OPERATING SYSTEMS

Storage Management - 2

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Course Syllabus - Unit 4

Unit 4: Storage Management

Mass-Storage Structur - Mass-Storage overview, Disk Scheduling, Swap-Space Management, RAID structure. File System Interface - file organization/structure and access methods, directories, sharing File System Implementation/Internals: File control Block (inode), partitions & mounting, Allocation methods.

Case Study: Linux/Windows File Systems

OPERATING SYSTEMS

Course Outline

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38	Disk Scheduling - FCFS, SSTF, SCAN, C-SCAN, LOOK	12.4	
39	Swap-Space Management, RAID Structure	12.6,12.7	
40	File Concept, File Structure, Access Methods	10.1-10.2	
41	Directory and Disk Structure	10.3	
42	File-System Mounting, File Sharing, Protecting	10.4-10.6	
43	Implementing File-Systems: File control Block (inode), partitions & mounting	11.1,11.2	
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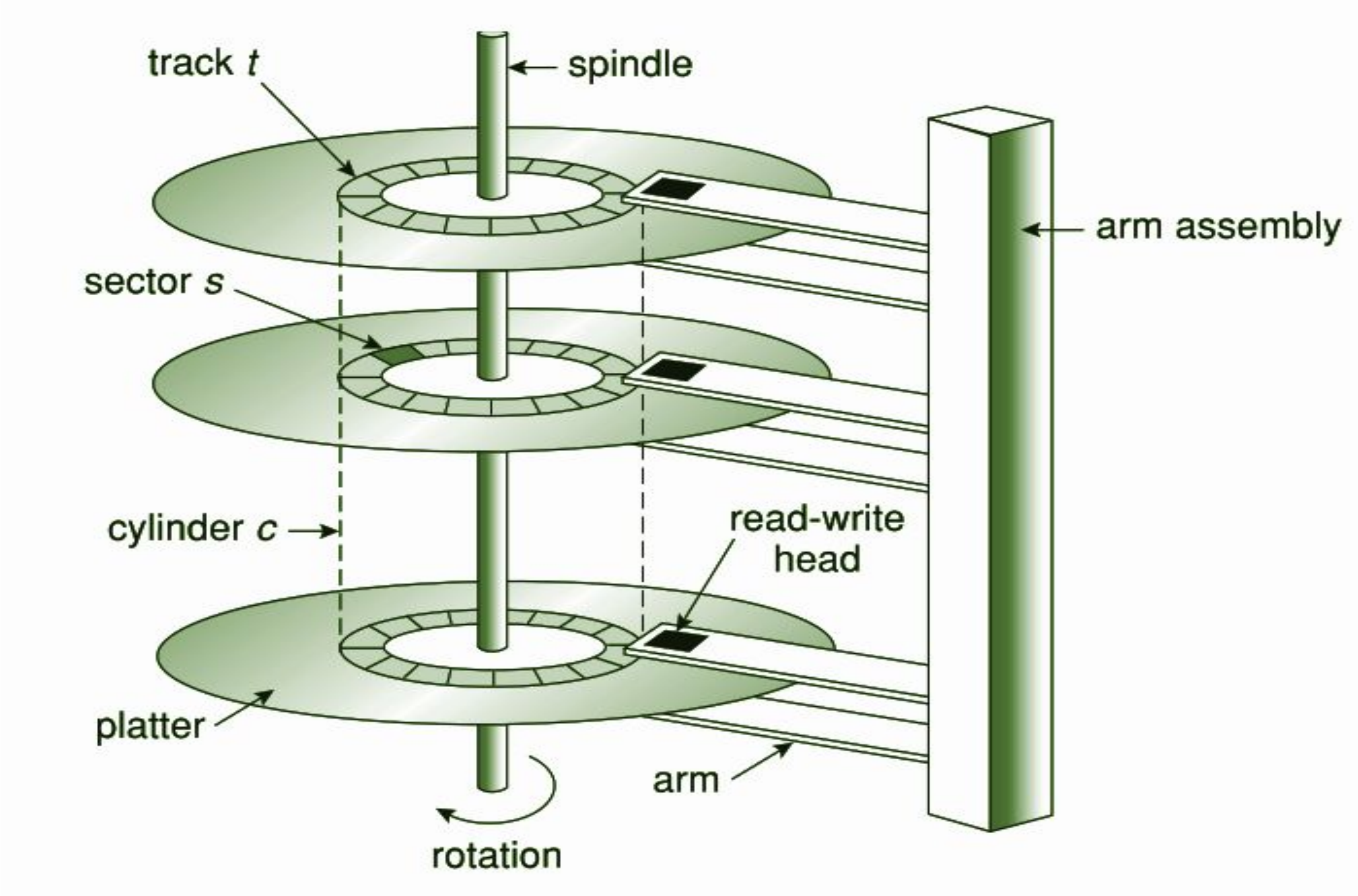
Topic Outline

