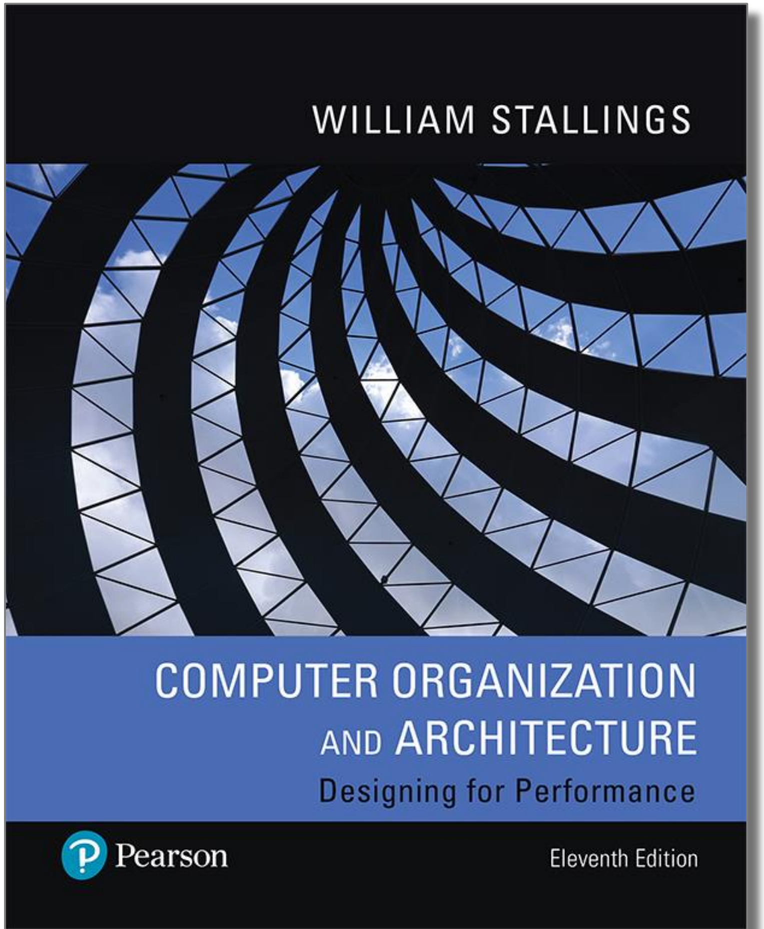
Computer Organization and Architecture
Designing for Performance

11th Edition



Chapter 7

External Memory

Redundant Array of Independent Disks (RAID)

- One way to enhance the performance is to use parallel components.
- This idea applies also to disk storage.
- RAID is a standardized scheme that combines multiple disks to appear as one or more logical drive to the operating system for the purpose of **performance** of **reliability** enhancement.
- Seven levels of RAIDS from zero to six are available.

Redundant Array of Independent Disks (RAID)

- RAIDS share three common characteristics:
  1. RAID is a set of physical disk drives viewed by the operating system as a single logical unit.
  2. Data are distributed across the physical drives of an array in a scheme known as striping.
  3. Redundant disk capacity is used to store parity information, which guarantee data recovery in case of a disk failure (not all levels share this characteristic)

Redundant Array of Independent Disks (RAID)

- Even though, operating on disks simultaneously achieves higher I/O and transfer rates, the use of multiple devices increase the probability of failures.

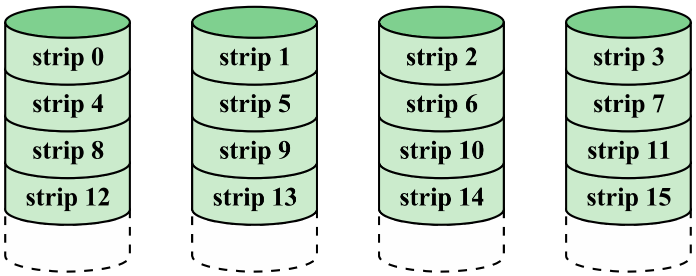
- To remedy this, stored parity information is used to recover data lost due to disk failure.

