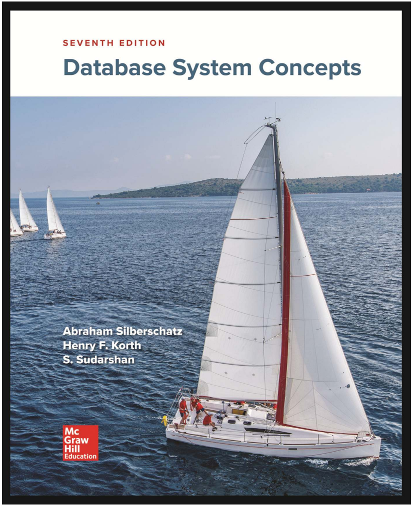
Database System Concepts, 7^{th} Edition
Chapter 6: Database Design Using the E-R Model

Silberschatz, Korth and Sudarshan

April 7, 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

Reducing E-R Diagrams to Relational Schemas

Extended E-R Features

Entity-Relationship Design Issues

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

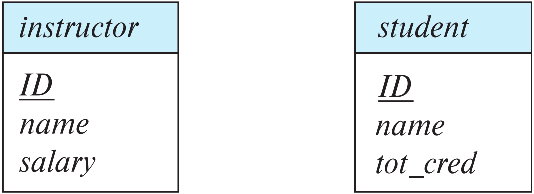
- An entity is an object that exists and is distinguishable from other objects.
  - Example: specific person, company, event, plant...
- An entity set is a set of entities of the same type that share the same properties.
  - Example: set of all persons, companies, trees, holidays...
- An entity is represented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



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.

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

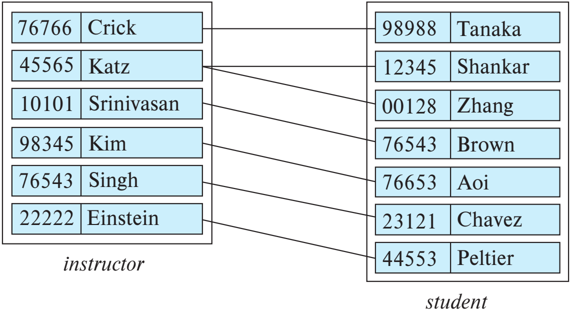
  where $(e_1, e_2, \ldots, e_n)$ is a relationship.
  - Example: (44553,22222) $\in$ advisor

Relationship Sets (Cont.)

Example

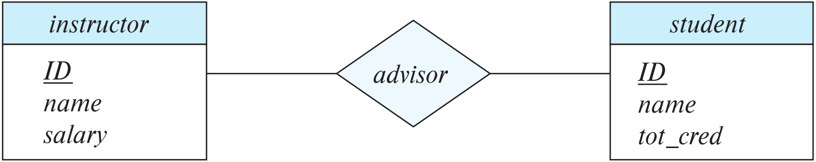
We define the relationship set advisor to denote the associations between students and the instructors who act as their advisors.

- Pictorially, we draw a line between related entities.



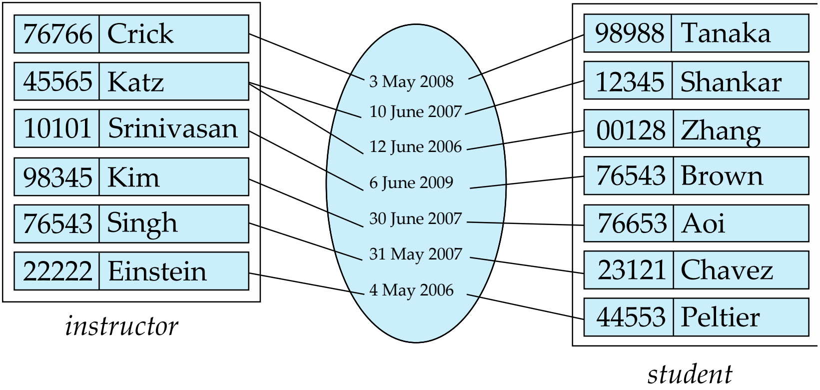
Representing Relationship Sets via ER Diagrams

- Diamonds represent relationship sets.

