Johns Hopkins Engineering

Principles of Database Systems

Module 1 / Lecture 1

Introduction to Databases

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Course Introduction

- Instructor: Dr. Dar-Ning Kung
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- Course Syllabus
  - Course Structure: Modules, Lectures, Readings, Discussion (10%), Assignments (10%), Database Project (40%) and Exams (40%)
  - Textbook
  - Office Hours via Adobe Connect and emails

Common Uses of Database Systems

- Companies and schools
- Supermarket purchases
- Bank credit card transactions
- Library borrowing activities
- Airline and hotel reservations
- PII in state and federal systems
- Online or traditional in-store shopping

What Is A Database System?

- A computerized record-keeping system essentially
- A kind of electronic filing cabinet
- A repository for a collection of computerized data files

Basic Database Operations by Its Users

- Add new, empty files to databases
- Insert new data into existing files
- Retrieve data from existing files
- Update data in existing files
- Delete data from existing files
- Remove existing files, empty or otherwise, from databases

Why Databases?

- Compactness: Reduce potentially voluminous paper files
- Speed: Perform database operations faster using computers
- Less labor: Save manpower for maintaining files
- Currency: Accurate, up-to-date information is available any time a user requests it
- Data Sharing: Access the data at the same time for multiple users (e.g., airline reservations)
- Security: Maintain access control to keep data from unauthorized access

Benefits of the Database Approach of A Multi-user System

- Redundancy can be reduced
- Inconsistency can be avoided
- Data can be shared
- Standards can be enforced
- Security restrictions can be applied
- Integrity can be maintained
- Conflicting requirements can be balanced

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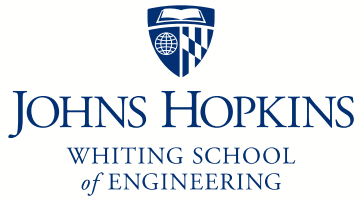
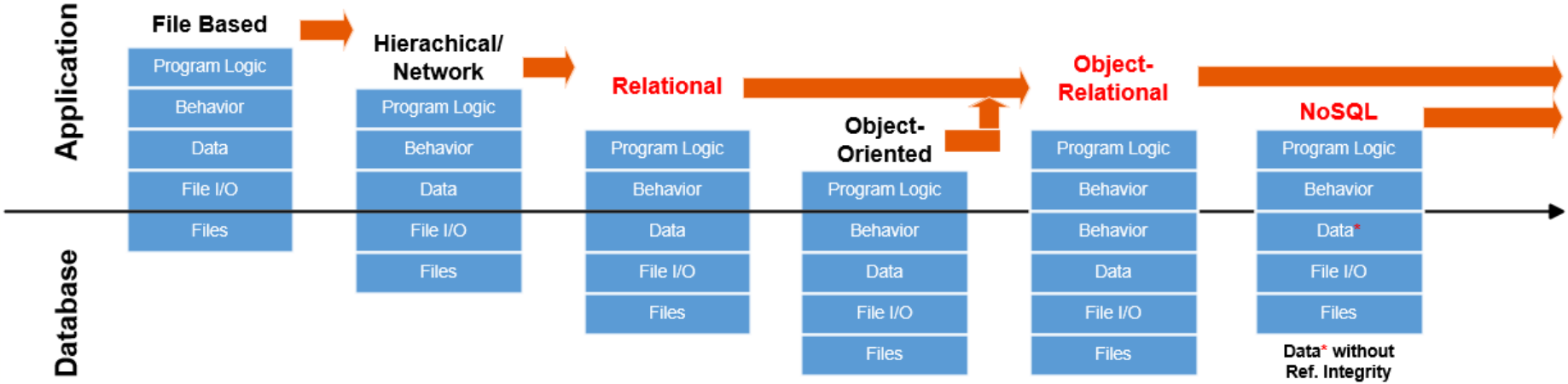


