RAID

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(Redirected from Redundant Array of Independent Disks)

RAID (originally **redundant array of inexpensive disks**; now commonly **redundant array of independent disks**) is a data storage virtualization technology that combines multiple disk drive components into a logical unit for the purposes of data redundancy and performance improvement.[1]

Data is distributed across the drives in one of several ways, referred to as RAID levels, depending on the specific level of redundancy and performance required. The different schemes or architectures are named by the word RAID followed by a number (e.g. RAID 0, RAID 1). Each scheme provides a different balance between the key goals: reliability and availability, performance and capacity. RAID levels greater than RAID 0 provide protection against unrecoverable (sector) read errors, as well as whole disk failure.

The term "RAID" was invented by David Patterson, Garth A. Gibson, and Randy Katz at the University of California, Berkeley in 1987, in a paper titled "*A Case for Redundant Arrays of Inexpensive Disks (RAID)*" in June 1988 at the SIGMOD conference.[2]

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History

The term "RAID" was first defined by David A. Patterson, Garth A. Gibson and Randy Katz at the University of California, Berkeley, in 1987. They studied the possibility of using two or more drives to appear as a single device to the host system and published a paper: "*A Case for Redundant Arrays of Inexpensive Disks (RAID)*" in June 1988 at the SIGMOD conference.[2]

Each of the five levels of RAID named in the paper were well established in the art prior to the paper's publications, for example:

- Around 1983, DEC began shipping subsystem mirrored RA8X disk drives (now known as *RAID 1*) as part of its HSC50 subsystem.[3]
- Around 1988, the Thinking Machines DataVault used error correction codes (now known as *RAID 2*) in an array of disk drives.[4] A similar approach was used in 1970s on the IBM 3330.[5]
- In 1977, Norman Ken Ouchi at IBM filed a patent disclosing what was subsequently named *RAID 4*.[6]
- In 1986, Clark et al. at IBM filed a patent disclosing what was subsequently named *RAID 5*.[7]

Industry RAID manufacturers later tended to interpret the acronym as standing for "redundant array of independent disks".[8][9][10][11]

Concept

Many RAID levels employ an error protection scheme called "parity", a widely used method in information technology to provide fault tolerance in a given set of data. Most use simple XOR, but RAID 6 uses two separate parities based respectively on addition and multiplication in a particular Galois Field or Reed–Solomon error correction.[12]

Standard levels

A number of standard schemes have evolved. These are called *levels*. Originally, there were five RAID levels, but many variations have evolved—notably several nested levels and many non-standard levels (mostly proprietary). RAID levels and their associated data formats are standardized by the Storage Networking Industry Association (SNIA) in the Common RAID Disk Drive Format (DDF) standard:[13][14]

RAID 0

RAID 0 comprises striping (but no parity or mirroring). This level provides no data redundancy nor fault tolerance, but improves performance through parallelism of read and write operations across multiple drives. RAID 0 has no error detection mechanism, so the failure of one disk causes the loss of all data on the array.[9]

RAID 1

RAID 1 comprises mirroring (without parity or striping). Data are written identically to two (or more) drives, thereby producing a "mirrored set". The read request is serviced by any of the drives containing the requested data. This can improve performance if data is read from the disk with the least seek latency and rotational latency. Conversely, write performance can be degraded because all drives must be updated; thus the write performance is determined by the slowest drive. The array continues to operate as long as at least one drive is functioning.[9]

RAID 2

RAID 2 comprises bit-level striping with dedicated Hamming-code parity. All disk spindle rotation is synchronized and data is striped such that each sequential bit is on a different drive. Hamming-code parity is calculated across corresponding bits and stored on at least one parity drive.[9] This level is of historical significance only. Although it was used on some early machines (e.g. the Thinking Machines CM-2),[15] it is only recently used by high-performance commercially available systems.[16]

RAID 3

RAID 3 comprises byte-level striping with dedicated parity. All disk spindle rotation is synchronized and data is striped such that each sequential byte is on a different drive. Parity is calculated across corresponding bytes and stored on a dedicated parity drive.[9] Although implementations exist,[17] RAID 3 is not commonly used in practice.

