Review of Last Lecture

- HD access: 3 steps, block access
- RAID technologies
  - Striping, mirroring, parity
  - RAID 0, 1 and 5

Performance	0	1	5
Access speed	Striping, N timers faster	Mirroring No improvement N must be even	Striping and parity N timers faster
Space Efficiency	100%	50%	(N-1/)N
Fault tolerance	None, data loss greatly increase	No problem for 1 HD failure, and up to N/2 if lucky	One and only one HD failure, no problem

Today's Plan

- Data backup
  - Online vs. offline
  - Full vs. incremental
- SSD and tape drive
  - SSD: used a primary storage, not as backup
  - Tape: use only for offline backup

How to put this into practical use?

- On Feb 1, 2004, 3 days before FB launches, Mark Zuckerberg asks his CIO (you) :“We spent $10 Million to build a data server with 10,000 HDs setup in RAID 5. Do you think it is fast enough to handle user demands?”
- Answer #1: “Mark, you are asking the wrong person. My major from UW is NOT computer science ....”.
- Answer #1:”Yes, I think so. If not, we can always add more later on.
- Answer #2:”Let’s do some user testing.” Delay launch. After coding for many months, testing servers (simulating millions of concurrent access is not easy).
- Answer #3:”Let me apply what I learned at UW and show you some math.”

Fired

replaced

Demoted

Is it enough?

One HD =50MBps
10,000HD=50MBps * 10,000=500GBps

- Speed performance for RAID 5 with 10,000 HDs.
  - How much user traffic can it handle?

Approach one: how many users do you expect daily?
ANS: 1M => 12 users per second!

Approach two: how many users can it handle at maximal?
How long can a user wait for a page?
How big is a page?
5MB in 3 second => 5MB/3s = 1.7MBps
500GBps / 1.7MBps = = 294,118 visitors every 3 seconds

Meaning: capacity is 8.4 billion users daily!

Data Backup

- Online backup (hot backup)
  - Instant real-time backup
  - Example: RAID 1 and RAID 5
  - Protect against one HD failure
- Offline backup (archive)
  - Done at the end of the day, copy and ship to a different location
  - Example: backup to tape drive
  - Protect against complete failure, but can only recover data from one day (some time) ago.
  - Full vs. incremental backup

