CS425 – Fall 2017
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Chapter 1: Introduction

Modified from:

Database System Concepts, 6th Ed.

Textbook: Chapter 1

Database Management System (DBMS)

- DBMS contains information about a particular domain
  - Collection of interrelated data
  - Set of programs to access the data
  - An environment that is both *convenient* and *efficient* to use
- Database Applications:
  - Banking: 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 can be very large.
- Databases touch all aspects of our lives

University Database Example

- Application program examples
  - 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

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

Drawbacks of using file systems to store data (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
    - Example: 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!

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.

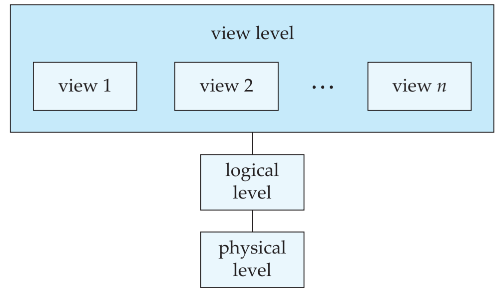
  type *instructor* = **record**

  ID : string;
  name : string;
  dept_name : string;
  salary : integer;

  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.
- **Logical Data Independence** – the ability to modify the logical schema without changing the applications
  - For example, add new information to each employee

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
- Other newer (or revived) models:
  - Key-value

Relational Model

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

Columns (attributes)

Rows (tuples)

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
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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

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 query language

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)
    - Referential integrity (**references** constraint in SQL)
      - e.g. *dept_name* value in any *instructor* tuple must appear in *department* relation
  - Authorization

SQL

- **SQL**: widely used **declarative** (non-procedural) language
  - Example: Find the name of the instructor with ID 22222

    select *name*
    from *instructor*
    where *instructor.ID* = '22222'
  - Example: Find the ID and building of instructors in the Physics dept.

    select *instructor.ID*, *department.building*
    from *instructor*, *department*
    where *instructor.dept_name* = *department.dept_name* **and**
    department.dept_name = 'Physics'
- 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 a database:

- Logical Design – Deciding on the database schema. Database design requires that we find a "good" representation of the information from an application domain (e.g., banking) as a collection of relation schemas.
  - Business decision – What information 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 Design?

- Is there any problem with this design?

ID	*name*	*salary*	*dept_name*	*building*	*budget*
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Database Design?

- **Example:** Changing the budget of the 'Physics' department
  - Updates to many rows!
  - Easy to break **integrity**
    - If we forget to update a row, then we have multiple budget values for the physics department!

ID	*name*	*salary*	*dept_name*	*building*	*budget*
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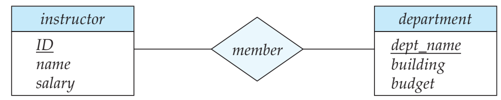
Design Approaches

- Normalization Theory (Chapter 8)
  - Formalize what designs are “good”, and test for them
  - Translate a “bad” into a “good” design
- Entity Relationship Model (Chapter 7)
  - Models an domainas a collection of *entities* and *relationships*
    - Entity: a “thing” or “object” in the domain 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*

The Entity-Relationship Model

- Models a domain as a collection of *entities* and *relationships*
  - Entity: a “thing” or “object” in the domain 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:*



What happened to dept_name of instructor and student?

Object-Relational Data Models

- Relational model: flat, “atomic” values
  - E.g., integer
- 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: XML and JSON

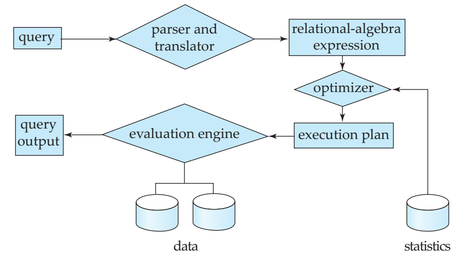
- **XML**: Defined by the WWW Consortium (W3C)
  - Originally intended as a document markup language not a database language
  - The ability to specify new tags, and to create nested tag structures made XML a great way to exchange **data**, not just documents
  - XML used to be the basis for many data interchange formats
  - A wide variety of tools is available for parsing, browsing and querying XML documents/data
- **JSON**: Javascript Object Notation
  - Semistructured data format similar to XML, but simpler
  - Well integrated with web technologies
  - Is widely used today

