Device Management

Contents

- Classification of IO devices, Controllers, Memory Mapped IO, DMA Operation, Interrupts
- Goals of IO Software, Handling IO (Programmed IO, Interrupt Driven IO, IO using DMA), IO Software Layers (Interrupt Handlers, Device Drivers)
- Disk Formatting (Cylinder Skew, Interleaving, Error handling), RAID
- Disk Structure, Disk Scheduling (FCFS, SSTF, SCAN, CSCAN, LOOK, CLOOK)

Principles of I/O hardware

- Different people look at I/O hardware in different ways.
- Electrical engineers look at it in terms of chips, wires, power supplies, motors, and all the other physical components that comprise the hardware.
- Programmers look at the interface presented to the software—the commands the hardware accepts, the functions it carries out, and the errors that can be reported back.

- Conceptually, a simple personal computer can be abstracted to a model resembling that of Fig. 6-1.
- The CPU, memory, and I/O devices are all connected by a system bus and communicate with one another over it.
- Modern personal computers have a more complicated structure, involving multiple buses, which we will look at later. For the time being, this model will be sufficient.
- In the following sections, we will briefly review these components and examine some of the hardware issues that are of concern to operating system designers. Needless to say, this will be a very compact summary. Many books have been written on the subject of computer hardware and computer organization. Two well-known ones are by Tanenbaum and Austin (2012) and Patterson and Hennessy (2013).

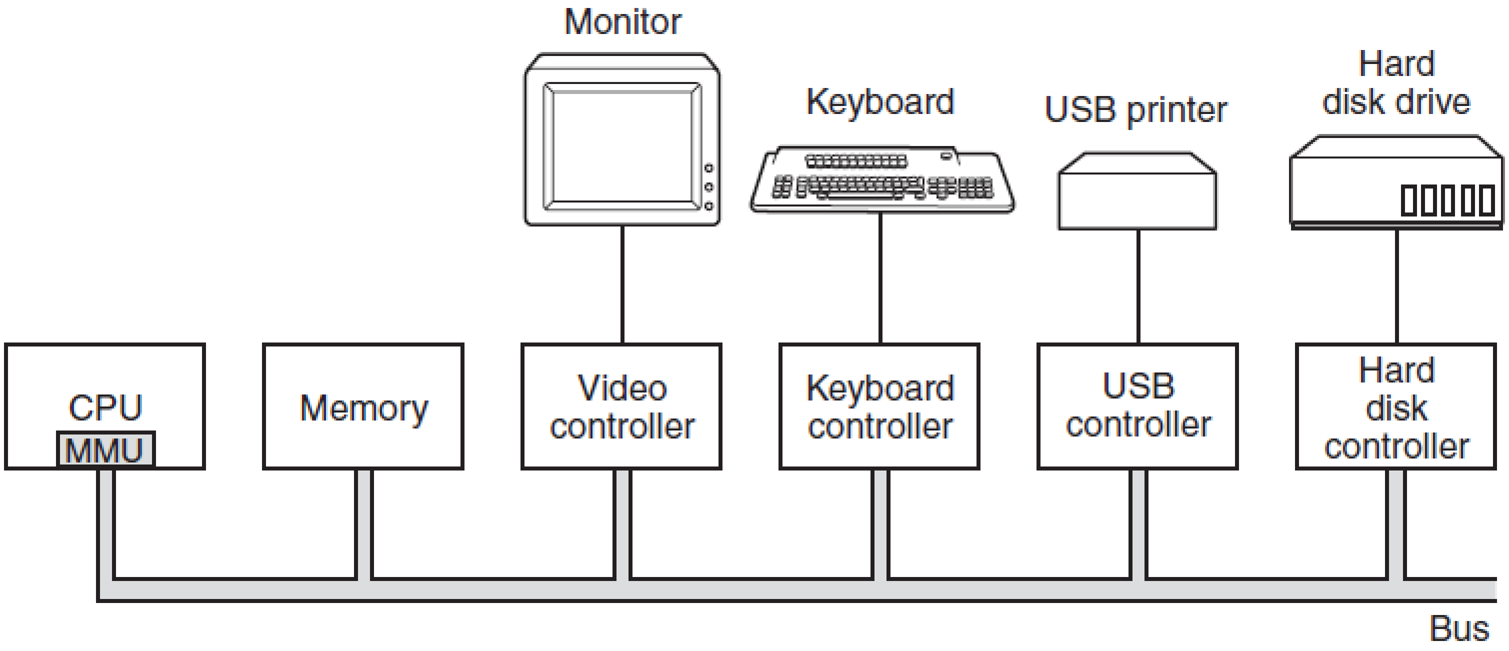
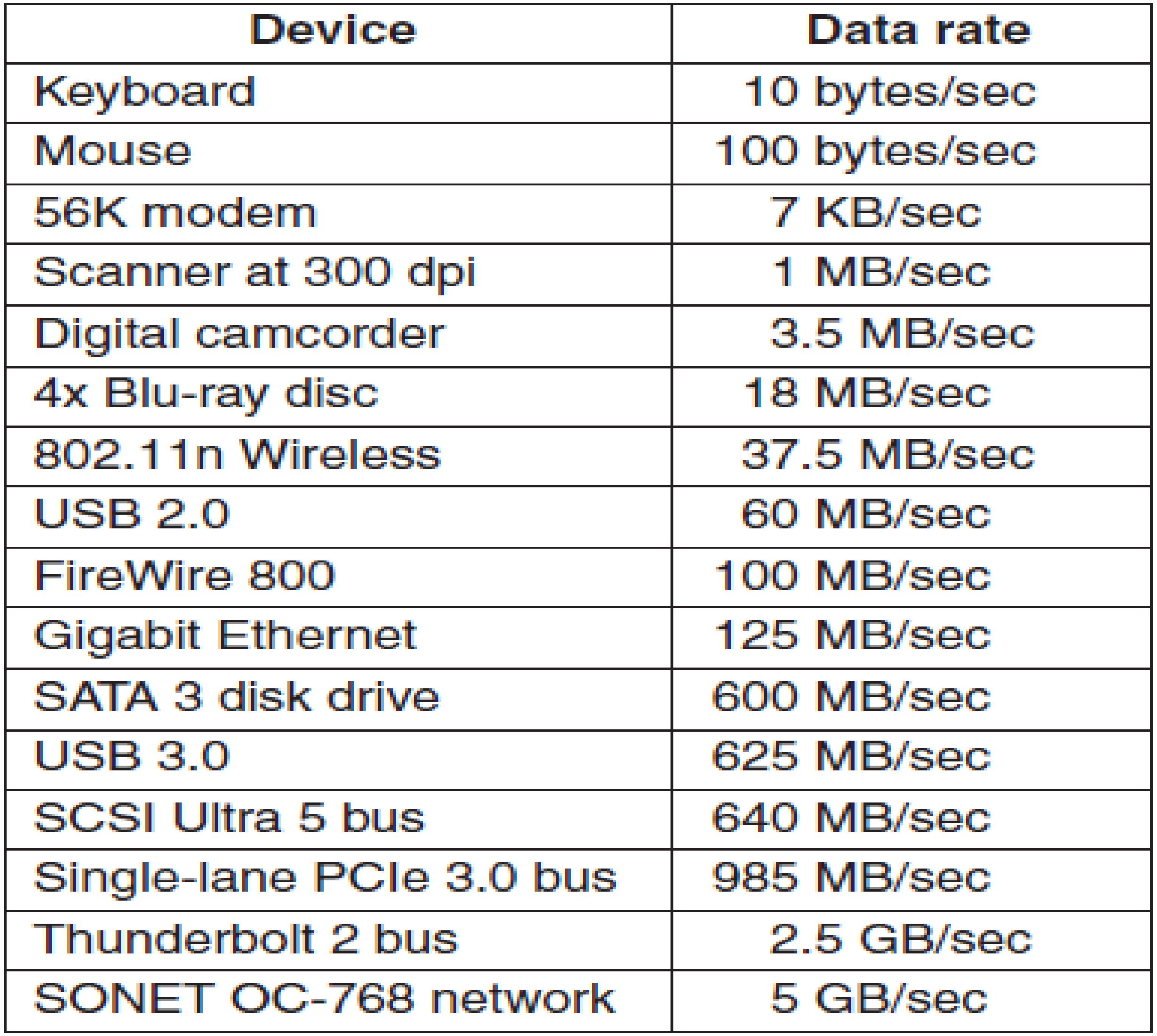


Figure 6-1. Some of the components(memory, controllers and i/o devices) of a simple personal computer.

I/O Devices

- I/O devices can be roughly divided into two categories:
  - **block devices** and
  - **character devices**.
- A **block device** is one that stores information in fixed-size blocks, each one with its own address. Common block sizes range from 512 to 65,536 bytes.
- It is possible to read/write each and every block independently in case of block device.
- Hard disks, Blu-ray discs, and USB sticks are common block devices.
- A **character device** delivers or accepts a stream of characters, without regard to any block structure.
- It is not addressable and does not have any seek operation.
- Printers, network interfaces, mice (for pointing), rats (for psychology lab experiments), and most other devices that are not disk-like can be seen as character devices



Device	Data rate
Keyboard	10 bytes/sec
Mouse	100 bytes/sec
56K modem	7 KB/sec
Scanner at 300 dpi	1 MB/sec
Digital camcorder	3.5 MB/sec
4x Blu-ray disc	18 MB/sec
802.11n Wireless	37.5 MB/sec
USB 2.0	60 MB/sec
FireWire 800	100 MB/sec
Gigabit Ethernet	125 MB/sec
SATA 3 disk drive	600 MB/sec
USB 3.0	625 MB/sec
SCSI Ultra 5 bus	640 MB/sec
Single-lane PCIe 3.0 bus	985 MB/sec
Thunderbolt 2 bus	2.5 GB/sec
SONET OC-768 network	5 GB/sec

Figure 6-2. Some typical device, network, and bus data rates.

Device Controllers

- A **device controller** is a system that handles the incoming and outgoing signals of the CPU.
- A **device** is connected to the computer via a plug and socket, and the socket is connected to a **device controller**. **Device controllers** use binary and digital codes.
- Many controllers can handle two, four, or even eight identical devices. If the interface between the controller and device is a standard interface, either an official ANSI, IEEE, or ISO standard or a de facto one, then companies can make controllers or devices that fit that interface.
- Many companies, for example, make disk drives that match the SATA, SCSI, USB, Thunderbolt, or FireWire (IEEE 1394) interfaces.

Memory-Mapped I/O

- **Memory-mapped I/O** uses the same address space to address both **memory** and I/**O** devices.
- The **memory** and registers of the I/**O** devices are **mapped** to (associated with) address values. So when an address is accessed by the CPU, it may refer to a portion of physical **RAM**, or it can instead refer to **memory** of the I/**O** device.
- Each controller has a few registers that are used for communicating with the CPU. By writing into these registers, the operating system can command the device to deliver data, accept data, switch itself on or off, or otherwise perform some action.
- By reading from these registers, the operating system can learn what the

device’s state is, whether it is prepared to accept a new command, and so on.

- In addition to the control registers, many devices have a data buffer that the operating system can read and write. For example, a common way for computers to display pixels on the screen is to have a video RAM, which is basically just a data buffer, available for programs or the operating system to write into.
- The issue thus arises of how the CPU communicates with the control registers and also with the device data buffers. Two alternatives exist. In the first approach,

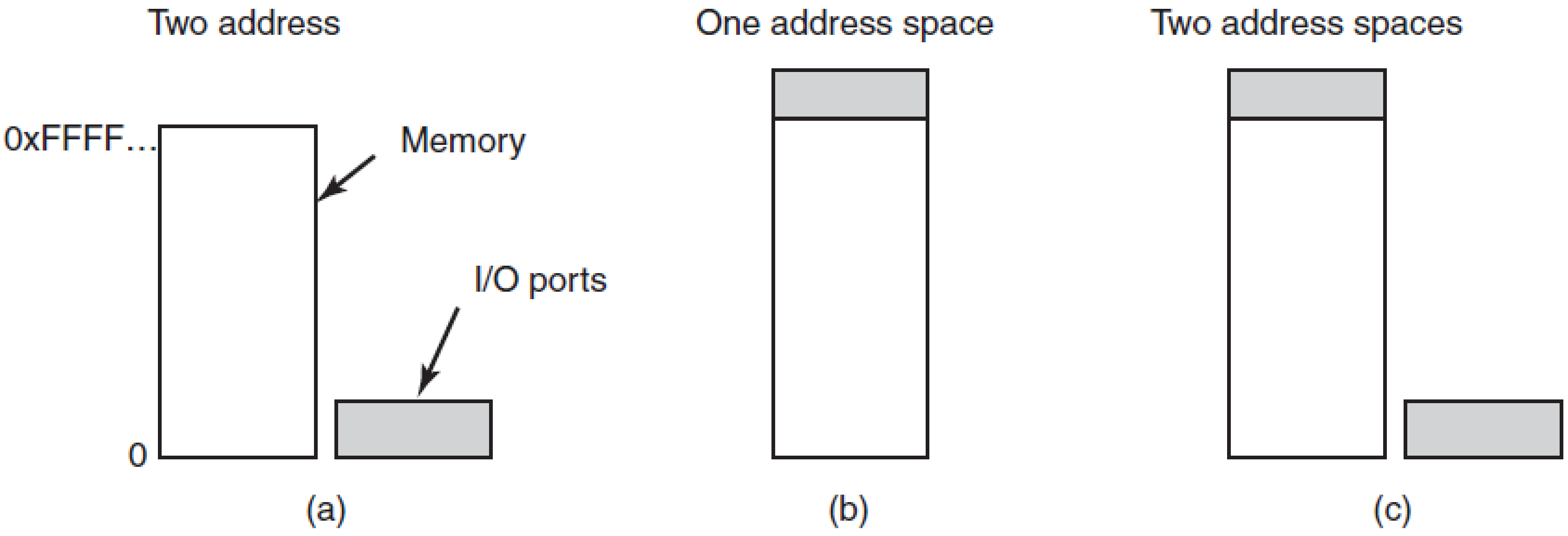


Figure 6-3. (a) Separate I/O and memory space. (b) Memory-mapped I/O. (c) Hybrid.