RAID 4

RAID 4 comprises block-level striping with dedicated parity. This level was previously used by NetApp, but has now been largely replaced by a proprietary implementation of RAID 4 with two parity disks, called RAID-DP.[18]

RAID 5

RAID 5 comprises block-level striping with distributed parity. Unlike in RAID 4, parity information is distributed among the drives. It requires that all drives but one be present to operate. Upon failure of a single drive, subsequent reads can be calculated from the distributed parity such that no data is lost. RAID 5 requires at least three disks.[9] RAID 5 is seriously affected by the general trends regarding array rebuild time and chance of failure during rebuild.[19] In August 2012, Dell posted an advisory against the use of RAID 5 in any configuration and of RAID 50 with "Class 2 7200 RPM drives of 1 TB and higher capacity".[20]

RAID 6

RAID 6 comprises block-level striping with double distributed parity. Double parity provides fault tolerance up to two failed drives. This makes larger RAID groups more practical, especially for high-availability systems, as large-capacity drives take longer to restore. As with RAID 5, a single drive failure results in reduced performance of the entire array until the failed drive has been replaced.[9] With a RAID 6 array, using drives from multiple sources and manufacturers, it is possible to mitigate most of the problems associated with RAID 5. The larger the drive capacities and the larger the array size, the more important it becomes to choose RAID 6 instead of RAID 5.[21] RAID 10 also minimizes these problems.[22]

Nested (hybrid) RAID

In what was originally termed *hybrid RAID*,[23] many storage controllers allow RAID levels to be nested. The elements of a *RAID* may be either individual drives or arrays themselves. Arrays are rarely nested more than one level deep.

The final array is known as the top array. When the top array is RAID 0 (such as in RAID 1+0 and RAID 5+0), most vendors omit the "+" (yielding RAID 10 and RAID 50, respectively).

- RAID 0+1: creates a second striped set to mirror a primary striped set. The array continues to operate with one or more drives failed in the same mirror set, but if drives fail on both sides of the mirror the data on the RAID system is lost.

- RAID 1+0: creates a striped set from a series of mirrored drives. The array can sustain multiple drive losses so long as no mirror loses all its drives.[24]

Non-standard levels

Many configurations other than the basic numbered RAID levels are possible, and many companies, organizations, and groups have created their own non-standard configurations, in many cases designed to meet the specialized needs of a small niche group. Such configurations include the following:

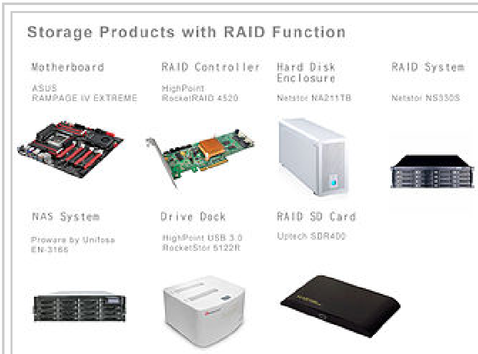
- Linux MD RAID 10 provides a general RAID driver that in its "near" layout defaults to a standard RAID 1 with two drives, and a standard RAID 1+0 with four drives; though, it can include any number of drives, including odd numbers. With its "far" layout, MD RAID 10 can run both striped and mirrored, even with only two drives in `f2` layout; this runs mirroring with striped reads, giving the read performance of RAID 0. Regular RAID 1, as provided by Linux software RAID, does not stripe reads, but can perform reads in parallel.[24][25][26]
- Hadoop has a RAID system that generates a parity file by xor-ing a stripe of blocks in a single HDFS file.[27]

Implementations

The distribution of data across multiple drives can be managed either by dedicated computer hardware or by software. A software solution may be part of the operating system, or it may be part of the firmware and drivers supplied with a hardware RAID controller.

Hardware-based

Software-based



Storage products with RAID functionality

Software RAID implementations are now provided by many operating systems. Software RAID can be implemented as:

- A layer that abstracts multiple devices, thereby providing a single virtual device (e.g. Linux's md)
- A more generic logical volume manager (provided with most server-class operating systems, e.g. Veritas or LVM)
- A component of the file system (e.g. ZFS or Btrfs)

Some advanced file systems are designed to organize data across multiple storage devices directly (without needing the help of a third-party logical volume manager):

- ZFS supports equivalents of RAID 0, RAID 1, RAID 5 (RAID Z), RAID 6 (RAID Z2) and a triple-parity version RAID Z3. As it always stripes over top-level vdevs, it supports equivalents of the 1+0, 5+0, and 6+0 nested RAID levels (as well as striped triple-parity sets) but not other nested combinations. ZFS is the native file system on Solaris and also available on FreeBSD and Linux.[28]

