Universidade Estadual de Campinas
Instituto de Computação

MC504 Sistemas Operacionais

T26 Hard Disk Drives

Referência principal
Ch.37 of *Operating Systems: Three Easy Pieces* by Remzi and Andrea Arpaci-Dusseau (pages.cs.wisc.edu/~remzi/OSTEP/)

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Hard disk drives have been the main form of persistent data storage in computer systems for decades. . .

- How do modern hard disks store data?
- What is their interface?
- How is data actually laid out and accessed?
- How does disk scheduling affect performance?

The hard-disk drive interface

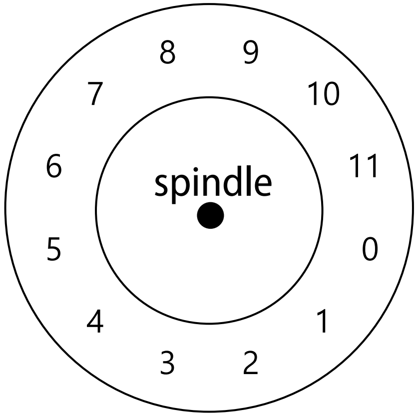
- The basic interface for all modern drives is straightforward.
- The drive consists of a large number of sectors (512-byte blocks), each of which can be read or written.
- The sectors are numbered from $\mathbf{0}$ to $n-1$ on a disk with n sectors.
- Thus, we can view the disk as an array of sectors; $\mathbf{0}$ to $n-1$ is the **address space** of the drive.

The hard-disk drive interface

- Multi-sector operations are possible.
  - Many file systems will read or write 4KB or more at a time.
  - However, the only guarantee is that a single 512- byte write is **atomic** (i.e., it will either complete in its entirety or it won't complete at all).
  - Thus, if an untimely power loss occurs, only a portion of a larger write may complete (sometimes called a **torn write**).
- There are some assumptions most clients of disk drives make, but that are not specified directly in the interface (an **unwritten contract**):
  - Accessing two blocks that are near one-another within the drive's address space is faster than accessing two blocks that are far apart.
  - Accessing blocks in a contiguous chunk (i.e., a sequential read or write) is the fastest access mode, much faster than any random access pattern.

The basic geometry of a hard disk

- Platter
  - A circular hard surface (aluminum coated with a thin magnetic layer)
  - Data is stored persistently by inducing magnetic changes to it.
  - Each platter has 2 sides, each of which is called a **surface**.

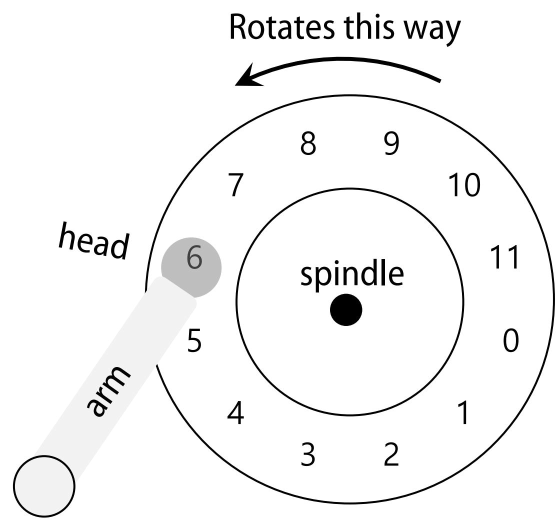


A Disk with Just One Single Track (12 sectors)

- Spindle
  - Spindle is connected to a motor that spins the platters around.
  - The rate of rotation today is typically 7,200 to 15,000 RPM.
  - At 10,000 RPM a full rotation takes about 6 ms.
- Track
  - Concentric circles of sectors
  - Data is encoded on each surface in a track.
  - A single surface contains many thousands and thousands of tracks.

