Chapter 12: Mass-Storage Systems

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- Overview of Mass Storage Structure
- Disk Structure
- Disk Attachment
- Disk Scheduling
- Disk Management
- Swap-Space Management
- RAID Structure
- Disk Attachment
- Stable-Storage Implementation
- Tertiary Storage Devices
- Operating System Issues
- Performance Issues

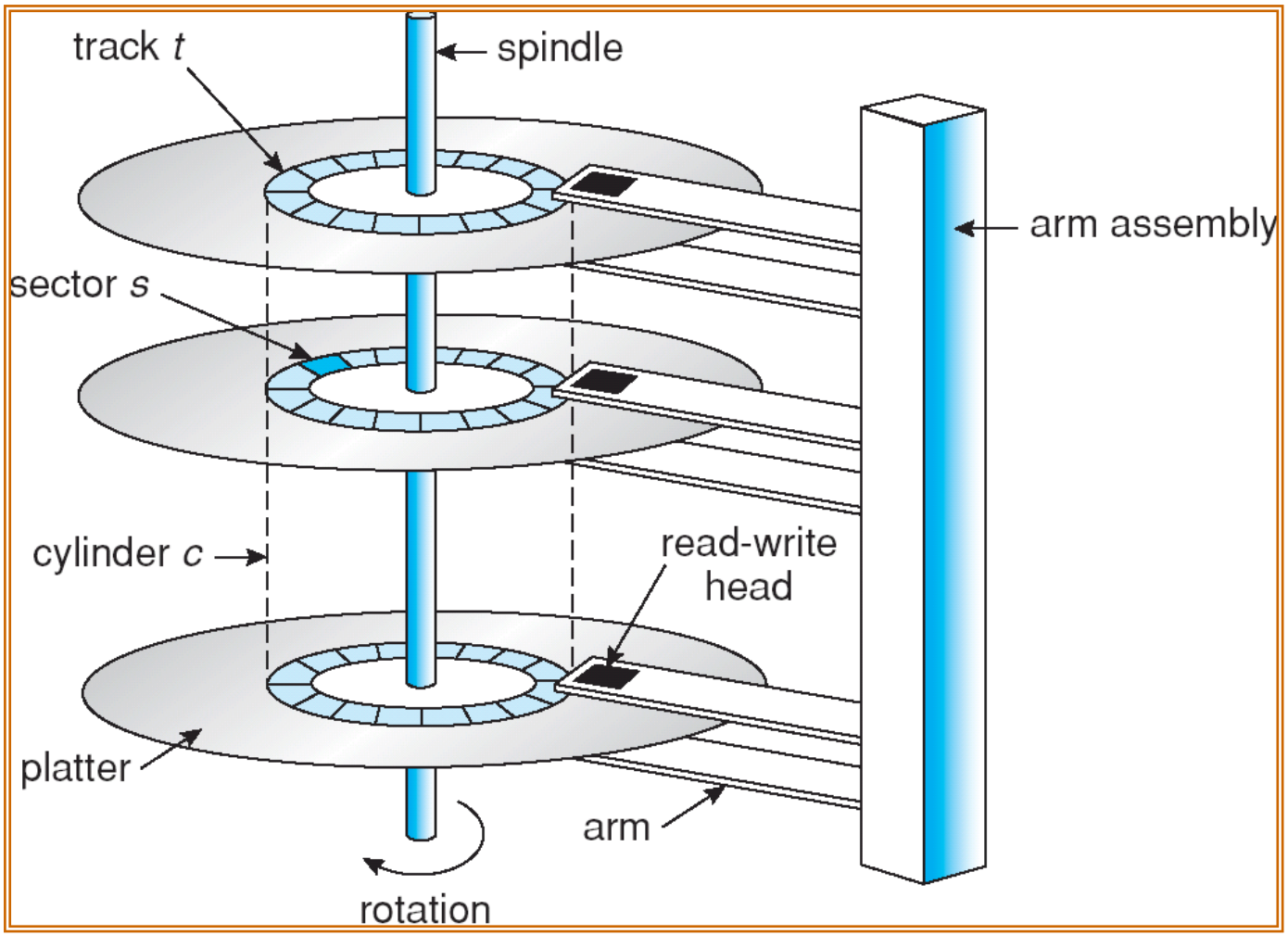
Objectives

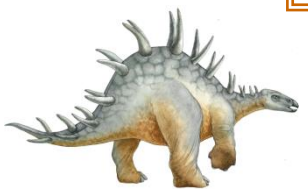
- Describe the physical structure of secondary and tertiary storage devices and the resulting effects on the uses of the devices
- Explain the performance characteristics of mass-storage devices
- Discuss operating-system services provided for mass storage, including RAID and HSM

Overview of Mass Storage Structure

- Magnetic disks provide bulk of secondary storage of modern computers
  - Drives rotate at 60 to 200 times per second
  - **Transfer rate** is rate at which data flow between drive and computer
  - **Positioning time** (**random-access time**) is time to move disk arm to desired cylinder (**seek time**) and time for desired sector to rotate under the disk head (**rotational latency**)
  - **Head crash** results from disk head making contact with the disk surface
    - That's bad
- Disks can be **removable**
- Drive attached to computer via **I/O bus**
  - Busses vary, including **EIDE, ATA, SATA, USB, Fiber Channel, SCSI**
  - **Host controller** in computer uses bus to talk to **disk controller** built into drive or storage array

Moving-head Disk Mechanism





What's Inside A Disk Drive?

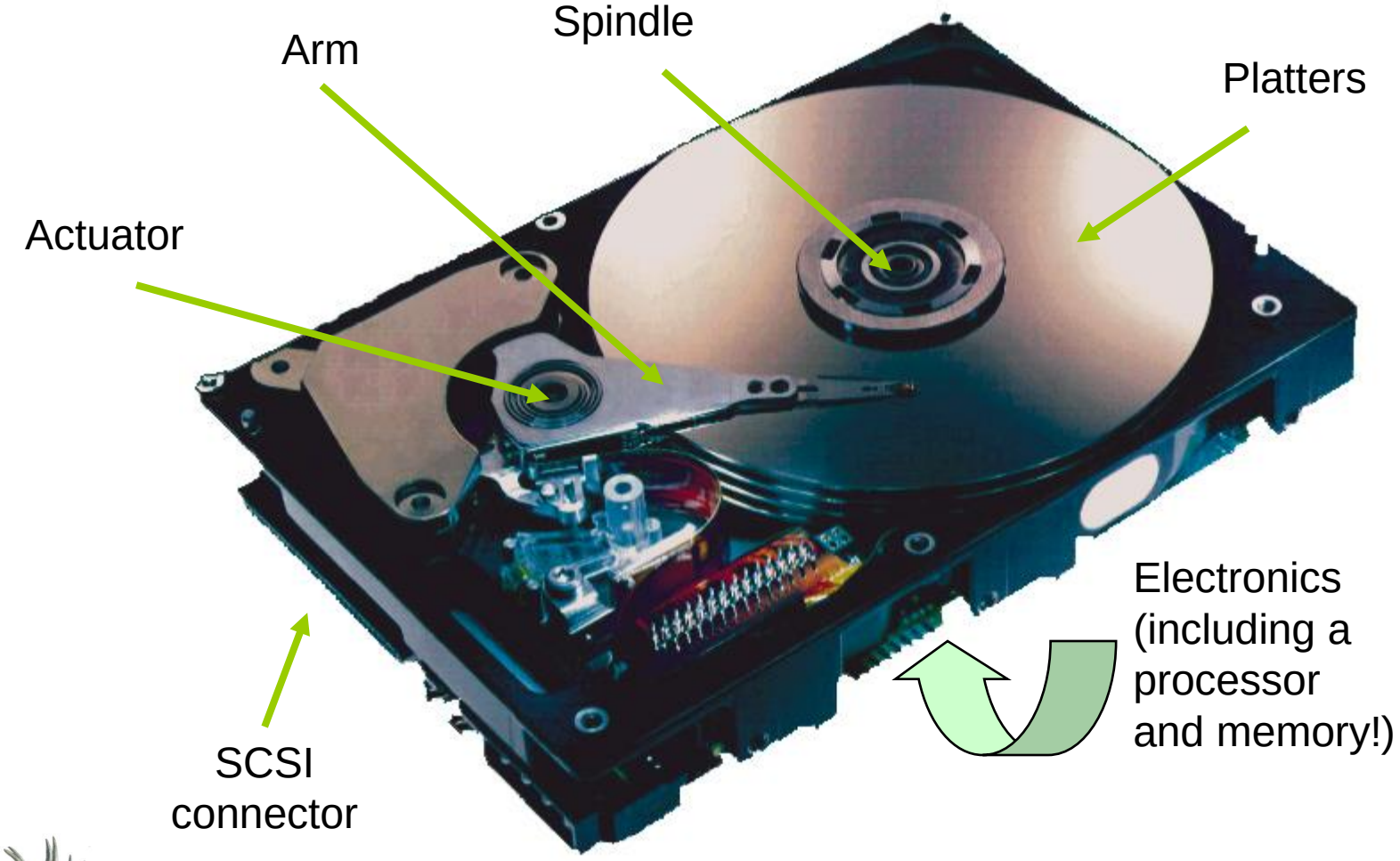
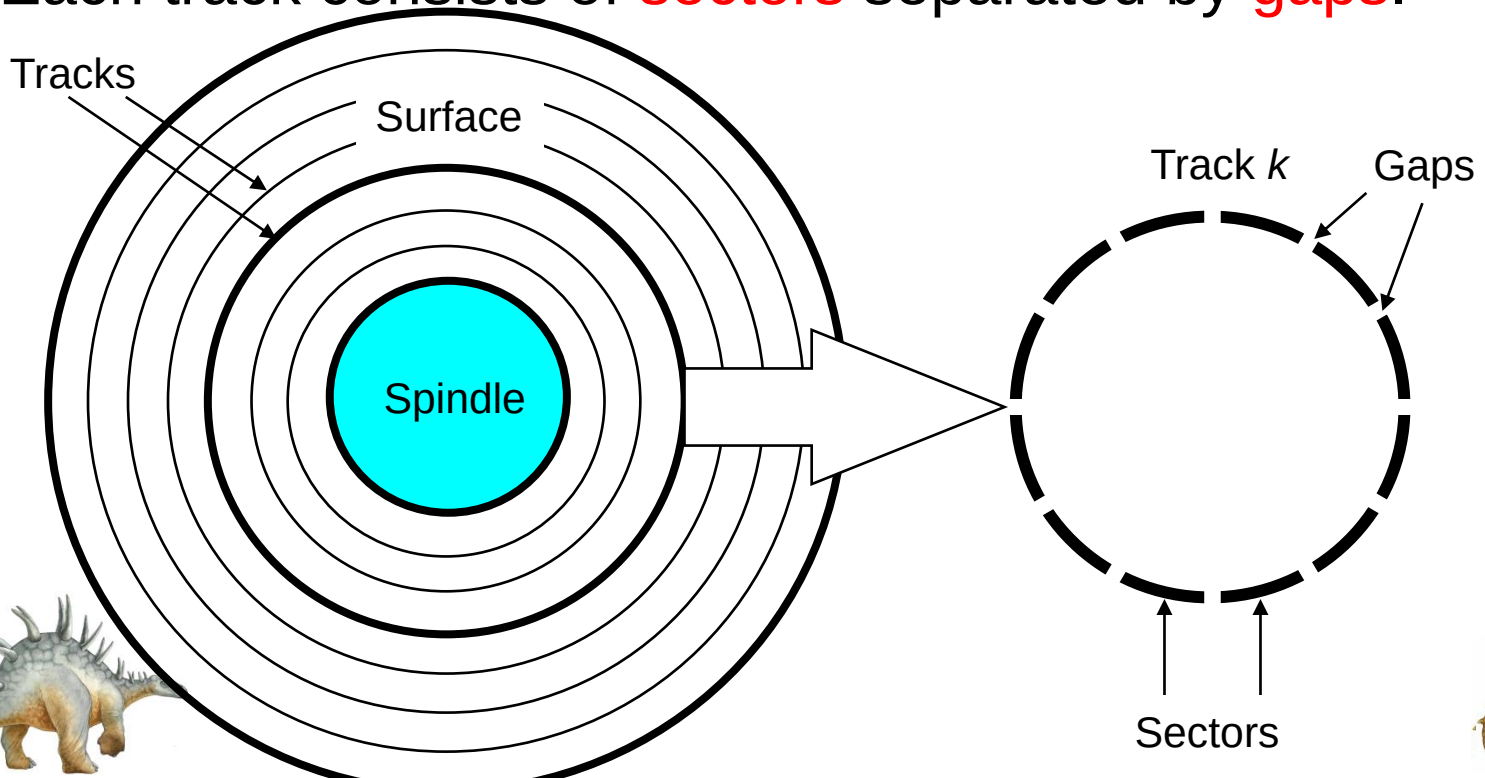