Storage Management

- **Storage manager** is a program module that provides the interface between the low-level data stored in the database (on disk) 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



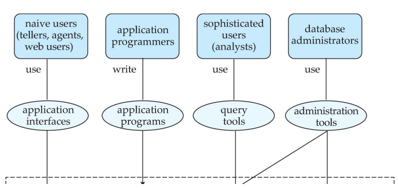
Query Processing (Cont.)

- 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
- Need to search for a good plan (low costs)
  - Traversing the search space of alternative ways (plans) to compute the query result
  - This is called **query optimization**

Transaction Management

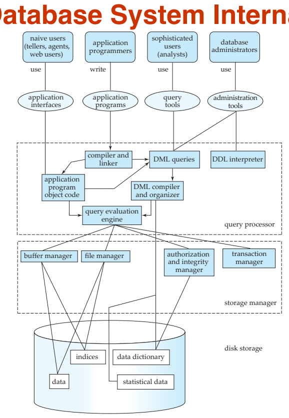
- What if the system fails?
- What if more than one user is concurrently updating the same data?
- A **transaction** is a collection of operations that performs a single logical function in a database application
- **Transaction-management component** ensures that the database remains in a consistent (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 Users and Administrators



Database

Database System Internals



Database Architecture

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

- Centralized (embedded, e.g., SQLite)
- vs. Client-server (e.g., Postgres, DB2, Oracle, …)
- Parallel (multi-processor) (most systems)
- Distributed (e.g., DB2, Hive, SparkSQL …)

Build a Complete Database System in your free time?

- How much time do you need?
- To get a rough idea:
  - Postgres (about 800,000 lines of code)
    - Hundreds of man-years of work
  - Oracle (about 8,000,000 lines of code)
    - Probably thousands of man-years of work?
- Hmm, … probably not!
- Maybe a limited research prototype or new feature ;-)

History of Database Systems

- 1950s and early 1960s:
  - Data processing using magnetic tapes for storage
    - Tapes provided only sequential access
  - 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 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
- Early 2000s:
  - XML and XQuery standards

History (cont.)

- Later 2000s:
  - Scalable data storage systems
    - Google BigTable, Yahoo PNuts, Amazon, ..
  - Scalable distributed query processing
    - Hive, Spark SQL, Impala, Apache Flink, …
  - Scalable transaction processing
    - H-store, Spanner, F1, ...
  - Scalable machine learning
    - Tensorflow
  - Software-Hardware co-design (e.g., Oracle Sparc M7)

Recap

- Why databases?
- What do databases do?
- Data independence
  - Physical and Logical
- Database design
- Data models
  - Relational, object, XML, network, hierarchical
- Query languages
  - DML
  - DDL
- Architecture and systems aspects of database systems
  - Recovery
  - Concurrency control
  - Query processing (optimization)
  - File organization and indexing
- History of databases

End of Chapter 1

Outline

- Introduction
- **Relational Data Model**
- Formal Relational Languages (relational algebra)
- SQL
- Database Design
- Transaction Processing, Recovery, and Concurrency Control
- Storage and File Structures
- Indexing and Hashing
- Query Processing and Optimization

Figure 1.02

ID	*name*	*dept_name*	*salary*
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(b) The *department* table

Figure 1.04

ID	*name*	*salary*	*dept_name*	*building*	*budget*
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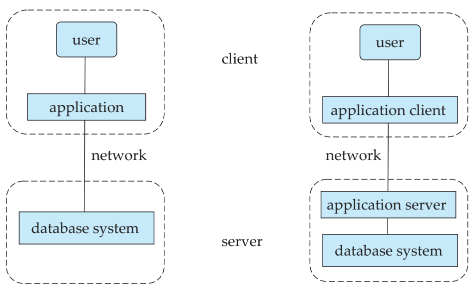
Figure 1.06



(a) Two-tier architecture (b) Three-tier architecture