Chapter 11A – Overview of Disks and Disk Drives

This chapter presents an overview of one member of a class of devices that might be called "permanent, secondary storage". There are a number of features that the devices in this class have in common.

1. Unlike all common technologies for main computer memory, these devices are non–volatile; they do not require constant power to retain their contents.
2. These devices tend to have larger capacities than most main computer memories.
3. With one exception, the mechanisms used to store data are magnetic in nature.

As always, there are exceptions to the above statements. A large IBM z/10 mainframe might be configured with 384 GB of main memory, while a smaller USB "stick drive" might contain only 16 GB, but these are extreme examples.

In discussing external storage we mention, only in passing, two other technologies that once were quite important: punch paper cards and punch paper tape. Those readers interested in these are referred to the discussion of computer history found in chapter 1 of this text.

Sequential Access and Direct Access
External data storage devices come in two varieties: sequential access, and direct access. Magnetic tape is the standard example of a medium that is accessed sequentially. In order to read a record in the middle of the tape, the read/write heads must be moved over all of the records that precede the target record.

Direct access devices, such as disks, allow for direct access to a desired record without moving the read/write heads over a large number of unrelated records. Unlike true random access devices, the time to access a record on a direct access device does depend somewhat on its address on the device.

Aside from the average speed of access, one of the more important differences between disks and magnetic tape is the fact that a record on a disk can be updated in place; the data can be read, changed, and written back to the same place on the disk. For a number of reasons, this was never considered feasible for magnetic tapes. In order to update records on a magnetic tape, each record is read into the computer, possibly changed, and then written out to a new tape. This process, called "**old master, new master**", in reference to its use in updating master copies of data files, continues to be important in the business community.

The class of direct access data storage devices includes three primary examples: the disk, the magnetic drum, and the late–comer, the USB "stick drive". While the magnetic drum is now obsolete, it competed well with the disk in the 1960's, and had a similar control interface to the CPU. As a result of this similarity, IBM coined the term "**DASD**" (pronounced "dahz – dee") for the two **D**irect **A**ccess **S**torage **D**evices.

At present (Summer 2011) there are two main examples of direct access data storage devices: the magnetic disk and the USB "stick drive". The latter is a solid–state memory device, sharing many characteristics of the main memory discussed earlier. The reason that it is considered a disk is that it is accessed over a USB bus in the same manner as an external disk drive. The stick drive is organized with a directory and file structure identical to those used on earlier disk drives. It acts like a disk, so it is called a disk.

Is It Memory or an I/O Device?

There are two ways of viewing a DASD, either as an extension of memory or as an Input / Output device. Both views are equally valid; the one to use depends on the feature that is to be discussed. As a part of a memory system, the disk plays a key role in virtual memory. However, it is accessed as an I/O device, and its interfacing must be discussed in those terms. This textbook will discuss disk drives a number of times.

Early History of the Disk and Disk Drive

As noted earlier in this textbook, data storage reached a crisis stage in the early 1950's, when the amount of physical floor space required to house the punched cards holding the data became excessive. The only option was to develop new technology. IBM addressed the problem and delivered three new technologies: magnetic tape, the magnetic drum, and the magnetic disk. Each of these were smaller and much faster to access than paper cards.

The first magnetic tape drive was the IBM 729, released in 1952. While the dominant form of secondary data storage for quite some time, magnetic tape drives are not much used any more. For that reason, we shall not discuss magnetic tapes in any more detail.

The first magnetic drum memory was the ERA 110, built for the U.S. Navy by Engineering Research Associates of Minneapolis, MN. The ERA 110 could store 1 million bits of information, approximately 125 kilobytes. One of the test engineers present at the first sea trials of this device communicated the following to the author of this textbook.

> "The device spun at a high rate in order to allow fast access to the data. At first, the trials were a success. When the ship turned rapidly, the gyroscope effect took hold and ripped the drive out of its mountings."

Magnetic drum memory was announced by IBM in 1953, and first shipped in 1954. While the drum memory seemed to be a viable competitor for the magnetic disk, its high cost and low data density limited its use. The only significant use by IBM for the drum memory was as the main memory for the IBM 650, a first–generation computer announced in July 1953 and last manufactured in 1962.

The RAMAC

The origin of the magnetic disk drive was a research project started in 1952 by a group from IBM in San Jose, CA. One of its main goals was to develop a better technology for data storage. Magnetic drums were considered, but the choice was finally made to use a flat platter design, as first reported by Jacob Rainbow of the National Bureau of Standards (now known as NIST) in 1952. The disk was correctly assessed as having a bright future.

The first commercial disk drive, called the RAMAC (**R**andom–**A**ccess **M**ethod of **A**ccounting **C**ontrol) 305 was demonstrated on September 13, 1956. The unit comprised fifty aluminum disks of 24 inch diameter, coated on both sides with a magnetic oxide material that was a variant of the paint used on the Golden Gate Bridge.

