CSE 202: Fundamentals of Database Systems
Winter 2020

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Broad objectives

- Learn database principles
- Learn how to design databases
- Learn languages for developing database applications
  - SQL
  - Java-interfaces
- Learn some aspects of DB system internals
  - About storage, indexing, query execution, etc

Text

- **Database System Concepts**

  Silberschatz, Korth, Sudarshan

  McGraw Hill, 6th Ed.

- **Book slides available online**
  - https://www.db-book.com/db6/slide-dir/

Some rules …

- **Attendance expected !**
  - **Straight-forward course …**
  - **Quizes will be announced, if any, for bonus marks**
- **Interactions in the class : welcome**
- **Coming late, talking in the class … : please avoid**
- **Copying : Institute policy applicable !**
- **Missing exams ? – IIITD Rules (no repeat exam)**

Evaluation Scheme:

- **Mid-term:** 20% (Open book/slides)
- **End-term:** 30% (Closed book/slides)
- **Project:** 40% (2 mid-project evaluation - 15% each, 10% project document submission)
- **Assignment:** 10% (will be given in week 9, and submission due in week 12)
- **Bonus:** 10% for innovation in Project. This will be evaluated by the cross-team member.

Project Details:

- Students would be required to develop the back-end of an online store (choose any application/domain of your liking) that requires extensive use of data entities selection and relationship between them, data modeling, database access and data manipulation.

- Each project will have 5 team members.

- The outcome will be judged by the basic concept followed through and implemented in the project, and the project document you have prepared at each stage of the project. The TA/TF/Instructor will ask the questions how and why/why-not ‘XXX’ has been considered for design/implemented?

- You are given a 10% bonus marks for demonstrating the innovation (beyond what you have chosen to design and implement) in the project. The cross-team member will decide whether the demonstrated innovative feature can be considered beyond the project deliverables or not.

Week-1

- Build your team and let the TF know the names and team name. Give a unique name to your team.
- Decide your application/domain that the whole team would like to build in the next 12 weeks.
- Identify who would be the stakeholders (minimum 4) and their roles in using your system/application.
- Document it very clearly and crisply so that any non-db background person can understand your project. (This would be your work in progress (w-in-p) document.

Week-2

- What are the key questions your system will be answering for each stakeholder, that is, for what purpose they will be using your system? Write at least 5 questions for each stakeholder.

- Think deeply.. What data entities you require for answering these questions, what would be their attributes and data types, the relationship between these data entities, ….?

- Update your w-in-p document

Week-3

- Based on the requirements identified in Week 2, create database schema and tables (your system should have minimum 10 tables - one for each data entity, and one for the relationship between them, if required).

- Define the schema for each table, and the constraints, like, Foreign key-Primary key relationship, Referential Integrity constraints, Domain Integrity constraints, range values, etc.

- Update your w-in-p document

Week-4

- Populate/Update these tables by simulated, but meaningful, data with all constrained as defined in week 3. Each table should have sizable data.

Week-5

- Mid-project evaluation 1 (based on your w-in-p document submission, and evaluation of your database application design).

Week-6

- Identify the attribute(s) to create Indexes based on your applications/queries.
- Write at least 10 queries involving various relational algebraic operations supporting the application features involving database access and manipulation.

Week-7

- Write at least 8 embedded SQL queries (PL/SQL), advanced aggregation functions, etc supporting your application features.

Week-8

- Draw the E-R model for your application and update your w-in-p document.

Week-9

- Continue your previous weeks work.
- Assignment will be given in this week to submit it in Week 12.

Week-10

- Continue your previous weeks work.
- Identify the key innovative feature and implement it in your application (for bonus marks).

Week-11

- Mid-project evaluation 2 (based on your updated (primarily E-R model) w-in-p document submission, and running (PL/)SQL queries.

Week-12

- Evaluation of innovative part of your project, if any, by the cross-team member. The evaluation team will be announced on the same day.

