



Chapter 1: Introduction

Database System Concepts, 7th Ed.

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Database Applications Examples

- Enterprise Information
 - Sales: customers, products, purchases
 - Accounting: payments, receipts, assets
 - Human Resources: Information about employees, salaries, payroll taxes.
- Manufacturing: management of production, inventory, orders, supply chain.
- Banking and finance
 - customer information, accounts, loans, and banking transactions.
 - Credit card transactions
 - Finance: sales and purchases of financial instruments (e.g., stocks and bonds; storing real-time market data
- Universities: registration, grades



Database Applications Examples (Cont.)

- Airlines: reservations, schedules
- Telecommunication: records of calls, texts, and data usage, generating monthly bills, maintaining balances on prepaid calling cards
- Web-based services
 - Online retailers: order tracking, customized recommendations
 - Online advertisements
- Document databases
- Navigation systems: For maintaining the locations of various places of interest along with the exact routes of roads, train systems, buses, etc.



Purpose of Database Systems

In the early days, database applications were built directly on top of file systems, which leads to:

- Data redundancy and inconsistency: data is stored in multiple file formats resulting in duplication of information in different files
- Difficulty in accessing data
 - Need to write a new program to carry out each new task
- Data isolation
 - Multiple files and formats
- Integrity problems
 - Integrity constraints (e.g., account balance > 0) become “buried” in program code rather than being stated explicitly
 - Hard to add new constraints or change existing ones



Purpose of Database Systems (Cont.)

- Atomicity of updates
 - Failures may leave database in an inconsistent state with partial updates carried out
 - Example: Transfer of funds from one account to another should either complete or not happen at all
- Concurrent access by multiple users
 - Concurrent access needed for performance
 - Uncontrolled concurrent accesses can lead to inconsistencies
 - Ex: Two people reading a balance (say 100) and updating it by withdrawing money (say 50 each) at the same time
- Security problems
 - Hard to provide user access to some, but not all, data

Database systems offer solutions to all the above problems



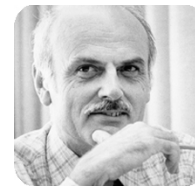
Data Models

- A collection of tools for describing
 - Data
 - Data relationships
 - Data semantics
 - Data constraints
- Relational model
- Entity-Relationship data model (mainly for database design)
- Object-based data models (Object-oriented and Object-relational)
- **Semi-structured data model (XML)**
 - The XML Schema as a Data Model which is the representation of data through Extensible Markup Language (XML) technology is used in Database Management Systems (DBMS) as a software tool for constructing a data model. It is a tool for the vice of storage, editing, and searching for structured information in a given hierarchy very much like this of XML.
- Other older models:
 - Network model
 - Hierarchical model



Relational Model

- All the data is stored in various tables.
- Example of tabular data in the relational model



Ted Codd
Turing Award 1981

Columns

<i>ID</i>	<i>name</i>	<i>dept_name</i>	<i>salary</i>
22222	Einstein	Physics	95000
12121	Wu	Finance	90000
32343	El Said	History	60000
45565	Katz	Comp. Sci.	75000
98345	Kim	Elec. Eng.	80000
76766	Crick	Biology	72000
10101	Srinivasan	Comp. Sci.	65000
58583	Califieri	History	62000
83821	Brandt	Comp. Sci.	92000
15151	Mozart	Music	40000
33456	Gold	Physics	87000
76543	Singh	Finance	80000

Rows

(a) The *instructor* table



A Sample Relational Database

<i>ID</i>	<i>name</i>	<i>dept_name</i>	<i>salary</i>
22222	Einstein	Physics	95000
12121	Wu	Finance	90000
32343	El Said	History	60000
45565	Katz	Comp. Sci.	75000
98345	Kim	Elec. Eng.	80000
76766	Crick	Biology	72000
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33456	Gold	Physics	87000
76543	Singh	Finance	80000