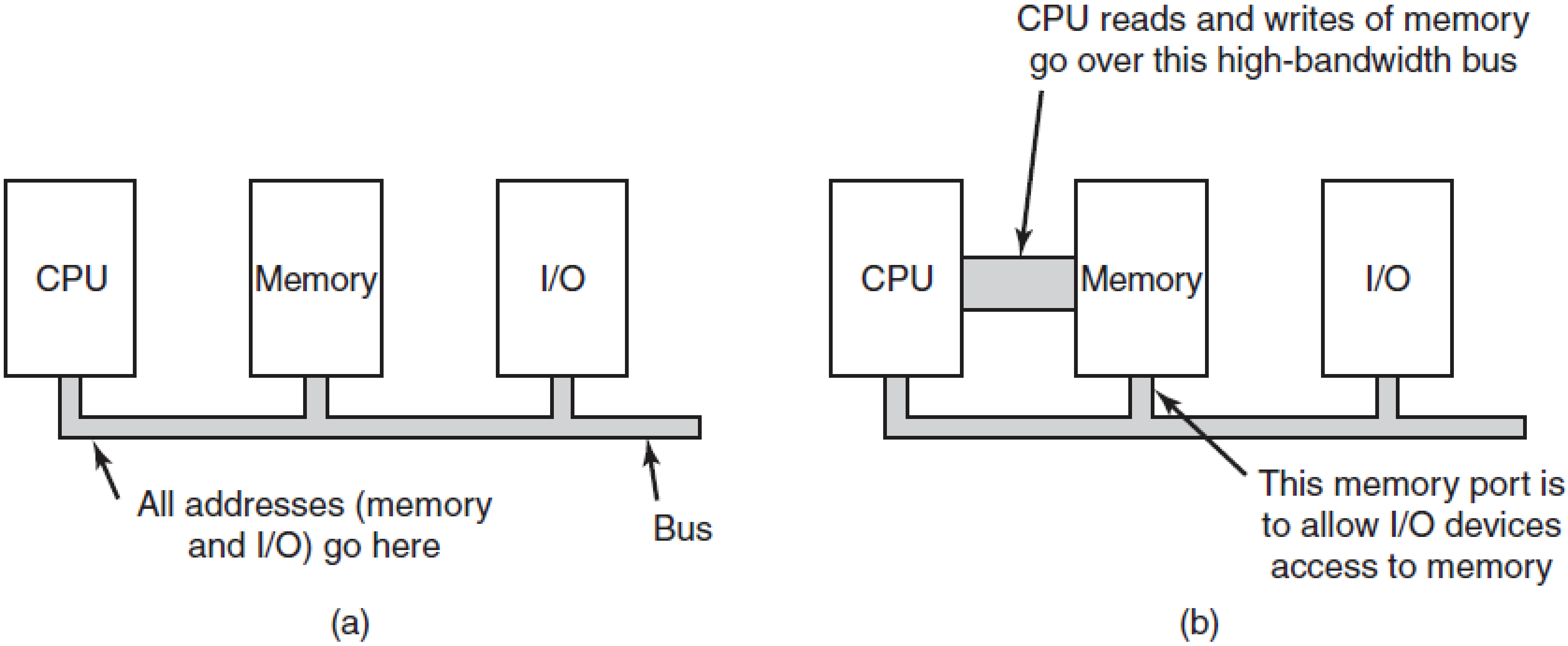

CPU reads and writes of memory go over this high-bandwidth bus
CPU
Memory
I/O
CPU
Memory
I/O
All addresses (memory and I/O) go here
Bus
This memory port is to allow I/O devices access to memory
(a)
(b)

Figure 6-4. (a) A single-bus architecture. (b) A dual-bus memory architecture.

Direct Memory Access

- The CPU can request data from an I/O controller one byte at a time, but doing so wastes the CPU’s time, so a different scheme, called **DMA** (**Direct Memory Access**) is often used.

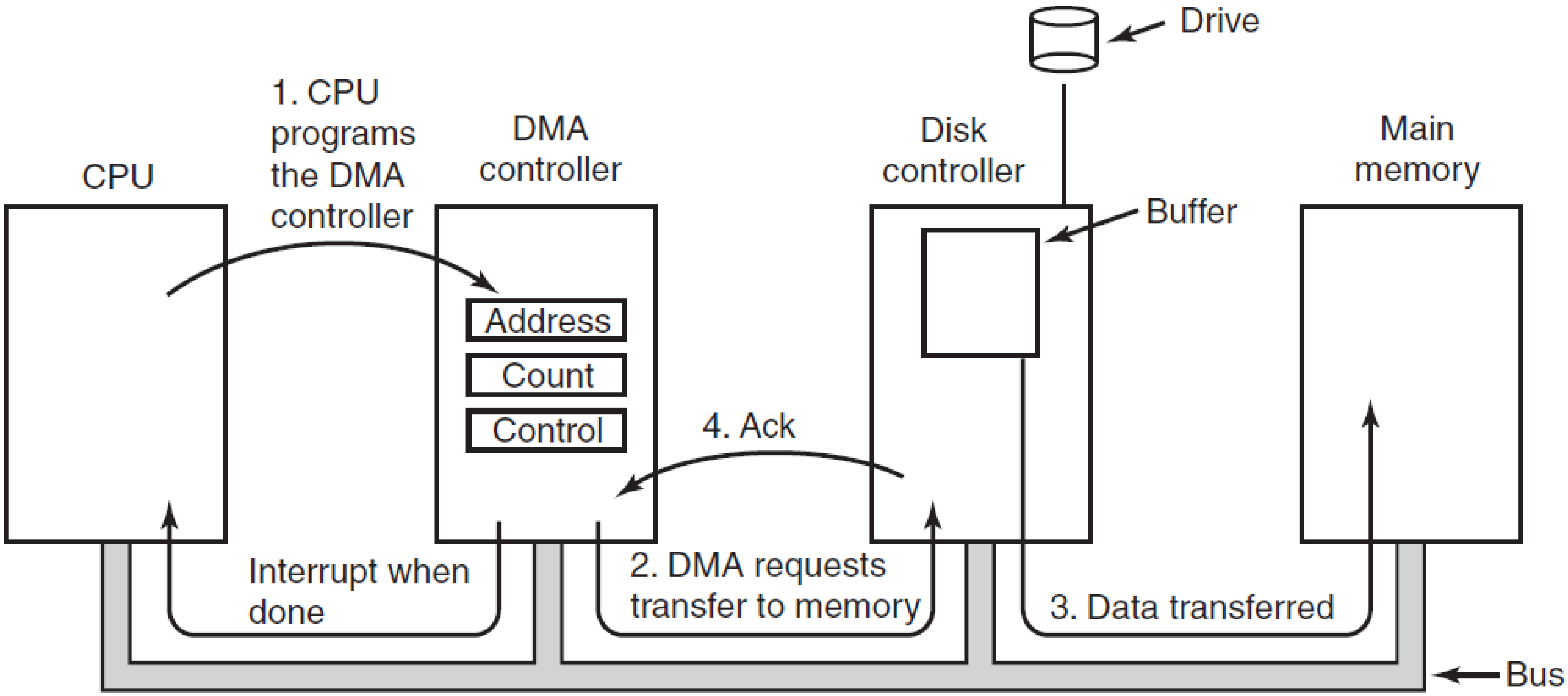


Figure 6-5. Operation of a DMA transfer.

- The operating system can use only DMA if the hardware has a DMA controller, which most systems do.
- Sometimes this controller is integrated into disk controllers and other controllers, but such a design requires a separate DMA controller for each device.
- DMA contains several registers that can be written and read by the CPU. These include a memory address register, a byte count register, and one or more control registers.
- The control registers specify the I/O port to use, the direction of the transfer (reading from the I/O device or writing to the I/O device), the transfer unit (byte at a time or word at a time), and the number of bytes to transfer in one burst.

Interrupts Revisited

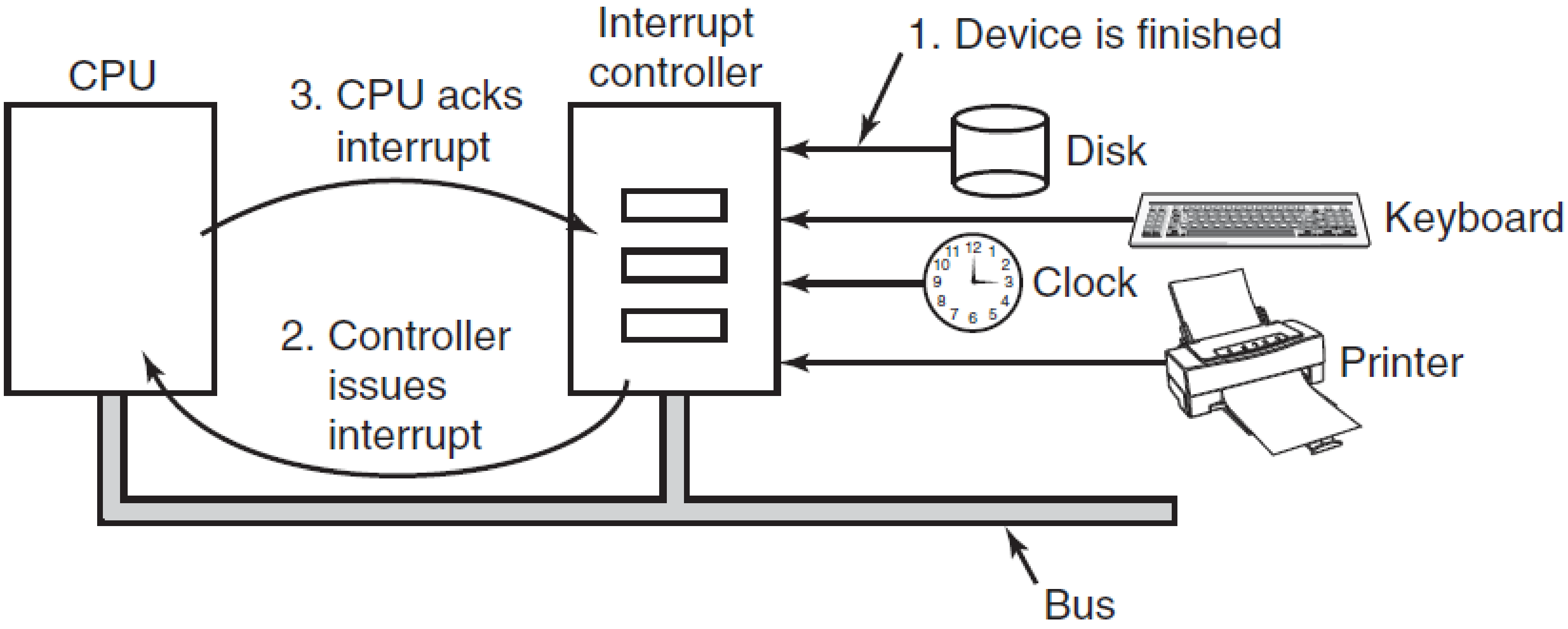


Figure 6-6. How an interrupt happens. The connections between the devices and the controller actually use interrupt lines on the bus rather than dedicated wires.

- An interrupt that leaves the machine in a well-defined state is called a **precise interrupt** (Walker and Cragon, 1995).

Properties of a precise interrupt:

1. PC (Program Counter) is saved in a known place.
2. All instructions before the one pointed to by the PC have fully executed.
3. No instruction beyond the one pointed to by the PC has been executed.
4. Execution state of the instruction pointed to by the PC is known.

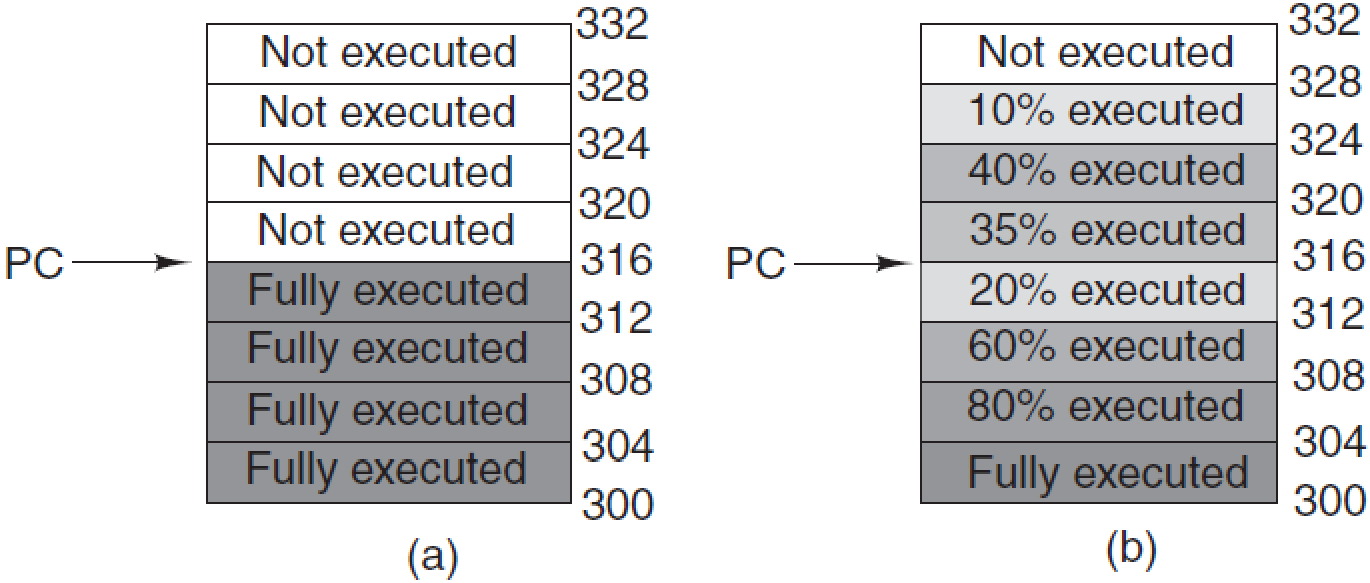


Figure 6-7. (a) A precise interrupt. (b) An imprecise interrupt.