The basic geometry of a hard disk

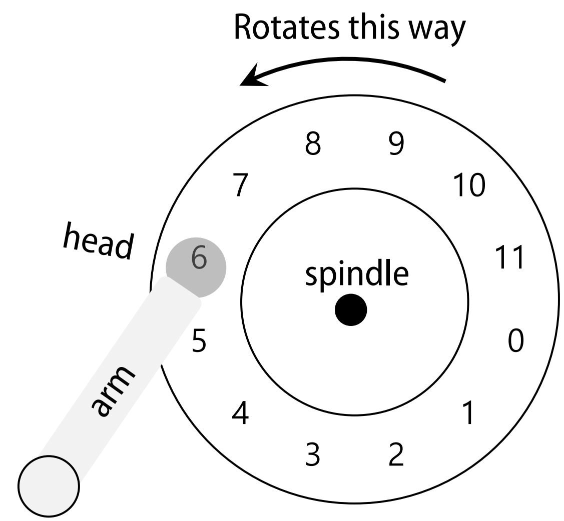
- Disk head
  - There is one head per surface of the drive
  - It is responsible for *reading* and *writing* the disk.
  - It is attached to a single **disk arm**, which moves across the surface.



A Single Track Plus A Head

Single track latency: Rotational Delay

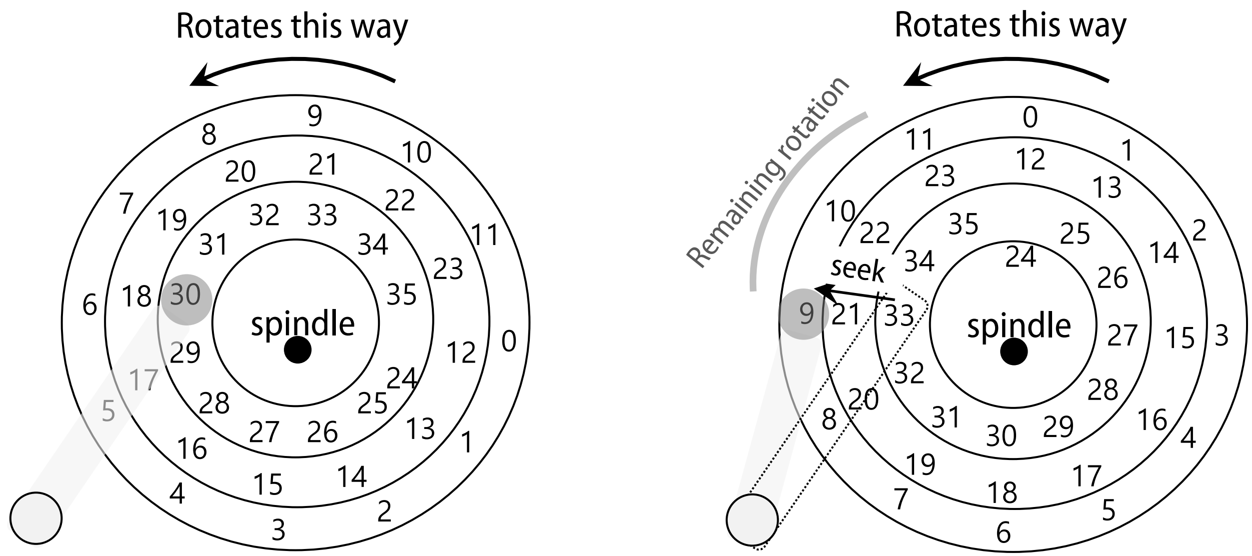
- Rotational delay
  - Time for the desired sector to reach the disk head
  - For example, if full rotational delay is R and we start at sector 6
    - Rotational delay to read sector 0 is $\frac{R}{2}$.
    - Rotational delay to read sector 5 is $R - 1$ (worst case).



A Single Track Plus A Head

Multiple Tracks: Seek Time

Three Tracks Plus A Head
(Right: With Seek)
(e.g., read to sector 11)



- **Seek**
  - Move the disk arm to the correct track
  - The time to move head to the track containing the desired sector is called **seek time**.
  - It is one of the most costly disk operations.

