



COMPSCI 351

Fundamentals of Database Systems

Database System Concepts and Architecture



Outline

- ▶ Data Models and Their Categories
- ▶ Schemas, Instances, and States
- ▶ Three-Schema Architecture
- ▶ Data Independence
- ▶ DBMS Languages and Interfaces
- ▶ Centralized and Client-Server Architectures
- ▶ Classification of DBMSs



Data Models

▶ Data Model:

- ▶ A set of concepts to describe the **structure** of a database, the **operations** for manipulating these structures, and certain **constraints** that the database should obey.

▶ Data Model Structure and Constraints:

- ▶ Constructs are used to define the database structure
- ▶ Constructs typically include **elements** (and their **data types**) as well as groups of elements (e.g. **entity**, **record**, **table**), and **relationships** among such groups
- ▶ Constraints specify some restrictions on valid data; these constraints must be enforced at all times



Data Models (continued)

▶ Data Model Operations:

- ▶ These operations are used for specifying database *retrievals* and *updates* by referring to the constructs of the data model.
- ▶ Operations on the data model may include ***basic model operations*** (e.g. generic insert, delete, update) and ***user-defined operations*** (e.g. compute_student_gpa, update_inventory)



Categories of Data Models

- ▶ **Conceptual (high-level, semantic) data models:**
 - ▶ Provide concepts that are close to the way many users perceive data.
 - ▶ (Also called **entity-based** or **object-based** data models.)
- ▶ **Physical (low-level, internal) data models:**
 - ▶ Provide concepts that describe details of how data is stored in the computer. These are usually specified in an ad-hoc manner through DBMS design and administration manuals
- ▶ **Implementation (representational) data models:**
 - ▶ Provide concepts that fall between the above two, used by many commercial DBMS implementations (e.g. relational data models used in many commercial systems).
- ▶ **Self-Describing Data Models:**
 - ▶ Combine the description of data with the data values. Examples include XML, key-value.



Schemas versus Instances

- ▶ Key Distinction:
 - ▶ The ***database schema*** changes very infrequently.
 - ▶ The ***database state*** changes every time the database is updated.
- ▶ Database Schema:
 - ▶ The ***description*** of a database.
 - ▶ Includes descriptions of the database structure, data types, and the constraints on the database.
- ▶ Schema Diagram:
 - ▶ An ***illustrative*** display of (most aspects of) a database schema.
- ▶ Schema Construct:
 - ▶ A ***component*** of the schema or an object within the schema, e.g., STUDENT, COURSE.



Schemas versus Instances

- ▶ Database State:
 - ▶ The actual data stored in a database at a ***particular moment in time***. This includes the collection of all the data in the database.
 - ▶ Also called database instance (or occurrence or snapshot).
 - ▶ The term *instance* is also applied to individual database components, e.g. *record instance, table instance, entity instance*
- ▶ Initial Database State:
 - ▶ Refers to the database state when it is initially loaded into the system.
- ▶ Valid State:
 - ▶ A state that satisfies the structure and constraints of the database



Example of a Database Schema

STUDENT

Name	Student_number	Class	Major
------	----------------	-------	-------

COURSE

Course_name	Course_number	Credit_hours	Department
-------------	---------------	--------------	------------

PREREQUISITE

Course_number	Prerequisite_number
---------------	---------------------

SECTION

Section_identifier	Course_number	Semester	Year	Instructor
--------------------	---------------	----------	------	------------

GRADE_REPORT

Student_number	Section_identifier	Grade
----------------	--------------------	-------

Figure 2.1

Schema diagram for the database in Figure 1.2.



Example of a database state

COURSE

Course_name	Course_number	Credit_hours	Department
Intro to Computer Science	CS1310	4	CS
Data Structures	CS3320	4	CS
Discrete Mathematics	MATH2410	3	MATH
Database	CS3380	3	CS

SECTION

Section_identifier	Course_number	Semester	Year	Instructor
85	MATH2410	Fall	04	King
92	CS1310	Fall	04	Anderson
102	CS3320	Spring	05	Knuth
112	MATH2410	Fall	05	Chang
119	CS1310	Fall	05	Anderson
135	CS3380	Fall	05	Stone

GRADE_REPORT

Student_number	Section_identifier	Grade
17	112	B
17	119	C
8	85	A
8	92	A
8	102	B
8	135	A

PREREQUISITE

Course_number	Prerequisite_number
CS3380	CS3320
CS3380	MATH2410
CS3320	CS1310

Figure 1.2

A database that stores student and course information.



