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Physical Storage Media

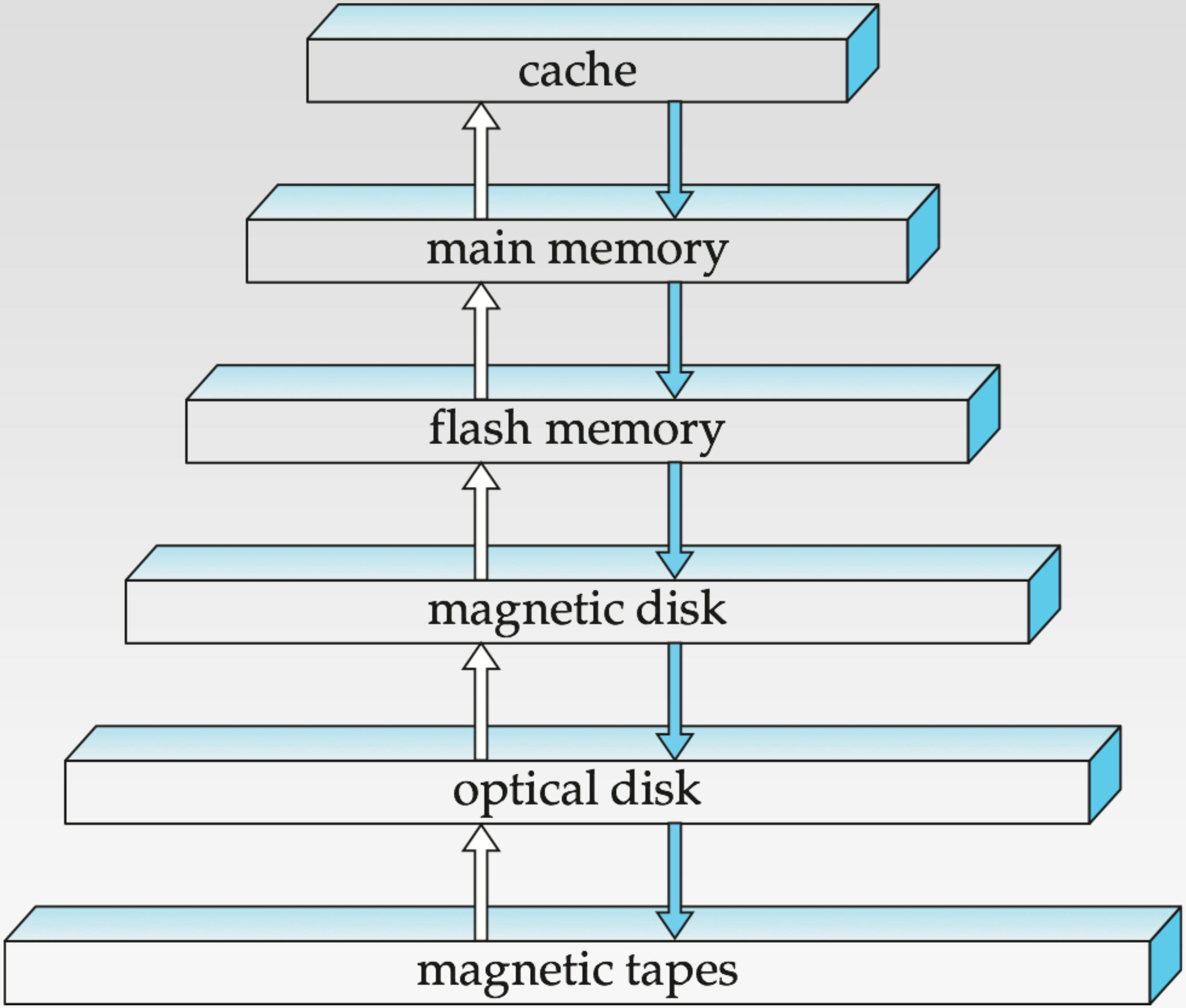
These slides are a modified version of the slides of the book "Database System Concepts, 5th Ed., McGraw-Hill, by Silberschatz, Korth and Sudarshan. Original slides are available at www.db-book.com

Classification of Physical Storage Media

- Speed with which data can be accessed
- Cost per unit of data
- Reliability
  - data loss on power failure or system crash
  - physical failure of the storage device

- Can differentiate storage into:
  - **volatile storage:** loses contents when power is switched off
  - **non-volatile storage**:
    - Contents persist even when power is switched off.
    - Includes secondary and tertiary storage, as well as batter-backed up main-memory.

