DSA5104
Principles of Data Management and Retrieval

Lecture 5: Entity-Relationship Model

Recap

- Aggregation with Null Values
- Nested Subqueries
  - Test for Empty Relations - **exists / not exists**
  - Correlation Name
  - Test for Absence of Duplicate Tuples - **unique / not unique**
  - **with** Clause
  - Scalar Subqueries
- Modification of the Database
  - **delete / insert / update**
    - **Case** Statement for Conditional Updates
- Join Expressions
  - Natural join
  - Inner join
  - Outer join (left, right, full)
- Integrity Constraints
  - **Not null / unique / check(P)**
  - FK constraint

How to Use a DBMS?

- Answer: SQL queries!
- Problem: Only if someone has already defined the schema!
- Question: How hard could that be? (Just define some tables and columns…)

How to Design a Database?

Not a database system

Steps in Database Design

- **Requirements Analysis**
  - Data needs; what must database do?
  - For small applications with requirements *fully* understood, db designers may decide the relations (attributes and constraints) to create directly
  - For real-world applications with high complexity, db designers need to interact extensively with domain experts and prospective users of the application to gain the full picture
- **Conceptual Design**
  - High level description (often done w/ER model)
- **Logical Design**
  - Translate ER into DBMS data model
- **Schema Refinement**
  - Consistency, normalization
- **Physical Design** - Indexes, disk layout
- **Security Design** - Who accesses what, and how

Steps in Database Design

- **Requirements Analysis**
  - User needs; what must database do?
- **Conceptual Design**
  - High level description (often done w/ER model)
  - Choose a data model, apply the concepts of the chosen data model to translate user requirements into a conceptual schema of the database
  - E.g., Entity-Relationship (ER) model → Specify entities (attributes) and their relationships, as well as constraints on entities and relationships.
- **Logical Design**
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- **Conceptual Design**
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- **Logical Design**
  - Translate ER into DBMS data model
  - Map the high-level conceptual schema onto the implementation data model of the database system
  - E.g., Map the conceptual schema defined using Entity-Relationship Model (ER Diagram) into a relation schema based on relational model (Schema Diagram)
- **Schema Refinement**
  - Consistency, normalization
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Design Phases

- For small applications - application requirements fully understood
  - Database designers may decide the relations (attributes and constraints) to create directly

- For real-world applications (high complexity) - partial understanding of data needs
  - Database designers need to interact with users of the application to gain the full picture

- Initial Phase - characterize fully the data needs of prospective database users
  - Database designers need to interact extensively with domain experts and users
  - Outcome: specification of user requirements (in textual descriptions)

Design Phases (Cont.)

- Second phase - choosing a data model
  - Applying the concepts of the chosen data model.
  - To translate user requirements into a conceptual schema of the database.
    - E.g., Entity-Relationship (ER) model → Specify entities (attributes) and their relationships, as well as constraints on entities and relationships.

- 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.
    - Map the high-level conceptual schema onto the implementation data model of the database system
    - E.g., Map the conceptual schema defined using Entity-Relationship Model into a relation schema based on relational model
  - Physical Design – Deciding on the physical layout of the database
    - E.g., the form of file organization and choice of index structures