Three-Schema Architecture

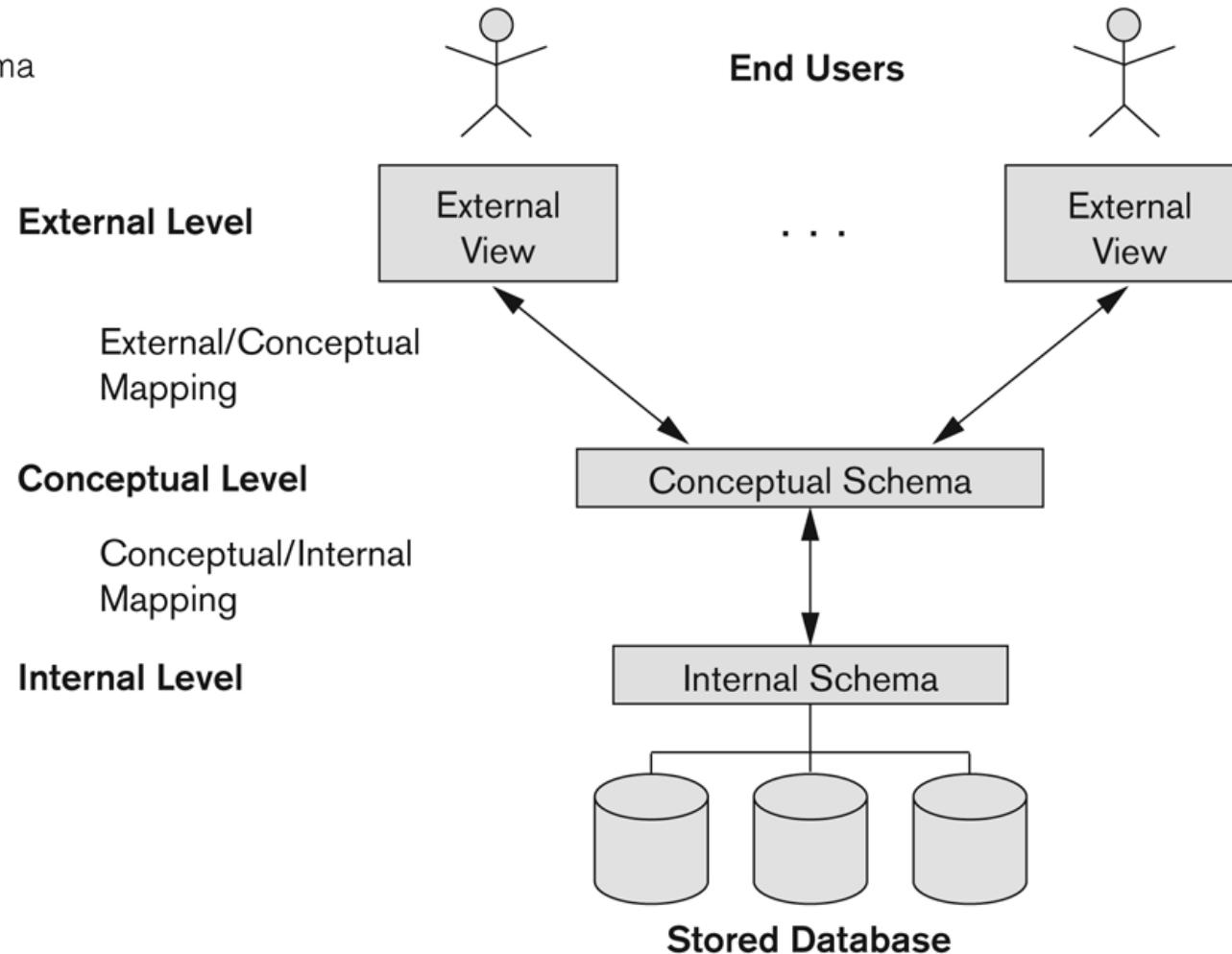
- ▶ Proposed to support DBMS characteristics of:
 - ▶ **Program-data independence.**
 - ▶ Support of **multiple views** of the data.
- ▶ Defines DBMS schemas at **three** levels:
 - ▶ **Internal schema** at the internal level to describe physical storage structures and access paths (e.g., indexes).
 - ▶ Typically uses a **physical** data model.
 - ▶ **Conceptual schema** at the conceptual level to describe the structure and constraints for the whole database for a community of users.
 - ▶ Uses a **conceptual** or an **implementation** data model.
 - ▶ **External schemas** at the external level to describe the various user views.
 - ▶ Usually uses the same data model as the conceptual schema.