The RAMAC 305 took up the better part of a room and could store all of 5MB of data -- the equivalent of 64,000 punch cards or 2,000 pages of text with 2,500 characters per page. The drive system had an input/output data rate of roughly 10 kilobytes per second. It sold for about $200,000 -- or you could lease it for about $3,200 a month. At that time, a good new car from General Motors sold for about $2,000.

Here is an early picture of the RAMAC, taken from the IBM archives. It is physically a large unit.

Figure: The Disks of the RAMAC 305

Later disk designs would all have at least one read/write head for each recording surface, or a pair of such heads for each platter. The problem to be solved before this innovation took hold was how to suspend the heads over the recording surface. The RAMAC took a very early approach, suggested probably by the music "Juke Boxes" of the time. It has one set of two read/write heads that served the entire drive.

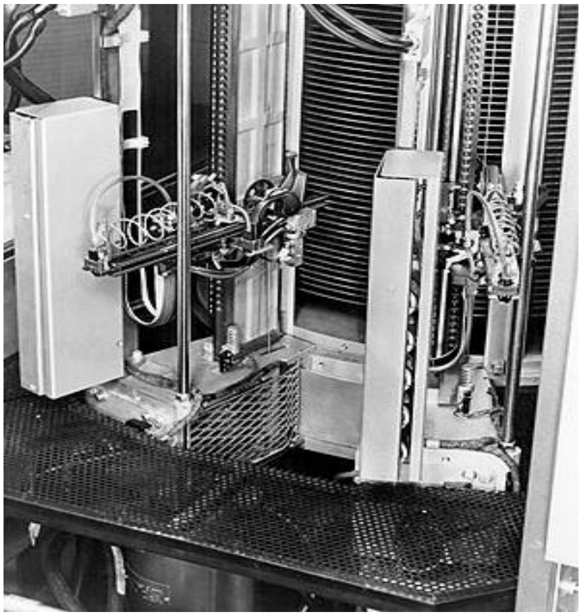


Figure: The RAMAC Read/Write Heads

The IBM 1301

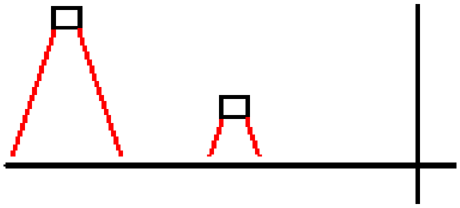
The RAMAC 305 was the precursor to the IBM 1301 disk storage unit. When released in 1961, the 1301 was the first storage system that used "flying heads" on actuator arms to read and write data to its 50 24-inch magnetic platters. The 1301's head and actuator arm assembly looked something like a bread-slicing machine turned on its side because each drive platter had its own read/write head.

The 1301 had 13 times the capacity of the RAMAC, and its platters rotated at 1,800 rpm -- compared with a spindle speed of 100 rpm for the RAMAC -- allowing heads to access the data more quickly.

Only two years after creating the 1301, IBM built the first removable hard drive, the 1311. The drive system, which shrunk storage technology from the size of a refrigerator to the size of a washing machine, had six 14-inch platters and contained a removable disk pack that had a maximum capacity of 2.6MB of data. The 1311 remained in use through the mid-1970s.

The concept of integrating the disks and the head arm assembly as a sealed unit was introduced by IBM with the “Winchester Drive” in 1973. Formally named the IBM 3340, this drive had two spindles, each of 30 MB capacity; hence “30/30 Winchester”. Though a project name, the term “Winchester” has been applied to the design concept. Almost all modern disk drives use the “Winchester design”. While earlier designs provided for removable disks, these allowed the disk to become dirty when exposed to the outside air. In the Winchester design, the entire assembly can be removed, thus keeping the disks in a more protected environment. With this higher quality operating environment, the read/write heads could be positioned closer to the disk platters, allowing for higher recording densities.

The relationship between head flying height and track density can be seen in the rough figure below. Each head will react to tracks within a specific angular dimension; think of a search light. The closer the head to the recording surface, the smaller the spot containing elements to which the head will react. The head must not be able to react to more than one data track at a time, hence its height dictates the minimum track spacing.



More Developments

In 1979, Al Shugart, who had helped develop the RAMAC with IBM, launched Seagate Technology Corp., which became the largest disk drive manufacturer in the world. Soon thereafter, the innovation floodgates opened. The "small form-factor" hard drive was invented in 1980 by Seagate. That five–inch ST506 drive held the same capacity as the RAMAC (5MB). From this point on, the mass market associated with the newly arrived PC (Personal Computer) movement guaranteed rapid evolution of the hard disk drive.

