Input/output Systems

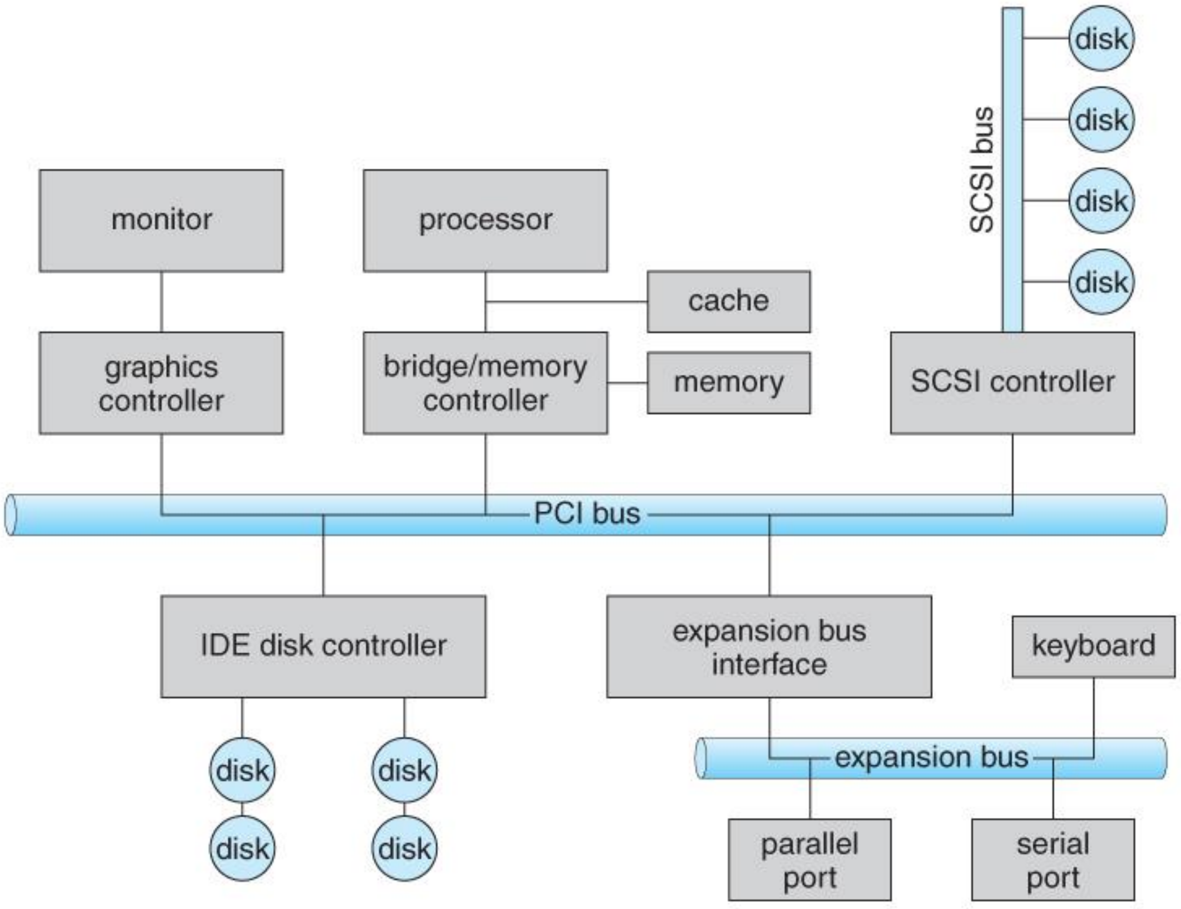
Computers are based on the fundamental idea that every input results in an output. For example, if you are running a word processor program and type a sentence on your keyboard, the text will appear on the screen. The keyboard is an input device and the screen is an output device. You might also print the text using a printer, which is another output device. The computer's CPU handles all the I/O operations, sending the data it receives to the correct path. The path may be to the video card, to the hard drive, or to the RAM, just to name a few.

I/O Hardware

- I/O devices can be roughly categorized as storage, communications, user-interface, and other
- Devices communicate with the computer via signals sent over wires or through the air.
- Devices connect with the computer via ports, e.g. a serial or parallel port.
- A common set of wires connecting multiple devices is termed a bus.
- Buses include rigid protocols for the types of messages that can be sent across the bus and the procedures for resolving contention issues.