- Fig. 5-7(a) illustrates a precise interrupt. All instructions up to the program counter (316) have completed and none of those beyond it have started (or have been rolled back to undo their effects).
- An interrupt that does not meet these requirements is called an **imprecise interrupt** and makes life most unpleasant for the operating system writer, who now has to figure out what has happened and what still has to happen.
- Fig. 5-7(b) illustrates an imprecise interrupt, where different instructions near the program counter are in different stages of completion, with older ones not necessarily more complete than younger ones.
- Machines with imprecise interrupts usually vomit a large amount of internal state onto the stack to give the operating system the possibility of figuring out what was going on.

Principles of I/O Software

Goals of the I/O Software

- A key concept in the design of I/O software is known as **device independence.**
- Device independence is the goal of **uniform naming**. The name of a file or a device should simply be a string or an integer and not depend on the device in any way.
- issue for I/O software :
- **Error handling**.
- **Synchronous** (blocking) vs. **asynchronous** (interrupt-driven) transfers.
- **Buffering**.
- sharable vs. dedicated devices: Some I/O devices, such as disks, can be used by many users at the same time. No problems are caused by multiple users having open files on the same disk at the same time. Other devices, such as

Fundamentally input/output can be performed in one of the following three ways: (Handling I/O):

Programmed I/O

- Programmed input–output is a method of data transmission, via input/output, between a central processing unit and a peripheral device, such as a network adapter or a Parallel ATA(PATA) storage device

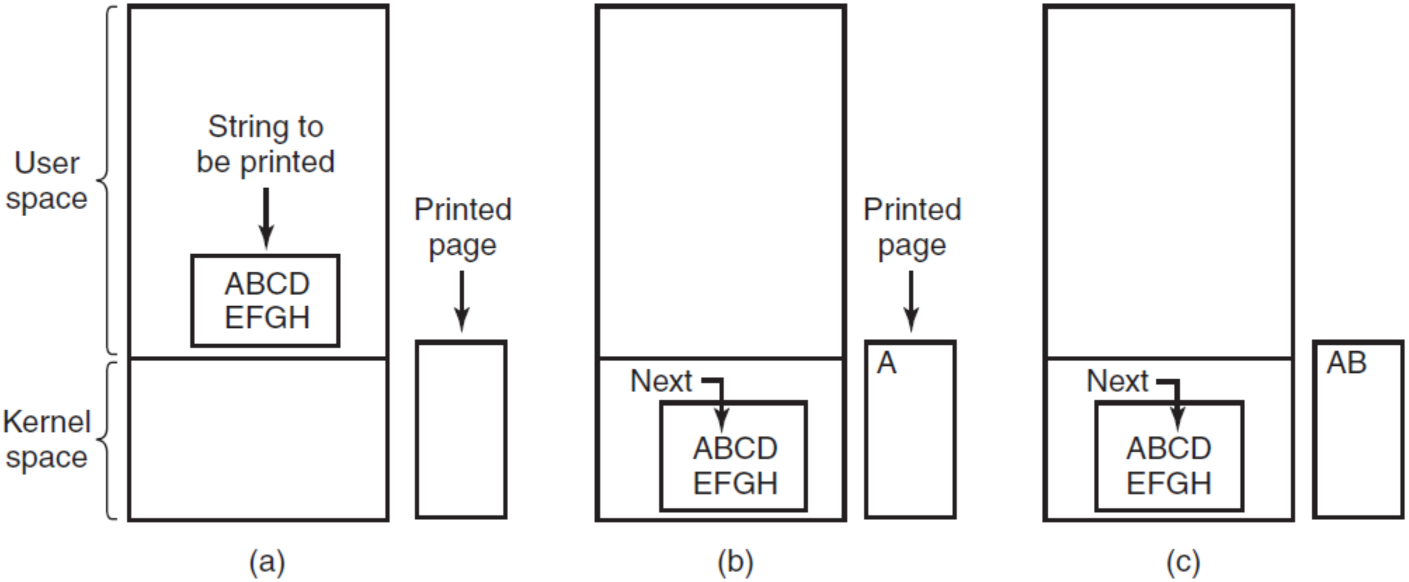
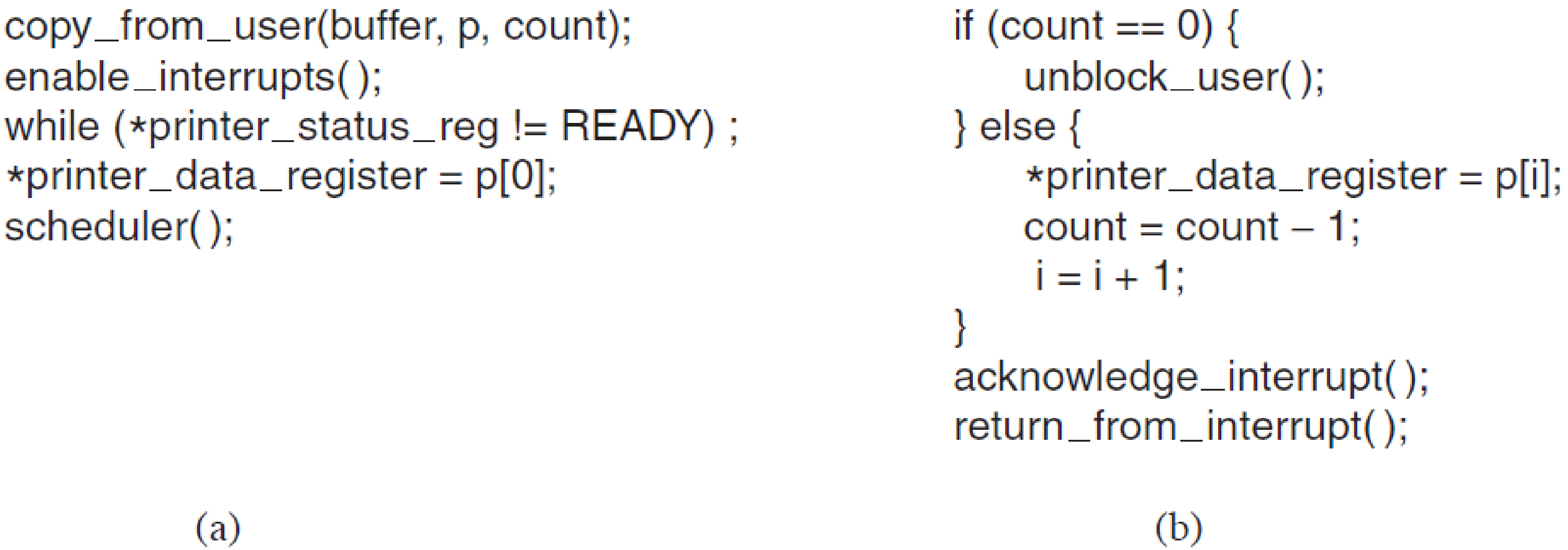


Figure 6-8. Steps in printing a string.

```
copy from user(buffer, p,count);                /* p is the ker nel buffer */
for (i = 0; i < count; i++) {                  /* loop on every character */
while (*pr inter status reg != READY) ;        /* loop until ready */
*pr inter data register = p[i];                /* output one character */
}
retur n to user( );
```

Figure 6-9. Writing a string to the printer using programmed I/O.

Interrupt-Driven I/O



```
copy_from_user(buffer, p, count);
enable_interrupts( );
while (*printer_status_reg != READY) ;
*printer_data_register = p[0];
scheduler( );
```

(a)

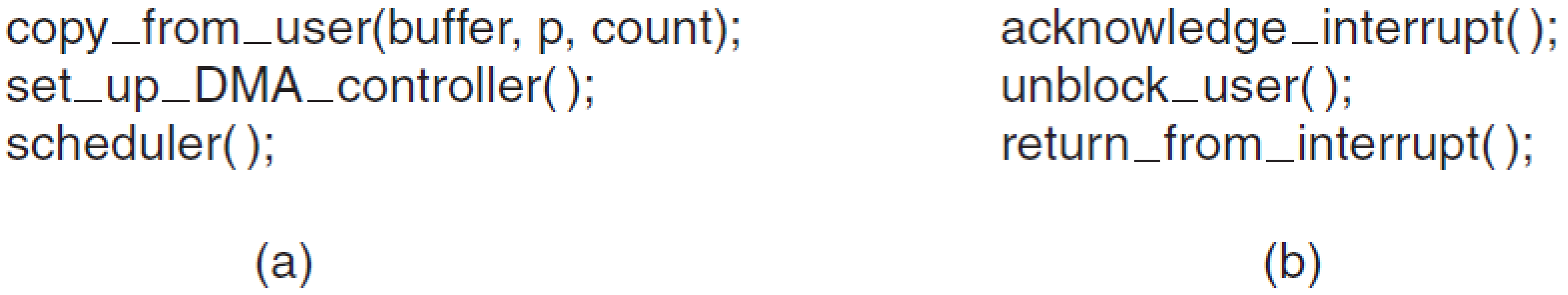
```
if (count == 0) {
    unblock_user( );
} else {
    *printer_data_register = p[i];
    count = count − 1;
     i = i + 1;
}
acknowledge_interrupt( );
return_from_interrupt( );
```

(b)

Figure 6-10. Writing a string to the printer using interrupt-driven I/O. (a) Code executed at the time the print system call is made. (b) Interrupt service procedure for the printer.

I/O using DMA

- Disadvantage of interrupt-driven I/O is that an interrupt occurs on every character. Interrupts take time, so this scheme wastes a certain amount of CPU time. A solution is to use DMA.
- DMA is programmed I/O, only with the DMA controller doing all the work, instead of the main CPU. This strategy requires special hardware (the DMA controller) but frees up the CPU during the I/O to do other work.



```
copy_from_user(buffer, p, count);
set_up_DMA_controller( );
scheduler( );
```

(a)

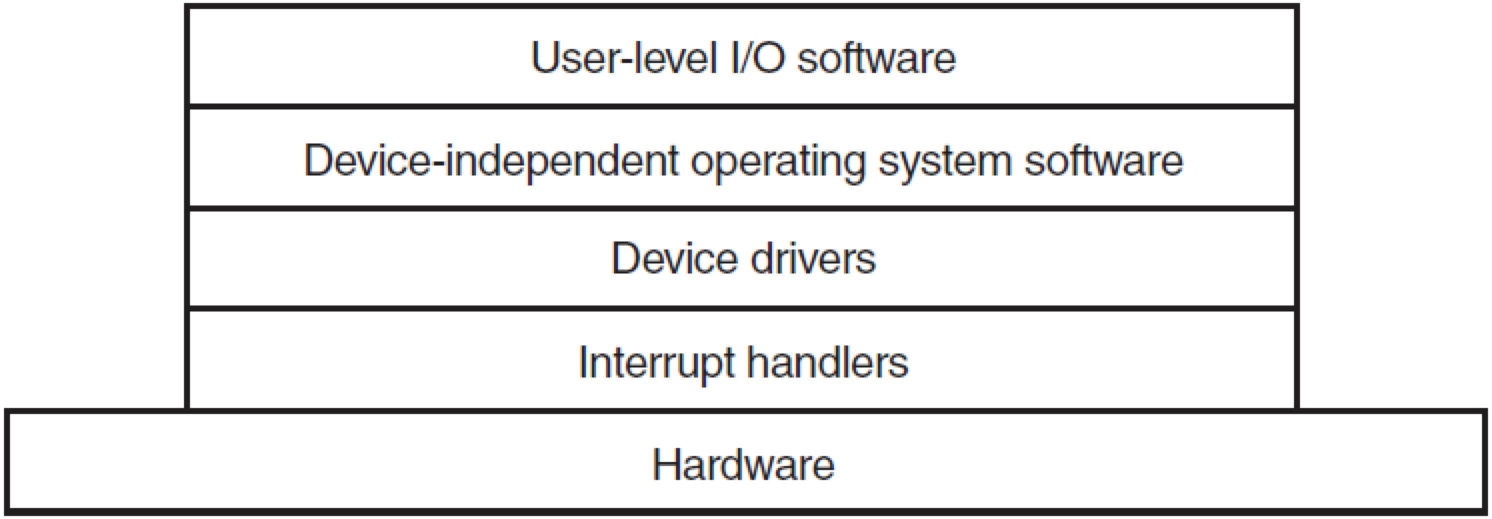
```
acknowledge_interrupt( );
unblock_user( );
return_from_interrupt( );
```

(b)

Figure 6-11. Printing a string using DMA. (a) Code executed when the print system call is made. (b) Interrupt-service procedure.

