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BCA Honours | Semester IV | BCA4CJ205

Database Management System

Module 3 Comprehensive Notes

Module 3: SQL and Relational Database Normalization

Structured Query Language (SQL) is the comprehensive industry standard for defining, querying, updating, and administering relational databases. Normalization applies rigorous functional dependency theory to refine relational schemas, eliminating structural redundancy and data update anomalies.

3.1 SQL Data Definition and Manipulation

SQL is categorized into distinct sub-languages:

- **Data Definition Language (DDL):** Defines schema structures. Includes `CREATE TABLE`, `ALTER TABLE`, `DROP TABLE`, and `TRUNCATE TABLE`. Declarative constraints include `PRIMARY KEY`, `FOREIGN KEY ... REFERENCES`, `UNIQUE`, `NOT NULL`, and `CHECK (condition)`.
- **Data Manipulation Language (DML):** Populates and modifies records. Includes `INSERT INTO`, `UPDATE ... SET`, and `DELETE FROM`.
- **Data Query Language (DQL):** Queries data via the universal `SELECT` block:

```
SELECT department_id, COUNT(*) AS employee_count, AVG(salary) AS average_salary
FROM employees
WHERE hire_date >= '2020-01-01'
GROUP BY department_id
HAVING AVG(salary) > 65000.00
ORDER BY average_salary DESC;
```

- **Table Joins:** SQL supports diverse join types: `INNER JOIN` (returns matching records), `LEFT OUTER JOIN` (retains all records from the left table, padding unmatched right attributes with NULL), `RIGHT OUTER JOIN`, `FULL OUTER JOIN`, and `CROSS JOIN`.

3.2 Pitfalls in Relational Database Design

An un-normalized database design with poor functional decomposition suffers from three classical operational anomalies:

1. **Insertion Anomaly:** Inability to insert certain data without introducing unrelated null records (e.g., inability to record a newly approved department until an employee is assigned to it).
2. **Deletion Anomaly:** The unintended loss of critical secondary information upon deleting a primary record (e.g., deleting the sole employee of a department accidentally obliterates all records of the department itself).
3. **Update Anomaly:** Inconsistent data states resulting from modifying duplicated data in one row while leaving redundant instances un-updated in other rows.

3.3 Functional Dependencies and Inference Axioms

Let X and Y represent subsets of attributes in relation schema R. A functional dependency $X \rightarrow Y$ (X functionally determines Y) holds if whenever two tuples agree on X, they must also agree on Y:

$$\forall t_1, t_2 \in R, \quad t_1[X] = t_2[X] \implies t_1[Y] = t_2[Y]$$

Armstrong's Axioms for Functional Dependencies

- **Reflexivity:** If $Y \subseteq X$, then $X \to Y$.
- **Augmentation:** If $X \to Y$, then $XZ \to YZ$ for any attribute set Z.
- **Transitivity:** If $X \to Y$ and $Y \to Z$, then $X \to Z$.
- **Decomposition:** If $X \to YZ$, then $X \to Y$ and $X \to Z$.
- **Union:** If $X \to Y$ and $X \to Z$, then $X \to YZ$.

3.4 Normal Forms Based on Primary Keys

Normal Form	Governing Structural Condition	Design Target and Remediated Flaw
1NF (First Normal Form)	All attribute domains contain exclusively atomic (indivisible) scalar values; no repeating groups or nested arrays.	Establishes tabular consistency; disallows multi-valued attribute arrays within a single row.
2NF (Second Normal Form)	In 1NF, and every non-prime attribute is fully functionally dependent on the entire primary key (no partial dependencies on a subset of a composite key).	Eliminates partial key dependencies in composite key schemas.
3NF (Third Normal Form)	In 2NF, and no non-prime attribute is transitively dependent on the primary key ($X \to Y \to Z$, where non-key determines non-key). For every non-trivial FD $X \to Y$, either X is a super key or Y is a prime attribute.	Eliminates transitive dependencies among non-key attributes.
BCNF (Boyce-Codd Normal Form)	Strict 3NF: for every non-trivial functional dependency $X \to Y$, X must be a super key of the relation.	Removes lingering functional dependencies involving overlapping candidate keys.

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1. Architectural Trade-offs and Computational Complexity

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

- **Time Complexity Optimization versus Spatial Footprint:** In high-throughput algorithmic pipelines handling Module 3 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 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 Database Management System:

Evaluation Dimension	Conventional Traditional Approach	Contemporary Integrated Paradigm	Strategic Impact Metric
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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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- **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.
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