Chapter 1: Introduction

- Purpose of Database Systems
- View of Data
- Data Models
- Database Languages
- Relational Databases
- Database Design
- Data Storage and Querying
- Transaction Management
- Database Architecture
- Database Users and Administrators
- Overall Structure
- History of Database Systems
- Some Popular DB Systems
- Databases vs. Information Retrieval

Database Management System (DBMS)

- Basically, a system for managing data
- DBMS contains information about a particular enterprise (application)
  - 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
  - Telecommunications: accounts, phone cards, 1-800

University Database Example

- Application and application program example:
  - University application
  - Add new students, instructors, and courses
  - Register students for courses, and generate class rosters
  - Assign grades to students, compute grade point averages (GPA) and generate transcripts
- In the early days, database applications were built directly on top of file systems

Purpose of Database 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 and usability
    - 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 data records (e.g., a customer) are stored.
- Logical level: describes data stored in database, and the relationships among the data.

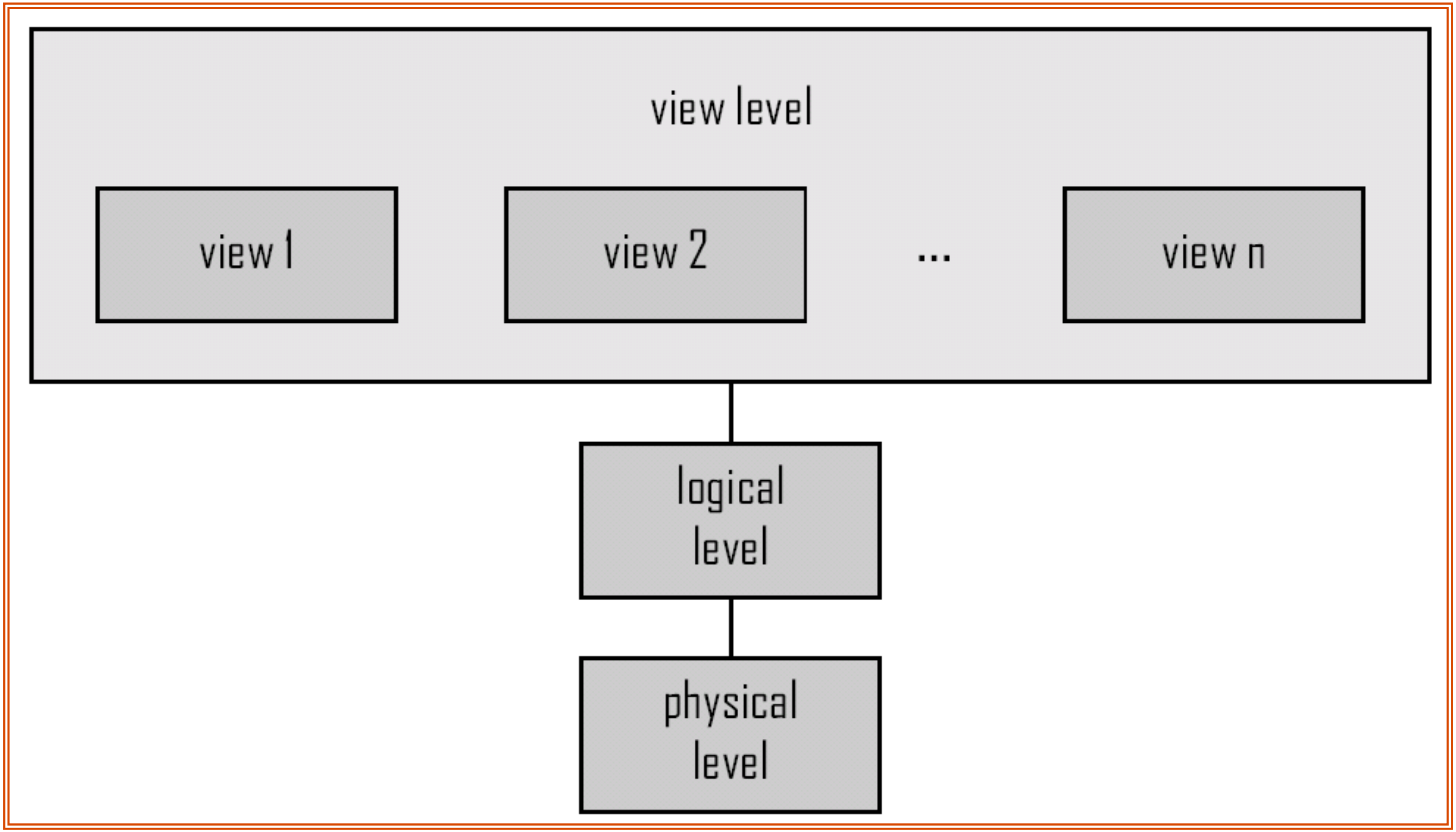
  type *customer* = **record**

  customer_id : integer;
  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 – in this case details are hidden *from* the application program

View of Data



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 current values of a set of variables
- Physical Data Independence – the ability to modify the physical schema without changing the logical schema
  - Applications depend on the logical schema (or the view level 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 (e.g., XML)
- Other older models:
  - Network model
  - Hierarchical model

Relational Model

- Relational model (Chapter 2)
- Example of tabular data in the relational model

Columns

Rows

ID	*name*	*dept_name*	*salary*
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

(a) The *instructor* table

A Sample Relational Database

ID	*name*	*dept_name*	*salary*
22222	Einstein	Physics	95000
12121	Wu	Finance	90000
32343	El Said	History	60000
45565	Katz	Comp. Sci.	75000
98345	Kim	Elec. Eng.	80000