Storage Hierarchy

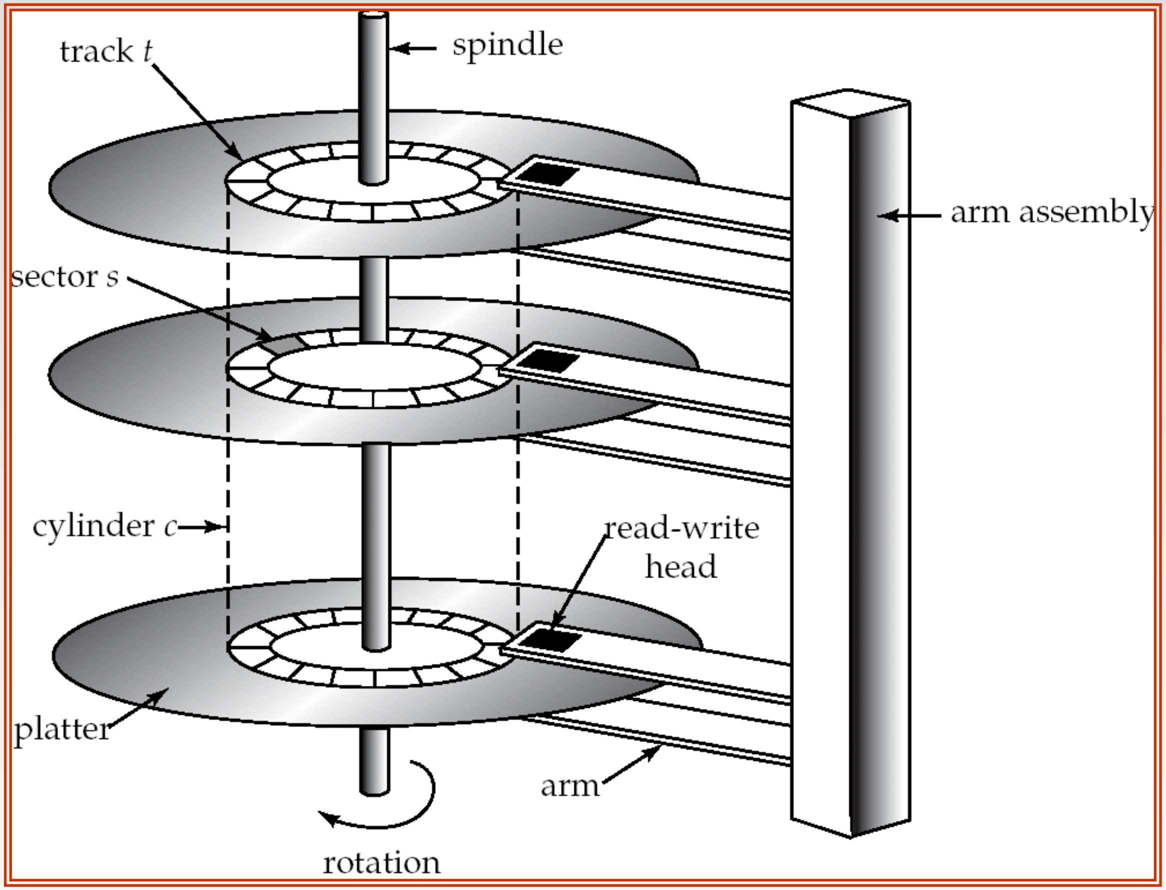


Physical Storage Media

- **Magnetic-disk**
  primary medium for the long term on-line storage of data

  - Data is stored on spinning disk, and read/written magnetically
  - Primary medium for the long-term storage of data; typically stores entire database.
  - Data must be moved from disk to main memory for access, and written back for storage
    - Much slower access than main memory (more on this later)
  - **direct-access** – possible to read data on disk in any order, unlike magnetic tape (sequential access)
  - Capacities range up to roughly 400 GB currently
    - Growing constantly and rapidly with technology improvements (factor of 2 to 3 every 2 years)

Magnetic Hard Disk Mechanism



NOTE: Diagram is schematic, and simplifies the structure of actual disk drives

Magnetic Disks

- **Read-write head**
  - Positioned very close to the platter surface (almost touching it)
  - Reads or writes magnetically encoded information.
- Surface of platter divided into circular **tracks**
  - Over 50K-100K tracks per platter on typical hard disks
- Each track is divided into **sectors.**
  - A sector is the smallest unit of data that can be read or written.
  - Sector size typically 512 bytes
  - Typical sectors per track: 500 (on inner tracks) to 1000 (on outer tracks)
- To read/write a sector
  - disk arm swings to position head on right track
  - platter spins continually; data is read/written as sector passes under head
- Head-disk assemblies
  - multiple disk platters on a single spindle (1 to 5 usually)
  - one head per each platter side, mounted on a common arm.
- **Cylinder** *i* consists of i^{th} track of all the platters

Magnetic Disks: reliability

- **Head crashes can be a problem**
  - Earlier generation disks were susceptible to head-crashes Surface of earlier generation disks had metal-oxide coatings which would disintegrate on head crash and damage all data on disk
  - Current generation disks are less susceptible to such disastrous failures, although **individual sectors** may get corrupted

Magnetic Disks: reliability

Disk controller – interfaces between the computer system and the disk drive hardware.