Image courtesy of Seagate Technology

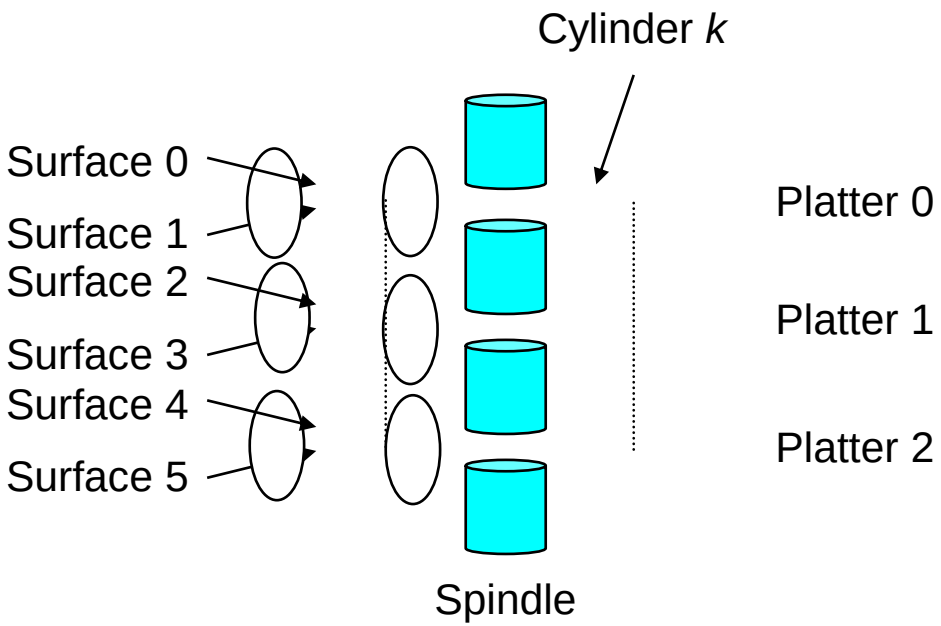
Disk Geometry

- Disks consist of platters, each with two surfaces.
- Each surface consists of concentric rings called tracks.
- Each track consists of sectors separated by gaps.



Disk Geometry (Muliple-Platter View)

- Aligned tracks form a cylinder.

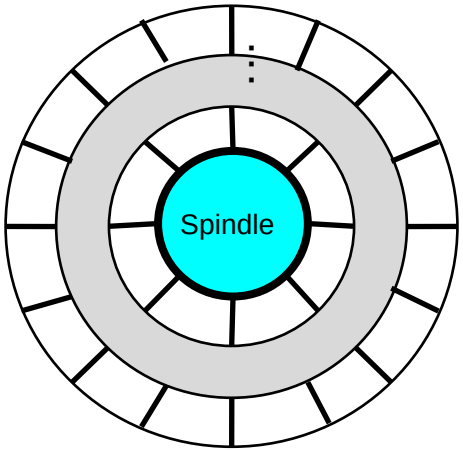


Disk Capacity

- **Capacity**: maximum number of bits that can be stored.
  - Vendors express capacity in units of gigabytes (GB), where
    1 GB = 10^9 Bytes.
- Capacity is determined by these technology factors:
  - **Recording density** (bits/in): number of bits that can be squeezed into a 1 inch segment of a track.
  - **Track density** (tracks/in): number of tracks that can be squeezed into a 1 inch radial segment.
  - **Areal density** (bits/in2): product of recording and track density.

Recording zones

- Modern disks partition tracks into disjoint subsets called recording zones
  - Each track in a zone has the same number of sectors, determined by the circumference of innermost track.
  - Each zone has a different number of sectors/track, outer zones have more sectors/track than inner zones.
  - So we use **average** number of sectors/track when computing capacity.



Computing Disk Capacity

Capacity = (# bytes/sector) x (avg. # sectors/track) x (# tracks/surface) x (# surfaces/platter) x (# platters/disk)

Example:

- 512 bytes/sector
- 300 sectors/track (on average)
- 20,000 tracks/surface
- 2 surfaces/platter
- 5 platters/disk

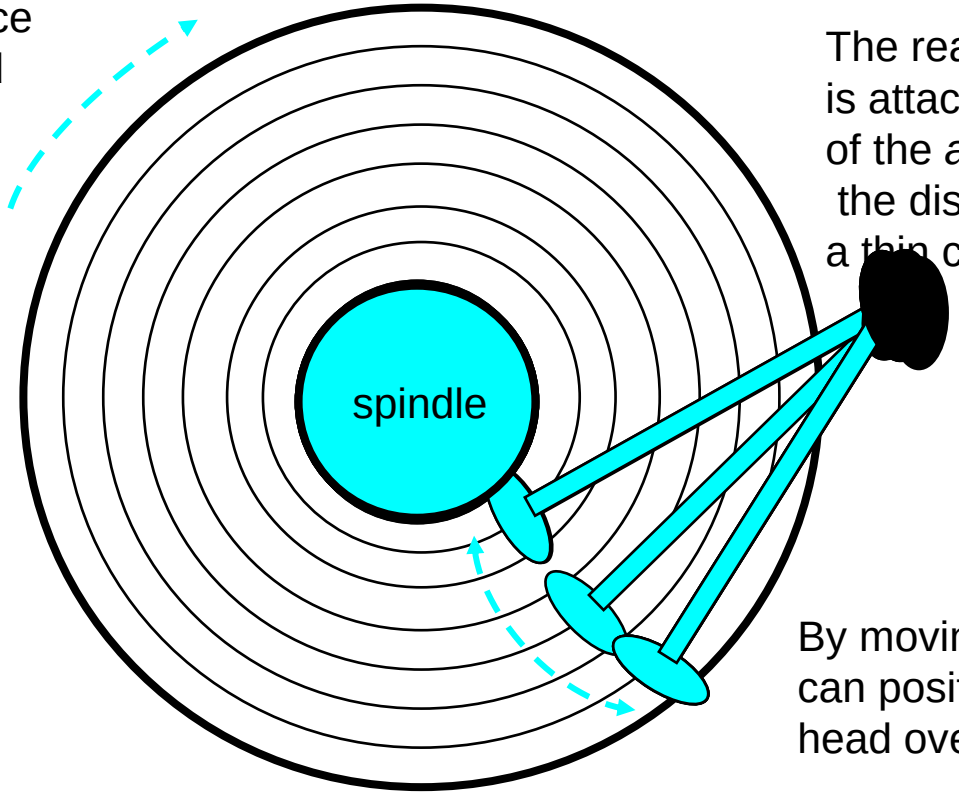
Capacity = 512 x 300 x 20000 x 2 x 5

= 30,720,000,000

= 30.72 GB

Disk Operation (Single-Platter View)

