Storage and reliability

Computer Architecture

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Magnetic disks

- High storage capacity (hundreds of GBs).
- Spin at constant angular velocity.
- Access time for data stream:
  - T = track seek + rotation latency.
  - Depends on the stream access sequence.

Density

- Bits stored along track (BPI).
- Number of tracks per surface (TPI).
- Disks design trend to increasing density of bits stored per area unit (Areal Density).
- Areal Density = BPI $\times$ TPI

Year	Density
1973	2
1979	8
1989	63
1997	3,090
2000	17,100
2006	130,000

History perspective

- 1956 IBM Ramac $\rightarrow$ Early 70s Winchester.
  - Developed for mainframes.
  - Proprietary interfaces.
  - Constant reduction of size: from 27 to 14 inches.
- 1970s.
  - 5.25 inches.
  - Industry of standard interfaces for storage emerge.
- Early 1980s: Personal Computers (PCs) and first generations of desktop computers.

History perspective

- Mid 1980s: Client/server computing.
  - Centralized storage in file servers.
  - Miniaturization increases: 8 inches to 5.25.
  - Mass production of disk units in the market.
  - Standards: SCSI, IPI, IDE.
  - 5.25 inches to 3.5 inches for PCs.
- 1900s: Laptops => 2.5 inches.
- 2000s: New devices leading to new units:
  - 1.8 inches: iPods, MP3 players.
  - 1 inch IBMs microdrive.
  - 0.85 inches (Toshiba) mobile phones.

Illiac IV

- University of Illinois (1974)
  - 30,000,000$.
  - Solid state memory.
  - Laser memory.
  - Fastest in the world until 1981.
  - Numeric computing for NASA.

Disk capacity and performance

- Continuous increase in capacity (60%/year) and bandwidth (40%/year).
- Slow increase of disk rotation (8%/year).
- Time to read the whole disk.

Year	Sequentially	Randomly (1 sector/seek)
1990	4 min.	6 hours
2000	12 min.	1 week
2006 (SCSI)	56 min.	3 weeks
2006 (SATA)	171 min.	7 weeks

2 Reliability and availability

- Reliability
- Availability

Reliability

- The lifetime of a system represented as a random variable X.
- System reliability defined as function $R(t)$

$$R(t) = P(X > t) : R(0) = 1 \quad y \quad R(\inf) = 0 \tag{1}$$

Reliability and failures

- From study of components failures we obtain reliability

- **Reliability**: Probability that a device works properly during a given period of time under specific operating conditions.

Reliability distributions

- Examples of distributions used for reliability:

  - Exponential:
    - If error rate is constant (generally true for electronic components), reliability follows an exponential distribution.

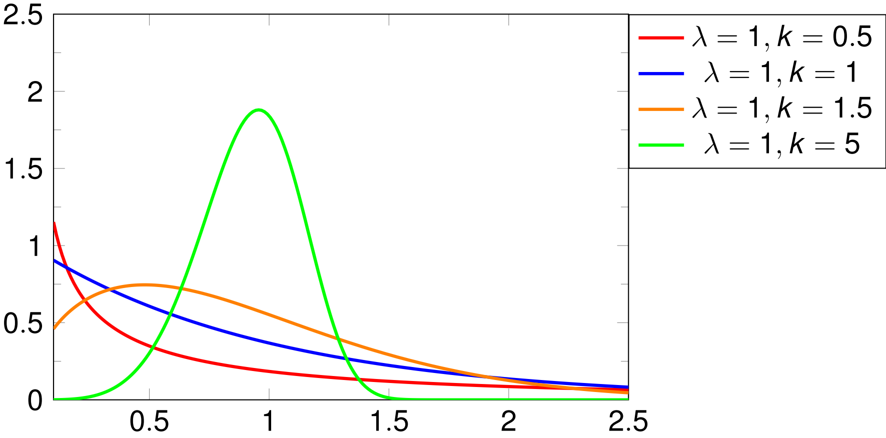
Reliability distributions

- Weibull:
  - Density function:

$$f(x;\lambda,k) = \begin{cases} \frac{k}{\lambda} \cdot \left(\frac{x}{\lambda}\right)^{k-1} \cdot e^{-\left(\frac{x}{\lambda}\right)^k} & x \geq 0 \\ 0 & x < 0 \end{cases} \quad (2)$$

  - Parameter k also called shape factor:
    - $k < 1 \rightarrow$ failure rate decreases over time.
    - $k = 1 \rightarrow$ failure rate is constant over time.
    - $k > 1 \rightarrow$ failure rate increases over timem.
  - Models failure distribution whe failure rate is proportional to a power of time.