- accepts high-level commands to read or write a sector
- initiates actions such as moving the disk arm to the right track and actually reading or writing the data
- To deal with read/write failure, computes and attaches **checksums** to each sector

- **Read failure**

  compute the **checksum** of data read to verify that data is read back correctly

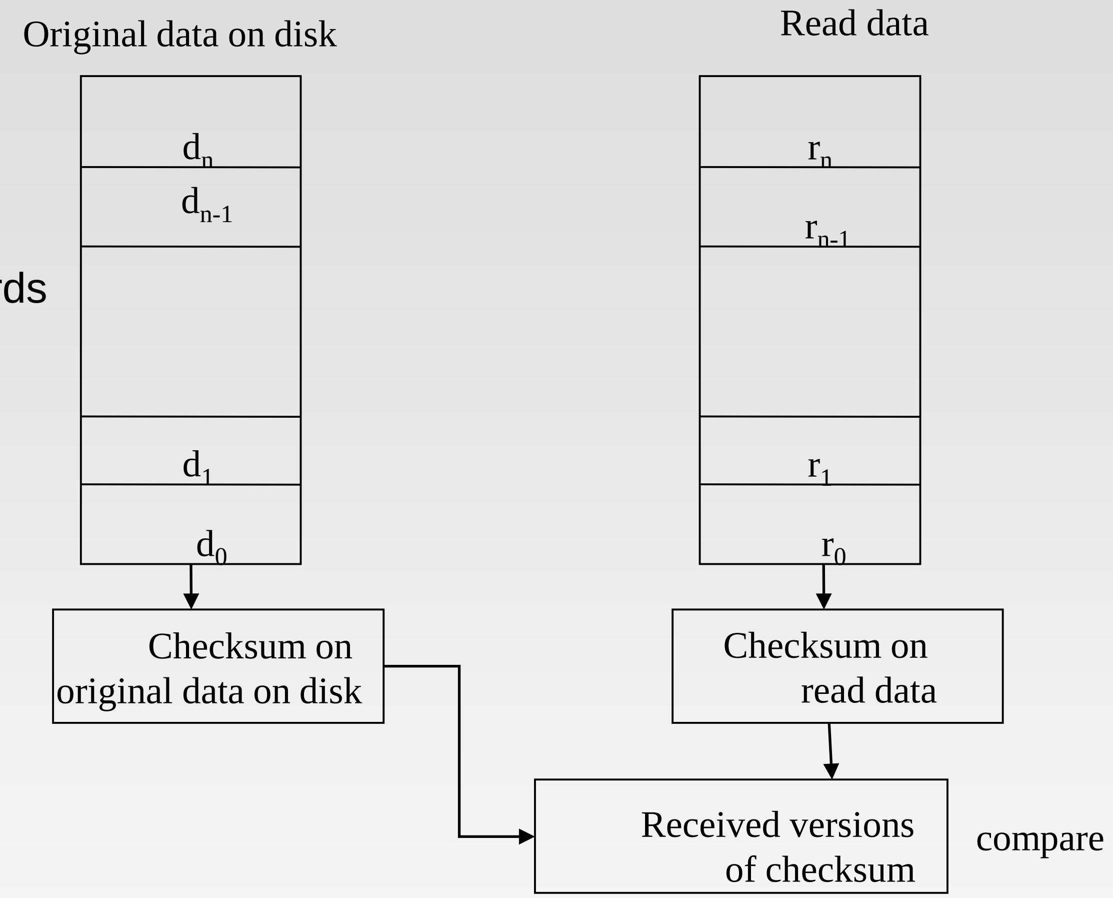
  - If data is corrupted, with very high probability stored checksum won't match recomputed checksum

- **Write failure**

  Ensure successful writing by reading back sector after writing it

Checksums

- a checksum is basically the sum of the data
- a checksum for a block of s words is formed by adding together all of the words in the block modulo-n, where n is arbitrary.