Database Management System (DBMS) Evolution

Database Systems
Database Applications and Databases



File Based DBMS

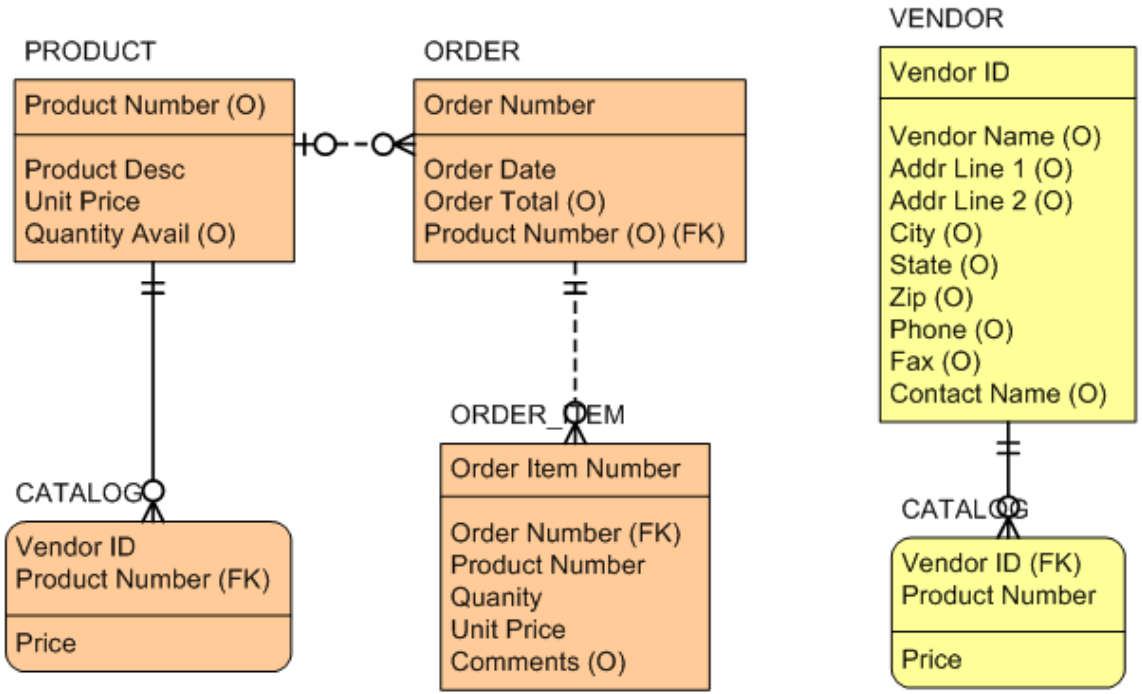
- File Based DBMS Characteristics
  - Access Method: Navigational
    - The data integrity problems due to duplication of data
    - The inability to represent logical data relationships easily
    - Program strongly depends data format (program-data dependence.)
  - Data is stored in text files or binary files

Hierarchical DBMS

- Hierarchical DBMS Characteristics
  - Access Method: Navigational (data access is only through the predefined relationships, and through the entity at the top of the hierarchy, the root, and must proceed in hierarchical order)
    - Fast access by following the predefined relationship
    - Do not provide multiple parents (or many-to-many relationships) for an entity that causes duplicated data and access restrictions
    - Do not have the ability to direct data access
    - Is not suitable for ad hoc query type applications
  - Commercial Product: IBM Information Management System (IMS), MUMPS