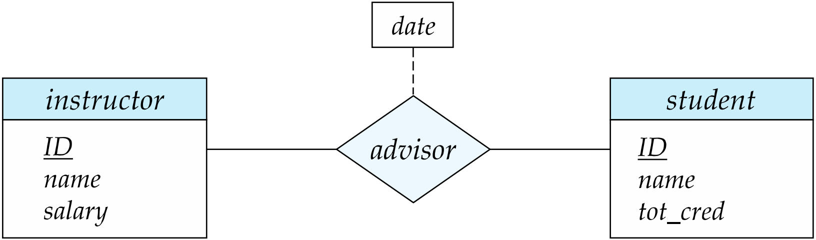


Relationship Sets (Cont.)

- 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

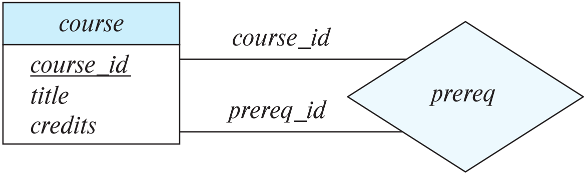


Relationship Sets with Attributes



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**.

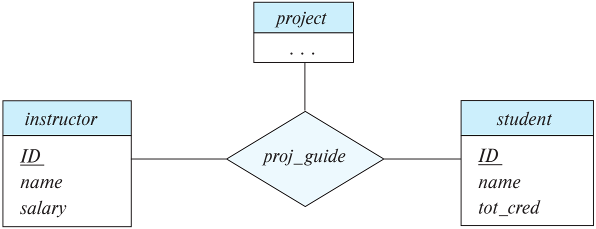


Degree of a Relationship Set

- 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:



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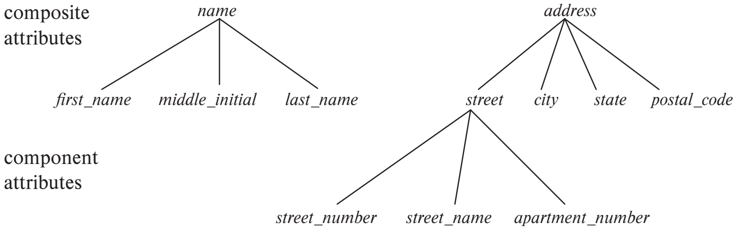
Complex Attributes

- 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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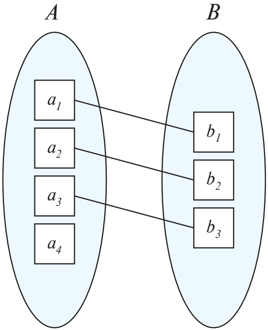
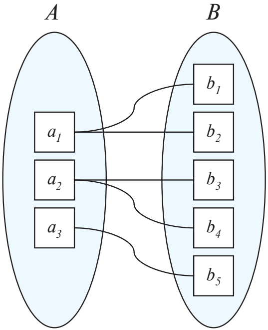


(a)

one to one



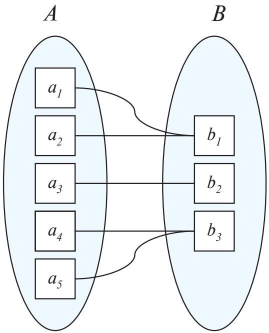
(b)

one to many

Note:

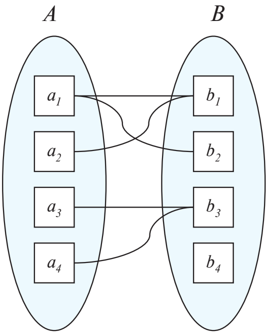
Some elements in A and B may not be mapped to any elements in the other set.

Mapping Cardinalities



(a)

many to one



(b)

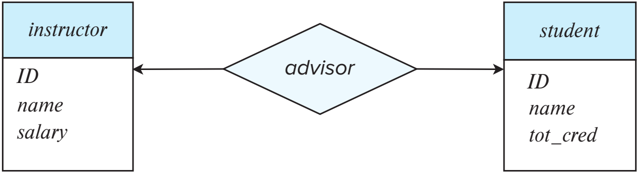
many to many

Note:

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

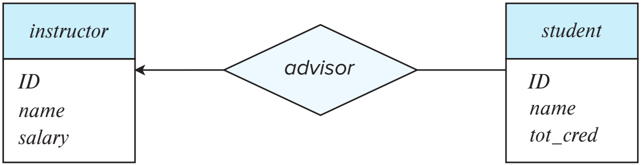
Representing Cardinality Constraints in ER Diagram

- We express cardinality constraints by drawing either a directed line ($\rightarrow$), 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.