- Btrfs supports RAID 0, RAID 1 and RAID 10 (RAID 5 and 6 are under development).[29][30]

Many operating systems provide basic RAID functionality independently of volume management:

- Apple's OS X and OS X Server support RAID 0, RAID 1, and RAID 1+0.[31][32]
- FreeBSD supports RAID 0, RAID 1, RAID 3, and RAID 5, and all nestings via GEOM modules and ccd.[33][34][35]
- Linux's md supports RAID 0, RAID 1, RAID 4, RAID 5, RAID 6, and all nestings.[36][37] Certain reshaping/resizing/expanding operations are also supported.[38]
- Microsoft's server operating systems support RAID 0, RAID 1, and RAID 5. Some of the Microsoft desktop operating systems support RAID. For example, Windows XP Professional supports RAID level 0, in addition to spanning multiple drives, but only if using dynamic disks and volumes. Windows XP can be modified to support RAID 0, 1, and 5.[39] Windows 8 and Windows Server 2012 introduces a RAID-like feature known as Storage Spaces, which also allows users to specify mirroring, parity, or no redundancy on a folder-by-folder basis.[40]
- NetBSD supports RAID 0, 1, 4, and 5 via its software implementation, named RAIDframe.[41]

If a boot drive fails, the system has to be sophisticated enough to be able to boot off the remaining drive or drives. For instance, consider a computer whose disk is configured as RAID 1 (mirrored drives); if the first drive in the array fails, then a first-stage boot loader might not be sophisticated enough to attempt loading the second-stage boot loader from the second drive as a fallback. The second-stage boot loader for FreeBSD is capable of loading a kernel from such an array.[42]

Firmware/driver-based

Software-implemented RAID is not always compatible with the system's boot process, and it is generally impractical for desktop versions of Windows. However, hardware RAID controllers are expensive and proprietary. To fill this gap, cheap "RAID controllers" were introduced that do not contain a dedicated RAID controller chip, but simply a standard drive controller chip with proprietary firmware and drivers; during early stage bootup, the RAID is implemented by the firmware, and once the operating system has been more completely loaded, then the drivers take over control. Consequently, such controllers may not work when driver support is not available for the host operating system.[43] An example is Intel Matrix RAID, implemented on many consumer-level motherboards.[44][45]

Because there is some minimal hardware support involved, this implementation approach is also called "hardware-assisted software RAID",[46][47][48] "hybrid model" RAID,[48] or even "fake RAID".[49] If RAID 5 is supported, the hardware may provide a hardware XOR accelerator. An advantage of this model over the pure software RAID is that—if using a redundancy mode—the boot drive is protected from failure (due to the firmware) during the boot process even before the operating systems drivers take over.[48]

Uses

RAID can provide data security with solid-state drives (SSDs) without the expense of an all-SSD system. For example, a fast SSD can be mirrored with a mechanical drive. For this configuration to provide a significant speed advantage an appropriate controller is needed that uses the fast SSD for all read operations. Adaptec calls this "hybrid RAID".[50]

Integrity

Data scrubbing (referred to in some environments as *patrol read*) involves periodic reading and checking by the RAID controller of all the blocks in an array, including those not otherwise accessed. This detects bad blocks before use.[51] Data scrubbing checks for bad blocks on each storage device in an array, but also uses the redundancy of the array to recover bad blocks on a single drive and to reassign the recovered data to spare blocks elsewhere on the drive.[52]

Frequently, a RAID controller is configured to "drop" a component drive (that is, to assume a component drive has failed) if the drive has been unresponsive for eight seconds or so; this might cause the array controller to drop a good drive because that drive has not been given enough time to complete its internal error recovery procedure. Consequently, using RAID for comsumer-marketed drives can be risky, and so-called "enterprise class" drives limit this error recovery time to reduce risk. Western Digital's desktop drives used to have a specific fix. A utility called WDTLER.exe limited a drive's error recovery time. The utility enabled TLER (time limited error recovery), which limits the error recovery time to seven seconds. Around September 2009, Western Digital disabled this feature in their desktop drives (e.g. the Caviar Black line), making such drives unsuitable for use in RAID configurations.[53] However, Western Digital enterprise class drives are shipped from the factory with TLER enabled. Similar technologies are used by Seagate, Samsung, and Hitachi. Of course, for non-RAID usage, an enterprise class drive with a short error recovery timeout that cannot be changed is therefore less suitable than a desktop drive.[53] In late 2010, the Smartmontools program began supporting the configuration of ATA Error Recovery Control, allowing the tool to configure many desktop class hard drives for use in RAID setups.[53]