The three-schema architecture

Figure 2.2

The three-schema architecture.





Three-Schema Architecture

- ▶ Mappings among schema levels are needed to transform requests and data.
 - ▶ Programs refer to an external schema, and are mapped by the DBMS to the internal schema for execution.
 - ▶ Data extracted from the internal DBMS level is reformatted to match the user's external view (e.g. formatting the results of an SQL query for display in a Web page)



Data Independence

▶ **Logical Data Independence:**

- ▶ The capacity to change the conceptual schema without having to change the external schemas and their associated application programs.

▶ **Physical Data Independence:**

- ▶ The capacity to change the internal schema without having to change the conceptual schema.
- ▶ For example, the internal schema may be changed when certain file structures are reorganized or new indexes are created to improve database performance
- ▶ When a schema at a lower level is changed, only the **mappings** between this schema and higher-level schemas need to be changed in a DBMS that fully supports data independence. The higher-level schemas are **unchanged**.



DBMS Languages

▶ Data Definition Language (DDL):

- ▶ Used by the DBA and database designers to specify the conceptual schema of a database.
- ▶ In many DBMSs, the DDL is also used to define internal and external schemas (views).
- ▶ In some DBMSs, separate **storage definition language (SDL)** and **view definition language (VDL)** are used to define internal and external schemas.
 - ▶ SDL is typically realized via DBMS commands provided to the DBA and database designers



DBMS Languages

▶ **Data Manipulation Language (DML):**

- ▶ Used to specify database retrievals and updates
- ▶ DML commands (data sublanguage) can be embedded in a general-purpose programming language (host language), such as COBOL, C, C++, or Java.
 - ▶ A library of functions can also be provided to access the DBMS from a programming language
- ▶ Alternatively, stand-alone DML commands can be applied directly (called a *query language*).



Types of DML

▶ **High Level or Non-procedural Language:**

- ▶ These include the SQL relational language
- ▶ Are “set”-oriented and specify what data to retrieve rather than how to retrieve it.
- ▶ Also called **declarative** languages.
- ▶ May be used in a standalone way or may be embedded in a programming language

▶ **Low Level or Procedural Language:**

- ▶ Retrieve data one record-at-a-time;
- ▶ Constructs such as looping are needed to retrieve multiple records, along with positioning pointers.
- ▶ These must be embedded in a programming language



DBMS Interfaces

- ▶ Stand-alone query language interfaces
 - ▶ Example: Entering SQL queries at the DBMS interactive SQL interface (e.g., SQL*Plus in ORACLE)
- ▶ Programmer interfaces for embedding DML in programming languages
- ▶ User-friendly interfaces
 - ▶ Menu-based (Web-based), popular for browsing on the web
 - ▶ Forms-based, designed for naïve users used to filling in entries
 - ▶ Graphics-based
 - ▶ Point and Click, Drag and Drop, etc.
 - ▶ Specifying a query on a schema diagram
 - ▶ Natural language: requests in written English, free text as a query



Other DBMS Interfaces

- ▶ Mobile Interfaces: interfaces allowing users to perform transactions using mobile apps
- ▶ Speech : Input query and Output response
- ▶ Web Browser with keyword search
- ▶ Parametric interfaces, e.g., bank tellers using function keys.
- ▶ Interfaces for the DBA:
 - ▶ Creating user accounts, granting authorizations
 - ▶ Setting system parameters
 - ▶ Changing schemas or access paths



DBMS Programming Language Interfaces

- ▶ Programmer interfaces for embedding DML in a programming languages:
 - ▶ **Embedded Approach:** e.g embedded SQL (for C, C++, etc.), SQLJ (for Java)
 - ▶ **Procedure Call Approach:** e.g. JDBC for Java, ODBC (Open Database Connectivity) for other programming languages as API's (application programming interfaces)
 - ▶ **Database Programming Language Approach:** e.g. ORACLE has PL/SQL, a programming language based on SQL; language incorporates SQL and its data types as integral components
 - ▶ **Scripting Languages:** PHP (client-side scripting) and Python (server-side scripting) are used to write database programs.