Table 7.3
RAID Levels

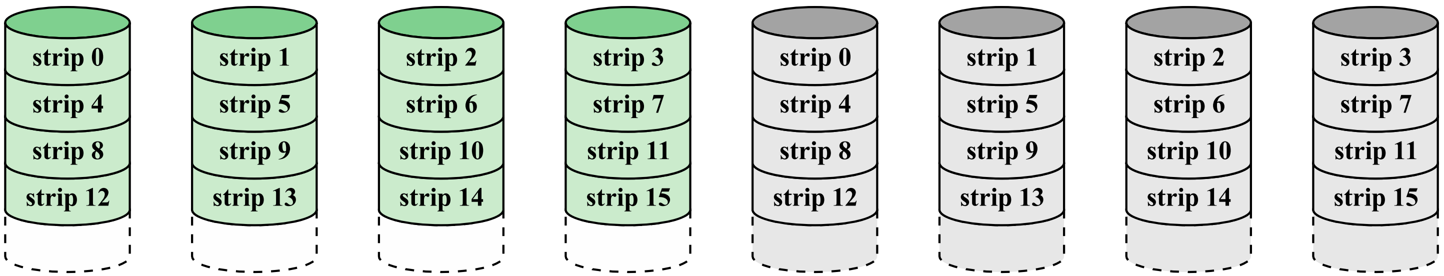
Category	Level	Description	Disks Required	Data Availability	Large I/O Data Transfer Capacity	Small I/O Request Rate
Striping	0	Nonredundant	N	Lower than single disk	Very high	Very high for both read and write
Mirroring	1	Mirrored	$2N$	Higher than RAID 2, 3, 4, or 5; lower than RAID 6	Higher than single disk for read; similar to single disk for write	Up to twice that of a single disk for read; similar to single disk for write
Parallel Access	2	Redundant via Hamming code	$N + m$	Much higher than single disk; comparable to RAID 3, 4, or 5	Highest of all listed alternatives	Approximately twice that of a single disk
	3	Bit-interleaved parity	$N + 1$	Much higher than single disk; comparable to RAID 2, 4, or 5	Highest of all listed alternatives	Approximately twice that of a single disk
Independent access	4	Block-interleaved parity	$N + 1$	Much higher than single disk; comparable to RAID 2, 3, or 5	Similar to RAID 0 for read; significantly lower than single disk for write	Similar to RAID 0 for read; significantly lower than single disk for write
	5	Block-interleaved distributed parity	$N + 1$	Much higher than single disk; comparable to RAID 2, 3, or 4	Similar to RAID 0 for read; lower than single disk for write	Similar to RAID 0 for read; generally lower than single disk for write
	6	Block-interleaved dual distributed parity	$N + 2$	Highest of all listed alternatives	Similar to RAID 0 for read; lower than RAID 5 for write	Similar to RAID 0 for read; significantly lower than RAID 5 for write

N = number of data disks; m proportional to log N

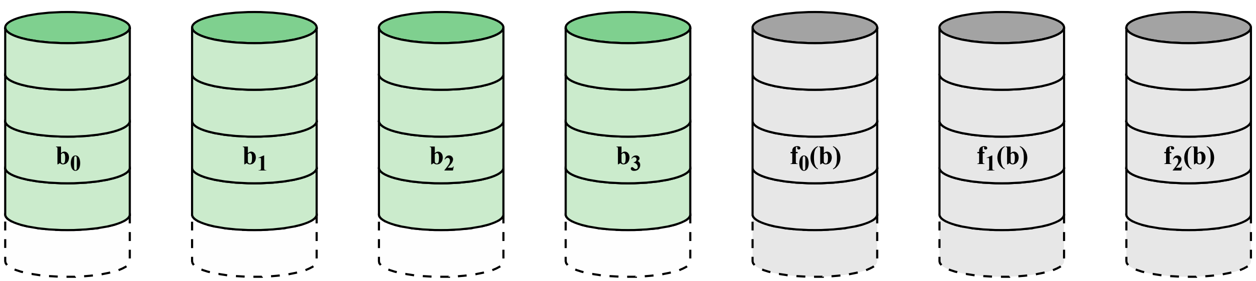
Figure 7.6
RAID Levels (1 of 2)



(a) RAID 0 (non-redundant)



(b) RAID 1 (mirrored)



(c) RAID 2 (redundancy through Hamming code)

Figure 7.6
RAID Levels (2 of 2)