- Overview of Mass Storage Structure
- Moving-head Disk Mechanism
- Hard Disks
- Hard Disk Performance
- Magnetic Tape
- Solid-State Drives

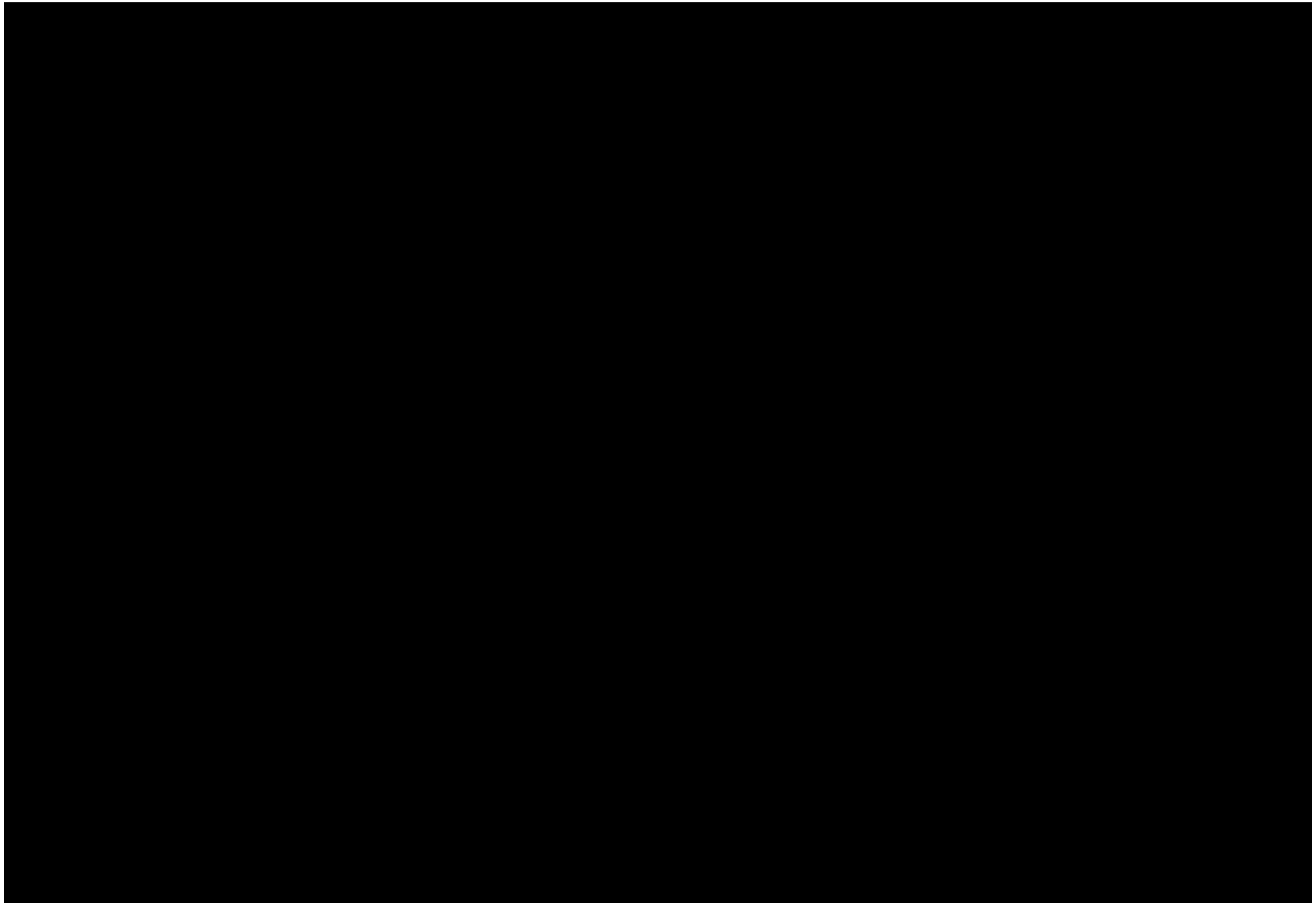
Overview of Mass Storage Structure

- Magnetic disks provide bulk of secondary storage of modern computers
- Drives rotate at 60 to 250 times per second i.e ranging from 3,600 RPM to 15,000 RPM
- Currently Hard drives have been engineered with spin rates as low as 1,200 RPM and as high as 15K RPM.
- Today's most common RPM rates, in both laptop and desktop PCs, are between 5,400 and 7,200 RPM
- Given two identically designed hard drives with the same **areal** densities, a 7,200 RPM drive will deliver data about 33% faster than the 5,400 RPM drive.
- Consequently, this specification is important when evaluating the expected performance of a hard drive or when comparing different HDD models.
- **The word "areal" refers to an area, which is an expanse of space or a region of land.**

Overview of Mass Storage Structure



Overview of Mass Storage Structure



Hard Disk

- Platters range from .85” to 14” (historically)
  - Commonly 3.5”, 2.5”, and 1.8”
- Range from 30GB to 3TB per drive
- Performance
  - Transfer Rate – theoretical – 6 Gb/sec
  - Effective Transfer Rate – real – 1Gb/sec (From Wikipedia)
  - Seek time from 3ms to 12ms – 9ms common for desktop drives
  - Average seek time measured or calculated based on 1/3 of tracks
  - Latency based on spindle speed
  - 1 / (RPM / 60) = 60 / RPM
  - Average latency = 1⁄2 latency

Spindle [rpm]	Average latency [ms]
4200	7.14
5400	5.56
7200	4.17
10000	3
15000	2

Hard Disk Performance

- Access Latency = Average access time = average seek time + average latency
  - For fastest disk 3ms + 2ms = 5ms
  - For slow disk 9ms + 5.56ms = 14.56ms
- Average I/O time = average access time + (amount to transfer / transfer rate) + controller overhead
- For example to transfer a 4KB block on a 7200 RPM disk with a 5ms average seek time, 1Gb/sec transfer rate with a .1ms
- Controller overhead = 5ms + 4.17ms + 0.1ms + transfer time
- Transfer time = 4KB / 1Gb/s * 8Gb / GB * 1GB / 1024^2 KB = 32 / (1024^2) = 0.031 ms
