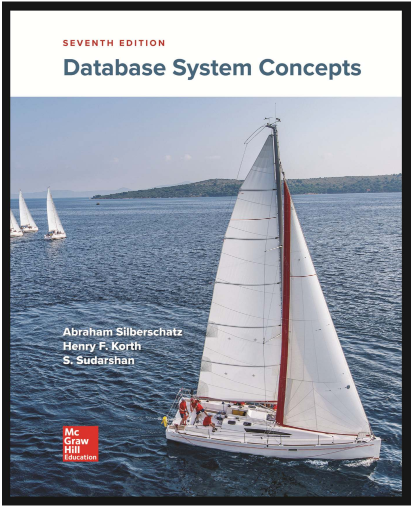
Database System Concepts, 7^{th} Edition
Chapter 6: Database Design Using the E-R Model

Silberschatz, Korth and Sudarshan

March 29, 2025

Database System Concepts



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Plan

Overview of the Design Process

The Entity-Relationship Model

Complex Attributes

Mapping Cardinalities

Primary Key

Removing Redundant Attributes in Entity Sets

Design Phases

- Initial phase –characterize fully the data needs of the prospective database users.
- Second phase –choosing a data model:
  - Applying the concepts of the chosen data model.
  - Translating these requirements into a conceptual schema of the database.
  - A fully developed conceptual schema indicates the functional requirements of the enterprise.
    - Describe the kinds of operations (or transactions) that will be performed on the data.

Design Phases (Cont.)

- Final phase –Moving from an abstract data model to the implementation of the database.
    - Logical Design –Deciding on the database schema.
        - Database design: requires that we find a “good” collection of relation schemas.
        - Business decisions: 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 Alternatives

- In designing a database schema, we must ensure that we avoid two major pitfalls:
    - Redundancy: a bad design may result in repeat information.
        - Redundant representation of information may lead to data inconsistency among the various copies of information
    - Incompleteness: a bad design may make certain aspects of the enterprise difficult or impossible to model.
- Avoiding bad designs is not enough. There may be a large number of good designs from which we must choose.

Design Approaches

- Entity Relationship Model (covered in this chapter).
  - 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.
- Normalization Theory (Chapter 7).

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Entity Sets

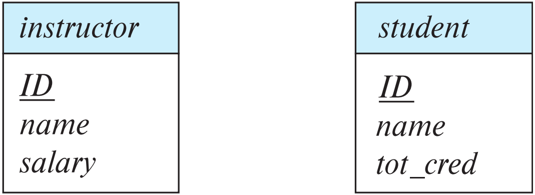
- An entity is an object that exists and is distinguishable from other objects.
  - Example: specific person, company, event, plant...
- An entity set is a set of entities of the same type that share the same properties.
  - Example: set of all persons, companies, trees, holidays...
- An entity is represented by a set of attributes; i.e., descriptive properties possessed by all members of an entity set.
  - Example:

    instructor = (ID, name, salary)

    course = (course_id, title, credits)
- A subset of the attributes form a primary key of the entity set; i.e., uniquely identifying each member of the set.

Representing Entity sets in ER Diagram

- Entity sets can be represented graphically as follows:
  - Rectangles represent entity sets.
  - Attributes listed inside entity rectangle.
  - Underline indicates primary key attributes.



instructor

ID
name
salary

student

ID
name
tot_cred

Relationship Sets

- A **relationship** is an association among several entities. For example:

44553 (Peltier)	advisor	22222 (Einstein)
student entity	relationship set	instructor entity

- A **relationship set** is a mathematical relation among $n \geq 2$ entities, each taken from entity sets.

  $$\{(e_1, e_2, \ldots, e_n) | e_1 \in E_1, e_2 \in E_2, \ldots, e_n \in E_n\}$$

  where $(e_1, e_2, \ldots, e_n)$ is a relationship.

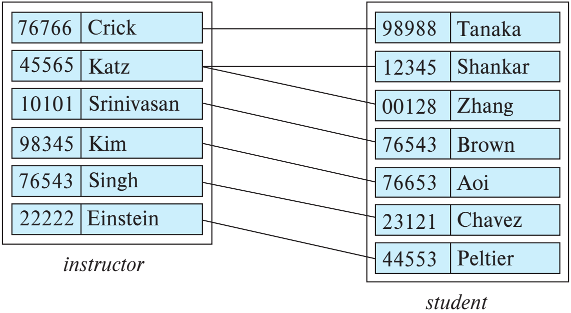
  - Example: (44553,22222) $\in$ advisor

Relationship Sets (Cont.)