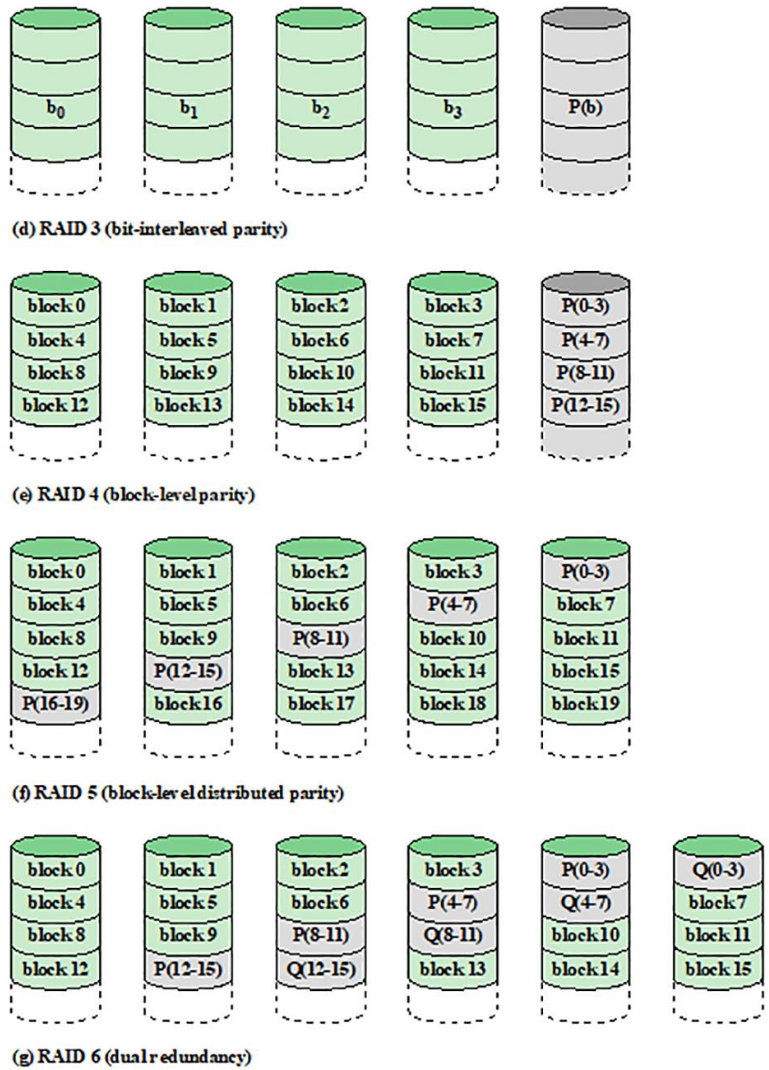
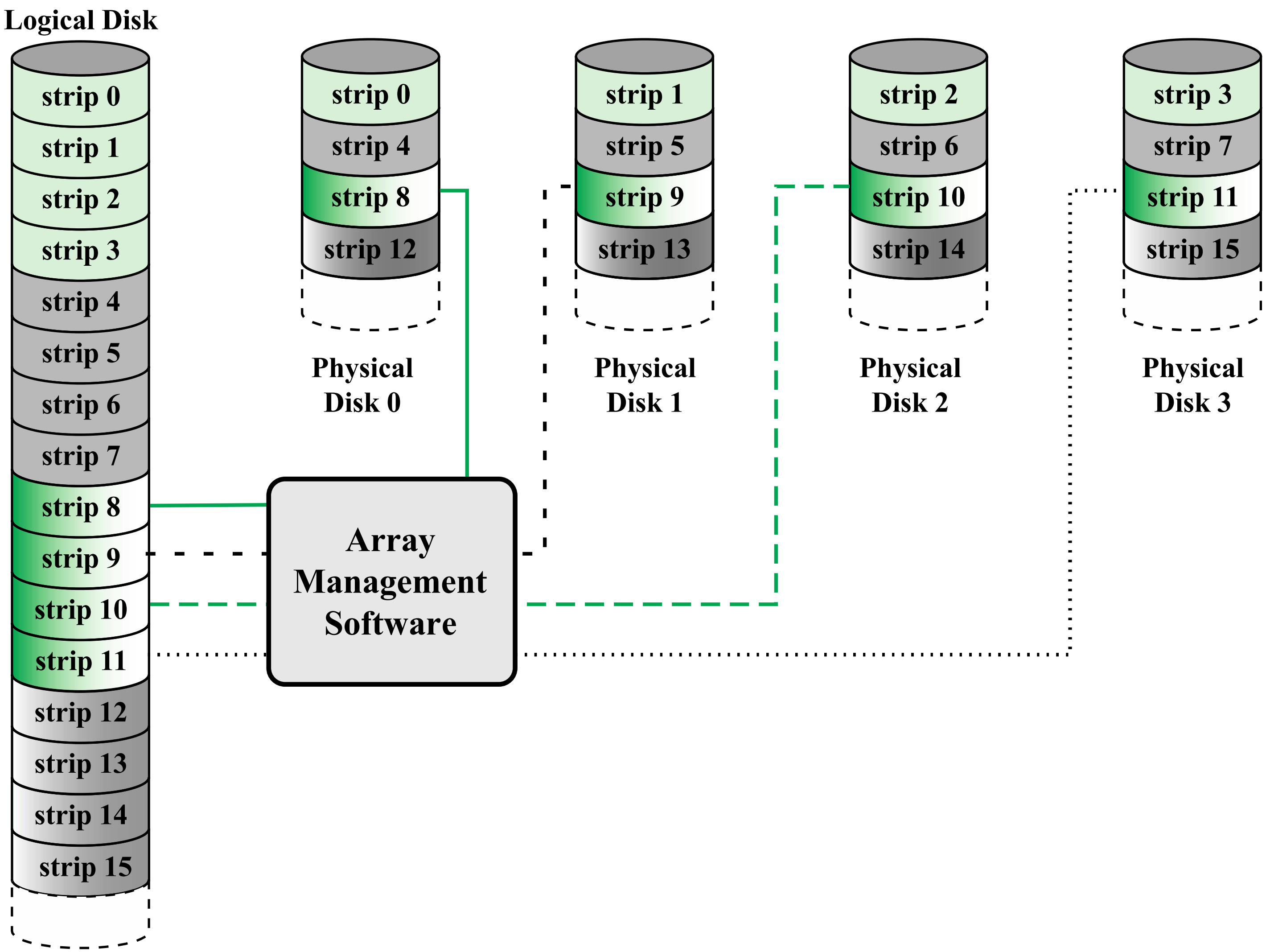