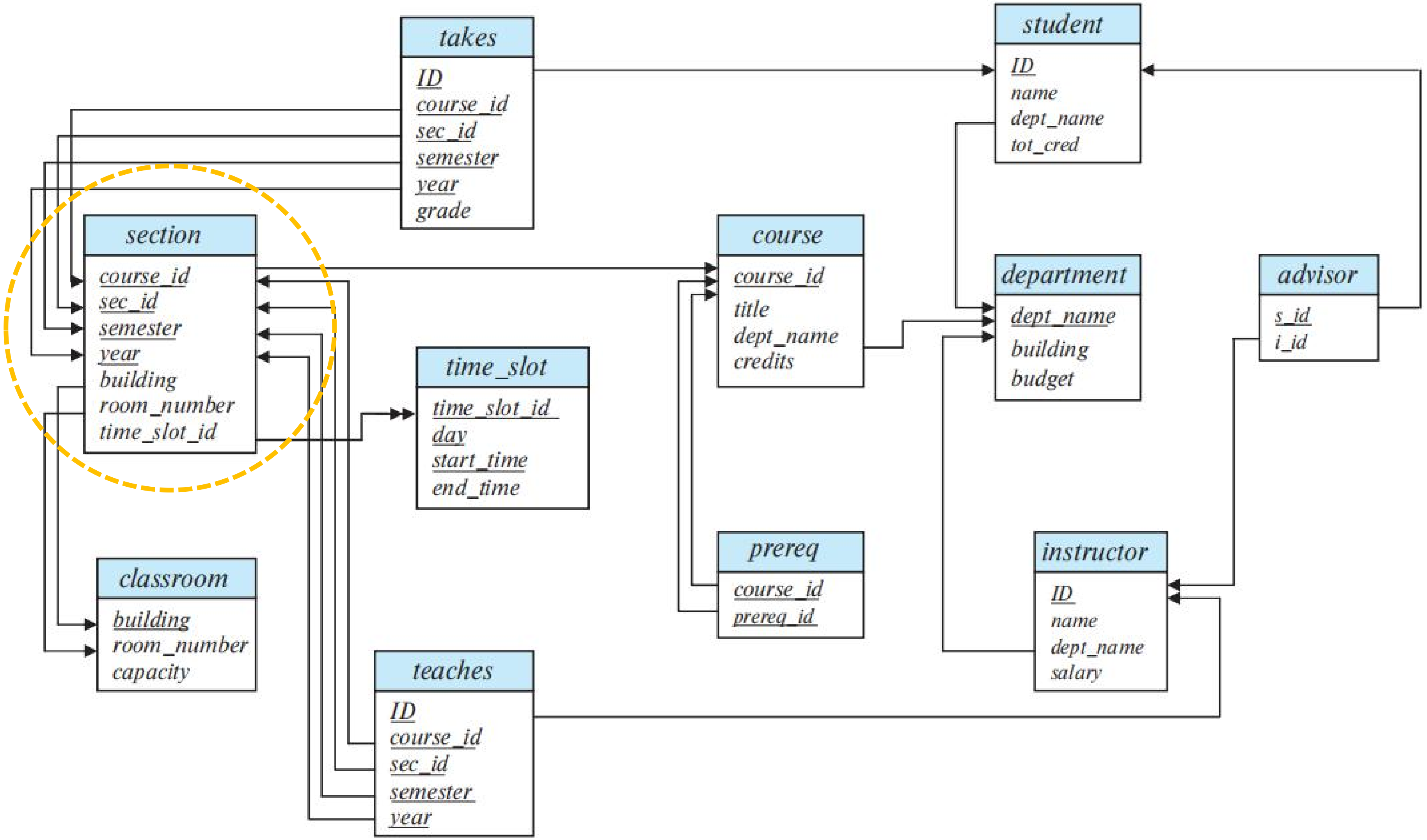
Design Alternatives

- 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
    - E.g., store course name repeatedly in *section* relation
  - **Incompleteness**: a bad design may make certain aspects of the enterprise difficult or impossible to model.
    - E.g., maintain all course info in *section* relation without *course* relation → Hard to store info for new course unless offered (or, use null values)
    - Lose info of a particular course if all sections are deleted.

- Avoiding bad designs is not enough. There may be a large number of good designs from which we must choose.

Customer ⟷ Sale ⟷ Product

Schema Diagram for University Database



Design Approaches

- Entity Relationship (ER) Model
  - 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
  - Formalize what designs are bad, and test for them

Describing data - Data Models

- **Data Model** - collection of *concepts* for describing data.

- **Schema -** description of a particular collection of data, using a given data model.

- **Relational model**
  - Main concepts - *relation* (table), attributes and tuples
  - Every relation has a schema
    - Describes the attributes
    - Specifies attribute names and domains

- **Entity-Relationship (ER) model**
  - Main concepts - entity set, relationship set & attributes
  - Schema - ER diagram (visual schema)

Data Models

- **Relational model** is a great formalism
  - Clean & common
  - But a bit detailed for design time
  - A bit fussy for brainstorming
  - Hard to communicate to "customers"

- **Entity-Relationship (ER) model** - a graphical "shim" over relational model
  - Translates to relational
  - Handy for design
  - Visual
  - Slightly higher level

Steps in Database Design

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Conceptual Design

- ER model fits in at the conceptual design step of database design

- What are the entities and relationships?
  - And what info about E’s & R’s should be in DB?

- What integrity constraints (“business rules”) hold? i.e.,
  - What must be true of these entities?
  - What must be true of the way entities relate to each other?

Outline of the ER Model

ER Model - Database Modeling

- The ER data mode was developed to facilitate database design by allowing specification of an **enterprise schema** that represents the overall logical structure of a database.

- The ER data model employs three basic concepts:
  - Entity sets,
  - Relationship sets,
  - Attributes.

- The ER model also has an associated diagrammatic representation, the **ER diagram**, which can express the overall logical structure of a database graphically.

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

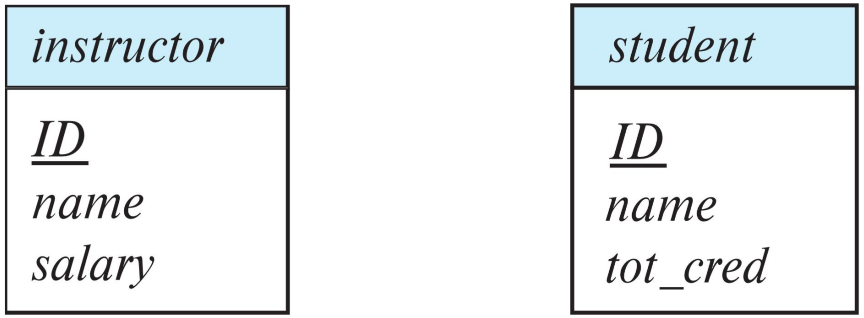
- An entity is represented by a set of **attributes**; i.e., descriptive properties possessed by all members of an entity set.
  - Example:

    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



  - **Extension** of the entity set - the actual collection of entities belonging to the entity set.
    - Extension: entity set → Instance: relation