In the figure below:

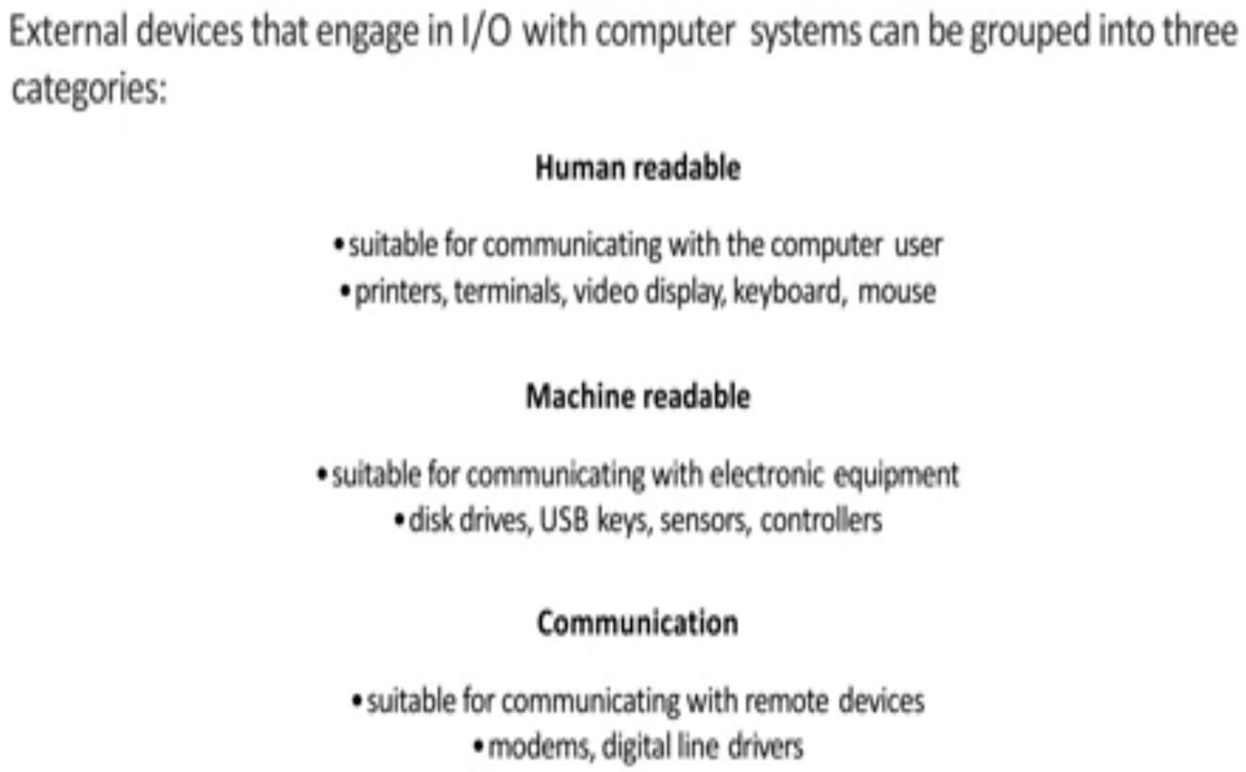
1. The PCI bus connects high-speed high-bandwidth devices to the memory subsystem (and the CPU)
2. The expansion bus connects slower low-bandwidth devices, which typically deliver data one character at a time (with buffering)
3. The SCSI bus connects a number of SCSI devices to a common SCSI controller.
4. A daisy-chain bus , is when a string of devices is connected to each other like beads on a chain, and only one of the devices is directly connected to the host.



One of the important jobs of an Operating System is to manage various I/O devices including mouse, keyboards, touch pad, disk drives, display adapters, USB devices, Bit-mapped screen, LED, Analog-to-digital converter, On/off switch, network connections, audio I/O, printers etc.

An I/O system is required to take an application I/O request and send it to the physical device, then take whatever response comes back from the device and send it to the application.

Input/Output devices



External devices that engage in I/O with computer systems can be grouped into three categories:

Human readable

- suitable for communicating with the computer user
- printers, terminals, video display, keyboard, mouse

Machine readable

- suitable for communicating with electronic equipment
- disk drives, USB keys, sensors, controllers