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15151	Mozart	Music	40000
33456	Gold	Physics	87000
76543	Singh	Finance	80000

(a) The *instructor* table

dept_name	*building*	*budget*
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

Another 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

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 desired and how to compute the data
  - Declarative (nonprocedural) – user specifies what data is desired without specifying how to compute the data
- SQL is the most widely used query language
- SQL is mostly regarded as nonprocedural

Data Definition Language (DDL)

- Specification notation for defining the database schema

  Example: **create table** *account* (
  account-number 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
  - Storage structure and supported access methods
    - Specified using a *data storage and definition language*
  - Integrity constraints
    - Domain constraints
    - Referential integrity (references constraint in SQL)
    - Assertions
  - Authorization

SQL

- **SQL**: widely used non-procedural language
  - Example: Find the name of the instructor with ID 22222
    select *name*
    from *instructor*
    where *instructor.ID* = '22222'
  - Example: Find the name of each instructor and the dept. name for all departments with budget larger than $95,000

    select *instructor*.*ID*, *department*.*dept name*
    from *instructor*, *department*
    where *instructor*.*dept name*= *department*.*dept name* **and**
    department.*budget* > 95000
- 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
- Chapters 3, 4 and 5

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
- Design at the application level (views, stored procedures, interfaces)
- Logical design based on experience *and* based on sound theory

Database Design?

- **Is there any problem with this design?**

ID	*name*	*salary*	*dept_name*	*building*	*budget*
22222	Einstein	95000	Physics	Watson	70000
12121	Wu	90000	Finance	Painter	120000
32343	El Said	60000	History	Painter	50000
45565	Katz	75000	Comp. Sci.	Taylor	100000
98345	Kim	80000	Elec. Eng.	Taylor	85000
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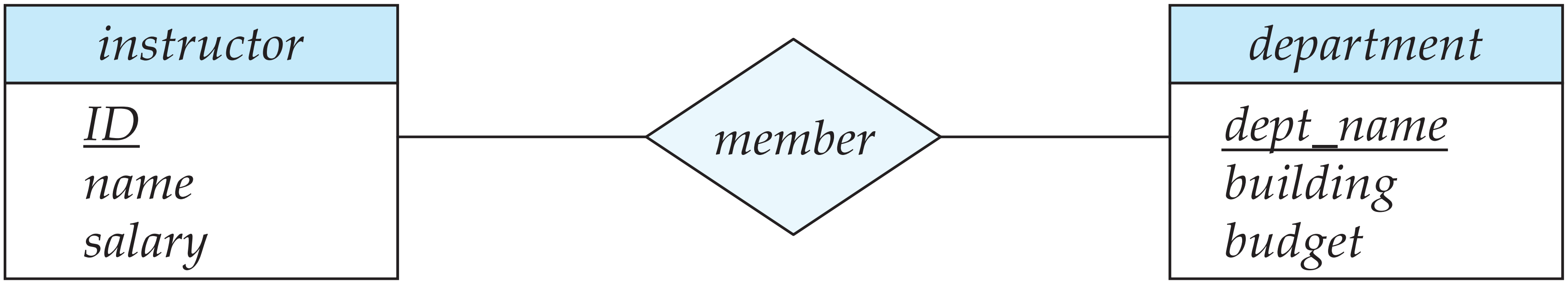
15151	Mozart	40000	Music	Packard	80000
33456	Gold	87000	Physics	Watson	70000
76543	Singh	80000	Finance	Painter	120000