History of Disk Costs

Here is a walk through history [R030]. From the days of $10,000/MB to 2004 (*from 2004 to 2009 the cost/GB has literally gone down to negligible levels*), take a look:

YEAR	MANUFACTURER	COST/GB
1956	IBM	$10,00,000
1980	North Star	$193,000
1981	Morrow Designs	$138,000
1982	Xebec	$260,000
1983	Davong	$119,000
1984	Pegasus (Great Lakes)	$80,000
1985	First Class Peripherals	$71,000
1987	Iomega	$45,000
1988	IBM	$16,000
1989	Western Digital	$36,000
1990	First Class Peripherals	$12,000
1991	WD	$9,000
1992	Iomega	$7,000
1994	Iomega	$2000
1995	Seagate	$850
1996	Maxtor	$259
1997	Maxtor	$93
1998	Quantum	$43
1999	Fujitsu IDE	$16
2000	Maxtor 7200rpm UDMA/66	$9.58
2001	Maxtor 5400 rpm IDE	$4.57
2002	Western Digital 7200 rpm	$2.68
2003	Maxtor 7200 rpm IDE	$1.39
2004	Western Digital Caviar SE 7200rpm	$1.15

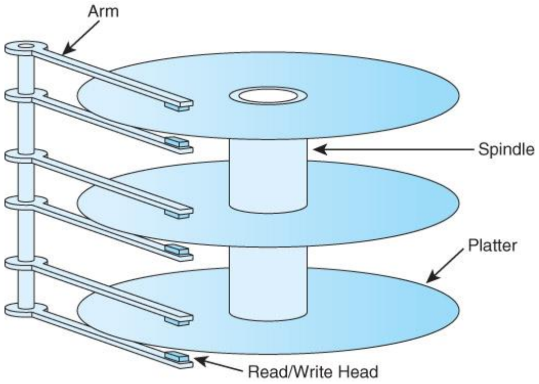
More recently disk prices have dropped even more. In November 2007, the author of this textbook purchased an external USB 500 GB disk drive for about $500.00 (or $0.50 per gigabyte). On July 7, 2011, the web site for Office Depot had the following prices:
a 500 GB USB external drive for $69.99 and a 1 TB USB external drive for $119.99.
These prices are about five to seven cents per gigabyte.

We now look at internal disk drives supporting the SATA standard. Also on July 7, 2011, these prices were found. The WD Caviar Blue 500 GB drive with a 16 MB buffer will sell for $38.00 and the 3 TB WD Caviar Green with a 64 MB buffer will sell for $140.
Do the math. This is very inexpensive.

How long shall we have to wait for the first 1 petabyte drive?

Structure of a Large Disk Drive

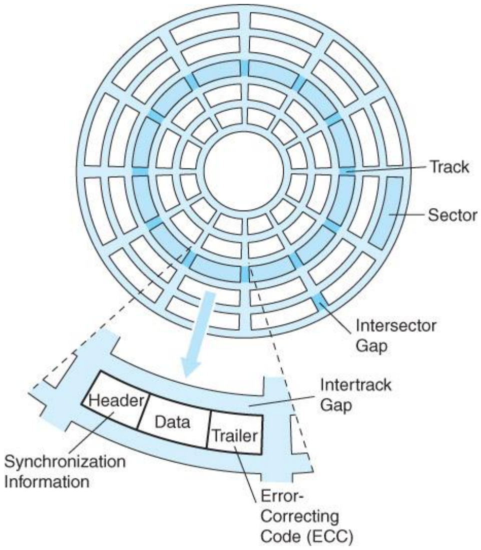
The typical large–capacity (and physically small) disk drive has a number of glass platters with magnetic coating. These spin at a high rate varying between 3,600 rpm (60/second) and 15,000 rpm (250/second), with 7,200 rpm (120/second) being average. This drawing shows a disk with three platters and six surfaces. In general, a disk drive with N platters will have 2•N surfaces, the top and bottom of each platter.



On early disk drives, before the introduction of sealed drives, the top and bottom surfaces would not be used because they would become dirty when the disk pack was removed. The introduction of the Winchester design, with its sealed disks, changed that for the better.

More on Disk Drive Structure

Each surface is divided into a number of concentric tracks. Each track has a number of sectors. This figure shows an older style layout, in which all tracks had the same number of sectors. In such a design, the time for a sector to move under the read/write head does not depend on the track location, simplifying the drive control logic.



A sector usually contains 512 bytes of data, along with a header and trailer part. Modern designs have moved towards larger sizes for sectors (say, 4,096) bytes, but the traditional design has considerable history.

Modern disk designs have divided the surface into a number of zones. This design is often called **ZBR** (**Z**oned **B**it **R**ecording). Within each zone, the sector count per track is constant. However, the zones near the outer rim of the disk have more sectors than the inner zones. This increases the linear density of the sectors for the outer zones, keeping that density nearer that found in the innermost zone, and making better use of the disk area. Here is a picture of a disk surface with color added to highlight the five zones. Note that the number of sectors per track increases as we move from the inner zone to the outer zone.