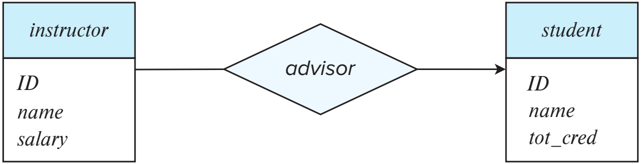
One-to-Many Relationship

- 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.



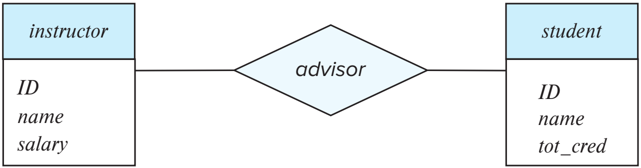
Many-to-One Relationship

- 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.



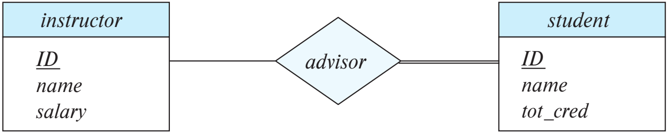
Many-to-Many Relationship

- 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.



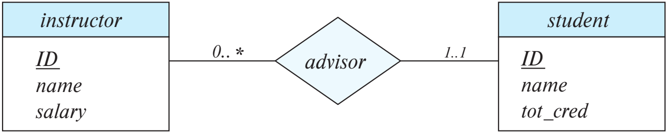
participation of student in advisor relation is total.

  - 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.)

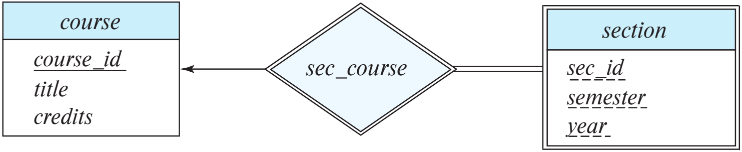
- An alternative way to deal with this redundancy is to not store the attribute *course_id* in the `section` entity and to only store the remaining attributes *section_id*, *year*, and *semester*.
  - However, the entity set `section` then does not have enough attributes to identify a particular section 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 attributes* 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**.

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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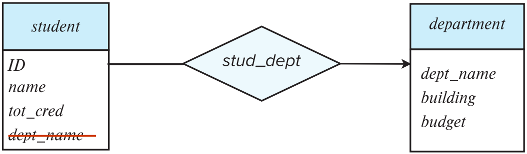
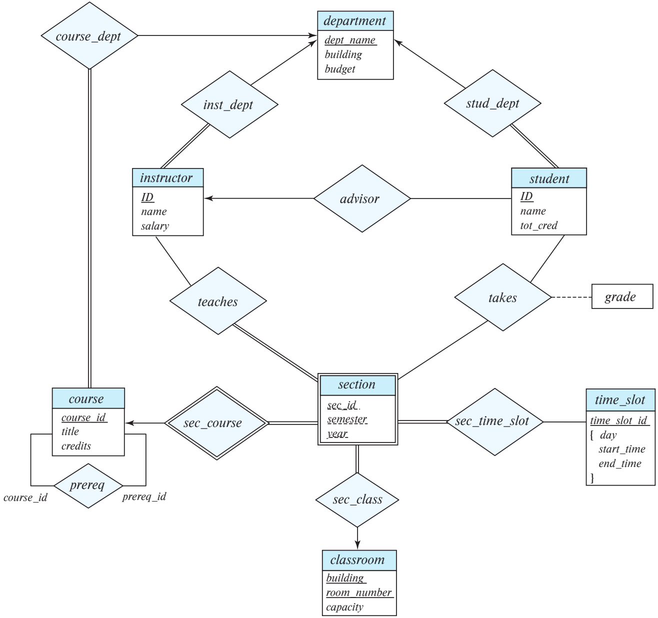
Redundant Attributes

- 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



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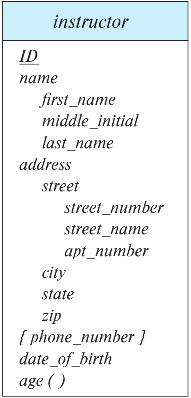
Reduction to Relation Schemas

- Entity sets and relationship sets can be expressed uniformly as relation schemas that represent the contents of the database.
- A database which conforms to an E-R diagram can be represented by a collection of schemas.
- For each entity set and relationship set there is a unique schema that is assigned the name of the corresponding entity set or relationship set.
- Each schema has a number of columns (generally corresponding to attributes), which have unique names.