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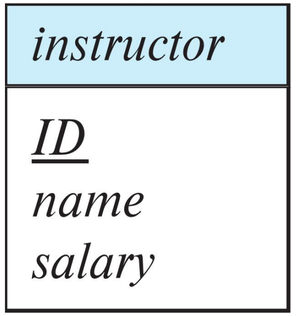

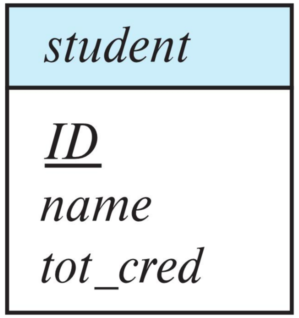

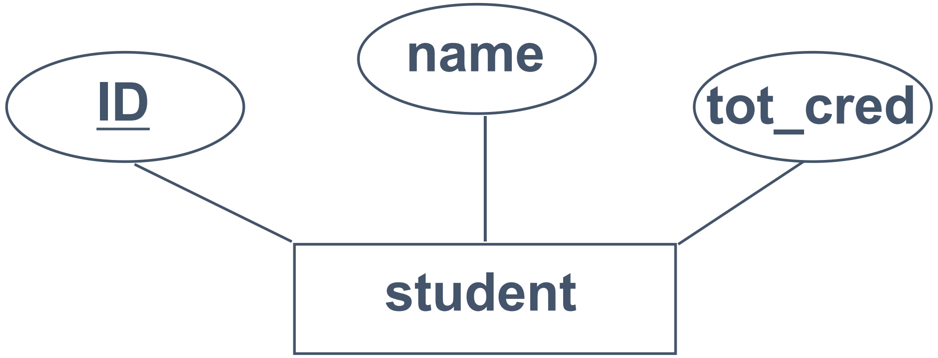

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Relationship Sets

- A **relationship** is an association among several entities

  Example:

  Instructor Crick (ID = 76766, instructor entity) is an *advisor* (relationship) of to student Tanaka (ID = 98988, student entity).

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

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

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

  - Example:

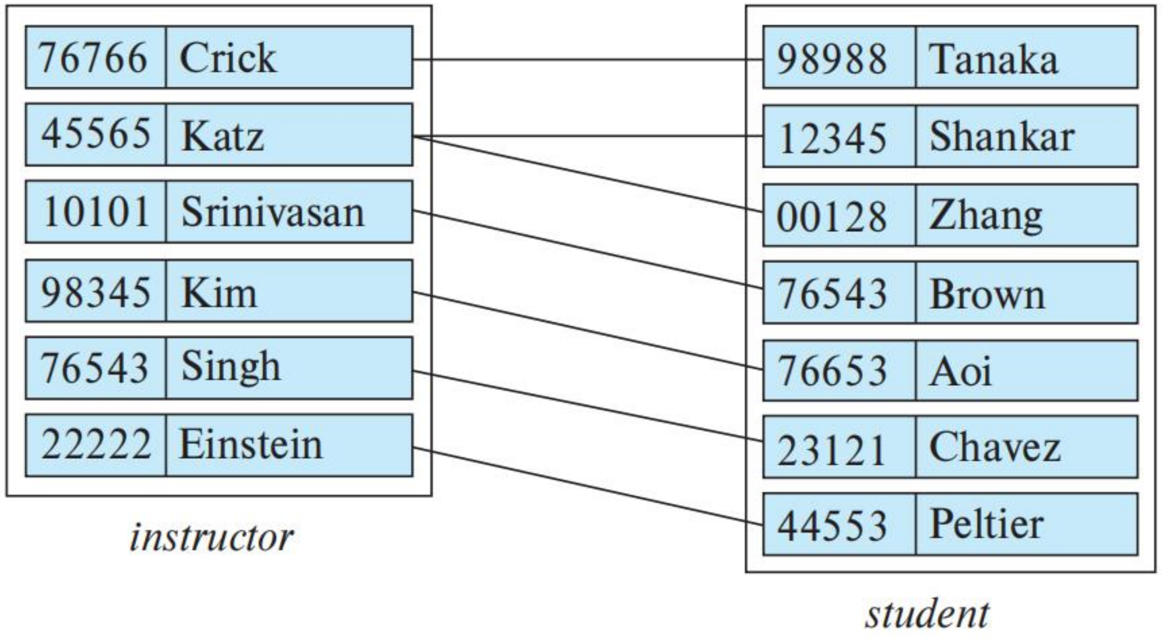
    $(98988, 76766) \in advisor$

- **Participation** - the entity sets $E_1, E_2, \ldots, E_n$ participate in relationship set R.

Relationship Sets (Cont.)

- *Example*: we define the relationship set *advisor* to denote the associations between students and the instructors who act as their advisors.