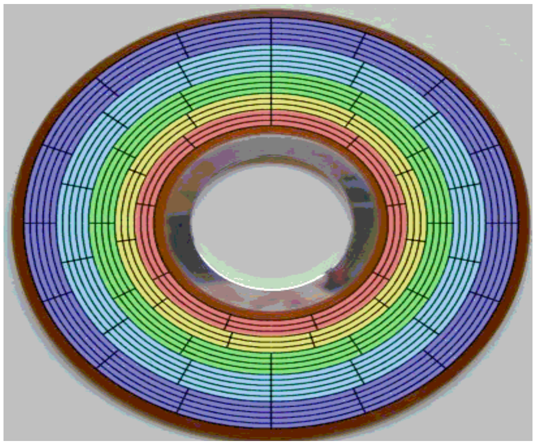


Figure: Disk Surface with Five Zones

One downside to the ZBR strategy is that the complexity of the disk–side controller must be increased. In the older strategy, which might be called one–zone, the sectors moved under the read/write heads at the same rate, without regard to track number. In the above design, the rate is constant within each zone, but the controller must allow for five distinct rates. Given the ability to fabricate complex electronics, this is deemed a fair trade–off.

The Disk Surface

The standard definition of a hard disk drive is quite simple.

> "The recording medium for hard disk drives is basically a very thin layer of magnetically hard material on a rigid substrate." [R031]

Up to the mid 1990's, aluminum was used exclusively for the substrate. Recently, glass has attracted interest for a substrate, mostly for its ability to be polished to a very fine surface finish. Remember that the design goal is to reduce the flying height of the read/write heads, and that requires a smoother surface over which to fly.

Since the earliest designs, each recording surface of a disk has been divided into concentric circles, called tracks. Optical disks, such as CDs and DVDs, as well as vinyl records, have a single spiral track on each recording surface. According to Jacob [R008]

> "The major reasons for this are partly historical … In the early days of disk drives, when open–loop mechanical systems were used to position the head, using concentric tracks seemed a natural choice. Today, the closed–loop embedded servo system … makes spiral track formatting feasible. Nonetheless concentric tracks are a well–understood and well–used technology and seem easier to implement than spiral tracks."

Timing of a Disk Transfer

Disks are electromechanical devices. The time for a data transfer has a number of components, including time to decode the command, time to move the read/write heads to the proper location on the disk, time to transfer the data to the on–disk data buffers, and time to transfer the data across the interface to the host–side interface. Here, we consider two of the more important disk timings: seek time and rotational latency.

The idea of **seek time** reflects the fact that, in order to access a disk track for either a read or write operation, the heads must be moved to the track. This is a mechanical action, as the read/write heads are physical devices. Some early designs seem to have avoided this problem by having one read/write head per track. This is not an option for modern drives, which have thousands of tracks per surface.

There are two seek times typically quoted for a disk.

Track–to–track:	the time to move the heads to the next track over
Average:	the average time to move the heads to any track.

The rotational delay is due to the fact that the disk is spinning at a fixed high speed. It takes a certain time for a specific sector to rotate under the read/write heads. Suppose a disk rotating at 12,000 RPM. That is 200 revolutions per second. Each sector moves under the read/write heads 200 times a second, once every 0.005 second or every 5 milliseconds. The **rotational latency**, or average rotational delay, is one half of the time for a complete revolution of the disk. Here it would be 2.50 milliseconds.

Rotational latency is a major component of the time to access data on a disk. For that reason, methods to minimize the rotational latency of a disk are under active investigation. One way would be to speed up the rotation of the disk. Unfortunately, this leads to stress on the physical platters that become unacceptable. This is seen in a design choice for the 5¼ floppy drives, which were spun at a leisurely 360 rpm. The reason for this rate is that a significantly higher rate would cause the disks to be torn apart by centrifugal forces.

Another method to reduce rotational latency would be to add a second actuator with its own set of read write heads to the disk drive. This would be positioned opposite the first set.

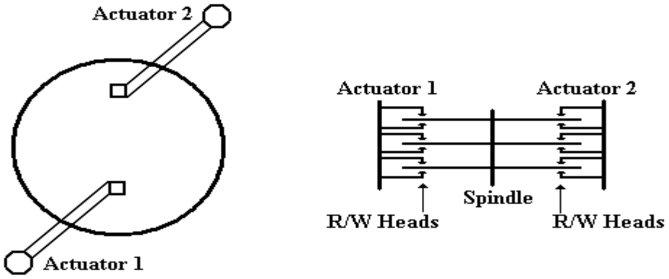


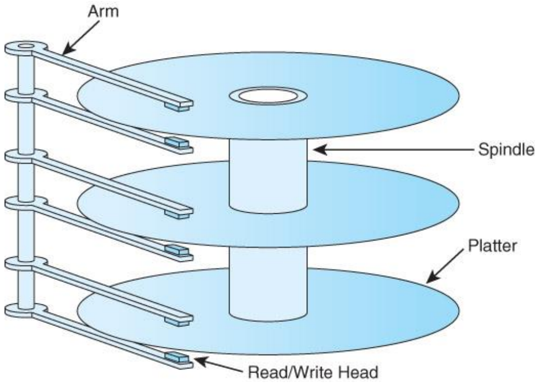
Figure: Two Views of Dual Actuators

Such a design would immediately halve the rotational latency, as the average time for a sector to move under one of the read/write heads would be one quarter of a revolution. For a 12,000 rpm disk, the rotational delay would be cut from 2.50 to 1.25 milliseconds. Put another way, the reduction is from 2, 500, 000 nanoseconds to 1, 250, 000 nanoseconds. However, the addition of a second set of heads raises the price by about 35%, not acceptable in the highly competitive modern market. Conner Peripherals introduced such a product in 1994, but it was not popular. The design has never been attempted since.

