Introduction

Database Management System (DBMS)

DBMS contains information about a particular enterprise

- Collection of interrelated data
- Set of programs to access the data
- An environment that is both *convenient* and *efficient* to use

Database Applications:

- Banking: all transactions
- Airlines: reservations, schedules
- Universities: registration, grades
- Sales: customers, products, purchases
- Online retailers: order tracking, customized recommendations
- Manufacturing: production, inventory, orders, supply chain
- Human resources: employee records, salaries, tax deductions

Databases touch all aspects of our lives

Purpose of Database Systems

In the early days, database applications were built directly on top of file systems

Drawbacks of using file systems to store data:

- Data redundancy and inconsistency
  - Multiple file formats, 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.)

- Drawbacks of using file 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 accessed needed for performance
    - Uncontrolled concurrent accesses can lead to inconsistencies
      - Example: Two people reading a balance and updating it 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

Levels of Abstraction

Physical level: describes how a record (e.g., customer) is stored.

Logical level: describes data stored in database, and the relationships among the data.

type *customer* = **record**

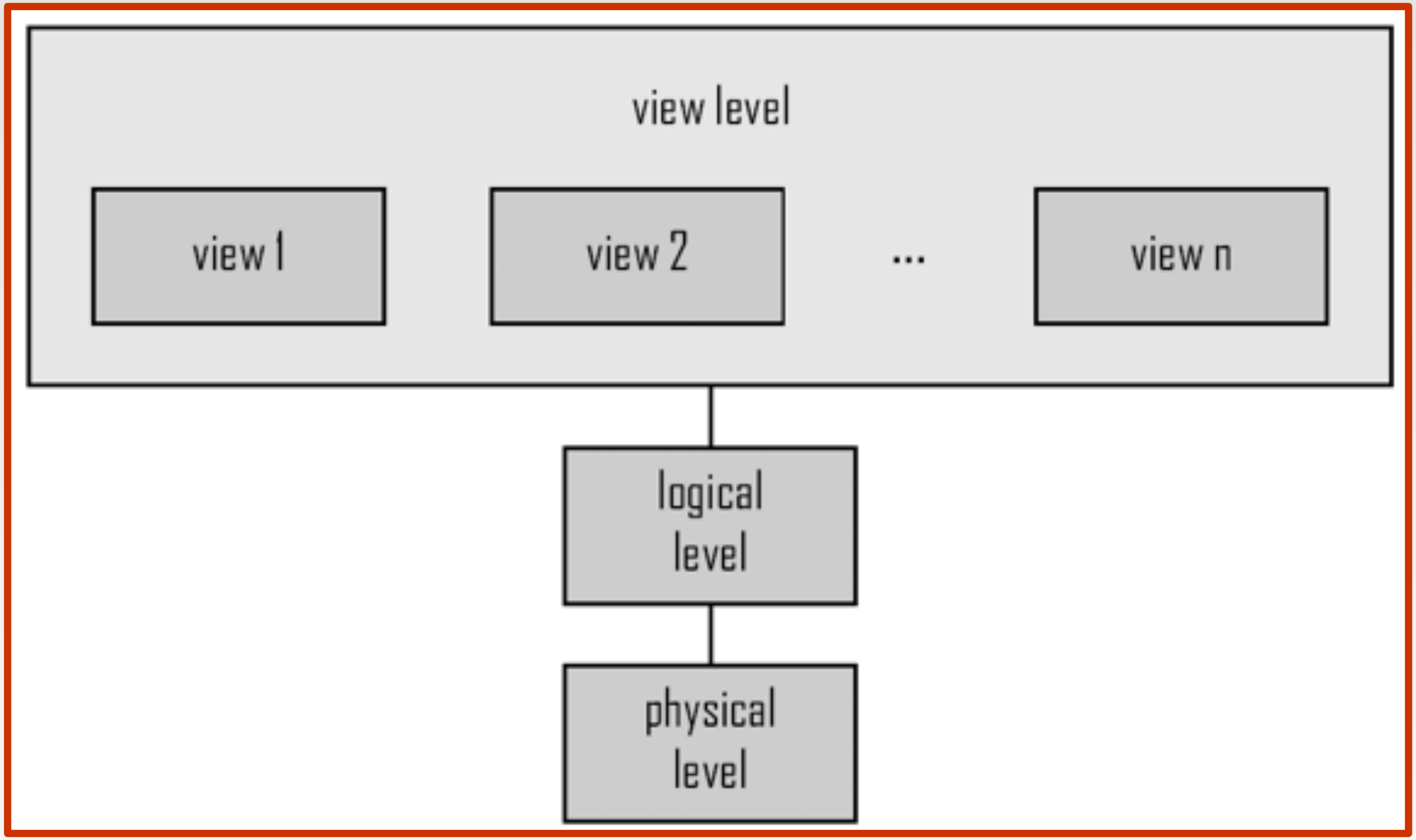
customer_id : string;
customer_name : string;
customer_street : string;
customer_city : string;

