Databases

Lecture 1

Introduction to Databases. Fundamental Concepts

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Databases

- Lecture2 + Seminar1 + Laboratory2
- grading
  - written exam (W) - 50%
  - practical test (P) - 25%
  - labs (L) - 25%
  - W, P >= 5
- To attend the exam, a student must have at least 12 laboratory attendances and at least 5 seminar attendances, according to the Computer Science Department's decision: http://www.cs.ubbcluj.ro/wp-content/uploads/Hotarare-CDI-15.03.2017.pdf
- http://www.cs.ubbcluj.ro/~sabina
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Context

- databases - virtually everywhere
  - education
  - research
  - financial services
  - media
  - e-commerce
  - social networks
  - tourism
  - telecommunications
  - …

Context

- extraordinary data growth, huge & complex **data sets**
- data owners (organizations, individuals, etc) need to **efficiently manage** their data, to extract correct information in a timely manner

=> need powerful & flexible **data management systems** that simplify data management

1. The Components of an Application

- data (stored in files or databases)
- management algorithm
- user interface

2. Data Storage Methods

- files
- databases
- distributed databases

3. Files: Characteristics and Limitations

* ex: bank storing a large collection of data on employees, clients, accounts, transactions, etc; requirements:

  - quick answers to questions about the data
  - protecting the data from inconsistent changes made by users accessing it at the same time
  - restricting access to some parts of the data, e.g., salaries

- difficulties encountered when storing and managing the data using a collection of files ->

3. Files: Characteristics and Limitations

- multiple data storage formats
- data redundancy
  - some parts of the data can be stored in multiple files => potential inconsistencies
- read / write operations are described in the program (using certain record structures) => difficulties in program development (changes in the file structure lead to changes in the program)
- changing data (modifying / removing records), retrieving data based on search criteria - difficult operations
- integrity constraints - checked in the program
- main memory management, e.g., how is a data collection of tens / hundreds of GB loaded for processing?

3. Files: Characteristics and Limitations

- no adequate security policies, allowing different users to access different segments of data
- concurrent data access is difficult to manage
- data must be restored to a consistent state in the event of a system failure, e.g., a bank transaction transferring money from account A to account B is interrupted by a blackout after having debited account A, but prior to crediting account B; money must be put back into account A
- files: useful for single-user programs dealing with a small amount of data

4. Data Description Models

- data must be described according to a model (to be managed automatically)
- **data description model**: set of **concepts and rules** used to model data; such concepts describe:
  - the structure of the data
  - consistency constraints
  - relationships with other data
- the **schema** of the database (the data structure or template)
  - data structures used to describe a collection of data stored in a database
  - data in the collection: an **instance** of the schema (analogy: classes and objects in object-oriented programming)
- the data description constructs in a model are *high-level*, hiding many low-level details about data storage, e.g., there's a long way from the *Student* entity to the computer stored bits ☺

4. Data Description Models

- entity-relationship
- relational
- network
- hierarchical
- object-oriented
- noSQL
- semistructured (XML)

4. Data Description Models: The Relational Model

- **relation:** the main concept used to describe data
- the schema of a relation:
  - the relation's name
  - for each field (column): its name and type
- example: Movie(*mid*: string, *title*: string, *director*: string, *year*: integer)

4. Data Description Models: The Relational Model

- example:
  - instance of the Movie relation
  - every row has 4 columns

mid	*title*	*director*	*year*
84386	Hibernatus	Édouard Molinaro	1969
7583	Moscow Does Not Believe in Tears	Vladimir Menshov	1980
47288	Close Encounters of the Third Kind	Steven Spielberg	1977
32	Contact	Robert Zemeckis	1997
46747	E.T. the Extra-Terrestrial	Steven Spielberg	1982

4. Data Description Models: The Entity-Relationship Model

- **semantic**, more abstract, high-level model
- eases the task of developing a good initial description of the data
- such a semantic model is useful since, even though the database management system's model hides many details, it's still closer to the manner in which the data is stored than to the user's perspective on the data
- a design in such a model is subsequently expressed in terms of the database management system's model
  - e.g., the ER -> relational mapping

4. Data Description Models: The Entity-Relationship Model

- main **concepts**: entities, attributes, relationships
- **entity**
  - a piece of data, an object in the real world
  - described by attributes (properties)
- **entity set** (class / entity schema)
  - entities with the same structure (e.g., the set of students)
  - name, list of attributes
- **attribute**
  - name, domain of possible values, conditions to check correctness
- **key**
  - a restriction defined on an entity set
  - set of attributes with distinct values in the entity set's instances