Typical DBMS Component Modules

- ▶ The top part refers to the various users of the database environment.
- ▶ The lower part shows the internal modules of the DBMS responsible for storage of data and processing of transactions.

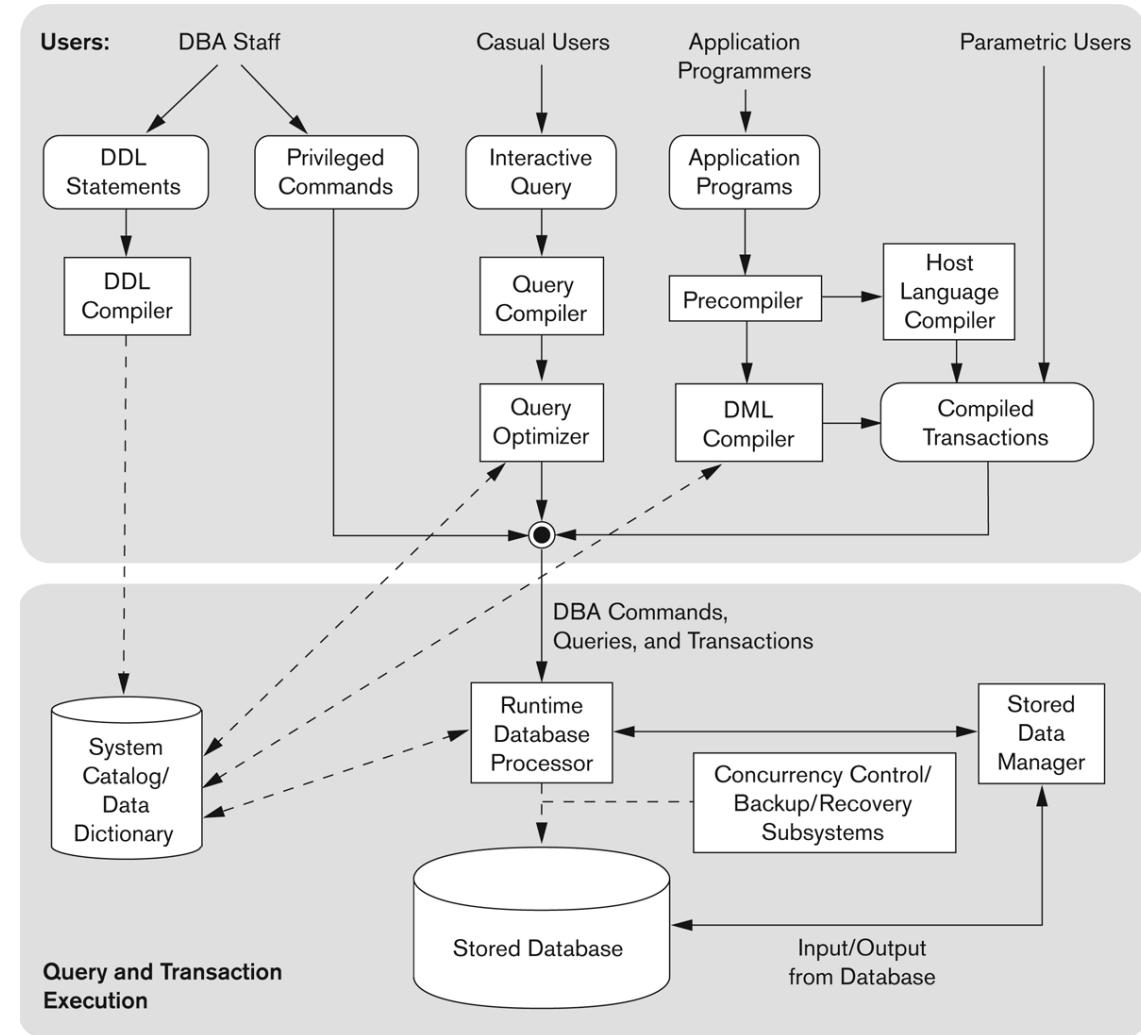


Figure 2.3
Component modules of a DBMS and their interactions.



Database System Utilities

- ▶ To perform certain functions such as:
 - ▶ Loading data stored in files into a database. Includes data conversion tools.
 - ▶ Backing up the database periodically on tape.
 - ▶ Reorganizing database file structures.
 - ▶ Performance monitoring utilities.
 - ▶ Report generation utilities.
 - ▶ Other functions, such as sorting, user monitoring, data compression, etc.