- Submission of assignment.

- Submission of final project document. Each team member should do the self-evaluation of your project, and give marks to **yourself** out of 100. This self-grading information should be written in the first page itself (Project Title, <Team member, Std ID, Marks expected in project>).

Any quick questions ??

Outline

- The Need for Databases
- Data Models
- Relational Databases
- Database Design
- Storage Manager
- Query Processing
- Transaction Manager

What is required for large data centric applications

- Large no of users
- Large volume of work (transactions)
- Simple to use – interactive
- Rich data
- Ensure correctness
- Availability 24 x 7
- Performance, maintainable
  - A lot expected from the system : data management

What does a typical DB application has ?

- Consider IIITD example : multiple systems
  - Data
  - Applications/programs
  - Workflows
    - **Access, update of data**
  - DB and system administration
  - ‘mission’ critical
  - Evolving requirements

Nature and volume of Data

- Structured and unstructured
  - Structured : alphanumeric, fixed contents and types :
    - **master data - student data, account data**
    - **Transactions – register, funds transfer**
  - Unstructured : text, images
    - **Brochures, emails**
    - **Dominates in organizations**
- Large sizes
- DBMS traditionally handled structured data

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: 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

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
  - 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

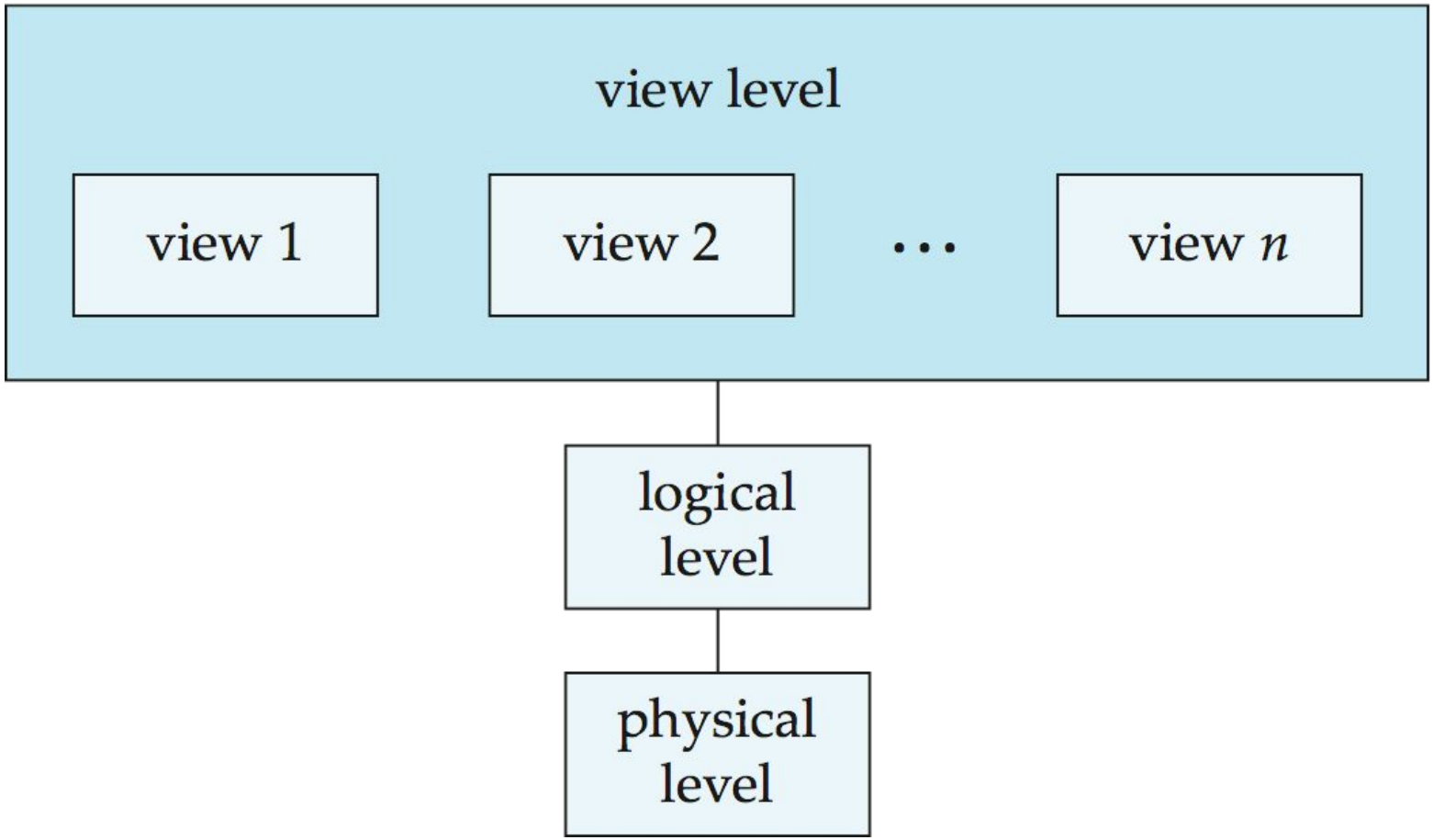
- **Physical level:** describes how a record (e.g., instructor) is stored.
- **Logical level:** describes data stored in database, and the relationships among the data.

```
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
- **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
- **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

Relational Model

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

Columns

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

Rows

