Database System Concepts and Architecture

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Outline

- Traditional File Processing and Drawbacks
- Basic Concepts of Database System
- Database System Architecture

Traditional File Processing
(University Example)

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
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GRADE_REPORT

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

Course_number	Prerequisite_number
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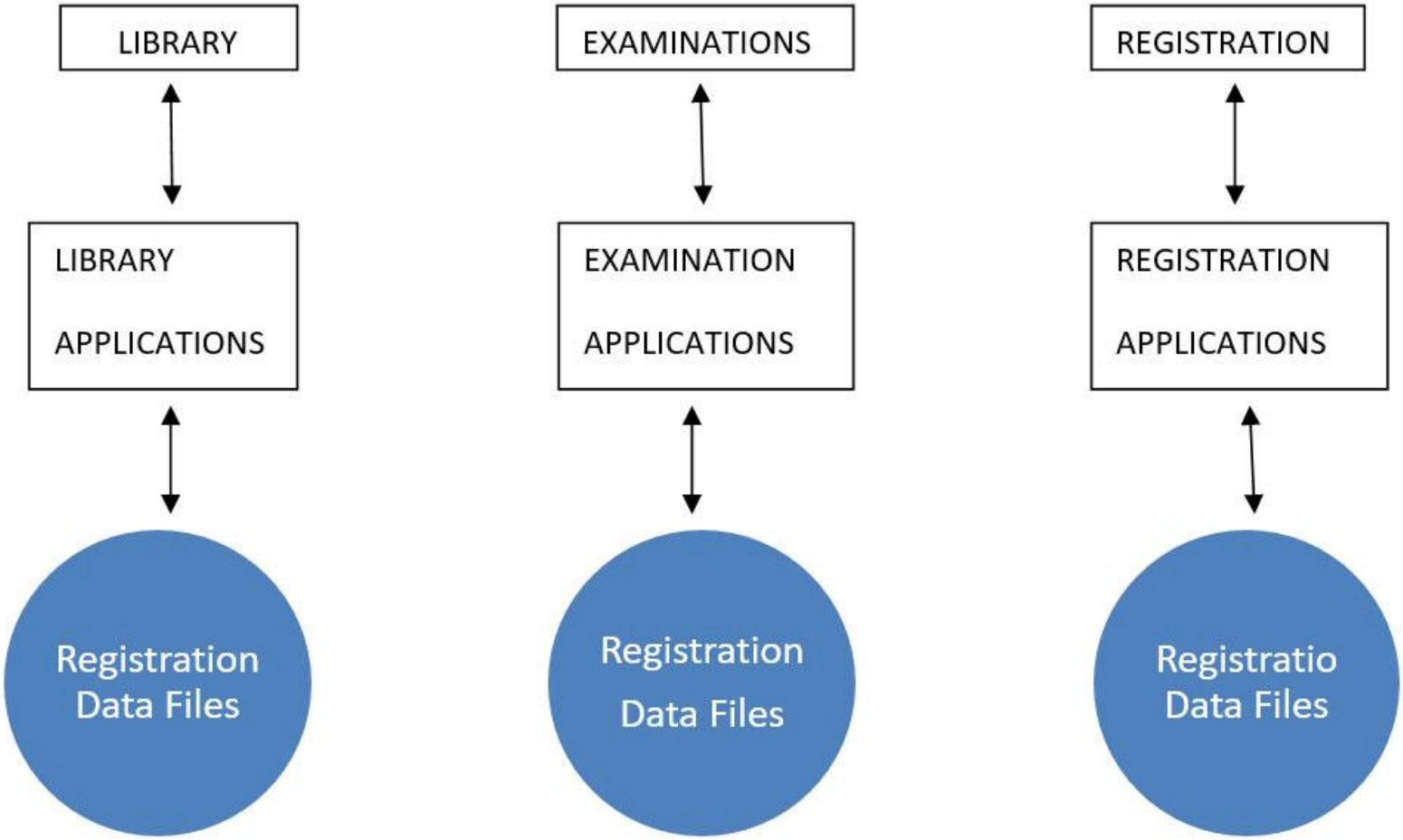
CS3380	MATH2410
CS3320	CS1310

Traditional File Processing



Data Manipulation

Queries:

- Retrieve transcript - a list of all courses and grades - of `Smith'
- List the names of students who took the section of the `Database' course offered in fall 2008 and their grades in that section
- List the prerequisites of the `Database' course

Updates:

- Change the class of `Smith' to sophomore
- Create a new section for the `Database' course for this semester
- Enter a grade of `A' for `Smith' in the `Database' section of last semester

Drawbacks of Traditional File System

- Data Redundancy and Inconsistency
- Difficulty in Accessing Data
- Data Isolation
- Integrity Problems
- Atomicity Problems
- Concurrent-Access Anomalies
- Security Problems

Data Redundancy and Inconsistency

- **Different programmers**
  - create files
  - application programs.
  - different file structures.
  - several programming languages.
- **Information duplicated in several places**, called **redundancy**. It leads to higher storage and access cost.
- **In addition, it may lead to data inconsistency**.

Difficulty in Accessing Data

- University clerks needs to find out the names of all students who live within a particular postal-code area.
- The clerk asks the data-processing department to generate such a list.
- The university clerk has now two choices:
  - obtain the list of all students and extract the needed information manually
  - ask a programmer to write the necessary application program
- Both alternatives are obviously unsatisfactory.
- The point here is that conventional file-processing environments do not allow needed data to be retrieved in a convenient and efficient manner.

Data Isolation

- Data are scattered in various files
- Files may be in different formats
- So, writing new application programs to retrieve the appropriate data is difficult

Integrity Problems

- The data values stored in the database must satisfy certain types of **consistency constraints**.
- Suppose the university maintains an account for each department, and records the balance amount in each account.
- Suppose also that the university requires that
  - the account balance of a department may never fall below zero.
- Developers enforce these constraints in the system by adding appropriate code in the various application programs.
- However, when new constraints are added, it is difficult to change the programs to enforce them.
- The problem is compounded when constraints involve several data items from different files.

