RAID Technology

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Abstract— **This document covers RAID technology, its standard implementations, as well as the latest advancements in its design.**

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I. Introduction

RAID technology (Redundant Array of Inexpensive or Independent Disks) is a combination of physical hard disk drives working in parallel as a single logical state. The term "Redundant Array" indicates the use of one or more "Independent Disks" working together to create a storage mechanism. RAID technology addresses several concerns surrounding secondary storage, namely the rate of improvement of secondary storage versus that of processor and main memory performance[1], where the former is lesser than the latter two. RAID also addresses reliability and availability with data redundancy, as well as improved capacity from additional physical storage space.

The basic concept of RAID technology is separating data between disks to ensure availability and attempt to guarantee recovery in the event of drive failure. Different levels of RAID indicate different methods of separation and recovery methods. There are 7 universally agreed-upon levels, though some among these are unrealistic and therefore out of widespread use. There are new levels and technologies being developed and distributed to increase the functionality of RAID. Each level provides its own advantages, and choosing which level to implement depends on what is needed out of the array.

II. History

David Patterson, Garth Gibson and Randy Katz of the university of California at Berkeley pioneered the development of RAID technology [PATT88][2]. They intended to achieve higher I/O transfer rates and larger capacities of storage despite the small sizes of disk drive measurements at the time. Because of the high cost of large drives, the "I" in RAID meant "Inexpensive". However, now that terminology is inappropriate because of the ever-decreasing costs of hardware, so RAID is now known as "Redundant Array of Independent Disks" to remain an accurate description of the technology.

The probability of hardware failure complicated the otherwise-simple task of joining multiple physical disks into one logical drive. All disks have some chance of failing. Combining many disks into one multiplied the chance of a single disk failure times the number of disks in the array. For example, if a 10GB disk has a 1% chance of failure, then creating a 100GB RAID with ten 10GB disks increased the chance of failure to 10%. Not only were the chances of failure increased, but the amount of data subject to loss would be multiplied by the same amount. The breakthrough in overcoming this design issue came with the methods of striping, mirroring and parity techniques.

III. Findings

A. How Does RAID Work?

If a hardware failure occurs, every disk drive has a certain probability of failure. When such a failure occurs, the array as a whole would continue to service the applications as if nothing had happened. Engineers would replace the faulty disk at a convenient time without any data loss by using RAID.

With this breakthrough, the theoretical concept of grouping several inexpensive disks in an array to simulate one very large disk was finally practical.

RAID technology is implementable either through a software driver in the operating system or using a separate hardware device. Controlling and managing two or more disk drives requires the use of a RAID controller. The RAID controller can be a slide-in card inserted into the computer, or embedded into a separate drive enclosure that functions as an external disk drive. Either way, the RAID controller functions independently from the computer system it is attached to. Configuration is through the controller's panel or configuration software. As far as the computer is concerned, the controller and its array of multiple disks looks like one ordinary disk drive.

In the case of software-based RAID, users incorporate a software module (a driver) into the operating system to create a new device node which looks like an ordinary disk drive to the rest of the system, but which actually corresponds to an array of two or more physical disks, usually housed within the computer cabinet. Under this scenario, users configure and monitor RAID using operating system commands and utilities.[3]

B. RAID Storage Techniques

1) *Striping*: As mentioned, RAID is a collection of multiple disks. In these disks is a predefined number of contiguously addressable disk blocks, called strips. A collection of strips aligned in multiple disks is a stripe. Striping is a way of writing data to member disks. The data flow is split onto the strips and then written to the disks in turn. Without mirroring and parity, striped RAID cannot protect data. However, striping may significantly improve I/O performance.

2) *Mirroring*: This technique works by storing two identical data copies on the array member disks. In the event of failure on one disk, the controller uses the second disk to serve the data. Thus, data availability is continuous. When the failed disk is replaced with a new disk, the controller copies the data from the surviving disk of the mirrored pair. Data is simultaneously recorded on both the disks. Although this type of RAID gives the highest availability of data, it is costly as it requires double the amount of disk space.

