Computer Architecture
(CSC-3501)
Lecture 24
(22 April 2008)

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Announcement

7.7 Optical Disks

- Optical disks provide large storage capacities very inexpensively.
- They come in a number of varieties including CD-ROM, DVD, and WORM.
- Many large computer installations produce document output on optical disk rather than on paper. This idea is called COLD-- *Computer Output Laser Disk*.
- It is estimated that optical disks can endure for a hundred years. Other media are good for only a decade-- at best.

7.7 Optical Disks

- CD-ROMs were designed by the music industry in the 1980s, and later adapted to data.
- This history is reflected by the fact that data is recorded in a single spiral track, starting from the center of the disk and spanning outward.
- Binary ones and zeros are delineated by bumps in the polycarbonate disk substrate. The transitions between pits and lands define binary ones.
- If you could unravel a full CD-ROM track, it would be nearly five miles long!

7.7 Optical Disks

- The logical data format for a CD-ROM is much more complex than that of a magnetic disk. (See the text for details.)
- Different formats are provided for data and music.
- Two levels of error correction are provided for the data format.
- Because of this, a CD holds at most 650MB of data, but can contain as much as 742MB of music.

7.7 Optical Disks

- DVDs can be thought of as quad-density CDs.
  - Varieties include single sided, single layer, single sided double layer, double sided double layer, and double sided double layer.
- Where a CD-ROM can hold at most 650MB of data, DVDs can hold as much as 17GB.
- One of the reasons for this is that DVD employs a laser that has a shorter wavelength than the CD's laser.
- This allows pits and land to be closer together and the spiral track to be wound tighter.

7.7 Optical Disks

- A shorter wavelength light can read and write bytes in greater densities than can be done by a longer wavelength laser.
- This is one reason that DVD's density is greater than that of CD.
- The manufacture of blue-violet lasers can now be done economically, bringing about the next generation of laser disks.
- Two incompatible formats, HD-CD and Blu-Ray, are competing for market dominance.

7.7 Optical Disks

- Blu-Ray was developed by a consortium of nine companies that includes Sony, Samsung, and Pioneer.
  - Maximum capacity of a single layer Blu-Ray disk is 25GB.
- HD-DVD was developed under the auspices of the DVD Forum with NEC and Toshiba leading the effort.
  - Maximum capacity of a single layer HD-DVD is 15GB.
- The big difference between the two is that HD-DVD is backward compatible with red laser DVDs, and Blu-Ray is not.

7.7 Optical Disks

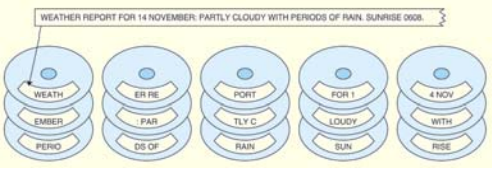
- Blue-violet laser disks have also been designed for use in the data center.
- The intention is to provide a means for long term data storage and retrieval.
- Two types are now dominant:
  - Sony's Professional Disk for Data (PDD) that can store 23GB on one disk and
  - Plasmon's Ultra Density Optical (UDO) that can hold up to 30GB.
- It is too soon to tell which of these technologies will emerge as the winner.

7.9 RAID

- RAID, an acronym for *Redundant Array of Independent Disks* was invented to address problems of disk reliability, cost, and performance.
- In RAID, data is stored across many disks, with extra disks added to the array to provide error correction (redundancy).
- The inventors of RAID, David Patterson, Garth Gibson, and Randy Katz, provided a RAID taxonomy that has persisted for a quarter of a century, despite many efforts to redefine it.

7.9 RAID

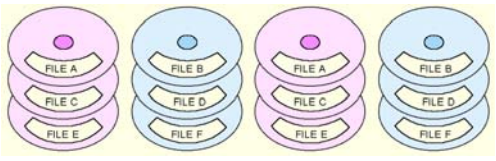
- RAID Level 0, also known as *drive spanning*, provides improved performance, but no redundancy.
  - Data is written in blocks across the entire array



  - The disadvantage of RAID 0 is in its low reliability.