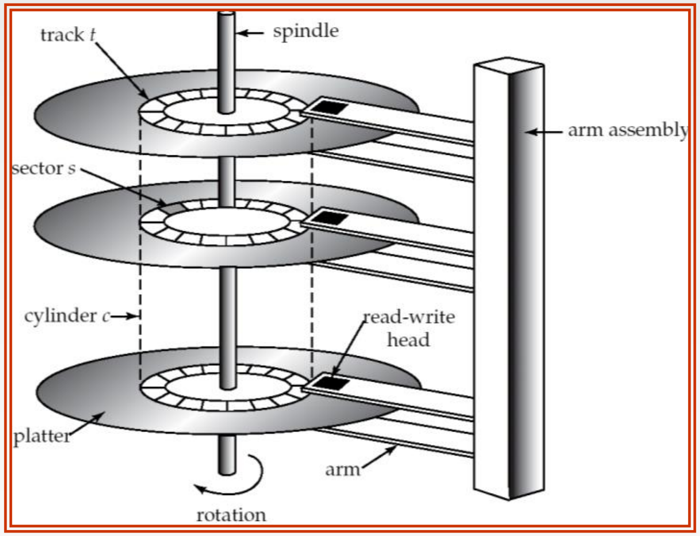


Magnetic Disks: reliability

- Disk controller performs remapping of bad sectors

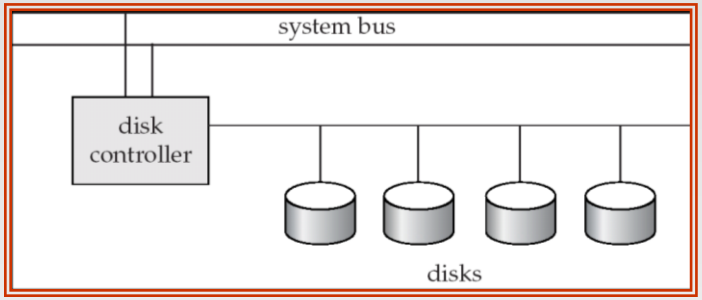
  If the controller detects that a sector is damaged, the controller can logically map the bad sector to a different physical location (when the disk is formatted or when an attempt is made to write the sector), allocated by a pool of extra sectors set aside for this purpose.

- The write is carried out on the new location.



Disks organization

- Disks can be
  - connected directly to the disk interface of the computer system
  - situated remotely and connected by a high speed network to the disk controller interface of the computer system (case of mainframes and servers)



- Remote access to disks means that
  - disks can be shared by multiple computers that could run different parts of an application in parallel (SAN - storage area network architecture)
  - disks can be kept in a central server room where they are monitored
  - disks can be organized locally using a storage organization technique called **RAID** (Redundant Arrays of Independent Disks)

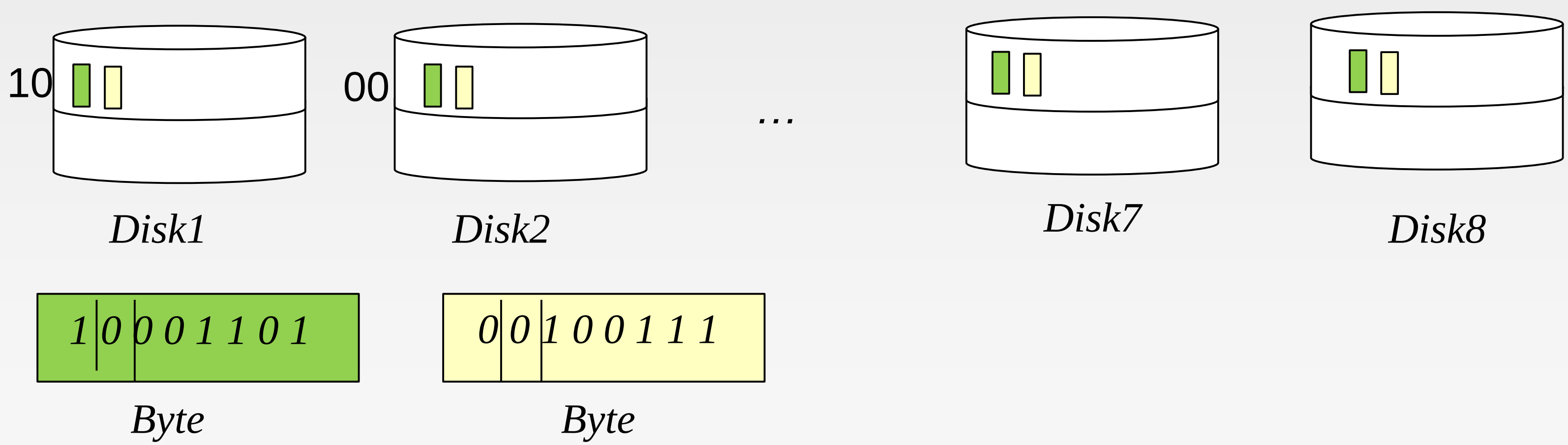
RAID
Redundant Arrays of Independent Disks

- This technology provides a view of a single disk of high capacity and high speed by using multiple disks in parallel, and high reliability, by storing data redundantly, so that data can be recovered even if a disk fails
- If disks are operated in parallel, this presents opportunities for improving the rate at which data can be read/written
- Moreover, the reliability of data storage can be improved because redundant information can be stored on multiple disks.