3) *Parity*: Since mirroring demands a high cost, a new technique to protect the data is available for use in conjunction with striping, called parity. It is a reliable and low-cost solution for data protection. In this method, an additional disk is added to the stripe width to hold a parity bit. Parity is a redundancy check that ensures full protection of data without maintaining a full set of duplicate data. The parity bits are used to re-create data at the time of failure.

C. The Most Popular RAID Levels

1) *RAID 0 (Striping):* A non-redundant array based on the striping technique. Created to increase system performance. N-disk arrays provide N times read and write speed improvement as compared to a single disk. By using multiple disks (at least 2) at the same time, level 0 offers superior I/O performance. Performance can be enhanced further by using multiple controllers, ideally one controller per disk. For a controller failure, if one of the disks is unreadable, almost nothing can be recovered.

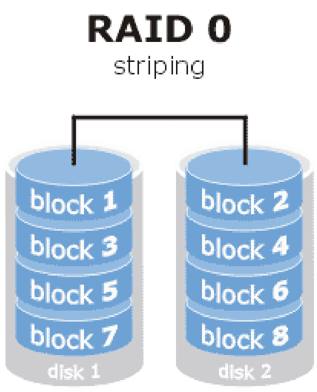

Fig. 1 RAID 0

2) *RAID 1 (Mirroring):* Based on the mirroring technique. Used where system reliability is critical. Data is stored twice by writing to both the data disk and a mirror disk (or set of disks). Mirroring duplicates the data across the set. If a disk fails, the controller uses either the data drive or the mirror drive(s) for data recovery and continues operation. A level 1 array requires at least 2 disks.

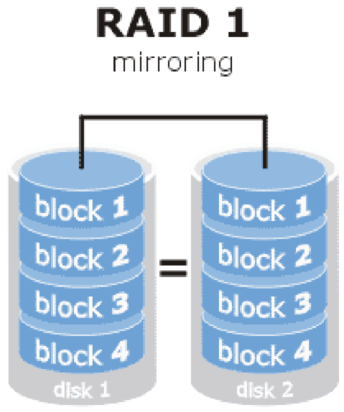

Fig. 2 RAID 1

3) *RAID 2 (Bit Striping with ECC):* Every disk is accessed on every read and every I/O request execution. Level 2 uses data striping, but its stripes are comparably small in size, usually just one byte or word. An error correcting code, such as Hamming code, corrects single bit errors. Multiple parity disks store the positions of the corresponding bits. Requested data as well as the correcting code are sent to the controller on an access operation. Write operations must access all data and parity disks. Level 2 is costly, and ineffective, since its main purpose is eliminating many errors. It is inefficient today because disks and drives are highly reliable in themselves, so implementing RAID level 2 is tedious and unnecessary.

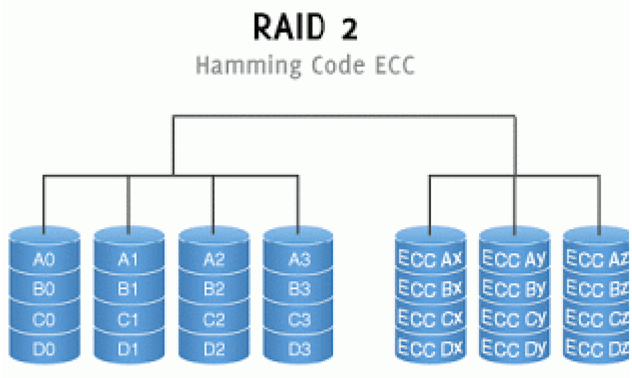

Fig. 3 RAID 2

4) *RAID 3 (Bit Striping with Parity):* On level 3 systems, data blocks are striped and written in parallel on two or

more drives using the same theory of level 0, but adds an additional drive to the array. The additional drive maintains parity information about the data in the stripe set. With this parity information, the failed drive can be re-computed or derived. This technology adds fault tolerance to the stripe set. Although this protection is not as great as having a full mirror of the data, it does reduce the amount of expensive downtime.