end;

View level: application programs hide details of data types. Views can also hide information (such as an employee's salary) for security purposes.

View of Data

An architecture for a database system



Instances and Schemas

Similar to types and variables in programming languages

Schema – the logical structure of the database

- Example: The database consists of information about a set of customers and accounts and the relationship between them)
- Analogous to type information of a variable in a program
- **Physical schema**: database design at the physical level
- **Logical schema**: database design at the logical level

Instance – the actual content of the database at a particular point in time

- Analogous to the value of a variable

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.

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)

Semistructured data model (XML)

Other older models:

- Network model
- Hierarchical model

Data Definition Language (DDL)

Specification notation for defining the database schema

Example: **create table** *account* (
account_number **char**(10),
branch_name **char**(10),
balance **integer**)

DDL compiler generates a set of tables stored in a *data dictionary*

Data dictionary contains metadata (i.e., data about data)

- Database schema
- Data *storage and definition* language
  - Specifies the storage structure and access methods used
- Integrity constraints
  - Domain constraints
  - Referential integrity (e.g. *branch_name* must correspond to a valid branch in the *branch* table)
- Authorization

Data Manipulation Language (DML)

Language for accessing and manipulating the data organized by the appropriate data model

- DML also known as query language

Two classes of languages

- **Procedural** – user specifies what data is required and how to get those data
- **Declarative (nonprocedural)** – user specifies what data is required without specifying how to get those data

SQL is the most widely used non-procedural query language

Relational Model

Attributes

Example of tabular data in the relational model

customer_id	customer_name	customer_street	customer_city	account_number
192-83-7465	Johnson	12 Alma St.	Palo Alto	A-101
192-83-7465	Johnson	12 Alma St.	Palo Alto	A-201
677-89-9011	Hayes	3 Main St.	Harrison	A-102
182-73-6091	Turner	123 Putnam St.	Stamford	A-305
321-12-3123	Jones	100 Main St.	Harrison	A-217
336-66-9999	Lindsay	175 Park Ave.	Pittsfield	A-222
019-28-3746	Smith	72 North St.	Rye	A-201

A Sample Relational Database

customer_id	*customer_name*	*customer_street*	*customer_city*
192-83-7465	Johnson	12 Alma St.	Palo Alto
677-89-9011	Hayes	3 Main St.	Harrison
182-73-6091	Turner	123 Putnam Ave.	Stamford
321-12-3123	Jones	100 Main St.	Harrison
336-66-9999	Lindsay	175 Park Ave.	Pittsfield
019-28-3746	Smith	72 North St.	Rye

(a) The *customer* table

account_number	*balance*
A-101	500
A-215	700
A-102	400
A-305	350
A-201	900
A-217	750
A-222	700

(b) The *account* table

customer_id	*account_number*
192-83-7465	A-101
192-83-7465	A-201
019-28-3746	A-215
677-89-9011	A-102
182-73-6091	A-305
321-12-3123	A-217
336-66-9999	A-222
019-28-3746	A-201

(c) The *depositor* table

SQL

SQL: widely used non-procedural language

- Example: Find the name of the customer with customer-id 192-83-7465

  select *customer.customer_name*
  from *customer*
  where *customer.customer_id* = '192-83-7465'

- Example: Find the balances of all accounts held by the customer with customer-id 192-83-7465

  select *account.balance*
  from *depositor*, *account*
  where *depositor.customer_id* = '192-83-7465' **and**
  depositor.account_number = account.account_number

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

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?