The disk surface spins at a fixed rotational rate



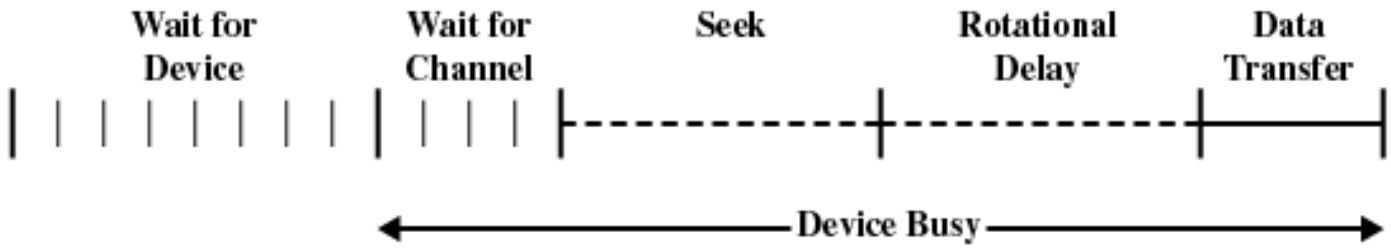
The read/write *head* is attached to the end of the *arm* and flies over the disk surface on a thin cushion of air.

By moving radially, the arm can position the read/write head over any track.

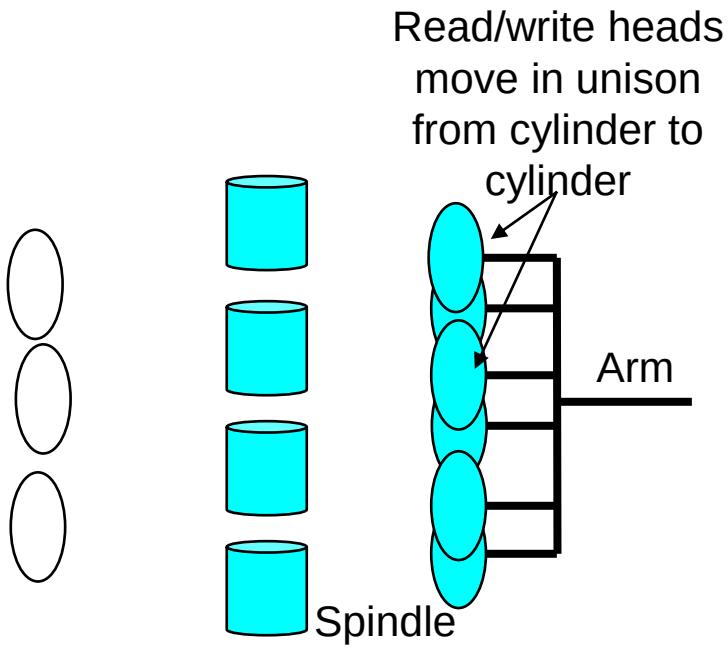
磁盘性能参数

为了读写，磁头必须定位于指定的磁道和该磁道中指定的扇区开始处

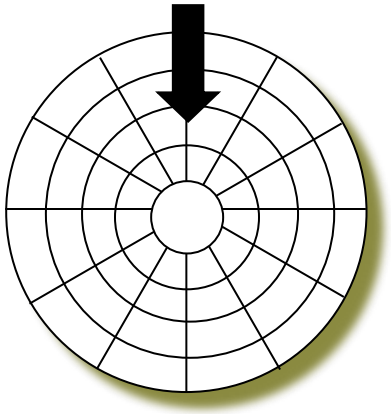
- **寻道时间**
  - 磁头定位到磁道所需要的时间；
- **旋转延迟**
  - 磁头到达扇区开始位置的时间；
- **传送时间**
  - 传送所需的时间；



Disk Operation (Multi-Platter View)