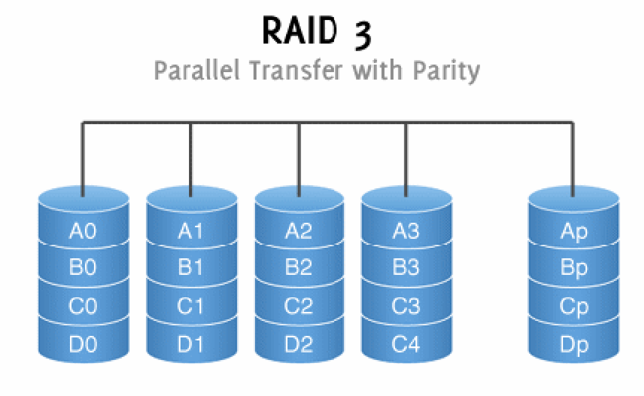

Fig. 4 RAID 3

5) *RAID 4 (Block Striping with Parity):* Uses multiple data disks at a block level across several drives, and a dedicated disk to store parity. The parity information allows recovery from the failure of any single drive. Level 4 maintains powerful read efficiency. However, writes require that parity data to be updated each time. Level 4 is similar to level 3 in having the dedicated parity disk, but level 4 has blocks striped. Level 4 is also similar to level 5 in striping the blocks across the data disks, but level 4 has only one parity disk. However, level 4 is not commonly used.

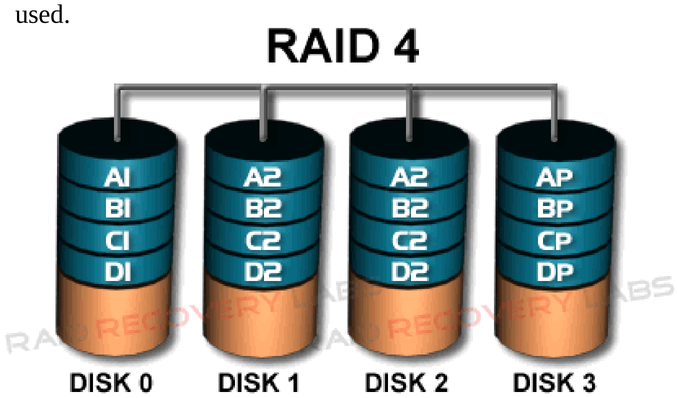

Fig. 5 RAID 4

6) *RAID 5 (Striping with Distributed Parity):* Utilizes striping and parity techniques (XOR), and provides fault tolerance. In case of a single disk failure, the missing data is reconstructed using parity data and data from other member disks. Level 5 is the most common secure RAID level. It is similar to level 3 except that data are transferred to disks by independent read and write operations (not in parallel). Instead of a dedicated parity disk, parity information is spread across all the drives. A level 5 array can withstand a single disk failure without losing data or access to data. Although level 5 is achievable with only software, a hardware controller is recommended. Often extra cache memory is used on these controllers to improve the write performance.

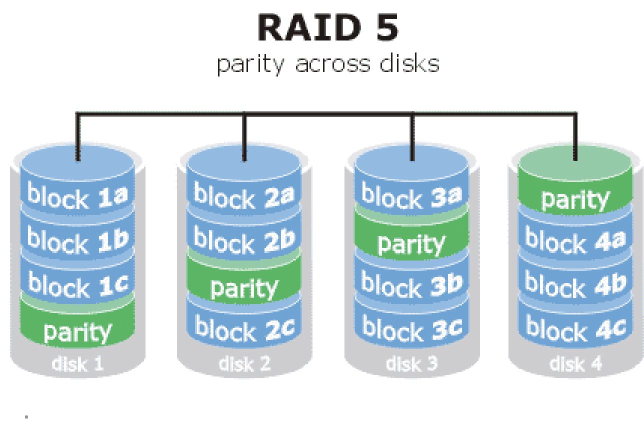

Fig. 6 RAID 5

7) *RAID 6 (Striping with Dual Parity):* Similar to level 5, but with two different parity functions. One is the same as in level 5 (XOR), but the second is more complex. Using the two parity functions enables level 6 to recover a dual hard drive failure. Unfortunately, the need to store parity data for two functions results in the disk space overhead equalling the capacity of two member disks. Level 6 recovery is very complex.