Representing Entity Sets

- A strong entity set reduces to a schema with the same attributes:
  `student(ID, name, tot_cred)`
- A weak entity set becomes a table that includes a column for the primary key of the identifying strong entity set:
  `section(course_id, sec_id, sem, year)`
- Example:

Representation of Entity Sets with Composite Attributes



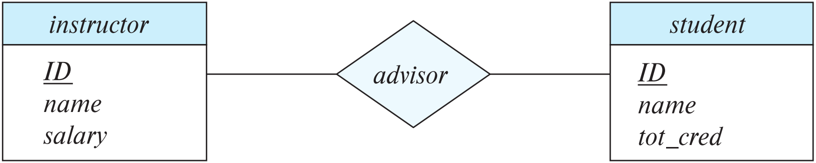
- Composite attributes are flattened out by creating a separate attribute for each component attribute.
  - Example: given entity set `instructor` with composite attribute `name` with component attributes `first_name` and `last_name` the schema corresponding to the entity set has two attributes `name_first_name` and `name_last_name`.
    - Prefix omitted if there is no ambiguity (`name_first_name` could be `first_name`)
- Ignoring multivalued attributes, extended `instructor` schema is:
  - `instructor(ID, first_name, middle_initial, last_name, street_number, street_name, apt_number, city, state, zip_code, date_of_birth)`

Representation of Entity Sets with Multivalued Attributes

- A multivalued attribute M of an entity E is represented by a separate schema EM.
- Schema EM has attributes corresponding to the primary key of E and an attribute corresponding to multivalued attribute M.
- Example: Multivalued attribute `phone_number` of `instructor` is represented by a schema:
  `inst_phone = (ID, phone_number)`.
- Each value of the multivalued attribute maps to a separate tuple of the relation on schema EM:
  - For example, an instructor entity with primary key 22222 and phone numbers 456-7890 and 123-4567 maps to two tuples: (22222, 456-7890) and (22222, 123-4567)

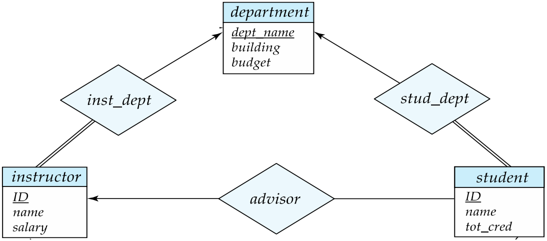
Representing Relationship Sets

- A many-to-many relationship set is represented as a schema with attributes for the primary keys of the two participating entity sets, and any descriptive attributes of the relationship set.
- Example: schema for relationship set advisor.
  `advisor = (s_id, i_id)`



Redundancy of Schemas

- Many-to-one and one-to-many relationship sets that are total on the many-side can be represented by adding an extra attribute to the "many" side, containing the primary key of the "one" side.
- Example: Instead of creating a schema for relationship set `inst_dept`, add an attribute *dept_name* to the schema arising from entity set `instructor`.



Redundancy of Schemas (Cont.)

- For one-to-one relationship sets, either side can be chosen to act as the “many” side:
  - That is, an extra attribute can be added to either of the tables corresponding to the two entity sets.
- If participation is partial on the “many” side, replacing a schema by an extra attribute in the schema corresponding to the “many” side could result in `null` values.

Redundancy of Schemas (Cont.)

- The schema corresponding to a relationship set linking a weak entity set to its identifying strong entity set is redundant.
- Example: The `section` schema already contains the attributes that would appear in the `sec_course` schema.