- Average I/O time for 4KB block = 9.27ms + .031ms = 9.301ms

Spindle [rpm]	Average latency [ms]
4200	7.14
5400	5.56
7200	4.17
10000	3
15000	2

Hard Disk Performance

- Usually the **number of sectors** is the **same for all tracks**, but some hard disks put more **sectors** in outer **tracks** (**all sectors** are of the **same** physical size, so more of them fit in the longer outer **tracks**). Typically, a **sector** will hold 512 bytes of data.

Hard Disk Performance

- Consider a disk pack with the following specifications- 16 surfaces, 128 tracks per surface, 256 sectors per track and 512 bytes per sector.
  - What is the capacity of disk pack ?
  - What is the number of bits required to address the sector ?
  - If the format overhead is 32 bytes per sector, What is the formatted disk space ?
  - If the format overhead is 64 bytes per sector, How much amount of memory is lost due to formatting ?
  - If the diameter of innermost track is 21 cm, What is the maximum recording density ?
  - If the diameter of innermost track is 21 cm with 2 KB/cm, What is the capacity of one track ?
  - If the disk is rotating at 3600 RPM, What is the data transfer rate ?
  - If the disk system has rotational speed of 3000 RPM, What is the average access time with a seek time of 11.5 msec ?

Hard Disk Performance

- **Given:**
  - **Number of surfaces = 16**
  - **Number of tracks per surface = 128**
  - **Number of sectors per track = 256**
  - **Number of bytes per sector = 512 bytes**

What is the capacity of disk pack ?

= Total number of surfaces x Number of tracks per surface x Number of sectors per track x Number of bytes per sector

= 16 x 128 x 256 x 512 bytes

= $2^4 \times 2^7 \times 2^8 \times 2^9$

= 2^{28} **bytes**

= 256 MB

Hard Disk Performance

- Consider a disk pack with the following specifications- 16 surfaces, 128 tracks per surface, 256 sectors per track and 512 bytes per sector.
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Hard Disk Performance

- **Given:**
  - Number of surfaces = 16
  - Number of tracks per surface = 128
  - Number of sectors per track = 256
  - Number of bytes per sector = 512 bytes

What is the number of bits required to address the sector ?