While RAID may protect against physical drive failure, the data are still exposed to operator, software, hardware, and virus destruction. Many studies cite operator fault as the most common source of malfunction,[54] such as a server operator replacing the incorrect drive in a faulty RAID, and disabling the system (even temporarily) in the process.[55]

An array can be overwhelmed by catastrophic failure that exceeds its recovery capacity and, of course, the entire array is at risk of physical damage by fire, natural disaster, and human forces, while backups can be stored off site. An array is also vulnerable to controller failure because it is not always possible to migrate it to a new, different controller without data loss.[56]

Weaknesses

Correlated failures

In practice, the drives are often the same age (with similar wear) and subject to the same environment. Since many drive failures are due to mechanical issues (which are more likely on older drives), this violates the assumptions of independent, identical rate of failure amongst drives; failures are in fact statistically correlated.[9] In practice, the chances of a second failure before the first has been recovered (causing data loss) is higher than four random failures. In a study of about 100,000 drives, the probability of two drives in the same cluster failing within one hour was four times larger than predicted by the exponential statistical distribution—which characterizes processes in which events occur continuously and independently at a constant average rate. The probability of two failures in the same 10-hour period was twice as large as predicted by an exponential distribution.[57]

Unrecoverable read errors during rebuild

Unrecoverable read errors (URE) present as sector read failures. The unrecoverable bit-error (UBE) rate is typically specified at one bit in 10^{15} for enterprise class drives (SCSI, FC, SAS), and one bit in 10^{14} for desktop class drives (IDE/ATA/PATA, SATA). Increasing drive capacities and large RAID 5 redundancy groups have led to an increasing inability to successfully rebuild a RAID group after a drive failure because an unrecoverable sector is found on the remaining drives.[9][58] Parity schemes such as RAID 5 when rebuilding are particularly prone to the effects of UREs as they affect not only the sector where they occur but also reconstructed blocks using that sector for parity computation; typically an URE during a RAID 5 rebuild leads to a complete rebuild failure.[59]

Double protection schemes such as RAID 6 are attempting to address this issue, but suffer from a very high write penalty. Schemes that duplicate (mirror) data such as RAIDs 1 and 10 have a lower risk from UREs than those using parity computation.[22] Background scrubbing can be used to detect and recover from UREs (which are latent and invisibly compensated for dynamically by the RAID controller) as a background process, by reconstruction from the redundant RAID data and then re-writing and re-mapping to a new sector; and so reduce the risk of double-failures to the RAID system.[60][61]

Increasing rebuild time and failure probability

Drive capacity has grown at a much faster rate than transfer speed, and error rates have only fallen a little in comparison. Therefore, larger capacity drives may take hours, if not days, to rebuild. The re-build time is also limited if the entire array is still in operation at reduced capacity.[62] Given an array with only one drive of redundancy (RAIDs 3, 4, and 5), a second failure would cause complete failure of the array. Even though individual drives' mean time between failure (MTBF) have increased over time, this increase has not kept pace with the increased storage capacity of the drives. The time to rebuild the array after a single drive failure, as well as the chance of a second failure during a rebuild, have increased over time.[19]

Some commentators have declared that RAID 6 is only a "band aid" in this respect, because it only pushes the problem a little further down the road.[19] However, according to a 2006 NetApp study of Berriman et al., the chance of failure decreases by a factor of about 3,800 (relative to RAID 5) for a proper implementation of RAID 6, even when using commodity drives.[63] Nevertheless, if the currently observed technology trends remain unchanged, in 2019 a RAID 6 array will have the same chance of failure as its RAID 5 counterpart had in 2010.[58][63]

Mirroring schemes such as RAID 10 have a bounded recovery time as they require the copy of a single failed drive, compared with parity schemes such as RAID 6, which require the copy of all blocks of the drives in an array set. Triple parity schemes, or triple mirroring, have been suggested as one approach to improve resilience to an additional drive failure during this large rebuild time.[63]