Weibull

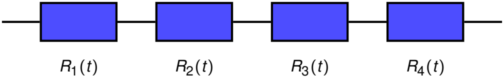

2.5
2
1.5
1
0.5
0
0.5
1
1.5
2
2.5
$\lambda = 1, k = 0.5$
$\lambda = 1, k = 1$
$\lambda = 1, k = 1.5$
$\lambda = 1, k = 5$

Reliability distributions

- Weibull:
  - Characteristic life η (time in which 63.2% of population fails) and form factor β
    - Associated to error rate, with $\beta = 1 \rightarrow$ constant error rate.

Serial systems

- Let $R_i(t)$ reliability for component **i**.
- System fails when some component fails.



- If failures are independent then:

$$R(t) = \prod_{i=1}^{N} R_i(t)$$

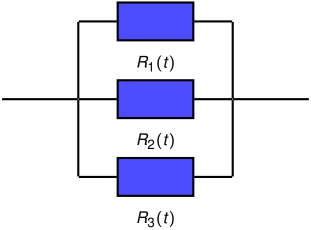
- System reliability is lower:

$$R(t) < R_i(t) \forall i$$

Paralel system

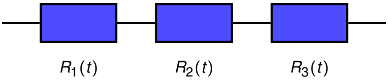
- System fails when all components fail.

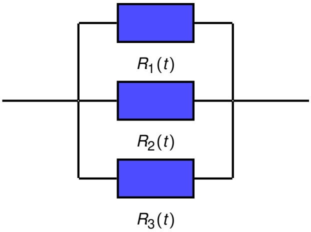
$$R(t) = 1 - \prod_{i=1}^{N} Q_i(t) : Q_i(t) = 1 - R_i(t)$$



Example

Para $t = 100$ $R_i(t) = 0.9$





$$R(t) = 0.9 \cdot 0.9 \cdot 0.9 = 0.729$$

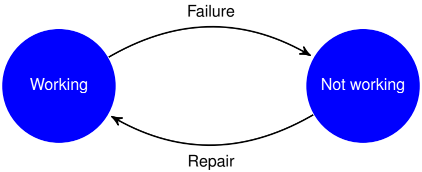
$$R(t) = 1 - (1 - 0.9)^3 = 0.999$$

2 Reliability and availability

- Reliability
- Availability

Availability

- In many cases, it is more interesting to know availability.
- Availability of a system $A(t)$ defined as the probability that the system is working correctly at instant t.
  - Reliability considers interval $[0, t]$.
  - Availability considers a concrete instant in time.
- A system modelled as following state diagram.



Availability measurement

- Let MTTF the average time to failure.
- Let MTTR the average time to repair.
- System availability A is defined as:

$$A = \frac{MTTF}{MTTF + MTTR}$$

- What does a reliability of 99% mean?
  - In 365 days, it works correctly $\frac{99 \cdot 365}{100} = 361.35$ days.
  - Out of service 3.65 days.

Annual time without service

Availability (%)	Days without service in a year
98%	7.3 days
99%	3.65 days
99.8%	17 hours y 30 minutes
99.9%	8 hours y 45 minutes
99.99%	52 minutes y 30 seconds
99.999%	5 minutes y 15 seconds
99.9999%	31.5 seconds

Computing availability

- Elements availability
  - HW: 99.99%
  - Disk: 99.9%
  - SO: 99.99%
  - Application: 99.9%
  - Communications: 99.9%

- System availability:
  - Product of elements availability.

$$A(t) = \prod_{i=1}^{N} A_i(t) = 99.6804 \Rightarrow 1.17 \text{days without service}$$

Sectors with most service interruptions

Sector	Percentage
Bank and finance	26%
Government, public administrations and institutions	19.1%
Education	11.3%
Industry	10.9%
Services	9.5%
Communications	8.2%

Cost of stopping one hour

Cost	Percentage
Up to 50,000$	46%
50,000$ – 100,000$	15%
100,000$ – 250,000$	13%
250,000$ – 500,000$	9%
500,000$ – 1,000,000$	9%
1,000,000$ – 5,000,000$	4%
More than 5,000,000$	4%

What to do with failures?