4. Data Description Models: The Entity-Relationship Model

- **relationship**
  - specifies an association among 2 or more entities
  - descriptive attributes can be used
- **relationship set** (relationship schema)
  - describes all relationships with the same structure
  - name, entity sets used in the association, descriptive attributes

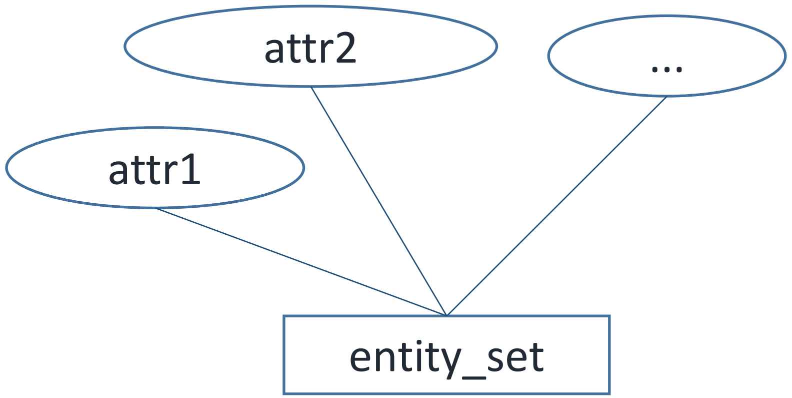
- **the schema of the model**
  - set of entity sets and relationship sets

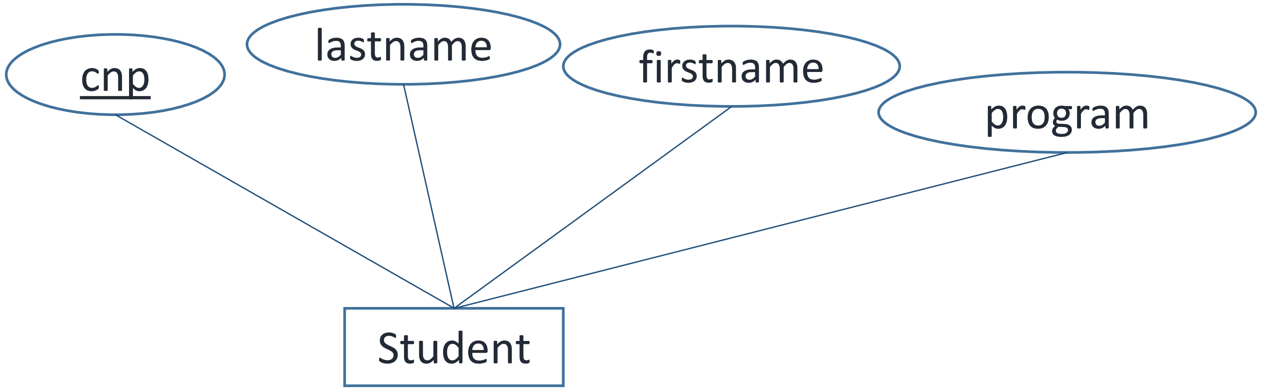
4. Data Description Models: The Entity-Relationship Model

- **binary relationships** (between entity sets T1 and T2) - **relationship types**:
  - **1:1**: one T1 entity can be associated with at most one T2 entity, and one T2 entity can be associated with at most one T1 entity
    - e.g., the association between group and faculty member (e.g., to specify the groups' tutors)
  - **1:n**: one T1 entity can be associated with any number of T2 entities, and one T2 entity can be associated with at most one T1 entity
    - e.g., the association between group and students
  - **m:n:** one T1 entity can be associated with any number of T2 entities, and one T2 entity can be associated with any number of T1 entities
    - e.g., the association between courses and students
- considered as **restrictions** in the database; when the database is changed, the system checks whether the relationship is of the specified type