Centralized and Client-Server DBMS Architectures

▶ Centralized DBMS:

- ▶ Combines everything into single system including- DBMS software, hardware, application programs, and user interface processing software.
- ▶ User can still connect through a remote terminal – however, all processing is done at centralized site.



A Physical Centralized Architecture

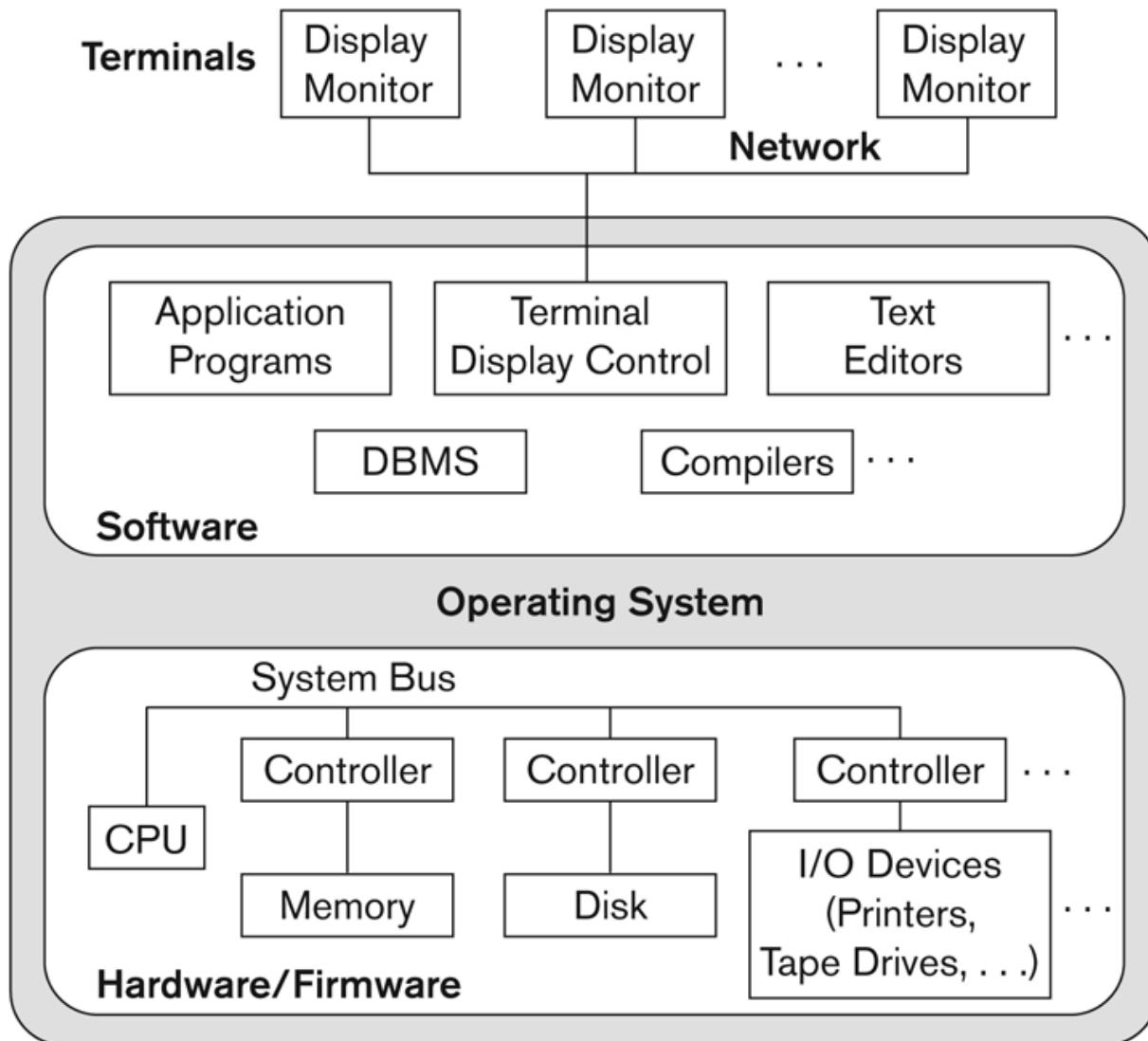


Figure 2.4

A physical centralized architecture.