7.9 RAID

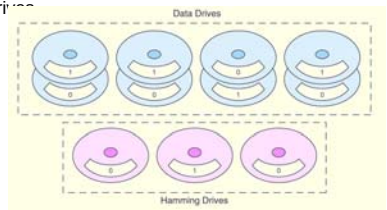
- RAID Level 1, also known as *disk mirroring*, provides 100% redundancy, and good performance.
  - Two matched sets of disks contain the same data.



  - The disadvantage of RAID 1 is cost.

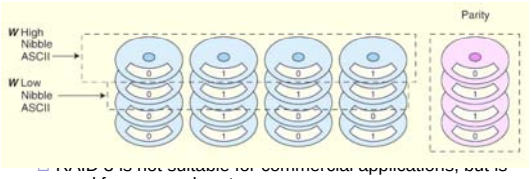
7.9 RAID

- A RAID Level 2 configuration consists of a set of data drives, and a set of Hamming code drives.
  - Hamming code drives provide error correction for the data dri
  - RAID 2 performance is poor and the cost is relatively high.



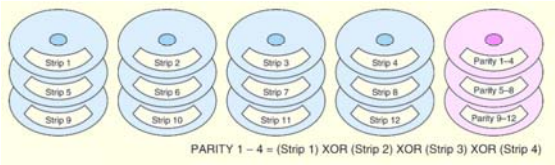
7.9 RAID

- RAID Level 3 stripes bits across a set of data drives and provides a separate disk for parity.
  - Parity is the XOR of the data bits.
  - RAID 3 is not suitable for commercial applications, but is good for personal systems.



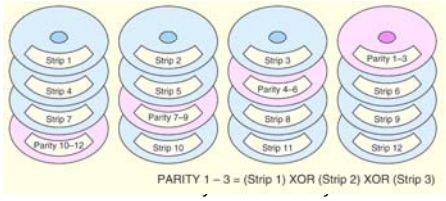
7.9 RAID

- RAID Level 4 is like adding parity disks to RAID 0.
  - Data is written in blocks across the data disks, and a parity block is written to the redundant drive.
  - RAID 4 would be feasible if all record blocks were the same size.



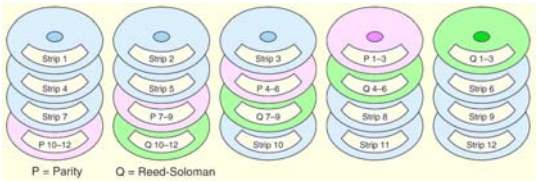
7.9 RAID

- RAID Level 5 is RAID 4 with distributed parity.
  - With distributed parity, some accesses can be serviced concurrently, giving good performance and high reliability.



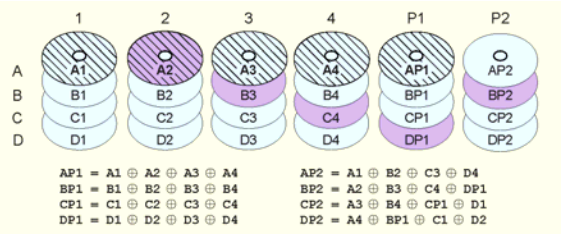
7.9 RAID

- RAID Level 6 carries two levels of error protection over striped data: Reed-Soloman and parity.
  - It can tolerate the loss of two disks.
  - RAID 6 is write-intensive, but highly fault-tolerant.



7.9 RAID

- Double parity RAID (RAID DP) employs pairs of over-lapping parity blocks that provide linearly independent parity functions.



7.9 RAID

- Like RAID 6, RAID DP can tolerate the loss of two disks.
- The use of simple parity functions provides RAID DP with better performance than RAID 6.
- Of course, because two parity functions are involved, RAID DP's performance is somewhat degraded from that of RAID 5.
  - RAID DP is also known as EVENODD, diagonal parity RAID, RAID 5DP, advanced data guarding RAID (RAID ADG) and-- erroneously-- RAID 6.