4. Data Description Models: The Entity-Relationship Model

- graphical representation of the model
  - entity set and associated attributes





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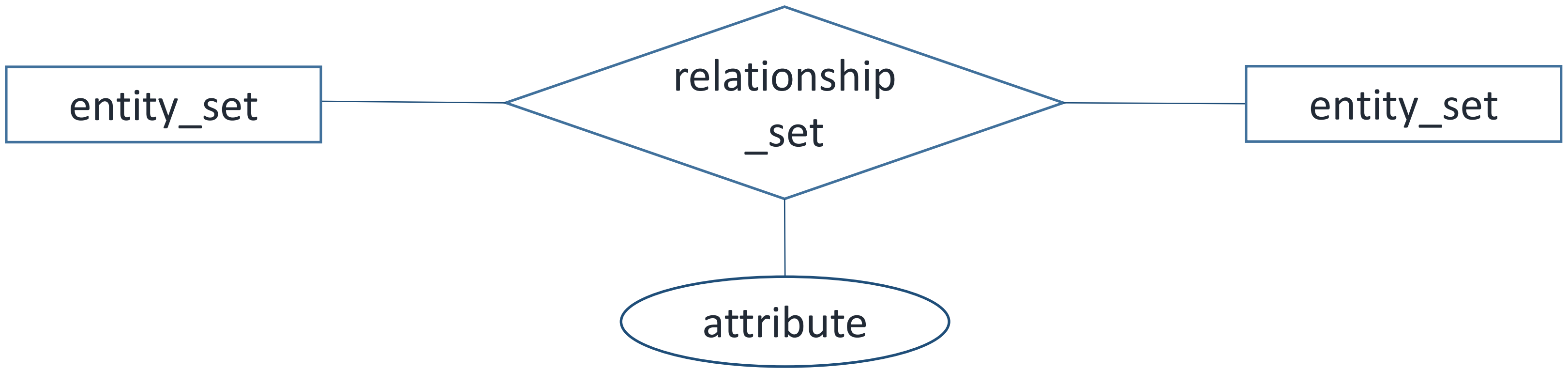
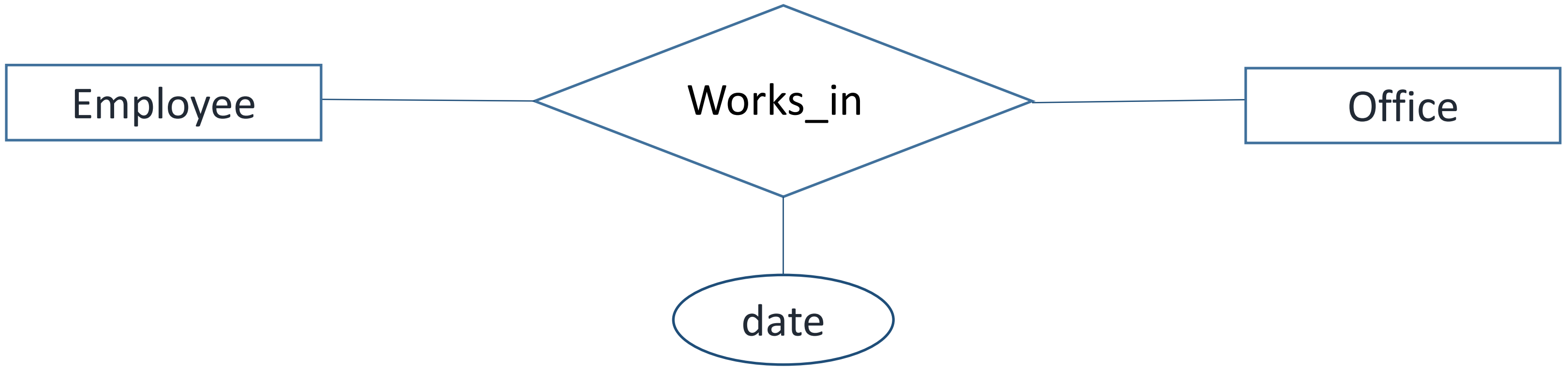
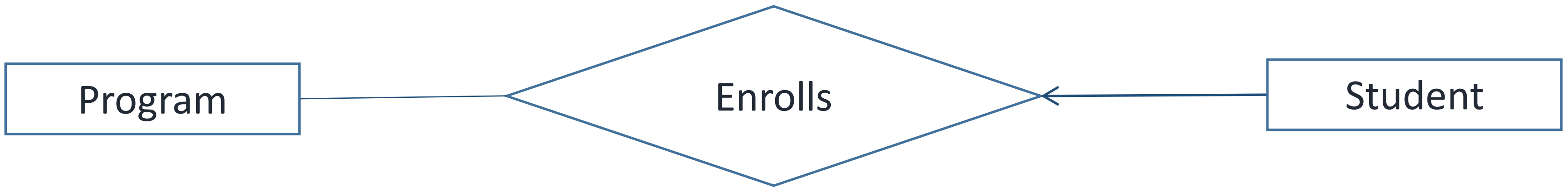