Phases of Seek

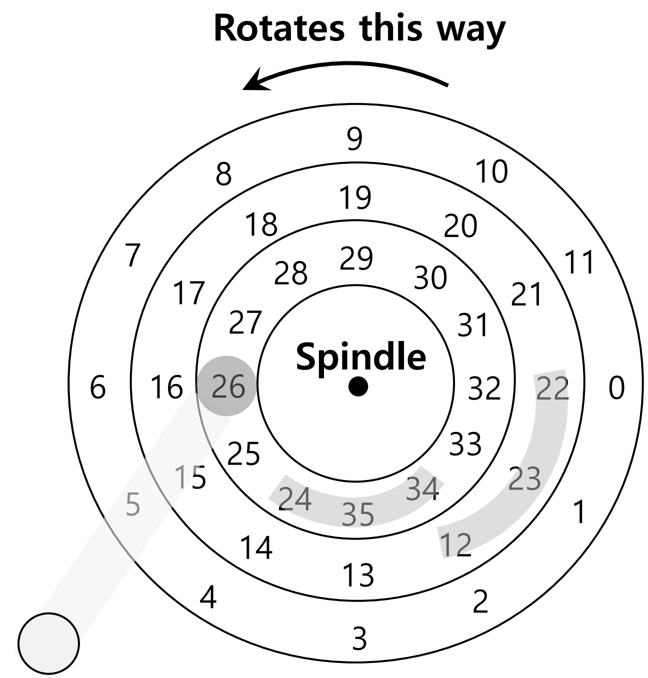
- Acceleration → Coasting → Deceleration → Settling
  - **Acceleration**: The disk arm gets moving.
  - **Coasting**: The arm is moving at full speed.
  - **Deceleration**: The arm slows down.
  - **Settling**: The head is *carefully positioned* over the correct track.
    - The settling time is often quite significant, e.g., 0.5 to 2ms.

Phases of I/O

- Seek → Rotational delay → Transfer
- **Transfer**: The final phase of I/O
  - Data is either actually *read from* or *written to* the surface.

Track Skew

- Used in some hard disks to make sure that sequential reads can be properly serviced *even when crossing track boundaries*.
- *Without track skew*, the head would be moved to the next track but the desired next block might have already rotated under the head.



Three Tracks: Track Skew Of 2

Cache or Track Buffer

- The cache holds data read from or written to the disk.
  - Allows the drive to *quickly respond* to requests.
  - Small amount of memory (usually around 8 or 16 MB)

Write on cache

- **Writeback** (immediate reporting)
  - Acknowledge that a write has completed when it has put the data in its memory.
  - Faster but dangerous.
- **Write through**
  - Acknowledge that a write has completed only after the data has actually been written to disk.

I/O Time: Doing The Math

- I/O time
  - $T_{I/O} = T_{seek} + T_{rotation} + T_{transfer}$
- Rate of I/O
  - $R_{I/O} = \frac{Size_{Transfer}}{T_{I/O}}$

Disk Drive Specs: SCSI Versus SATA

	Cheetah 15K.5	Barracuda
Capacity	300 GB	1 TB
RPM	15,000	7,200
Average Seek	4 ms	9 ms
Max Transfer	125 MB/s	105 MB/s
Platters	4	4
Cache	16 MB	16/32 MB
Connects Via	SCSI	SATA

I/O Time: Doing The Math

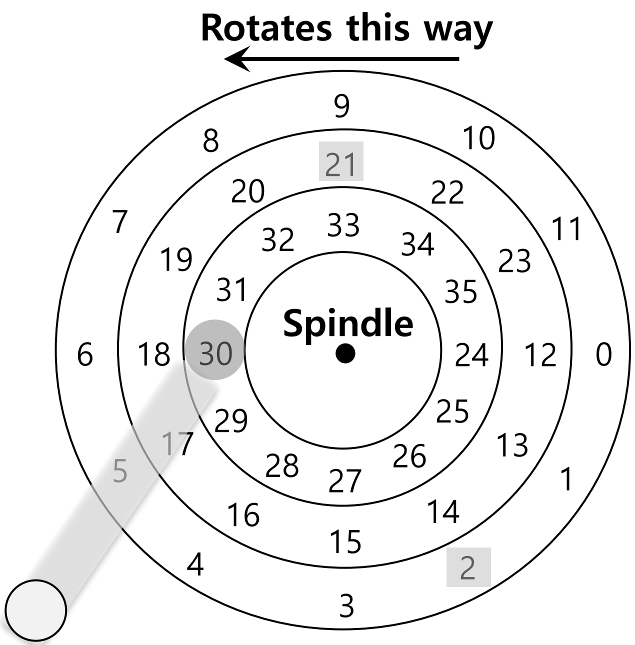
- **Random workload**: Issue 4KB read to random locations on the disk
- **Sequential workload**: Read 100MB consecutively from the disk