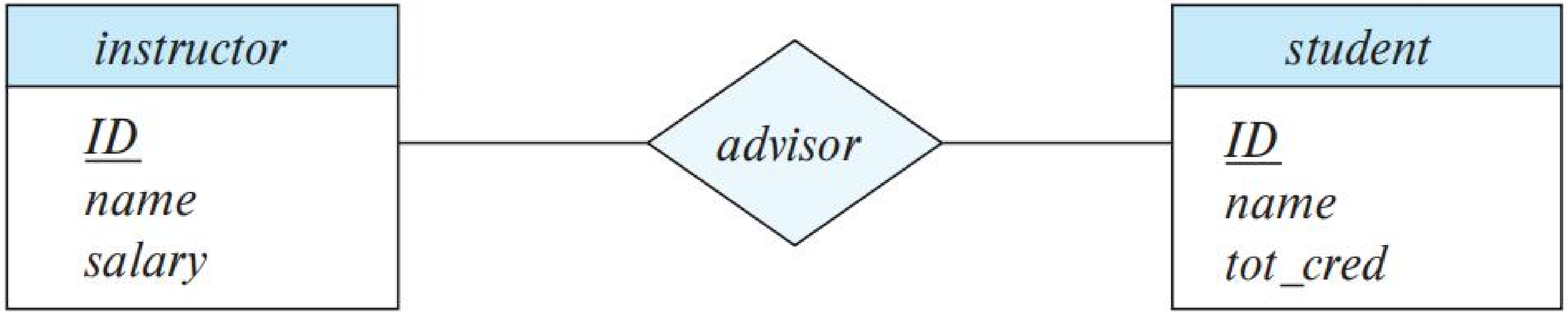
- Pictorially, we draw a line between related entities.



The *instructor* entity Crick (ID = 76766) and the *student* entity Tanaka (ID = 98988) **participates** in a **relationship instance** of *advisor.*

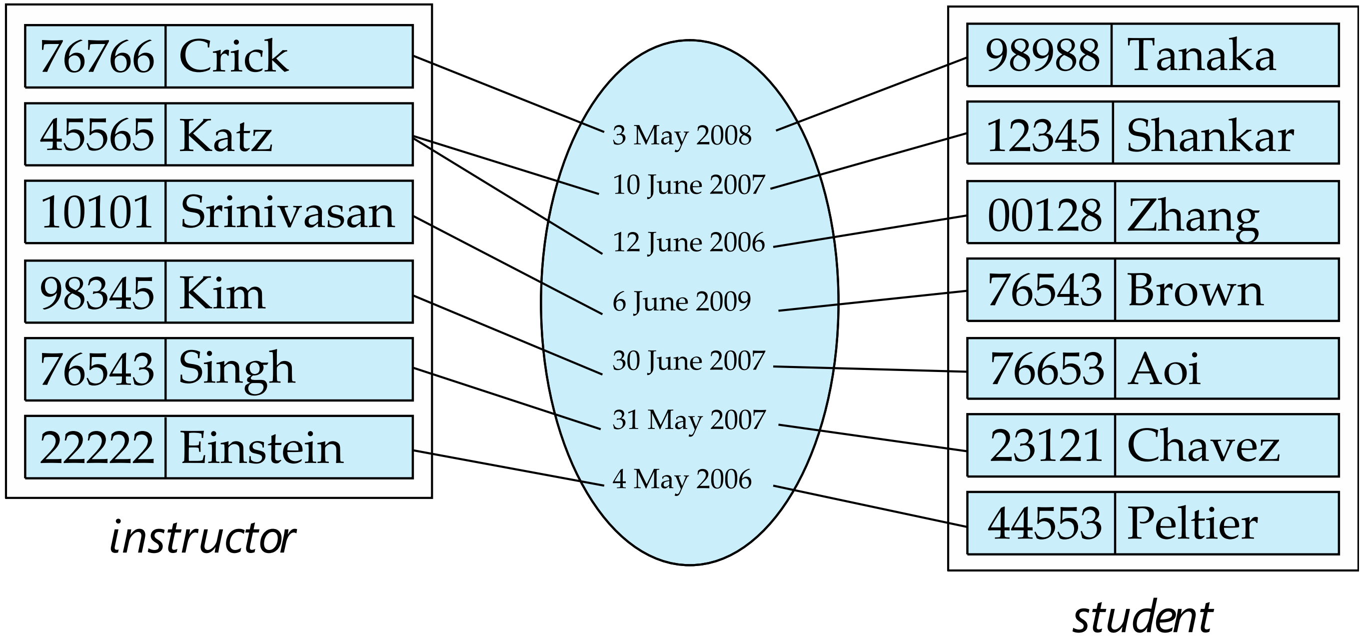
Representing Relationship Sets via ER Diagram

- Diamonds represent relationship sets.