Atomicity: including parity inconsistency due to system crashes

A system crash or other interruption of a write operation can result in states where the parity is inconsistent with the data due to non-atomicity of the write process, such that the parity cannot be used for recovery in the case of a disk failure (the so-called RAID 5 write hole).[9] The RAID write hole is a known data corruption issue in older and low-end RAIDs, caused by interrupted destaging of writes to disk.[64]

This is a little understood and rarely mentioned failure mode for redundant storage systems that do not utilize transactional features. Database researcher Jim Gray wrote "Update in Place is a Poison Apple" during the early days of relational database commercialization.[65]

Write-cache reliability

A concern about write-cache reliability exists, specifically regarding devices equipped with a write-back cache—a caching system that reports the data as written as soon as it is written to cache, as opposed to the non-volatile medium.[66]

See also

- Network-attached storage (NAS)
- Non-RAID drive architectures
- Redundant array of independent memory

References

1. ^ Arpaci-Dusseau, Remzi H.; Arpaci-Dusseau, Andrea C. (2014), *Operating Systems: Three Easy Pieces [Chapter: RAID]* (http://pages.cs.wisc.edu/~remzi/OSTEP/file-raid.pdf), Arpaci-Dusseau Books
2. ^ *a b* Patterson, David; Gibson, Garth A.; Katz, Randy (1988). "A Case for Redundant Arrays of Inexpensive Disks (RAID)" (http://www.eecs.berkeley.edu/Pubs/TechRpts/1987/CSD-87-391.pdf) (PDF). *SIGMOD Conferences*. pp. 109–116. Retrieved 2006-12-31.
3. ^ "HSC50/70 Hardware Technical Manual" (http://www.textfiles.com/bitsavers/pdf/dec/ci/EK-HS571-TM-001_HSC_hwTech.pdf) (PDF). DEC. July 1986. pp. 29, 32. Retrieved 2014-01-03.
4. ^ US patent 4899342 (http://worldwide.espacenet.com/textdoc?DB=EPODOC&IDX=US4899342), Norman Ken Ouchi, "Method and Apparatus for Operating Multi-Unit Array of Memories", issued 1988-02-01
5. ^ "IBM 3330 data storage" (http://www-03.ibm.com/ibm/history/exhibits/storage/storage_3330.html). *IBM.com*. IBM. Retrieved 2014-01-02.
6. ^ US patent 4092732 (http://worldwide.espacenet.com/textdoc?DB=EPODOC&IDX=US4092732), Norman Ken Ouchi, "System for Recovering Data Stored in Failed Memory Unit", issued 1978-05-30
7. ^ US patent 4761785 (http://worldwide.espacenet.com/textdoc?DB=EPODOC&IDX=US4761785), Brian E. Clark, et al., "Parity Spreading to Enhance Storage Access", issued 1988-08-02
8. ^ "Originally referred to as Redundant Array of Inexpensive Disks, the concept of RAID was first developed in the late 1980s by Patterson, Gibson, and Katz of the University of California at Berkeley. (The RAID Advisory Board has since substituted the term Inexpensive with Independent.)" Storagecc Area Network Fundamentals; Meeta Gupta; Cisco Press; ISBN 978-1-58705-065-7; Appendix A.
9. ^ *a b c d e f g h i j* Chen, Peter; Lee, Edward; Gibson, Garth; Katz, Randy; Patterson, David (1994). "RAID: High-Performance, Reliable Secondary Storage" (http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.41.3889). *ACM Computing Surveys* **26**: 145–185.
10. ^ Donald, L. (2003). *MCSA/MCSE 2006 JumpStart Computer and Network Basics* (2nd ed.). Glasgow: SYBEX.
11. ^ Howe, Denis (ed.). "Redundant Arrays of Independent Disks from FOLDOC" (http://foldoc.org/RAID). *Free On-line Dictionary of Computing* (Imperial College Department of Computing (http://www.doc.ic.ac.uk/)). Retrieved 2011-11-10.
12. ^ Dawkins, Bill and Jones, Arnold. "Common RAID Disk Data Format Specification" (http://www.snia.org/tech_activities/standards/curr_standards/ddf/SNIA-DDFv1.2.pdf) *[Storage Networking Industry Association]* Colorado Springs, 28 July 2006. Retrieved on 22 February 2011.
13. ^ "Common RAID Disk Drive Format (DDF) standard" (http://www.snia.org/tech_activities/standards/curr_standards/ddf/). *SNIA.org*. SNIA. Retrieved 2012-08-26.