Improvement in Performance via Parallelism

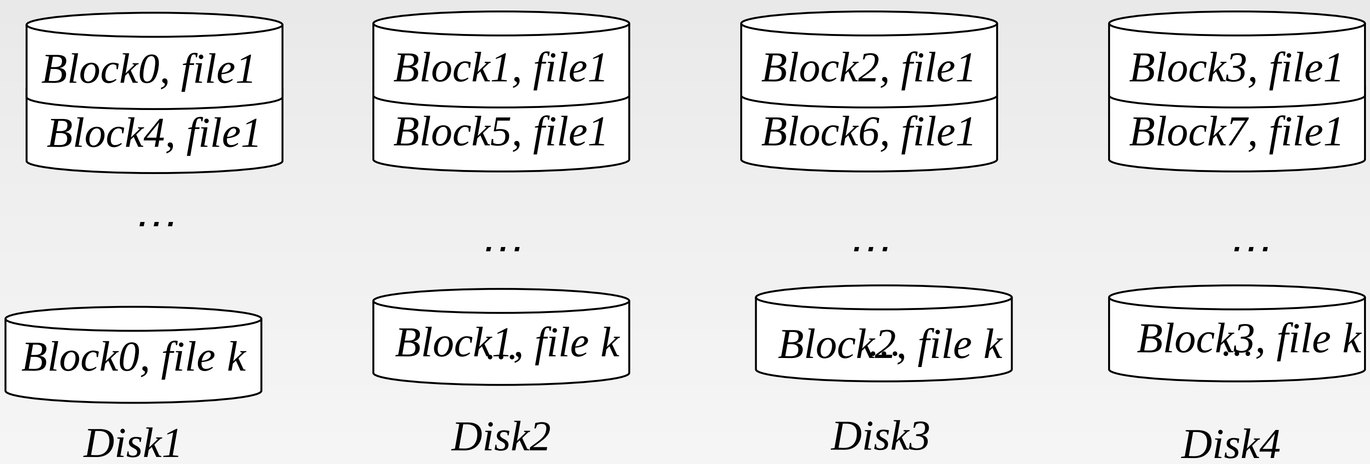
- Improve transfer rate by striping data across multiple disks.

- **Bit-level striping** – split the bits of each byte across multiple disks
  - In an array of eight disks, write bit *i* of each byte to disk *i.*
  - Each access can read data at eight times the rate of a single disk.
  - But seek/access time worse than for a single disk
    - Bit level striping is not used much any more



Improvement in Performance via Parallelism

- **Block-level striping** – with *n* disks, block *i* of a file goes to disk (*i* mod *n*) + 1
  - Requests for different blocks can run in parallel if the blocks reside on different disks
  - A request for a long sequence of blocks can utilize all disks in parallel

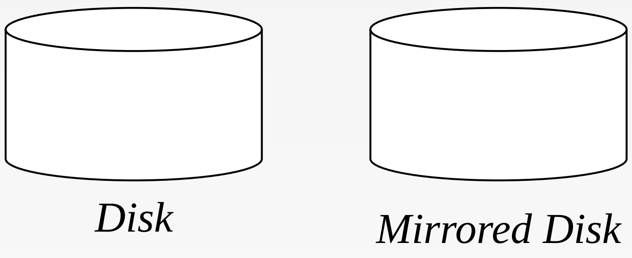


Improvement of Reliability via Redundancy

- **Redundancy** – store extra information that can be used to rebuild information lost in a disk failure (Coding)

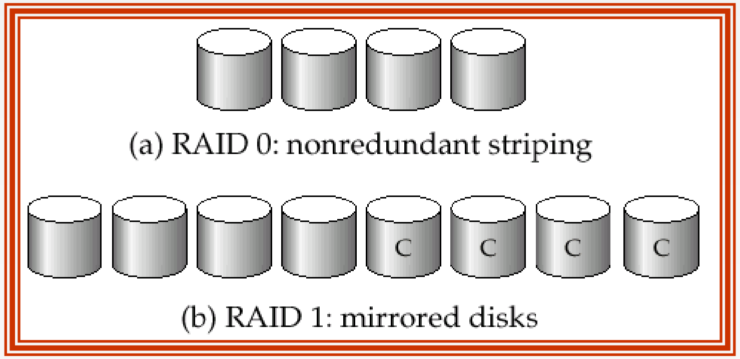
E.g., **Mirroring** (or **shadowing**)