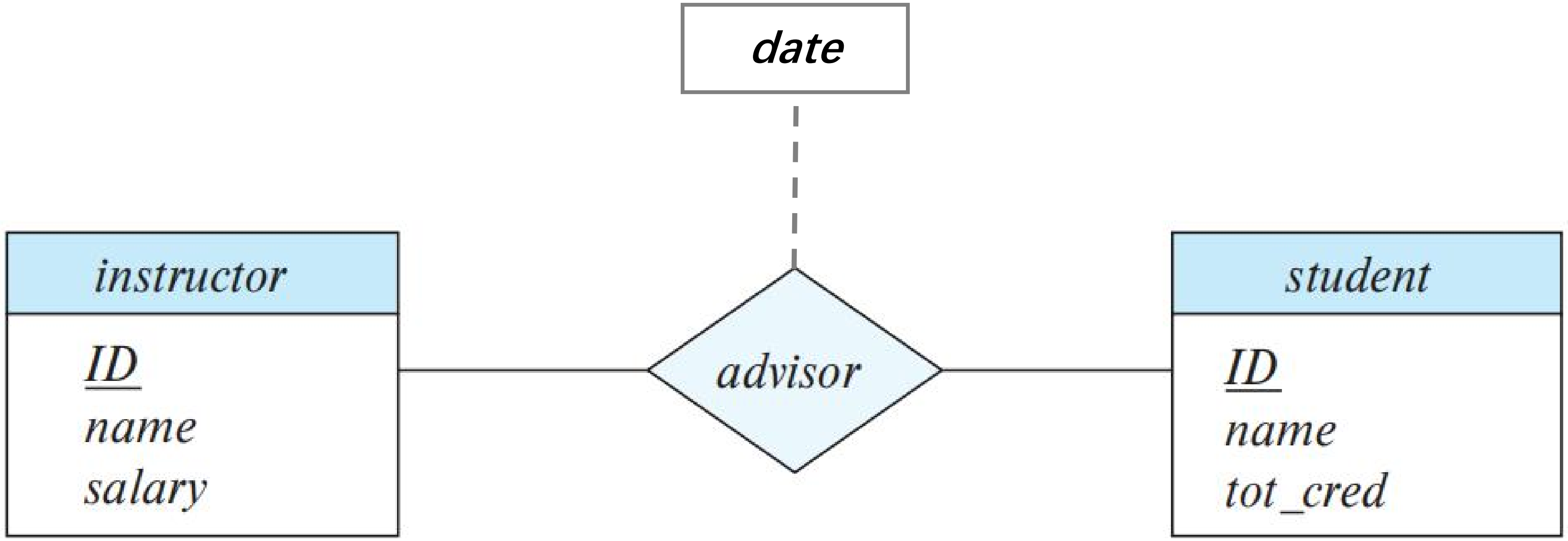


Relationship Sets (Cont.)

- 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 in ER Diagram

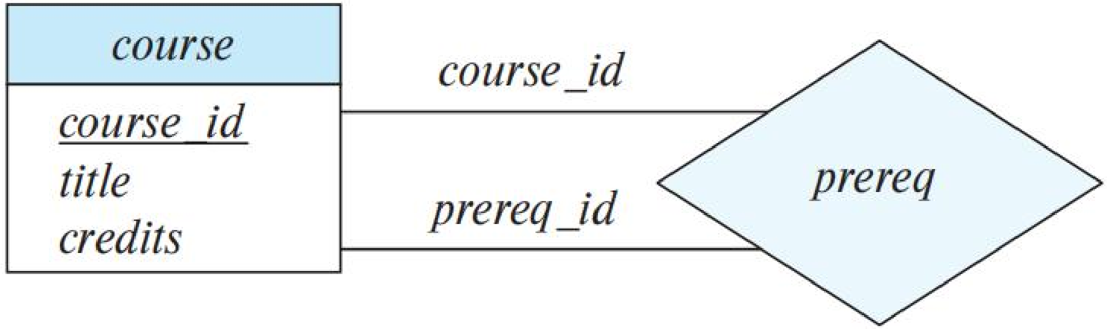


Roles

- **Role** - the function that an entity plays in a relationship

- Entity sets of a relationship need not be distinct
  - The *same* entity set participates in a relationship set more than once, in different roles.
  - Sometimes called a ‘recursive’ relationship set
  - Needs to specify the role names explicitly

- The labels “*course_id*” and “*prereq_id*” are called **roles**.