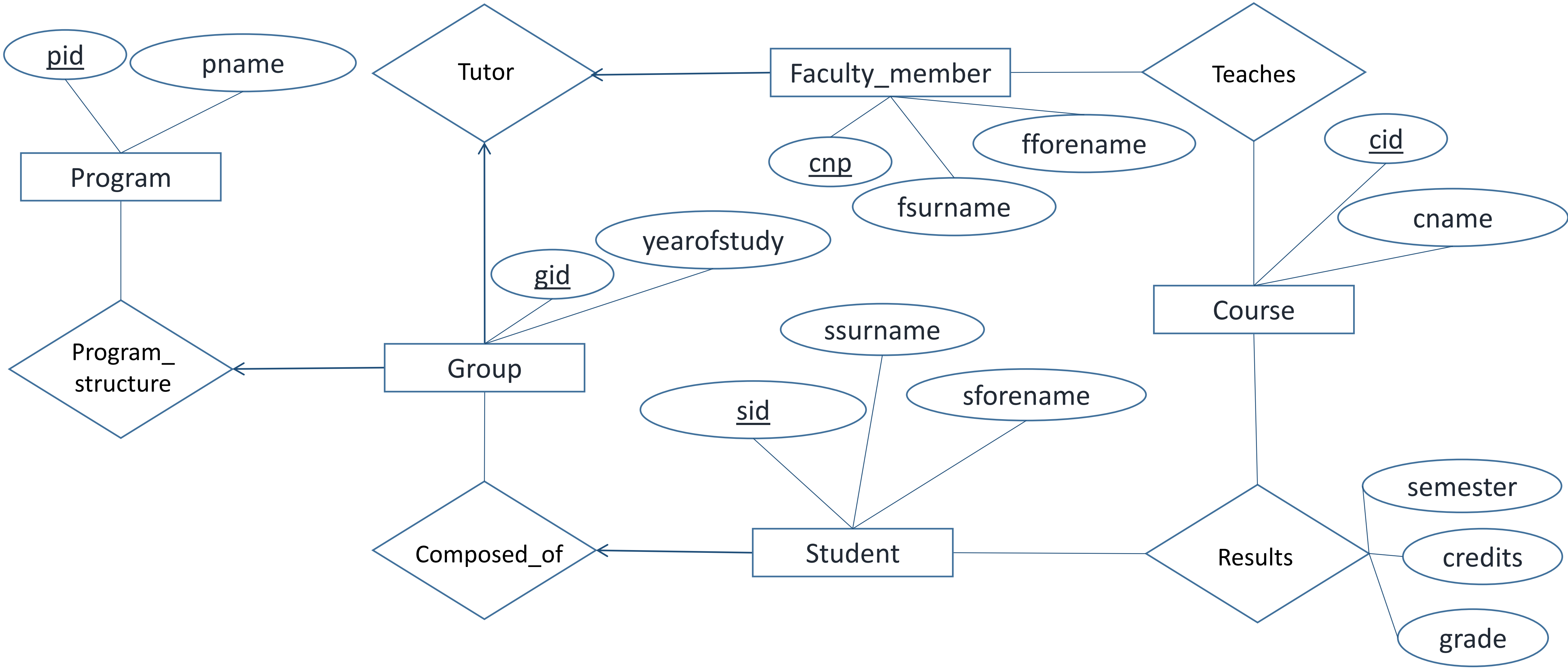
4. Data Description Models: The Entity-Relationship Model

- graphical representation of the model
  - 1:n relationship sets - graphical convention:



4. Data Description Models: The Entity-Relationship Model

- example:



5. Databases and Database Management Systems

- a **database** contains:
  - the database schema
    - **description of data structures** used to model the data
    - kept in a database dictionary
  - a **collection of data** - instances of the schema
  - various **components**: views, procedures, functions, roles, users, etc
- separation between:
  - **data definition** (kept in the database dictionary)
  - **data management** (insert / delete / update) and querying
- database **design**
  - describe an organization in terms of the data in a database
- data **analysis**
  - answer questions about the organization by formulating queries that involve the data in the database