Atomicity Problems

- A computer system, like any other device, is subject to failure.
- In many applications, it is crucial that, if a failure occurs, the data be restored to the consistent state that existed prior to the failure.
- **Transfer $500** from the department *A* to department *B's* account.
- If a system failure occurs during the execution of the program
  - It may possible that $500 debited from department *A'* account, but not credited to department *B'* account.
  - It resulting in an **inconsistent database state**.
- Clearly, it is essential to database consistency that either both the credit and debit occur, or that neither occur.
- That is, the funds transfer must be ***atomic*** - it must happen in its entirety or not at all.
- **It is difficult to ensure atomicity in a conventional file-processing system.**

Concurrent-Access Anomalies

- For the sake of overall performance of the system and faster response, many systems allow multiple users to update the data simultaneously.
- Consider department *A*, with an account balance of $10,000.
- If two department clerks debit the department *A*'s account by, say $500 and $100, respectively, at almost exactly the same time.
- If the two programs run concurrently, they may both read the value $10,000, and write back $9500 and $9900, respectively.
- Depending on which one writes the value last, the account balance of department *A* may contain either $9500 or $9900, rather than the correct value of $9400.
- But, supervision is difficult to provide because data may be accessed by many different application programs that have not been coordinated previously.

Security Problems

- Not every user of the database system should be able to access all the data.
- For example, in a university, payroll personnel need to see only that part of the database that has financial information.
- They do not need access to information about academic records.
- But, since application programs are added to the file-processing system in an ad hoc manner, enforcing such security constraints is difficult.

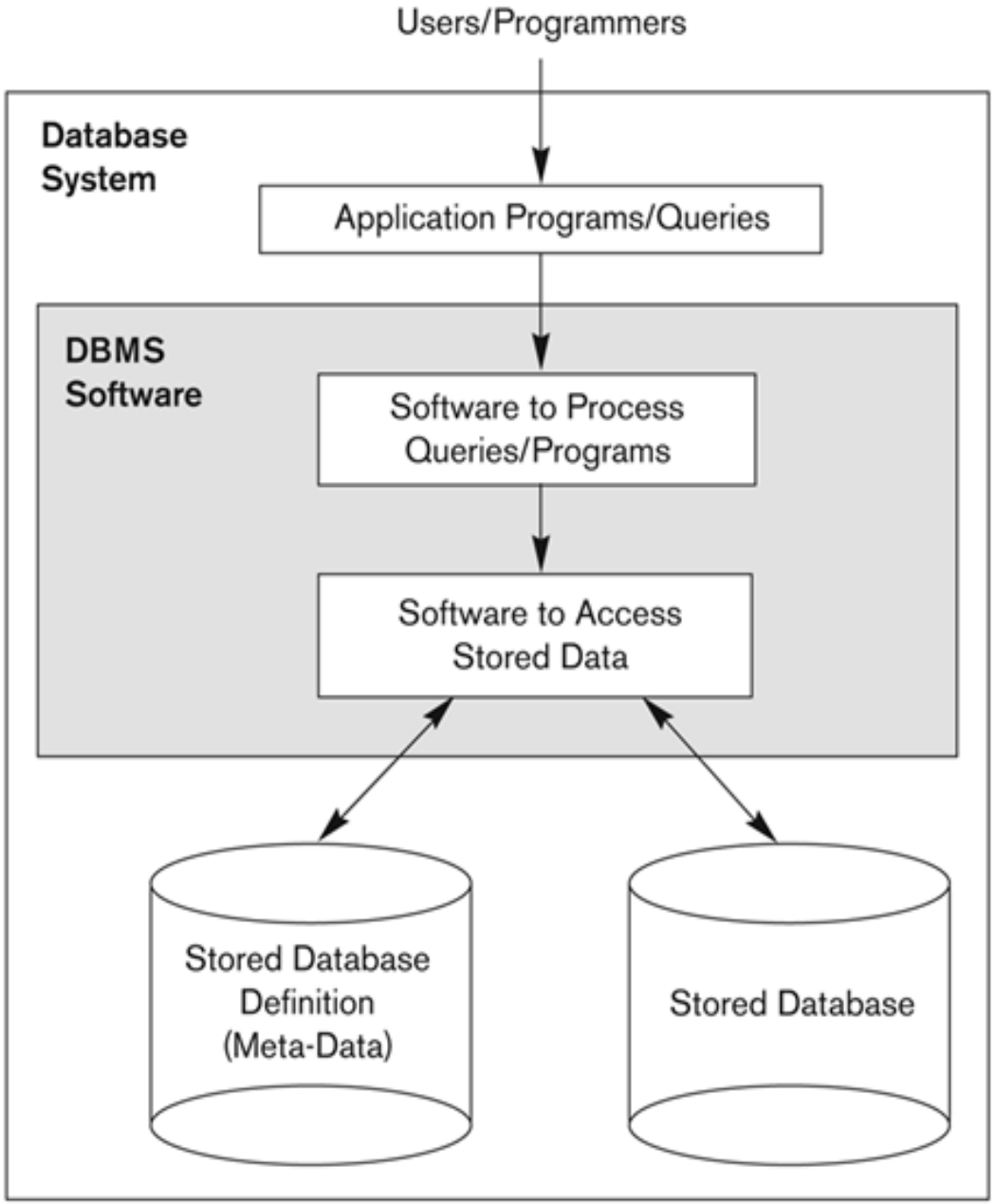
Types of Databases and Applications

- **Traditional Applications:**
  - Numeric and Textual Databases
- **More Recent Applications:**
  - Multimedia Databases
  - Geographic Information Systems (GIS)
  - Data Warehouses
  - Real-time and Active Databases
  - Many other applications

Basic Definitions

- **Database:**
  - A collection of related data.
- **Data:**
  - Known facts that can be recorded and have an implicit meaning.
- **Mini-world:**
  - Some part of real-world about which data is stored in a database.
  - For example, student grades and transcripts at a university.
- **Database Management System (DBMS):**
  - A software package/system to facilitate the creation and maintenance of a computerized database.
- **Database System:**
  - The DBMS software together with the data itself.
  - Sometimes, the applications are also included.