Hierarchical DBMS Implementation

Implementation Example

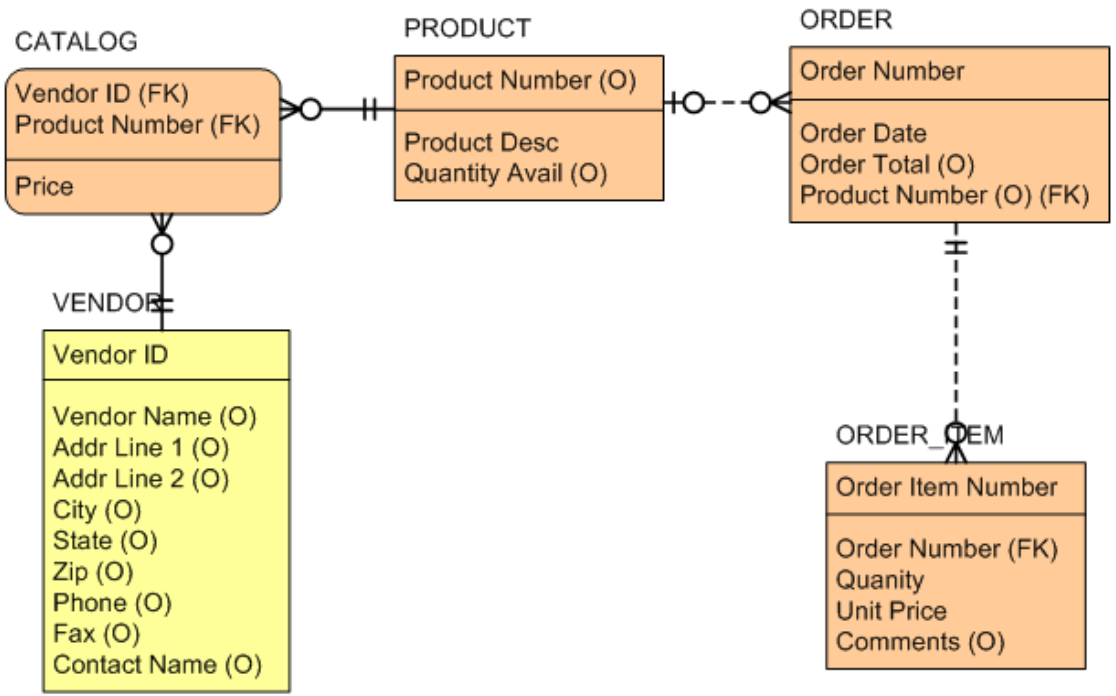


Network DBMS

- Network DBMS Characteristics
  - Access Method: Navigational
    - Design to eliminate the hierarchical database restrictions
    - Allow multiple parents for an entity
    - Fast access by following the predefined relationship
    - Allow direct access through hashing algorithm
    - Is not suitable for ad hoc query type applications
  - Commercial Product: CA-IDMS
    - Advantage CA-IDMS database is navigational and non-relational legacy sources
    - SQL is integrated in the database engine to enable SQL access to existing Advantage CA-IDMS

Network DBMS implementation

Implementation Example



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Relational DBMS

- Relational DBMS Characteristics
  - Access Method: Use primary key and foreign key for the logical relationships
    - Allow one-to-one or one-to-many relationships between entities
    - Use proper logical design with indexes, and careful query formulation to improve performance
    - Benefit from a sound theory and the SQL standard (Non-procedural, e.g., no IF-THEN-ELSE logic)
    - Vendor and platform independent
    - Provide superior ad hoc query support
    - Has been widely deployed and dominates the DBMS market

Relational DBMS (cont.)

- Relational DBMS Characteristics
  - Non-navigational: No need to follow chains or pointers. User specifies only "what", not "how". DBMS "optimizer" determines access path.
  - Properties: Atomicity, Consistency, Isolation, Durability (ACID)
  - Commercial/Open Source Products: IBM DB2 UDB, Microsoft SQL Server, Oracle, Sybase, MySQL, Postgre SQL, MariaDB, ...under mainframe, midrange, LAN, workstation, PC, …

  Note: Most vendors also support user-defined data types and other object-oriented functions, and their products become object-relational DBMS.

Object-Oriented DBMS

- Object-Oriented DBMS (ODBMS or OODBMS) Characteristics
  - Access Method: Navigational using object ids
    - Allow data and procedures to be stored together
    - Reuse the self-contained entities
    - Access data through relationships stored within the data themselves
    - Support complex objects, classes, methods, inheritance, and encapsulation
    - Is not suited for ad hoc querying as relational databases are
  - Commercial Products: ObjectDB, ObjectStore, Versant

Object-Relational DBMS

- Object-Relational DBMS (ORDBMS) Characteristics
  - Access Method: Using both key index and object ids (navigational)
    - Inherit all strengths from the RDBMS
    - Allow data and procedures to be stored together
    - Reuse the self-contained entities
    - Support complex objects, classes, methods, inheritance, and encapsulation
    - Support SQL (Structural Query Language) standards
  - Commercial Products: IBM DB2 UDB, Microsoft Server, and Oracle

NoSQL

- NoSQL Characteristics
  - Access Method: Navigational and non-navigational
  - Do not use fixed schema structures, referential integrity, defined joins, or a common storage model
  - Is good for scaling out horizontally, and is well suited for Big Data; while RDMBS is good for scaling up vertically
  - Follow BASE: Basically Available, Soft state, Eventual Consistency; do not follow the strict ACID rules of relational databases

NoSQL (cont.)