Design Approaches

- Normalization Theory (Chapter 8)
  - Formalize what designs are bad, and test for them
- Entity Relationship Model (Chapter 7)
  - 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:*



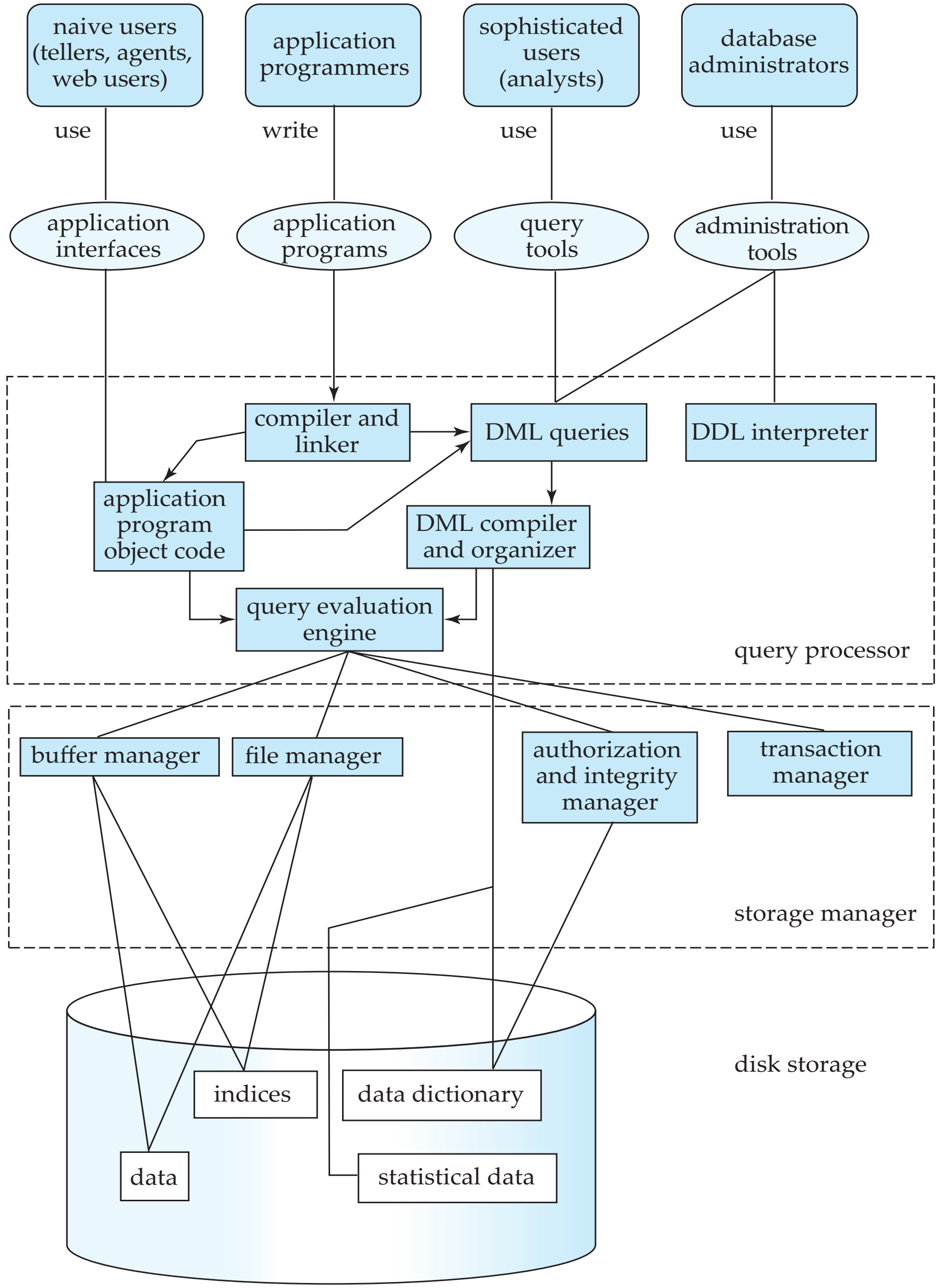
Object-Relational Data Models

- 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.