I/O Software layers

- I/O software is typically organized in four layers, as shown in Fig. 5-11. Each layer has a well-defined function to perform and a well-defined interface to the adjacent layers.



User-level I/O software

Device-independent operating system software

Device drivers

Interrupt handlers

Hardware

Figure 6-12. Layers of the I/O software system.

The four input/output software layers that are listed above are:

Interrupt handlers

1.Save registers not already been saved by interrupt hardware.

2. Set up a context for the interrupt service procedure.

3. Set up a stack for the interrupt service procedure.

4. Acknowledge the interrupt controller. If there is no centralized interrupt controller, reenable interrupts.

5. Copy the registers from where they were saved to the process table.

6. Run the interrupt service procedure.

7. Choose which process to run next.

8. Set up the MMU context for the process to run next.

9. Load the new process’ registers, including its psw(program status word).

10. Start running the new process.

Device Drivers

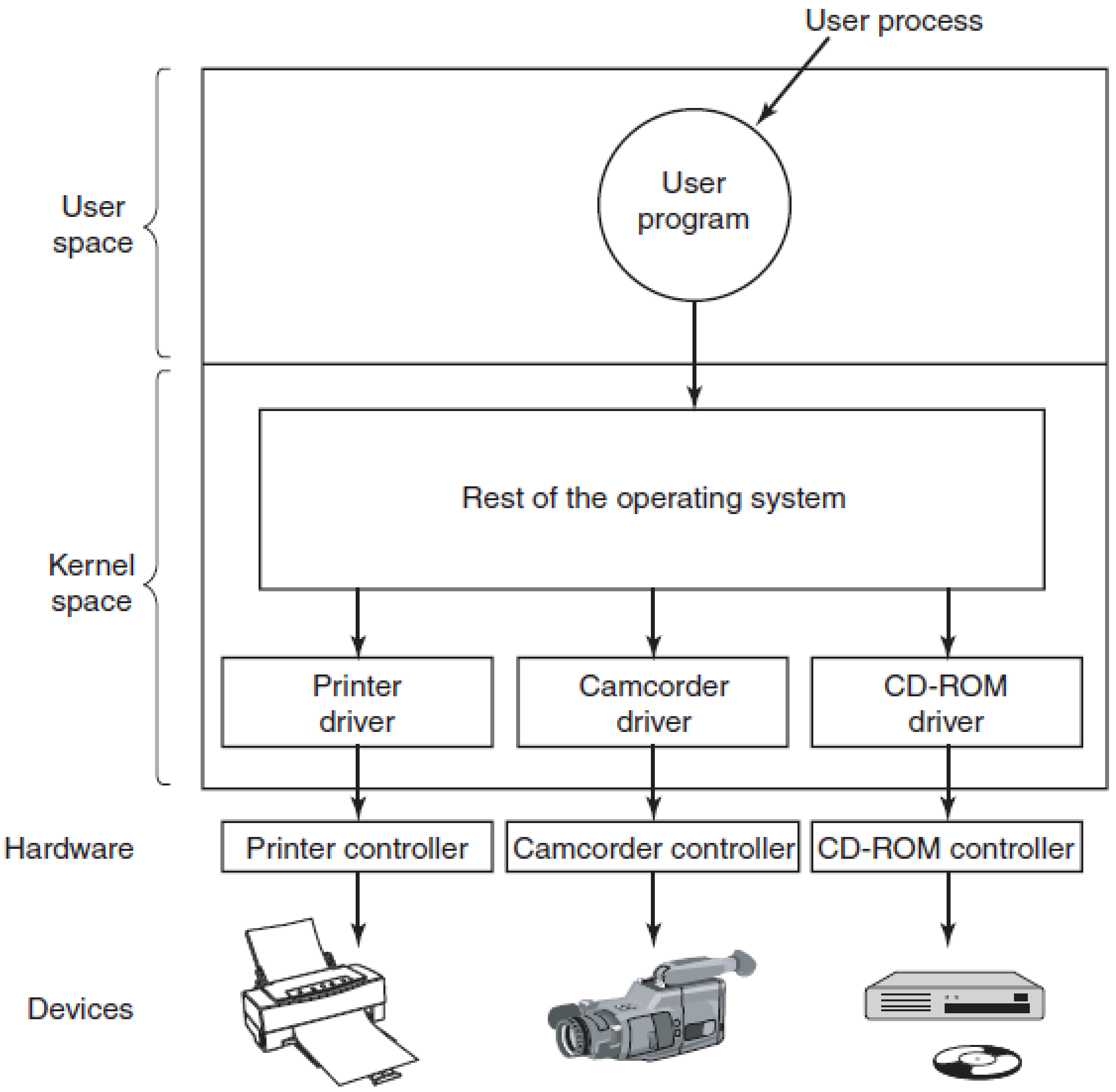
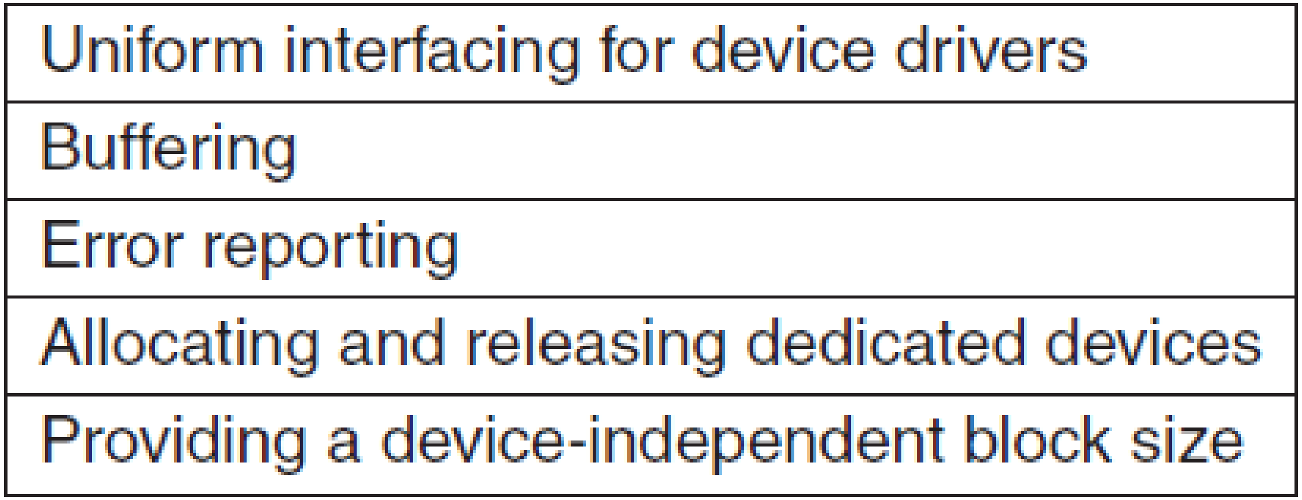


Figure 6-13. Logical positioning of device drivers. In reality all communication between drivers and device controllers goes over the bus.

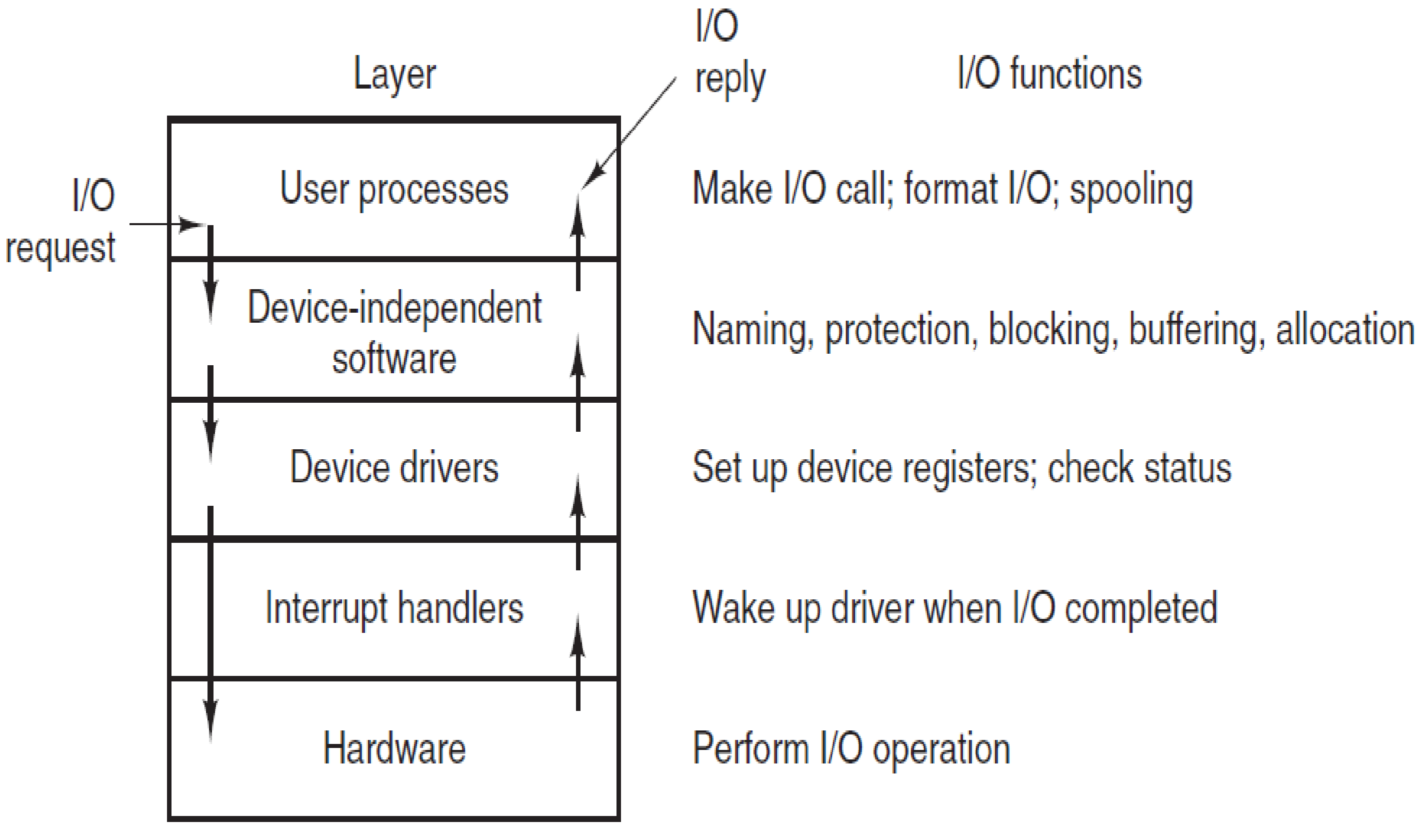
Device-Independent I/O Software



Uniform interfacing for device drivers
Buffering
Error reporting
Allocating and releasing dedicated devices
Providing a device-independent block size

Figure 6-14. Functions of the device-independent I/O software.

User-Space I/O Software



Layer
I/O reply
I/O functions
I/O request
User processes
Make I/O call; format I/O; spooling
Device-independent software
Naming, protection, blocking, buffering, allocation
Device drivers
Set up device registers; check status
Interrupt handlers
Wake up driver when I/O completed
Hardware
Perform I/O operation

Figure 6-15. Layers of the I/O system and the main functions of each layer.

Disks

Disk Hardware

- Disks come in a variety of types. The most common ones are the magnetic hard disks. They are characterized by the fact that reads and writes are equally fast, which makes them suitable as secondary memory (paging, file systems, etc.).
- For distribution of programs, data, and movies, optical disks (DVDs and Blu-ray) are also important.

Disk Formatting

Before disk can be used, it must be formatted:

- **Low level format :** Disk sector layout, Cylinder skew and Interleaving
- **High level format** : Boot block ,Free block list, Root directory, Empty file system
- Typical sector is 512 bytes
  - Preamble identifying start code and sector address
  - Data
  - Error correction code (16 bits). At least detecting errors possible with probability almost 1

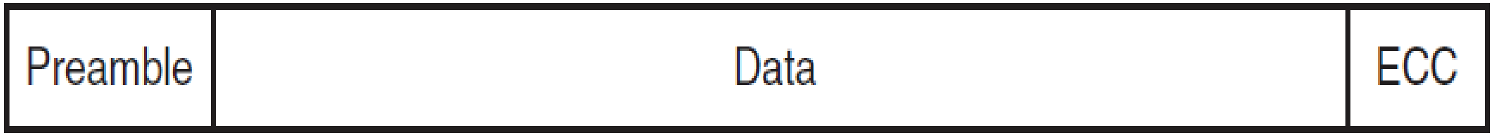


Figure 5-21. A disk sector.

- **Cylinder skew:** After reading an entire track, as head is moved across a cylinder, seeking next sector shouldn’t cause waiting for full rotation
- When reading sequential blocks, the seek time can result in missing block 0 in the next track.