Tracks and Cylinders

The idea of a cylinder is an artifact of the mechanical nature of the actuators used to move the read/write heads on a modern disk. It is faster to read sectors from the same track than it is to move to another track, even one close by. We now consider the fact that standard disk drives with concentric tracks and multiple recording surfaces have the same number of tracks and track geometry on each of the surfaces.

When the actuator is functioning properly, as it almost always is, each read/write head is over (or near to) the same numbered track on its disk. This leads to the idea of a **cylinder** as the set of tracks that can be read without significant repositioning of the read/write heads. In early disk designs, with wider tracks, there would be no positioning required to move from surface to surface on a cylinder. All that would be required was an electronic switching of the active head, a matter of nanoseconds and not milliseconds.



We close this part of the chapter with some related questions. How many bytes of data can be read from a disk before the read/write heads must be moved? What is the maximum data transfer rate from a multi–platter disk? How long can this rate be sustained?

Disk Capacity

The first question is how to calculate the capacity of a disk. Here are a number of equivalent ways, assuming the standard 512 bytes per sector.

Disk Capacity = (number of surfaces)•(bytes per surface)
= (number of surfaces)•(tracks per surface)•(bytes per track)
= (number of surfaces)•(tracks per surface)• (sectors per track)•512

Here are data from an earlier disk drive (now rather small).

8 surfaces
3196 tracks per surface
132 sectors per track
512 bytes per sector

Surface capacity = 3196•132•512 = 421872•512 = 210936•1024 bytes
= 210936 KB ≈ 206.0 MB

Disk capacity = 8•210936 KB = 1,687,488 KB ≈ 1.61 GB

Computing Disk Maximum Transfer Rate

We now compute the maximum transfer rate. This is computed from the size of a track in bytes and the rotation rate of the disk. For modern disks, the transfer rate would depend on the zone in which the track is located, as each zone has a different number of sectors per track. For this example, we use the older disk with only one track size.

Disk rotation rates are given in RPM (Revolutions per Minute). Common values are 3,600 RPM, 7,200 RPM, and higher. 3,600 RPM is 60 revolutions per second. 7,200 PRM is 120 per second. Consider our sample disk. Suppose it rotates at 7,200 RPM, which is one revolution every (1/120) second.

One track contains 132•512 bytes = 66•1024 bytes = 66KB.
This track can be read in (1/120) of a second.
The maximum data rate is 66 KB in (1/120) of a second.
120 • 66 KB in one second.
7,920 KB per second = 7.73 MB per second.

Sustaining the Maximum Data Transfer Rate

Recall the definition of a cylinder as a set of tracks, one per surface. Each track can be read in one revolution of the disk drive. The data rate can be sustained for as long as it takes to read all tracks from the cylinder.

The number of tracks per cylinder is always exactly the same as the number of surfaces in the disk drive. Our sample drive has 8 surfaces; each cylinder has 8 tracks.

In our sample drive, rotating at 7200 RPM or 120 per second:
Each track can be read in 1/120 second.
The cylinder, containing 8 tracks, is read in 8/120 second or 1/15 second.

The maximum data transfer rate can be sustained for 1/15 second.

How Much Data Can Be Transferred at This Rate?

Each track can be read in 1/120 of a second. The cylinder can be read in 1/15 second.
The cylinder contains 8 tracks of 66•1024 bytes, thus 8•66•1024 = 528 KB.

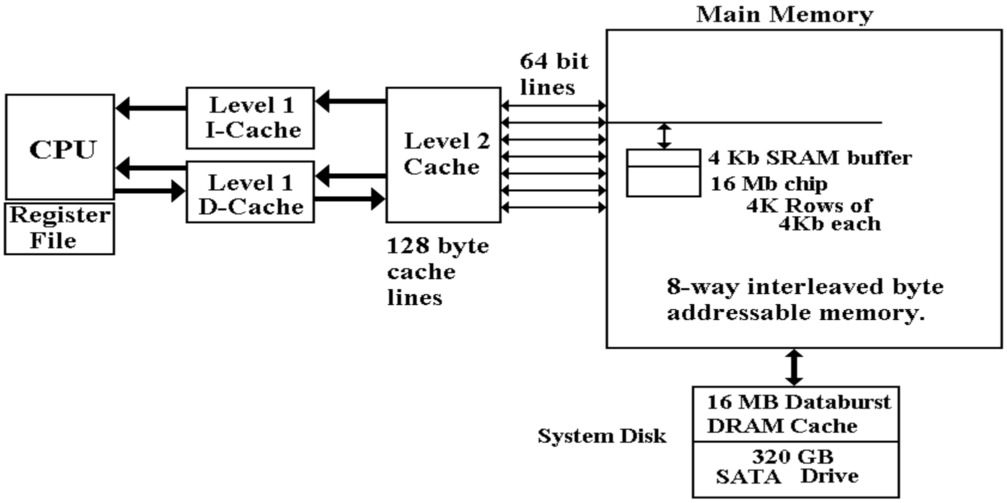
The Drive Cache

Modern disk drives have a cache memory associated with the on–disk controller. Some manufacturers call this a **“databurst cache”**. On modern drives, this can vary between 2 MB and 64 MB; DRAM is quite cheap these days.