Example

We define the relationship set advisor to denote the associations between students and the instructors who act as their advisors.

- Pictorially, we draw a line between related entities.



76766	Crick
45565	Katz
10101	Srinivasan
98345	Kim
76543	Singh
22222	Einstein

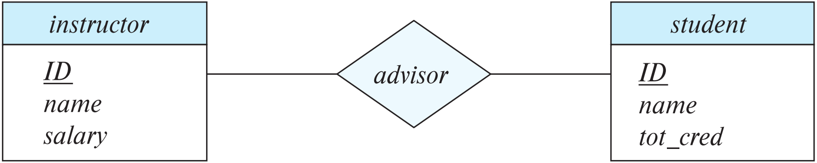
instructor

98988	Tanaka
12345	Shankar
00128	Zhang
76543	Brown
76653	Aoi
23121	Chavez
44553	Peltier

student

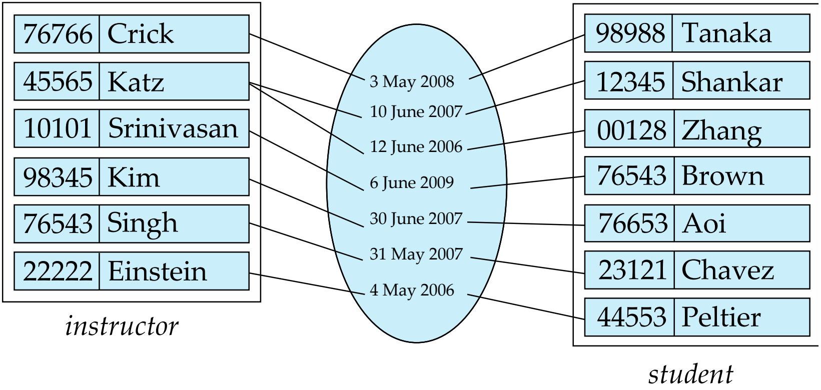
Representing Relationship Sets via ER Diagrams

- Diamonds represent relationship sets.



Relationship Sets (Cont.)

- An attribute can also be associated with a relationship set.
- For instance, the advisor relationship set between entity sets instructor and student may have the attribute date which tracks when the student started being associated with the advisor



76766	Crick
45565	Katz
10101	Srinivasan
98345	Kim
76543	Singh
22222	Einstein

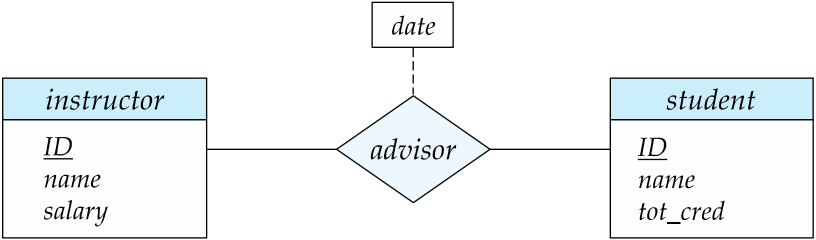
instructor

3 May 2008
10 June 2007
12 June 2006
6 June 2009
30 June 2007
31 May 2007
4 May 2006

98988	Tanaka
12345	Shankar
00128	Zhang
76543	Brown
76653	Aoi
23121	Chavez
44553	Peltier

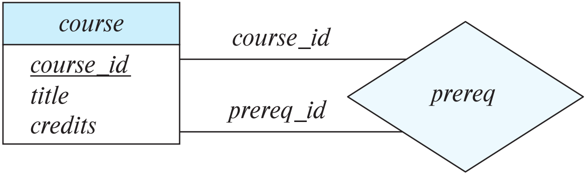
student

Relationship Sets with Attributes



Roles

- Entity sets of a relationship need not be distinct.
  - Each occurrence of an entity set plays a "role" in the relationship.
- The labels *"course_id"* and *"prereq_id"* are called **roles**.