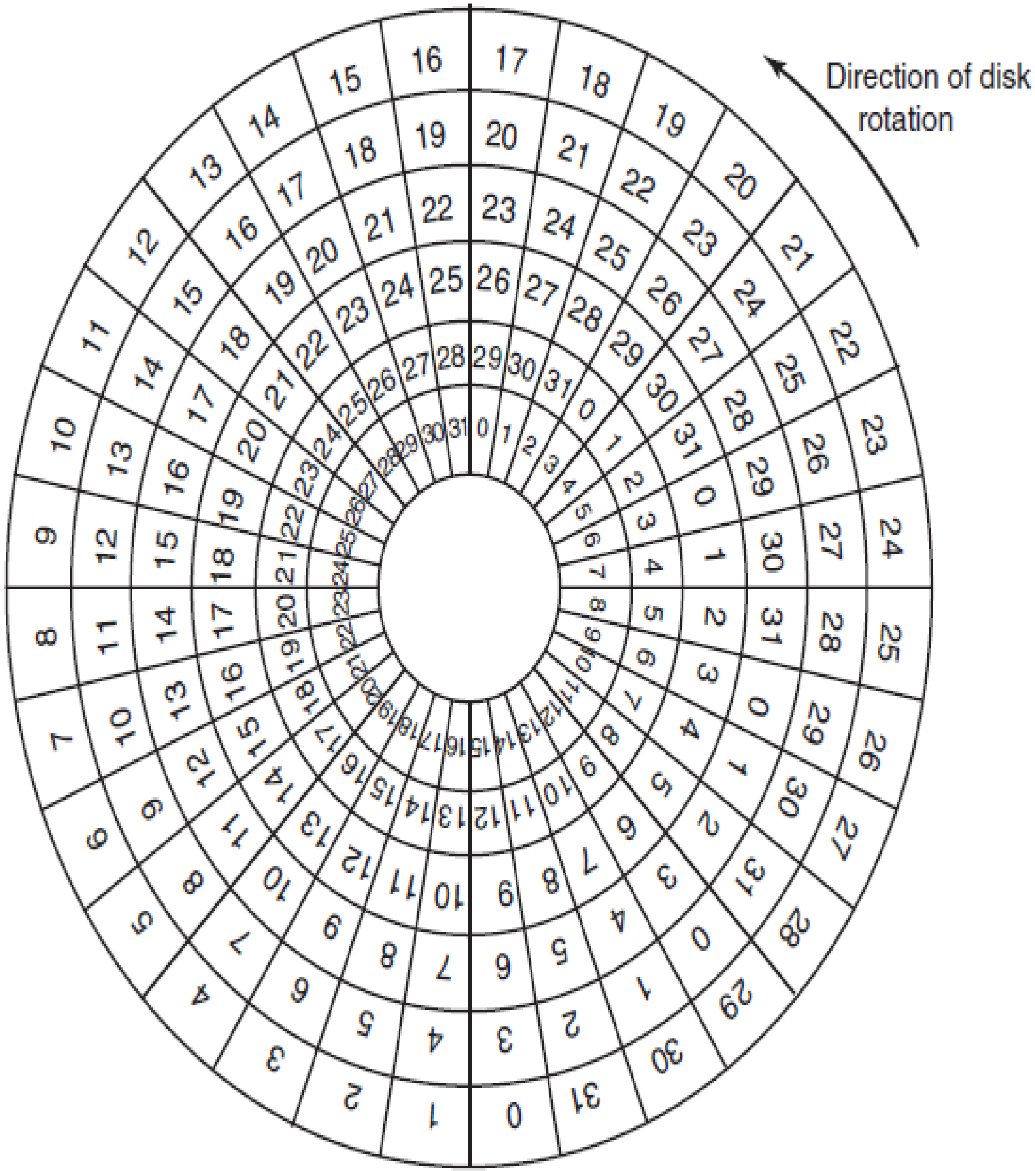


Figure 5-22. An illustration of cylinder skew.

- Issue: After reading one sector, the time it takes to transfer the data to the OS and receive the next request results in missing reading the next sector.
- To overcome this, we can use interleaving
- Interleaving sectors: As a sector is copied into controller buffer, it needs to be copied into main memory. So next sector should not be adjacent if we wish to avoid waiting for one full rotation

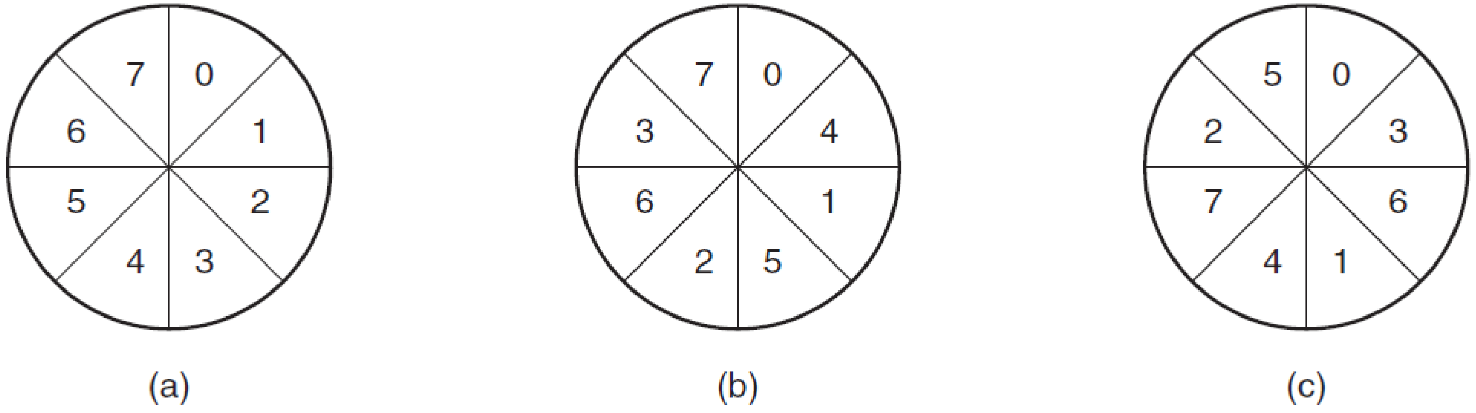


Figure 5-23. (a) No interleaving. (b) Single interleaving. (c) Double interleaving.

Disk Access

- Physical address on a disk

  (cylinder number, head number, sector number)

- Sectors can be given logical numbers that get decoded by Disk Controller
- Design considerations
  - Seek time (moving head to correct cylinder) and rotational latency time (waiting for correct sector) are greater than data transfer time (time to read)
  - Lots of errors possible (bad sectors, bad bits)
  - Caching blocks that happen to pass under disk head commonly used

Q. A disk has 8 sectors per track and spins at 600 rpm. It takes the controller time 10ms from the end of one I/O operation before it can issue a subsequent one. How long does it take to read all 8 sectors using the following interleaving system?

a) No interleaving

b) Single interleaving

c) Double interleaving

Solution:

1 Minute = 600 revolution , 1/600 Minute = 1 revolution ,1/10 Second = 1 revolution

100 Millisecond = 1 revolution

a) No Interleaving:

Time to read total sector = $8\times100\ ms$=$800\ ms$

b) Single Interleaving:

Time to read total sector = $2\times100\ ms$=$200\ ms$

c) Double Interleaving:

Time to read total sector = $8/3\times100\ ms$=$266.67\ ms$

RAID

- Redundant Array of Inexpensive/Independent Disks
- RAID is a data storage virtualization technology that combines multiple physical disk drive components into one or more logical units for the purposes of data redundancy, performance improvement, or both.
- RAID is a technology that is used to increase the performance and/or reliability of data storage.
- A RAID system consists of two or more drives working in parallel. These can be hard discs, but there is a trend to also use the technology for SSD (Solid State Drives).
- In a SLED (Single Large Expensive Disk) reliabity becomes a big problem as the data in an entire disk may be lost.
- As the number of disks per component increases, the probability of failure also increases .

- Suppose a (reliable) disk fails every 100,000 hrs. reliabity of a disk in an array of N disks = Reliability of 1 disk / N

  100000hrs / 100 = 1000 hrs = 41.66 days !!

  Solution ?

  Redundancy

- RAID levels:

  RAID 0: striping

  RAID 1: mirroring

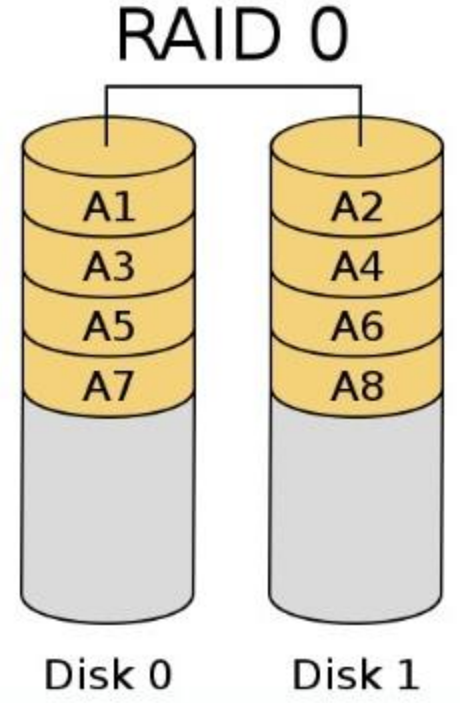
  RAID 5: striping with parity

  RAID 6: striping with double parity

  RAID 10: combining mirroring and striping

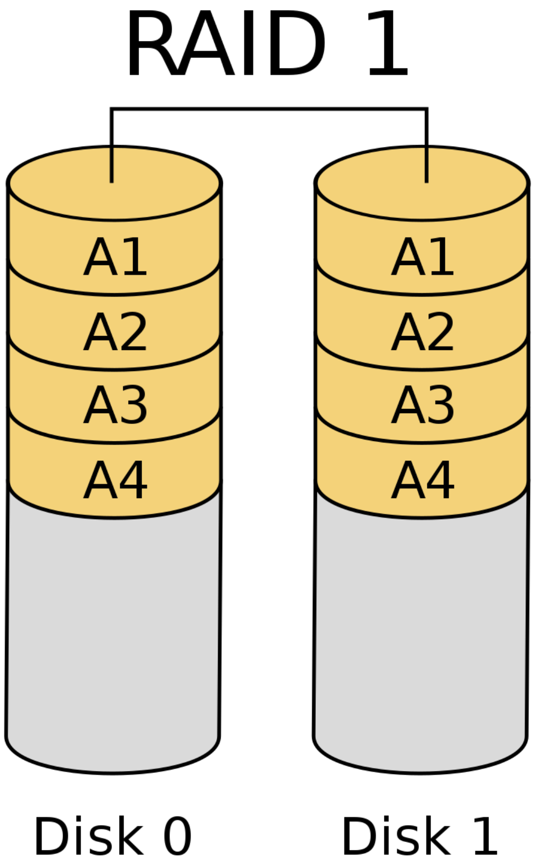
RAID level 0 : Striping

- RAID Level 0 is block-level striping and non-redundant disk array
- Files are striped across disks, no redundant information
- Best I/O performance achieved when data is striped across multiple controllers with only one drive per controller.
- High read throughput but no fault-tolerance
- Best write throughput (no redundant info to write)
- Any disk failure results in data loss; sometimes a file, sometimes the entire volume



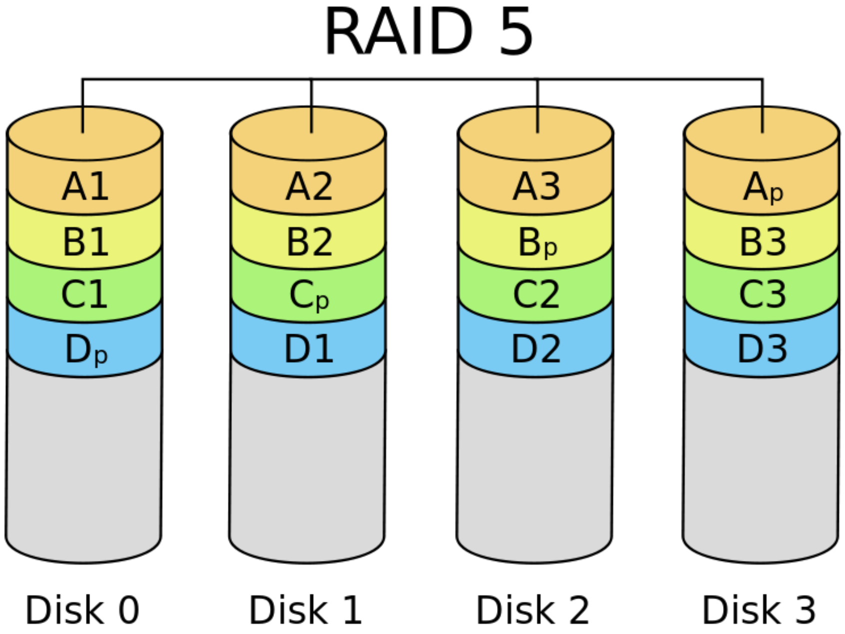
RAID level 1 : Mirroring

- RAID Level 1 is mirrored disks with no parity
- Files are striped across (half) the disks
- Data is written to multiple (two) places – data disks and mirror disks
- Best fault-tolerance
- On failure, just use the surviving disk(s)
- Factor of N (2x) space expansion