The disk–side cache grew out of the small disk–side data buffers required to match the speed of the disk internal transfers with the speed of the bus connecting it to the controller logic on the host side. Buffering is also required in those cases when the interface to the host is busy at the time the disk read/write heads are ready to initiate a transfer. On a disk write, the host controller would transfer the data to the disk–side buffer for later writing to the disk itself.

As DRAM prices dropped, this simple data buffer grew into a full–fledged cache. The utility of this cache does not depend on a high hit rate, as it does for the cache between primary memory and the CPU. One of its main uses is in allowing the disk controller to prefetch data; that is, to copy the data into the buffer before it is requested. This increases the efficiency of disk reads. As a write buffer, the cache speeds up disk writes.

We now have quite a few levels of cache memory between the disk surfaces and the CPU. Here is a diagram showing the configuration on a computer built in 2007. The disk has a 16 MB DRAM cache. Each memory chip has a 4 Kb (kilobit) SRAM buffer. There are two levels of cache between the main memory and the CPU.



The Disk Directory Structure

We now turn our attention to the disk directory structure. Rather than discussing the more modern structures, such as NTFS, we shall limit ourselves to older and simpler structures.

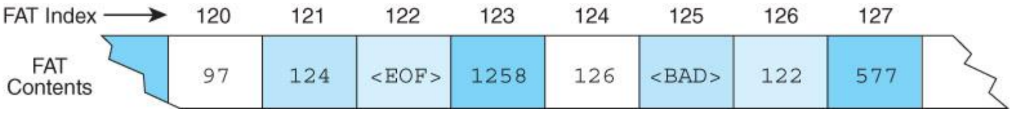
The FAT (File Allocation Table)

Physically the disk contains a large number of sectors, each of which contains either data or programs. Logically the disk contains a large number of files, also program and data. The disk will have one or more index structures that associate files with their sectors.

The two important structures are

the disk directory	associates a file with its first sector
the File Allocation Table	maintains the "linked list" of sectors for that file.

This example shows the structure of the FAT.



FAT Index →	120	121	122	123	124	125	126	127
FAT Contents	97	124	<EOF>	1258	126	<BAD>	122	577

Here the disk directory indicates that the first sector for a file is at address 121.
The FAT entry at 121 indicates that the next sector is at address 124.
The FAT entry at 126 indicates that the next sector is at address 122.
The FAT entry at 122 indicates that sector 122 is the last for this file. Sector 125 is bad.

The FAT–16 system was implemented by Microsoft for early versions of MS–DOS. This system used a 16–bit index into the FAT. As there is one FAT entry per sector, this makes this limits the sector count to 2^{16}. The maximum disk size is thus $2^{16} \bullet 512 = 2^{16} \bullet 2^9 = 2^{25} = 2^5 \bullet 2^{20}$ = 32 MB. In 1987, my brand–new PC/XT had a 20MB disk! FAT–16 worked very well. What about a 40 MB disk? How about a 256 MB disk?

Few people in the late 1980's contemplated disk drives with capacities of over 100 GB, but it was obvious that unmodified FAT–16 would not do the job. We consider two short–term remedies to this problem, one transient and one with longer term consequences.

The first solution was to partition a larger physical disk drive into two logical disk drives.

A 40 MB disk drive would support two logical disks, each with its own directory structure and File Allocation Table. Using the drive names suggested at the time, this 40 MB physical disk would support two logical disks: Drive C with capacity of 32 MB, and Drive D with capacity of 8 MB.

As a short–term fix, this worked well. However, it just raised the limit to 64 MB. This solution was obsolete by about 1992. The main problem with the FAT–16 system arose from the fact that each sector was individually addressable. With 2^{16} addresses available, we have a maximum of 2^{16} sectors or 32 MB for each logical drive.

The second solution was to remove the restriction that each sector be addressable. Sectors were grouped into clusters, and only clusters could be addressed. The number of sectors a cluster contained was constrained to be a power of 2; so we had 2, 4, 8, 16, etc. sectors per cluster. The effect on disk size is easy to see.