(a) The *instructor* table

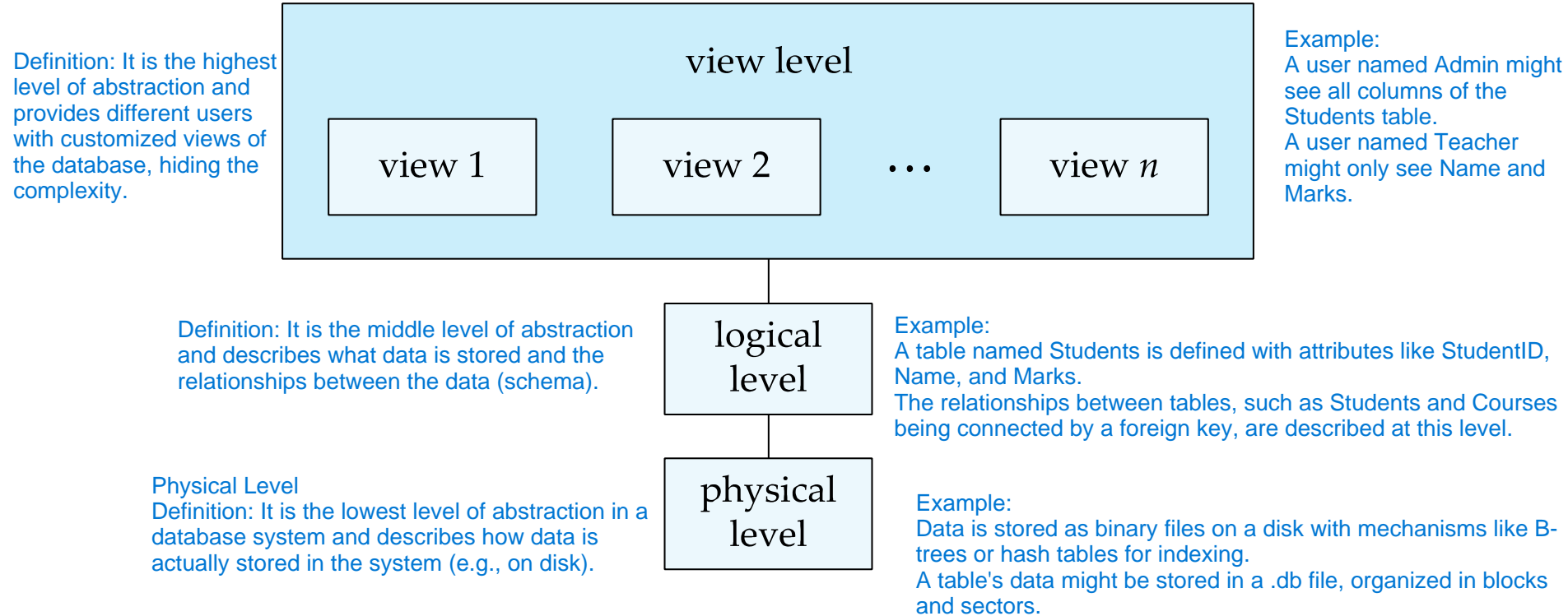
<i>dept_name</i>	<i>building</i>	<i>budget</i>
Comp. Sci.	Taylor	100000
Biology	Watson	90000
Elec. Eng.	Taylor	85000
Music	Packard	80000
Finance	Painter	120000
History	Painter	50000
Physics	Watson	70000

(b) The *department* table



View of Data

An architecture for a database system





Instances and Schemas

- Similar to types and variables in programming languages
- **Logical Schema** – the overall logical structure of the database
 - Example: The database consists of information about a set of customers and accounts in a bank and the relationship between them
 - Analogous to type information of a variable in a program
- **Physical schema**– the overall physical structure of the database
- **Instance** – the actual content of the database at a particular point in time
 - Analogous to the value of a variable

A physical schema describes how data is physically stored in the database, including details like file structures, indexing methods, and storage mechanisms.



Physical Data Independence

- **Physical Data Independence** – the ability to modify the physical schema without changing the logical schema
 - Applications depend on the logical schema
 - In general, the interfaces between the various levels and components should be well defined so that changes in some parts do not seriously influence others.

Components of a Database System

Hardware – The physical storage devices (servers, hard drives, SSDs) that store the database.

Software – The Database Management System (DBMS), which manages data storage, retrieval, and security.

Data – The actual stored information, structured as tables, indexes, and schemas.

Users – Different types of users (end-users, database administrators, application programmers) interact with the database.

Procedures – Rules, guidelines, and methodologies for managing and maintaining the database.



Data Definition Language (DDL)

- Specification notation for defining the database schema

Example: **create table** *instructor* (
 ID **char**(5),
 name **varchar**(20),
 dept_name **varchar**(20),
 salary **numeric**(8,2))

- DDL compiler generates a set of table templates stored in a ***data dictionary***
- Data dictionary contains metadata (i.e., data about data)
 - Database schema
 - Integrity constraints
 - Primary key (ID uniquely identifies instructors)
 - Authorization
 - Who can access what



Data Manipulation Language (DML)

- Language for accessing and updating the data organized by the appropriate data model
 - DML also known as query language
- Two classes of languages
 - **Pure** – used for proving properties about computational power and for optimization
 - Relational Algebra
 - Tuple relational calculus
 - Domain relational calculus
 - **Commercial** – used in commercial systems
 - SQL is the most widely used commercial language

A data model defines how data is structured, stored, and accessed. For example, in a relational model, data is organized into tables (e.g., a "Customers" table with columns like ID, Name, and Email).