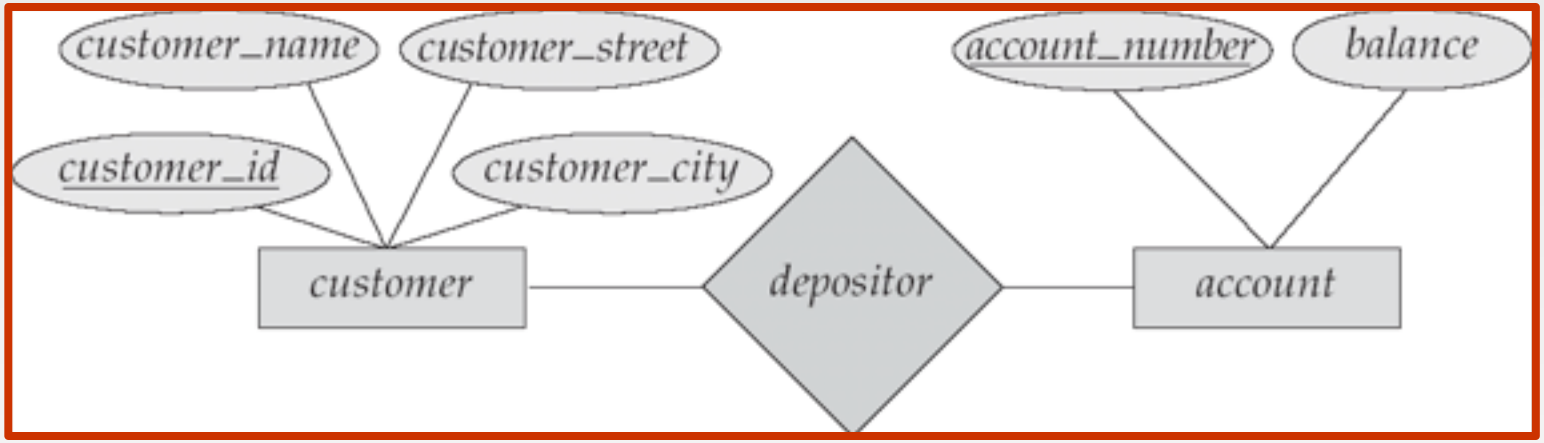
Physical Design – Deciding on the physical layout of the database

The Entity-Relationship Model

Models an enterprise as a collection of *entities* and *relationships*

- Entity: a “thing” or “object” in the enterprise that is distinguishable from other objects
  - Described by a set of *attributes*
- Relationship: an association among several entities