Communication

- suitable for communicating with remote devices
- modems, digital line drivers

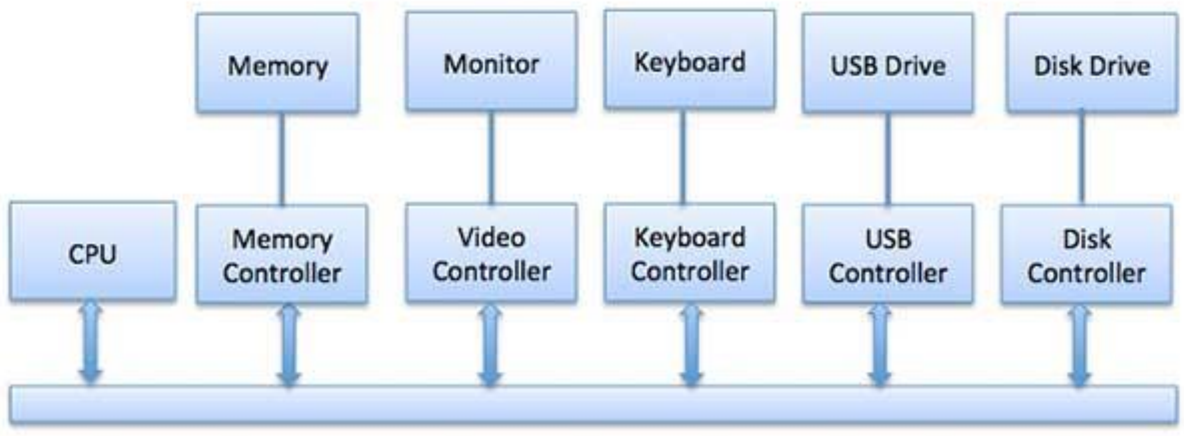
Device Controllers

Device drivers are software modules that can be plugged into an OS to handle a particular device. Operating System takes help from device drivers to handle all I/O devices.

The Device Controller works like an interface between a device and a device driver. I/O units (Keyboard, mouse, printer, etc.) typically consist of a mechanical component and an electronic component where electronic component is called the device controller.

There is always a device controller and a device driver for each device to communicate with the Operating Systems. A device controller may be able to handle multiple devices. As an interface its main task is to convert serial bit stream to block of bytes, perform error correction as necessary.

Any device connected to the computer is connected by a plug and socket, and the socket is connected to a device controller. Following is a model for connecting the CPU, memory, controllers, and I/O devices where CPU and device controllers all use a common bus for communication.



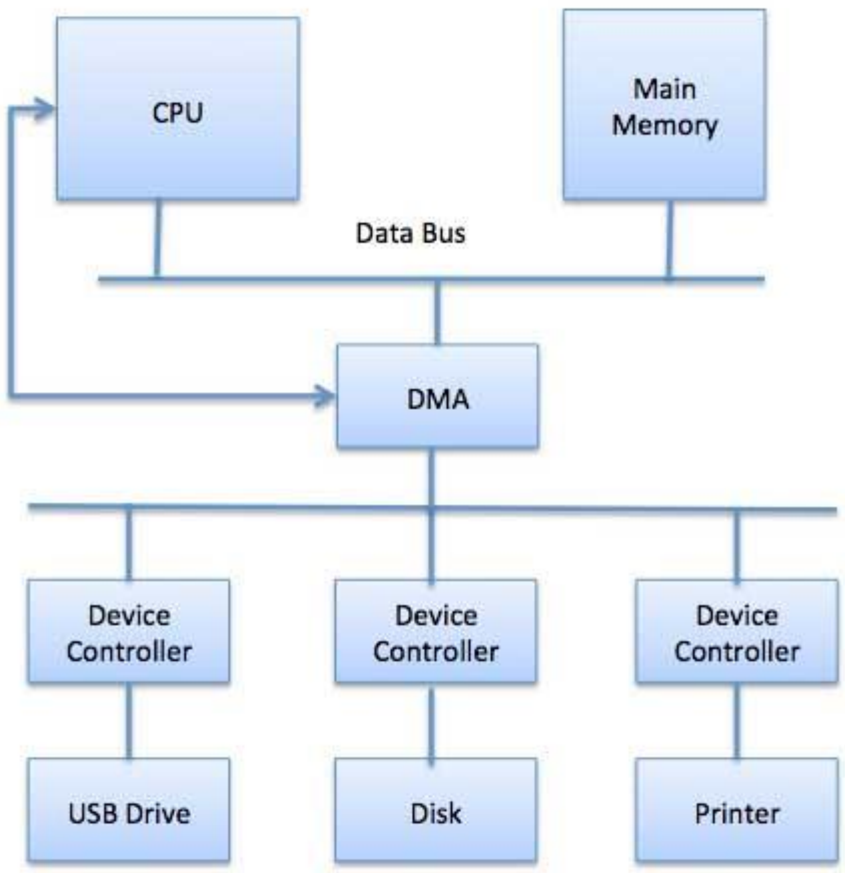
Communication to I/O Devices

The CPU must have a way to pass information to and from an I/O device. There are three approaches available to communicate with the CPU and Device.