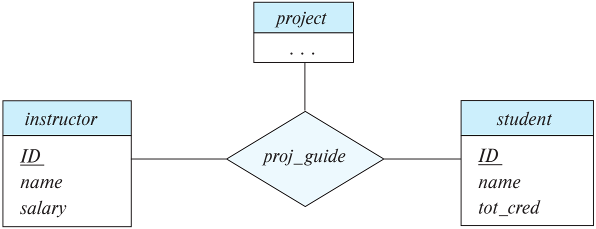


Degree of a Relationship Set

- Binary relationship.
  - involve two entity sets (or degree two).
  - most relationship sets in a database system are binary.
- Relationships between more than two entity sets are rare. Most relationships are binary. (More on this later.)
  - Example: students work on research projects under the guidance of an instructor.
  - relationship *proj_guide* is a ternary relationship between instructor, student, and project.

Non-binary Relationship Sets

- Most relationship sets are binary.
- There are occasions when it is more convenient to represent relationships as non-binary.
- E-R Diagram with a Ternary Relationship:



Plan

Overview of the Design Process

The Entity-Relationship Model

Complex Attributes

Mapping Cardinalities

Primary Key

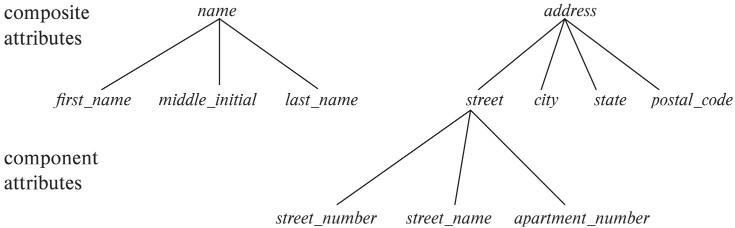
Removing Redundant Attributes in Entity Sets

Complex Attributes

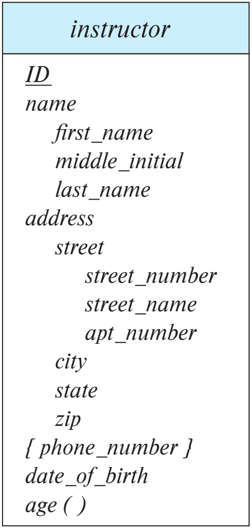
- Attribute types:
    - **Simple** and **composite** attributes.
    - **Single-valued** and **multivalued** attributes.
        - Example: multivalued attribute: phone_numbers.
    - **Derived** attributes.
        - Can be computed from other attributes.
        - Example: age, given date_of_birth.
- **Domain** –the set of permitted values for each attribute.

Composite Attributes

- Composite attributes allow us to divided attributes into subparts (other attributes).



Representing Complex Attributes in ER Diagram



instructor

- *ID*
- *name*
    - *first_name*
    - *middle_initial*
    - *last_name*
- *address*
    - *street*
        - *street_number*
        - *street_name*
        - *apt_number*
    - *city*
    - *state*
    - *zip*
- *{ phone_number }*
- *date_of_birth*
- *age ( )*

Mapping Cardinality Constraints

- Express the number of entities to which another entity can be associated via a relationship set.
- Most useful in describing binary relationship sets.
- For a binary relationship set the mapping cardinality must be one of the following types:
  - One to one
  - One to many
  - Many to one
  - Many to many

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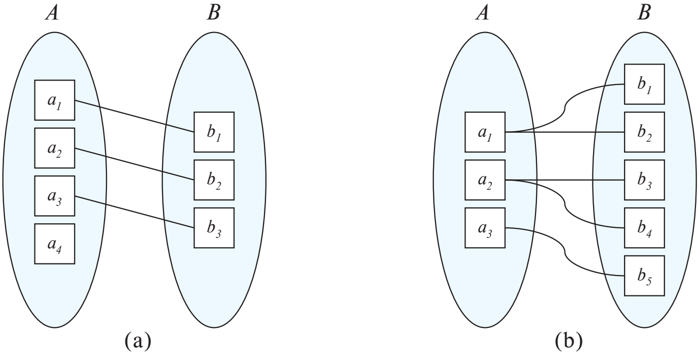


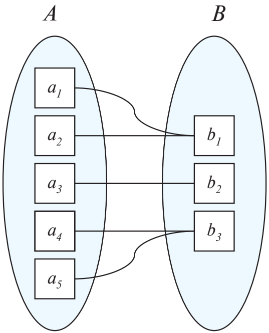
one to one

one to many

Note:

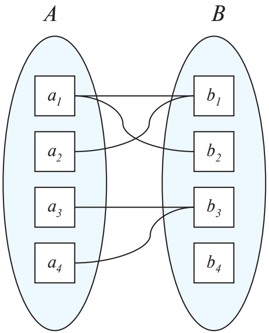
Some elements in A and B may not be mapped to any elements in the other set.