Simplified database system environment



The database definition or descriptive information is stored by the DBMS in the form of a database catalog or dictionary;

it is called **meta-data**

Typical DBMS Functionality

- ***Define*** a particular database in terms of its data types, structures, and constraints
- ***Construct*** or **Load** the initial database contents on a secondary storage medium
- ***Manipulating*** the database:
  - **Retrieval:** Querying, generating reports
  - **Modification:** Insertions, deletions and updates to its content
  - **Accessing** the database through Web applications
- ***Processing*** and ***Sharing*** by a set of concurrent users and application programs -- yet, keeping all data valid and consistent

Typical DBMS Functionality

- **Other features:**
  - Protection or Security measures to prevent unauthorized access
  - "Active" processing to take internal actions on data
  - Presentation and Visualization of data
  - Maintaining the database and associated programs over the lifetime of the database application
    - Called database, software, and system maintenance

Example of a Database (with a Conceptual Data Model)

- **Mini-world for the example:**
  - Part of a UNIVERSITY environment.
- **Some mini-world *entities*:**
  - STUDENTs
  - COURSEs
  - SECTIONs (of COURSEs)
  - (academic) DEPARTMENTs
  - INSTRUCTORs

Example of a Database (with a Conceptual Data Model)

- **Some mini-world *relationships*:**
  - SECTIONs *are of specific* COURSEs
  - STUDENTs *take* SECTIONs
  - COURSEs *have prerequisite* COURSEs
  - INSTRUCTORs *teach* SECTIONs
  - COURSEs *are offered by* DEPARTMENTs
  - STUDENTs *major in* DEPARTMENTs

- Note: The above entities and relationships are typically expressed in a conceptual data model, such as the ENTITY-RELATIONSHIP data model.

Example of a simple database

COURSE

Course_name	Course_number	Credit_hours	Department
Intro to Computer Science	CS1310	4	CS
Data Structures	CS3320	4	CS
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PREREQUISITE

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CS3380	CS3320
CS3380	MATH2410
CS3320	CS1310

Main Characteristics of the Database Approach

- **Self-describing nature of a database system:**
  - A DBMS **catalog** stores the description of a particular database (e.g. data structures, types, and constraints)
  - The description is called **meta-data**.
  - This allows the DBMS software to work with different database applications.
- **Insulation between programs and data:**
  - Called **program-data independence**.
  - Allows changing data structures and storage organization without having to change the DBMS access programs.

Example of a simplified database catalog

RELATIONS

Relation_name	No_of_columns
STUDENT	4
COURSE	4
SECTION	5
GRADE_REPORT	3
PREREQUISITE	2

COLUMNS

Column_name	Data_type	Belongs_to_relation
Name	Character (30)	STUDENT
Student_number	Character (4)	STUDENT
Class	Integer (1)	STUDENT
Major	Major_type	STUDENT
Course_name	Character (10)	COURSE
Course_number	XXXXNNNN	COURSE
....	....	.....
....	....	.....
....	....	.....
Prerequisite_number	XXXXNNNN	PREREQUISITE

Main Characteristics of the Database Approach (continued)

- **Data Abstraction:**
  - A **data model** is used to hide storage details and present the users with a conceptual view of the database.
  - Programs refer to the data model constructs rather than data storage details
- **Support of multiple views of the data:**
  - Each user may see a different view of the database, which describes **only** the data of interest to that user.

Main Characteristics of the Database Approach (continued)

- **Sharing of data and multi-user transaction processing:**
  - Allowing a set of **concurrent users** to retrieve from and to update the database.
  - *Concurrency control* within the DBMS guarantees that each **transaction** is correctly executed or aborted
  - *Recovery* subsystem ensures each completed transaction has its effect permanently recorded in the database
  - **OLTP** (Online Transaction Processing) is a major part of database applications. This allows hundreds of concurrent transactions to execute per second.

Database Users

- **Users may be divided into**
  - actually **use and control** the database content
  - Other- **design, develop and maintain** database applications (called "Actors on the Scene")
  - who design and develop the DBMS software and related tools, and the computer systems operators (called "Workers Behind the Scene").

Database Users

- **Actors on the scene**
  - **Database administrators:**
    - Responsible for authorizing access to the database, for coordinating and monitoring its use, acquiring software and hardware resources, controlling its use and monitoring efficiency of operations.
  - **Database Designers:**
    - Responsible to define the content, the structure, the constraints, and functions or transactions against the database.
    - They must communicate with the end-users and understand their needs.

Categories of End-users

- **Actors on the scene (continued)**
  - **End-users:** They use the data for queries, reports and some of them update the database content. End-users can be categorized into:
    - **Casual**: access database occasionally when needed
    - **Naïve** or **Parametric**: they make up a large section of the end-user population.
      - They use previously well-defined functions in the form of "canned transactions" against the database.
      - Examples are bank-tellers or reservation clerks who do this activity for an entire shift of operations.

Categories of End-users (continued)

- **Sophisticated:**
  - These include business analysts, scientists, engineers, others thoroughly familiar with the system capabilities.
  - Many use tools in the form of software packages that work closely with the stored database.
- **Stand-alone:**
  - Mostly maintain personal databases using ready-to-use packaged applications.
  - An example is a tax program user that creates its own internal database.
  - Another example is a user that maintains an address book

Advantages of Using the Database Approach

- Controlling redundancy in data storage and in development and maintenance efforts.
  - Sharing of data among multiple users.
- Restricting unauthorized access to data.
- Providing persistent storage for program Objects
  - In Object-oriented DBMSs
- Providing Storage Structures (e.g. indexes) for efficient Query Processing

Advantages of Using the Database Approach (continued)

- Providing backup and recovery services.
- Providing multiple interfaces to different classes of users.
- Representing complex relationships among data.
- Enforcing integrity constraints on the database.
- Drawing inferences and actions from the stored data using deductive and active rules

Additional Implications of Using the Database Approach

- Potential for enforcing standards:
  - This is very crucial for the success of database applications in large organizations.
  - **Standards** refer to
    - data item names
    - display formats
    - report structures
    - meta-data (description of data)
    - Web page layouts, etc.
- Reduced application development time:
  - Incremental time to add each new application is reduced.