- NoSQL Characteristics
  - Four types NoSQL databases based on storage category:
    - Column-based Store: Cassandra, Hbase, Google - Big Table
    - Key Value-based Store: Amazon DynamoDB, Riak, Berkeley DB
    - Document-based Store: MongoDB, Couchbase, CouchDB, MarkLogic
    - Graph-based Store: Neo4j, OrientDB
  - Usage:
    - Big Data, schema-less design, better horizontal scalability, not mission critical applications
  - NoSQL does not replace SQL databases; it is a complementary addition to RDMBS and SQL to support business needs

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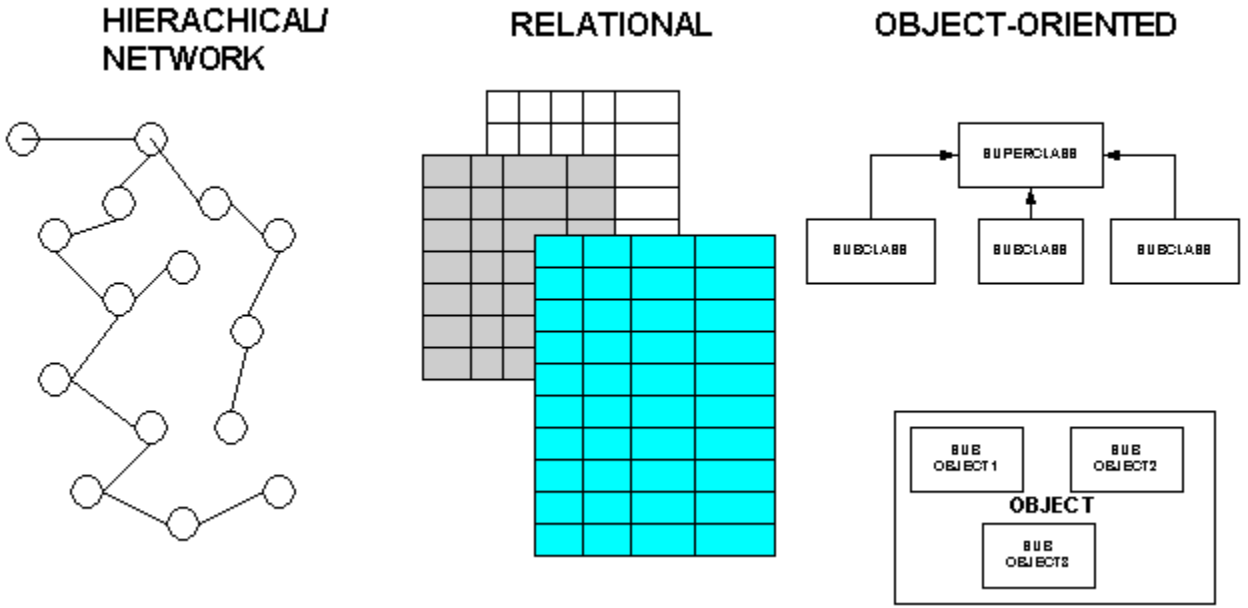
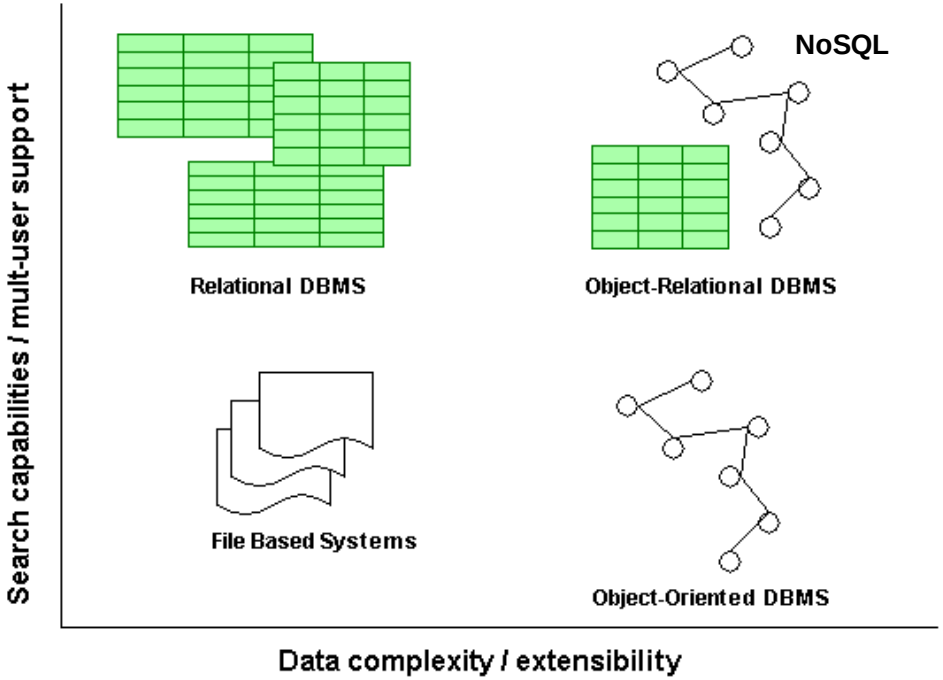
Graphical Representations for Various Data Models