Figure 7.7
Data Mapping for a RAID Level 0 Array



Pearson

RAID Level 0

- Addresses the issues of request patterns of the host system and layout of the data
- Impact of redundancy does not interfere with analysis

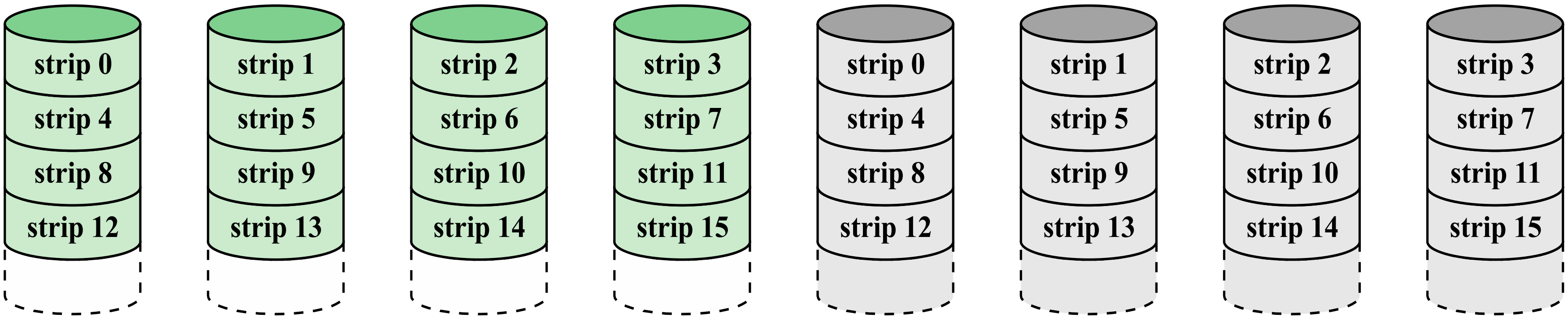
RAID 0 for High Data Transfer Capacity

- For applications to experience a high transfer rate two requirements must be met:
  1. A high transfer capacity must exist along the entire path between host memory and the individual disk drives
  2. The application must make I/O requests that drive the disk array efficiently

RAID 0 for High I/O Request Rate

- For an individual I/O request for a small amount of data the I/O time is dominated by the seek time and rotational latency
- A disk array can provide high I/O execution rates by balancing the I/O load across multiple disks
- If the strip size is relatively large multiple waiting I/O requests can be handled in parallel, reducing the queuing time for each request

RAID
Level 1



(b) RAID 1 (mirrored)