Additional Implications of Using the Database Approach (continued)

- Flexibility to change data structures:
  - Database structure may evolve as new requirements are defined.
- Availability of current information:
  - Extremely important for on-line transaction systems such as airline, hotel, car reservations.
- Economies of scale:
  - Wasteful overlap of resources and personnel can be avoided by consolidating data and applications across departments.

Historical Development of Database Technology

- Early Database Applications:
  - The Hierarchical and Network Models were introduced in mid 1960s and dominated during the seventies.
  - A bulk of the worldwide database processing still occurs using these models, particularly, the hierarchical model.
- Relational Model based Systems:
  - Relational model was originally introduced in 1970, was heavily researched and experimented within IBM Research and several universities.
  - Relational DBMS Products emerged in the early 1980s.

Historical Development of Database Technology (continued)

- Object-oriented and emerging applications:
  - Object-Oriented Database Management Systems (OODBMSs) were introduced in late 1980s and early 1990s to cater to the need of complex data processing in CAD and other applications.
    - Their use has not taken off much.
  - Many relational DBMSs have incorporated object database concepts, leading to a new category called *object-relationa*l DBMSs (ORDBMSs)
  - *Extended relational* systems add further capabilities (e.g. for multimedia data, XML, and other data types)

Extending Database Capabilities

- New functionality is being added to DBMSs in the following areas:
  - Scientific Applications
  - XML (eXtensible Markup Language)
  - Image Storage and Management
  - Audio and Video Data Management
  - Data Warehousing and Data Mining
  - Spatial Data Management
  - Time Series and Historical Data Management

- The above gives rise to *new research and development* in incorporating new data types, complex data structures, new operations and storage and indexing schemes in database systems.

When not to use a DBMS

- **Main inhibitors (costs) of using a DBMS:**
  - High initial investment and possible need for additional hardware.
  - Overhead for providing generality, security, concurrency control, recovery, and integrity functions.
- **When a DBMS may be unnecessary:**
  - If the database and applications are simple, well defined, and not expected to change.
  - If access to data by multiple users is not required.
- **When no DBMS may suffice:**
  - If the database system is not able to handle the complexity of data because of modeling limitations.
  - If database users need special operations not supported by DBMS.

Summary

- Traditional File Processing Their Drawbacks
- Types of Databases and Database Applications
- Basic Definitions
- Typical DBMS Functionality
- Example of a Database (UNIVERSITY)
- Main Characteristics of the Database Approach
- Database Users
- Advantages of Using the Database Approach
- When Not to Use Databases

BREAK

Outline

- Data Models and Their Categories
- History of Data Models
- Schemas, Instances, and States
- Three-Schema Architecture
- Data Independence
- DBMS Languages and Interfaces
- Database System Utilities and Tools

Data Models

- **Data Model:**
  - A set of concepts to describe
    - ***structure*** of a database
    - ***operations*** for manipulating these structures
    - ***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)
    - ***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.

Schemas versus Instances

- **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.

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

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*

Database Schema vs. Database State

- **Database State:**
  - Refers to the ***content*** of a database at a moment in time.
- **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.

Database Schema vs. Database State (continued)

- Distinction
  - The ***database schema*** changes very infrequently.
  - The ***database state*** changes every time the database is updated.

- **Schema** is also called **intension**.
- **State** is also called **extension**.

Example of a database state

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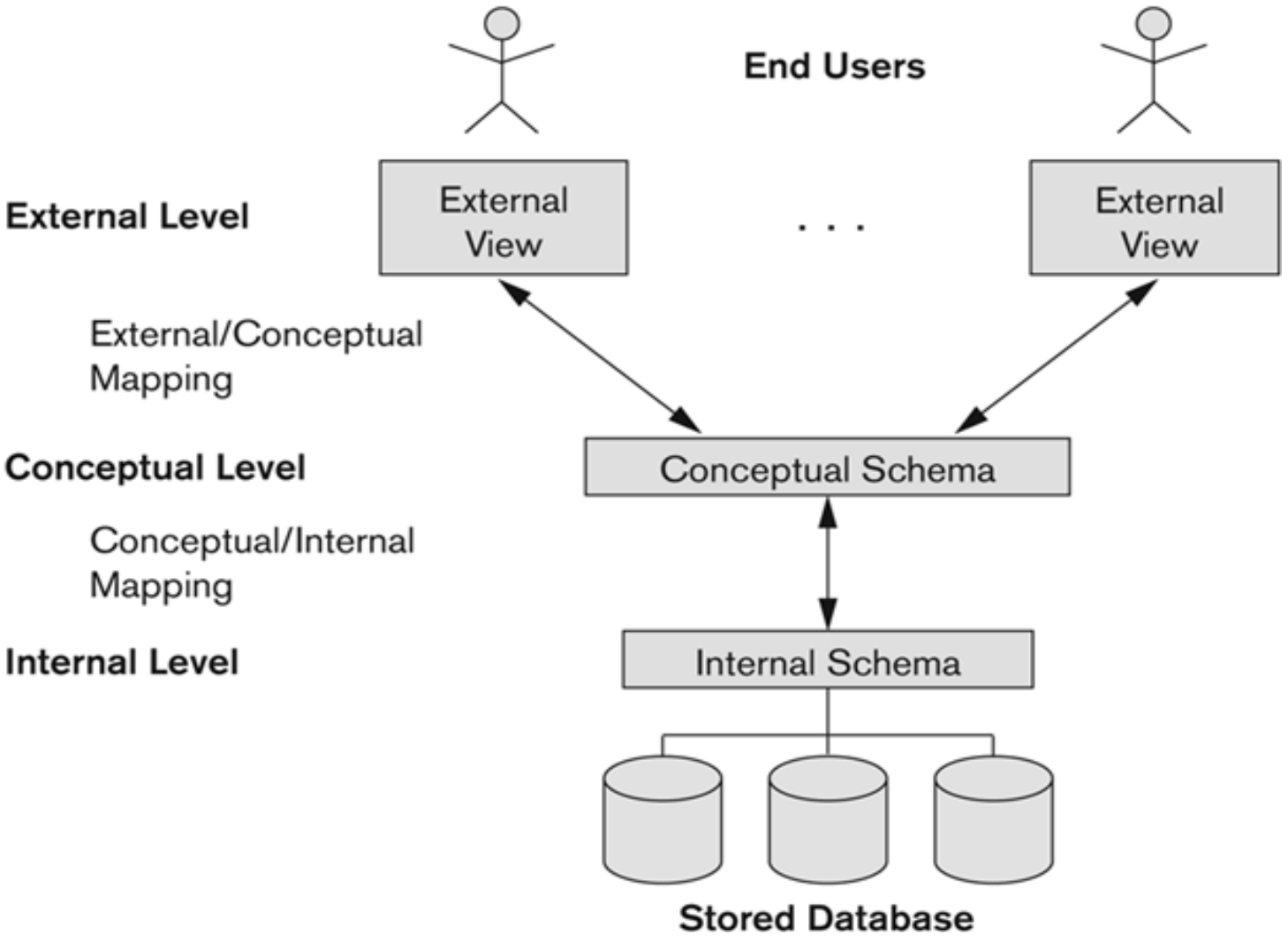
Three-Schema Architecture