Represented diagrammatically by an *entity-relationship diagram:*

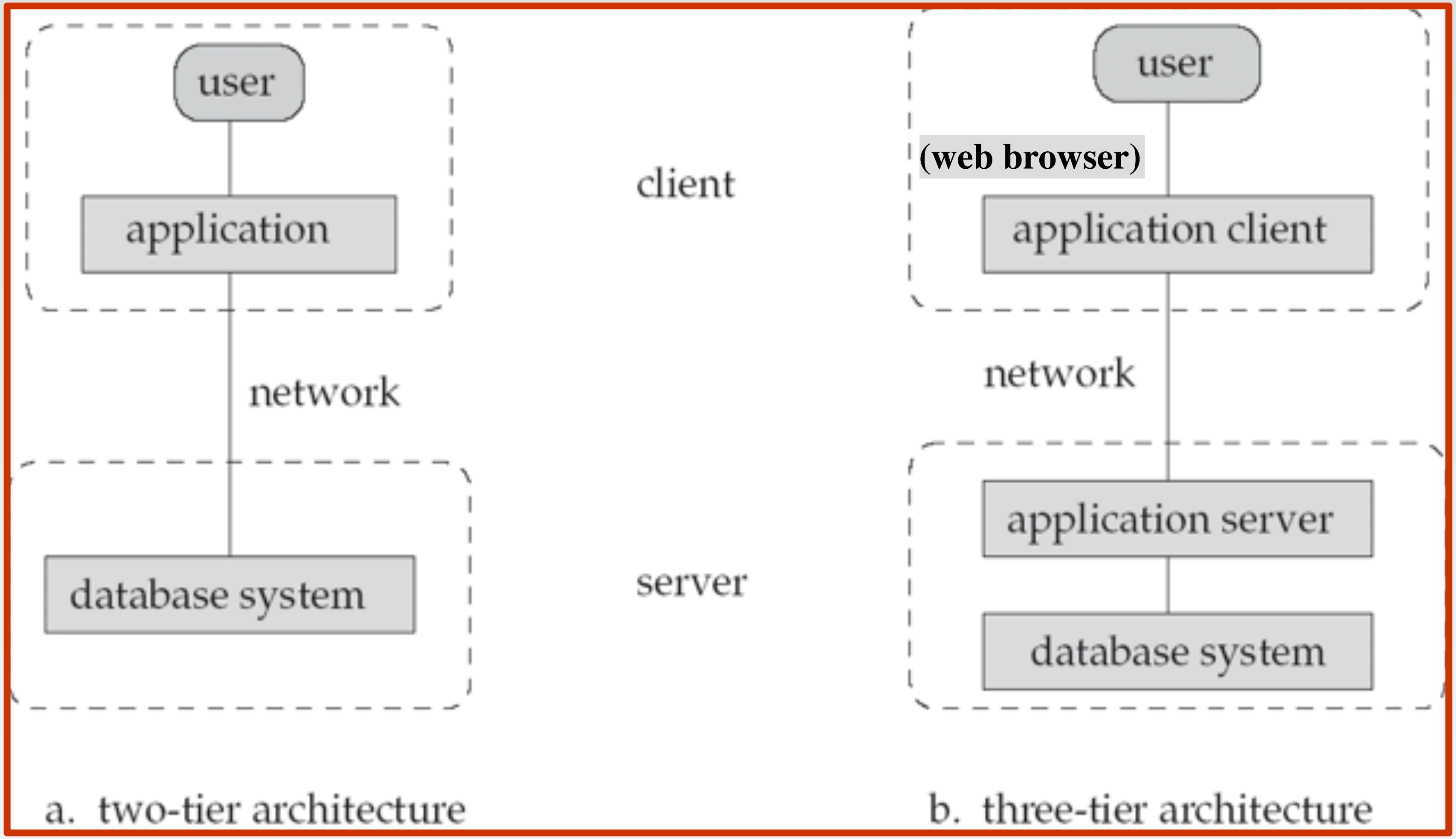


Other Data Models

Object-oriented data model

Object-relational data model

Database Application Architectures



Old

Modern

Database Management System Internals