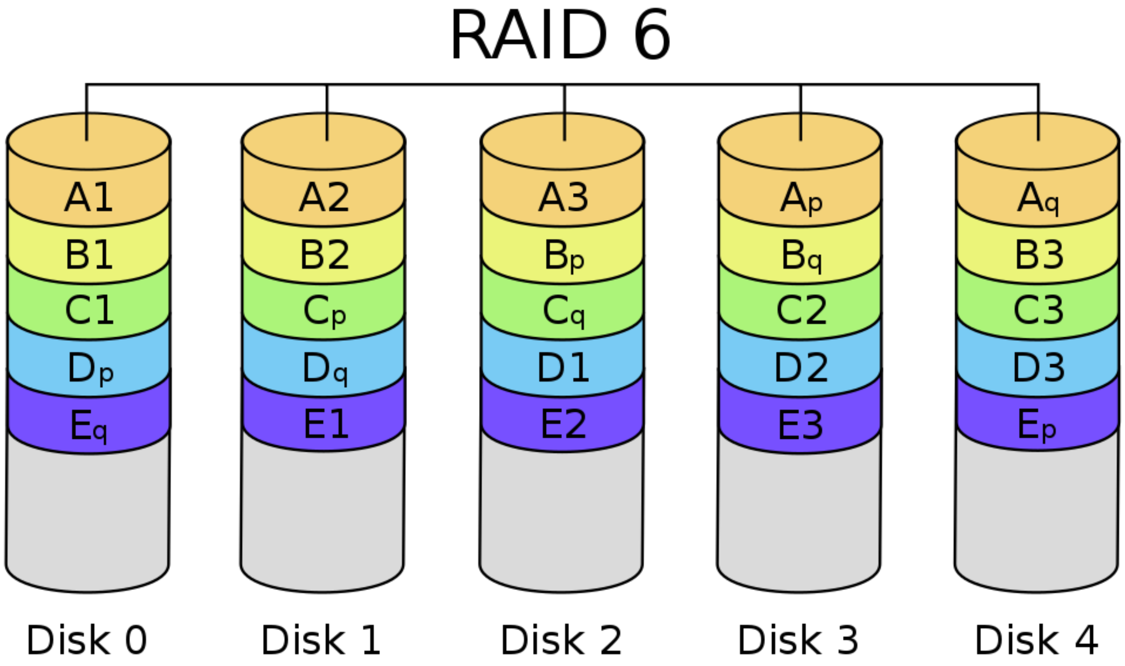
RAID 5: striping with parity

- The parity information is distributed over all the disks instead of storing them in a dedicated disk.
- Parity for blocks in the same rank is generated on writes, recorded in a distributed location and checked on reads.
- No more a bottleneck as the parity stress evens out by using all the disks to store parity information
- No possibility of losing data redundancy since one disk does not store all the parity information.
- Can only handle up to a single disk failure



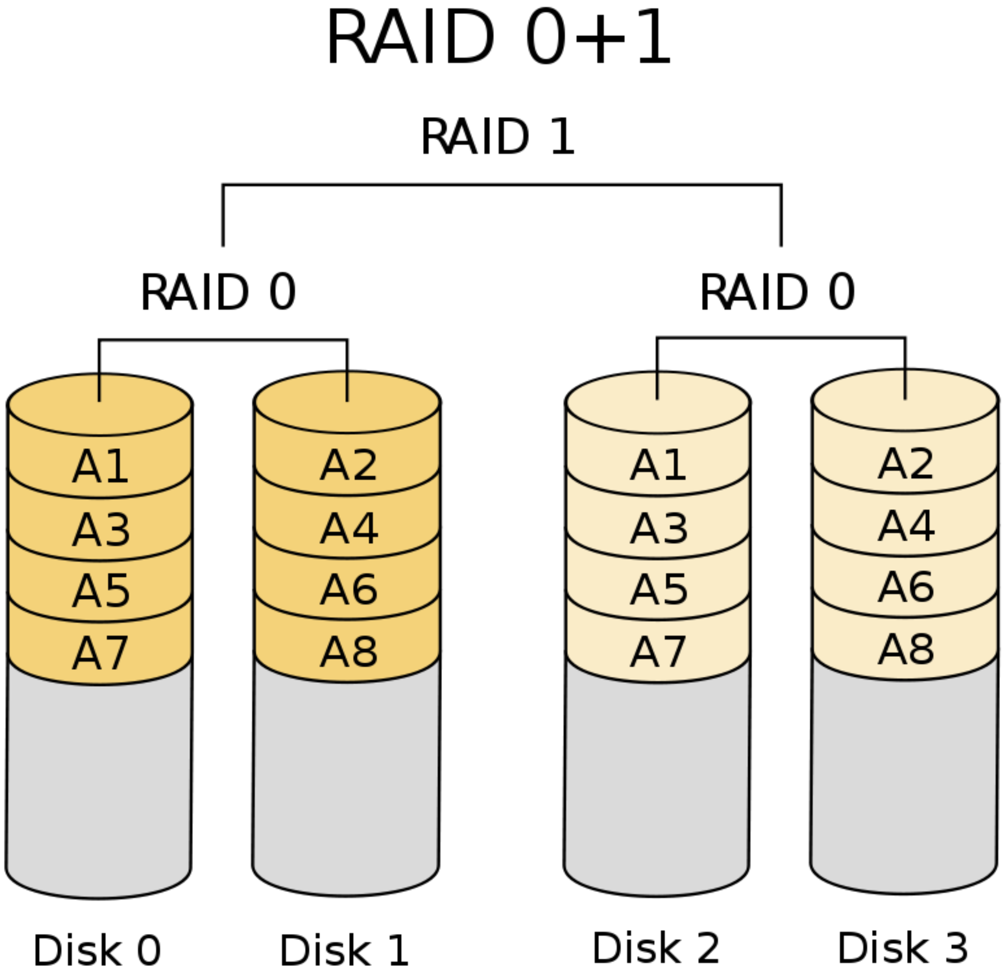
RAID 6: striping with double parity

- Block –level striping with double distributed parity.
- This increases the fault tolerance for up to two drive failures in the array.
- Each disk has two parity blocks which are stored on different disks across the array.
- RAID 6 is a very practical infrastructure for maintaining high availability systems.
- Large parity overhead



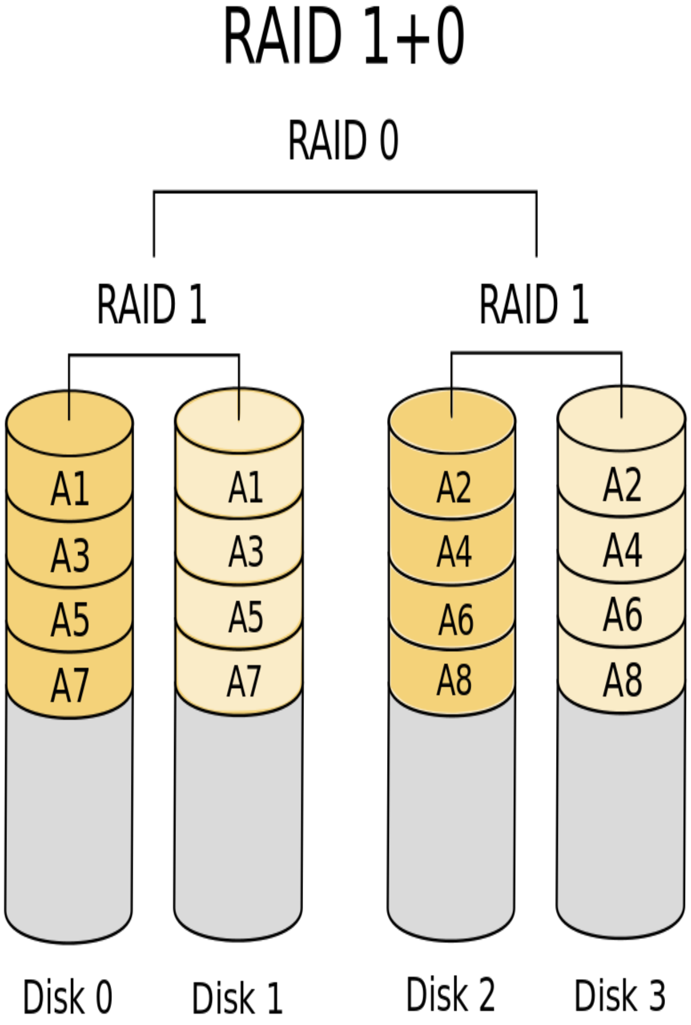
RAID 01 (RAID 0+1)

- RAID level using a mirror of stripes, achieving both replication and sharing of data between disks.
- The usable capacity of a RAID 01 array is the same as in a RAID 1 array made of the same drives, in which one half of the drives is used to mirror the other half.



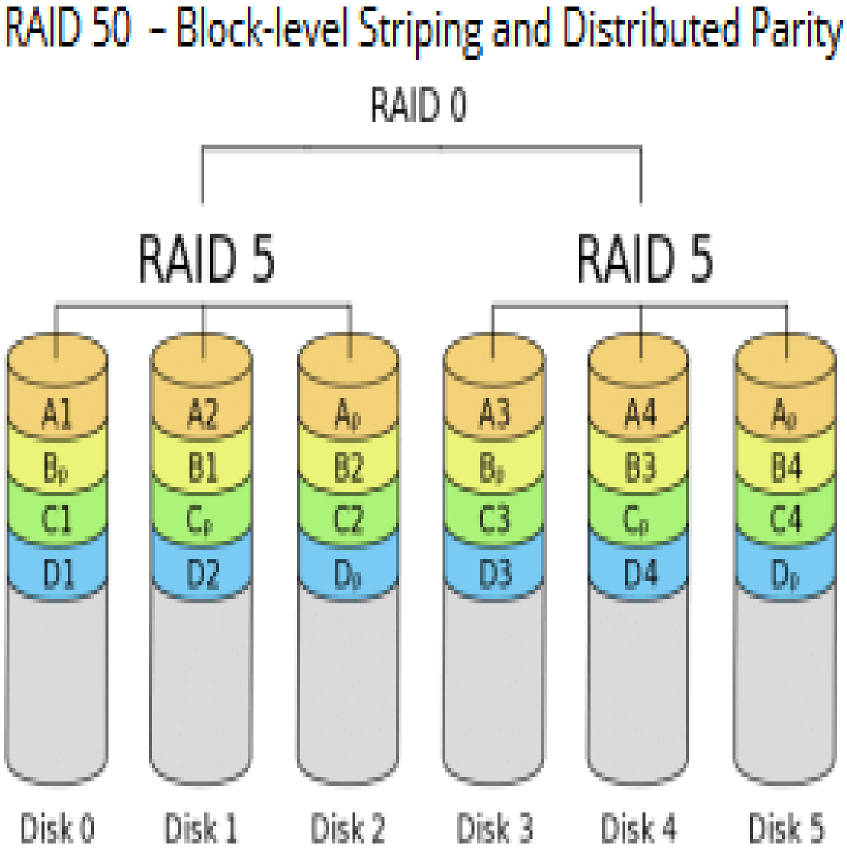
RAID 10: Combining Mirroring And Striping

- Also called **RAID 1+0** and sometimes **RAID 1 & 0**
- RAID 10 combines both RAID 1 and RAID 0 by layering them in opposite order.
- In this setup, multiple RAID 1 blocks are connected with each other to make it like RAID 0.
- This is a nested or hybrid RAID configuration.
- It is used in cases where huge disk performance (greater than RAID 5 or 6) along with redundancy is required.
- Cost per unit memory is high since data is mirrored



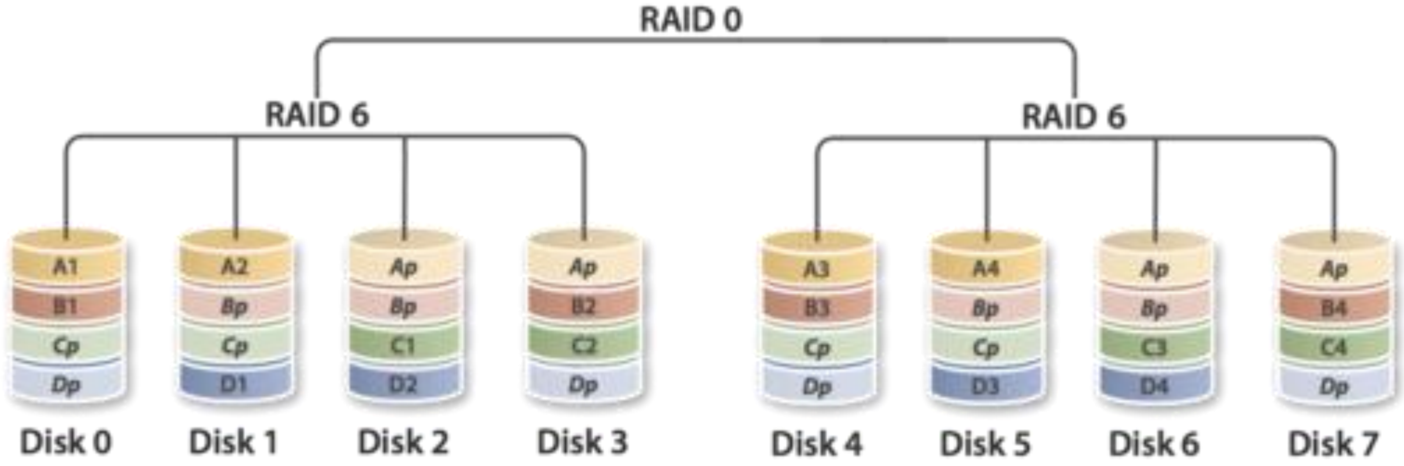
RAID 50:

- **RAID 50 a**lso called **RAID 5+0**
- combines the straight block-level striping of RAID 0 with the distributed parity of RAID 5**.**
- As a RAID 0 array striped across RAID 5 elements, minimal RAID 50 configuration requires six drives.
- This takes advantage of the distributed parity of the RAID 5 level with the extra speed gained by using the data striping of RAID 0.