Semistructured Data Models

- Use XML (Extensible Markup Language) defined by the World Wide Web Consortium (W3C)
- Originally intended as a document markup language, not a DB 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 basis for all new generation data interchange formats.
- A wide variety of tools is available for parsing, browsing and querying XML documents/data

Database System Internals

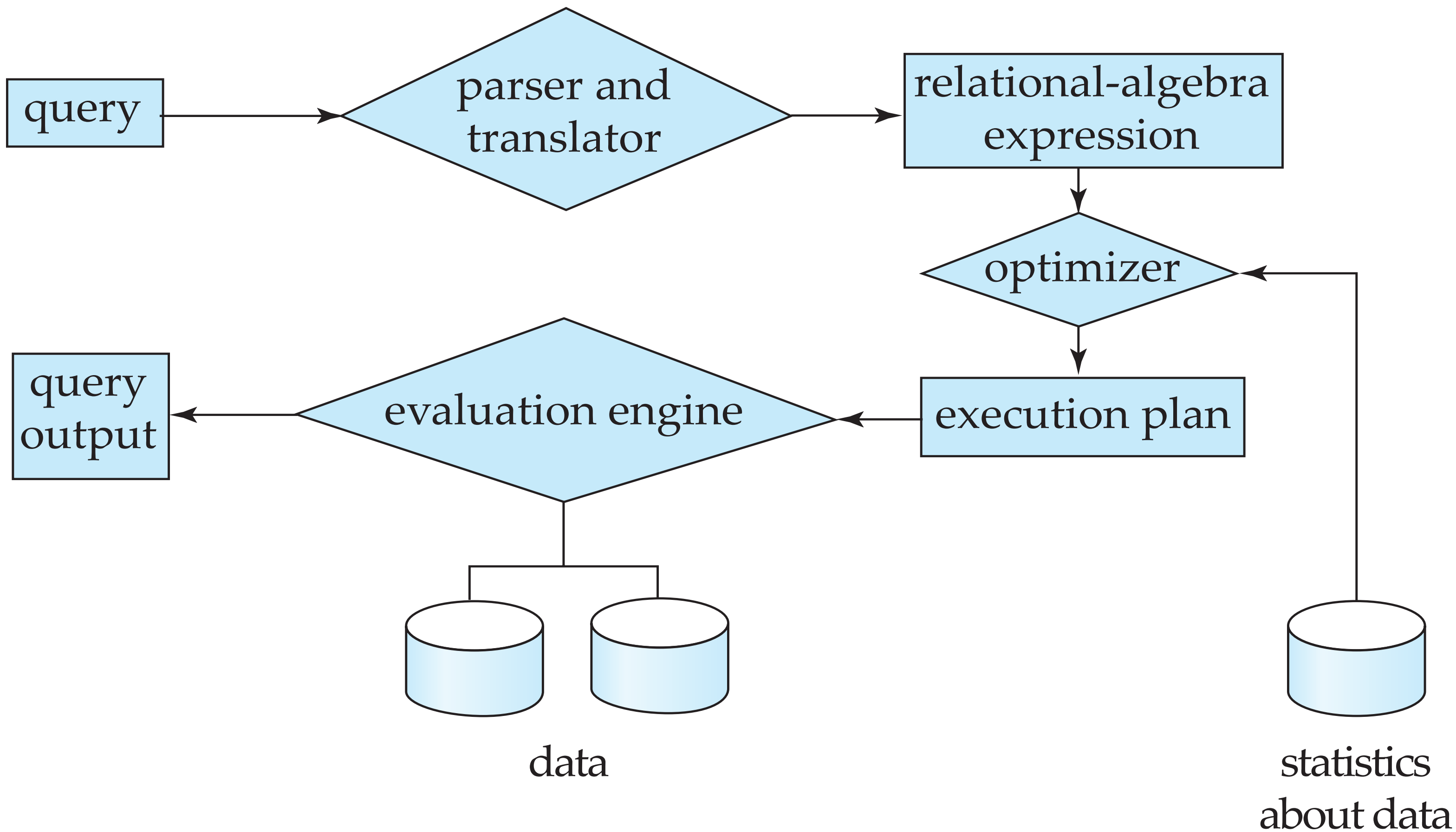


Storage Management

- **Storage manager:** program module that provides 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 for the following tasks:
  - interaction with the file manager (OS)
  - efficient storage, retrieval and updating of data
- Components:
  - authorization/integrity manager
  - transaction manager
  - file manager
  - buffer manager
- Stores
  - data (relations)
  - data dictionary (sometimes called catalog)
  - indexes