Degree of a Relationship Set

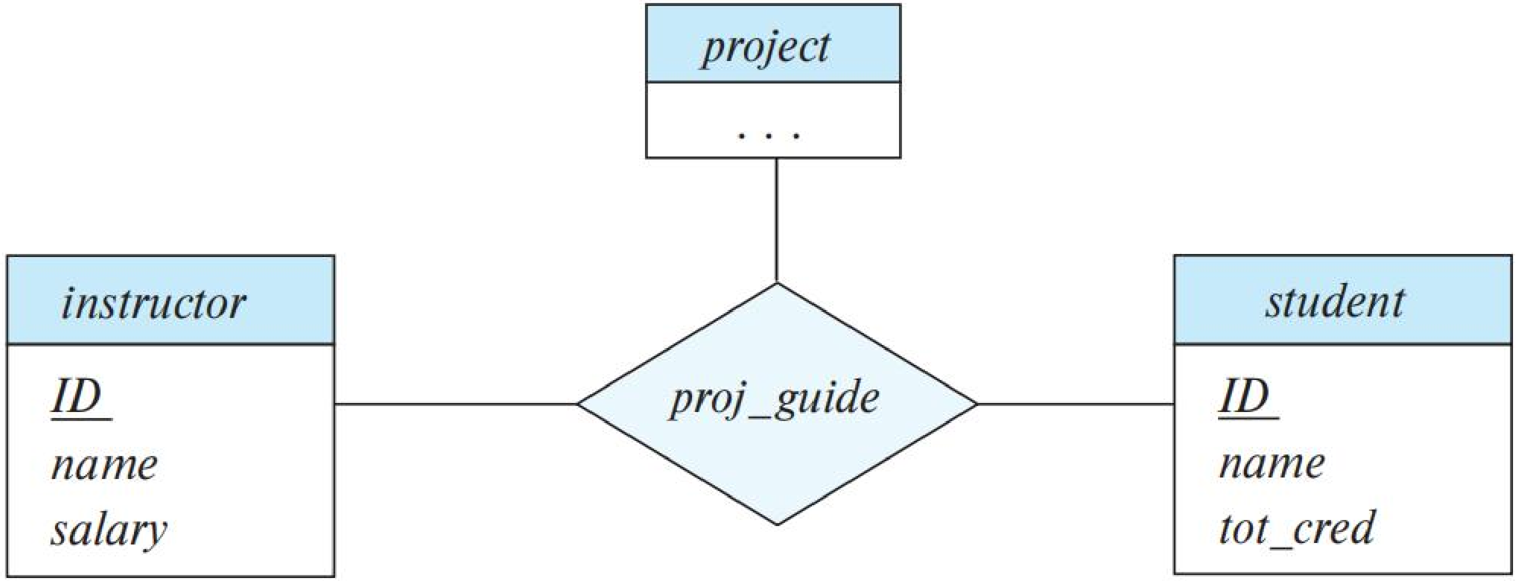
- Binary relationship
  - Involve two entity sets (or degree two).
  - Most relationship sets in a database system are binary.
  - E.g., binary relationship sets:
    - *advisor* between *student* & *instructor*
    - *takes* between *student* & *section*

- Relationships between more than two entity sets are rare.
  - 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

- There are occasions when it is more convenient to represent relationships as non-binary.

- E.g., ER Diagram with a Ternary Relationship



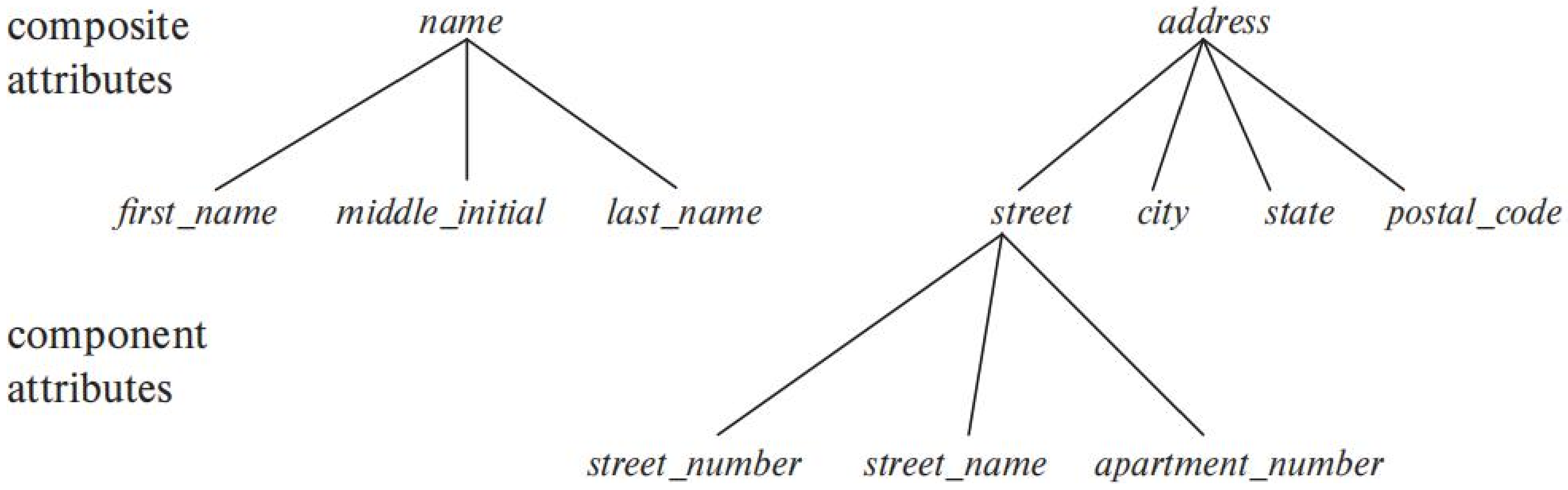
Complex Attributes

- 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* coudl be calculated from *given date_of_birth* and the current date
    - Example: *no_students_advised* could be calculated from *sid* of *advisor*
    - The value of a derived attribute could be computed when required.