Implementation Example



Data Complexity / Search Capabilities for Various Data Models

Implementation Example



Support of Multiple Views of Data

- Provide a means to present a different representation of data that resides within the base tables
- Are powerful because they allow the database designer or application developer to tailor the presentation of data to different types of users

Sharing of Data and Multi-user

- Transaction process
  - A logical unit of work on the database
  - An action or actions that perform database record reads or updates by a user or program

- Concurrency control
  - Managing simultaneous operations on the database without having them interface with one another
  - Without proper control, the updated data may be lost, cause inconsistent analysis, or cause uncommitted dependency problems

Types of Database Users

- Database Administrators (DBA)
  - Install and upgrade the DBMS on database server and application tools
  - Allocate system storage and plan for future storage requirements for the database system
  - Create primary database storage structures (tablespaces) once application developers have designed an application
  - Create primary objects (tables, views, indexes) once application developers have designed an application

Types of Database Users (cont.)

- Database Administrators (DBA)
  - Modify the database structure, as necessary, from information given by application developers
  - Enroll users and maintain system security
  - Control and monitor user access to the database
  - Monitor and optimize the performance of the database
  - Plan for back-up and recovery of database information
  - Back-up and restore the database
  - Create redundancy or replicate database instances

Types of Database Users (cont.)

- System Analysts / Database Designers / Application Developers
  - Design the database structure for an application
  - Design and develop the database application
  - Estimate storage requirements for an application
  - Specify modifications of the database structure for an application

Types of Database Users (cont.)

- System Analysts / Database Designers / Application Developers
  - Relay the above information to a database administrator
  - Tune the application during development
  - Establish an application's security measures during development
  - Remediate application vulnerabilities reported by static or dynamic scans

Types of Database Users (cont.)

- Database Users (ad-hoc, regular, or power users)
  - Enter, modify, and delete data, where permitted
  - Generate reports of data
  - Provide input of new features and enhancements for an application
  - Test new release of a database application and report issues

A DBMS Simplified Environment

- A simplified database system environment
  - Application, DBMS, Database Definition (Meta Data), Database
- Program-Data Independence
  - Programs to form an application do not depend on the data storage structure or access technique.