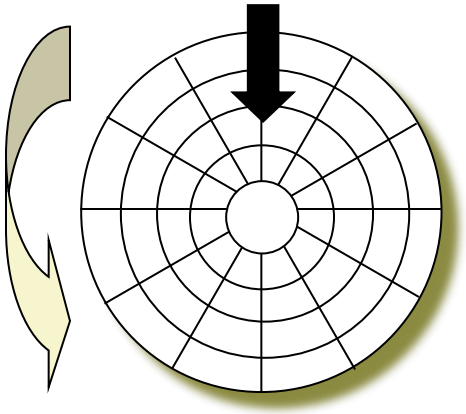


Disk Access



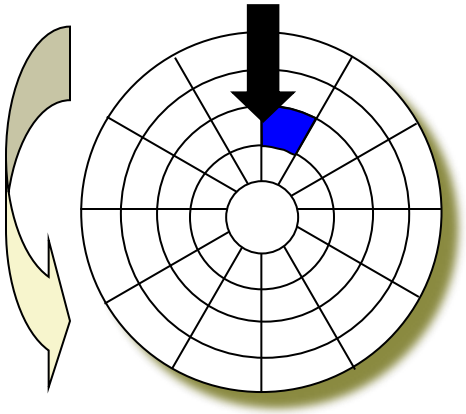
Head in position above a track

Disk Access



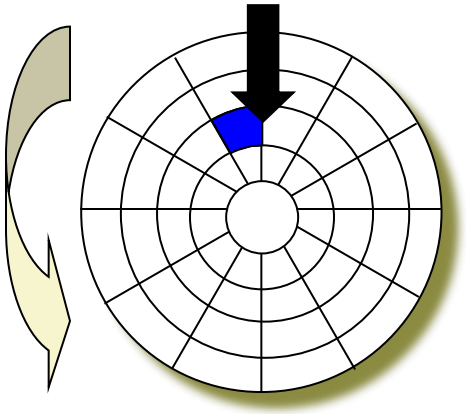
Rotation is counter-clockwise

Disk Access – Read



About to read blue sector

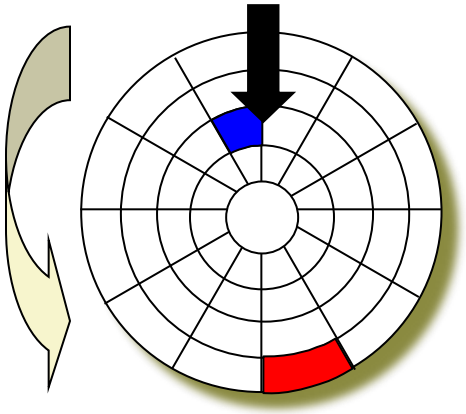
Disk Access – Read



After BLUE read

After reading blue sector

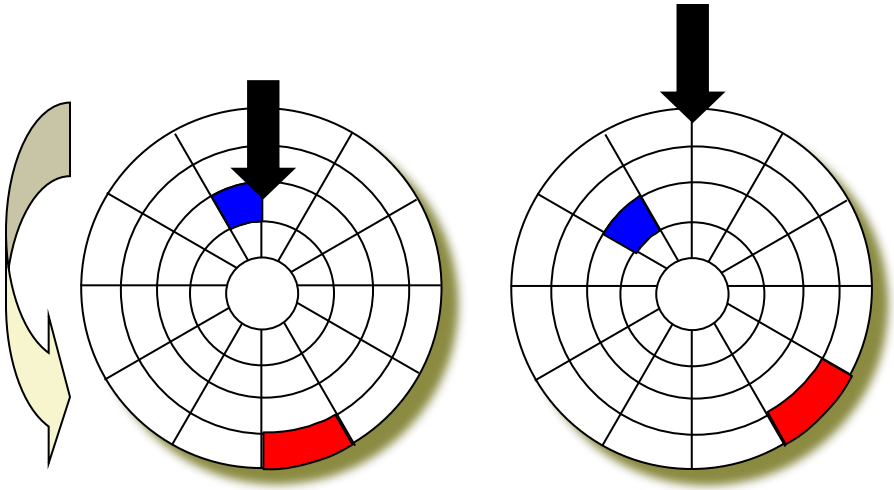
Disk Access – Read



After BLUE read

Red request scheduled next

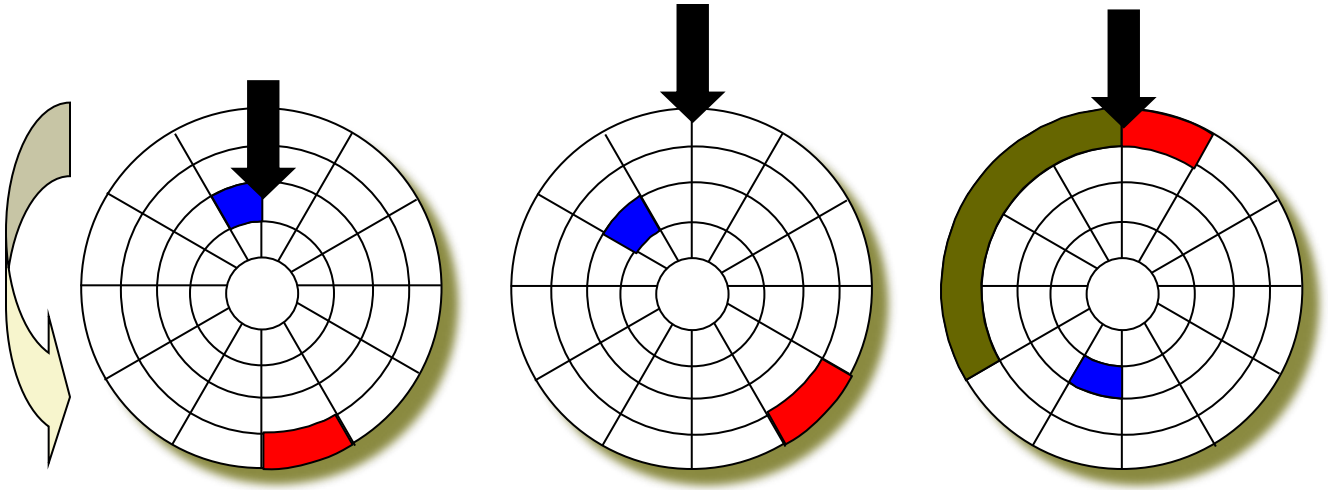
Disk Access – Seek



After BLUE read Seek for RED

Seek to red's track

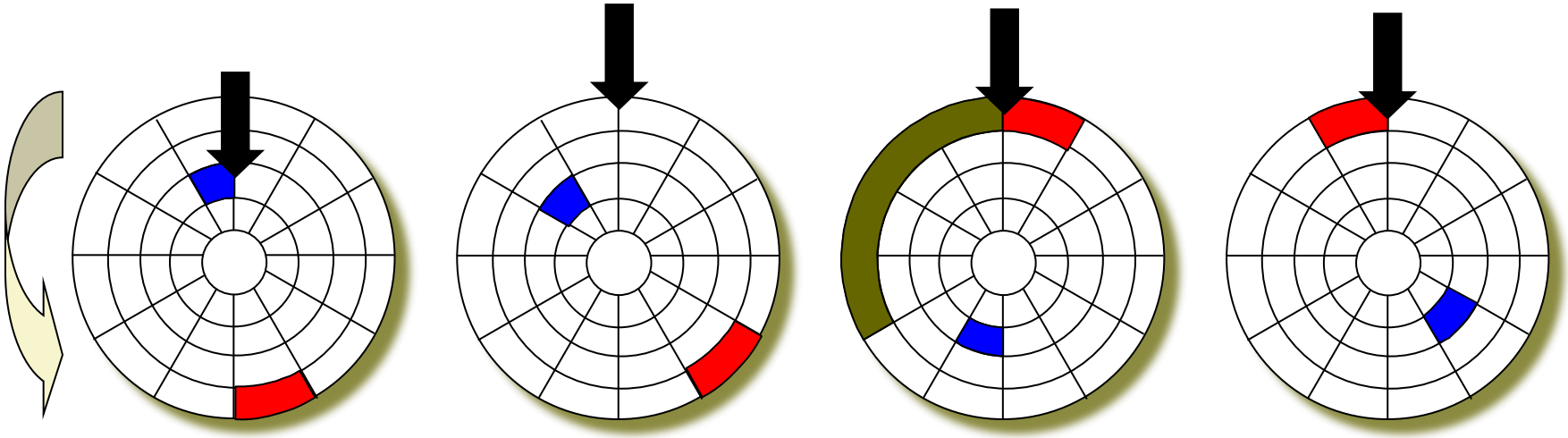
Disk Access – Rotational Latency



After BLUE read Seek for RED Rotational latency

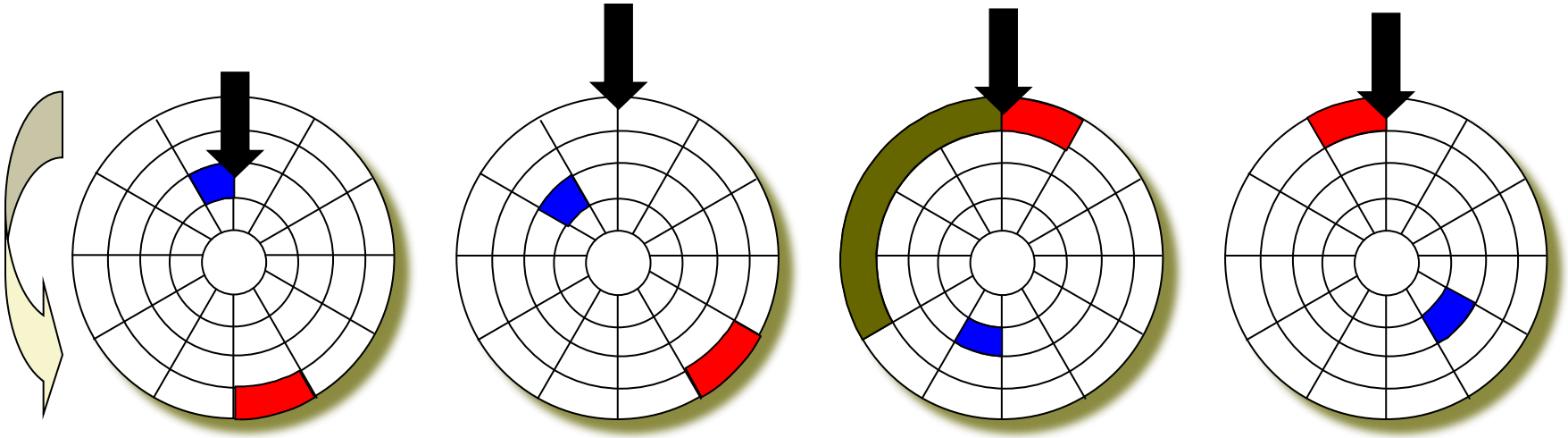
Wait for red sector to rotate around

Disk Access – Read



Complete read of red

Disk Access – Service Time Components



Disk Access Time

平均寻道时间为4ms,转速为7500r/m,每个磁道有500个扇区，读取2500个扇区

- **顺序访问**

  读第一个磁道4ms(平均寻址)+
  4ms(旋转延迟)+
  8ms(读500个扇区)=16ms

  总时间=16+4*（4+8）=64ms

- **随机访问**

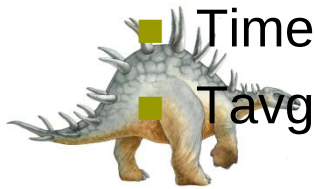
  读一个扇区4+4+0.016=8.016ms

  总时间=2500*8.016=20040ms

显然，磁盘读取扇区的顺序对I/O性能影响很大！

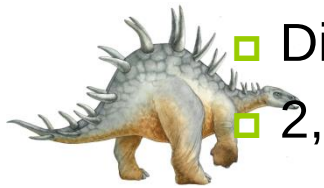
Disk Access Time

- Average time to access some target sector approximated by :
  - Taccess = Tavg seek + Tavg rotation + Tavg transfer
- **Seek time (Tavg seek)**
  - Time to position heads over cylinder containing target sector.
  - Typical Tavg seek is 3—9 ms
- **Rotational latency (Tavg rotation)**
  - Time waiting for first bit of target sector to pass under r/w head.
  - Tavg rotation = 1/2 x 1/RPMs x 60 sec/1 min
  - Typical Tavg rotation = 7200 RPMs
- **Transfer time (Tavg transfer)**
  - Time to read the bits in the target sector.
  - Tavg transfer = 1/RPM x 1/(avg # sectors/track) x 60 secs/1 min.



Disk Access Time Example

- **Given:**
  - Rotational rate = 7,200 RPM
  - Average seek time = 9 ms.
  - Avg # sectors/track = 400.
- **Derived:**
  - Tavg rotation = 1/2 x (60 secs/7200 RPM) x 1000 ms/sec = 4 ms.
  - Tavg transfer = 60/7200 RPM x 1/400 secs/track x 1000 ms/sec = 0.02 ms
  - Taccess = 9 ms + 4 ms + 0.02 ms
- **Important points:**
  - Access time dominated by seek time and rotational latency.
  - First bit in a sector is the most expensive, the rest are free.
  - SRAM access time is about 4 ns/doubleword, DRAM about 60 ns
    - Disk is about 40,000 times slower than SRAM,
    - 2,500 times slower then DRAM.



Overview of Mass Storage Structure (Cont.)

- Magnetic tape
  - Was early secondary-storage medium
  - Relatively permanent and holds large quantities of data
  - Access time slow
  - Random access ~1000 times slower than disk
  - Mainly used for backup, storage of infrequently-used data, transfer medium between systems
  - Kept in spool and wound or rewound past read-write head
  - Once data under head, transfer rates comparable to disk
  - 20-200GB typical storage
  - Common technologies are 4mm, 8mm, 19mm, LTO-2 and SDLT

Disk Structure

- Disk drives are addressed as large 1-dimensional arrays of *logical blocks*, where the logical block is the smallest unit of transfer.

- The 1-dimensional array of logical blocks is mapped into the sectors of the disk sequentially.
  - Sector 0 is the first sector of the first track on the outermost cylinder.
  - Mapping proceeds in order through that track, then the rest of the tracks in that cylinder, and then through the rest of the cylinders from outermost to innermost.