- Special Instruction I/O
- Memory-mapped I/O
- Direct memory access (DMA)

Direct Memory Access (DMA)

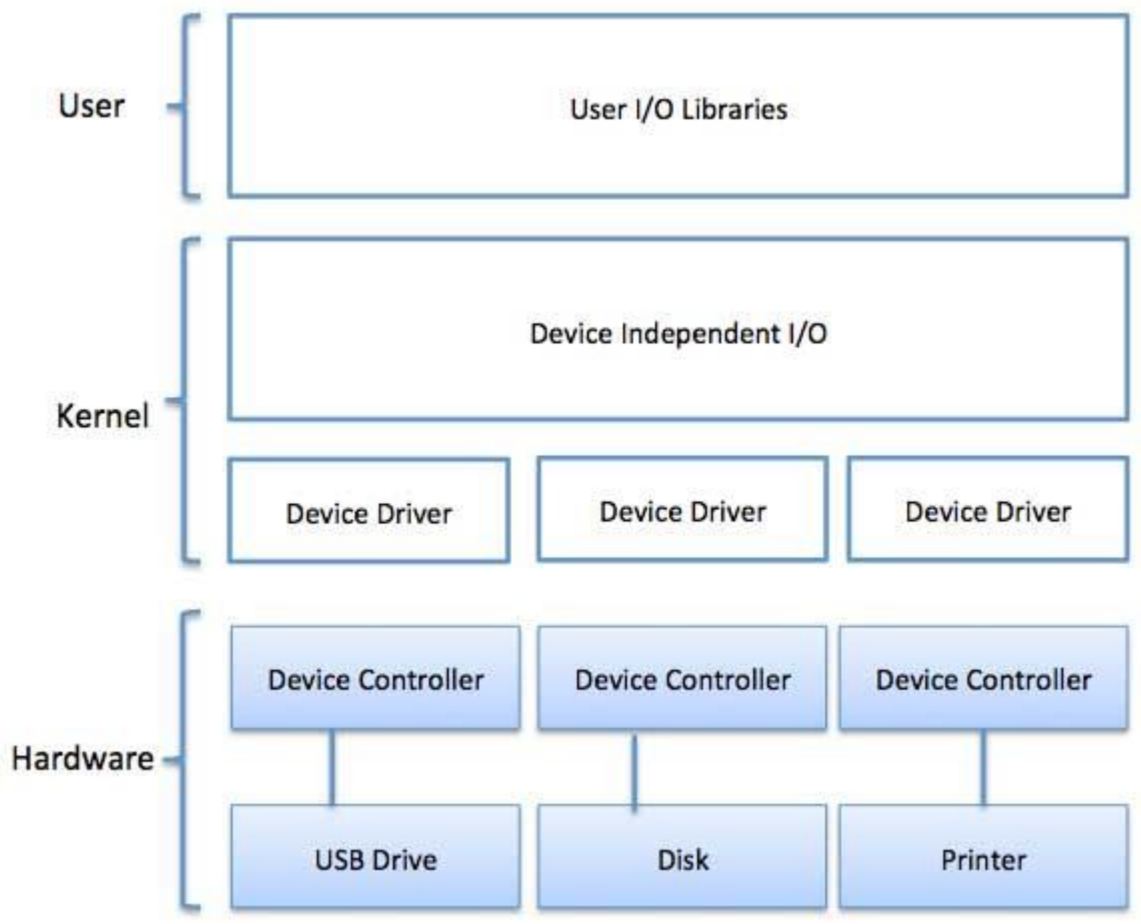
- Slow devices like keyboards will generate an interrupt to the main CPU after each byte is transferred. If a fast device such as a disk generated an interrupt for each byte, the operating system would spend most of its time handling these interrupts. So a typical computer uses direct memory access (DMA) hardware to reduce this overhead.
- Direct Memory Access (DMA) means CPU grants I/O module authority to read from or write to memory without involvement. DMA module itself controls exchange of data between main memory and the I/O device. CPU is only involved at the beginning and end of the transfer and interrupted only after entire block has been transferred.
- Direct Memory Access needs a special hardware called DMA controller (DMAC) that manages the data transfers and arbitrates access to the system bus. The controllers are programmed with source and destination pointers (where to read/write the data), counters to track the number of transferred bytes, and settings, which includes I/O and memory types, interrupts and states for the CPU cycles.



I/O software is often organized in the following layers −

- **User Level Libraries** − This provides simple interface to the user program to perform input and output. For example, **stdio** is a library provided by C and C++ programming languages.
- **Kernel Level Modules** − This provides device driver to interact with the device controller and device independent I/O modules used by the device drivers.
- **Hardware** − This layer includes actual hardware and hardware controller which interact with the device drivers and makes hardware alive.

A key concept in the design of I/O software is that it should be device independent where it should be possible to write programs that can access any I/O device without having to specify the device in advance. For example, a program that reads a file as input should be able to read a file on a floppy disk, on a hard disk, or on a CD-ROM, without having to modify the program for each different device.



Device Drivers

Device drivers are software modules that can be plugged into an OS to handle a particular device. Operating System takes help from device drivers to handle all I/O devices. Device drivers encapsulate device-dependent code and implement a standard interface in such a way that code contains device-specific register reads/writes. Device driver, is generally written by the device's manufacturer and delivered along with the device on a CD-ROM.