Disk Drive Performance: SCSI vs SATA, Random vs Sequential

		Cheetah 15K.5	**Barracuda**
T_{seek}		4 ms	9 ms
$T_{rotation}$		2 ms	4.2 ms
Random	$T_{transfer}$	30 μs	38 μs
	$T_{I/O}$	6 ms	13.2 ms
	$R_{I/O}$	0.66 MB/s	0.31 MB/s
Sequential	$T_{transfer}$	800 ms	950 ms
	$T_{I/O}$	806 ms	963.2 ms
	$R_{I/O}$	125 MB/s	105 MB/s

Disk Scheduling

- **Disk Scheduler** decides which I/O request to schedule next.
- **SSTF** (Shortest Seek Time First)
  - Order the queue of I/O request by track
  - Pick requests on the nearest track to complete first



SSTF: Scheduling Request 21 and 2

Issue the request to 21 → issue the request to 2

SSTF is not a panacea.

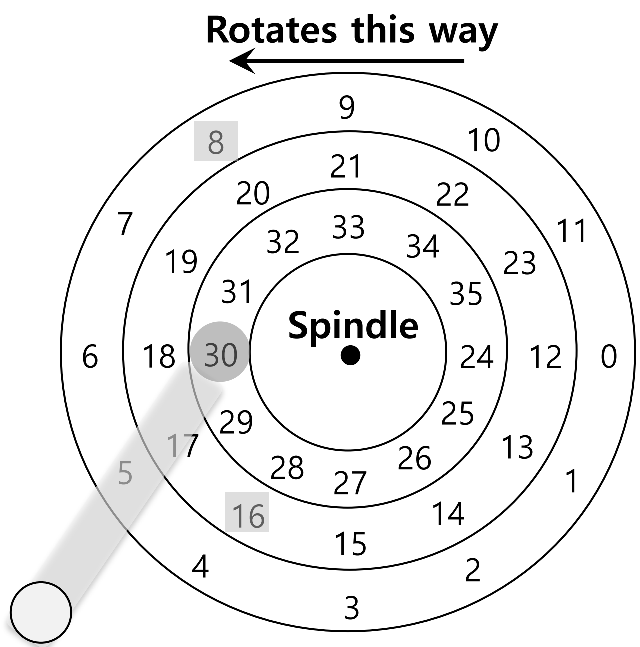
- **Problem 1**: The drive geometry is not available to the host OS
  - Solution: OS can simply implement Nearest-block-first (NBF)

- **Problem 2**: Starvation
  - If there were a steady stream of request to the inner track, request to other tracks would then be ignored completely.

Elevator (a.k.a. SCAN or C-SCAN)

- Move across the disk servicing requests in order across the tracks.
  - **Sweep**: A single pass across the disk
    - If a request comes for a block on a track that has already been services on this sweep of the disk, it is queued until the next sweep.
  - **F-SCAN**
    - Freeze the queue to be serviced when it is doing a sweep
    - Avoid starvation of far-away requests
  - **C-SCAN** (Circular SCAN)
    - Sweep from outer-to-inner, and then inner-to-outer, etc.

How to account for Disk rotation costs?



SSTF: Sometimes Not Good Enough

- If rotation is faster than seek : request 16 → request 8
- If seek is faster than rotation : request 8 → request 16

On modern drives, both seek and rotation are roughly equivalent:
Thus, SPTF (Shortest Positioning Time First) is useful.

I/O merging

- **Reduce the number of request** sent to the disk and lowers overhead
  - E.g., read blocks 33, then 8, then 34:
    - The scheduler merge the request for blocks 33 and 34 *into a single two-block request*.