14. ^ "SNIA Dictionary" (http://www.snia.org/education/dictionary). *SNIA.org*. SNIA. Retrieved 2010-08-24.
15. ^ Andrew S. Tanenbaum. *Structured Computer Organization 6th ed*. p. 95.
16. ^ "GT70 2OD" (http://www.msi.com/product/nb/GT70_2OD.html#specification). *MSI.com*. Micro-Star International. Retrieved 2014-05-16.
17. ^ "FreeBSD Handbook, Chapter 20.5 GEOM: Modular Disk Transformation Framework" (http://www.freebsd.org/doc/handbook/geom-raid3.html). Retrieved 2012-12-20.
18. ^ White, Jay; Lueth, Chris (May 2010). "RAID-DP:NetApp Implementation of Double Parity RAID for Data Protection. NetApp Technical Report TR-3298" (http://www.netapp.com/us/library/technical-reports/tr-3298.html). Retrieved 2013-03-02.
19. ^ ***a b c*** Newman, Henry (2009-09-17). "RAID's Days May Be Numbered" (http://www.enterprisestorageforum.com/technology/features/article.php/3839636). *EnterpriseStorageForum*. Retrieved 2010-09-07.
20. ^ Peltoniemi, Mikko (2012-08-07). "New RAID level recommendations from Dell" (http://community.spiceworks.com/topic/251735-new-raid-level-recommendations-from-dell). Retrieved 2012-12-01.
21. ^ "Why RAID 6 stops working in 2019" (http://www.zdnet.com/blog/storage/why-raid-6-stops-working-in-2019/805). ZDNet. 22 February 2010.
22. ^ ***a b*** Scott Lowe (2009-11-16). "How to protect yourself from RAID-related Unrecoverable Read Errors (UREs). Techrepublic." (http://www.techrepublic.com/blog/datacenter/how-to-protect-yourself-from-raid-related-unrecoverable-read-errors-ures/1752). Retrieved 2012-12-01.
23. ^ Vijayan, S.; Selvamani, S. ; Vijayan, S (1995). "Dual-Crosshatch Disk Array: A Highly Reliable Hybrid-RAID Architecture" (http://books.google.com/?id=QliANH5G3_gC&dq=%22hybrid+raid%22). *Proceedings of the 1995 International Conference on Parallel Processing: Volume 1*. CRC Press. pp. I–146*ff*. ISBN 0-8493-2615-X.
24. ^ ***a b*** Jeffrey B. Layton: "Intro to Nested-RAID: RAID-01 and RAID-10" (http://www.linux-mag.com/id/7928?hq_e=el&hq_m=1151565&hq_l=36&hq_v=3fa9646c7f), Linux Magazine, January 6, 2011
25. ^ "Performance, Tools & General Bone-Headed Questions" (http://www.tldp.org/HOWTO/Software-RAID-0.4x-HOWTO-8.html). tldp.org. Retrieved 2013-12-25.
26. ^ "Main Page - Linux-raid" (http://linux-raid.osdl.org/). osdl.org. 2010-08-20. Retrieved 2010-08-24.
27. ^ "Hdfs Raid" (http://hadoopblog.blogspot.com/2009/08/hdfs-and-erasure-codes-hdfs-raid.html). Hadoopblog.blogspot.com. 2009-08-28. Retrieved 2010-08-24.
28. ^ "ZFS on Linux" (http://zfsonlinux.org/). Retrieved 2013-07-15.
29. ^ "Btrfs Wiki: Feature List" (https://btrfs.wiki.kernel.org/index.php/Main_Page#Features). 2012-11-07. Retrieved 2012-11-16.
30. ^ "Btrfs Wiki: Changelog" (https://btrfs.wiki.kernel.org/index.php/Changelog). 2012-10-01. Retrieved 2012-11-14.
31. ^ "Mac OS X: How to combine RAID sets in Disk Utility" (http://support.apple.com/kb/TA24359). Retrieved 2010-01-04.
32. ^ "Apple Mac OS X Server File Systems" (http://www.apple.com/server/macosx/technology/file-system.html). Retrieved 2008-04-23.
33. ^ "FreeBSD System Manager's Manual page for GEOM(8)" (http://www.freebsd.org/cgi/man.cgi?query=geom). Retrieved 2009-03-19.
34. ^ "freebsd-geom mailing list - new class / geom_raid5" (http://lists.freebsd.org/pipermail/freebsd-geom/2006-July/001356.html). Retrieved 2009-03-19.
35. ^ "FreeBSD Kernel Interfaces Manual for CCD(4)" (http://www.freebsd.org/cgi/man.cgi?query=ccd). Retrieved 2009-03-19.
36. ^ "The Software-RAID HOWTO" (http://tldp.org/HOWTO/Software-RAID-HOWTO.html). Retrieved 2008-11-10.
37. ^ "RAID setup" (http://linux-raid.osdl.org/index.php/RAID_setup). Retrieved 2008-11-10.
38. ^ "RAID setup" (https://raid.wiki.kernel.org/index.php/RAID_setup). Retrieved 2010-09-30.