Incremental Backup

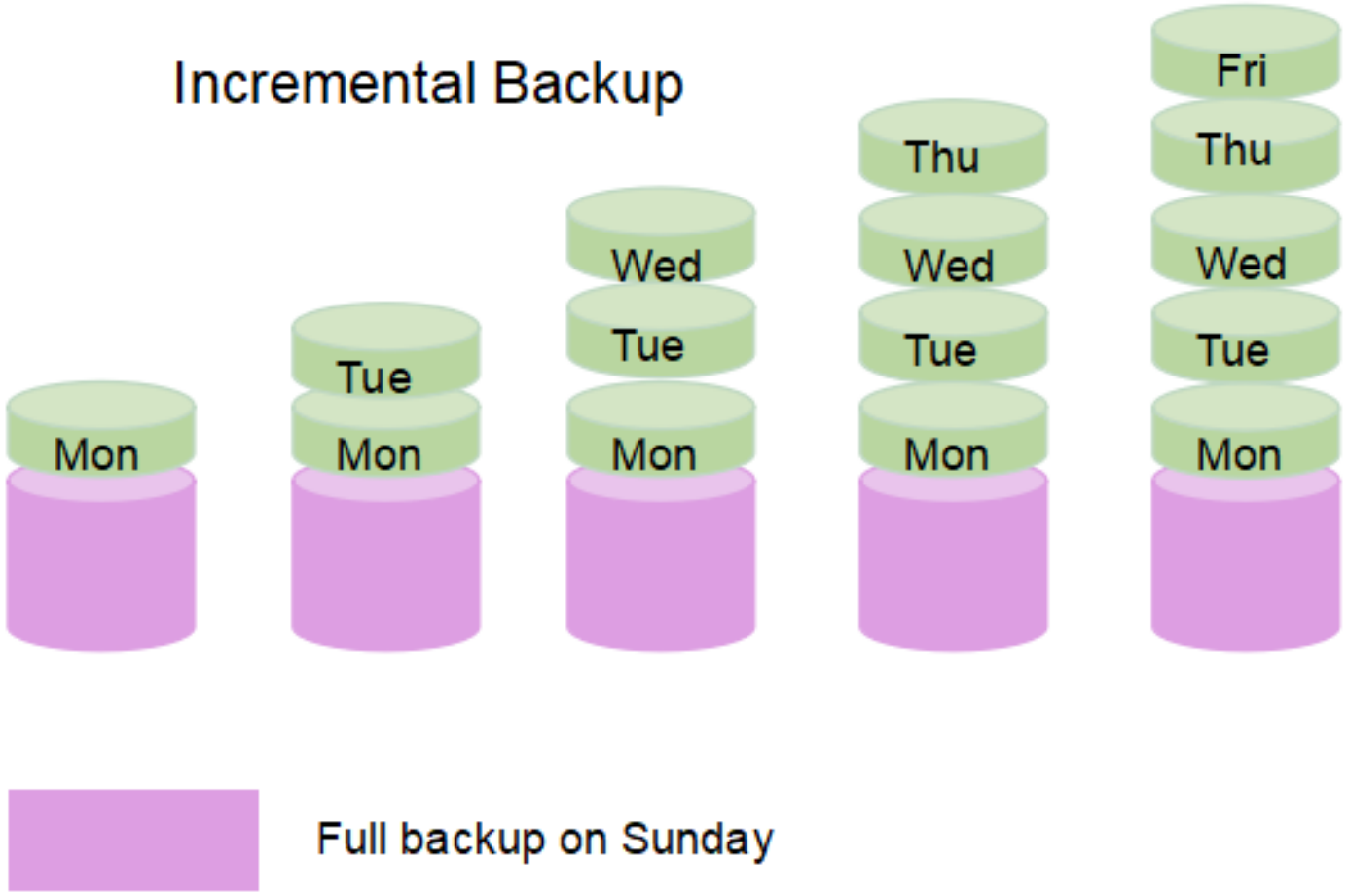


Image Source: https://www.easeus.com/backup-utility/differential-backup-vs-incremental-backup.html

Alternative Mass Storage Devices

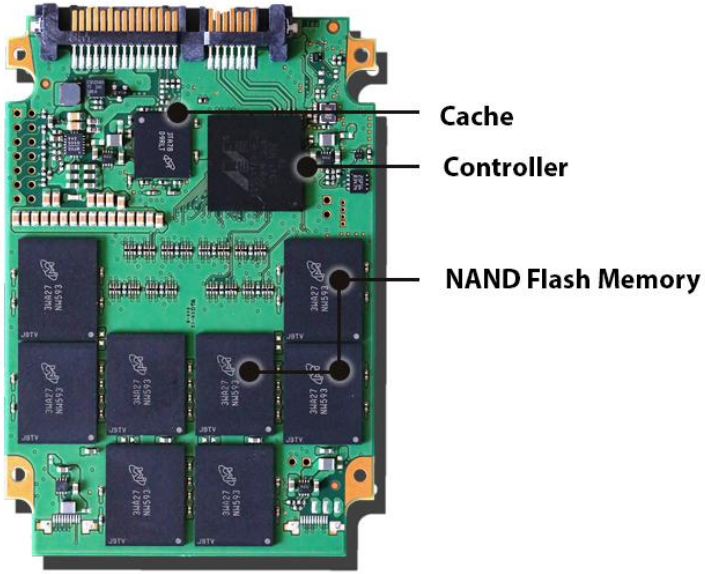
- Solid State Drive (SSD)
- Tape drive
- Optical drive
  - Not modifiable (or too slow to modify), hence not considered here

HDD vs. SSD

HDD
3.5″

Shock resistant up to 55g (operating)
Shock resistant up to 350g (non-operating)

SSD
2.5″



Shock resistant up to 1500g
(operating and non-operating)

Image Source: https://www.backblaze.com/blog/ssd-vs-hdd-future-of-storage/

Comparison: HDD vs. SSD

	HDD	SSD
Failure Rate	Mean time between failure rate of 1.5 million hours	Mean time between failure rate of 2.0 million hours
File Copy / Write Speed	The range can be anywhere from 50–120MB/s	Generally above 200 MB/s and up to 550 MB/s for cutting edge drives
File Opening Speed	Slower than SSD	Up to 30% faster than HDD
Affected by Magnetism	Magnets can erase data	An SSD is safe from any effects of magnetism
Ruggedness	Vulnerable to physical jolts and movement	Not vulnerable to jolts and vibration

Source: https://www.backblaze.com/blog/hdd-vs-ssd-in-data-centers/

Comparison: HDD vs. SSD

	HDD	SSD
Power Draw/Battery Life	More power draw, averages 6–7 watts and therefore uses more battery	Less power draw, averages 2–3 watts, resulting in 30+ minute battery boost
Cost	Only around $0.03 per gigabyte, very cheap (buying a 4TB model)	Expensive, roughly $0.20- $0.30 per gigabyte (based on buying a 1TB drive)
Capacity	Typically around 500GB and 2TB maximum for notebook size drives; 10TB max for desktops	Typically not larger than 1TB for notebook size drives; 4TB for desktops
Operating System Boot Time	Around 30-40 seconds average bootup time	Around 8-13 seconds average bootup time
Noise	Audible clicks and spinning platters can be heard	There are no moving parts, hence no sound
Vibration	The spinning of the platters can sometimes result in vibration	No vibration as there are no moving parts