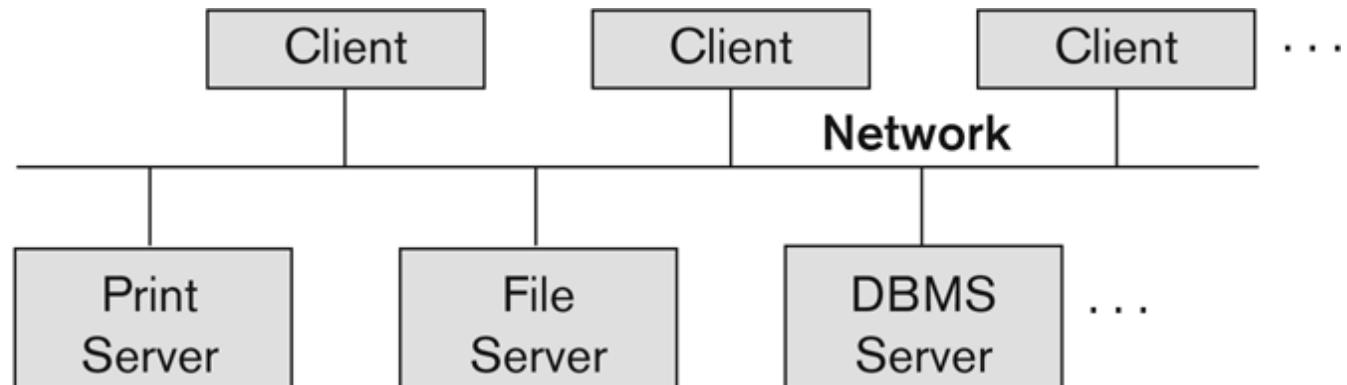


Basic 2-tier Client-Server Architectures

▶ Specialized Servers with Specialized functions

- ▶ Print server
- ▶ File server
- ▶ DBMS server
- ▶ Web server
- ▶ Email server

Figure 2.5
Logical two-tier
client/server
architecture.



▶ Clients can access the specialized servers as needed



Clients and Servers

▶ Clients

- ▶ Provide appropriate interfaces through a client software module to access and utilize the various server resources.
- ▶ Clients may be diskless machines or PCs or Workstations with disks with only the client software installed.
- ▶ Connected to the servers via some form of a network (LAN: local area network, wireless network, etc.)

▶ Server

- ▶ Provides database query and transaction services to the clients
- ▶ Relational DBMS servers are often called SQL servers, query servers, or transaction servers
- ▶ Applications running on clients utilize an Application Program Interface (**API**) to access server databases via standard interface such as: ODBC (Open Database Connectivity standard) or JDBC - for Java programming access



Two Tier Client-Server Architecture

- ▶ Client and server must install appropriate client module and server module software for ODBC or JDBC
- ▶ A client program may connect to several DBMSs, sometimes called the data sources.
- ▶ In general, data sources can be files or other non-DBMS software that manages data.
- ▶ Details will be discussed in the late sessions on Database Programming