- Duplicate every disk. Logical disk consists of two physical disks.
- Every write is carried out on both disks
  - Reads can take place from either disk
- If one disk in a pair fails, data are still available in the other
  - Data loss would occur only if a disk fails, and its mirror disk also fails before the system is repaired
    - Probability of combined event is very small
      - » Except for dependent failure modes such as fire or electrical power outage



RAID Levels

- Schemes to provide redundancy at lower cost by using disk striping combined with parity bits
  - Different RAID organizations, or RAID levels, have differing cost, performance and reliability characteristics
- **RAID Level 0**: Block striping; non-redundant.
  - Refer to disk array with striping at level of blocks (1 or a group of continuous blocks).
    Used in high-performance applications where data lose is not critical.
- **RAID Level 1**: Mirrored disks with block striping
  - Offers best write performance.
  - Popular for applications such as storing **log files** in a database system.



RAID Levels (Cont.)

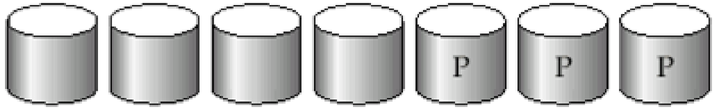
- **RAID Level 2**: **Memory-Style Error-Correcting-Codes (ECC) organization with bit striping**

- Parity codes or Hamming code ….

- If one bit in gets damaged the parity of the data changes and will not match the computed parity
  ALL 1-BIT ERRORS ARE DETECTED (Error Detection Code)

- Error correcting codes store extra bits to reconstruct the data if a single bit gets damaged (more bits for error correction)

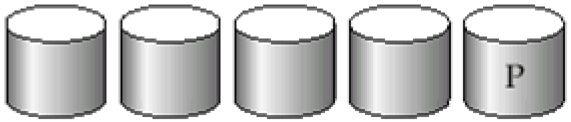
- Disks labelled P store the ECC



(c) RAID 2: memory-style error-correcting codes

RAID Levels (Cont.)

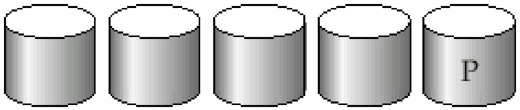
- **RAID Level 3**: Bit-Interleaved Parity
  exploit the fact that disk controllers can detect whether a sector has been read correctly
  - a single parity bit is enough for error correction since we know which disk has failed
    - When writing data, corresponding parity bits must also be computed and written to a parity bit disk
    - To recover data in a damaged disk, compute the parity of the bits from the sectors in the other disks. If the parity is equal to the stored parity, the missing bit is 0; otherwise the missing bit is 1.
  - Good as Level 2, but less expensive in the number of extra disks (one disk overhead)
  - Benefits over Level 1: needs only one parity disk for several disks (Level 1, one mirror disk for every disk)



(d) RAID 3: bit-interleaved parity

RAID Levels (Cont.)

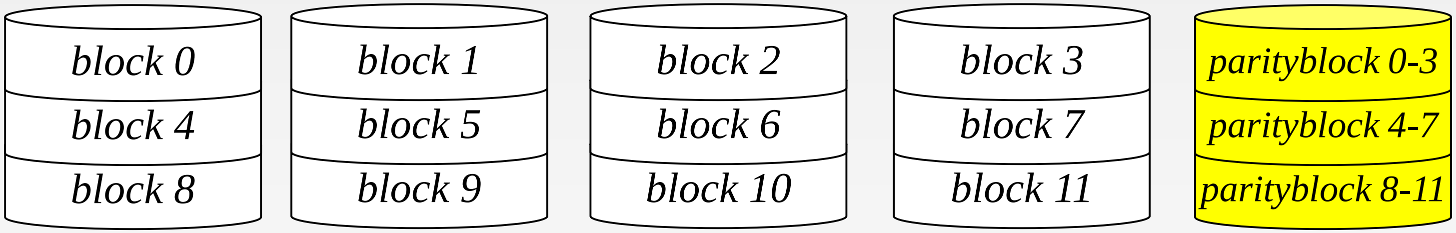
- **RAID Level 4:** Block-Interleaved Parity
  uses block-level striping, and keeps a parity block on a separate disk for corresponding blocks from *N* other disks.
  - When writing data block, corresponding block of parity bits must also be computed and written to parity disk
  - To find value of a damaged block, compute parity of bits from corresponding blocks (including parity block).