= Total number of surfaces x Number of tracks per surface x Number of sectors per track

= 16 x 128 x 256 sectors

= $2^4 \times 2^7 \times 2^8$

= 2^{19} sectors

Thus, Number of bits required to address the sector = 19 bits

Hard Disk Performance

- Consider a disk pack with the following specifications- 16 surfaces, 128 tracks per surface, 256 sectors per track and 512 bytes per sector.
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Hard Disk Performance

- **Given:**
  - **Number of surfaces = 16**
  - **Number of tracks per surface = 128**
  - **Number of sectors per track = 256**
  - **Number of bytes per sector = 512 bytes**

If the format overhead is 32 bytes per sector, What is the formatted disk space ?

Formatting overhead

= Total number of sectors x overhead per sector

=2^{19} x 2^5 bytes

=2^{24} bytes

= 16 Mega bytes

Now, Formatted disk space

= Total disk space – Formatting overhead

= 256 MB – 16 MB

= 240 MB

Hard Disk Performance

- Consider a disk pack with the following specifications- 16 surfaces, 128 tracks per surface, 256 sectors per track and 512 bytes per sector.
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Hard Disk Performance

- Given:
  - Number of surfaces = 16
  - Number of tracks per surface = 128
  - Number of sectors per track = 256
  - Number of bytes per sector = 512 bytes

If the format overhead is 64 bytes per sector, How much amount of memory is lost due to formatting ?

Formatting overhead

= Total number of sectors x overhead per sector

$=2^{19} \times 2^{6}$ bytes

$=2^{25}$ bytes

= 32 Mega bytes

Hard Disk Performance

- **Consider a disk pack with the following specifications- 16 surfaces, 128 tracks per surface, 256 sectors per track and 512 bytes per sector.**
  - **What is the capacity of disk pack ?**
  - **What is the number of bits required to address the sector ?**
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Hard Disk Performance

- Given:
  - Number of surfaces = 16
  - Number of tracks per surface = 128
  - Number of sectors per track = 256
  - Number of bytes per sector = 512 bytes

If the diameter of innermost track is 21 cm, What is the maximum recording density ?

Storage capacity of a track

= Number of sectors per track x Number of bytes per sector

= 256 x 512 bytes

= 2^8 x 2^9 bytes

= 128 Kilo bytes

Hard Disk Performance

- **Given:**
  - Number of surfaces = 16
  - Number of tracks per surface = 128
  - Number of sectors per track = 256
  - Number of bytes per sector = 512 bytes

If the diameter of innermost track is 21 cm, What is the maximum recording density ?

Circumference of innermost track

= 2 x π x radius

= π x Diameter

= 3.14 x 21 cm

= 65.94 cm

Hard Disk Performance

- Given:
  - Number of surfaces = 16
  - Number of tracks per surface = 128
  - Number of sectors per track = 256
  - Number of bytes per sector = 512 bytes

If the diameter of innermost track is 21 cm, What is the maximum recording density ?

Now, Maximum recording density

= Recording density of innermost track

= Capacity of a track / Circumference of innermost track

= 128 KB / 65.94 cm

= 1.94 KB/cm

Hard Disk Performance

- Consider a disk pack with the following specifications- 16 surfaces, 128 tracks per surface, 256 sectors per track and 512 bytes per sector.
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Hard Disk Performance

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If the diameter of innermost track is 21 cm with 2 KB/cm, What is the capacity of one track ?

Circumference of innermost track

= 2 x π x radius

= π x diameter

= 3.14 x 21 cm

= 65.94 cm

Hard Disk Performance

- **Given:**
  - **Number of surfaces = 16**
  - **Number of tracks per surface = 128**
  - **Number of sectors per track = 256**
  - **Number of bytes per sector = 512 bytes**

If the diameter of innermost track is 21 cm with 2 KB/cm, What is the capacity of one track ?

Capacity of a track

= Storage density of the innermost track x Circumference of the innermost track

= 2 KB/cm x 65.94 cm

= 131.88 KB

≅ 132 KB

Hard Disk Performance

- Consider a disk pack with the following specifications- 16 surfaces, 128 tracks per surface, 256 sectors per track and 512 bytes per sector.
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Hard Disk Performance

- **Given:**
  - **Number of surfaces = 16**
  - **Number of tracks per surface = 128**
  - **Number of sectors per track = 256**
  - **Number of bytes per sector = 512 bytes**

If the disk is rotating at 3600 RPM, What is the data transfer rate ?