39. ^ "Using Windows XP to Make RAID 5 Happen" (http://www.tomshardware.com/reviews/windowsxp-make-raid-5-happen,925.html). Tomshardware.com. Retrieved 2010-08-24.
40. ^ Sinofsky, Steven. "Virtualizing storage for scale, resiliency, and efficiency" (http://blogs.msdn.com/b/b8/archive/2012/01/05/virtualizing-storage-for-scale-resiliency-and-efficiency.aspx). Microsoft.
41. ^ Metzger, Perry (1999-05-12). "NetBSD 1.4 Release Announcement" (http://www.netbsd.org/releases/formal-1.4/NetBSD-1.4.html). *NetBSD.org*. The NetBSD Foundation. Retrieved 2013-01-30.
42. ^ "FreeBSD Handbook" (http://www.freebsd.org/doc/en_US.ISO8859-1/books/handbook/geom-mirror.html). *Chapter 19 GEOM: Modular Disk Transformation Framework*. Retrieved 2009-03-19.
43. ^ "SATA RAID FAQ" (https://ata.wiki.kernel.org/index.php/SATA_RAID_FAQ). Ata.wiki.kernel.org. 2011-04-08. Retrieved 2012-08-26.
44. ^ Red Hat Enterprise Linux - Storage Administrator Guide - RAID Types (https://access.redhat.com/site/documentation/en-US/Red_Hat_Enterprise_Linux/6/html/Storage_Administration_Guide/s1-raid-approaches.html)
45. ^ Charlie Russel; Sharon Crawford; Andrew Edney (2011). *Working with Windows Small Business Server 2011 Essentials* (http://books.google.com/books?id=R2gJ9kcX2ywC&pg=PA90). O'Reilly Media, Inc. p. 90. ISBN 978-0-7356-5670-3.
46. ^ http://www.freebsd.org/doc/handbook/geom-graid.html
47. ^ Ronald L. Krutz; James Conley (2007). *Wiley Pathways Network Security Fundamentals* (http://books.google.com/books?id=Gdux_6ckDYwC&pg=PA422). John Wiley & Sons. p. 422. ISBN 978-0-470-10192-6.
48. ^ ***a b c*** Hardware RAID vs. Software RAID: Which Implementation is Best for my Application? Adaptec Whitepaper (http://www.adaptec.com/nr/rdonlyres/14b2fd84-f7a0-4ac5-a07a-214123ea3dd6/0/4423_sw_hwraid_10.pdf)
49. ^ Gregory Smith (2010). *PostgreSQL 9.0: High Performance* (http://books.google.com/books?id=OWOAu0GcsqoC&pg=PT72). Packt Publishing Ltd. p. 31. ISBN 978-1-84951-031-8.
50. ^ "Adaptec Hybrid RAID Solutions" (http://www.adaptec.com/nr/pdfs/hybrid-raid_wp.pdf). *Adaptec.com*. Adaptec. 2012. Retrieved 2013-09-07.
51. ^ Ulf Troppens, Wolfgang Mueller-Friedt, Rainer Erkens, Rainer Wolafka, Nils Haustein. Storage Networks Explained: Basics and Application of Fibre Channel SAN, NAS, ISCSI, InfiniBand and FCoE. John Wiley and Sons, 2009. p.39
52. ^ Dell Computers, Background Patrol Read for Dell PowerEdge RAID Controllers, By Drew Habas and John Sieber, Reprinted from Dell Power Solutions, February 2006 http://www.dell.com/downloads/global/power/ps1q06-20050212-Habas.pdf
53. ^ ***a b c*** "Error Recovery Control with Smartmontools" (http://www.csc.liv.ac.uk/~greg/projects/erc/). Retrieved 2011.
54. ^ These studies are: Gray, J (1990), Murphy and Gent (1995), Kuhn (1997), and Enriquez P. (2003).
55. ^ Patterson, D., Hennessy, J. (2009), 574.
56. ^ "The RAID Migration Adventure" (http://www.tomshardware.com/reviews/RAID-MIGRATION-ADVENTURE,1640.html). Retrieved 2010-03-10.
57. ^ Disk Failures in the Real World: What Does an MTTF of 1,000,000 Hours Mean to You? (http://www.usenix.org/events/fast07/tech/schroeder.html) Bianca Schroeder and Garth A. Gibson
58. ^ ***a b*** Harris, Robin (2010-02-27). "Does RAID 6 stop working in 2019?" (http://storagemojo.com/2010/02/27/does-raid-6-stops-working-in-2019/). *StorageMojo.com*. TechnoQWAN. Retrieved 2013-12-17.
59. ^ J.L. Hafner, V. Deenadhaylan, K. Rao, and J.A. Tomlin. "Matrix methods for lost data reconstruction in erasure codes. USENIX Conference on File and Storage Technologies, p15-30, Dec. 13-16, 2005.
60. ^ M.Baker, M.Shah, D.S.H. Rosenthal, M.Roussopoulos, P.Maniatis, T.Giuli, and P.Bungale. 'A fresh look at the reliability of long-term digital storage." EuroSys2006, Apr. 2006.
61. ^ "L.N. Bairavasundaram, GR Goodson, S. Pasupathy, J.Schindler. "An analysis of latent sector errors in disk drives". Proceedings of SIGMETRICS'07, June 12-16,2007." (http://research.cs.wisc.edu/adsl/Publications/latent-sigmetrics07.pdf).