(e) RAID 4: block-interleaved parity

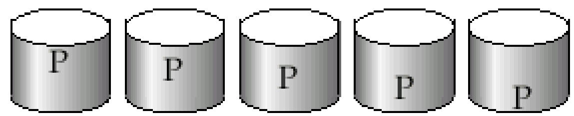
RAID Levels (Cont.)

- RAID Level 4 (Cont.)
  - Before writing a block, parity data must be computed
    - Can be done by using old parity block, old value of current block and new value of current block (2 block reads + 2 block writes)
    - Or by recomputing the parity value using the new values of blocks corresponding to the parity block
  - Parity block becomes a bottleneck for independent block writes since every block write also writes to parity disk



RAID Levels (Cont.)

- **RAID Level 5:** Block-Interleaved Distributed Parity; partitions data and parity among all $N + 1$ disks, rather than storing data in N disks and parity in 1 disk.
  - E.g., with 5 disks, parity block for nth set of blocks is stored on disk (n *mod* 5) + 1, with the data blocks stored on the other 4 disks.



(f) RAID 5: block-interleaved distributed parity

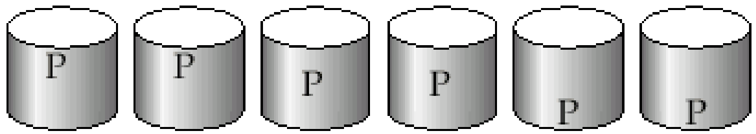
P0	0	1	2	3
4	P1	5	6	7
8	9	P2	10	11
12	13	14	P3	15
16	17	18	19	P4

RAID Levels (Cont.)

- **RAID Level 5 (Cont.)**
  - For each set of N logical blocks, one of the disks store the parity and the other N disks store the blocks
  - The P’s are distributed across all the disks
  - A parity block can not store parity for bocks of the same disk, since then, a disk failure would result in loss of data as well as of parity(failure not recoverable)
  - Level 5 subsumes Level 4

RAID Levels (Cont.)

- **RAID Level 6**: P+Q Redundancy scheme;
  similar to Level 5, but stores extra redundant information to guard against multiple disk failures.
  - Better reliability than Level 5 at a higher cost; not used as widely.
  - Level 6, instead of using parity, uses ECC.
  - In the figure 2 bits of redundant data are stored for every 4 bits of data and the system can tolerate two disk failures



(g) RAID 6: P + Q redundancy

According to the Storage Networking Industry Association (SNIA), the definition of RAID 6 is: "Any form of RAID that can continue to execute read and write requests to all of a RAID array's virtual disks in the presence of any two concurrent disk failures.

Choice of RAID Level

- Factors in choosing RAID level
  - Monetary cost
  - Performance: Number of I/O operations per second, and bandwidth during normal operation
  - Performance during failure
  - Performance during rebuild of failed disk
    - Including time taken to rebuild failed disk
- RAID 0 is used only when data safety is not important
- Level 2 and 4 never used since they are subsumed by 3 and 5
- Level 3 is not used anymore since bit-striping forces single block reads to access all disks, wasting disk arm movement, which block striping (level 5) avoids
- Level 6 is rarely used since levels 1 and 5 offer adequate safety for almost all applications
- So competition is between 1 and 5 only

