a block is known as the blocking factor.
- The system reads an entire block into the computer's storage and transfers one record at a time to the program.
- All programs that process a file should use the same record length and blocking factor.
- Records and blocks may be fixed in length, where each has the same length throughout the entire file, or variable in length, where the length of each record and the blocking factor are not predetermined.
- The two main types of disk devices are count-key-data (CKD) architecture, which stores records according to count, key, and data area, and fixed-block architecture (FBA), which stores data in fixed-length blocks.