62. ^ Patterson, D., Hennessy, J. (2009). *Computer Organization and Design*. New York: Morgan Kaufmann Publishers. pp 604-605.
63. ^ *a b c* Leventhal, Adam (2009-12-01). "Triple-Parity RAID and Beyond. ACM Queue, Association of Computing Machinery" (https://queue.acm.org/detail.cfm?id=1670144). Retrieved 2012-11-30.
64. ^ " "Write hole" in RAID5, RAID6, RAID1, and other arrays" (http://www.raid-recovery-guide.com/raid5-write-hole.aspx). ZAR team. Retrieved 15 February 2012.
65. ^ Jim Gray: The Transaction Concept: Virtues and Limitations (http://www.informatik.uni-trier.de/~ley/db/conf/vldb/Gray81.html) (Invited Paper) VLDB 1981 (http://www.informatik.uni-trier.de/~ley/db/conf/vldb/vldb81.html#Gray81): 144-154
66. ^ "Definition of write-back cache at SNIA dictionary" (http://www.snia.org/education/dictionary/w/).

External links

- RAID (http://www.dmoz.org/Computers/Hardware/Storage/Subsystems/RAID) at DMOZ
- "Empirical Measurements of Disk Failure Rates and Error Rates" (http://research.microsoft.com/research/pubs/view.aspx?msr_tr_id=MSR-TR-2005-166), by Jim Gray and Catharine van Ingen, December 2005
- The mathematics of RAID-6 (https://www.kernel.org/pub/linux/kernel/people/hpa/raid6.pdf), by H. Peter Anvin
- Does fake RAID offer any advantage over software RAID? (http://superuser.com/questions/245928/does-fake-raid-offer-any-advantage-over-software-raid) – Discussion on superuser.com
- Differences between Hardware RAID, HBAs, and Software RAID (http://www.servethehome.com/difference-hardware-raid-hbas-software-raid/) – ServeTheHome.com (details more relative advantages and disadvantages)
- Anatomy of a Hardware RAID Controller (http://www.servethehome.com/anatomy-hardware-raid-controller/) – ServeTheHome.com (focused on contemporary SAS products)
- Comparing RAID Implementation Methods (ftp://ftp.dell.com/app/3q03-Dum.pdf) – Dell.com
- BAARF: Battle Against Any Raid Five (http://www.miracleas.com/BAARF/BAARF2.html) (RAID 3, 4 and 5 versus RAID 10)