Number of rotations in one second

= (3600 / 60) rotations/sec

= 60 rotations/sec

Now, Data transfer rate

= Number of heads x Capacity of one track x Number of rotations in one second

= 16 x (256 x 512 bytes) x 60

= 2^4 x 2^8 x 2^9 x 60 bytes/sec

= 60 x 2^{21} bytes/sec

= 120 MBPS

Hard Disk Performance

- Consider a disk pack with the following specifications- 16 surfaces, 128 tracks per surface, 256 sectors per track and 512 bytes per sector.
  - What is the capacity of disk pack ?
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Hard Disk Performance

- Given:
  - Number of surfaces = 16
  - Number of tracks per surface = 128
  - Number of sectors per track = 256
  - Number of bytes per sector = 512 bytes

If the disk system has rotational speed of 3000 RPM, What is the average access time with a seek time of 11.5 msec ?

Time taken for one full rotation

= (60 / 3000) sec

= (1 / 50) sec

= 0.02 sec

= 20 msec

Hard Disk Performance

- **Given:**
  - **Number of surfaces = 16**
  - **Number of tracks per surface = 128**
  - **Number of sectors per track = 256**
  - **Number of bytes per sector = 512 bytes**

If the disk system has rotational speed of 3000 RPM, What is the average access time with a seek time of 11.5 msec ?

Average rotational delay

= 1/2 x Time taken for one full rotation

= 1/2 x 20 msec

= 10 msec

Hard Disk Performance

- Given:
    - Number of surfaces = 16
    - Number of tracks per surface = 128
    - Number of sectors per track = 256
    - Number of bytes per sector = 512 bytes

If the disk system has rotational speed of 3000 RPM, What is the average access time with a seek time of 11.5 msec ?

Now, average access time

= Average seek time + Average rotational delay + Other factors

= 11.5 msec + 10 msec + 0

= 21.5 msec

Hard Disk Performance

A disk pack has 19 surfaces and storage area on each surface has an outer diameter of 33 cm and inner diameter of 22 cm. The maximum recording storage density on any track is 200 bits/cm and minimum spacing between tracks is 0.25 mm. Calculate the capacity of disk pack.

Given-

- Number of surfaces = 19
- Outer diameter = 33 cm
- Inner diameter = 22 cm
- Maximum recording density = 200 bits/cm
- Inter track gap = 0.25 mm

Hard Disk Performance

Given-

- **Number of surfaces = 19**
- **Outer diameter = 33 cm**
- **Inner diameter = 22 cm**
- **Maximum recording density = 200 bits/cm**
- **Inter track gap = 0.25 mm**

Number of Tracks on each surface

- Number of tracks on each surface
- = (Outer radius – Inner radius) / Inter track gap
- = (16.5 cm – 11 cm) / 0.25 mm
- = 5.5 cm / 0.25 mm
- = 55 mm / 0.25 mm
- = 220 tracks

Hard Disk Performance

Given-

- **Number of surfaces = 19**
- **Outer diameter = 33 cm**
- **Inner diameter = 22 cm**
- **Maximum recording density = 200 bits/cm**
- **Inter track gap = 0.25 mm**

Capacity of Each Track -

- Capacity of each track
- = Maximum recording density x Circumference of innermost track
- = 200 bits/cm x (3.14 x 22 cm)
- = 200 x 69.08 bits
- = 13816 bits
- = 1727 bytes

Hard Disk Performance

Given-

- Number of surfaces = 19
- Outer diameter = 33 cm
- Inner diameter = 22 cm
- Maximum recording density = 200 bits/cm
- Inter track gap = 0.25 mm

Capacity of Disk Pack

- Capacity of disk pack

- = Total number of surfaces x Number of tracks per surface x Capacity of one track

- = 19 x 220 x 1727 bytes
- = 7218860 bytes
- = 6.88 MB

Magnetic Tape

- Was early secondary-storage medium
    - Evolved from open spools to cartridges
- 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

Magnetic Tape

- Once data under head, transfer rates comparable to disk
    - 140MB/sec and greater
    - 200GB to 1.5TB typical storage
- Common technologies are LTO-{3,4,5} and T10000
- **Linear Tape-Open (LTO)** is a magnetic tape data storage technology originally developed in the late 1990s
- **LTO** is widely used with small and large computer systems, especially for backup.
- The T10000 is the latest Oracle/Sun StorageTek tape drive and cartridge product line for mainframe and open systems.

