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BCA Honours | Semester VI | BCA6CJ305

Principles of Operating System

Module 4 Comprehensive Notes

Module 4: Secondary Storage Management and Distributed File Systems

Secondary storage systems provide persistent, non-volatile data retention. The operating system abstracts physical storage blocks into structured file systems and coordinates disk I/O scheduling to optimize throughput.

4.1 Disk Scheduling Algorithms

Magnetic Hard Disk Drives (HDDs) require mechanical positioning of read/write heads over rotating magnetic platters. Access time is dominated by **Seek Time** (moving the arm to the target track) and **Rotational Latency** (waiting for the sector to rotate beneath the head). Schedulers optimize track seek sequences:

- **FCFS (First-Come, First-Served):** Processes I/O requests strictly in arrival order. Fair, but incurs erratic head thrashing across the platter surface.
- **SSTF (Shortest Seek Time First):** Selects the pending request closest to the current head position. Minimizes average seek time, but risks starvation for requests at platter edges.
- **SCAN (Elevator Algorithm):** The disk arm moves continuously in one direction servicing requests until reaching the disk boundary, then reverses direction servicing requests on the return sweep. Prevents starvation and stabilizes variance.
- **C-SCAN (Circular SCAN):** Moves from one end to the other servicing requests; upon reaching the edge, immediately snaps back to the beginning without servicing requests on the return trip, providing uniform wait times.
- **LOOK and C-LOOK:** Variants of SCAN/C-SCAN that travel only as far as the final pending request in each direction before reversing, eliminating unnecessary sweeps to empty disk boundaries.

4.2 RAID Storage Architectures

Redundant Array of Independent Disks (RAID) combines multiple physical disk drives into a single logical storage unit to achieve performance acceleration (via data striping) and fault tolerance (via mirroring or parity):

RAID Level	Data Organization Architecture	Fault Tolerance Profile	Read / Write Performance Impact
RAID 0	Block-level data striping across N disks without parity or redundancy.	Zero fault tolerance. Failure of any single drive destroys the entire array volume.	Maximum throughput; read and write bandwidth scales linearly with disk count.
RAID 1	Disk mirroring: duplicate copies of data written simultaneously to 2 drives.	Survives failure of 1 drive in each mirrored pair. 50% capacity storage overhead.	Fast read throughput (parallel reads from either drive); write speed bounded by slower drive.

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RAID Level	Data Organization Architecture	Fault Tolerance Profile	Read / Write Performance Impact
RAID 5	Block-level striping with distributed XOR parity across minimum 3 disks.	Survives single disk failure. Storage capacity is $(N-1) \times \text{DiskSize}$.	Excellent read speeds; write penalty due to parity computation and read-modify-write cycles.
RAID 6	Block-level striping with dual independent distributed parity (Reed-Solomon).	Survives simultaneous failure of any two independent drives.	High resilience; requires minimum 4 disks; higher write penalty than RAID 5.
RAID 10 (1+0)	Mirrored striped array: stripes data across pairs of mirrored disks.	Survives multiple drive failures as long as no mirrored pair loses both drives.	Combines the high I/O throughput of RAID 0 with the fault tolerance of RAID 1.

4.3 File Systems and Directory Architectures

A file is a named collection of related information recorded on secondary storage. File systems allocate disk blocks using three primary strategies:

- **Contiguous Allocation:** Each file occupies a contiguous set of disk blocks. Delivers fast sequential read performance, but suffers from external fragmentation and file growth limitations.
- **Linked Allocation:** Each file is a linked list of disk blocks; each block contains a pointer to the next block. Eliminates external fragmentation, but slow for random access and vulnerable to broken pointer links.
- **Indexed Allocation (i-nodes):** Each file maintains an index block (inode) containing an array of pointers to data blocks. Supports fast direct random access without external fragmentation (standard in UNIX/Linux ext4 file systems).

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1. Architectural Trade-offs and Computational Complexity

Software architects and systems engineers designing scalable computational pipelines centered on Principles of Operating System must methodically navigate core trade-offs:

- **Time Complexity Optimization versus Spatial Footprint:** In high-throughput algorithmic pipelines handling Module 4 Core Concepts and Methods, pre-computing intermediate lookup tables, spatial indices, and hashing structures achieves near-instantaneous $O(1)$ query latency, but inflates the physical memory footprint. Conversely, in-place algorithms minimize RAM utilization at the cost of higher CPU cycle counts. Modern architectures dynamically calibrate memory allocations using memory-mapped files and cache-aware structures.
- **Concurrency Scalability versus Thread Contention:** While multi-core hardware allows horizontal execution, concurrent modifications to shared state structures create severe lock contention, thread

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synchronization bottlenecks, and cache line invalidation storms. High-performance frameworks deploy lock-free algorithms, optimistic concurrency control, and atomic compare-and-swap (CAS) primitives.

- **Algorithmic Determinism versus Heuristic Scalability:** Exact mathematical algorithms frequently encounter NP-hard combinatorial barriers as problem dimensions scale. Contemporary systems bridge this gap by deploying bounded approximation algorithms and meta-heuristics that produce near-optimal solutions within guaranteed execution time windows.

2. Empirical Comparative Framework

A structured comparative assessment clarifies operational distinctions across conventional paradigms and modern production implementations in Principles of Operating System:

Evaluation Dimension	Conventional Traditional Approach	Contemporary Integrated Paradigm	Strategic Impact Metric
Architecture Paradigm	Monolithic single-threaded architectures with tightly coupled state.	Distributed microservices with asynchronous event queues and thread-safe data structures.	Linear scalability and resilient fault isolation under peak transactional loads.
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Resilience & Failover	Manual failover mechanisms requiring operator intervention and scheduled downtime.	Automated self-healing clusters with dynamic health checking and zero-downtime rolling deployments.	Continuous availability meeting strict 99.999% Service Level Agreements (SLAs).
System Telemetry & Auditing	Passive log file aggregation with retrospective forensic analysis.	Distributed tracing, structured metrics collection, and real-time observability telemetry.	Proactive bottleneck resolution and sub-second mean time to detection (MTTD).

3. Production Implementation Patterns and Resilience Engineering

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- **Graceful Degradation and Circuit Breaking:** Under cascading upstream failures or extreme operational saturation, systems isolate failing components and serve cached or degraded responses, preserving core availability.
- **State Immutability and Event Sourcing:** Maintaining an append-only log of immutable state changes guarantees verifiable auditability, eliminates data race hazards, and facilitates seamless system recovery.
- **Defensive Memory Management:** High-throughput applications implement strict resource pools, bounded buffer queues, and proactive leak detection to ensure predictable garbage collection pause times and prevent memory exhaustion.

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