Disk Scheduling

- The operating system is responsible for using hardware efficiently — for the disk drives, this means having a fast access time and disk bandwidth.
- Access time has two major components
  - *Seek time* is the time for the disk are to move the heads to the cylinder containing the desired sector.
  - *Rotational latency* is the additional time waiting for the disk to rotate the desired sector to the disk head.
- Minimize seek time
- Seek time seek distance
- Disk bandwidth is the total number of bytes transferred, divided by the total time between the first request for service and the completion of the last transfer.

Disk Scheduling (Cont.)

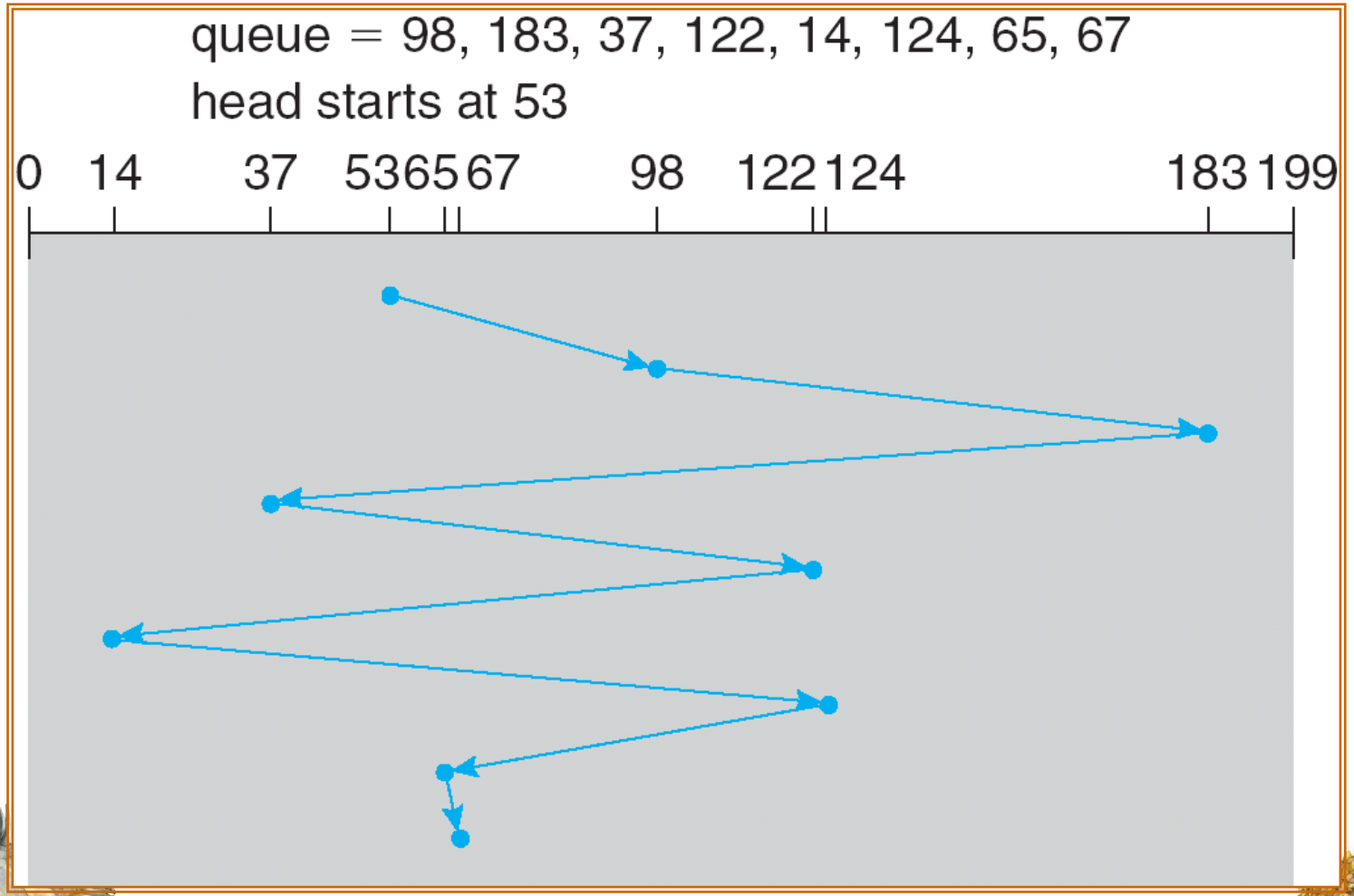
- Several algorithms exist to schedule the servicing of disk I/O requests.
- We illustrate them with a request queue (0-199).

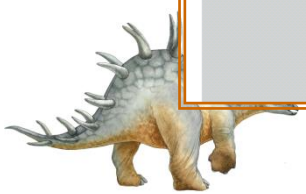
98, 183, 37, 122, 14, 124, 65, 67

Head pointer 53

FCFS

Illustration shows total head movement of 640 cylinders.

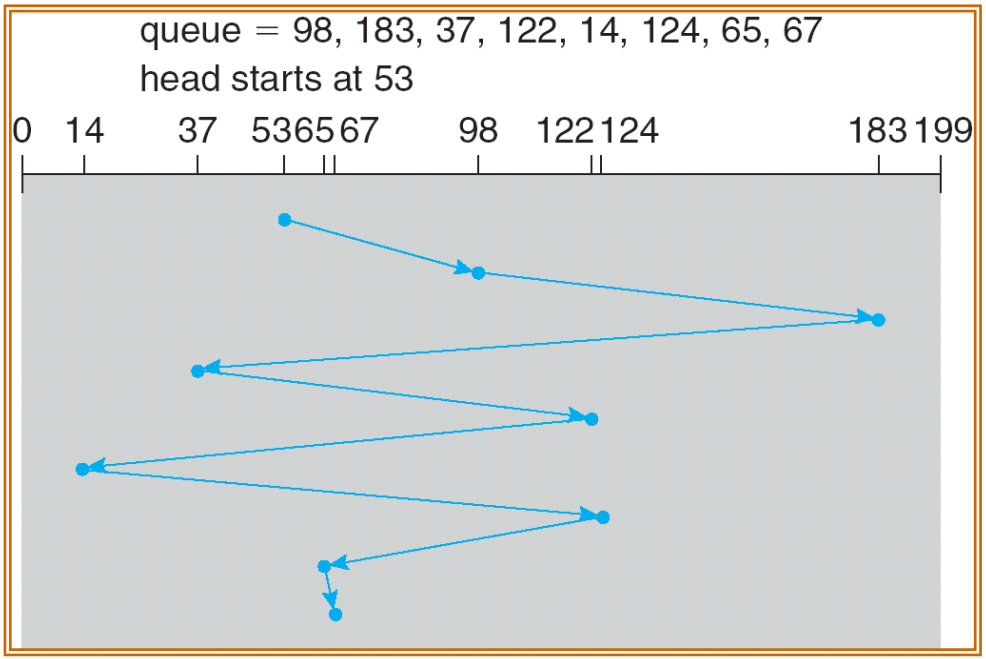




Pickup（搭便车）

它将会在在即将经过的有操作请求在队列中的任何一个磁道处停留下来并给于相应的操作服务。(相应调度实现模块在 Linux系统中称为Noop调度器，这里Noop即即No Operation。)