Solid-State Drive

- Nonvolatile memory used like a hard drive
    - Many technology variations
- Can be more reliable than HDDs
- More expensive per MB
- Maybe have shorter life span
- Less capacity
- Busses can be too slow -> connect directly to PCI for example
- No moving parts, so no seek time or rotational latency

Solid-State Disks - Additional Input

- Solid-state drives are called that specifically because they don’t rely on moving parts or spinning disks.

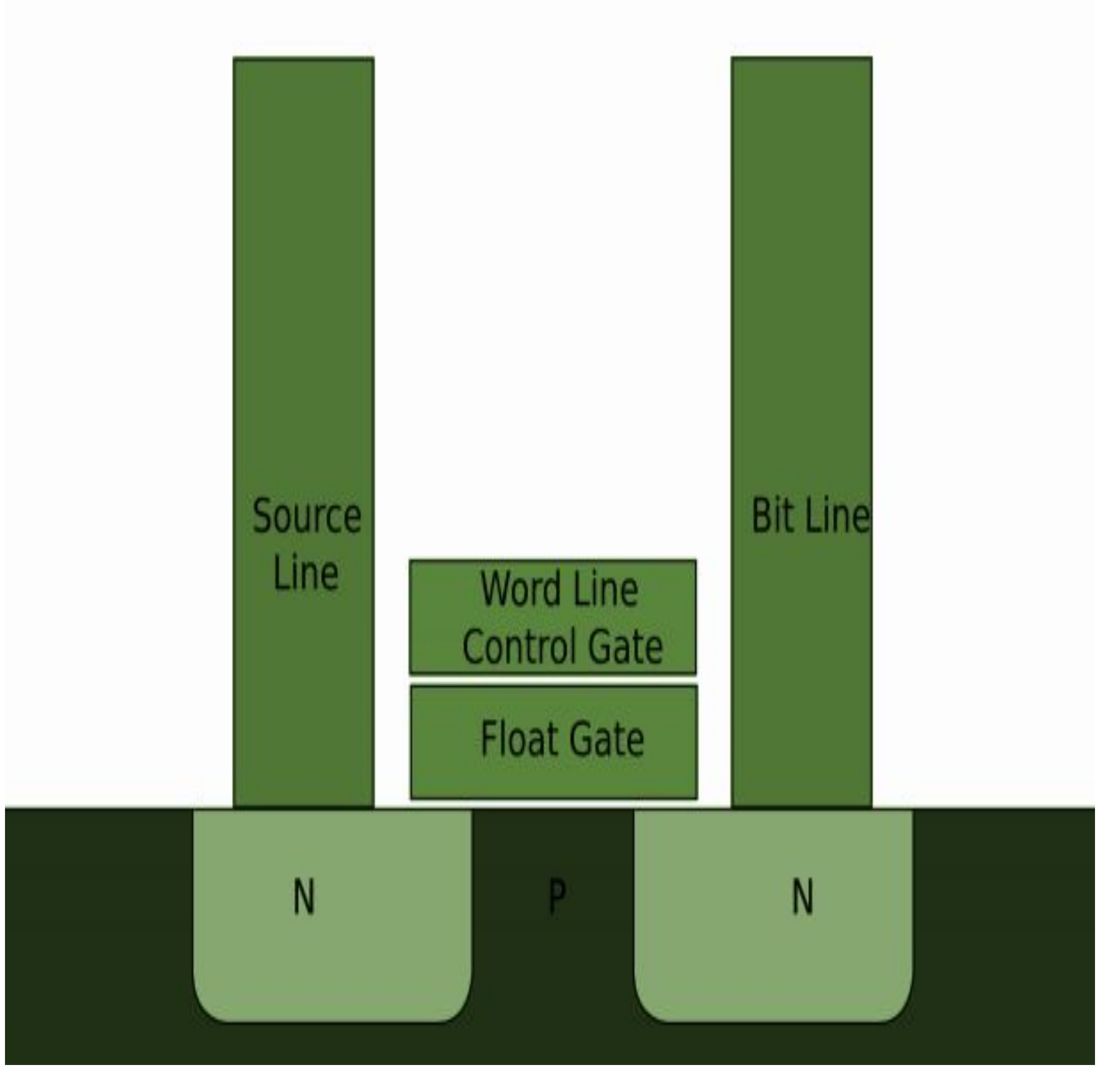
- Instead, data is saved to a pool of NAND flash

- NAND itself is made up of what are called floating gate transistors.