5. Databases and DBMSs

- **database management system** (DBMS)
  - set of programs that are used to manage a database
- DBMS examples
  - Oracle, DB2 (IBM), SQL Server, Informix (IBM), Teradata, MySQL, PostgreSQL, Access, Paradox, Foxpro, ...
- **database system**
  - database + DBMS

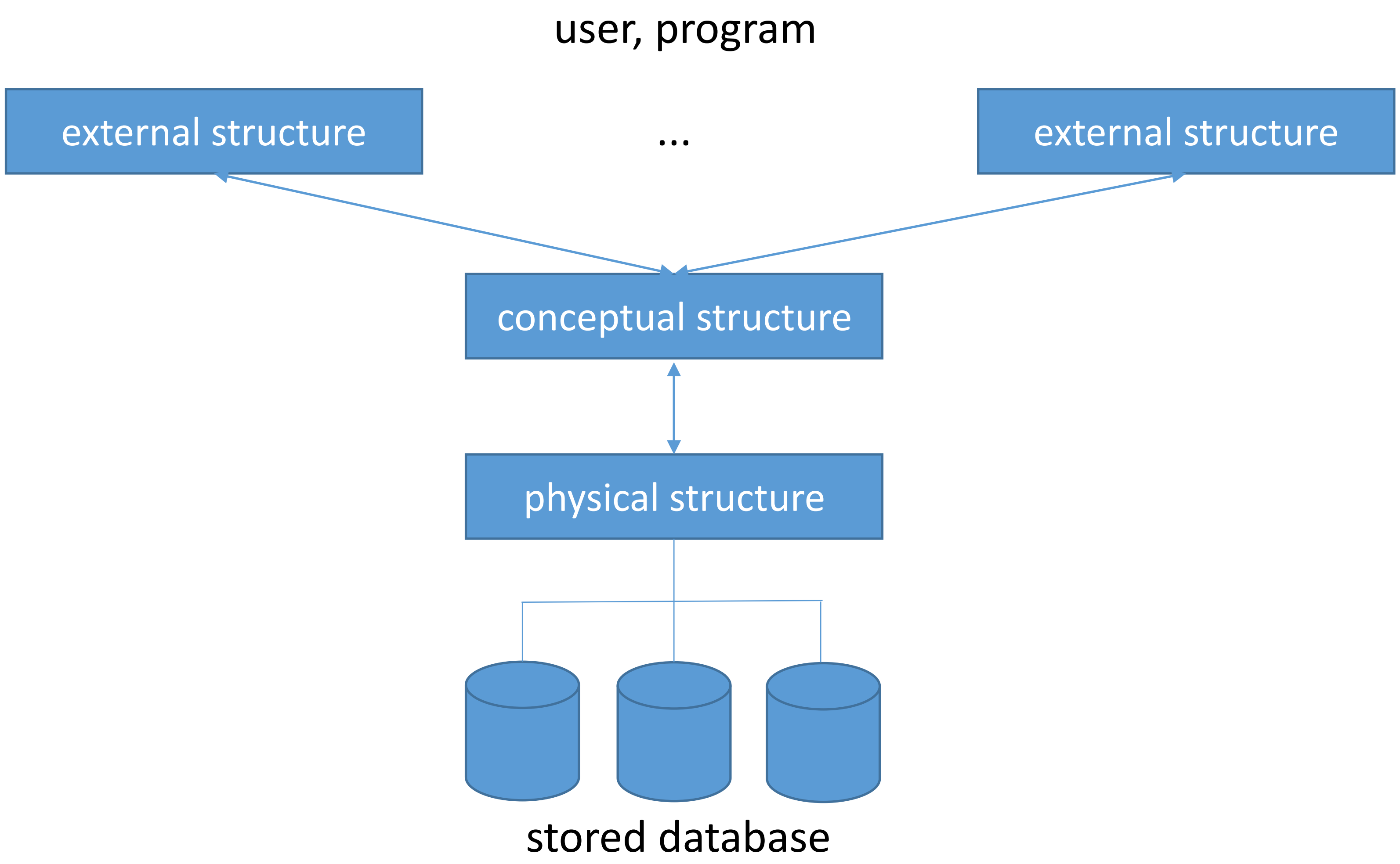
6. The Structures of a Database

- when thinking about how to organize and store information about an organization in a database, users operate with high-level concepts corresponding to the entities and relationships in the organization
- on the other hand, the DBMS stores data in the form of a very large number of bits
- the difference between the way users think about their data and the manner in which the data is stored is reconciled through the levels of abstraction in a DBMS