Mapping Cardinalities



(a)

many to one



(b)

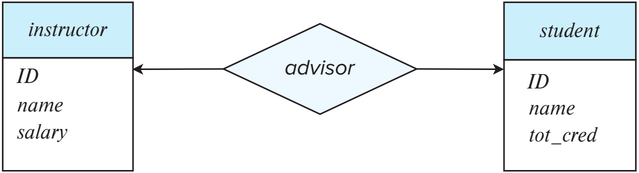
many to many

Note:

Some elements in A and B may not be mapped to any elements in the other set.

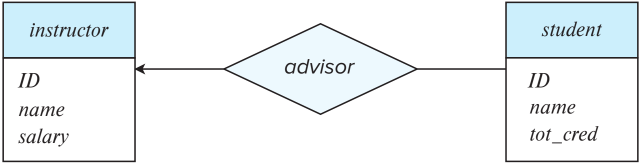
Representing Cardinality Constraints in ER Diagram

- We express cardinality constraints by drawing either a directed line (→), signifying “one,” or an undirected line (—), signifying “many,” between the relationship set and the entity set.
- One-to-one relationship between an *instructor* and a *student*:
  - A student is associated with at most one instructor via the relationship advisor.
  - An instructor is associated with at most one student via the relationship advisor.



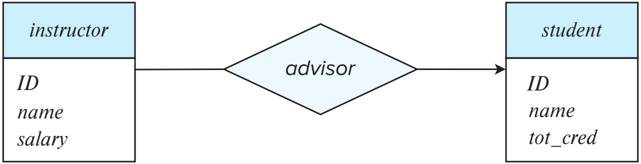
One-to-Many Relationship

- In a one-to-many relationship between an instructor and a student:
    - an instructor is associated with several (including 0) students via advisor.
    - a student is associated with at most one instructor via advisor.



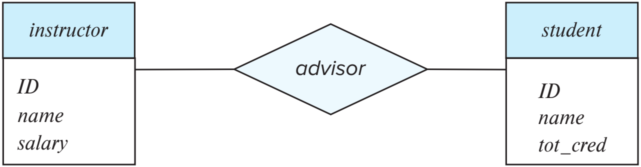
Many-to-One Relationship

- In a many-to-one relationship between an instructor and a student:
  - an instructor is associated with at most one student via advisor.
  - a student is associated with several (including 0) instructors via advisor.



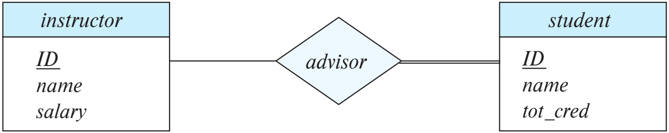
Many-to-Many Relationship

- In a many-to-many relationship between an instructor and a student:
  - an instructor is associated with several (possibly 0) students via advisor.
  - a student is associated with several (possibly 0) instructors via advisor.



Total and Partial Participation

- **Total participation** (indicated by double line): every entity in the entity set participates in at least one relationship in the relationship set.



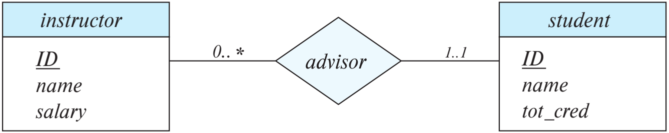
participation of student in advisor relation is total.

  - every student must have an associated instructor.

- **Partial participation**: some entities may not participate in any relationship in the relationship set.
  - Example: participation of instructor in advisor is partial.

Notation for Expressing More Complex Constraints

- A line may have an associated minimum and maximum cardinality, shown in the form $l..h$, where l is the minimum and h the maximum cardinality.
  - A minimum value of 1 indicates total participation.
  - A maximum value of 1 indicates that the entity participates in at most one relationship.
  - A maximum value of * indicates no limit.
- Example: Instructor can advise 0 or more students. A student must have 1 advisor; cannot have multiple advisors.