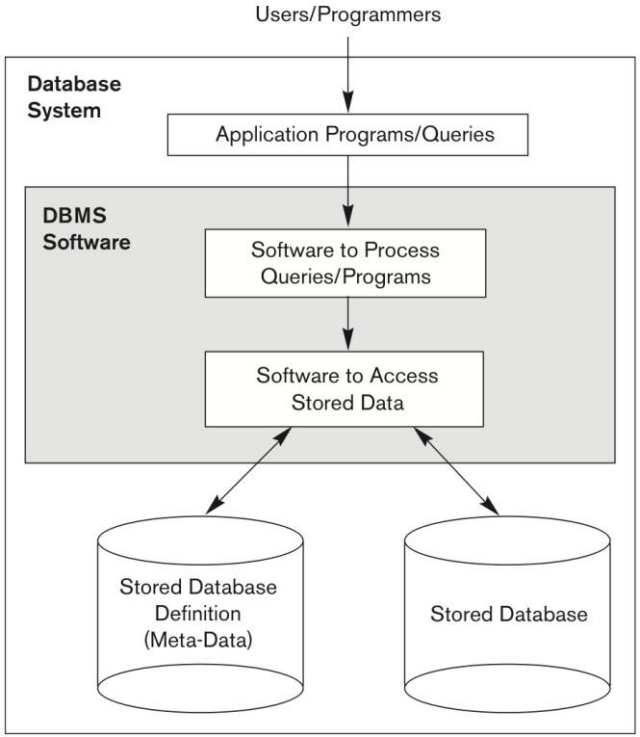


Figure 1.1 A simplified database system environment.

Data Abstraction

- Program-data independence and program-operation (function) independence.
- DBMS allows a conceptual representation of data.
- Database can grow without considering the applications.

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Data Models, Schemas, and Instances

- A data model is a set of concepts that can be used to describe the structure of a database including data types, relationships, and constraints of the data.

- The description of a database is called the database schema (meta-data). It is a collection of schema objects, such as tables, views, clusters, procedures, and packages used by a database.

Data Models, Schemas, and Instances (cont.)

- The data in the database at a particular moment is called database state (or set of occurrences or instances.) For example, STUDENT or ORDER is an instance construct. They can have multiple occurrences or instances.

- However, an Oracle instance, as a database engine, represents a set of background processes and allocated memory structure that are shared by all users to access the data in the database.

Data Models, Schemas, and Instances (cont.)

- An Oracle *database* is a collection of data that is treated as a unit. The purpose of a database is to store and retrieve related information.

- The database has *logical structures* and *physical structures*. Because the physical and logical structures are separate, the physical storage of data can be managed without affecting the access to logical storage structures.

Database Architecture - Three-schema Architecture

- External level
  - Include a number of external schemas or user views
- Conceptual level
  - Has a conceptual schema, which describes the structure of the entire database for a community of users
- Internal level
  - Has an internal schema, which describes the physical storage structure (data storage, and access path) of the database

Database Architecture - Three-schema Architecture (cont.)