RAID Level 1

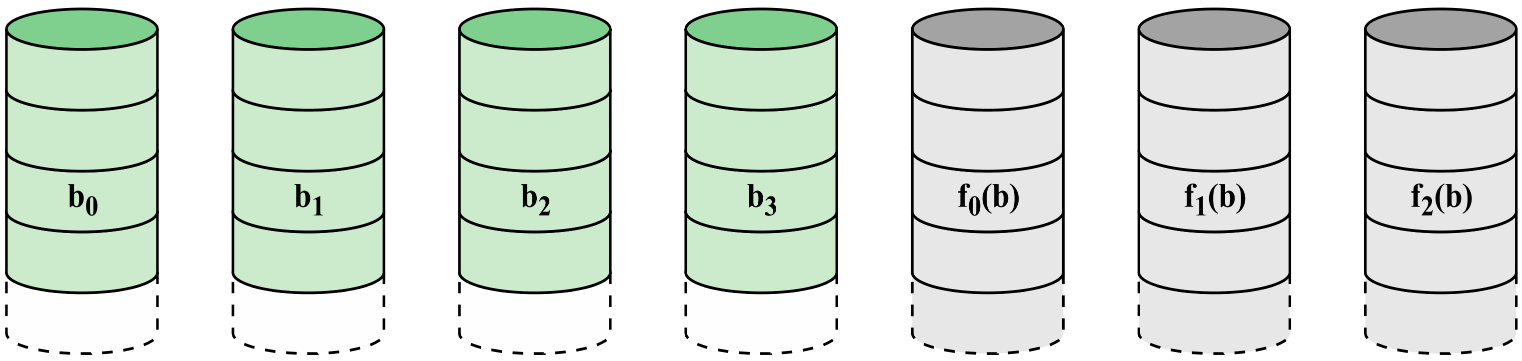
Characteristics

- Differs from RAID levels 2 through 6 in the way in which redundancy is achieved
- Redundancy is achieved by the simple expedient of duplicating all the data
- Data striping is used but each logical strip is mapped to two separate physical disks so that every disk in the array has a mirror disk that contains the same data
- RAID 1 can also be implemented without data striping, although this is less common

Positive Aspects

- A read request can be serviced by either of the two disks that contains the requested data
- There is no “write penalty”
- Recovery from a failure is simple, when a drive fails the data can be accessed from the second drive
- Provides real-time copy of all data
- Can achieve high I/O request rates if the bulk of the requests are reads
- Principal disadvantage is the cost

RAID Level 2



(c) RAID 2 (redundancy through Hamming code)

RAID Level 2

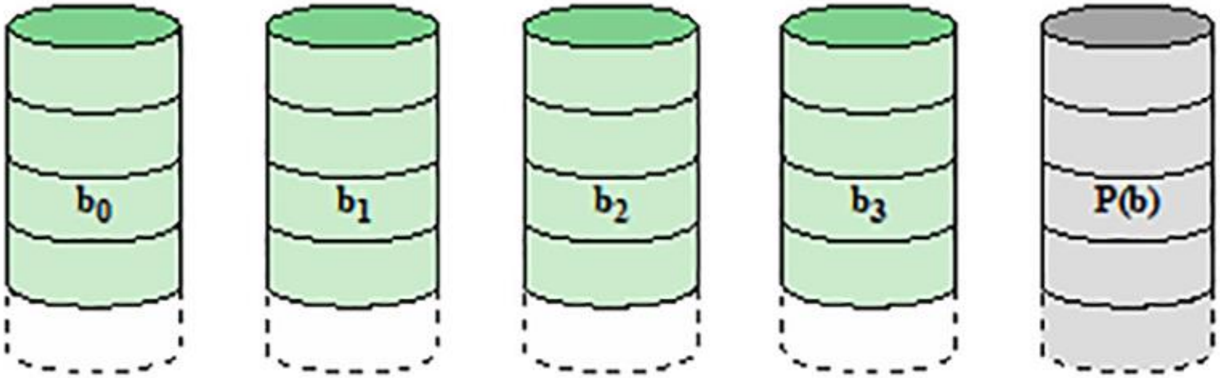
Characteristics

- Makes use of a parallel access technique
- In a parallel access array all member disks participate in the execution of every I/O request
- Spindles of the individual drives are synchronized so that each disk head is in the same position on each disk at any given time
- Data striping is used
  - Strips are very small, often as small as a single byte or word

Performance

- An error-correcting code is calculated across corresponding bits on each data disk and the bits of the code are stored in the corresponding bit positions on multiple parity disks
- Typically a Hamming code is used, which is able to correct single-bit errors and detect double-bit errors
- The number of redundant disks is proportional to the log of the number of data disks
- Would only be an effective choice in an environment in which many disk errors occur