Data Manipulation Language (Cont.)

- There are basically two types of data-manipulation language
 - **Procedural DML** -- require a user to specify what data are needed and how to get those data. like C
 - **Declarative DML** -- require a user to specify what data are needed without specifying how to get those data. like Prolog
- Declarative DMLs are usually easier to learn and use than are procedural DMLs.
- Declarative DMLs are also referred to as non-procedural DMLs
- The portion of a DML that involves information retrieval is called a **query language**.



SQL Query Language

- SQL query language is nonprocedural. A query takes as input several tables (possibly only one) and always returns a single table.
- Example to find all instructors in Comp. Sci. dept

```
select name  
from instructor  
where dept_name = 'Comp. Sci.'
```
- SQL is NOT a Turing machine equivalent language
- To be able to compute complex functions SQL is usually embedded in some higher-level language
- Application programs generally access databases through one of
 - Language extensions to allow embedded SQL
 - Application program interface (e.g., ODBC/JDBC) which allow SQL queries to be sent to a database

ODBC: Open Database Connectivity
JDBC: Java Database Connectivity



Database Access from Application Program

- Non-procedural query languages such as SQL are not as powerful as a universal Turing machine.
- SQL does not support actions such as input from users, output to displays, or communication over the network.
- Such computations and actions must be written in a **host language**, such as C/C++, Java or Python, with embedded SQL queries that access the data in the database.
- **Application programs** -- are programs that are used to interact with the database in this fashion.



Database Design

The process of designing the general structure of the database:

- Logical Design – Deciding on the database schema. Database design requires that we find a “good” collection of relation schemas.
 - Business decision – What attributes should we record in the database?
 - Computer Science decision – What relation schemas should we have and how should the attributes be distributed among the various relation schemas?
- Physical Design – Deciding on the physical layout of the database



Database Engine

- A database system is **partitioned into modules** that deal with each of the responsibilities of the overall system.
- The **functional components of a database system** can be divided into
 - The storage manager,
 - The query processor component,
 - The transaction management component.

The Transaction Management Component in a database system ensures the execution of database operations adheres to the ACID properties (Atomicity, Consistency, Isolation, Durability). It manages transactions by coordinating commit and rollback operations to maintain data integrity even during failures or concurrent access.



Storage Manager

- A program module that provides the interface between the low-level data stored in the database and the application programs and queries submitted to the system.
- The storage manager is responsible to the following tasks:
 - Interaction with the OS file manager
 - Efficient storing, retrieving and updating of data\
- The storage manager components include:
 - Authorization and integrity manager
 - Transaction manager
 - File manager
 - Buffer manager



Storage Manager (Cont.)

- The storage manager implements several data structures as part of the physical system implementation:
 - Data files -- store the database itself
 - Data dictionary -- stores metadata about the structure of the database, in particular the schema of the database.
 - Indices -- can provide fast access to data items. A database index provides pointers to those data items that hold a particular value.