7.9 RAID

- Large systems consisting of many drive arrays may employ various RAID levels, depending on the criticality of the data on the drives.
  - A disk array that provides program workspace (say for file sorting) does not require high fault tolerance.
- Critical, high-throughput files can benefit from combining RAID 0 with RAID 1, called RAID 10.
- Keep in mind that a higher RAID level does not necessarily mean a "better" RAID level. It all depends upon the needs of the applications that use the disks.

7.10 The Future of Data Storage

- Advances in technology have defied all efforts to define the ultimate upper limit for magnetic disk storage.
  - In the 1970s, the upper limit was thought to be around 2Mb/in^2.
  - Today's disks commonly support 20Gb/in^2.
- Improvements have occurred in several different technologies including:
  - Materials science
  - Magneto-optical recording heads.
  - Error correcting codes.

7.10 The Future of Data Storage

- As data densities increase, bit cells consist of proportionately fewer magnetic grains.
- There is a point at which there are too few grains to hold a value, and a 1 might spontaneously change to a 0, or vice versa.
- This point is called the superparamagnetic limit.
  - In 2006, the superparamagnetic limit is thought to lie between 150Gb/in^2 and 200Gb/in^2 .
- Even if this limit is wrong by a few orders of magnitude, the greatest gains in magnetic storage have probably already been realized.

7.10 The Future of Data Storage

- Future exponential gains in data storage most likely will occur through the use of totally new technologies.
- Research into finding suitable replacements for magnetic disks is taking place on several fronts.
- Some of the more interesting technologies include:
  - Biological materials
  - Holographic systems and
  - Micro-electro-mechanical devices.

7.10 The Future of Data Storage

- Present day biological data storage systems combine organic compounds such as proteins or oils with inorganic (magentizable) substances.
- Early prototypes have encouraged the expectation that densities of 1Tb/in^2 are attainable.
- Of course, the ultimate biological data storage medium is DNA.
  - Trillions of messages can be stored in a tiny strand of DNA.
- Practical DNA-based data storage is most likely decades away.

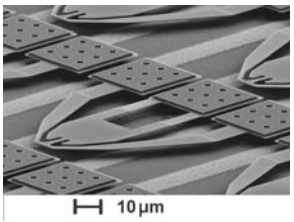
7.10 The Future of Data Storage

- Micro-electro-mechanical storage (MEMS) devices offer another promising approach to mass storage.
- IBM's Millipede is one such device.
- Prototypes have achieved densities of 100Gb/in^2 with 1Tb/in^2 expected as the technology is refined.

A photomicrograph of Millipede is shown on the next slide.

7.10 The Future of Data Storage

- Millipede consists of thousands of cantilevers that record a binary 1 when it dips into the polymer substrate.
- The tip reads a binary 1 when it dips into the imprint in the polymer



Photomicrograph courtesy of the IBM Corporation.

Chapter 7 Conclusion

- I/O systems are critical to the overall performance of a computer system.
- Amdahl's Law quantifies this assertion.
- I/O systems consist of memory blocks, cabling, control circuitry, interfaces, and media.
- I/O control methods include programmed I/O, interrupt-based I/O, DMA, and channel I/O.
- Buses require control lines, a clock, and data lines. Timing diagrams specify operational details.

Chapter 7 Conclusion

- Magnetic disk is the principal form of durable storage.
- Disk performance metrics include seek time, rotational delay, and reliability estimates.
- Optical disks provide long-term storage for large amounts of data, although access is slow.
- Magnetic tape is also an archival medium. Recording methods are track-based, serpentine, and helical scan.

Chapter 7 Conclusion

- RAID gives disk systems improved performance and reliability. RAID 3 and RAID 5 are the most common.
- RAID 6 and RAID DP protect against dual disk failure, but RAID DP offers better performance.
- Any one of several new technologies including biological, holographic, or mechanical may someday replace magnetic disks.
- The hardest part of data storage may be end up be in locating the data after it's stored.