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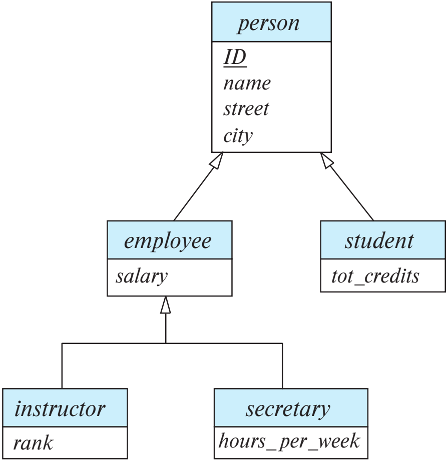
Specialization

- Top-down design process; we designate sub-groupings within an entity set that are distinctive from other entities in the set.
- These sub-groupings become lower-level entity sets that have attributes or participate in relationships that do not apply to the higher-level entity set.
- Depicted by a triangle component labeled ISA (e.g., `instructor` "is a" `person`).
- **Attribute inheritance** – a lower-level entity set inherits all the attributes and relationship participation of the higher-level entity set to which it is linked.

Specialization Example

- Overlapping – employee and student.
- Disjoint – instructor and secretary.
- Total and partial.



Representing Specialization via Schemas

- Method 1:
  - Form a schema for the higher-level entity.
  - Form a schema for each lower-level entity set, include primary key of higher-level entity set and local attributes.

Schema	Attributes
person	ID, name, stree, city
student	ID, tot_cred
employee	ID, salary

  - Drawback: getting information about, an employee requires accessing two relations, the one corresponding to the low-level schema and the one corresponding to the high-level schema.

Representing Specialization via Schemas

- Method 2:
  - Form a schema for each entity set with all local and inherited attributes.

Schema	Attributes
person	ID, name, stree, city
student	ID, name, stree, city, tot_cred
employee	ID, name, stree, city, salary

  - Drawback: *name*, *street* and *city* may be stored redundantly for people who are both students and employees.

Generalization

- **A bottom-up design process** – combine a number of entity sets that share the same features into a higher-level entity set.
- Specialization and generalization are simple inversions of each other; they are represented in an E-R diagram in the same way.
- The terms specialization and generalization are used interchangeably.

Completeness constraint

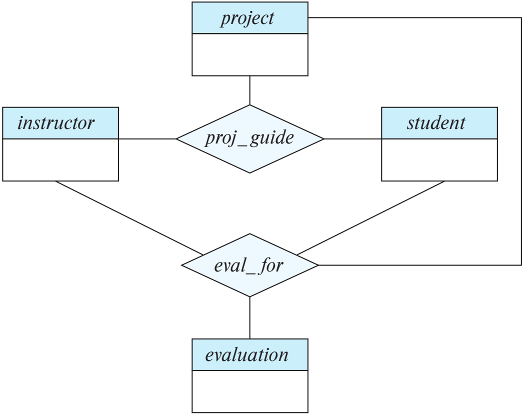
- Completeness constraint – specifies whether or not an entity in the higher-level entity set must belong to at least one of the lower-level entity sets within a generalization.
  - total: an entity must belong to one of the lower-level entity sets.
  - partial: an entity need not belong to one of the lower-level entity sets.

Completeness constraint (Cont.)

- Partial generalization is the default.
- We can specify total generalization in an E-R diagram by adding the keyword **total** in the diagram and drawing a dashed line from the keyword to the corresponding hollow arrow-head to which it applies (for a total generalization), or to the set of hollow arrow-heads to which it applies (for an overlapping generalization).
- The `student` generalization is total: All student entities must be either graduate or undergraduate. Because the higher-level entity set arrived at through generalization is generally composed of only those entities in the lower-level entity sets, the completeness constraint for a generalized higher-level entity set is usually total.

Aggregation

- Consider the ternary relationship *proj_guide*, which we saw earlier.
- Suppose we want to record evaluations of a student by a guide on a project.

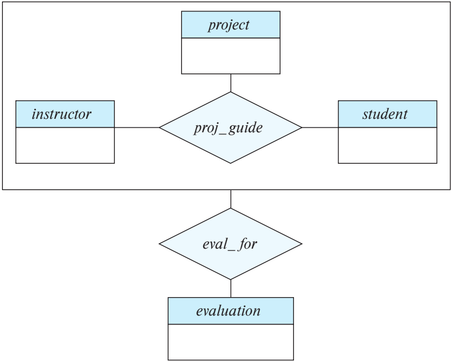


Aggregation (Cont.)