Tape Drive

Image Source: https://www.mlogic.com/products/desktop-sas-lto-8-tape-drive

Tape Drive

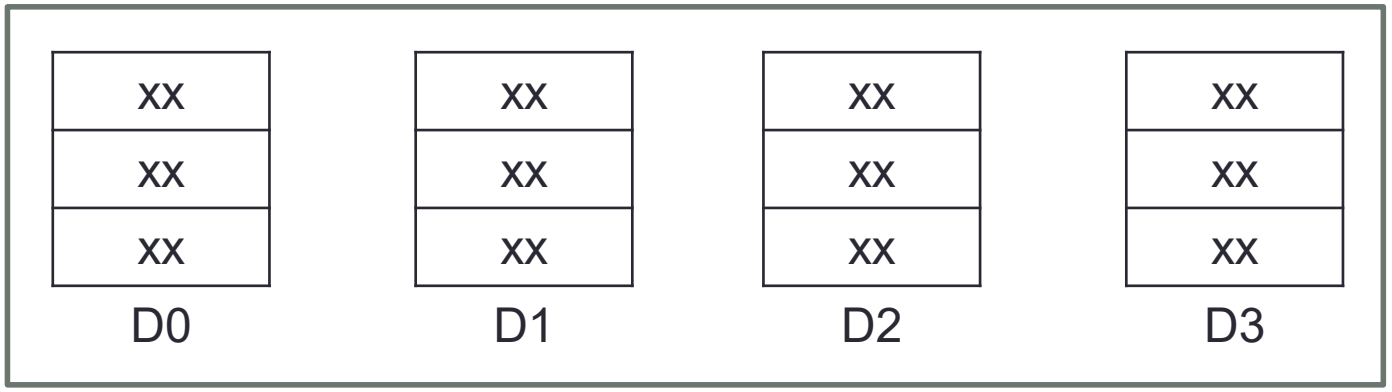
Pros (Compared to HDD)	Cons
• 3x cheaper than HDD for large system (50TB+) • Cost-effective in terms of expenses, i.e. electricity, cooling, maintenance • Hard drives require power to run - Tape requires no electrical power when not being actively used • Faster than HDD for sequential access. Hence fast for full system recovery • Less sensitive to mechanical damage and drop • 30 year shelf life • Tape can sit cold and unused for decades. Hard drives need to be spun up occasionally or they freeze up and/or errors build up.	• High entry cost. Besides the tapes, need a special drive (it costs over $1,000) • Not for random access • Proper storage conditions (temperature/humidity) required to achieve 10+ year shelf life • If re-used often (approx. 100x), tapes are prone to wear and tear. Therefore better suited for long-term archive. If used for recurring backup, tapes should be replaced in approx. 3-year cycles • Not as plug-and-play like HDD. Technology requires proper/proprietary drivers and/or a technology-aware application for driving it.

Comprehensive Exercise

- For simplicity: each block is 2-bit
- File F

F1	01
F2	11
F3	10
F4	00
F5	11

- 4 HDs



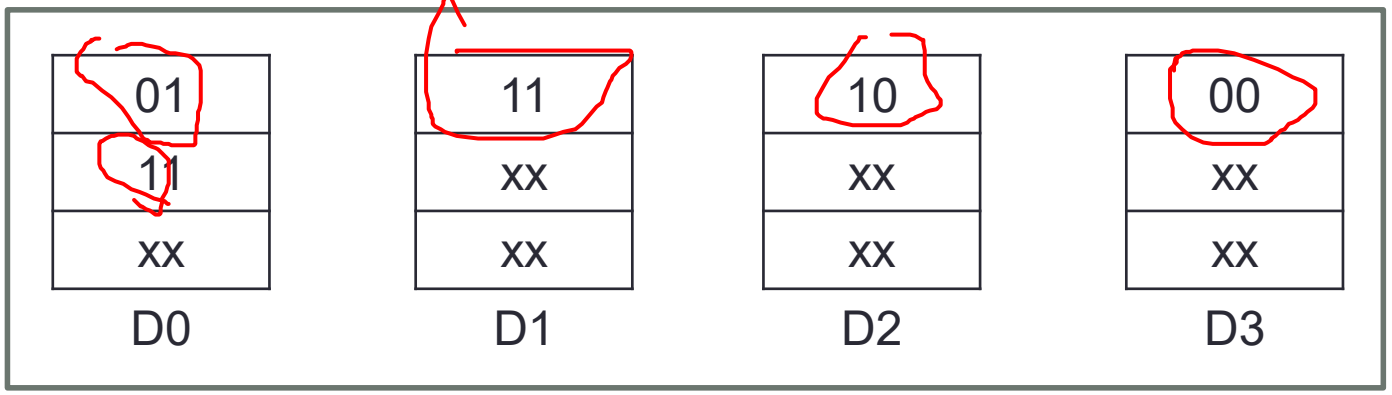
- How is F stored in RAID 0, RAID 1, RAID 5?