- **Domain** (or **value set**) – the set of permitted values for each attribute

Composite Attributes

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



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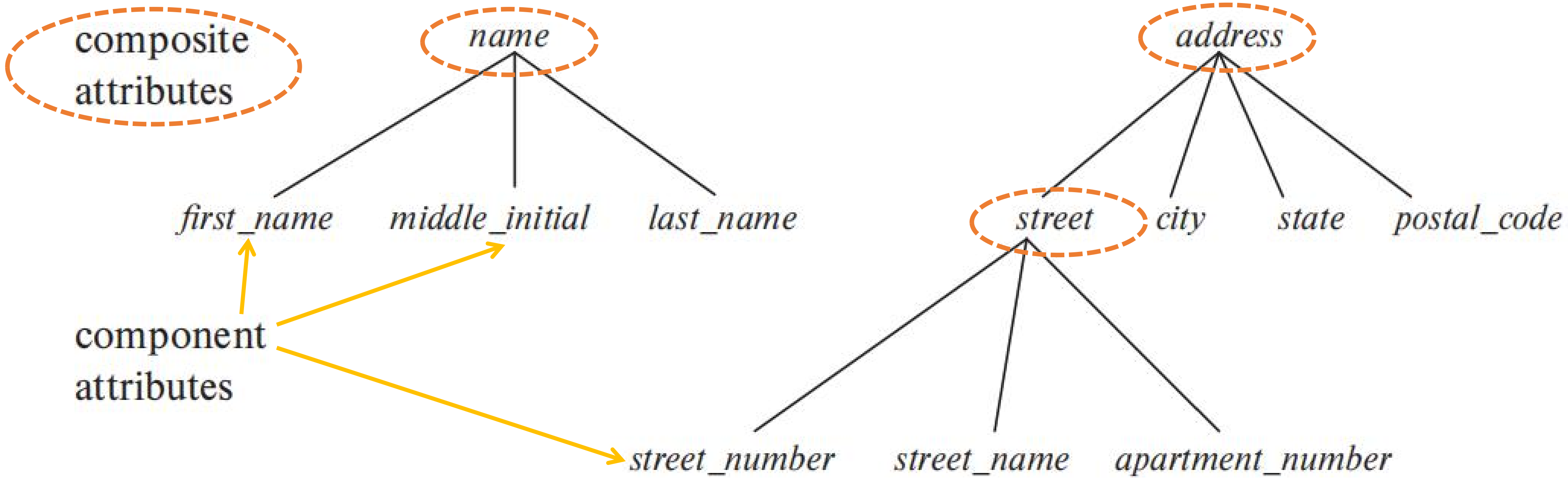
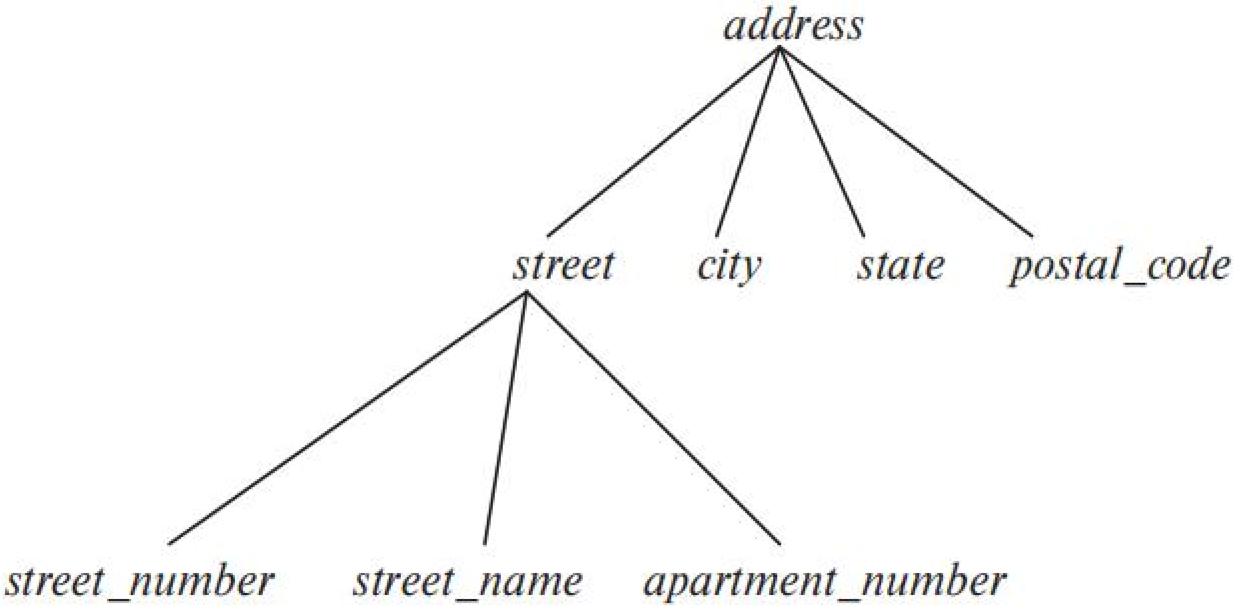
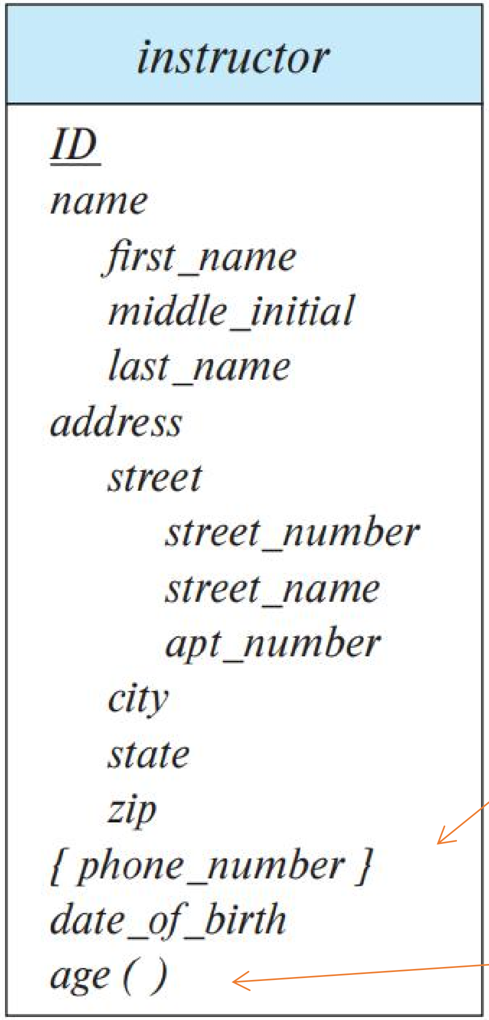