RAID Level 3



(d) RAID 3 (bit-interleaved parity)

RAID Level 3

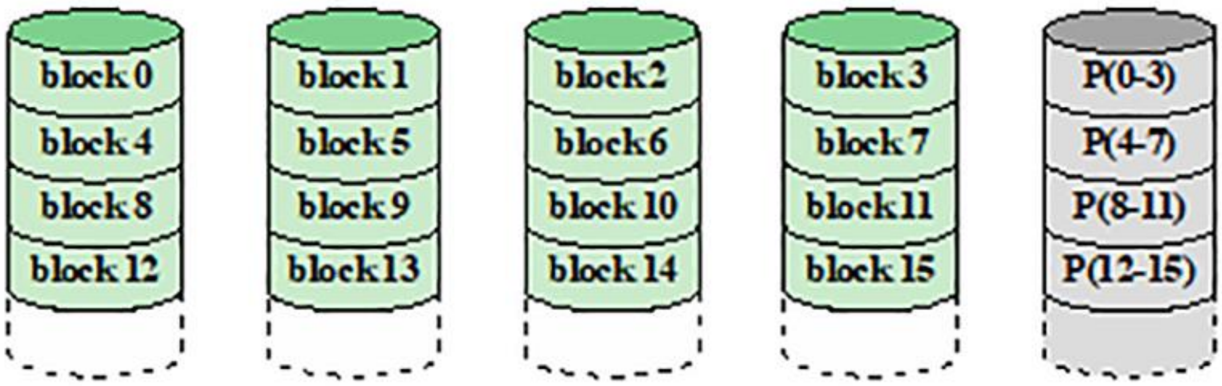
Redundancy

- Requires only a single redundant disk, no matter how large the disk array
- Employs parallel access, with data distributed in small strips
- Instead of an error correcting code, a simple parity bit is computed for the set of individual bits in the same position on all of the data disks
- Can achieve very high data transfer rates

Performance

- In the event of a drive failure, the parity drive is accessed and data is reconstructed from the remaining devices
- Once the failed drive is replaced, the missing data can be restored on the new drive and operation resumed
- In the event of a disk failure, all of the data are still available in what is referred to as reduced mode
- Return to full operation requires that the failed disk be replaced and the entire contents of the failed disk be regenerated on the new disk
- In a transaction-oriented environment performance suffers

RAID Level 4



(e) RAID 4 (block-level parity)

RAID Level 4

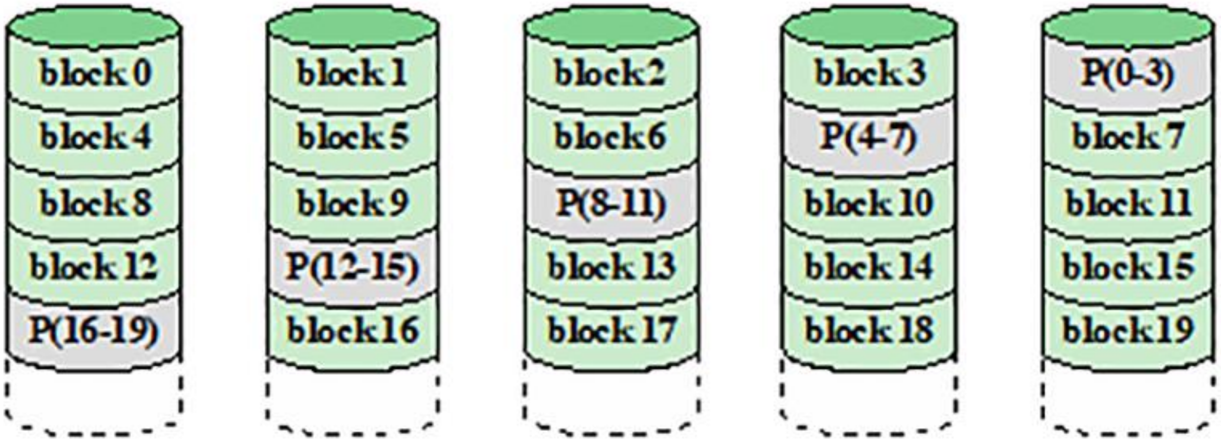
Characteristics

- Makes use of an independent access technique
  - In an independent access array, each member disk operates independently so that separate I/O requests can be satisfied in parallel
- Data striping is used
  - Strips are relatively large
- To calculate the new parity the array management software must read the old user strip and the old parity strip