- Proposed to support DBMS characteristics of:
  - **Program-data independence.**
  - Support of **multiple views** of the data.
- Not explicitly used in commercial DBMS products, but has been useful in explaining database system organization

Three-Schema Architecture

- 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



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

  For example:

  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

Data Independence (continued)

- 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 themselves are **unchanged**.
  - Hence, the application programs need not be changed since they refer to the external schemas.

DBMS Languages

- Data Definition Language (DDL)
- Data Manipulation Language (DML)
  - High-Level or Non-procedural Languages: These include the relational language SQL
  - Low Level or Procedural Languages:
    - These must be embedded in a programming language

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:**
  - For example, the SQL relational language
  - Are "set"-oriented and specify what data to retrieve rather than how to retrieve it.
  - Also called **declarative** languages.
- **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.

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, forms-based, graphics-based, etc.

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 for other programming languages
  - **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

DBMS Interfaces

- Speech as Input and Output
- Web Browser as an interface
- 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

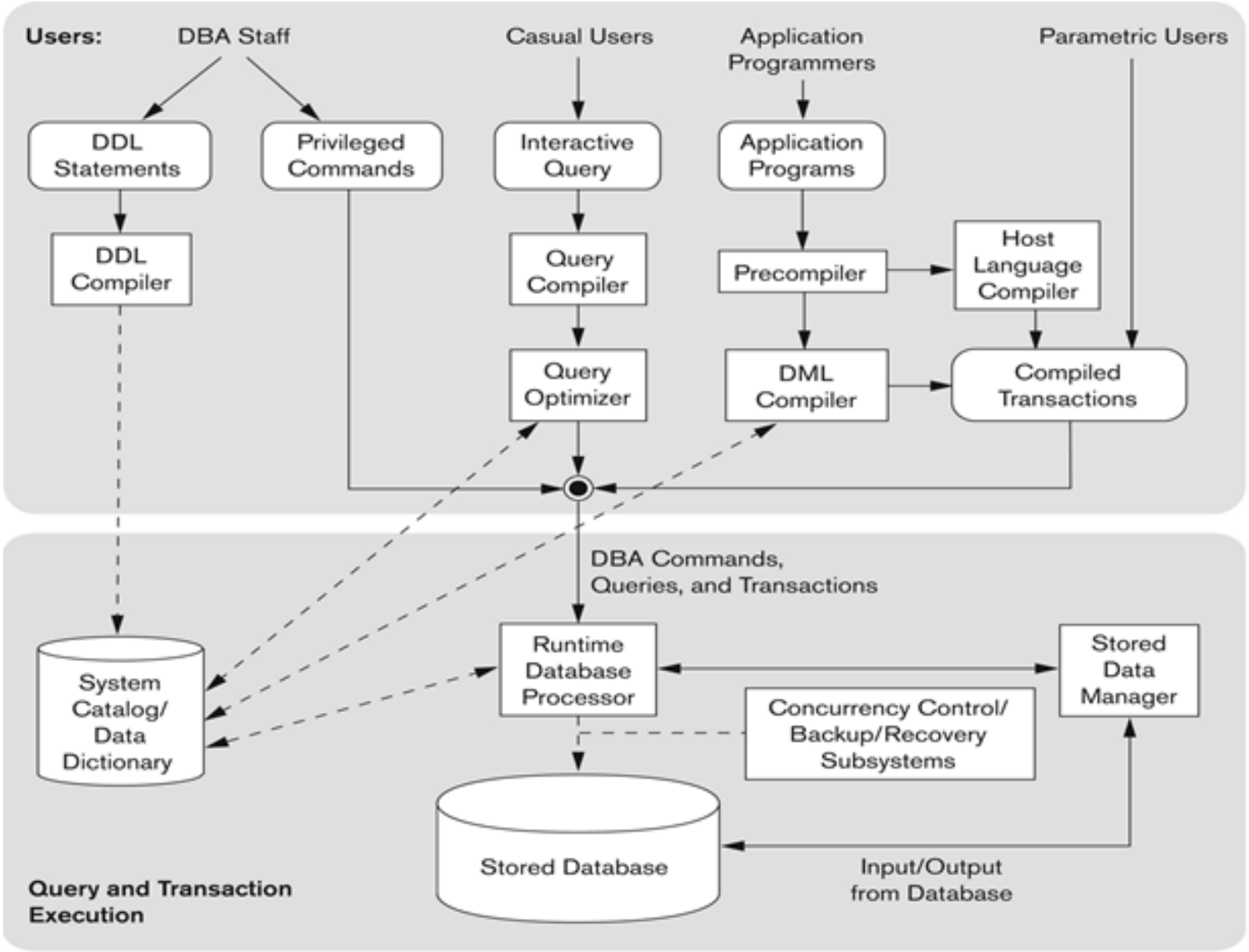
Database System Utilities

- 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.
  - Report generation utilities.
  - Performance monitoring utilities.
  - Other functions, such as sorting, user monitoring, data compression, etc.