Sectors in Cluster	1	2	4	8	16	32	64
Bytes in Cluster	512	1024	2048	4096	8192	16384	32768
Disk Size	32 MB	64 MB	128 MB	256 MB	512 MB	1 GB	2 GB

In the early 1990's, it seemed that this solution would work for a while. Nobody back then envisioned multi–gigabyte disk drives on personal computers. There is a problem associated with large clusters; it is called **"internal fragmentation"**.

This problem arises from the fact that files must occupy an integer number of clusters.

Consider a data file having exactly 6,000 bytes of data, with several cluster sizes.

Sectors in Cluster	1	2	4	8	16	32	64
Bytes in Cluster	512	1024	2048	4096	8192	16384	32768
Clusters needed	12	6	3	2	1	1	1
File size on disk	6144	6144	6144	8192	8192	16384	32768
Disk efficiency	97.7%	97.7%	97.7%	73.2%	73.2%	36.6%	18.3%

Security Issues: Erasing and Reformatting

Remember the disk directory and the FAT. What happens when a file is erased from the disk? The data are not removed. Here is what actually happens.

1. The file name is removed from the disk directory.
2. The FAT is modified to place all the sectors (clusters) for that file into a special file, called the **"Free List"**.
3. Sectors do not have their data erased or changed until they are allocated to another file and that a program writes data to that file.

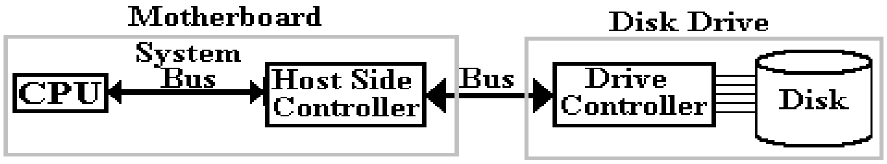
For this reason, many companies sell utilities to "Wipe the File" or "Shred the File".

How about reformatting the disk? Certainly, that removes file links. Again the data are not removed. The directory structure and FAT are reinitialized and the free list reorganized. The sectors containing the data are not overwritten until they are reused.

Interfaces to Disk Drives

The disk drive is not a stand–alone device. In order to function as a part of a system, the disk must be connected to the motherboard through a bus. We shall discuss details of disk drives in the next chapter. In this one, we focus on two popular bus technologies used to interface a disk: ATA and SATA. Much of this material is based on discussions in chapter 20 of the book on memory systems by Bruce Jacob, et al [R008].

The top–level organization is shown in the figure below. We are considering the type of bus used to connect the disk drive to the motherboard; more specifically, the host controller on the motherboard to the drive controller on the disk drive. While the figure suggests that the disk is part of the disk drive, this figure applies to removable disks as well. The important feature is the nature of the two controllers and the protocol for communication.



One of the primary considerations when designing a disk interface, and the bus to implement that interface, is the size of the drive controller that is packaged with the disk. Jacob [R008] noted:

> "In the early days, before Large Scale Integration (LSI) made adequate computational power economical to be put in a disk drive, the disk drives were 'dumb' peripheral devices. The host system had to micromanage every low–level action of the disk drive. … The host system had to know the detailed physical geometry of the disk drive; e.g., number of cylinders, number of heads, number of sectors per track, etc."

> "Two things changed this picture. First, with the emergence of PCs, which eventually became ubiquitous, and the low–cost disk drives that went into them, interfaces became standardized. Second, large–scale integration technology in electronics made it economical to put a lot of intelligence in the disk side controller"

As of Summer 2011, the four most popular interfaces (bus types) were the two varieties of ATA (Advanced Technology Attachment, SCSI (Small Computer Systems Interface), and the FC (Fibre Channel). The SCSI and FC interfaces are more costly, and are commonly used on more expensive computers where reliability is a premium. We here discuss the two ATA busses.

The ATA interface is now managed by Technical Committee 13 of INCITS (www.t13.org), the International Committee for Information Technology Standards (www.incits.org). The interface was so named because it was designed to be attached to the IBM PC/AT, the "Advanced Technology" version of the IBM PC, introduced in 1984. To quote Jacob again:

> "The first hard disk drive to be attached to a PC was Seagate's ST506, a 5.25 inch form factor 5–MB drive introduced in 1980. The drive itself had little on–board control electronics; most of the drive logic resided in the host side controller. Around the second half of the 1980's, drive manufacturers started to move the control logic from the host side and integrate it with the drive. Such drives became known as IDE (Integrated Drive Electronics) drives."