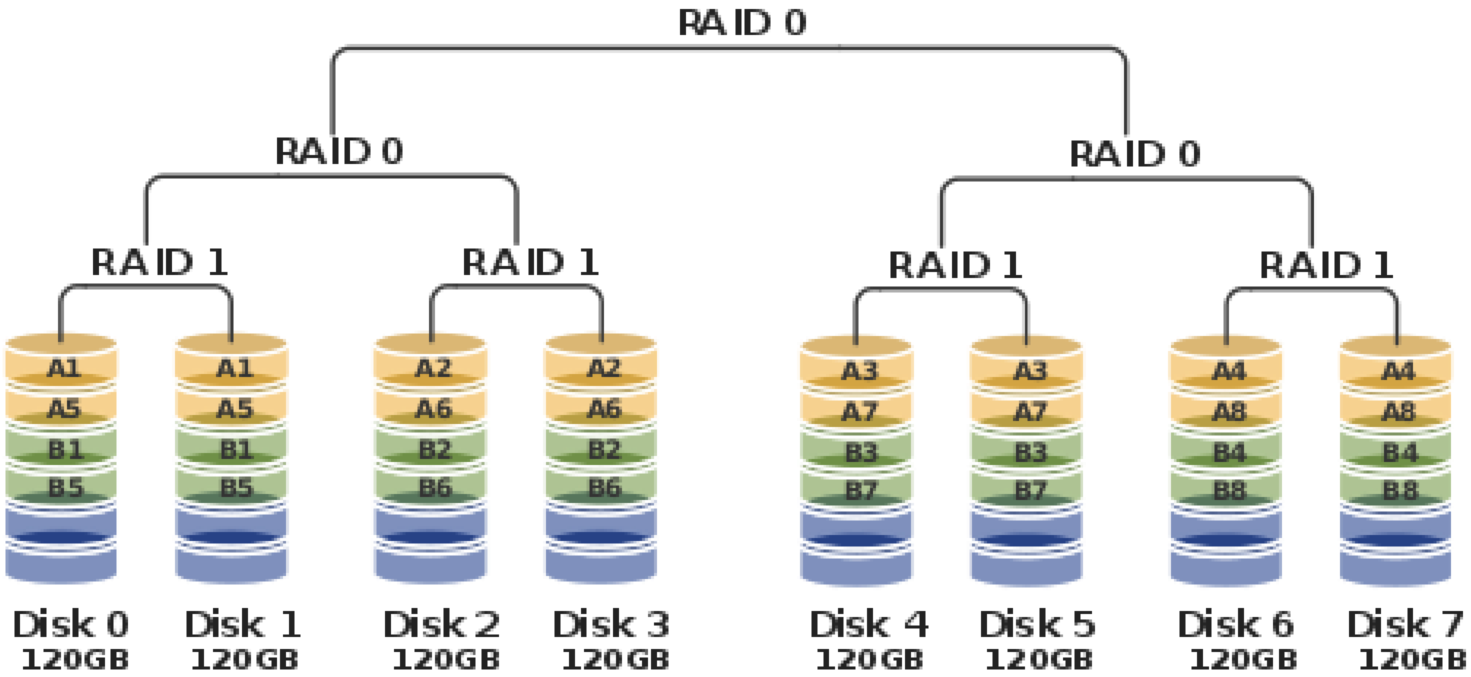
RAID 60 (RAID 6+0)

- **RAID 60**, also called **RAID 6+0**,
- Combines the straight block-level striping of RAID 0 with the distributed double parity of RAID 6, resulting in a RAID 0 array striped across RAID 6 elements. It requires at least eight disks



RAID 100 (RAID 10+0)

- **RAID 100**, sometimes also called **RAID 10+0**, is a stripe of RAID 10s.
- This is logically equivalent to a wider RAID 10 array, but is generally implemented using software RAID 0 over hardware RAID 10. Being "striped two ways", RAID 100 is described as a "plaid RAID"



Disk Arm Scheduling Algorithms

- How long it takes to read or write a disk block. The time required is determined by three factors:

1. Seek time (the time to move the arm to the proper cylinder).

2. Rotational delay (how long for the proper sector to appear under the reading head).

3. Actual data transfer time.

- Error checking is done by controllers

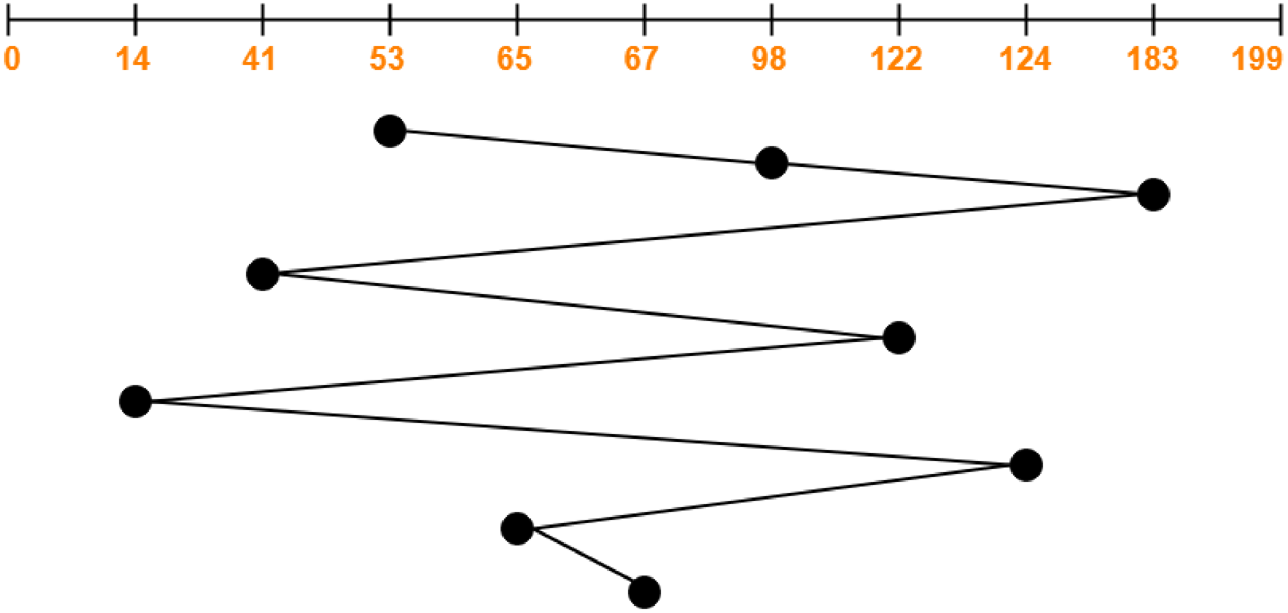
Disk Scheduling Algorithms

- FCFS Algorithm
- SSTF Algorithm
- SCAN Algorithm
- C-SCAN Algorithm
- LOOK Algorithm
- C-LOOK Algorithm

FCFS Scheduling

- It stands **first-come first-served**
- Simplest
- It services the IO requests in the order in which they arrive
- No **starvation**: every request is serviced
- Doesn’t provide fastest service: does not optimize the seek time.
- The request may come from different processes therefore there is the possibility of inappropriate movement of the head.

Q. A disk contains 200 cylinders ,the track sequence is 98, 183, 41, 122, 14, 124, 65, 67 and current position of R/W head is 53 calculate total no of arm movement of head.



Total head movements incurred while servicing these requests

= (98 – 53) + (183 – 98) + (183 – 41) + (122 – 41) + (122 – 14) + (124 – 14) + (124 – 65) + (67 – 65)= 45 + 85 + 142 + 81 + 108 + 110 + 59 + 2

= 632

SSTF Scheduling

- SSTF stands for **Shortest Seek Time First**.
- This algorithm services that request next which requires least number of head movements from its current position regardless of the direction.
- It breaks the tie in the direction of head movement.

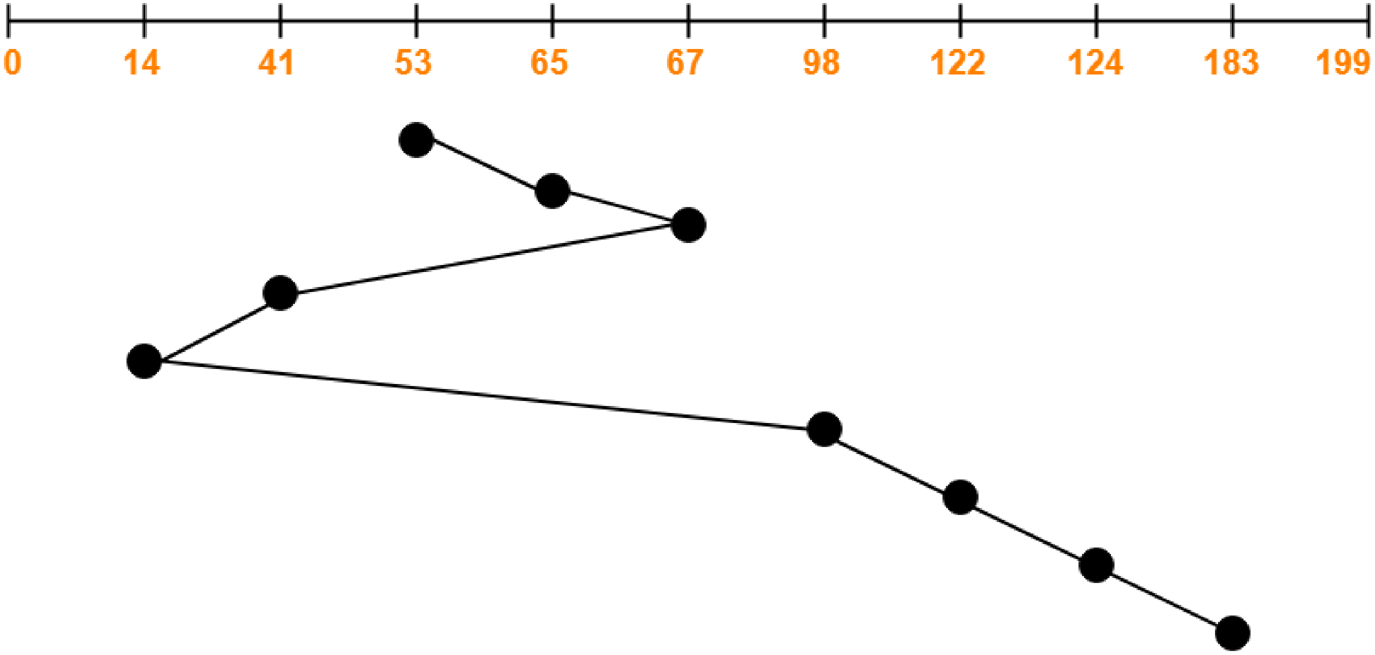
Advantages:

- It reduces the total seek time as compared to **FCFS.**
- It provides increased throughput.
- It provides less average response time and waiting time.

Disadvantages:

- There is an overhead of finding out the closest request.
- The requests which are far from the head might starve for the CPU.
- It provides high variance in response time and waiting time.
- Switching the direction of head frequently slows down the algorithm.

Q. Suppose that a disk drive has the cylinder numbered from 0 to 199. The head is currently at cylinder number 53. The queue for services of cylinder is as 98, 183, 41, 122, 14, 124, 65, and 67. What is the total head movement in each of the following disk algorithm to satisfy the requests?

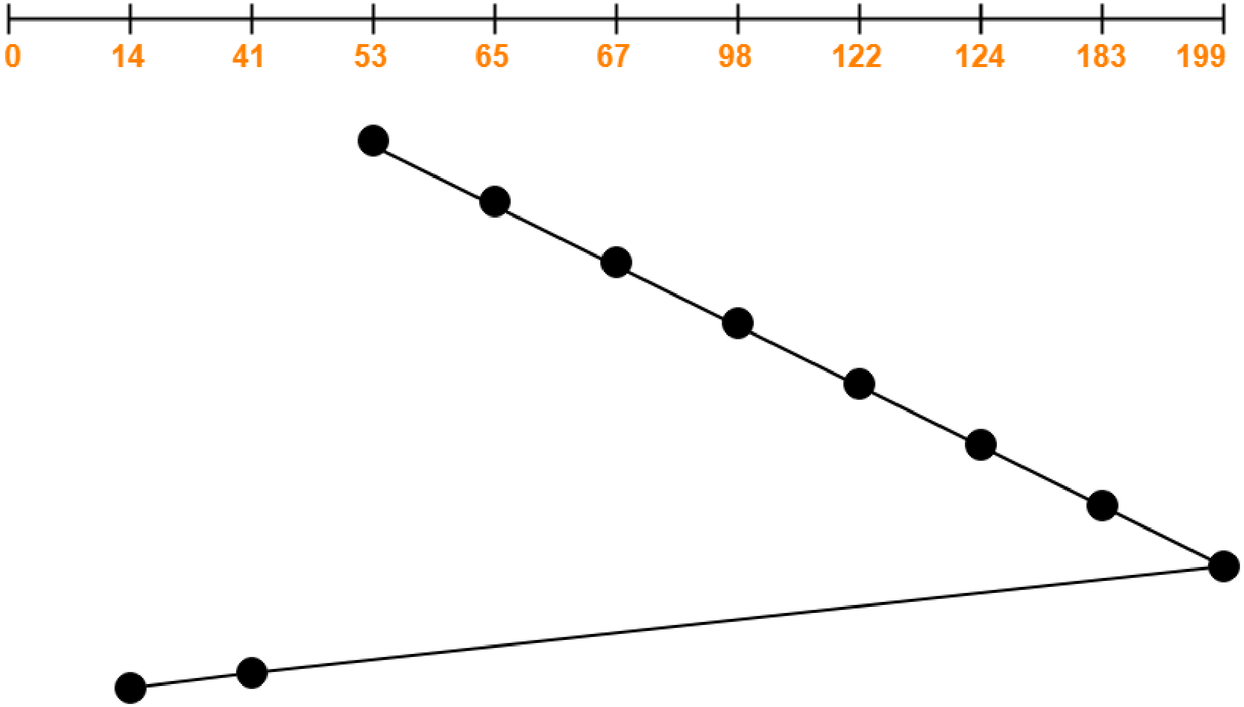


Total head movements incurred while servicing these requests
= (65 – 53) + (67 – 65) + (67 – 41) + (41 – 14) + (98 – 14) + (122 – 98) + (124 – 122) + (183 – 124)= 12 + 2 + 26 + 27 + 84 + 24 + 2 + 59
= 236

SCAN Scheduling

- Also called the **elevator** algorithm.
- This algorithm scans all the cylinders of the disk back and forth.
- The disk arm moves into a particular direction till the end, satisfying all the requests coming in its path and then it turns back and moves in the reverse direction satisfying requests coming in its path.
- It works in the way an elevator works, elevator moves in a direction completely till the last floor of that direction and then turns back.
- High throughput
- Low variance of response time
- Average response time
- Long waiting time for requests for locations just visited by disk arm

Q. Consider a disk queue with requests for I/O to blocks on cylinders 98, 183, 41, 122, 14, 124, 65, 67. The head is initially at cylinder number 53 moving towards larger cylinder numbers on its servicing pass. The cylinders are numbered from 0 to 199.