A device driver performs the following jobs −

- To accept request from the device independent software above to it.
- Interact with the device controller to take and give I/O and perform required error handling
- Making sure that the request is executed successfully

How a device driver handles a request is as follows: Suppose a request comes to read a block N. If the driver is idle at the time a request arrives, it starts carrying out the request immediately. Otherwise, if the driver is already busy with some other request, it places the new request in the queue of pending requests.

Interrupt handlers

An interrupt handler, also known as an interrupt service routine or ISR, is a piece of software or more specifically a callback function in an operating system or more specifically in a device driver, whose execution is triggered by the reception of an interrupt.

When the interrupt happens, the interrupt procedure does whatever it has to in order to handle the interrupt, updates data structures and wakes up process that was waiting for an interrupt to happen.

The interrupt mechanism accepts an address ─ a number that selects a specific interrupt handling routine/function from a small set. In most architectures, this address is an offset stored in a table called the interrupt vector table. This vector contains the memory addresses of specialized interrupt handlers.

Disk Scheduling

Disk scheduling is done by operating systems to schedule I/O requests arriving for the disk. Disk scheduling is also known as I/O scheduling.

Disk scheduling is important because:

- Multiple I/O requests may arrive by different processes and only one I/O request can be served at a time by the disk controller. Thus other I/O requests need to wait in the waiting queue and need to be scheduled.
- Two or more request may be far from each other so can result in greater disk arm movement.
- Hard drives are one of the slowest parts of the computer system and thus need to be accessed in an efficient manner.

Important terms in Disk Scheduling are:

- **Seek Time:** Seek time is the time taken to locate the disk arm to a specified track where the data is to be read or write. So the disk scheduling algorithm that gives minimum average seek time is better.
- **Rotational Latency:** Rotational Latency is the time taken by the desired sector of disk to rotate into a position so that it can access the read/write heads. So the disk scheduling algorithm that gives minimum rotational latency is better.
- **Transfer Time:** Transfer time is the time to transfer the data. It depends on the rotating speed of the disk and number of bytes to be transferred.
- **Disk Access Time:** Disk Access Time is:

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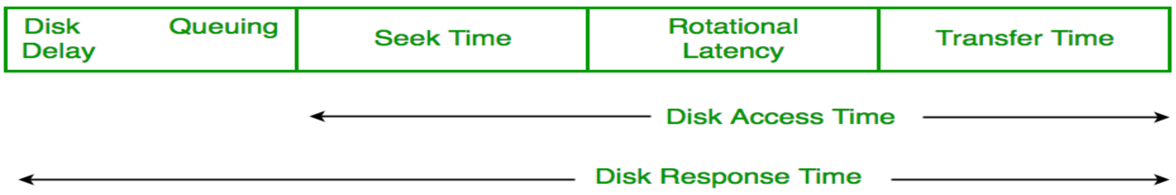
Disk Access Time = Seek Time +
                   Rotational Latency +
                   Transfer Time
```

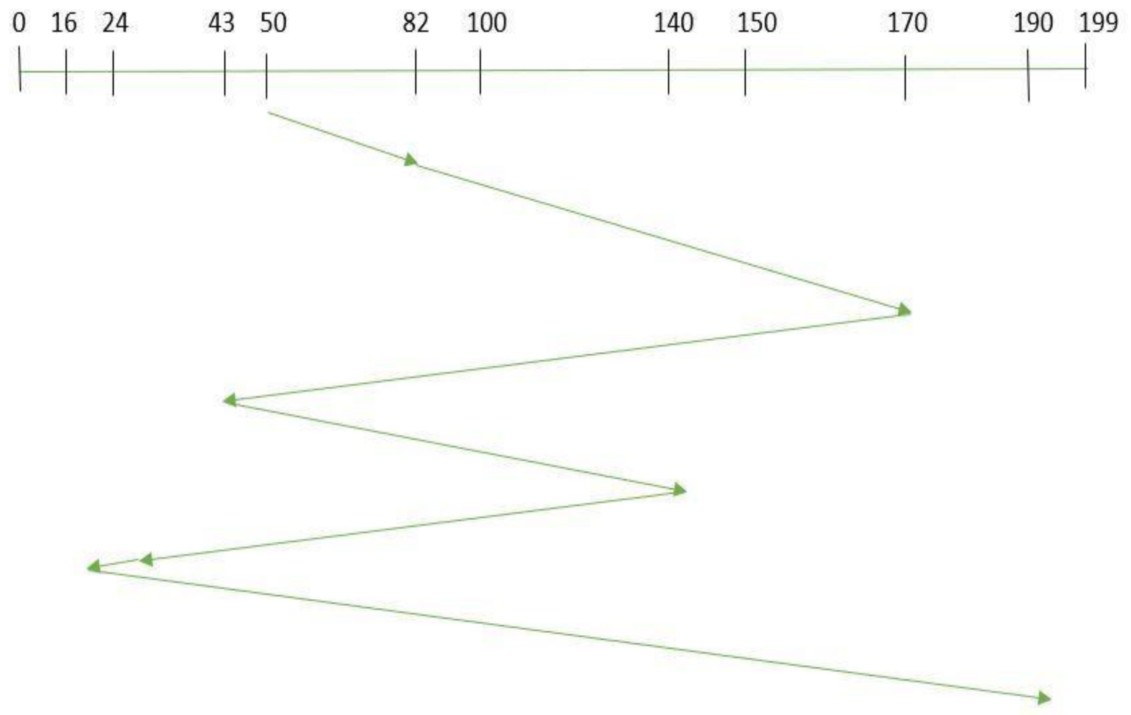


- **Disk Response Time:** Response Time is the average of time spent by a request waiting to perform its I/O operation. *Average Response time* is the response time of the all requests. *Variance Response Time* is measure of how individual request are serviced with respect to average response time. So the disk scheduling algorithm that gives minimum variance response time is better.

Disk Scheduling Algorithms

1. **FCFS:** FCFS is the simplest of all the Disk Scheduling Algorithms. In FCFS, the requests are addressed in the order they arrive in the disk queue. Let us understand this with the help of an example.

Example:
Suppose the order of request is- (82,170,43,140,24,16,190)
And current position of Read/Write head is : 50



So, total seek time:
=(82-50)+(170-82)+(170-43)+(140-43)+(140-24)+(24-16)+(190-16)
=642

Advantages of FCFS:

- Every request gets a fair chance
- No indefinite postponement

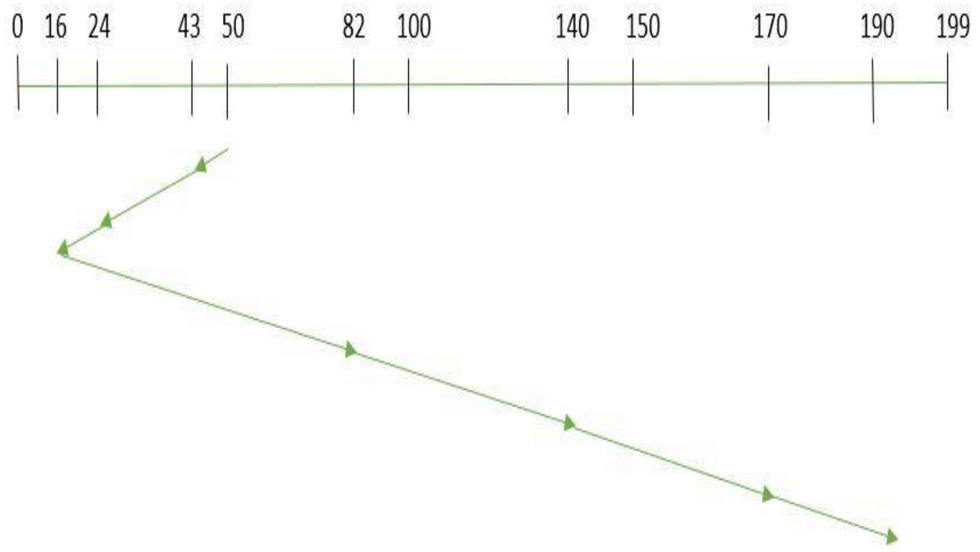
Disadvantages of FCFS:

- Does not try to optimize seek time
- May not provide the best possible service

2. **SSTF:** In SSTF (Shortest Seek Time First), requests having shortest seek time are executed first. So, the seek time of every request is calculated in advance in the queue and then they are scheduled according to their calculated seek time. As a result, the request near the disk arm will get executed first. SSTF is certainly an improvement over FCFS as it decreases the average response time and increases the throughput of system.Let us understand this with the help of an example.

   Example:

   Suppose the order of request is- (82,170,43,140,24,16,190)