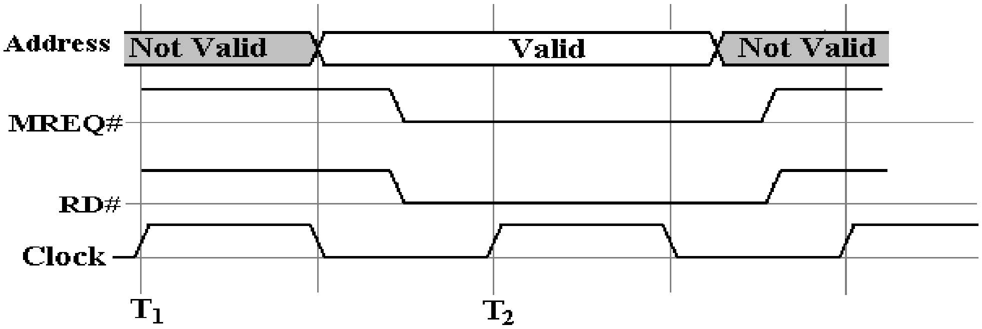
In recent years, the ATA standard has being explicitly referred to at the "PATA" (Parallel ATA) standard to distinguish it from the SATA (Serial ATA standard) that is now becoming popular. The original PATA standard called for a 40–wire cable. As the bus clock rate increased, noise from crosstalk between the unshielded cables became a nuisance. The new design included 40 extra wires, all ground wires to reduce the crosstalk.

As an example of a parallel bus, we show a picture of the PDP–11 Unibus. This had 72 wires, of which 56 were devoted to signals, and 16 to grounding. This bus is about 1 meter in length.

Figure: The Unibus of the PDP–11 Computer

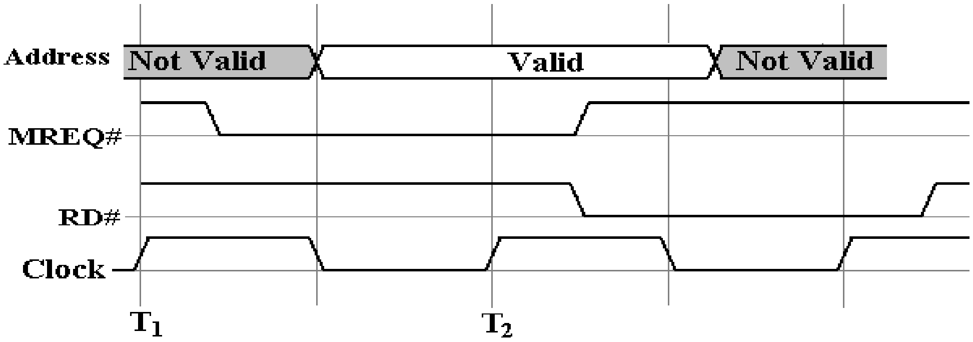
Up to this point, we have discussed parallel busses. These are busses that transmit N data bits over N data lines, such as the Unibus™ that used 16 data lines to transmit two bytes per transfer. Recently serial busses have become popular; especially the SATA (Serial Advanced Technology Attachment) busses used to connect internally mounted disk drives to the motherboard. There are two primary motivations for the development of the SATA standard: clock skews and noise.

The problem of clock skew is illustrated by the following pair of figures. The first figure shows a part of the timing diagram for the intended operation of the bus. While these figures may be said to be inspired by actual timing diagrams, they are probably not realistic.



In the above figure, the control signals MREQ# and RD# are asserted simultaneously one half clock time, after the address becomes valid. The two are simultaneously asserted for two clock times, after which the data are read.

We now imagine what could go wrong when the clock time is very close to the gate delay times found in the circuitry that generates these control signals. For example, let us assume a 1 GHz bus clock with a clock time of one nanosecond. The timing diagram above calls for the two control signals, MREQ# and RD#, to be asserted 0.5 nanoseconds (500 picoseconds) after the address is valid. Suppose that the circuit for each of these is skewed by 0.5 nanoseconds, with the MREQ# being early and the RD# being late.



What we have in this diagram is a mess, one that probably will not lead to a functional read operation. Note that MREQ# and RD# are simultaneously asserted for only an instant, far too short a time to allow any operation to be started. The MREQ# being early may or may not be a problem, but the RD# being late certainly is. A bus with these skews will not work.

As discussed above, the ribbon cable of the PATA bus has 40 unshielded wires. These are susceptible to cross talk, which limits the permissible clock rate. What happens is that crosstalk is a transient phenomenon; the bus must be slow enough to allow its effects to dissipate.

We have already seen a solution to the problem of noise when we considered the PCI Express bus. This is the solution adopted by the SATA bus. The standard SATA bus has a seven–wire cable for signals and a separate five–wire cable for power. The seven–wire cable for data has three wires devoted to ground (noise reduction) and four wires devoted to a serial lane, as described above for PCI Express. As noted above in that discussion, the serial lane is relatively immune to noise and crosstalk, while allowing for very good transmission speeds.

One might note that parallel busses are inherently faster than serial busses. An N–bit bus will transmit data N times faster than a 1–bit serial bus. The experience seems to be that the data transmission rate can be so much higher on the SATA bus than on a parallel bus, that the SATA bus is, in fact, the faster of the two. Data transmission on these busses is rated in bits per second. In 2007, according to Jacob [R008] “SATA controllers and disk drives with 3 Gbps are starting to appear, with 6 Gbps on SATA’s roadmap.” The encoding used is called “8b/10b”, in which an 8–bit byte is padded with two error correcting bits to be transmitted as 10 bits. The two speeds above correspond to 300 MB per second and 600 MB per second.