Other Tools

- Data dictionary / repository:
  - Used to store schema descriptions and other information such as design decisions, application program descriptions, user information, usage standards, etc.
  - **Active data dictionary** is accessed by DBMS software and users/DBA.
  - **Passive data dictionary** is accessed by users/DBA only.

Typical DBMS Component Modules



BREAK

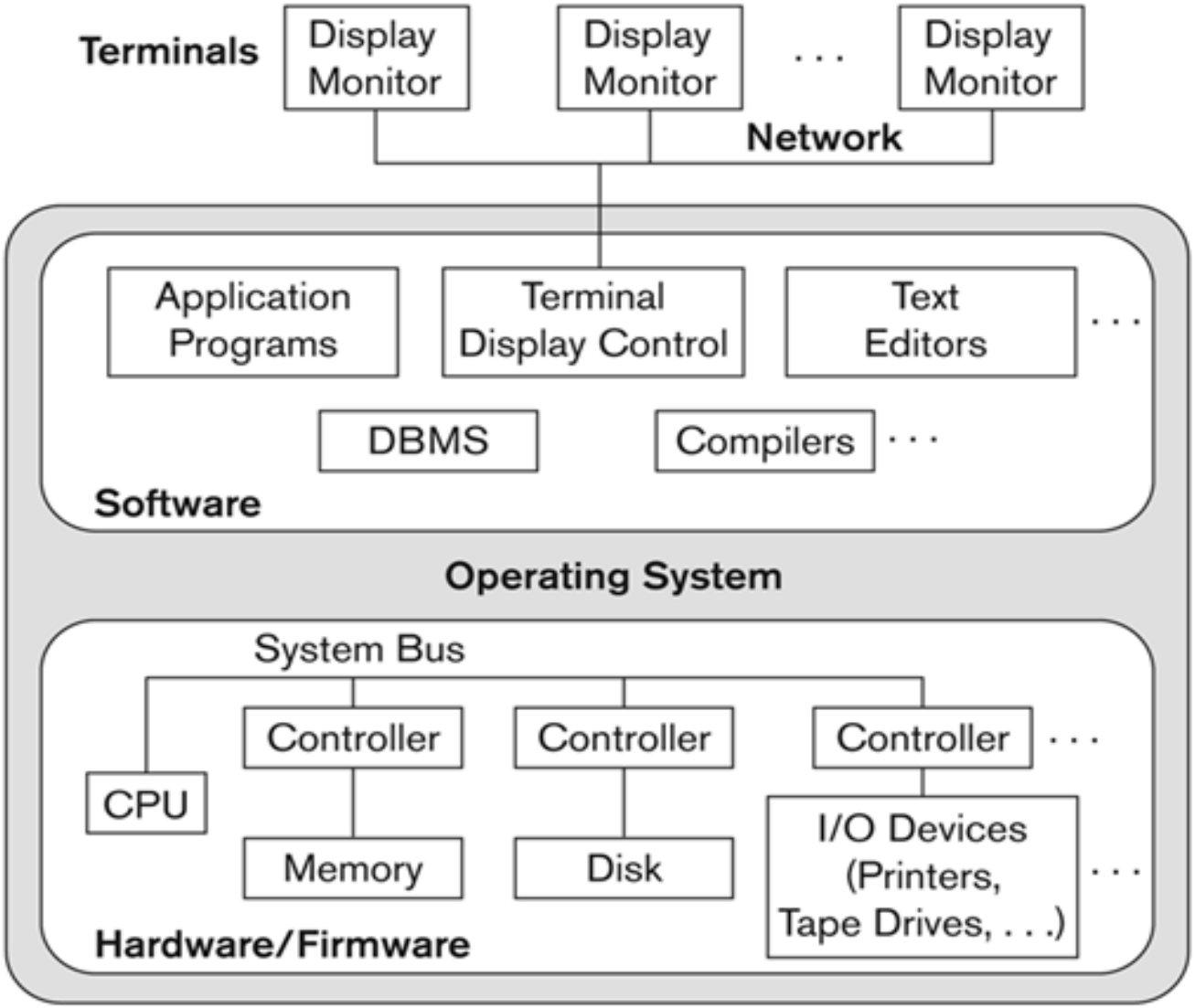
Outline

- Centralized and Client-Server Architectures
- Classification of DBMSs
- History of Data Models

Centralized and Client-Server DBMS Architectures

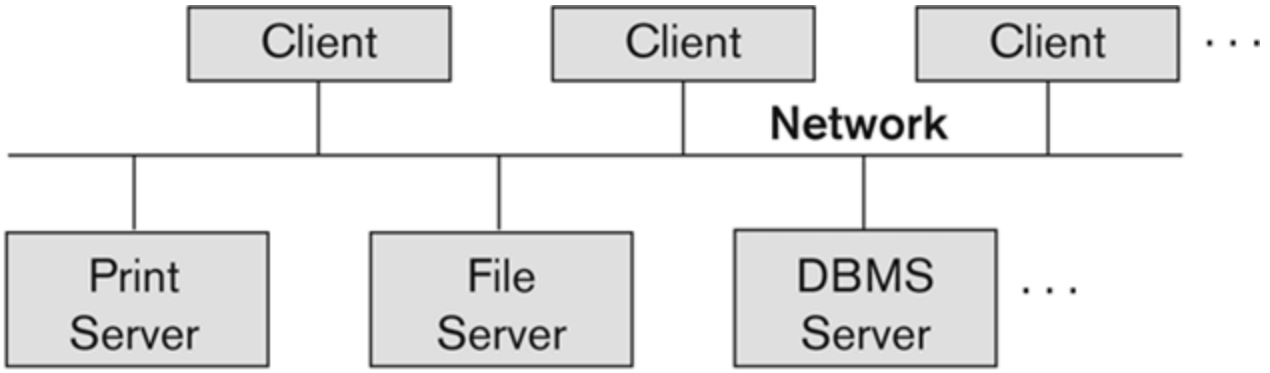
- Centralized DBMS:
  - Combines everything into single system including- DBMS software, hardware, application programs, and user interface processing software.
  - User can still connect through a remote terminal – however, all processing is done at centralized site.