(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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83821	Brandt	Comp. Sci.	92000
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 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 manipulating 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

SQL

- The most widely used commercial language
- 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

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 Design (Cont.)

- Is there any problem with this relation?

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
76766	Crick	72000	Biology	Watson	90000
10101	Srinivasan	65000	Comp. Sci.	Taylor	100000
58583	Califieri	62000	History	Painter	50000
83821	Brandt	92000	Comp. Sci	Taylor	100000
15151	Mozart	40000	Music	Packard	80000
33456	Gold	87000	Physics	Watson	70000
76543	Singh	80000	Finance	Painter	120000

Design Approaches

- Need to come up with a methodology to ensure that each of the relations in the database is "good"
- Two ways of doing so:
  - Entity Relationship Model (Chapter 7)
    - Models an enterprise as a collection of *entities* and *relationships*
    - Represented diagrammatically by an *entity-relationship diagram:*
  - Normalization Theory (Chapter 8)
    - Formalize what designs are bad, and test for them

Object-Relational Data Models

- Relational model: flat, “atomic” values
- 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

Database Engine

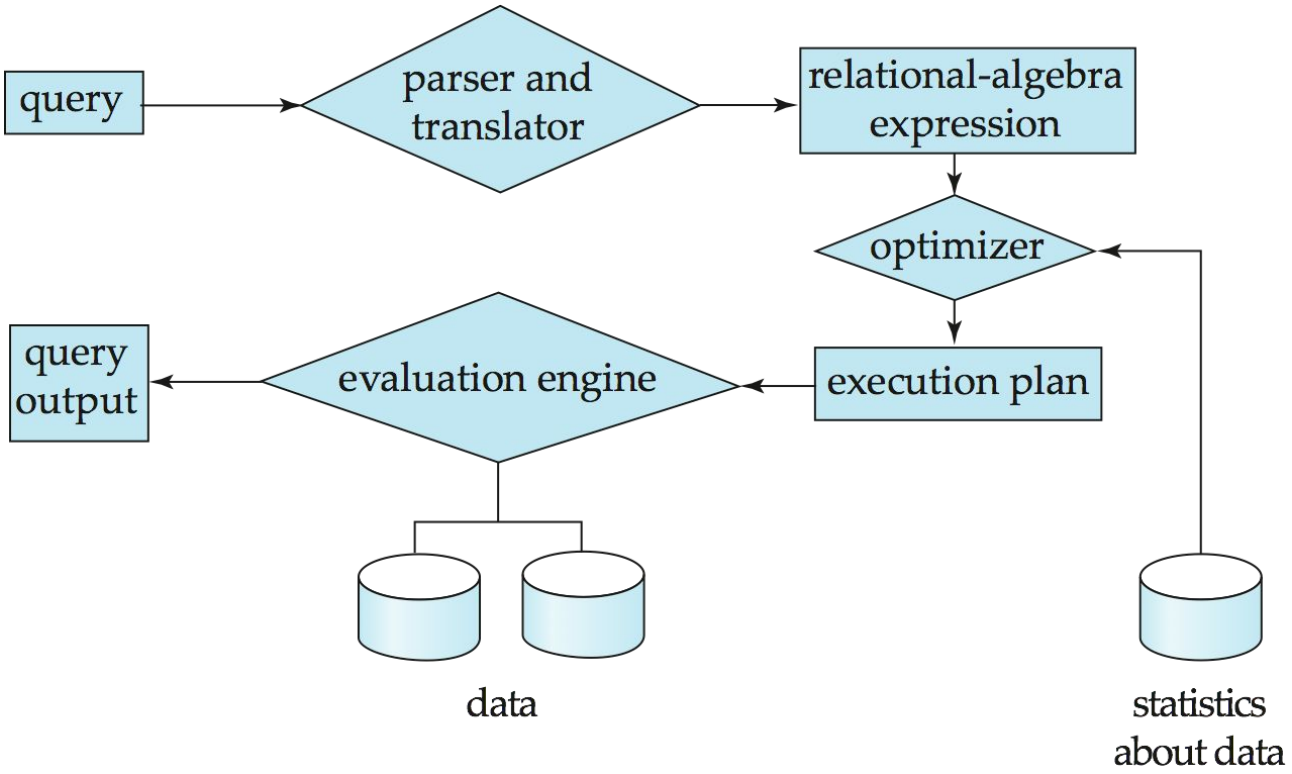
- Storage manager
- Query processing
- Transaction manager

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 OS 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



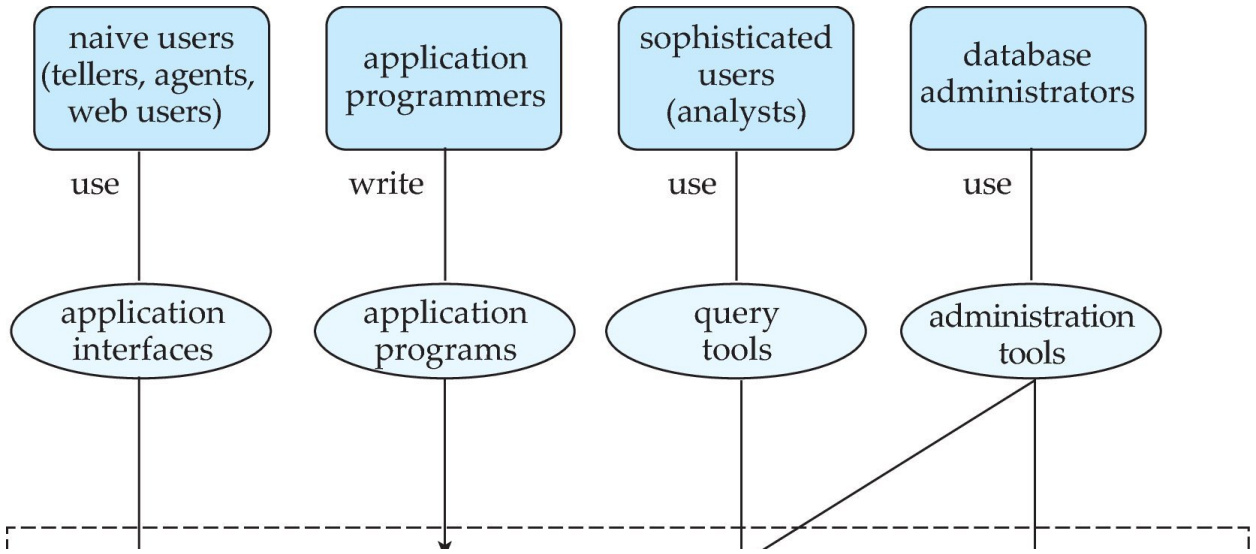
Query Processing (Cont.)

- 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

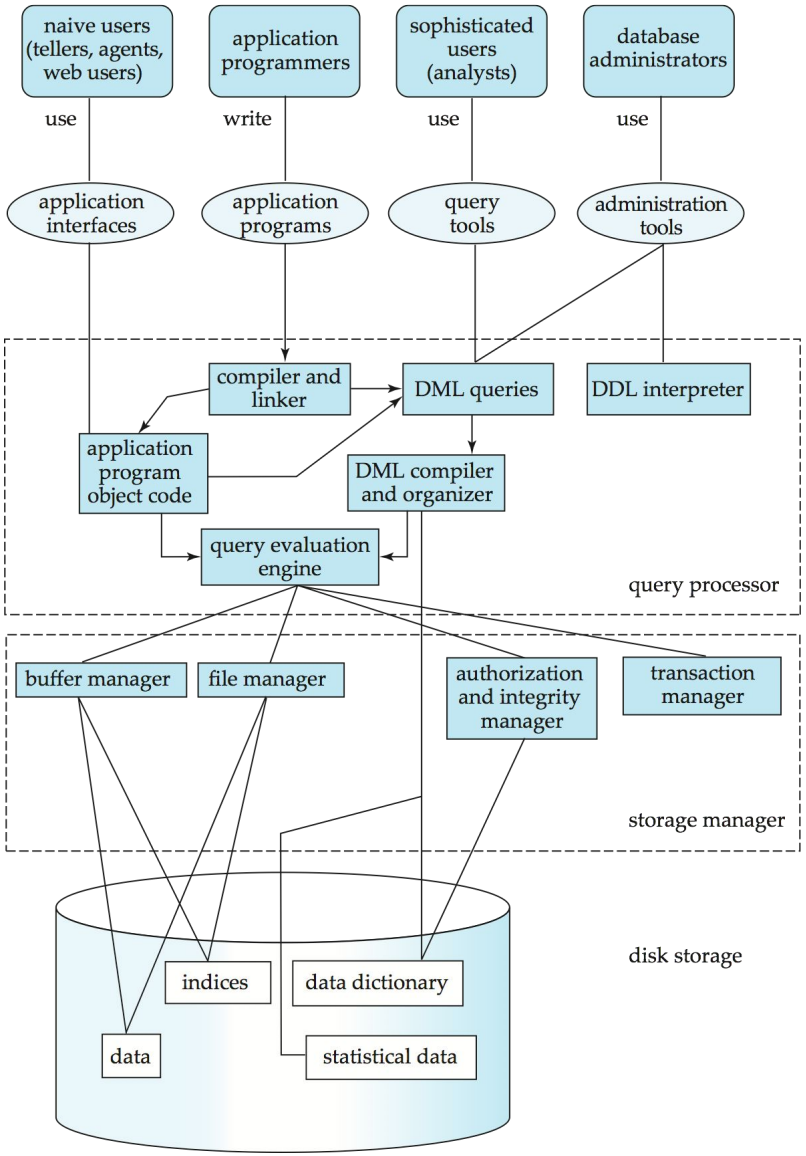
Transaction Management

- 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 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
- Client-server
- Parallel (multi-processor)
- Distributed

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
  - Automated database administration
- Later 2000s:
  - Giant data storage systems
    - Google BigTable, Yahoo PNuts, Amazon, ..

End of Chapter 1