- Relationship sets *eval_for* and *proj_guide* represent overlapping information:
  - Every *eval_for* relationship corresponds to a *proj_guide* relationship.
  - However, some *proj_guide* relationships may not correspond to any *eval_for* relationships.
    - So we can't discard the *proj_guide* relationship.
- Eliminate this redundancy via aggregation:
  - Treat relationship as an abstract entity.
  - Allows relationships between relationships.
  - Abstraction of relationship into new entity.

Aggregation (Cont.)

- Eliminate this redundancy via **aggregation** without introducing redundancy, the following diagram represents:
  - A student is guided by a particular instructor on a particular project.
  - A student, instructor, project combination may have an associated evaluation.



Reduction to Relational Schemas

- To represent aggregation, create a schema containing:
  - Primary key of the aggregated relationship,
  - The primary key of the associated entity set,
  - Any descriptive attributes.
- In our example:
  - The schema `eval_for` is:
    `eval_for(s_ID, project_id, i_ID, evaluation_id)`
  - The schema `proj_guide` is redundant.

Plan

Overview of the Design Process

The Entity-Relationship Model

Complex Attributes

Mapping Cardinalities

Primary Key

Removing Redundant Attributes in Entity Sets

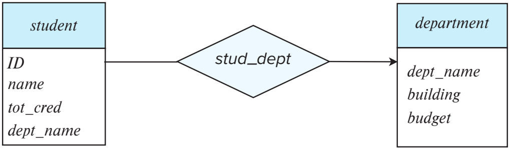
Reducing E-R Diagrams to Relational Schemas

Extended E-R Features

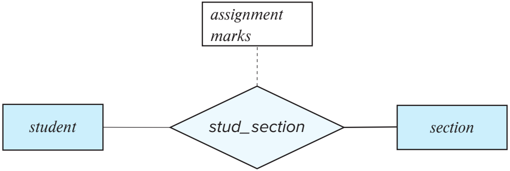
Entity-Relationship Design Issues

Common Mistakes in E-R Diagrams

- Example of erroneous E-R diagrams:

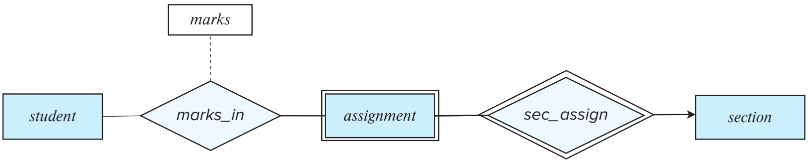


(a) Incorrect use of attribute

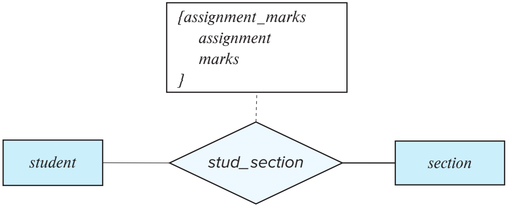


(b) Erroneous use of relationship attributes

Common Mistakes in E-R Diagrams (Cont.)



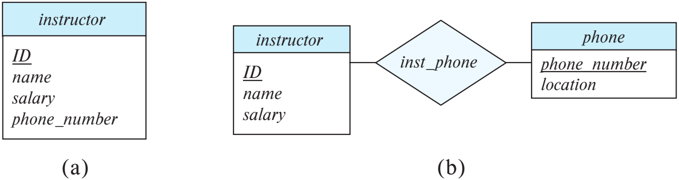
(c) Correct alternative to erroneous E-R diagram (b)



(d) Correct alternative to erroneous E-R diagram (b)

Entities vs. Attributes

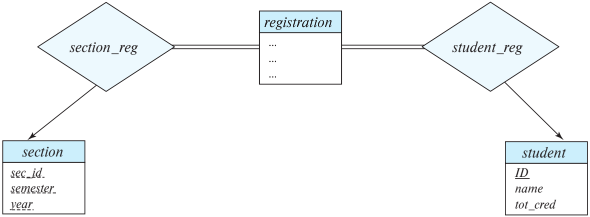
- Use of entity sets vs. attributes:



- Use of phone as an entity allows extra information about phone numbers (plus multiple phone numbers).