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
- Cost-based and rule-based optimization
- Cost-based: 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

- What if the system fails?
- What if more than one user is concurrently accessing the same data?

- A *transaction* is a collection of operations that performs a single logical function in a database application
  - e.g., deposit, withdrawal, transfer between accounts

- 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
  - e.g., system crash cannot wipe out "committed" transactions

- Concurrency-control manager controls the interaction among the concurrent transactions, to ensure the consistency of the database
  - e.g., two users accessing the same bank account cannot "corrupt" the system or withdraw more than allowed

Database Users

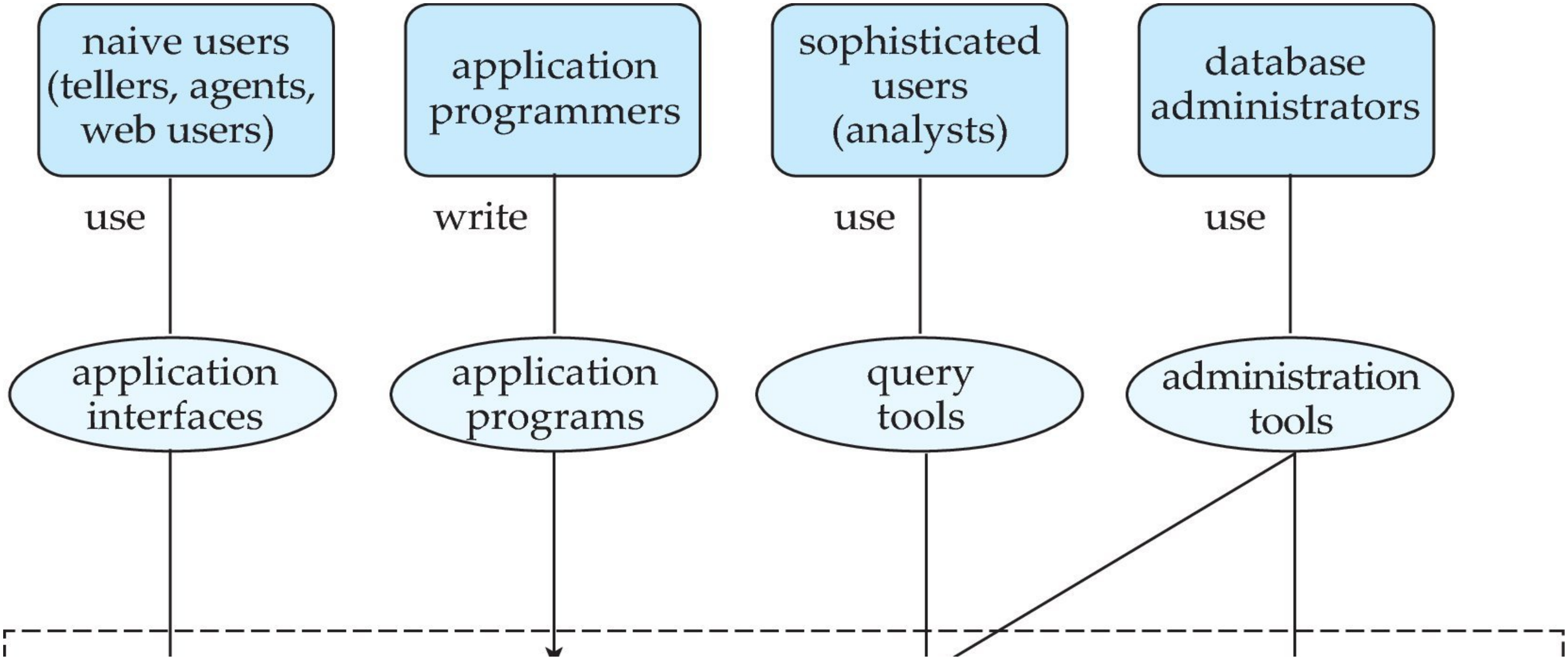
Users are differentiated by the way they expect to interact with system