A Physical Centralized Architecture



Basic 2-tier Client-Server Architectures

- Specialized Servers with Specialized functions
  - Print server
  - File server
  - DBMS server
  - Web server
  - Email server
- Clients can access the specialized servers as needed



Logical two-tier client server architecture

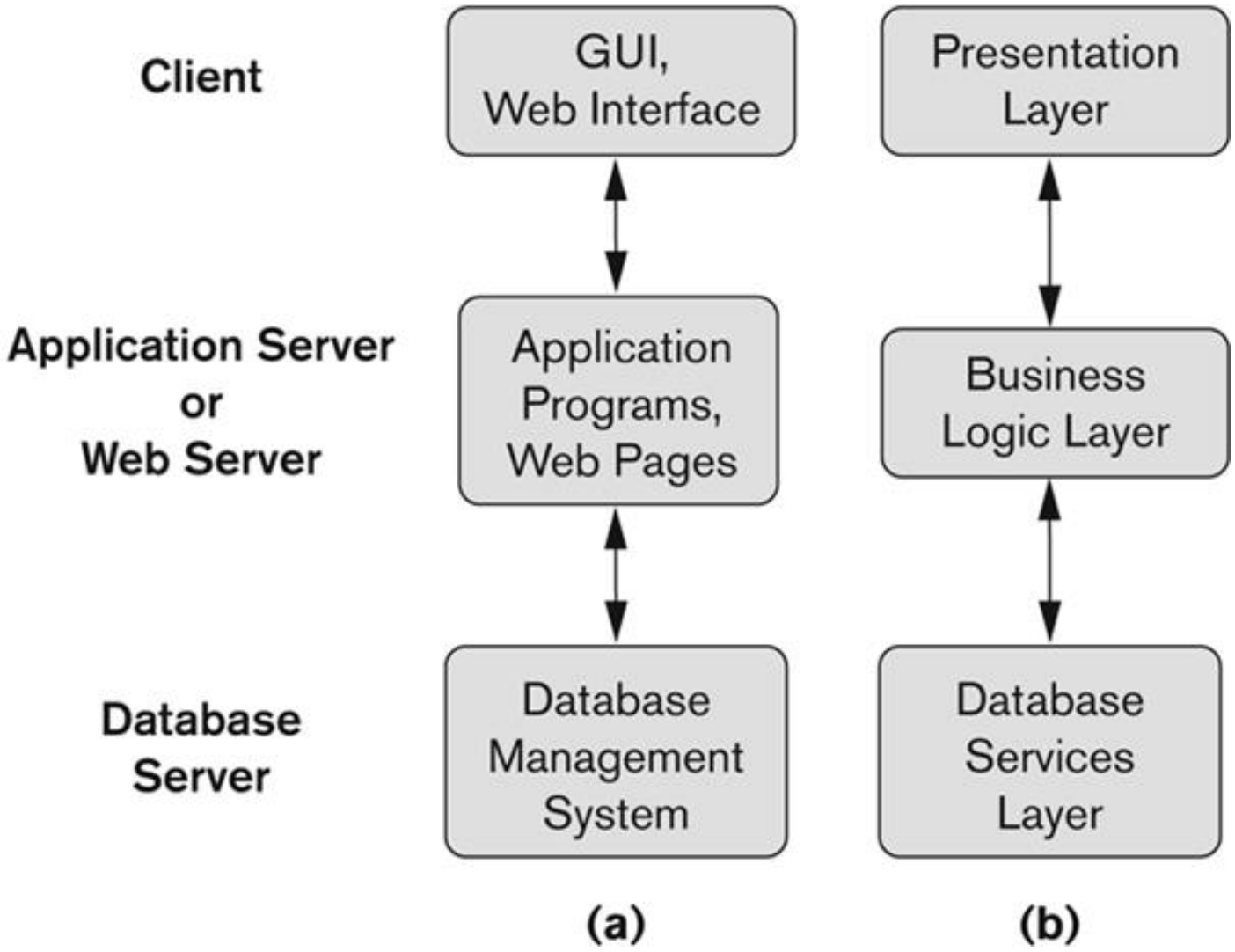
Two Tier Client-Server Architecture

- 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.
- Other variations of clients are possible: e.g., in some object DBMSs, more functionality is transferred to clients including data dictionary functions, optimization and recovery across multiple servers, etc.

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

Three-tier client-server architecture



Classification of DBMSs

- Based on the data model used
  - Traditional: Relational, Network, Hierarchical.
  - Emerging: Object-oriented, Object-relational.
- Other classifications
  - Single-user (typically used with personal computers) vs. multi-user (most DBMSs).
  - Centralized (uses a single computer with one database) vs. distributed (uses multiple computers, multiple databases)

Cost considerations for DBMSs

- Cost Range: from free open-source systems to configurations costing millions of dollars
- Examples of free relational DBMSs: MySQL, PostgreSQL, others
- Commercial DBMS offer additional specialized modules, e.g. time-series module, spatial data module, document module, XML module
  - These offer additional specialized functionality when purchased separately
  - Sometimes called cartridges (e.g., in Oracle) or blades
- Different licensing options: site license, maximum number of concurrent users (seat license), single user, etc.