Cardinality Constraints on Ternary Relationship

- We allow at most one arrow out of a ternary (or greater degree) relationship to indicate a cardinality constraint.
- For example, an arrow from proj_guide to instructor indicates each student has at most one guide for a project.
- If there is more than one arrow, there are two ways of defining the meaning.
  - For example, a ternary relationship R between A, B and C with arrows to B and C could mean:
    1. Each A entity is associated with a unique entity from B and C or
    2. Each pair of entities from (A, B) is associated with a unique C entity, and each pair (A, C) is associated with a unique B.
  - Each alternative has been used in different formalisms.
  - To avoid confusion we outlaw more than one arrow.

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Primary Key

- Primary keys provide a way to specify how entities and relations are distinguished. We will consider:
  - Entity sets.
  - Relationship sets.
  - Weak entity sets.

Primary key for Entity Sets

- By definition, individual entities are distinct.
- From database perspective, the differences among them must be expressed in terms of their attributes.
- The values of the attribute values of an entity must be such that they can uniquely identify the entity.
  - No two entities in an entity set are allowed to have exactly the same value for all attributes.
- A key for an entity is a set of attributes that suffice to distinguish entities from each other.

Primary Key for Relationship Sets

- To distinguish among the various relationships of a relationship set we use the individual primary keys of the entities in the relationship set.
  - Let R be a relationship set involving entity sets $E_1, E_2, \ldots, E_n$.
  - The primary key for R is consists of the union of the primary keys of entity sets $E_1, E_2, \ldots, E_n$
  - If the relationship set R has attributes $a_1, a_2, \ldots, a_m$ associated with it, then the primary key of R also includes the attributes $a_1, a_2, \ldots, a_m$.
- Example: relationship set "advisor".
  - The primary key consists of `instructor.ID` and `student.ID`.
- The choice of the primary key for a relationship set depends on the mapping cardinality of the relationship set.

Choice of Primary key for Binary Relationship

- Many-to-Many relationships. The preceding union of the primary keys is a minimal superkey and is chosen as the primary key.
- One-to-Many relationships. The primary key of the “Many” side is a minimal superkey and is used as the primary key.
- Many-to-one relationships. The primary key of the “Many” side is a minimal superkey and is used as the primary key.
- One-to-one relationships. The primary key of either one of the participating entity sets forms a minimal superkey, and either one can be chosen as the primary key.

Weak Entity Sets

- Consider a section entity, which is uniquely identified by a course_id, semester, year, and sec_id.
- Clearly, section entities are related to course entities. Suppose we create a relationship set sec_course between entity sets section and course.
- Note that the information in sec_course is redundant, since section already has an attribute course_id, which identifies the course with which the section is related.
- One option to deal with this redundancy is to get rid of the relationship sec_course; however, by doing so the relationship between section and course becomes implicit in an attribute, which is not desirable.

Weak Entity Sets (Cont.)

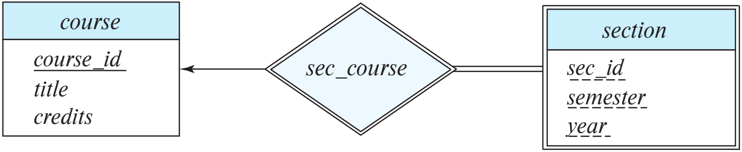
- An alternative way to deal with this redundancy is to not store the attribute course_id in the section entity and to only store the remaining attributes section_id, year, and semester.
    - However, the entity set section then does not have enough attributes to identify a particular section entity uniquely.
- To deal with this problem, we treat the relationship sec_course as a special relationship that provides extra information, in this case, the course_id, required to identify section entities uniquely.
- A **weak entity set** is one whose existence is dependent on another entity, called its **identifying entity**.
- Instead of associating a primary key with a weak entity, we use the identifying entity, along with extra attributes called discriminator to uniquely identify a weak entity.

Weak Entity Sets (Cont.)

- An entity set that is not a weak entity set is termed a **strong entity set**.
- Every weak entity must be associated with an identifying entity; that is, the weak entity set is said to be **existence dependent** on the identifying entity set.
- The identifying entity set is said to **own** the weak entity set that it identifies.
- The relationship associating the weak entity set with the identifying entity set is called the **identifying relationship**.
- Note that the relational schema we eventually create from the entity set section does have the attribute course_id, for reasons that will become clear later, even though we have dropped the attribute course_id from the entity set section.

Expressing Weak Entity Sets

- In E-R diagrams, a weak entity set is depicted via a double rectangle.
- We underline the discriminator of a weak entity set with a dashed line.
- The relationship set connecting the weak entity set to the identifying strong entity set is depicted by a double diamond.
- Primary key for section –(course_id, sec_id, semester, year).