Entities vs. Relationship sets

- **Use of entity sets vs. relationship sets:** Possible guideline is to designate a relationship set to describe an action that occurs between entities.



- **Placement of relationship attributes:** For example, attribute date as attribute of advisor or as attribute of student.

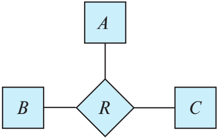
Binary Vs. Non-Binary Relationships

- Although it is possible to replace any non-binary (n-ary, for $n > 2$) relationship set by a number of distinct binary relationship sets, a n-aryrelationship set shows more clearly that several entities participate in a single relationship.
- Some relationships that appear to be non-binary may be better represented using binary relationships:
  - For example, a ternary relationship parents, relating a child to his/her father and mother, is best replaced by two binary relationships, father and mother:
    - Using two binary relationships allows partial information (e.g., only mother being known).
  - But there are some relationships that are naturally non-binary. Example: `proj_guide`.

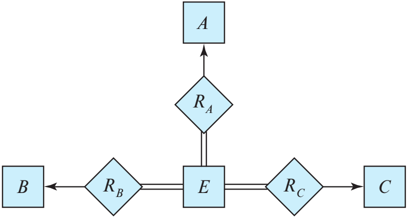
Converting Non-Binary Relationships to Binary Form

In general, any non-binary relationship can be represented using binary relationships by creating an artificial entity set:

- Replace R between entity sets A, B and C by an entity set E, and three relationship sets:
  1. R_A, a many-to-one relationship set from E to A.
  2. R_B, a many-to-one relationship set from E to B.
  3. R_C, a many-to-one relationship set from E to C.



(a)

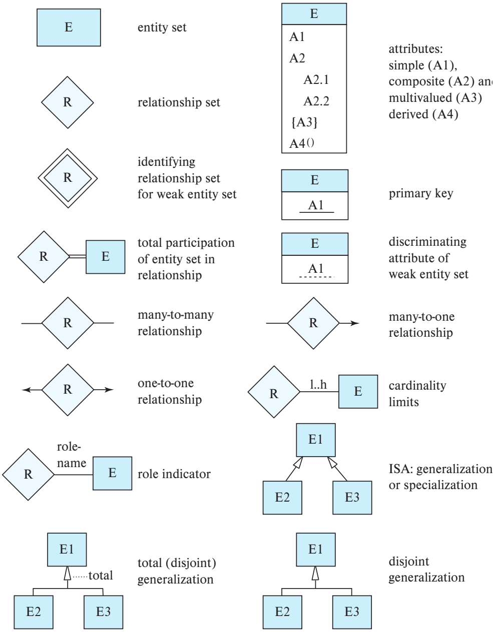


(b)

E-R Design Decisions

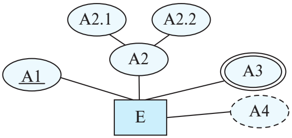
- The use of an attribute or entity set to represent an object.
- Whether a real-world concept is best expressed by an entity set or a relationship set.
- The use of a ternary relationship versus a pair of binary relationships.
- The use of a strong or weak entity set.
- The use of specialization/generalization – contributes to modularity in the design.
- The use of aggregation – can treat the aggregate entity set as a single unit without concern for the details of its internal structure.

Summary of Symbols Used in E-R Notation

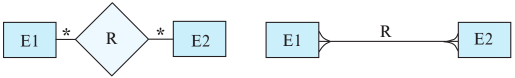


Alternative ER Notations

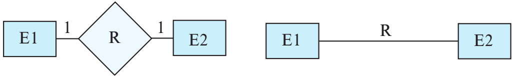
entity set E with
simple attribute A1,
composite attribute A2,
multivalued attribute A3,
derived attribute A4,
and primary key A1