   And current position of Read/Write head is : 50



So, total seek time:

=(50-43)+(43-24)+(24-16)+(82-16)+(140-82)+(170-40)+(190-170)
=208

Advantages of SSTF:

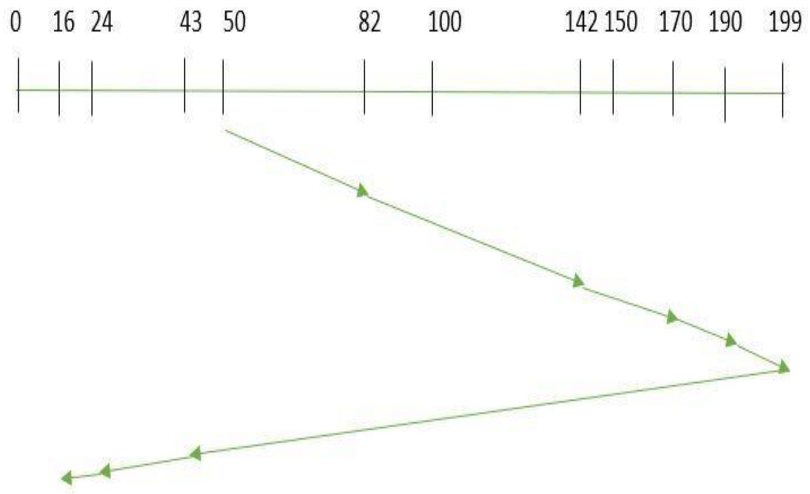
- Average Response Time decreases
- Throughput increases

Disadvantages of SSTF:

- Overhead to calculate seek time in advance
- Can cause Starvation for a request if it has higher seek time as compared to incoming requests
- High variance of response time as SSTF favours only some requests

3. **SCAN:** In SCAN algorithm the disk arm moves into a particular direction and services the requests coming in its path and after reaching the end of disk, it reverses its direction and again services the request arriving in its path. So, this algorithm works as an elevator and hence also known as **elevator algorithm.** As a result, the requests at the midrange are serviced more and those arriving behind the disk arm will have to wait.

   Example:
   Suppose the requests to be addressed are-82,170,43,140,24,16,190. And the Read/Write arm is at 50, and it is also given that the disk arm should move **"towards the larger value".**



Therefore, the seek time is calculated as:

=(199-50)+(199-16)
=332

Advantages of SCAN:

- High throughput
- Low variance of response time
- Average response time

Disadvantages of SCAN:

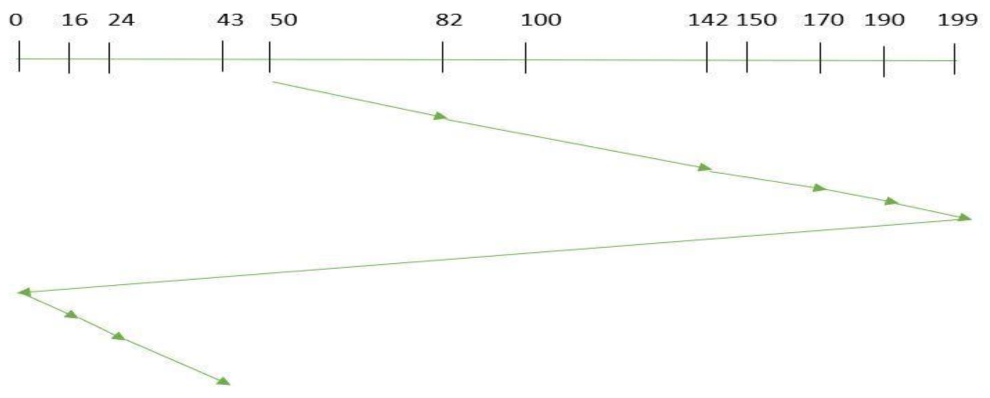
- Long waiting time for requests for locations just visited by disk arm

4. **CSCAN**: In SCAN algorithm, the disk arm again scans the path that has been scanned, after reversing its direction. So, it may be possible that too many requests are waiting at the other end or there may be zero or few requests pending at the scanned area.

These situations are avoided in *CSCAN* algorithm in which the disk arm instead of reversing its direction goes to the other end of the disk and starts servicing the requests from there. So, the disk arm moves in a circular fashion and this algorithm is also similar to SCAN algorithm and hence it is known as C-SCAN (Circular SCAN).