Storage management

Query processing

Transaction processing

Storage Management

Storage manager is 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:

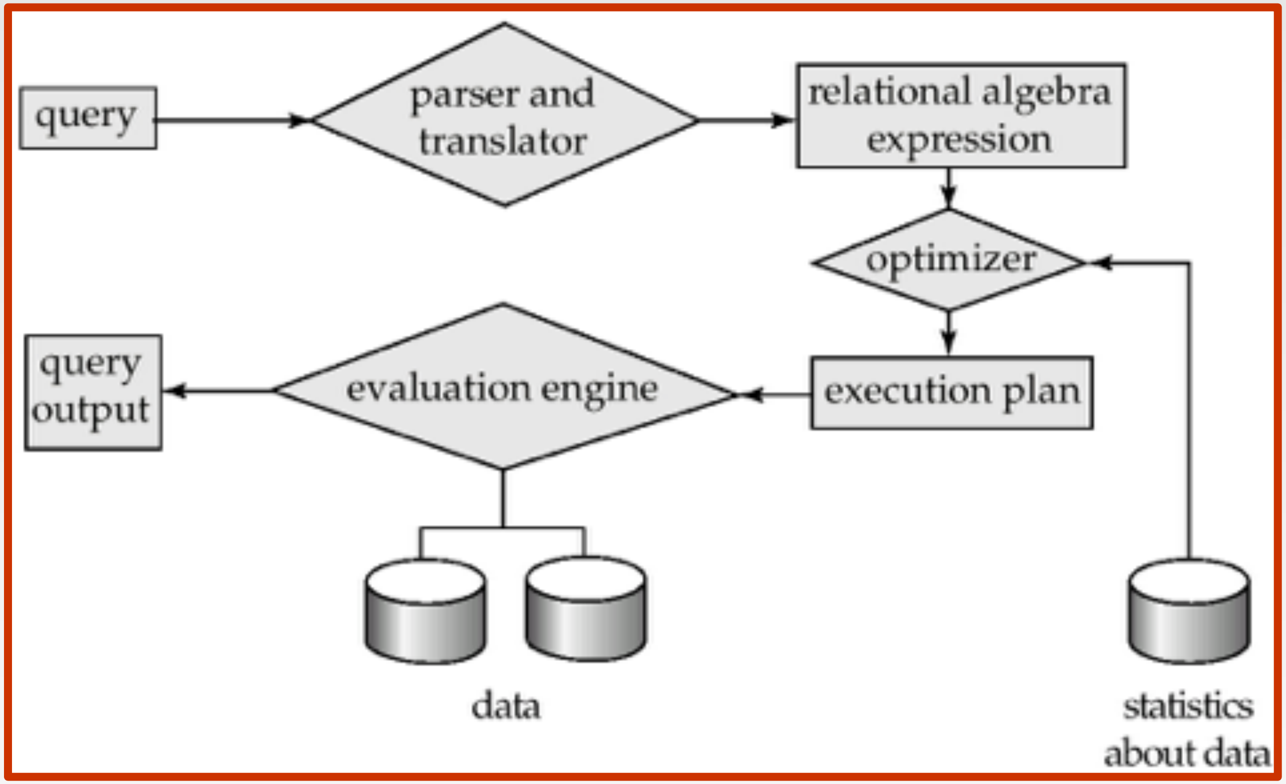
- Interaction with the file manager
- Efficient storing, retrieving and updating of data