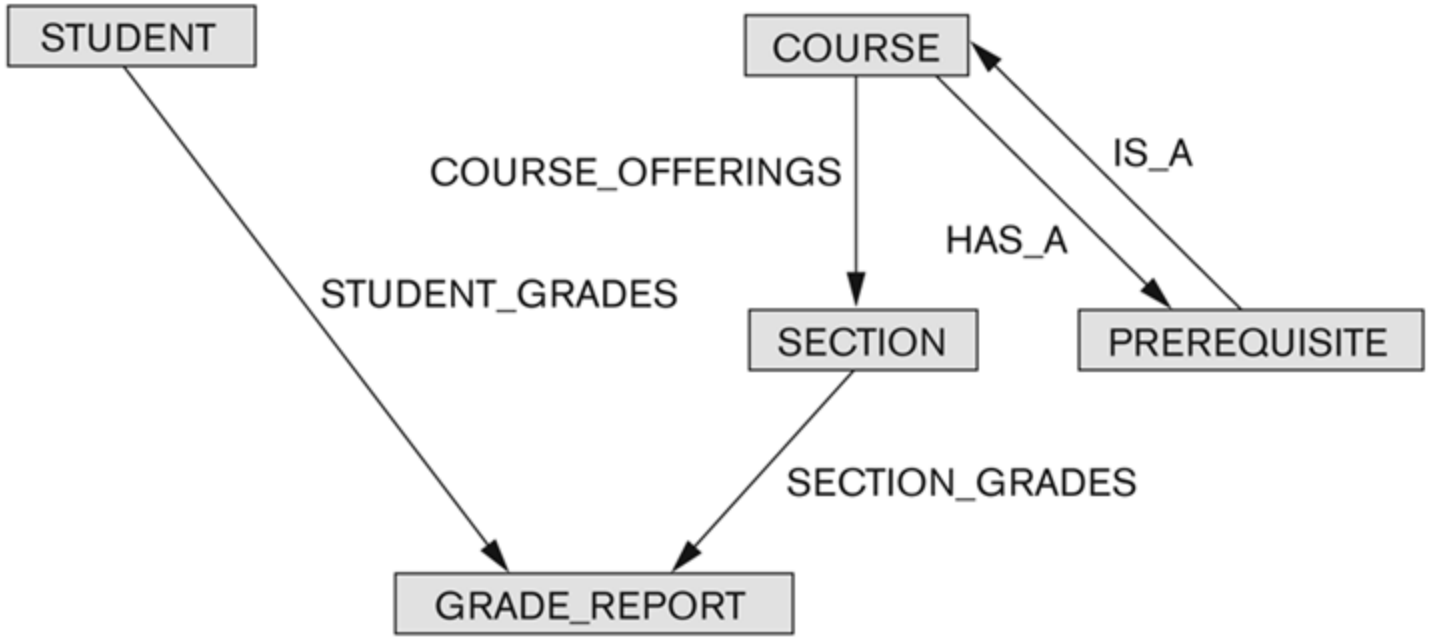
History of Data Models

- Network Model
- Hierarchical Model
- Relational Model
- Object-oriented Data Models
- Object-Relational Models

History of Data Models

- **Network Model:**
  - The first network DBMS was implemented by Honeywell in 1964-65 (IDS System).
  - Adopted heavily due to the support by CODASYL (Conference on Data Systems Languages) (CODASYL - DBTG report of 1971).
  - Later implemented in a large variety of systems - IDMS (Cullinet - now Computer Associates), DMS 1100 (Unisys), IMAGE (H.P. (Hewlett-Packard)), VAX -DBMS (Digital Equipment Corp., next COMPAQ, now H.P.).

Example of Network Model Schema



Network Model

- **Advantages:**
  - Network Model is able to model complex relationships and represents semantics of add/delete on the relationships.
  - Can handle most situations for modeling using record types and relationship types.
  - Language is navigational; uses constructs like FIND, FIND member, FIND owner, FIND NEXT within set, GET, etc.
    - Programmers can do optimal navigation through the database.
- **Disadvantages:**
  - Navigational and procedural nature of processing
  - Database contains a complex array of pointers that thread through a set of records.

History of Data Models

- **Hierarchical Data Model:**
  - Initially implemented in a joint effort by IBM and North American Rockwell around 1965. Resulted in the IMS family of systems.
  - IBM's IMS product had (and still has) a very large customer base worldwide
  - Hierarchical model was formalized based on the IMS system
  - Other systems based on this model: System 2k (SAS inc.)

Hierarchical Model

- **Advantages:**
  - Simple to construct and operate
  - Corresponds to a number of natural hierarchically organized domains, e.g., organization (“org”) chart
  - Language is simple:
    - Uses constructs like GET, GET UNIQUE, GET NEXT, GET NEXT WITHIN PARENT, etc.
- **Disadvantages:**
  - Navigational and procedural nature of processing
  - Database is visualized as a linear arrangement of records
  - Little scope for "query optimization"

History of Data Models

- **Relational Model:**
  - Proposed in 1970 by E.F. Codd (IBM), first commercial system in 1981-82.
  - Now in several commercial products (e.g. DB2, ORACLE, MS SQL Server, SYBASE, INFORMIX).
  - Several free open source implementations, e.g. MySQL, PostgreSQL
  - Currently most dominant for developing database applications.
  - SQL relational standards: SQL-89 (SQL1), SQL-92 (SQL2), SQL-99, SQL3, etc.

History of Data Models

- **Object-oriented Data Models:**
  - Several models have been proposed for implementing in a database system.
  - One set comprises models of persistent O-O Programming Languages such as C++ (e.g., in OBJECTSTORE or VERSANT), and Smalltalk (e.g., in GEMSTONE).
  - Additionally, systems like O2, ORION (at MCC - then ITASCA), IRIS (at H.P.- used in Open OODB).
  - Object Database Standard: ODMG-93, ODMG-version 2.0, ODMG-version 3.0.

History of Data Models

- **Object-Relational Models:**
  - Most Recent Trend. Started with Informix Universal Server.
  - Relational systems incorporate concepts from object databases leading to object-relational.
  - Exemplified in the latest versions of Oracle-10i, DB2, and SQL Server and other DBMSs.
  - Standards included in SQL-99 and expected to be enhanced in future SQL standards.

THANKS

References:

1. Silberschatz, H. Korth & S. Sudarshan, Database System Concepts, McGraw-Hill Education, 6th Edition, 2010.
2. R. Elmasri & S.B. Navathe, Fundamentals of Database Systems, Pearson Education, 6th edition, 2010.