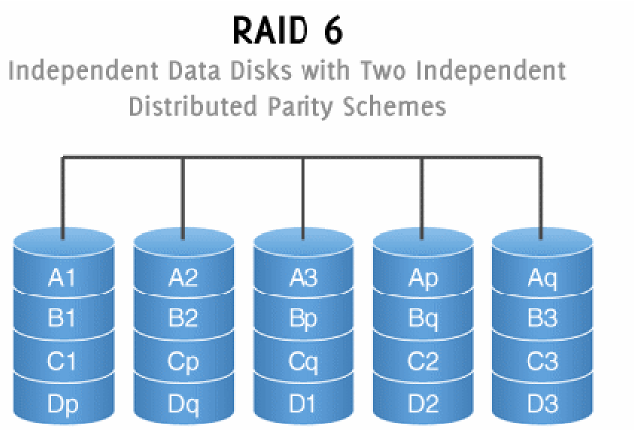

Fig. 7 RAID 6

8) *RAID 0+1 (Mirror over Stripes):* Based on mirroring and striping techniques. Level 0+1 combines the advantages and disadvantages of RAID 0 and RAID 1 in one single system. It inherits level 1's fault tolerance and level 0's speed efficiency. It provides security by mirroring all data on a secondary set of disks while using

striping across each set of disks to speed up data transfers. Such arrays are able to survive a single disk failure and, in some cases, multiple simultaneous disk failures as well. This is one of the most expensive RAID levels, because the capacity overhead increases with the number of disks.

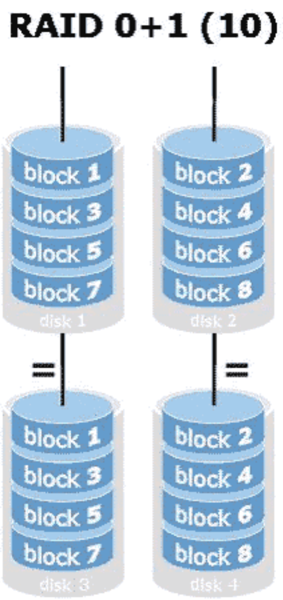

Fig. 8 RAID 0+1

There are many other levels that exist, such as 7, 30, 50 and 60. This document concentrates on the most commonly known and commonly used levels.[4]

D. Advantages of RAID

- Protecting Drive Failure. RAID allows backup of the data in the form of storage arrays in the event of a failure.

- Data Reliability. RAID ensures data reliability, an increase in I/O performance, and shadowing/mirroring at a lower cost.

- Improved Performance. RAID uses disk striping to write data to a disk, which improves performance by the interleaving of the bytes or the group of bytes.

- Data Recovery. Mirroring offers parity checks to ensure data from a crashed system matches the data stored on the other disk.[5]

E. Advantages of Various RAID Levels:

1) RAID 0:

- Improved I/O performance.
- All storage capacity is used (no parity calculation overhead is involved).
- Very simple design.
- Easy to implement.

2) RAID 1:

- Offers excellent read speed and a write-speed comparable to that of a single disk.
- Transfer rate per block is equal to that of a single disk.
- In case a disk fails, data does not have to be rebuilt, only copied to the replacement disk (100% redundancy of data).
- Simplest RAID storage subsystem design.

3) RAID 2:

- The rate of data transfer is very high.
- Single bit errors can be detected and corrected very easily.
- Multiple bit errors are also detectable.