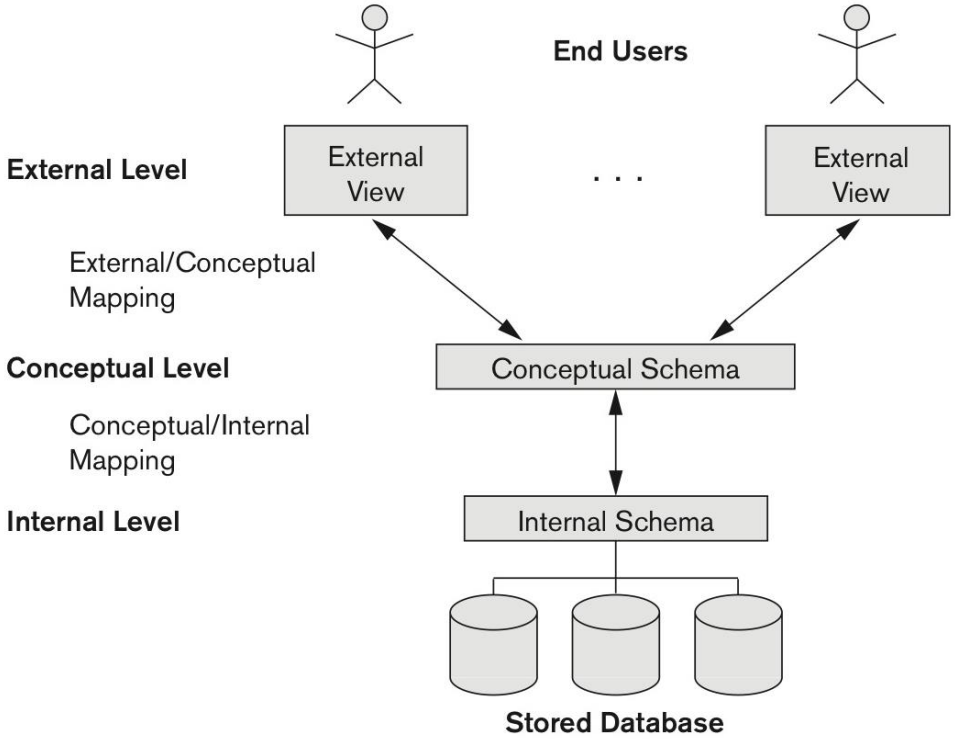


Figure 2.2 The three-schema architecture.

A DBMS Components And Their Interactions

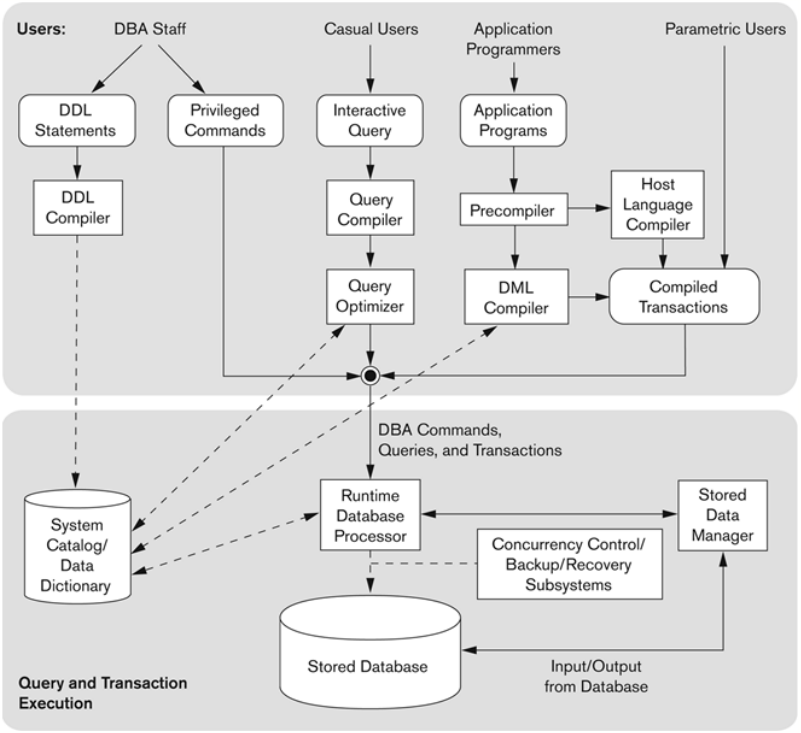
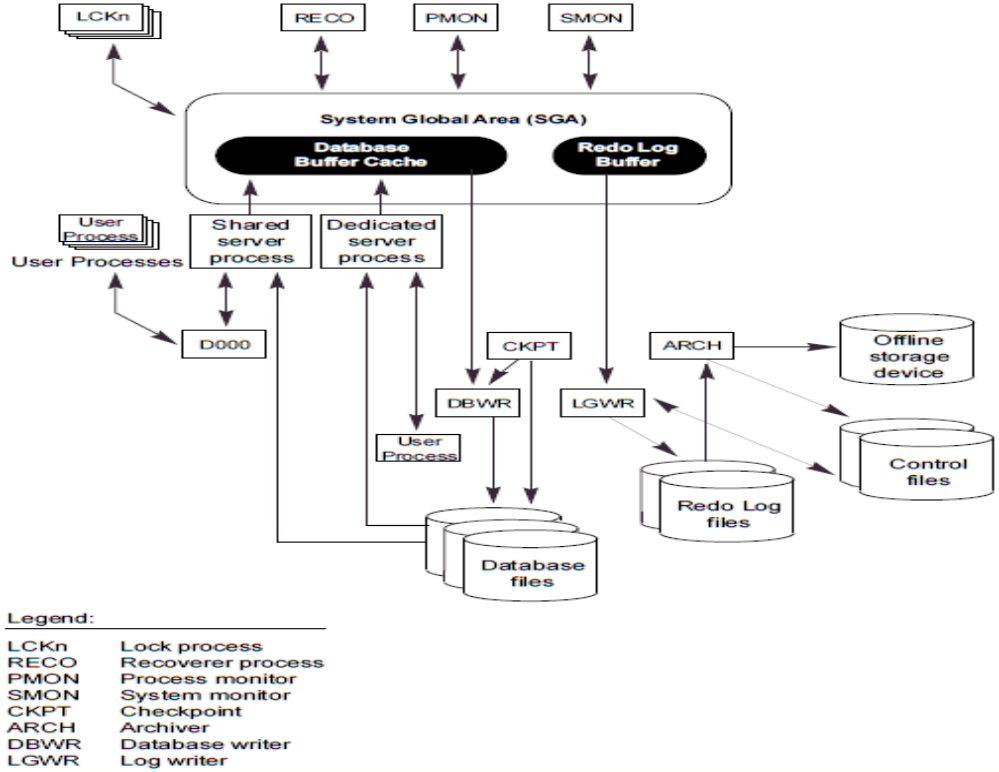