Performance

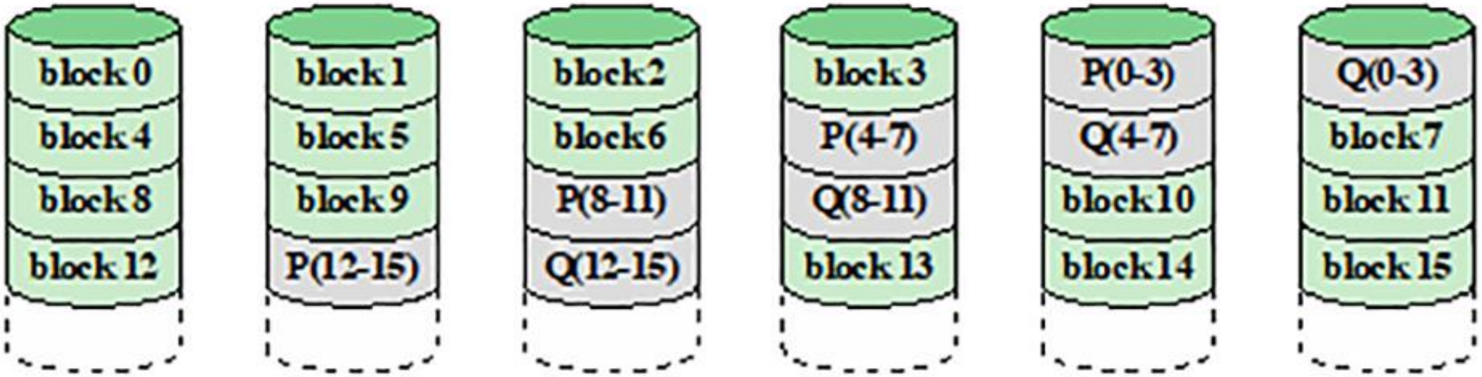
- Involves a write penalty when an I/O write request of small size is performed
- Each time a write occurs the array management software must update not only the user data but also the corresponding parity bits
- Thus each strip write involves two reads and two writes

RAID Level 5



(f) RAID 5 (block-level distributed parity)

RAID Level 6



(g) RAID 6 (dual redundancy)

RAID Level 5

Characteristics

- Organized in a similar fashion to RAID 4
- Difference is distribution of the parity strips across all disks
- A typical allocation is a round-robin scheme
- The distribution of parity strips across all drives avoids the potential I/O bottleneck found in RAID 4

RAID Level 6

Characteristics

- Two different parity calculations are carried out and stored in separate blocks on different disks
- Advantage is that it provides extremely high data availability
- Three disks would have to fail within the mean time to repair (MTTR) interval to cause data to be lost
- Incurs a substantial write penalty because each write affects two parity blocks

Table 7.4
RAID Comparison (1 of 2)

Level	Advantages	Disadvantages	Applications
0	I/O performance is greatly improved by spreading the I/O load across many channels and drives No parity calculation overhead is involved Very simple design Easy to implement	The failure of just one drive will result in all data in an array being lost	Video production and editing Image Editing Pre- press applications Any application requiring high bandwidth
1	100% redundancy of data means no rebuild is necessary in case of a disk failure, just a copy to the replacement disk Under certain circumstances, RAID 1 can sustain multiple simultaneous drive Failures Simplest RAID storage subsystem design	Highest disk overhead of all RAID types (100%)—inefficient	Accounting Payroll Financial Any application requiring very high availability
2	Extremely high data transfer rates possible The higher the data transfer rate required, the better the ratio of data disks to ECC disks Relatively simple controller design compared to RAID levels 3, 4, & 5	Very high ratio of ECC disks to data disks with smaller word sizes— inefficient Entry level cost very high—requires very high transfer rate requirement to justify	No commercial imple-mentations exist/not commercially viable
3	Very high read data transfer rate Very high write data transfer rate Disk failure has an insignificant impact on throughput Low ratio of ECC (parity) disks to data disks means high efficiency	Transaction rate equal to that of a single disk drive at best (if spindles are synchronized) Controller design is fairly complex	Video production and live streaming Image editing Video editing Prepress applications Any application requiring high throughput

(Table can be found on pages 230-231 in the textbook.)