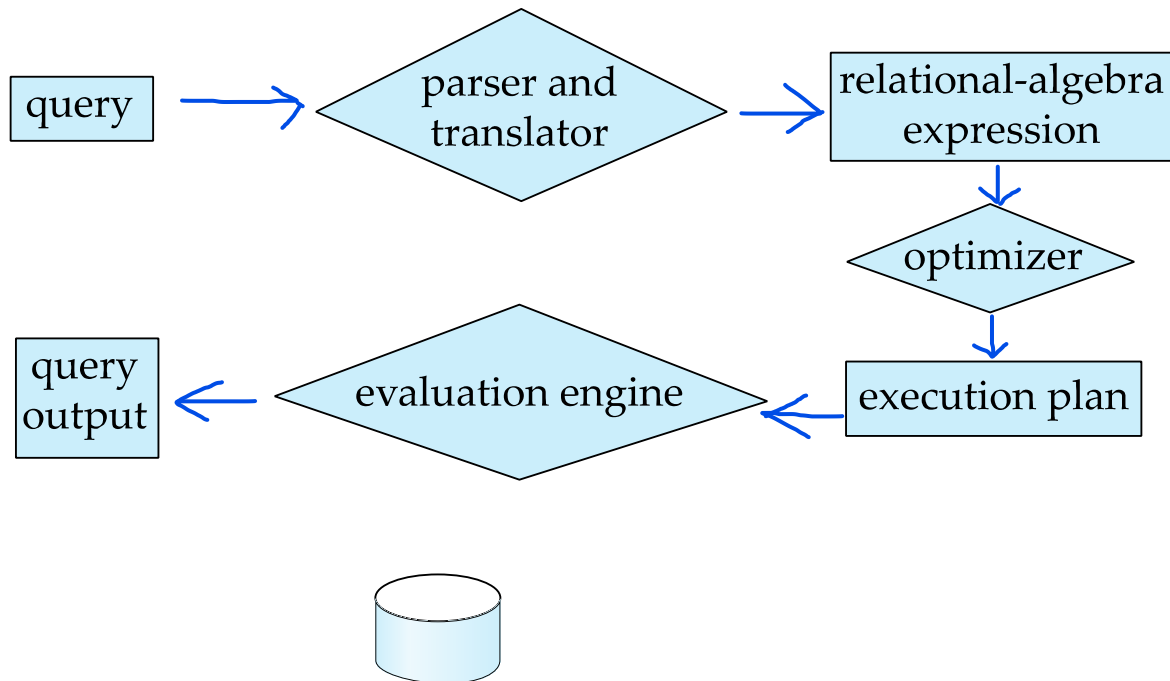
Query Processor

- The query processor components include:
 - **DDL interpreter** -- interprets DDL statements and records the definitions in the data dictionary.
 - **DML compiler** -- translates DML statements in a query language into an evaluation plan consisting of low-level instructions that the query evaluation engine understands.
 - The DML compiler performs query optimization; that is, it picks the lowest cost evaluation plan from among the various alternatives.
 - **Query evaluation engine** -- executes low-level instructions generated by the DML compiler.



Query Processing

1. Parsing and translation
2. Optimization
3. Evaluation





Transaction Management

- A **transaction** is a collection of operations that performs a single logical function in a database application
- **Transaction-management component** ensures that the database remains in a consistent (correct) state despite system failures (e.g., power failures and operating system crashes) and transaction failures.
- **Concurrency-control manager** controls the interaction among the concurrent transactions, to ensure the consistency of the database.



Database Architecture

- Centralized databases
 - One to a few cores, shared memory
- Client-server,
 - One server machine executes work on behalf of multiple client machines.
- Parallel databases
 - Many core shared memory
 - Shared disk
 - Shared nothing
- Distributed databases
 - Geographical distribution
 - Schema/data heterogeneity representation, format, or encoding of data varies across databases



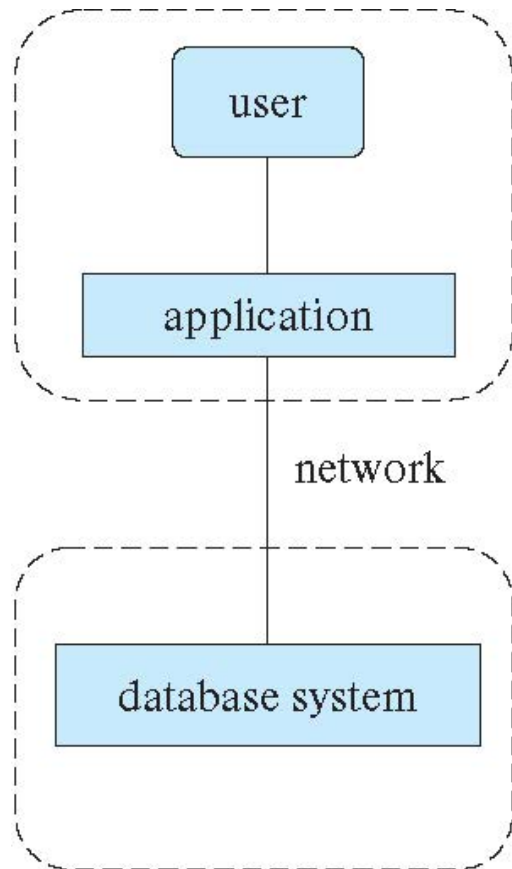
Database Applications

Database applications are usually partitioned into two or three parts

- **Two-tier architecture** -- the application resides at the client machine, where it invokes database system functionality at the server machine
- **Three-tier architecture** -- the client machine acts as a front end and does not contain any direct database calls.
 - The client end communicates with an application server, usually through a forms interface.
 - The application server in turn communicates with a database system to access data.