6. The Structures of a Database

- the **ANSI-SPARC architecture** - a three-level architecture for a database system, proposed in 1975; in general, this model is used by the main management systems and includes:
  - **the conceptual structure (the database schema)**: describes the data structures and restrictions in the database
  - **external structures**: describe the data structures used by a certain user / program; the description employs a certain model, and the DBMS can find the data in the conceptual structure
  - **the physical structure (internal structure)**: describes the storage structures in the database (data files, indexes, etc)

6. The Structures of a Database



6. The Structures of a Database

- e.g., the conceptual structure
  - information about entities, e.g., students, courses, and relationships among entities, e.g., courses taught by teachers:

    Student(*sid*: string, *slastname*: string, *sfirstname*: string, *gpa*: real)

    Teacher(*tid*: string, *tlastname*: string, *tfirstname*: string, *salary*: real)

    Course(*cid*: string, *cname*: string)

    Grade(*sid*: string, *cid*: string, *grade*: real)

    Teaches(*tid*: string, *cid*: string)

6. The Structures of a Database

- e.g., the physical structure
  - information about how relations are stored on the disk, about the creation of indexes (data structures that speed up queries):

    relations – stored as unsorted files of records

    indexes are created on the first column of the Student and Teacher relations

6. The Structures of a Database

- e.g., external structure with information about the best result for each student (the student's sid, last name and first name, the name of the corresponding course and the grade)

BestResults(*sid*: string, *slastname*: string, *sfirstname*: string, *cname*: string, *grade*: real)

- BestResults is a *view* whose definition is based on relations in the conceptual structure; conceptually, it's a relation, but its records are not stored in the database; they are computed on demand using BestResult's definition
- adding BestResults to the conceptual schema => redundancy, the database is prone to errors, e.g., a record for a new grade is introduced in the Grade relation without operating a corresponding (necessary) change in the BestResults relation
- a database can have several external structures, each customized for a group of users

7. Logical Independence and Physical Independence

- **data independence**: 3 levels of abstraction => applications are insulated from changes in the data structure / storage
- **logical data independence**: programs using data from the database are not affected by changes in the conceptual structure
  - important: applications can be developed in several stages
    - e.g., the Student relation is replaced by:

      StudentPublic(*sid*: string, *slastname*: string, *sfirstname*: string) StudentPrivate(*sid*: string, *gpa*: real, *dob*: date)
    - change the definition of BestResults, so it retrieves required data from StudentPublic

7. Logical Independence and Physical Independence

- **physical data independence**: applications are insulated from changes in the physical structure of the data
  - important: files (e.g., index) can be added for optimization purposes; users' programs don't check the files (the physical structure) directly

8. Functions of Database Management Systems

- database **definition**: definition language (or dedicated applications that generate DDL commands)
- data **management**: insert, update, delete, querying
- database **administration**: database access authorization, database usage monitoring, database performance monitoring and optimization, etc
- the **protection** of the database: *confidentiality* (protection against unauthorized data access), *integrity* (protection against inconsistent changes)

9. Types of Database Users

- database **administrators**
- database **designers**
  - schemas, restrictions, functions and procedures, optimizations
- data management **application users**
- **application programmers**