Table 7.4
RAID Comparison (2 of 2)

Level	Advantages	Disadvantages	Applications
4	Very high Read data transaction rate Low ratio of ECC (parity) disks to data disks means high efficiency	Quite complex controller design Worst write transaction rate and Write aggregate transfer rate Difficult and inefficient data rebuild in the event of disk failure	No commercial implementations exist/not commercially viable
5	Highest Read data transaction rate Low ratio of ECC (parity) disks to data disks means high efficiency Good aggregate transfer rate	Most complex controller design Difficult to rebuild in the event of a disk failure (as compared to RAID level 1)	File and application servers Database servers Web, e- mail, and news servers Intranet servers Most versatile RAID level
6	Provides for an extremely high data fault tolerance and can sustain multiple simultaneous drive failures	More complex controller design Controller overhead to compute parity addresses is extremely high	Perfect solution for mission critical applications

(Table can be found on pages 230-231 in the textbook.)

Pearson

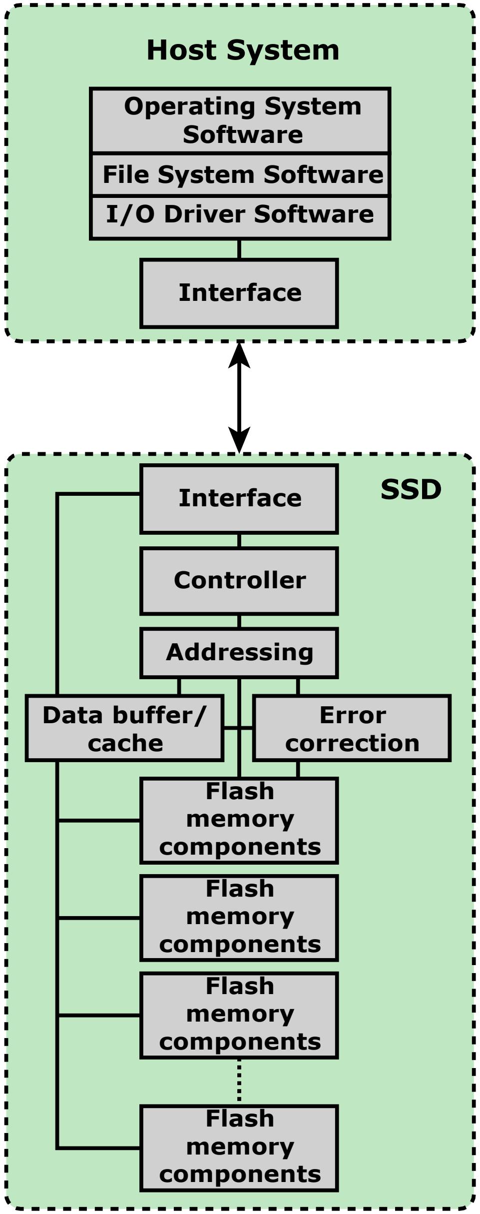
SSD Compared to HDD

- SSDs have the following advantages over HDDs:
  - High-performance input/output operations per second (IOPS)
  - Durability
  - Longer lifespan
  - Lower power consumption
  - Quieter and cooler running capabilities
  - Lower access times and latency rates

Table 7.5 Comparison of Solid State Drives and Disk Drives

	NAND Flash Drives	Seagate Laptop Internal HDD
File copy/write speed	200–550 Mbps	50–120 Mbps
Power draw/battery life	Less power draw, averages 2–3 watts, resulting in 30+ minute battery boost	More power draw, averages 6–7 watts and therefore uses more battery
Storage capacity	Typically not larger than 1 TB for Notebook size drives; 4 max for desktops	Typically around 500 GB and 2 TB max for notebook size drives; 10 TB max for desktops
Cost	Approx. $0.20 per GB for a 1-TB drive	Approx. $0.03 per GB for a 4-TB drive

Figure 7.8 Solid State Drive Architecture



Practical Issues

There are two practical issues peculiar to SSDs that are not faced by HDDs:

- SDD performance has a tendency to slow down as the device is used
  - The entire block must be read from the flash memory and placed in a RAM buffer
  - Before the block can be written back to flash memory, the entire block of flash memory must be erased
  - The entire block from the buffer is now written back to the flash memory
- Flash memory becomes unusable after a certain number of writes
  - Techniques for prolonging life:
    - Front-ending the flash with a cache to delay and group write operations
    - Using wear-leveling algorithms that evenly distribute writes across block of cells
    - Bad-block management techniques
  - Most flash devices estimate their own remaining lifetimes so systems can anticipate failure and take preemptive action

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