- Unlike the transistor designs used in DRAM, which must be refreshed multiple times per second, NAND flash is designed to retain its charge state even when not powered up.

- This makes NAND a type of non-volatile memory.

Solid-State Disks - Additional Input



- The diagram on your left shows a simple flash cell design.
- Electrons are stored in the floating gate, which then reads as charged “0” or not-charged “1.”
- In NAND flash, a 0 means data is stored in a cell — it’s the opposite of how we typically think of a zero or one.
- NAND flash is organized in a grid.
- The entire grid layout is referred to as a block, while the individual rows that make up the grid are called a page.
- Common page sizes are 2K, 4K, 8K, or 16K, with 128 to 256 pages per block. Block size therefore typically varies between 256KB and 4MB.

Solid-State Disks - Additional Input

	SLC	MLC	TLC	HDD	RAM
P/E cycles	100k	10k	5k	*	*
Bits per cell	1	2	3	*	*
Seek latency (µs)	*	*	*	9000	*
Read latency (µs)	25	50	100	2000-7000	0.04-0.1
Write latency (µs)	250	900	1500	2000-7000	0.04-0.1
Erase latency (µs)	1500	3000	5000	*	*

- **P/E** : **P**rogram **E**rase **C**ycle
- **SLC** : **S**ingle **L**evel **C**ell
- **MLC** : **M**ulti **L**evel **C**ell
- **TLC**: **T**riple **L**evel **C**ell

Solid-State Disks - Additional Input

	SLC	MLC	TLC	HDD	RAM
P/E cycles	100k	10k	5k	*	*
Bits per cell	1	2	3	*	*
Seek latency (μs)	*	*	*	9000	*
Read latency (μs)	25	50	100	2000-7000	0.04-0.1
Write latency (μs)	250	900	1500	2000-7000	0.04-0.1
Erase latency (μs)	1500	3000	5000	*	*

- NAND is nowhere near as fast as main memory, but it's multiple orders of magnitude faster than a hard drive.

- While write latencies are significantly slower for NAND flash than read latencies, they still outstrip traditional spinning media

- There are two things to notice in the chart on your left.

- First, note how adding more bits per cell of NAND has a significant impact on the memory's performance.

Solid-State Disks - Additional Input

	SLC	MLC	TLC	HDD	RAM
P/E cycles	100k	10k	5k	*	*
Bits per cell	1	2	3	*	*
Seek latency (μs)	*	*	*	9000	*
Read latency (μs)	25	50	100	2000-7000	0.04-0.1
Write latency (μs)	250	900	1500	2000-7000	0.04-0.1
Erase latency (μs)	1500	3000	5000	*	*