- Application programmers – interact with system through DML calls
- Sophisticated users – form requests in a database query language
- 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; the database administrator has a good understanding of the enterprise's information resources and needs.
- Database administrator's duties include:
  - Schema definition
  - Storage structure and access method definition
  - Schema and physical organization modification
  - Granting user authority to access the database
  - Specifying integrity constraints
  - Creating stored procedures
  - Acting as liaison with users
  - Monitoring performance and responding to changes in requirements
- Similar to Unix system administrator, but for the database (DBMS)

Database Users and Administrators



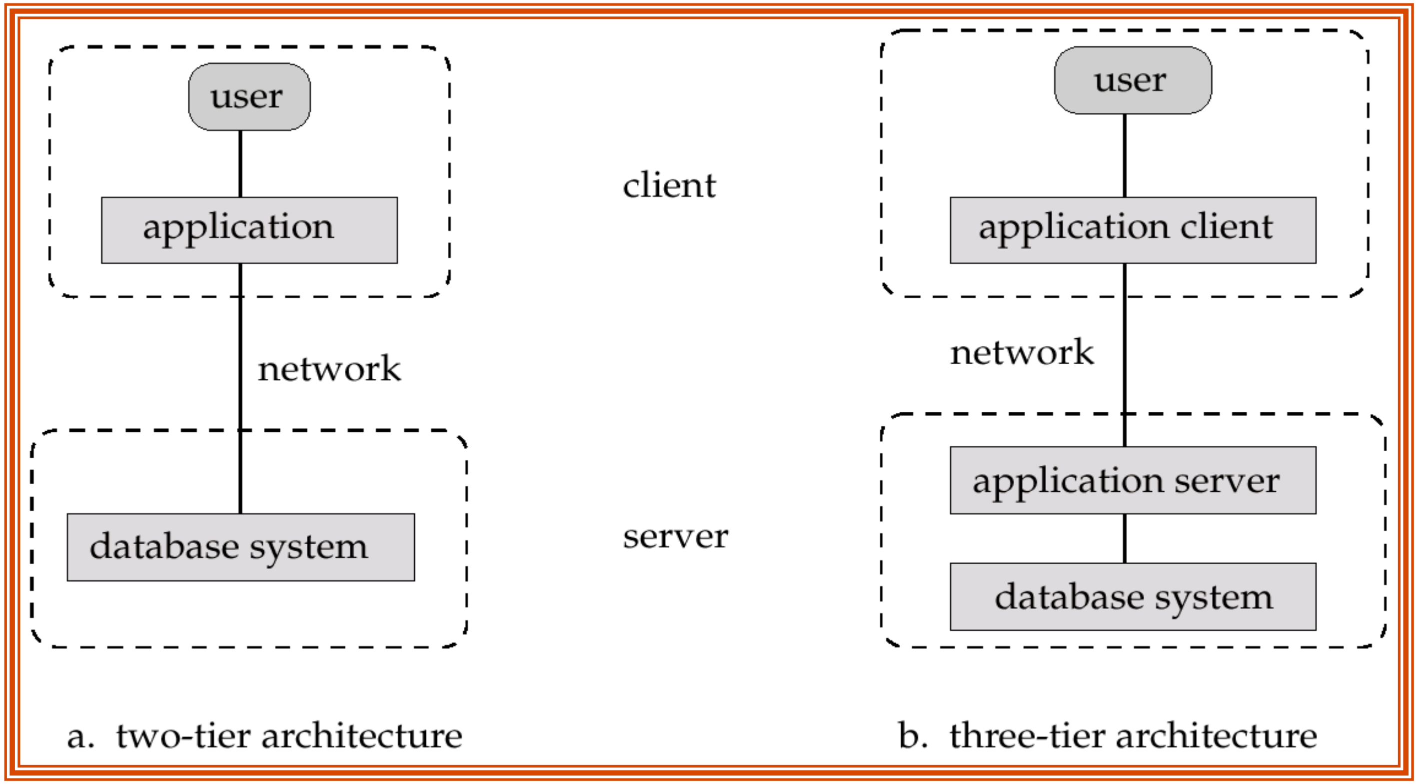
Database

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 (two-tier and three-tier)
- Parallel (multi-processor)
- Distributed

Client-Server Application Architectures



- Two-tier architecture: E.g. client programs using ODBC/JDBC to communicate with a database (or embedded SQL)
- Three-tier architecture: E.g. web-based applications, and applications built using "middleware"
- CAREFUL: different definitions of two- vs. three-tier !!!

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
  - Edward Codd defines the relational data model
    - Later wins 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 industrial 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
  - Web search
- Early 2000s:
  - XML and XQuery standards
  - Automated database administration
- Later 2000s:
  - Giant data storage systems: BigTable (Google), Hbase (Apache), PNuts (Yahoo!), Dynamo (Amazon), Cassandra (Facebook), Voldemort (LinkedIn)
  - MapReduce (Hadoop), Pig (Yahoo!), Dryad (MSFT), etc.

Some Popular Database Systems

- Big, expensive, “enterprise”
  - Oracle, IBM DB2 Universal Database, Sybase
  - Lots of features, tens of thousands of $
  - Multiple platforms, scalable to multiple machines
  - Many extension packages for text, images
  - Applications: SAP, Peoplesoft, IBM CICS
- Almost:
  - MS SQL Server
  - Many features, pretty good performance, cheaper
  - Windows platform only
- Not: MS Access
  - Easy to use, simple interface
  - Limited SQL, limited functionality
  - Not a real database

Some Popular Database Systems

- Open Source
  - MySQL:
    - Limited SQL, not good for OLAP (but getting better all the time)
    - Limited transaction support but fast lookups
    - Extremely widely used, e.g., web servers (Linux Apache MySQL PHP - LAMP)
  - PostgreSQL:
    - Rich SQL features, decent query optimizer
    - Not as widely used but popular in academia
  - SQLite:
    - SQL transactional DB, server-less, self-contained, zero-configuration
  - Berkeley DB
    - No SQL!!
    - Embedded database, a few hundred KB size
    - Basically a library of disk-based data structures with support for transactions
  - MapReduce, BigTable, PNuts, Dynamo, and others
    - No SQL
    - Used for data and text analysis (search engines etc) or to keep live data
  - Many other specialized systems for warehousing and continuous queries

OLTP, OLAP, and Data Mining

- **Online Transaction Processing**:
  - Many simple queries that update data
  - E.g., bank account transactions
  - Focus on data consistency, data protection, throughput
- **Online Analytical Processing**:
  - Complex query to explore data
  - E.g., find total sales listed by product or region
  - E.g., find customers that often fall behind in payments
  - Focus on complex queries and performance on such queries
  - Sometimes read-only
- **Data Mining**:
  - Find interesting patterns in data
  - Find rules or exceptions to rules
  - “tell me something interesting”
- Often all of these needed by different people
- Use the same system (DBMS) for all three???

Information Retrieval

"IR is concerned with the representation, storage, organization of, and access to information items"

- Focus on automatic processing (indexing, clustering, search) of unstructured data (text, images, audio, ...)
- Subfield of Computer Science, but with roots in Library Science, Information Science, and Linguistics
- Applications:
  - searching in a library catalog
  - categorizing a collection of medical (or other topics) articles by area
  - web search engines

Databases vs IR

- Databases: focus on structured data

customer-id	*customer-name*	*customer-street*	*customer-city*
192-83-7465	Johnson	12 Alma St.	Palo Alto
019-28-3746	Smith	4 North St.	Rye
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

- IR: focus on unstructured data → "documents"
  - Scientific articles, novels, web pages, emails, etc
- Data retrieval vs Information retrieval
- IR focused on human user
- DB all about building software on top