Three Tier Client-Server Architecture

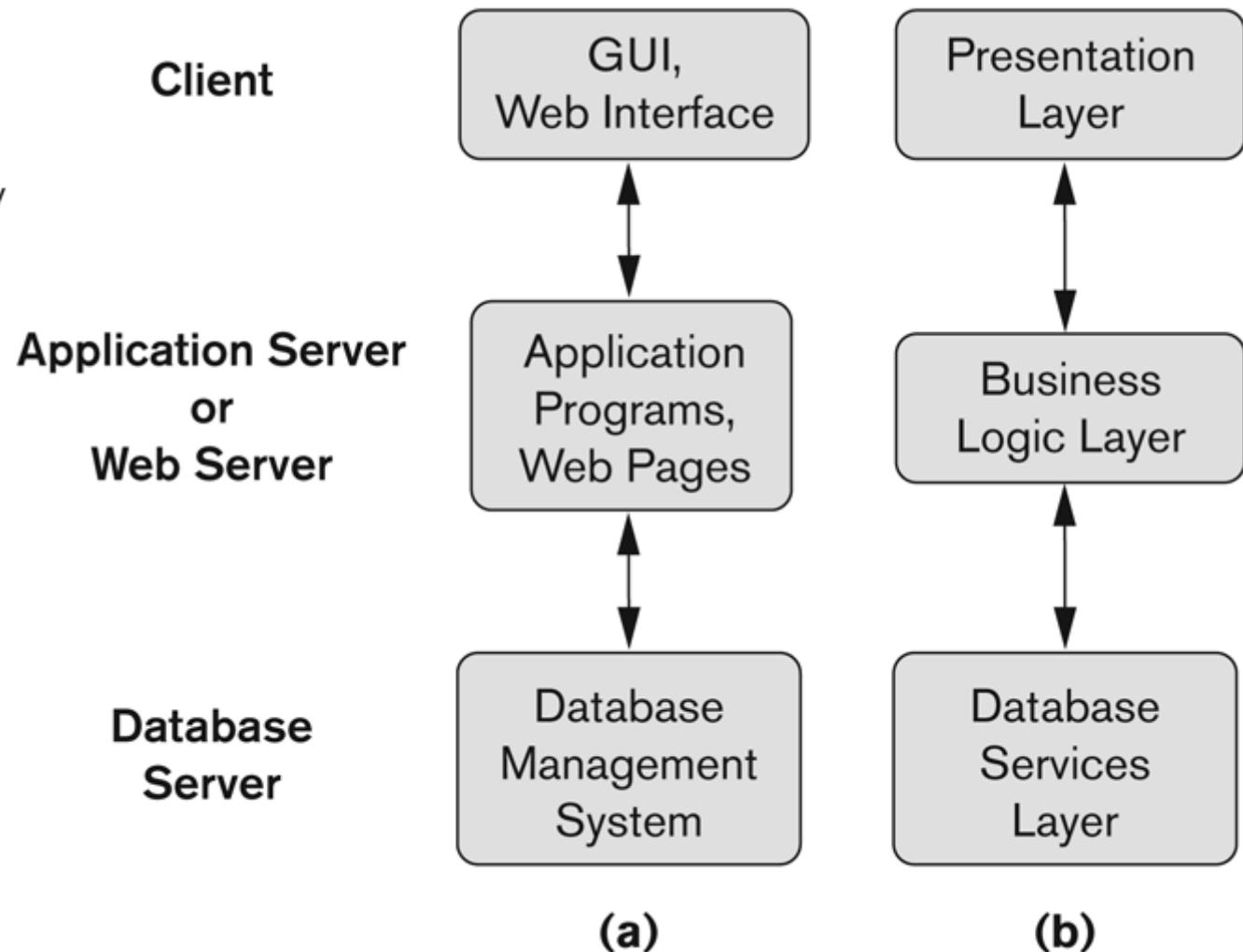
- ▶ Common for Web applications
- ▶ Intermediate Layer called Application Server or Web Server:
 - ▶ Stores the web connectivity software and the business logic part of the application used to access the corresponding data from the database server
 - ▶ Acts like a conduit for sending partially processed data between the database server and the client.
- ▶ Three-tier Architecture Can Enhance Security:
 - ▶ Database server only accessible via middle tier
 - ▶ Clients cannot directly access database server
 - ▶ Clients contain user interfaces and Web browsers
 - ▶ The client is typically a PC or a mobile device connected to the Web



Three-tier client-server architecture

Figure 2.7

Logical three-tier client/server architecture, with a couple of commonly used nomenclatures.





Classification of DBMSs

- ▶ Based on the data model used
 - ▶ Legacy: Network, Hierarchical.
 - ▶ Currently Used: Relational, Object-oriented, Object-relational
 - ▶ Recent Technologies: Key-value storage systems, NOSQL systems: document based, column-based, graph-based and key-value based. Native XML DBMSs.
- ▶ Other classifications
 - ▶ Single-user (typically used with personal computers) vs. multi-user (most DBMSs).
 - ▶ Centralized (uses a single computer with one database) vs. distributed (multiple computers, multiple DBs)



Summary

- ▶ We distinguish three main categories of data models:
 - ▶ High-level or conceptual data models (based on entities and relationships)
 - ▶ Low level or physical data models
 - ▶ Representation or implementation data models (record-based, object-oriented)
- ▶ We distinguished three-schema DBMS architecture, i.e., internal, conceptual and external.
- ▶ We discussed the main types of language and interfaces of DBMS.
- ▶ We discussed different types of interfaces of DBMS.
- ▶ We discussed an overview of two-tier and three-tier architecture for database applications.