Total head movements incurred while servicing these requests = (65 – 53) + (67 – 65) + (98 – 67) + (122 – 98) + (124 – 122) + (183 – 124) + (199 – 183) + (199 – 41) + (41 – 14)

= 12 + 2 + 31 + 24 + 2 + 59 + 16 + 158 + 27

= 331

C-SCAN Scheduling

- Circular-SCAN Algorithm is an improved version of the **SCAN Algorithm**.
- Head starts from one end of the disk and move towards the other end servicing all the requests in between.
- After reaching the other end, head reverses its direction.
- It then returns to the starting end without servicing any request in between. The same process repeats.

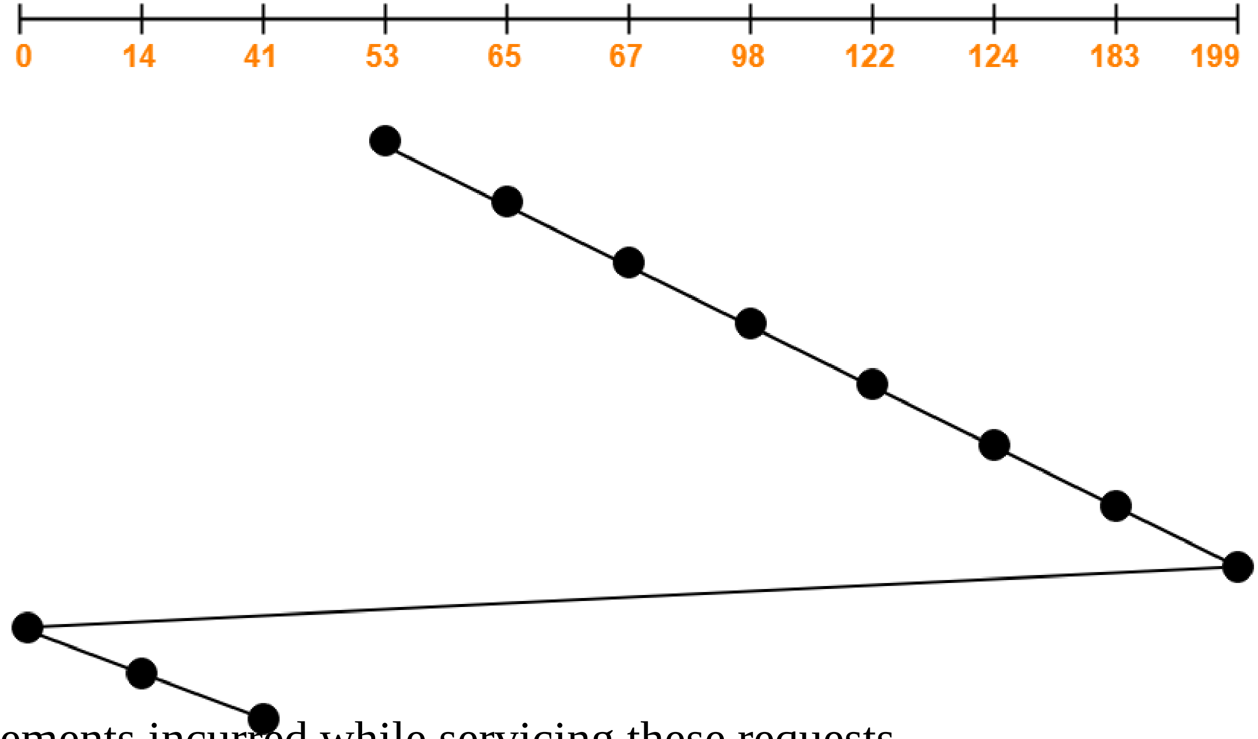
Advantages:

- The waiting time for the cylinders just visited by the head is reduced as compared to the SCAN Algorithm.
- It provides uniform waiting time.
- It provides better response time.

Disadvantages:

- It causes more seek movements as compared to SCAN Algorithm.
- It causes the head to move till the end of the disk even if there are no requests to be serviced.

Q. Suppose that a disk drive has the cylinder numbered from 0 to 199. The head is currently at cylinder number 53 moving towards larger cylinder numbers on its servicing pass. The queue for services of cylinder is as 98, 183, 41, 122, 14, 124, 65 and 67. What is the total head movement in each of the following disk algorithm to satisfy the requests?



Total head movements incurred while servicing these requests
= (65 – 53) + (67 – 65) + (98 – 67) + (122 – 98) + (124 – 122) + (183 – 124) + (199 –183)
+ (199 – 0) + (14 – 0) + (41 – 14)
= 12 + 2 + 31 + 24 + 2 + 59 + 16 + 199 + 14 + 27
= 386

LOOK Scheduling

- LOOK Algorithm is an improved version of the **SCAN Algorithm.**
- Head starts from the first request at one end of the disk and moves towards the last request at the other end servicing all the requests in between.
- After reaching the last request at the other end, head reverses its direction.
- It then returns to the first request at the starting end servicing all the requests in between.
- The same process repeats.

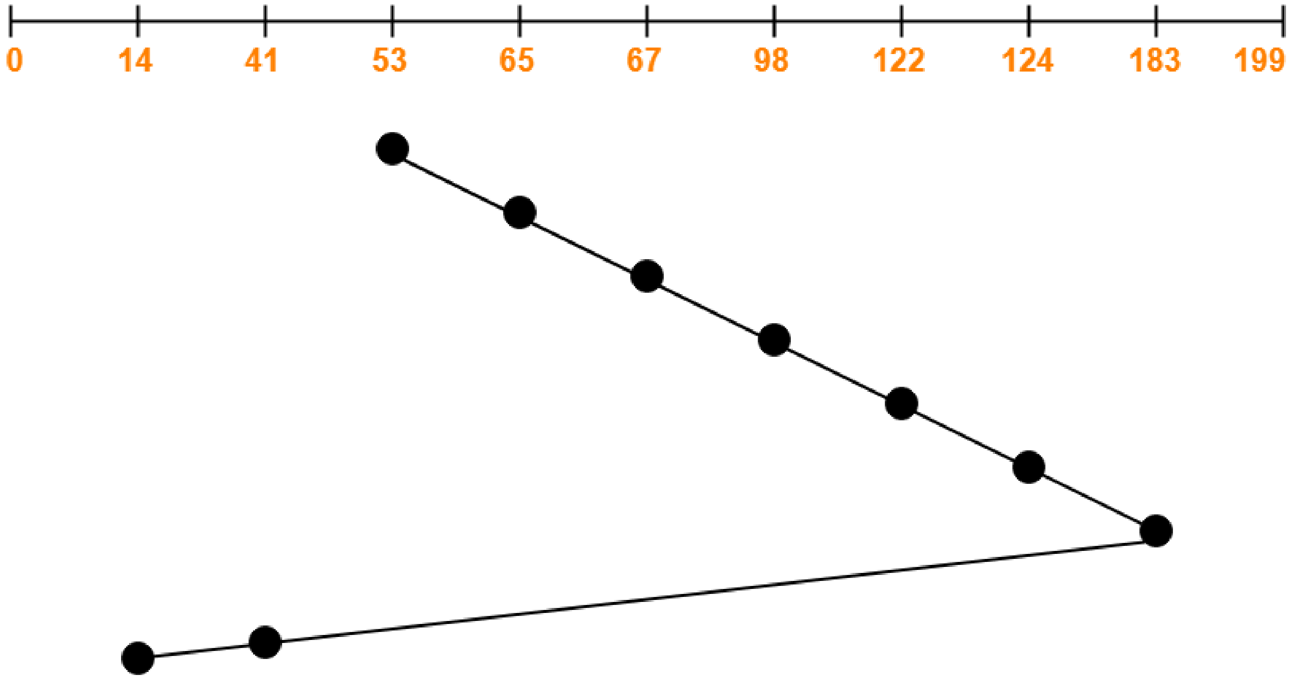
Advantages:

- It does not causes the head to move till the ends of the disk when there are no requests to be serviced.
- It provides better performance as compared to SCAN Algorithm.
- It does not lead to starvation.
- It provides low variance in response time and waiting time.

Disadvantages:

- There is an overhead of finding the end requests.
- It causes long waiting time for the cylinders just visited by the head.

Q. Consider a disk queue with requests for I/O to blocks on cylinders 98, 183, 41, 122, 14, 124, 65, 67. The head is initially at cylinder number 53 moving towards larger cylinder numbers on its servicing pass. The cylinders are numbered from 0 to 199.



Total head movements incurred while servicing these requests

= (183 – 53) + (183 – 14)

= 130 + 169

= 299

C-LOOK Scheduling

- Circular-LOOK Algorithm is an improved version of the **LOOK Algorithm.**
- Head starts from the first request at one end of the disk and moves towards the last request at the other end servicing all the requests in between.
- After reaching the last request at the other end, head reverses its direction.
- It then returns to the first request at the starting end without servicing any request in between.
- The same process repeats.

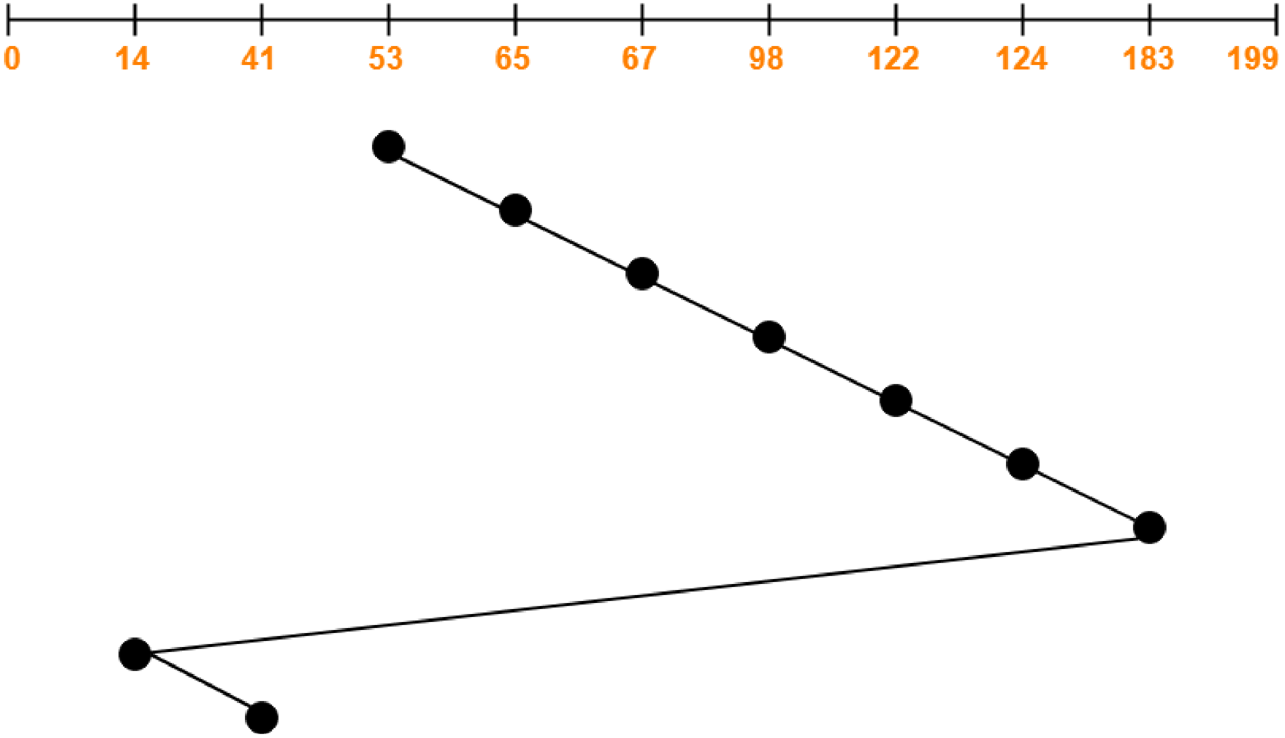
Advantages:

- It does not causes the head to move till the ends of the disk when there are no requests to be serviced.
- It reduces the waiting time for the cylinders just visited by the head.
- It provides better performance as compared to LOOK Algorithm.
- It does not lead to starvation.
- It provides low variance in response time and waiting time.

Disadvantages:

- There is an overhead of finding the end requests.

Q. Consider a disk queue with requests for I/O to blocks on cylinders 98, 183, 41, 122, 14, 124, 65, 67. The head is initially at cylinder number 53 moving towards larger cylinder numbers on its servicing pass. The cylinders are numbered from 0 to 199.



Total head movements incurred while servicing these requests
= (183 – 53) + (183 – 14) + (41 – 14)
= 130 + 169 + 27
= 326