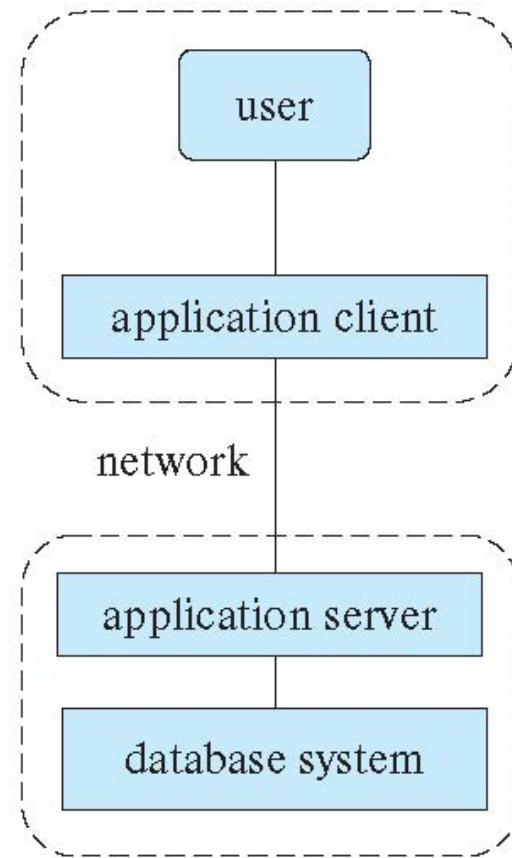
Two-tier and three-tier architectures



(a) Two-tier architecture

client

server



(b) Three-tier architecture



Database Users

There are **four different types of database-system users**

- Naive users -- unsophisticated users who interact with the system by invoking one of the application programs that have been written previously.
- Application programmers -- are computer professionals who write application programs.
- Sophisticated users -- **interact with the system** without writing programs
 - using a database query language or by
 - using tools such as data analysis software.
- Specialized users -- write specialized database applications that do not fit into the traditional data-processing framework. For example, CAD, graphic data, audio, video.

traditional data processing framework - conventional way to process data/queries in database



Database Administrator

A person who has **central control over the system** is called a **database administrator (DBA)**, whose functions are:

- Schema definition
- Storage structure and access-method definition
- Schema and physical-organization modification
- Granting of authorization for data access
- Routine maintenance
- Periodically backing up the database
- Ensuring that enough free disk space is available for normal operations, and upgrading disk space as required
- Monitoring jobs running on the database and ensuring that performance is not degraded by very expensive tasks submitted by some users



History of Database Systems

■ 1950s and early 1960s:

- Data processing using magnetic tapes for storage

- Tapes provided only sequential access

The Hierarchical Model organizes data in a tree-like structure with parent-child relationships, where each child has only one parent. Example: A Company Database where a Manager (Parent) has multiple Employees (Children) but each employee has only one manager. The Network Model allows many-to-many relationships using a graph structure where a child can have multiple parents. Example: A University Database where a Student can be linked to multiple Courses, and each course can have multiple students.

- Punched cards for input

■ Late 1960s and 1970s:

- Hard disks allowed direct access to data
- Network and hierarchical data models in widespread use
- Ted Codd defines the relational data model
 - Would win the ACM Turing Award for this work
 - IBM Research begins System R prototype
 - UC Berkeley (Michael Stonebraker) begins Ingres prototype
 - Oracle releases first commercial relational database
- High-performance (for the era) transaction processing



History of Database Systems (Cont.)

- 1980s:
 - Research relational prototypes evolve into commercial systems
 - SQL becomes industrial standard
 - Parallel and distributed database systems
 - Wisconsin, IBM, Teradata
 - Object-oriented database systems
- 1990s:
 - Large decision support and data-mining applications
 - Large multi-terabyte data warehouses
 - Emergence of Web commerce

Data mining is the process of discovering patterns, trends, and useful information from large databases using techniques like clustering, classification, and association rules. Example: A retail store database analyzes customer purchase history to identify frequently bought item pairs (e.g., "milk and bread") for better marketing strategies.



History of Database Systems (Cont.)

■ 2000s

- Big data storage systems

- Google BigTable, Yahoo PNuts, Amazon,
- “NoSQL” systems.

- Big data analysis: beyond SQL

- Map reduce and friends

MapReduce is a programming model paradigm for processing and generating large datasets that can be parallelized across a distributed cluster of computers. It consists of two main functions:

Map Function: Takes input data and transforms it into a set of intermediate key-value pairs.

Reduce Function: Takes the intermediate key-value pairs and merges them into a smaller set of values.

■ 2010s

- SQL reloaded

- SQL front end to Map Reduce systems
- Massively parallel database systems
- Multi-core main-memory databases



End of Chapter 1



END OF CHAPTER 1