- Problems in disks:
  - Failure in the disk itself.
  - Failure in the disk controller.
  - Failure in block (damaged sectors).
  - Transient failures.

- Using a redundant storage system:
  - **R**edundant **A**rray of **I**nexpensive/Independent **D**isks.
  - Proposed for the first time in 1998 by David A. Patterson, Garth A. Gibson and Randy H. Katz.
  - *"A case for inexpensive arrays of redundant disks (RAID)"*

RAID Disks

- Several types of RAID:
- Basic levels:
  - **RAID 0**: block distribution (striping) without fault tolerance.
  - **RAID 1**: disk mirroring.
  - **RAID 2**: bit level interleaving with Hamming.
  - **RAID 3**: bit level interleaving with redundant information (parity)
  - **RAID 4**: block distribution with parity disk.
  - **RAID 5**: block distribution with distributed parity.
- Combinations:
  - **RAID 10**: Stripping and mirroring (RAID 0 and 1).
  - **RAID 51**: Combination of RAID 5 and RAID 1.
  - . . .

RAID 0 (striping)

- Fault tolerance:
  - Does not offer fault tolerance.
- Performance:
  - Higher throughput in read/write operations.
- Capacity:
  - Addition.

RAID 1 (mirroring)

- Fault tolerance:
  - 1 failure.
- Performance:
  - Higher throughput in read operations.
- Capacity:
  - 50% of total.

RAID 2

- Failure detection.
- Use Hamming code.
- Bit level *Striping*.
- Very costly implementation.
- Not used.

RAID 3

- RAID 3 (*striping with dedicated parity, bit level*.
- Byte level stripping.
- Parity of written bytes.
- Tolerance to 1 failure.
- Use byte level redundancy.
- Improve throughput:
  Parallel access to block.
- Parity disk is a bottleneck.

RAID 4

- RAID 4 (*striping with dedicated parity*.
- Block level striping.
- Fault tolerance: 1 failure.
- Performance:
  - Costly writes (parity).
  - Parity disk is a bottleneck.
- Capacity: $\frac{100 \cdot (n-1)}{n}\%$

RAID 3 versus RAID 4

- **RAID 3**: Each byte in a disk.
- **RAID 4**: Each block in a disk.

RAID 5

- RAID 5 (*striping with distributed parity*.
- Block level striping.
- Parity striping.
- Parity is not in the same disk as associated blocks.
- Fault tolerance: 1 failure.
- There is no bottleneck in access to parity.
- Capacity: $\frac{100\cdot(n-1)}{n}\%$

RAID 6

- RAID 6 (*striping with distributed redundant parity*.
- Block level striping.
- Parity striping.
- Parity is replicated twice.
- Parity is not in the same disk than the associated blocks.
- Fault tolerance: 2 failures.
- There is no bottleneck in access to parity.

Reads in RAID 4-5

- If disk works:
  - Corresponding disk is read.
- If disk does not work:
  - Blocks in other disks and parity disk are read to compute new block.

Writes in RAID 4-5

- If disk works:
  - Write a block and the new parity, by:
    1. Read the old block OB and the parity block OP.
    2. New parity will be: $NP = (OB \oplus NB) \oplus OP$.
    3. Write the new block NB and the parity block NP.
- If disk does not work:
  - Update block and parity in working disk.

- Whe disk fails is substituted and its information is reconstructed.

Summary

- Reliability models system life time.
- Parallel systems allow improving system reliability while serial systems worsen system reliability.
- Availability models the probability of failures at instant in time.
- RAID systems improve both performance and reliability of storage systems.

References

- **Computer Architecture. A Quantitative Approach**
  5th Ed.
  Hennessy and Patterson.
  Sections D.1, D.2, D.3, D.4.

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