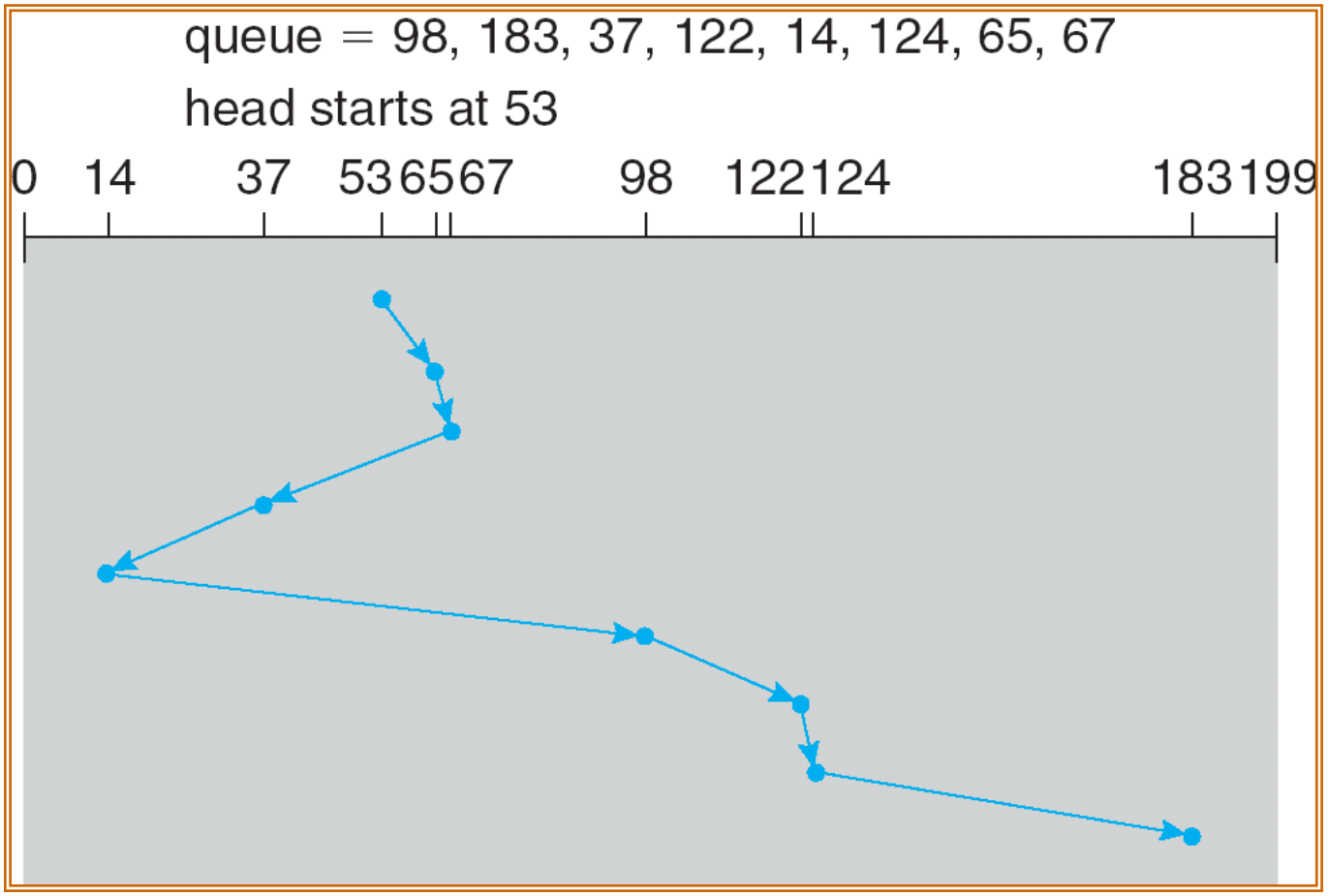
FCFS



SSTF(Shortest Seek Time First)

- Selects the request with the minimum seek time from the current head position.
- SSTF scheduling is a form of SJF scheduling; may cause starvation of some requests.
- Illustration shows total head movement of 236 cylinders.
- Shortest Positioning Time First(SPTF)

SSTF (Cont.)

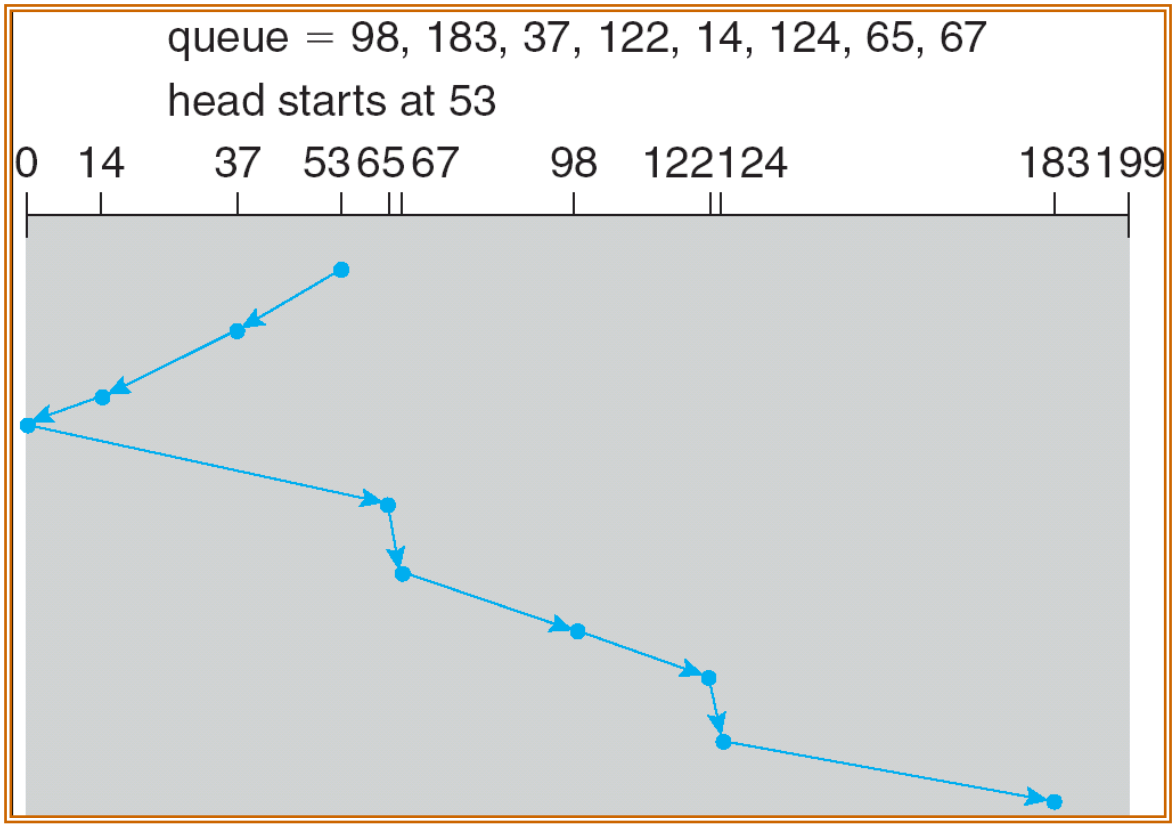


面向磁道的公平性问题?

SCAN

- The disk arm starts at one end of the disk, and moves toward the other end, servicing requests until it gets to the other end of the disk, where the head movement is reversed and servicing continues.
- Sometimes called the *elevator algorithm*.
- Illustration shows total head movement of 208 cylinders.

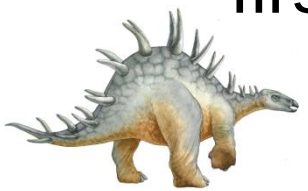
SCAN (Cont.)



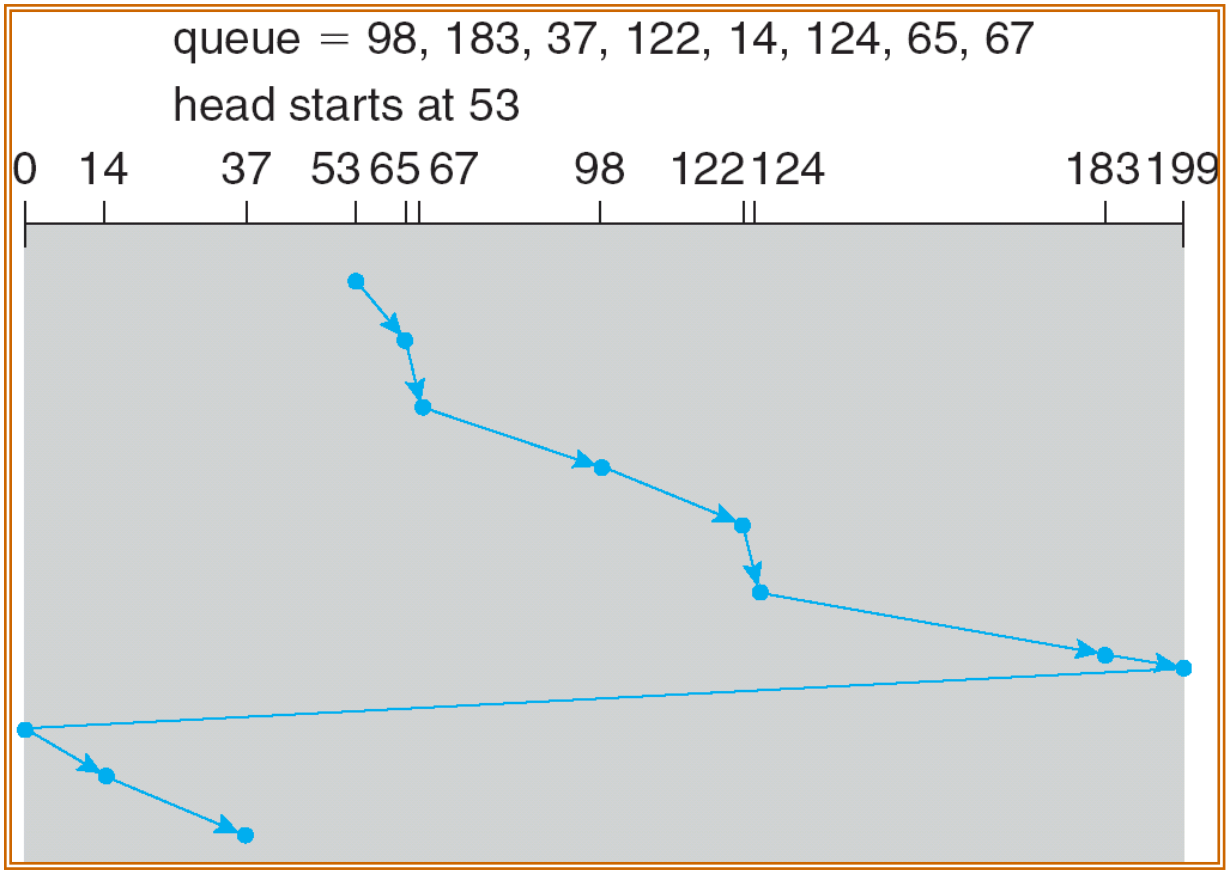
面向磁道的公平性问题?

C-SCAN (Circular-SCAN)

- Provides a more uniform wait time than SCAN.
- The head moves from one end of the disk to the other. servicing requests as it goes. When it reaches the other end, however, it immediately returns to the beginning of the disk, without servicing any requests on the return trip.
- Treats the cylinders as a circular list that wraps around from the last cylinder to the first one.



C-SCAN (Cont.)

