Chapter 38: Redundant Arrays of Inexpensive Disks (RAID)

1. Introduction to RAID

- **RAID** is a storage technology that combines multiple physical disk drives into a single logical unit for the purposes of data redundancy, performance improvement, or both.
- It presents a single logical disk to the operating system, hiding the complexity of the underlying disk array.
- Key evaluation criteria for RAID systems:
  - **Capacity:** How much data can be stored?
  - **Reliability:** How many disk failures can it tolerate?
  - **Performance:** How fast can data be read and written?

2. RAID Levels

2.1. RAID-0: Striping

- **Concept:** Data is split into blocks and spread across all disks in the array.
- **Pros:**
  - Excellent performance for both sequential and random I/O due to parallelization.
  - Full capacity of all disks is utilized.
- **Cons:**
  - **No redundancy:** The failure of a single disk results in the loss of all data.
- **Use Case:** Situations where performance is paramount and data loss is not a concern (e.g., temporary data).

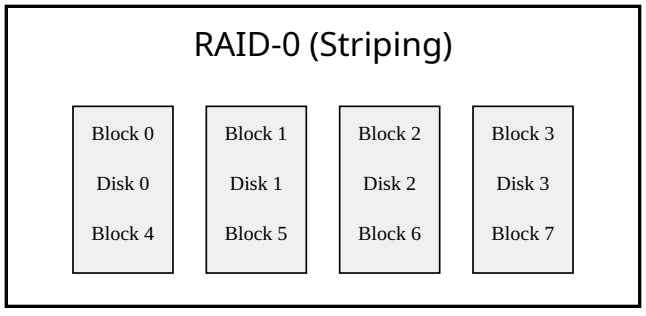

Figure 1: RAID-0

2.2. RAID-1: Mirroring

- **Concept:** Data is duplicated and written to two or more disks.
- **Pros:**
  - High reliability: Can tolerate the failure of one or more disks (depending on the number of mirrors).
  - Excellent read performance, as read requests can be serviced by any disk in the mirror.
- **Cons:**
  - High cost: Usable capacity is only 50% of the total disk capacity.
  - Write performance is slower as writes must be performed on all disks.
- **Use Case:** Applications that require high availability and fault tolerance.

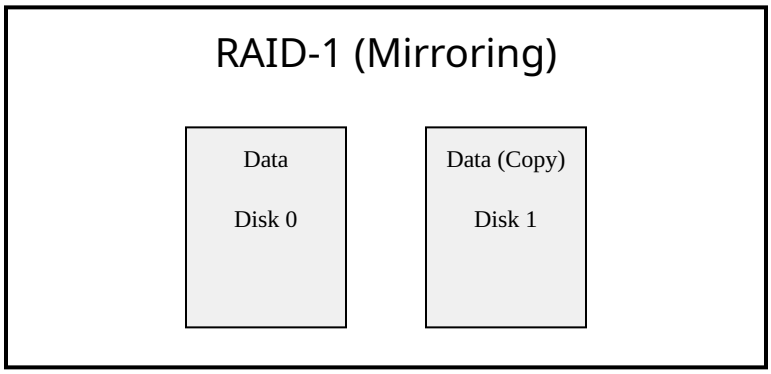

Figure 2: RAID-1

2.3. RAID-4: Parity

- **Concept:** Uses a dedicated parity disk to store redundant information. The parity is calculated using the XOR function.
- **Pros:**
  - Good capacity: Usable capacity is (N-1) * disk_size, where N is the number of disks.
  - Can tolerate the failure of a single disk.
- **Cons:**
  - **Parity disk bottleneck:** The parity disk must be updated on every write, which can become a performance bottleneck for small, random writes (the "small-write problem").
- **Use Case:** Less common today due to the parity bottleneck.

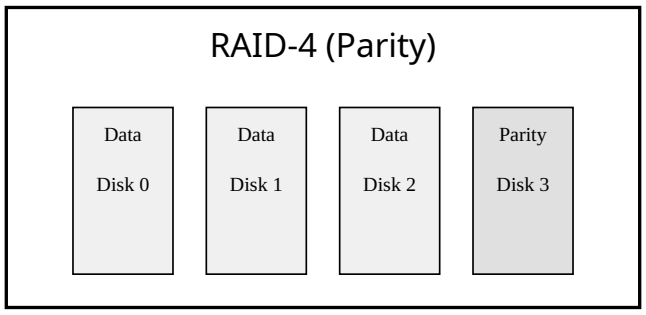

Figure 3: RAID-4

2.4. RAID-5: Rotating Parity

- **Concept:** Similar to RAID-4, but the parity information is distributed across all disks in the array.
- **Pros:**
  - Solves the parity disk bottleneck of RAID-4, allowing for better write performance.
  - Good balance of capacity, reliability, and performance.
- **Cons:**
  - Still suffers from the small-write problem, although to a lesser extent than RAID-4.
- **Use Case:** A popular choice for general-purpose storage.

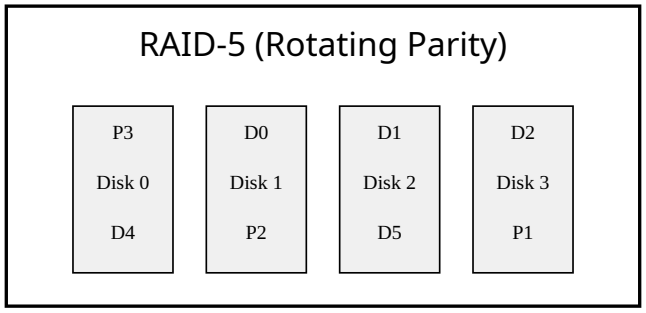

Figure 4: RAID-5

3. RAID Trade-offs Summary

RAID Level	Capacity	Reliability	Performance (Random Read)	Performance (Random Write)
RAID-0	High	None	Excellent	Excellent
RAID-1	Low	High	Excellent	Good
RAID-4	Medium	Medium	Good	Poor
RAID-5	Medium	Medium	Good	Fair