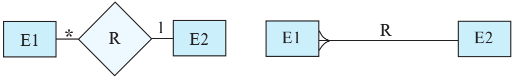
many-to-many
relationship



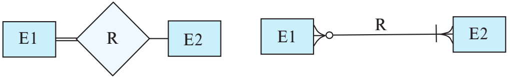
one-to-one
relationship



many-to-one
relationship



participation
in R: total (E1)
and partial (E2)



weak entity set

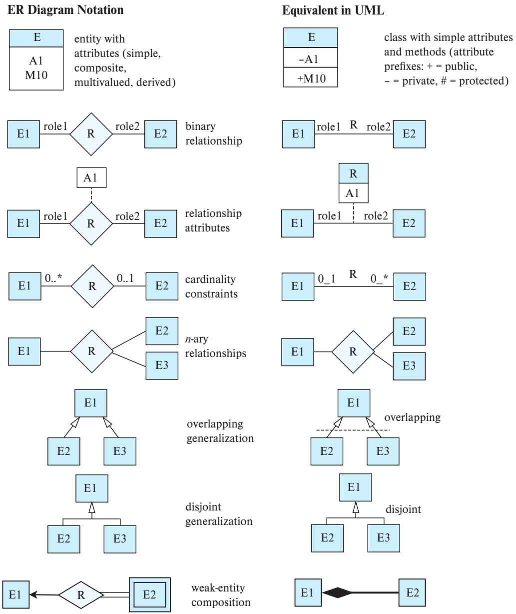
generalization

total
generalization

UML

- UML: Unified Modeling Language.
- UML has many components to graphically model different aspects of an entire software system.
- UML Class Diagrams correspond to E-R Diagram, but some differences.

ER vs. UML Class Diagrams



UML Class Diagrams (Cont.)

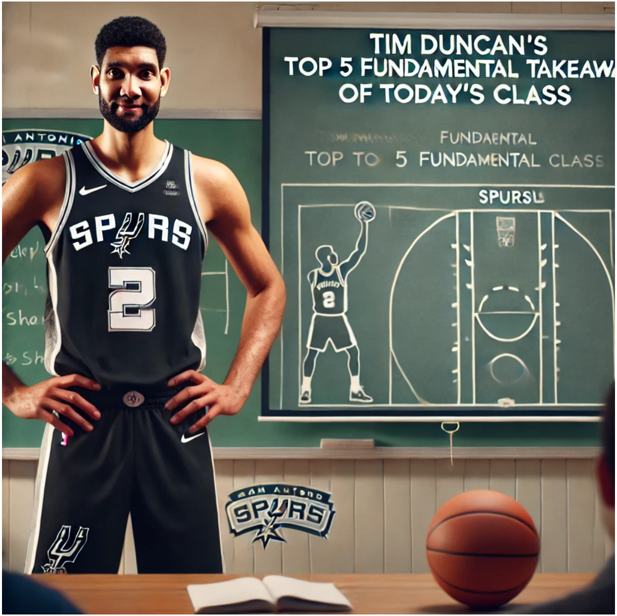
- Note reversal of position in cardinality constraint depiction.
- Generalization can use merged or separate arrows independent of disjoint/overlapping.
- Binary relationship sets are represented in UML by just drawing a line connecting the entity sets. The relationship set name is written adjacent to the line.
- The role played by an entity set in a relationship set may also be specified by writing the role name on the line, adjacent to the entity set.
- The relationship set name may alternatively be written in a box, along with attributes of the relationship set, and the box is connected, using a dotted line, to the line depicting the relationship set.

Other Aspects of Database Design

- Functional Requirements.
- Data Flow, Workflow.
- Schema Evolution.

End of Chapter 6.

TDT5FTOTTC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Top 5 Fundamental Takeaways

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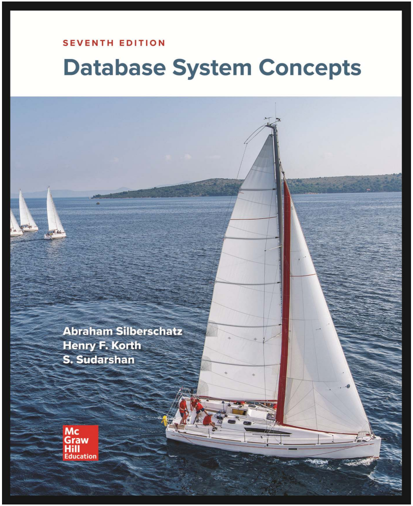
1 **Design Choices and Errors:** Good database design requires thoughtful decisions about how to represent real-world concepts and avoiding redundancy or incomplete modeling.

Database System Concepts



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