Issues:

- Storage access
- File organization
- Indexing and hashing

Query Processing

1. Parsing and translation
2. Optimization
3. Evaluation



Query Processing (Cont.)

Alternative ways of evaluating a given query

- Equivalent expressions
- Different algorithms for each operation

Cost difference between a good and a bad way of evaluating a query can be enormous

Need to estimate the cost of operations

- Depends critically on statistical information about relations which the database must maintain
- Need to estimate statistics for intermediate results to compute cost of complex expressions

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.

Overall System Structure

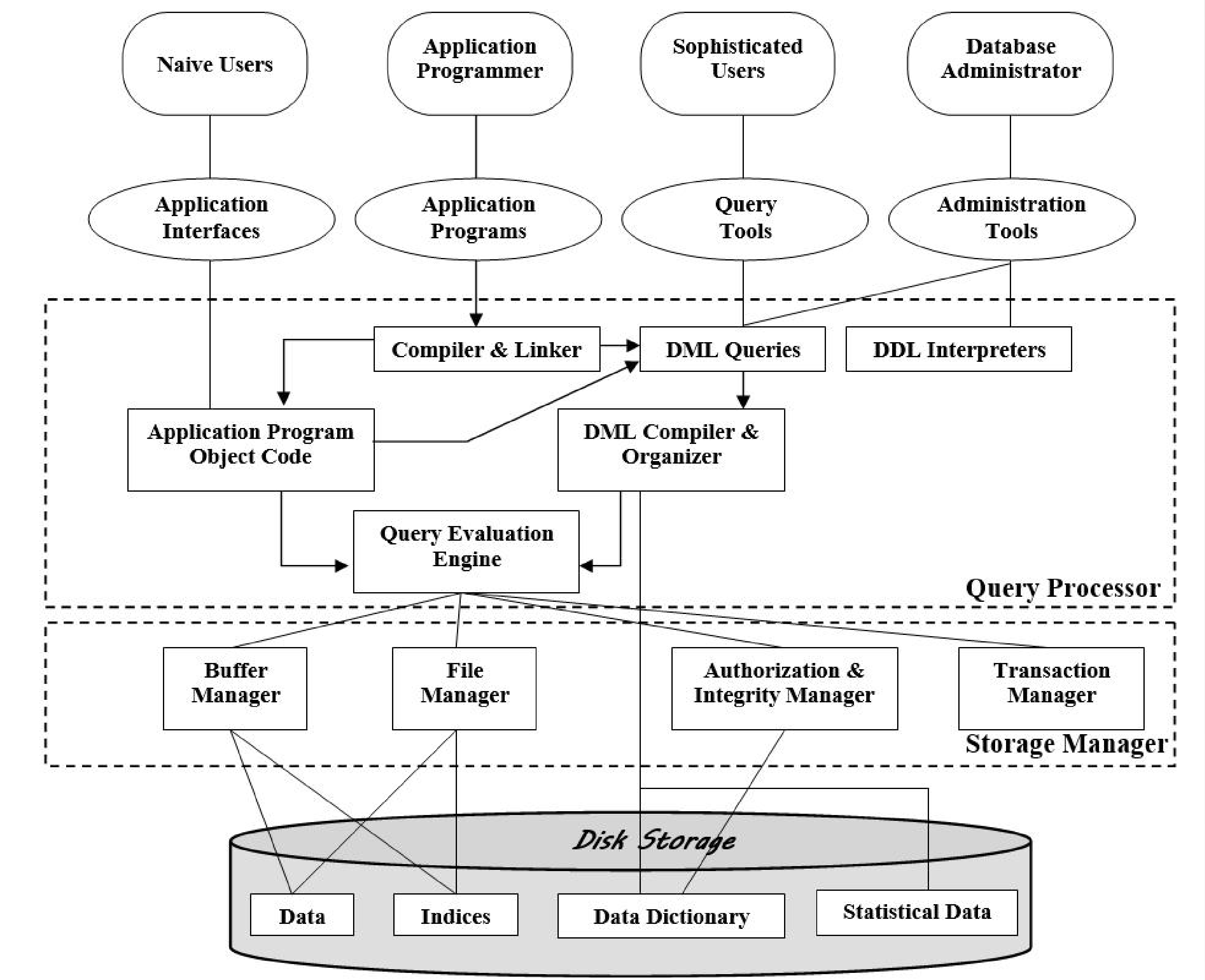


Figure: System Architecture

Database Users

Users are differentiated by the way they expect to interact with the system

- **Application programmers** – write application programmes.
- **Sophisticated users** – form requests in a database query language. These requests are submitted to query processor that breaks a DML statement down into instructions for the database manager module.
- **Specialized users** – write specialized database applications that do not fit into the traditional data processing framework. These may be CADD systems, knowledge based expert systems etc.
- **Naïve users** – invoke one of the permanent application programs that have been written previously
  - Examples, people accessing database over the web, bank tellers, clerical staff

Database Administrator

Coordinates all the activities of the database system

- has a good understanding of the enterprise's information resources and needs.

Database administrator's duties include:

- Storage structure and access method definition
- Schema and physical organization modification
- Granting users authority to access the database
- Backing up data
- Monitoring performance and responding to changes
  - Database tuning

History of Database Systems

- 1950s and early 1960s:
  - Data processing using magnetic tapes for storage
    - Tapes provide only sequential access
  - Punched cards for input
- Late 1960s and 1970s:
  - Hard disks allow 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 begins Ingres prototype
  - High-performance (for the era) transaction processing

History (cont.)

- 1980s:
  - Research relational prototypes evolve into commercial systems
    - SQL becomes industry standard
  - Parallel and distributed database systems
  - Object-oriented database systems
- 1990s:
  - Large decision support and data-mining applications
  - Large multi-terabyte data warehouses
  - Emergence of Web commerce
- 2000s:
  - XML and XQuery standards
  - Automated database administration
  - Increasing use of highly parallel database systems
  - Web-scale distributed data storage systems

Database Architecture

The architecture of a database systems is greatly influenced by the underlying computer system on which the database is running:

Centralized

Client-server

Parallel (multiple processors and disks)

Distributed

Object-Relational Data Models

Extend the relational data model by including object orientation and constructs to deal with added data types.

Allow attributes of tuples to have complex types, including non-atomic values such as nested relations.

Preserve relational foundations, in particular the declarative access to data, while extending modeling power.

Provide upward compatibility with existing relational languages.

XML: Extensible Markup Language

Defined by the WWW Consortium (W3C)

Originally intended as a document markup language not a database language

The ability to specify new tags, and to create nested tag structures made XML a great way to exchange **data**, not just documents

XML has become the basis for all new generation data interchange formats.