Comprehensive Example – R0

- For simplicity: each block is 2-bit
- File F

F1	01
F2	11
F3	10
F4	00
F5	11

- 4 HDs

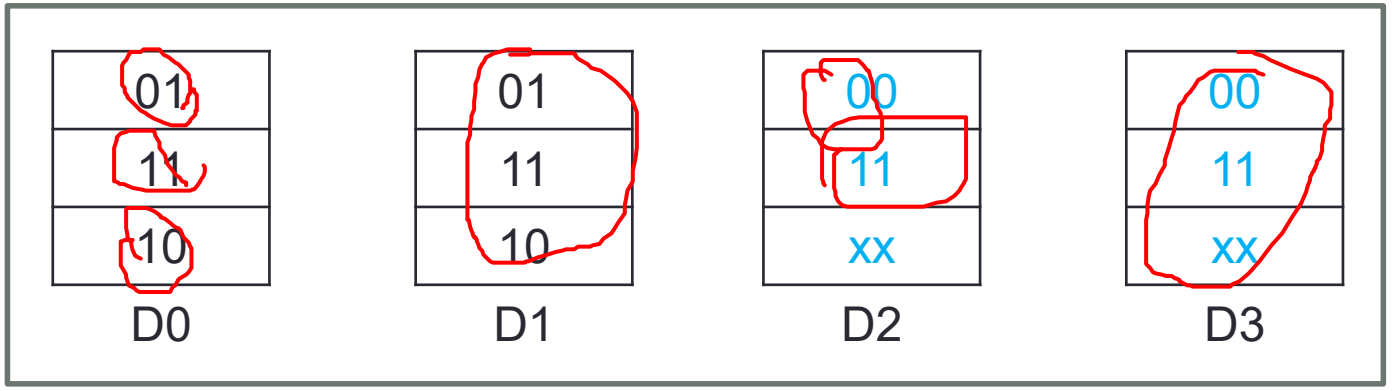


Comprehensive Example – R1

- For simplicity: each block is 2-bit
- File F

F1	01
F2	11
F3	10
F4	00
F5	11

- 4 HDs

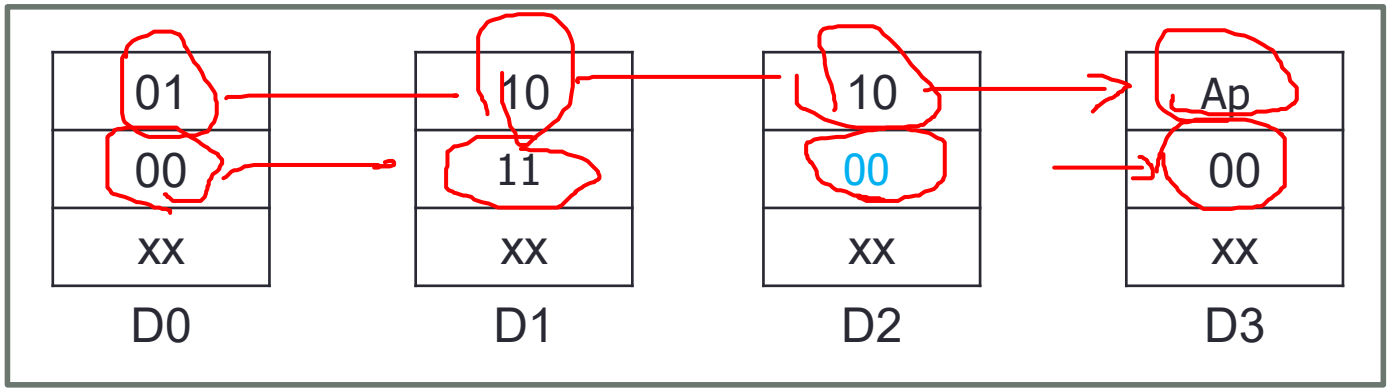


Comprehensive Example – R5

- For simplicity: each block is 2-bit, assume odd parity
- File F

F1	01
F2	10
F3	10
F4	00
F5	11

- 4 HDs



Summary of Today's Lecture

- Data backup
  - Online vs. offline
  - Full vs. incremental
- SSD and tape drive
  - SSD: used a primary storage, not as backup
  - Tape: use only for offline backup

Recap of Our Journey

- Database and DBMS
- Relational data model
- Relational algebra and SQL
- ERD and mapping
- Normalization
- Transaction control
- Storage technologies