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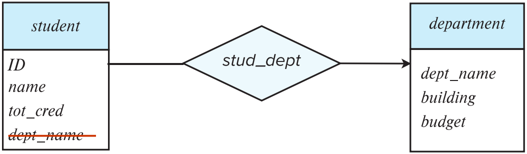
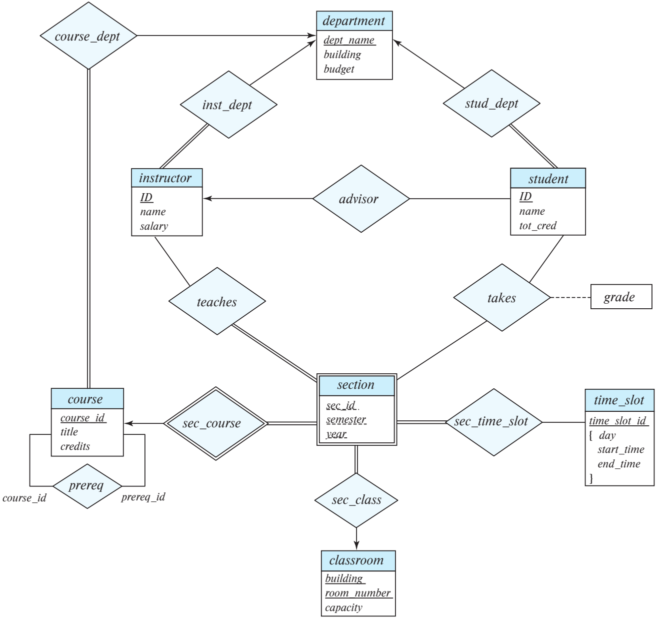
Redundant Attributes

- Suppose we have entity sets:
  - `student`, with attributes: ID, name, tot_cred, dept_name.
  - `department`, with attributes: dept_name, building, budget.
- We model the fact that each student has an associated department using a relationship set `stud_dept`.
- The attribute `dept_name` in student below replicates information present in the relationship and is therefore redundant...
  - and needs to be removed.
- BUT: when converting back to tables, in some cases the attribute gets reintroduced, as we will see later.



(a) Incorrect use of attribute

E-R Diagram for a University Enterprise



End of Chapter 6.

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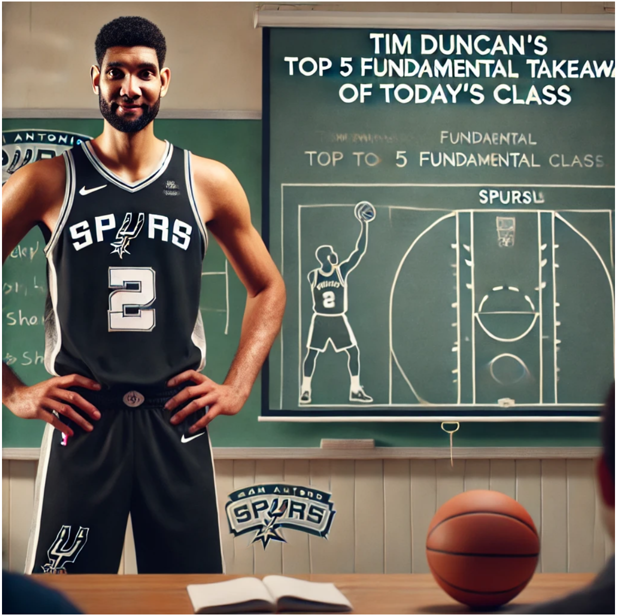
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TOP 5 FUNDAMENTAL TAKEAW
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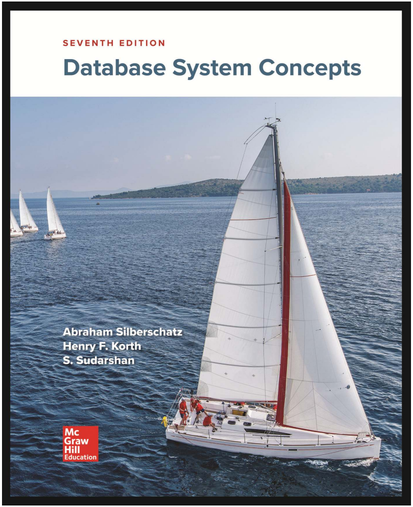
Top 5 Fundamental Takeaways

5

Database System Concepts



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