A wide variety of tools is available for parsing, browsing and querying XML documents/data

Figure 1.4

customer_id	*account_number*	*balance*
192-83-7465	A-101	500
192-83-7465	A-201	900
019-28-3746	A-215	700
677-89-9011	A-102	400
182-73-6091	A-305	350
321-12-3123	A-217	750
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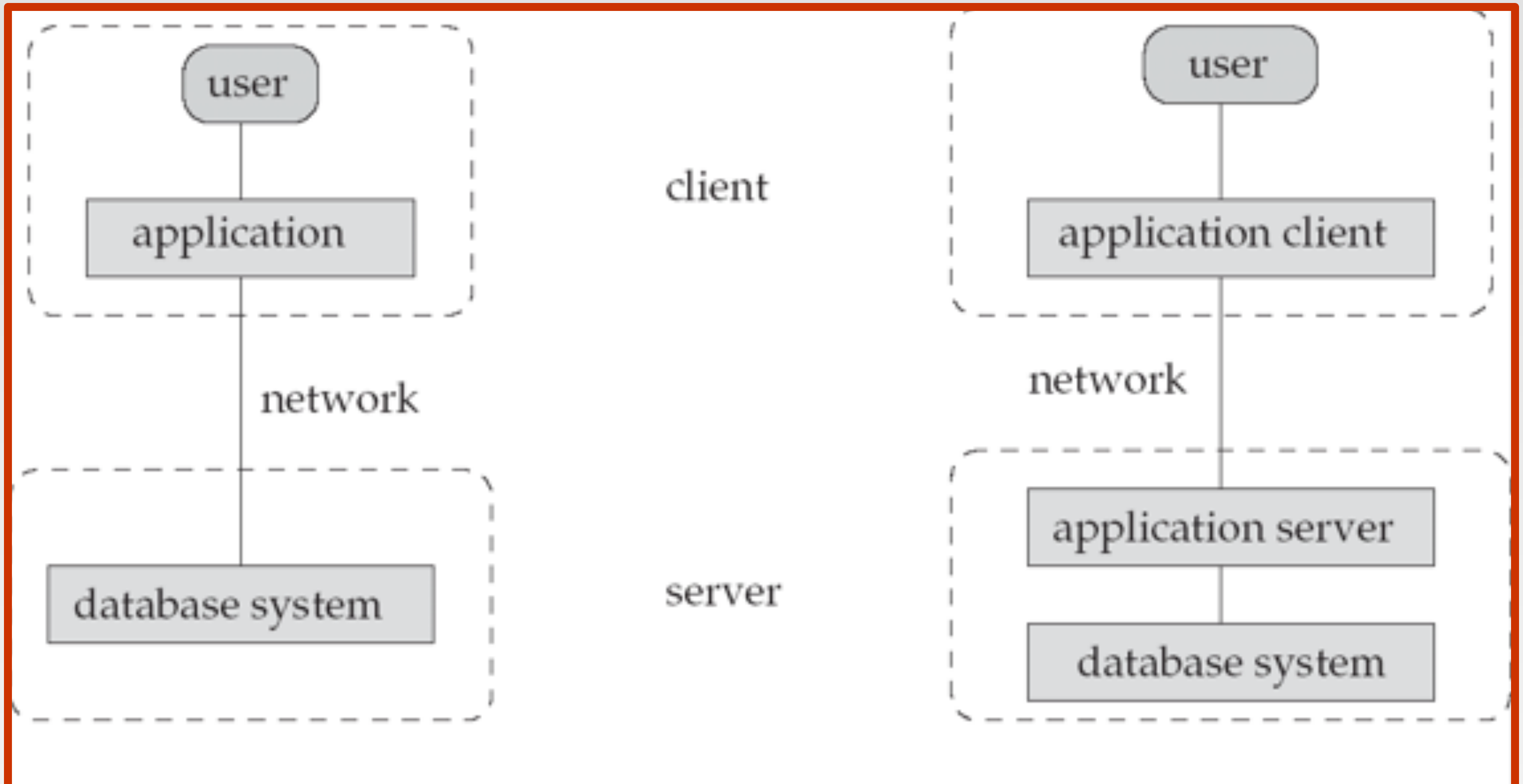
Figure 1.7



a. two-tier architecture

b. three-tier architecture