Example:

Suppose the requests to be addressed are-82,170,43,140,24,16,190. And the Read/Write arm is at 50, and it is also given that the disk arm should move **"towards the larger value".**



Seek time is calculated as:

=(199-50)+(199-0)+(43-0)
=391

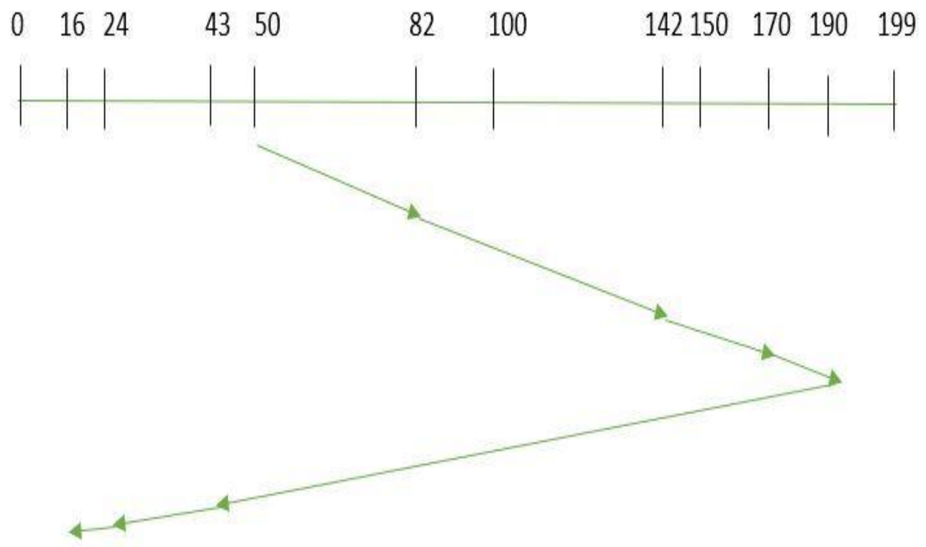
Advantages of CSCAN:

- Provides more uniform wait time compared to SCAN

5. **LOOK:** It is similar to the SCAN disk scheduling algorithm except for the difference that the disk arm in spite of going to the end of the disk goes only to the last request to be serviced in front of the head and then reverses its direction from there only. Thus it prevents the extra delay which occurred due to unnecessary traversal to the end of the disk.

   Example:

   Suppose the requests to be addressed are-82,170,43,140,24,16,190. And the Read/Write arm is at 50, and it is also given that the disk arm should move **"towards the larger value".**



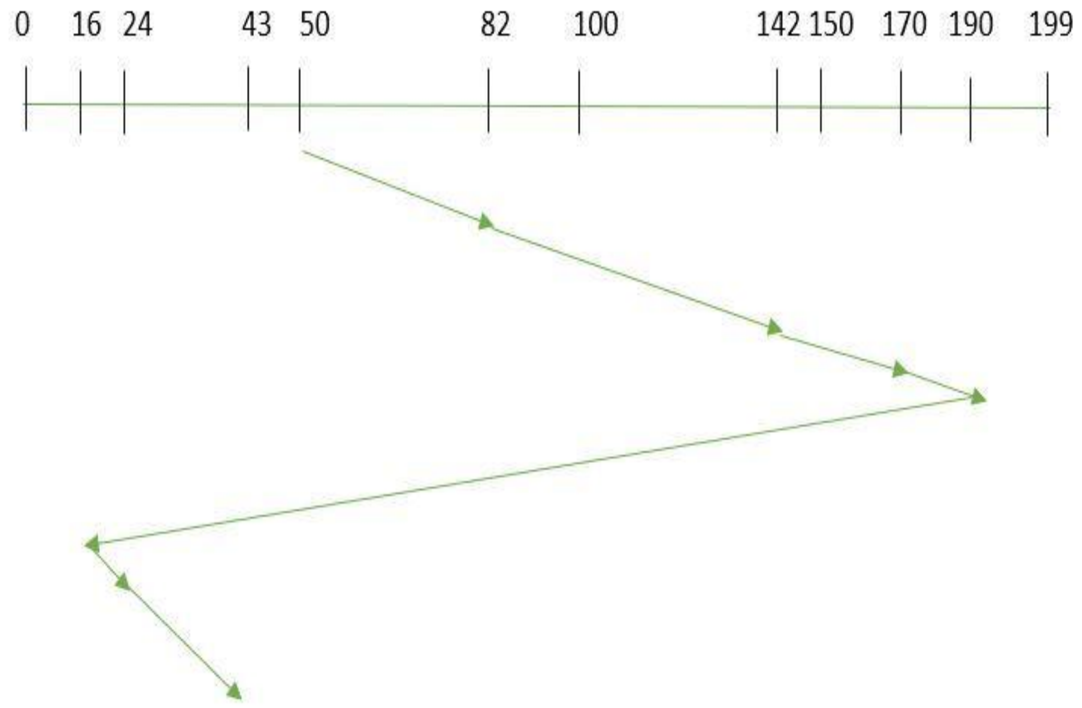
So, the seek time is calculated as:

=(190-50)+(190-16)
=314

6. **CLOOK:** As LOOK is similar to SCAN algorithm, in similar way, CLOOK is similar to CSCAN disk scheduling algorithm. In CLOOK, the disk arm in spite of going to the end goes only to the last request to be serviced in front of the head and then from there goes to the other end's last request. Thus, it also prevents the extra delay which occurred due to unnecessary traversal to the end of the disk.

   Example:

   Suppose the requests to be addressed are-82,170,43,140,24,16,190. And the Read/Write arm is at 50, and it is also given that the disk arm should move **"towards the larger value"**



So, the seek time is calculated as:

=(190-50)+(190-16)+(43-16)
=341