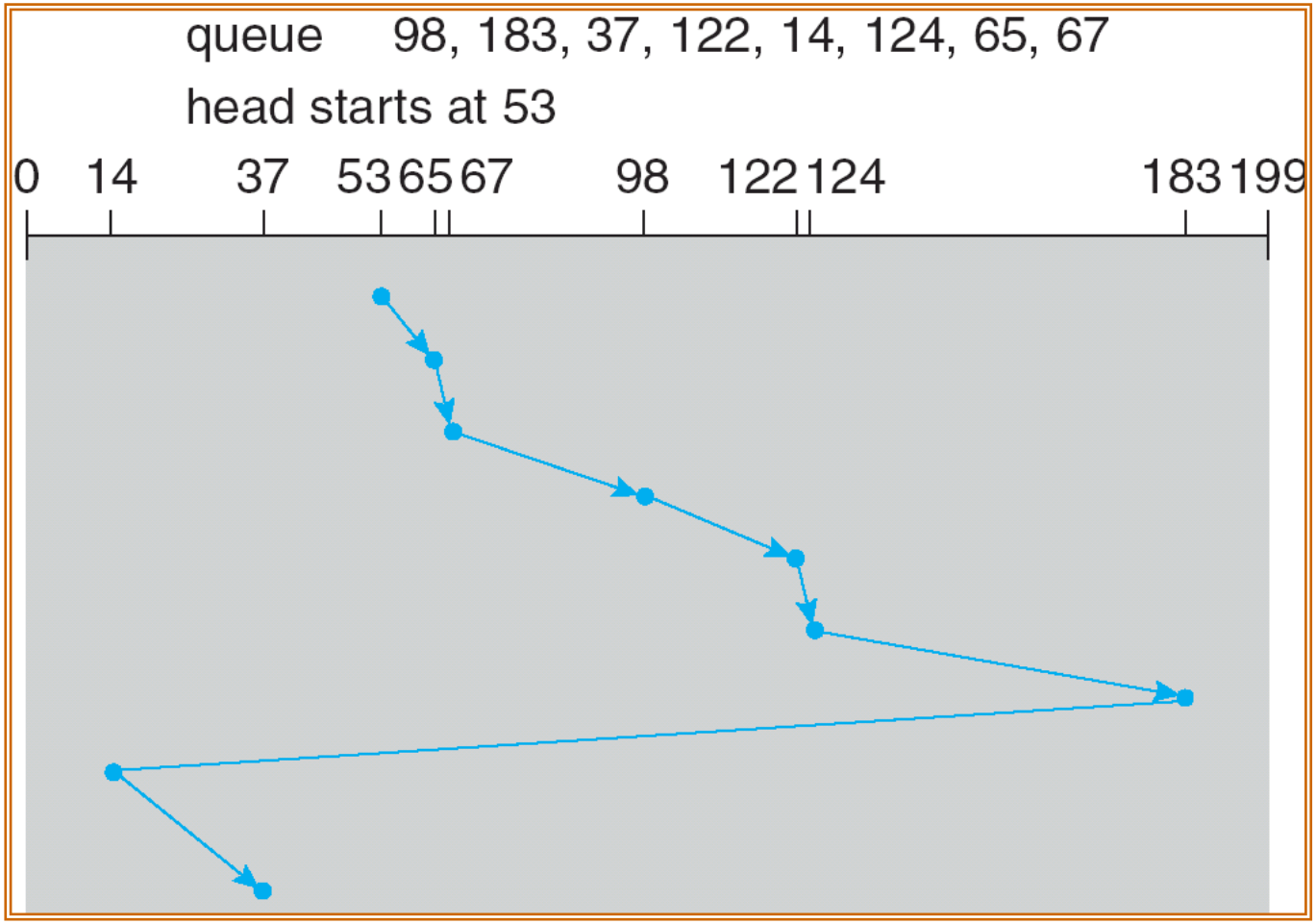


面向磁道的公平性问题?

C-LOOK

- Version of C-SCAN
- Arm only goes as far as the last request in each direction, then reverses direction immediately, without first going all the way to the end of the disk.

C-LOOK (Cont.)


queue 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53
0
14
37
53
65
67
98
122
124
183
199

磁盘调度算法对比

	FCFS	SSTF	SCAN	C-SCAN	C-LOOK
优点	公平、简单	性能较好，每次的寻道时间最短，不保证总体最短	性能较好，平均寻道时间短，不产生饥饿	对各个磁道访问响应时间均匀	提升效率，寻道时间进一步缩短
缺点	大量竞争使用时，访问分散时，性能差	饥饿现象	多余磁道访问 对各个位置磁道响应时间不均	相对SCAN算法，平均寻道时间更长，多余寻道访问	

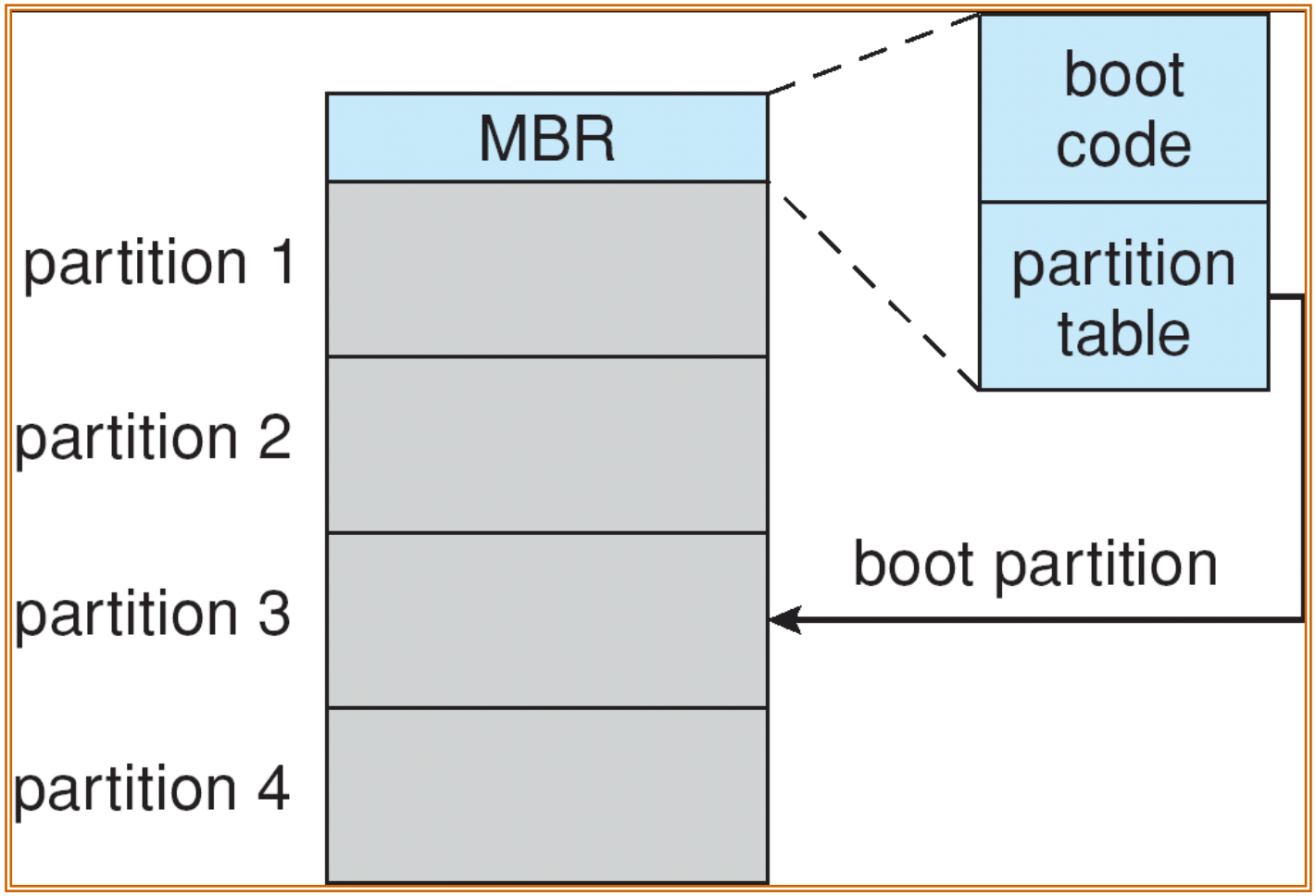
Selecting a Disk-Scheduling Algorithm

- SSTF is common and has a natural appeal
- SCAN and C-SCAN perform better for systems that place a heavy load on the disk.
- Performance depends on the number and types of requests.
- Requests for disk service can be influenced by the file-allocation method.
- The disk-scheduling algorithm should be written as a separate module of the operating system, allowing it to be replaced with a different algorithm if necessary.
- Either SSTF or LOOK is a reasonable choice for the default algorithm.

Disk Management

- *Low-level formatting*, or *physical formatting* — Dividing a disk into sectors that the disk controller can read and write.
- To use a disk to hold files, the operating system still needs to record its own data structures on the disk.
  - *Partition* the disk into one or more groups of cylinders.
  - *Logical formatting* or “making a file system”.
- Boot block initializes system.
  - The bootstrap is stored in ROM.
  - *Bootstrap loader* program.
- Methods such as *sector sparing* used to handle bad blocks.

Booting from a Disk in Windows 2000



Swap-Space Management

- Swap-space — Virtual memory uses disk space as an extension of main memory.
- Swap-space can be carved out of the normal file system,or, more commonly, it can be in a separate disk partition.
- Swap-space management
  - 4.3BSD allocates swap space when process starts; holds *text segment* (the program) and *data segment.*
  - Kernel uses *swap maps* to track swap-space use.
  - Solaris 2 allocates swap space only when a page is forced out of physical memory, not when the virtual memory page is first created.