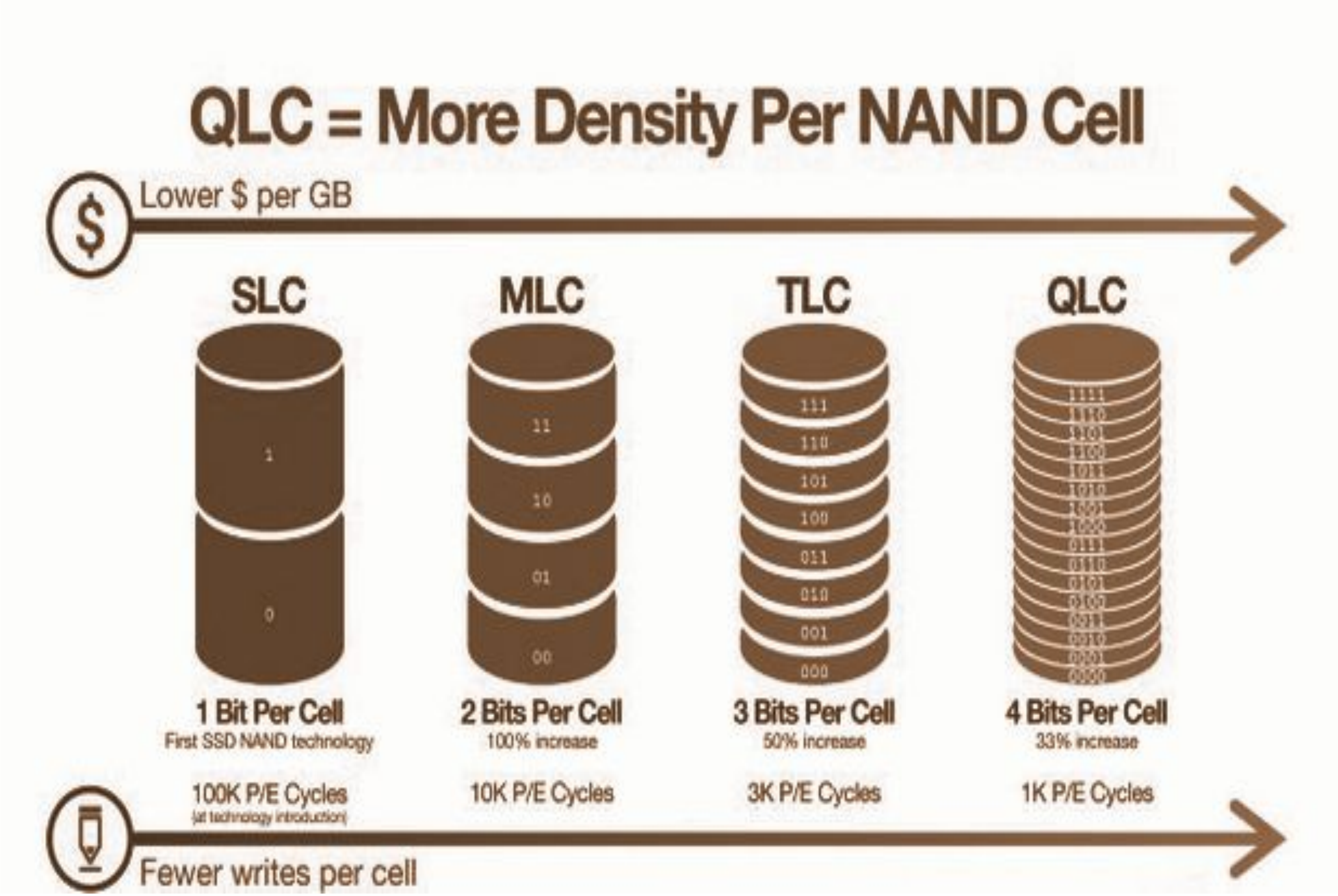
- It's worse for writes as opposed to reads — typical triple-level-cell (TLC) latency is 4x worse compared with single-level cell (SLC) NAND for reads, but 6x worse for writes.
- Erase latencies are also significantly impacted.
- The impact isn't proportional, either — TLC NAND is nearly twice as slow as MLC NAND, despite holding just 50% more data (three bits per cell, instead of two).
- This is also true for QLC drives, which store even more bits at varying voltage levels within the same cell.

Solid-State Disks - Additional Input

	SLC	MLC	TLC	HDD	RAM
P/E cycles	100k	10k	5k	*	*
Bits per cell	1	2	3	*	*
Seek latency (μs)	*	*	*	9000	*
Read latency (μs)	25	50	100	2000-7000	0.04-0.1
Write latency (μs)	250	900	1500	2000-7000	0.04-0.1
Erase latency (μs)	1500	3000	5000	*	*

- The reason TLC NAND is slower than MLC or SLC has to do with how data moves in and out of the NAND cell.
- With SLC NAND, the controller only needs to know if the bit is a 0 or a 1. With MLC NAND, the cell may have four values — 00, 01, 10, or 11.
- With TLC NAND, the cell can have eight values, and QLC has 16.
- Reading the proper value out of the cell requires the memory controller to use a precise voltage to ascertain whether any particular cell is charged.
- QLC : Quad Level Cell

Solid-State Disks - Additional Input



Solid-State Disks - Additional Input

Media	Estimated Lifespan
Magnetic data (tapes)	Up to 10 years
Nintendo cartridge	10-20 years
Floppy disk	10-20 years
CDs and DVDs	5-10 unrecorded, 2-5 recorded
Blu-Ray	Not certain, probably over 2-5 recorded
M-Disc	1,000 years (theoretically)
Hard disk	3-5 years
Flash storage	5-10 years or more (depends on write cycles)

Solid State Drive

Around 10 years

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Topics Uncovered in the Session

- Overview of Mass Storage Structure
- Moving-head Disk Mechanism
- Hard Disks
- Hard Disk Performance
- Magnetic Tape
- Solid-State Disks

THANK YOU

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