Figure 2.3 Component modules of a DBMS and their interactions.

Oracle RDBMS Architecture - An Instance



Source : Oracle

Database Languages

- Data definition language (DDL)
  - After a DBMS is chosen and the design of a database is completed, DDL is used to create a database. For RDBMS, basic commands include CREATE, ALTER, DROP, and RENAME.

- Data manipulation language (DML)
  - DML is used to perform basic operations on a database such as retrieve, insert, update, delete data; commit or rollback changes of data. These commands can be embedded as data sublanguage (DSL) into a host language.

Database Languages (cont.)

- Date query language (DQL)
  - A query language only involves data retrieval. Users may need complex queries with set operations or aggregate functions for reporting.
  - The database state remains the same.

- Data control language (DCL)
  - DCL provides user access control to a database. Basic commands are GRANT, REVOKE, AUDIT, and LOCK.

Database Interfaces

- Create forms-based applications that provide users access to information stored in a database
- Create applications with graphical user interface (GUI) environments
- Increase productivity for users by creating menu driven and mouse driven applications that do not require users to remember function keys, or understand commands and programming

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Centralized and Client/Server Architectures for DBMSs

- Centralized
  - Terminals and a DBMS server
- Basic two-tier client/server architecture
  - Clients and servers
  - Clients running programs interact with DBMS
- Three-tier client/server architecture
  - Client – GUI, Web Interfaces
  - Application server and/or Web server
  - Database server with DBMS

Classification of DBMSs

- Based on data model or DBMS implementation:
  - Hierarchical, network, relational, object-oriented and object-relational databases, NoSQL databases (based on column-based, key-value, document-based, and graph-based)
- Based on number of users:
  - Single-user, multi-user
- Based on number of sites:
  - Centralized, distributed

Classification of DBMSs (cont.)

- Based on purpose:
  - General – On-Line Transaction Processing (OLTP)
  - Data warehouse – On-Line Analytical processing (OLAP) for decision support or data mining
  - Special – XML DB, GIS, NoSQL, and others

DBMS Market

- Operational DBMSs – Oracle, Microsoft, IBM, and SAP as leaders
  - Dominate RDBMS and ORDBMS market shares
- Open-source relational DBMSs have matured significantly and can be used to replace commercial RDBMSs
  - Can be chosen for a substantial savings in Total Cost of Ownership (TCO)
  - MySQL, MariaDB, PostgreSQL and others

Continue Growth in the DBMS Market

- Maintain or increase levels of DBMS spending for most organizations

- Look for cost-savings for better business competitiveness
  - Increase the use of “open-source” RDBMSs
  - May use for mission-critical and internal applications
  - May have few functions, DB admin tools, DBA resources – can serve the needed features
  - Linux has become a leading DBMS platform
  - Oracle MySQL and Postgres SQL

Big Data

- Is a large and complex collection of data sets
  - Data characteristics/dimensions: volume, velocity, variety, and complexity
  - Data sources
    - Sensor/machine/device data (Internet of Things)
    - Unstructured content from email, office documents, etc.
    - Large audio/video/photographic data
    - Scientific/genomic data
  - NoSQL Databases and Big Data (See Ch 24 and Ch 25)