RAID Structure

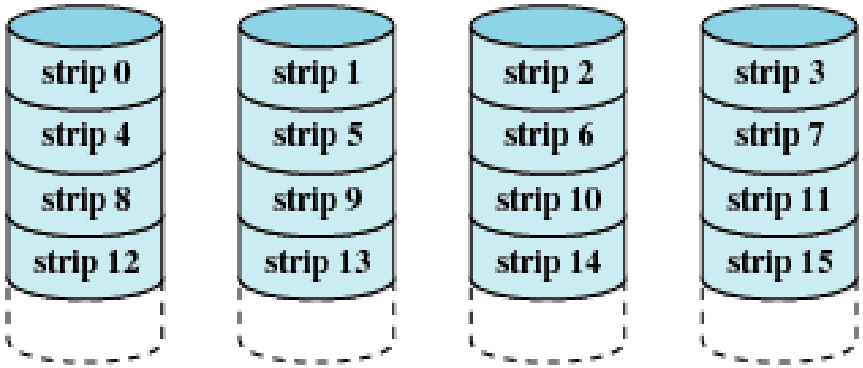
- **RAID** – multiple disk drives provides **reliability** via **redundancy**.
- RAID is arranged into six different levels.

RAID

独立磁盘冗余阵列是利用**一台磁盘阵列控制器**统一管理和控制一组磁盘驱动器，组成一个速度快 、可靠性高的大容量磁盘系统。

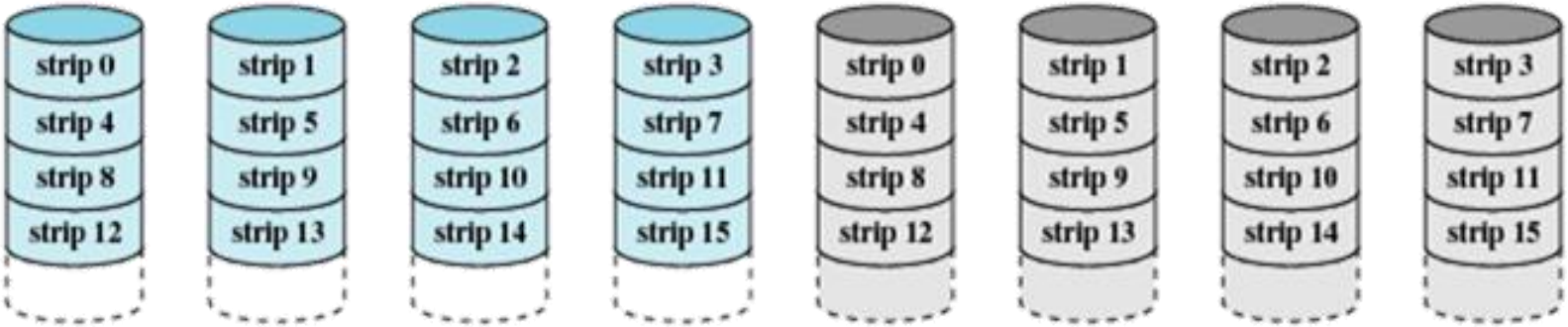
- RAID是一组物理磁盘驱动器，操作系统把它看作是一个单独的逻辑驱动器；
- 数据分布在物理驱动器阵列中；
- 使用冗余的磁盘容量保存奇偶校验信息，从而保证当一个磁盘失败时，数据具有可恢复性；

RAID



(a) RAID 0 (non-redundant)

RAID0
无冗余

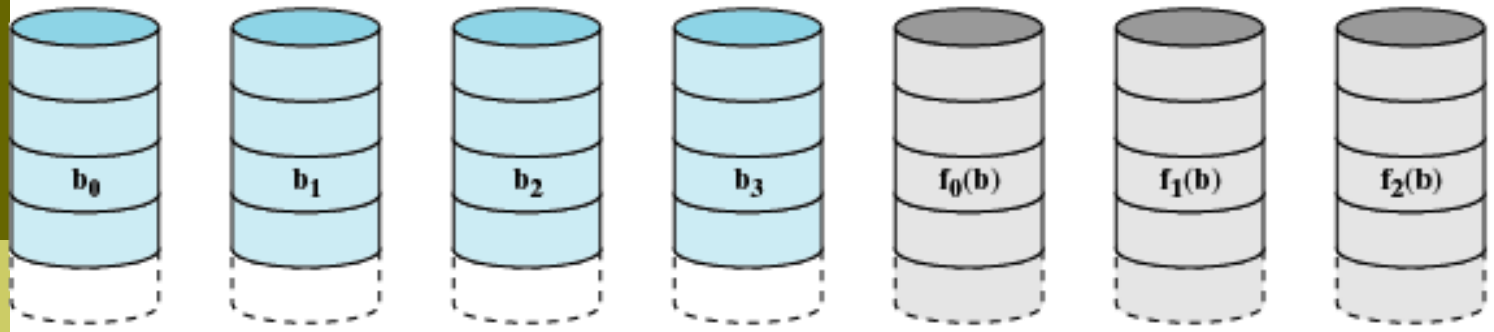


(b) RAID 1 (mirrored)

RAID1

镜像

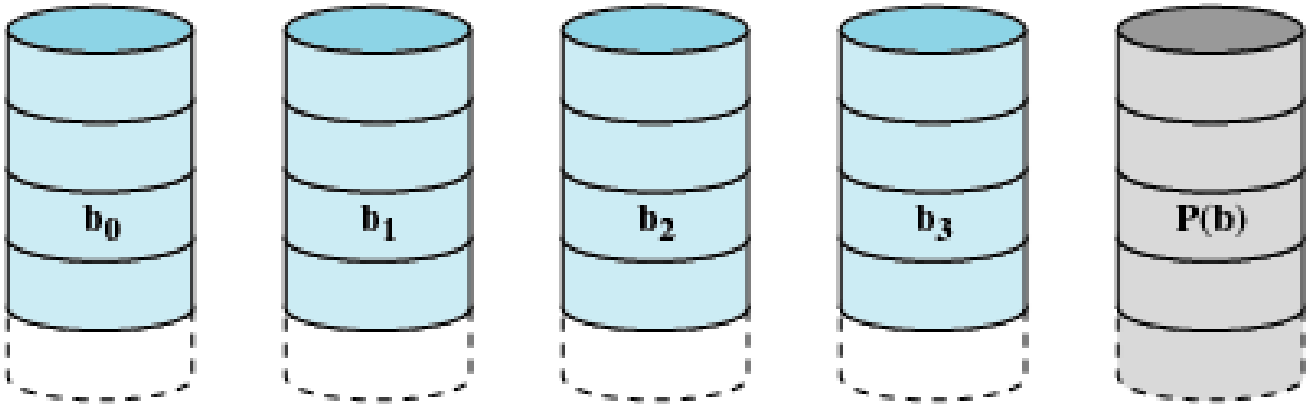
RAID



(c) RAID 2 (redundancy through Hamming code)

RAID2

通过汉明码冗余



(d) RAID 3 (bit-interleaved parity)

RAID3

交错位奇偶校验

SSD

- SSD = Solid State Disk，固态硬盘，用固态电子存储芯片阵列而制成的硬盘。
- 固态硬盘的接口规范和定义、功能及使用方法上与普通硬盘的相同，在产品外形和尺寸上也与普通硬盘一致。其芯片的工作温度范围很宽（-40~85℃）；
- 由于固态硬盘技术与传统硬盘技术不同，所以产生了不少新兴的存储器厂商。厂商只需购买NAND存储器，再配合适当的控制芯片，就可以制造固态硬盘了。新一代的固态硬盘普遍采用SATA-2接口。

SSD

固态硬盘的存储介质分为两种，一种是采用闪存（FLASH芯片）作为存储介质，另外一种是采用DRAM作为存储介质。

1、基于闪存的固态硬盘:

采用FLASH芯片作为存储介质，这也是我们通常所说的SSD。这种SSD固态硬盘最大的优点就是可以移动，而且数据保护不受电源控制，能适应于各种环境，但是使用年限不高，适合于个人用户使用。在基于闪存的固态硬盘中，存储单元又分为两类：SLC（Single Layer Cell 单层单元）和MLC（Multi-Level Cell多层单元）。

SLC的特点是成本高、容量小、但是速度快，而MLC的特点是容量大成本低，但是速度慢。MLC的每个单元是2bit的，相对SLC来说整整多了一倍。不过，由于每个MLC存储单元中存放的资料较多，结构相对复杂，出错的几率会增加，必须进行错误修正，这个动作导致其性能大幅落后于结构简单的SLC闪存。此外，SLC闪存的优点是复写次数高达100000次，比MLC闪存高10倍。此外，为了保证MLC的寿命，控制芯片都校验和智能磨损平衡技术算法，使得每个存储单元的写入次数可以平均分摊，达到100万小时故障间隔时间(MTBF)。

SSD

2、基于DRAM的固态硬盘：采用DRAM作为存储介质，目前应用范围较窄。它仿效传统硬盘的设计、可被绝大部分操作系统的文件系统工具进行卷设置和管理，并提供工业标准的PCI和FC接口用于连接主机或者服务器。应用方式可分为SSD硬盘和SSD硬盘阵列两种。它是一种高性能的存储器，而且使用寿命很长，美中不足的是需要独立电源来保护数据安全。

End of Chapter 12