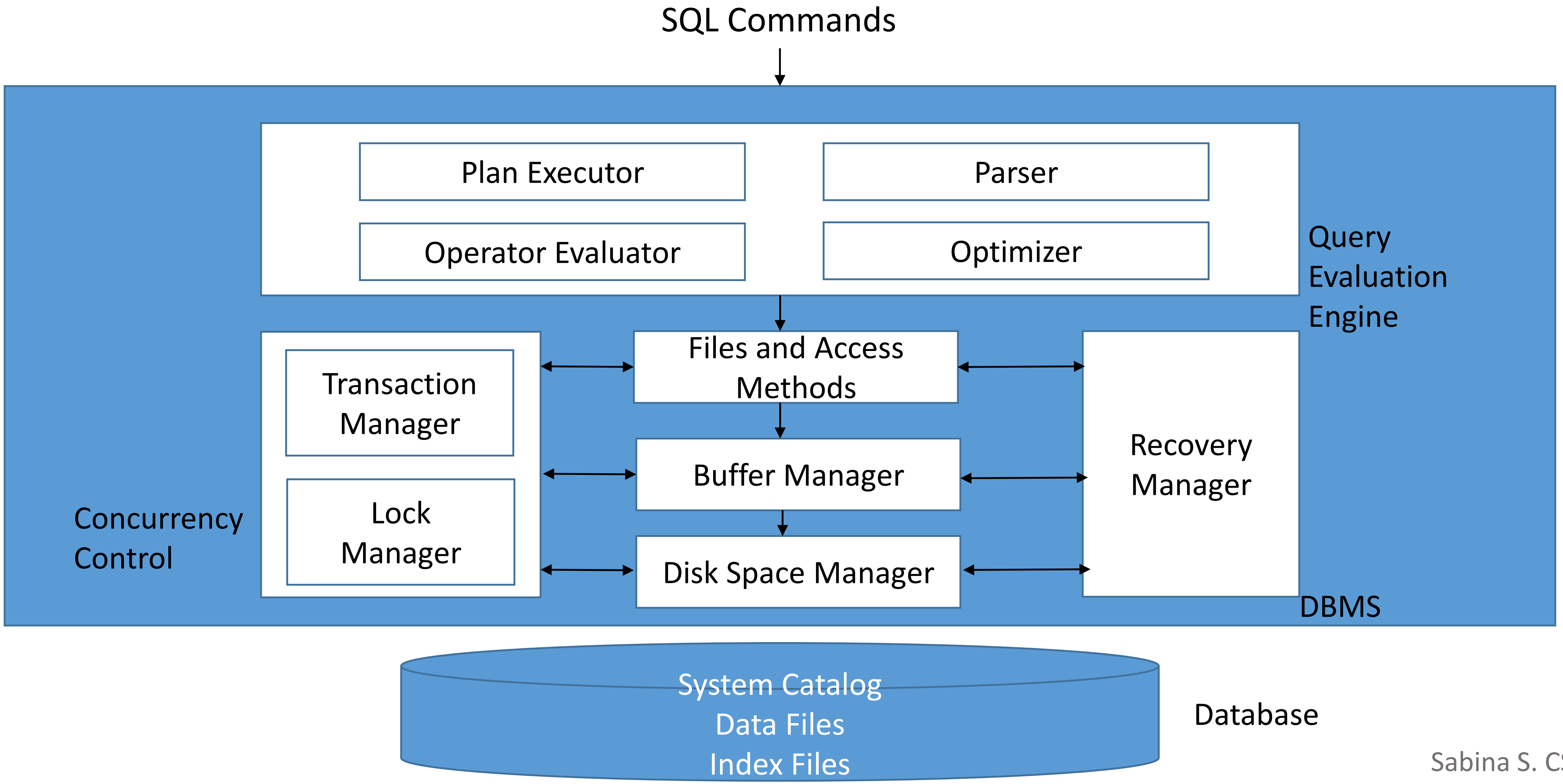
9. Types of Database Users

* applications - developed in different languages / programming environments (Web, Java, .NET apps, etc)

- executing an operation on a database (client / server technology):
  - app sends a command to the DB system (command written in SQL - Structured Query Language)
  - DB system executes command, sends answer back to the app

10. The Architecture of a DBMS

- [Ra07] proposes the following structure for a DBMS:



10. The Architecture of a DBMS

- SQL commands can come from different user interfaces (Web Forms, SQL interface, etc), and can be included in applications written in various programming languages, e.g., Java, C#, etc
- Optimizer
  - produces an efficient execution plan for query evaluation, taking into account storage information
- File & Access Methods, Buffer Manager, Disk Manager
  - abstraction of files, bringing pages from the disk into memory, managing disk space
- Transaction Manager, Lock Manager
  - concurrency control, monitoring lock requests, granting locks when database objects become available

10. The Architecture of a DBMS

- Recovery Manager
  - recovery after a crash

11. Using a DBMS - Advantages

- a DBMS can manage large collections of interrelated data
- applications are not managing database implementation details: an app sends a SQL command and receives the result set (the command is evaluated by the DBMS, which uses sophisticated data access programs)
- it allows systems to be developed in several stages (changing the database schema, changing the applications, developing new applications)
- it optimizes data access (very important for large collections of data; it stores and retrieves data efficiently)
- data access applications can be developed in a host of languages / programming environments

11. Using a DBMS - Advantages

- if data is always accessed through the system, it is up to date and correct (integrity constraints are automatically checked)
- database access control (for users with different roles)
- concurrent access management
- it enables data recovery (log)
- data import / export - various formats
- it provides data analysis tools (data mining)
- it reduces application development time

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