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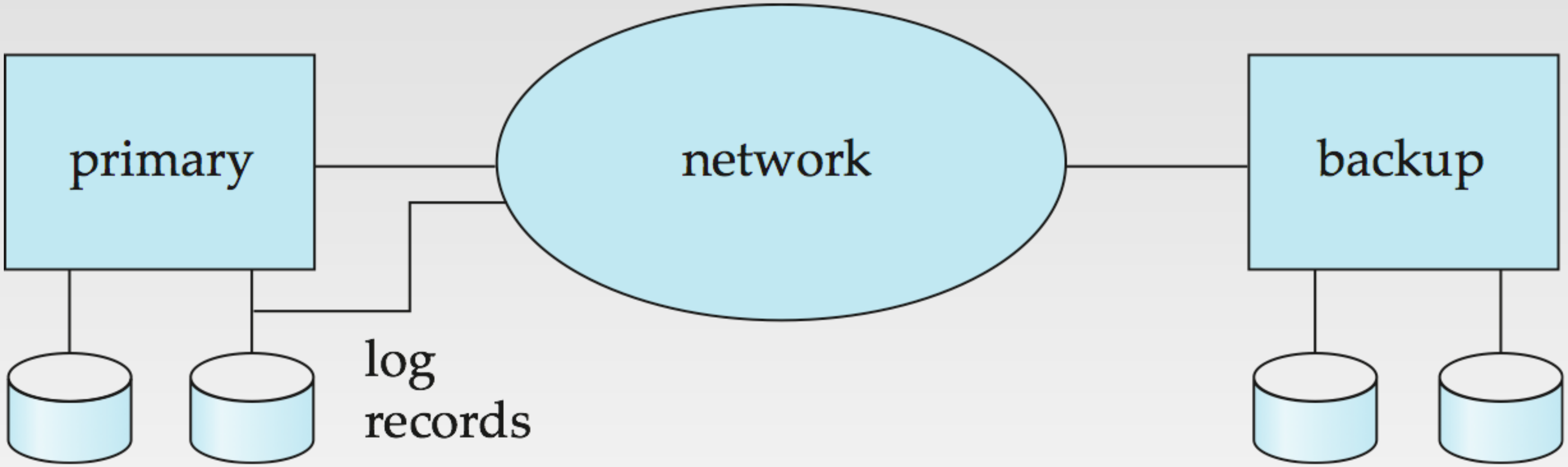
Remote Backup Systems

Remote Backup Systems

- Remote backup systems provide high availability by allowing transaction processing to continue even if the primary site is destroyed.



Remote Backup Systems (Cont.)

- **Detection of failure**: Backup site must detect when primary site has failed
  - to distinguish primary site failure from link failure maintain several communication links between the primary and the remote backup.
  - Heart-beat messages
- **Transfer of control**:
  - To take over control backup site first perform recovery using its copy of the database and all the long records it has received from the primary.
    - Thus, completed transactions are redone and incomplete transactions are rolled back.
  - When the backup site takes over processing it becomes the new primary
  - To transfer control back to old primary when it recovers, old primary must receive redo logs from the old backup and apply all updates locally.

Remote Backup Systems (Cont.)

- **Time to recover**: To reduce delay in takeover, backup site periodically proceses the redo log records (in effect, performing recovery from previous database state), performs a checkpoint, and can then delete earlier parts of the log.
- **Hot-Spare** configuration permits very fast takeover:
  - Backup continually processes redo log record as they arrive, applying the updates locally.
  - When failure of the primary is detected the backup rolls back incomplete transactions, and is ready to process new transactions.
- Alternative to remote backup: distributed database with replicated data
  - Remote backup is faster and cheaper, but less tolerant to failure

Remote Backup Systems (Cont.)

- Ensure durability of updates by delaying transaction commit until update is logged at backup; avoid this delay by permitting lower degrees of durability.
- **One-safe:** commit as soon as transaction's commit log record is written at primary
  - Problem: updates may not arrive at backup before it takes over.
- **Two-very-safe:** commit when transaction's commit log record is written at primary and backup
  - Reduces availability since transactions cannot commit if either site fails.
- **Two-safe:** proceed as in two-very-safe if both primary and backup are active. If only the primary is active, the transaction commits as soon as is commit log record is written at the primary.
  - Better availability than two-very-safe; avoids problem of lost transactions in one-safe.

Replication with Weak Consistency

- Many commercial databases support replication of data with weak degrees of consistency (I.e., without a guarantee of serializabiliy)
- E.g.: **master-slave replication**: updates are performed at a single "master" site, and propagated to "slave" sites.
  - Propagation is not part of the update transaction: its is decoupled
    - May be immediately after transaction commits
    - May be periodic
  - Data may only be read at slave sites, not updated
    - No need to obtain locks at any remote site
  - Particularly useful for distributing information
    - E.g. from central office to branch-office
  - Also useful for running read-only queries offline from the main database

Replication with Weak Consistency (Cont.)

- Replicas should see a **transaction-consistent snapshot** of the database
  - That is, a state of the database reflecting all effects of all transactions up to some point in the serialization order, and no effects of any later transactions.
- E.g. Oracle provides a **create snapshot** statement to create a snapshot of a relation or a set of relations at a remote site
  - snapshot refresh either by recomputation or by incremental update
  - Automatic refresh (continuous or periodic) or manual refresh

Multimaster and Lazy Replication

- With multimaster replication (also called update-anywhere replication) updates are permitted at any replica, and are automatically propagated to all replicas
  - Basic model in distributed databases, where transactions are unaware of the details of replication, and database system propagates updates as part of the same transaction
    - Coupled with 2 phase commit
- Many systems support **lazy propagation** where updates are transmitted after transaction commits
  - Allows updates to occur even if some sites are disconnected from the network, but at the cost of consistency