4) RAID 3:

- Provides high throughput (both read and write) for large data transfers.
- Disk failures do not significantly slow down throughput.
- Low ratio of ECC (parity) disks to data disks means high efficiency.

5) RAID 4:

- Very high read data transaction rate.
- Low ratio of ECC (parity) disks to data disks means high efficiency.
- High aggregate read transfer rate.

6) RAID 5:

- Redundancy through a parity stripe.
- Highest read data transaction rate.
- Medium write data transaction rate (due to the parity that has to be calculated).
- Low ratio of ECC (parity) disks to data disks means high efficiency.

7) RAID 6:

- Provides an extremely high data fault tolerance and can sustain multiple simultaneous drive failures.

- Perfect solution for mission critical applications.

8) RAID 0+1:

- High I/O rates are achieved by striping segments.
- Under certain circumstances, RAID 0+1 arrays can sustain multiple simultaneous drive failures.[6]

F. Latest Technology

1) *G-RAID*: G-RAID is a dual drive, professional RAID 0 storage solution. The best performance is available by setting up RAID 0, where data is striped between the two disks. This provides storage capacity that is the sum of the two disks inside. Uses high-speed USB 3.0 and FireWire® interfaces. Designed for professional content creation applications.

2) *Thunderbolt*: Thunderbolt is a data transfer connection protocol that combines with RAID storage, such as G-RAID, to maximize I/O transfer rates. It operates at double the speed of USB 3.0 and 12 times faster than Firewire 800. Thunderbolt technology is pre-equipped on Mac systems and not in wide use, and therefore costly. Thunderbolt can daisy-chain as many as five storage devices together without degrading data rates.[7]

3) *BeyondRAID*: Developed by Drobo Inc., BeyondRAID is not an official RAID ISO spec extension. It can use multiple storage sizes in the same array, while still allowing hot-swapping and efficient redundancy. It uses the techniques of RAID 1 and 5. BeyondRAID synchronizes its data protection algorithm to the protection requirements of the system at any given moment using a virtualization platform. Its disks and drivers seamlessly integrate into basic RAID systems, eliminating the cost of manipulation.

4) X-RAID: X-RAID is a single volume architecture developed by NetGear, and is only available for their ReadyNAS systems. X-RAID is auto-expandable and reformatting can be done online. It requires two disks minimum for disk failure protection, and any new disks are automatically accommodated. All disk space is used for storage except the capacity of one, which is always maintained for data protection. The parity disk is not maintained on a single physical disk however, it is actually spread across the collection.

5) Jetstor: Jetstor is based on RAID 7 architecture. It also includes advanced features related to RAID 6 where several simultaneous drive failures can be tolerated without data loss. It uses either SATA III or SAS2 drives and operates with a Dual Core RAID-On-Chip processor. Parity integrity is maintained with an online consistency verification feature. Its controller also provides use of RAID 0, 0+1, 3, 5, 6, 30, 50, and 60.

6) PARAID: PARAID stands for Power-Aware RAID and was developed to reduce energy levels used in server class arrays where typically large amounts of power are needed to maintain. PARAID reduced energy consumption by 34% in a five-drive prototype. A new, slightly altered striping algorithm allows system adaption by powering down disks with light loads. Performance demands are maintained by matching the number of powered disks to the system load.[8]

IV. Conclusions

RAID technology is the solution to expensive and slow secondary storage. By combining secondary storage devices in a number of different patterns, different advantages are achievable, which distinguishes the different levels of RAID. Some levels are advantageous towards read speeds, others towards write, others for data protection, and others for cost. This applies to the original standards, but looking at the latest technology surrounding RAID, it is apparent that read and write speeds, as well as data maintenance and cost are qualities that are expected and not meant to be sacrificed for one another. New models of RAID provide all the necessities of storage and reliability along with new characteristics of ease of manipulation and even power consumption.

The most important consideration while choosing which raid level or technology to use depends on the domain of the project's needs. RAID is incredibly important and useful for individual users and commercial users alike.

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