Representing Complex Attributes in ER Diagram





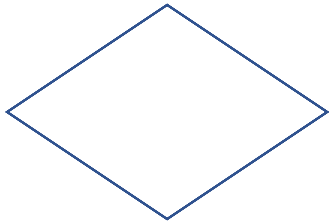
A multivalued attribute denoted as "{phone_number}"

A derived attribute, *"age* ( )"

Quick Check

- In ER diagrams, a rectangle is:
  - Entity Set? Relationship Set? Attribute?

- In ER diagrams, a diamond is:
  - Entity Set? Relationship Set? Attribute?



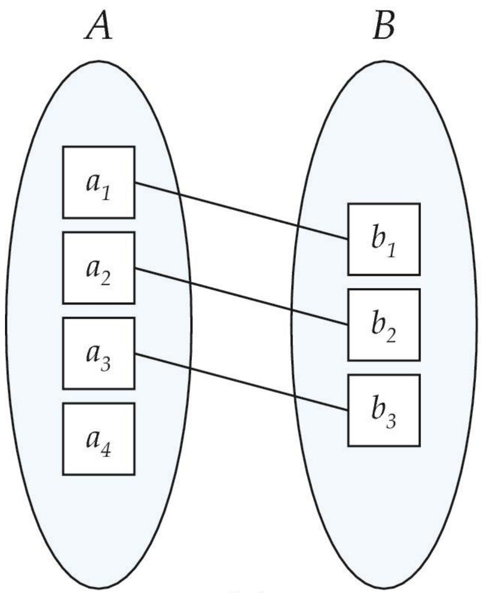
- Which of the following can exist on its own?
  - Entity Set
  - Relationship Set
  - Attribute

Mapping Cardinality Constraints

- **Mapping Cardinalities** (or cardinality ratios)
  - Express the number of entities to which another entity can be associated via a relationship set.
  - Most useful in describing binary relationship sets.

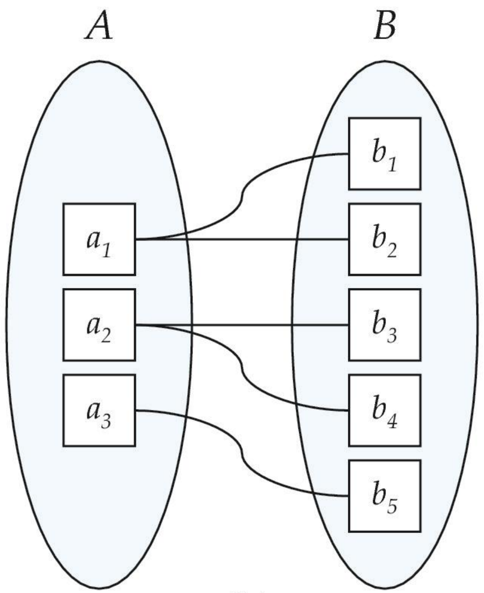
- For a binary relationship set, the mapping cardinality must be one of the following types:
  - One to one
  - One to many
  - Many to one
  - Many to many

Mapping Cardinalities



(a)

One to one

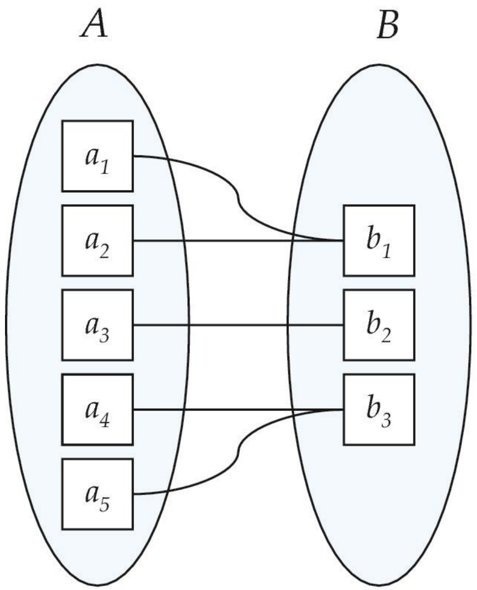


(b)

One to many

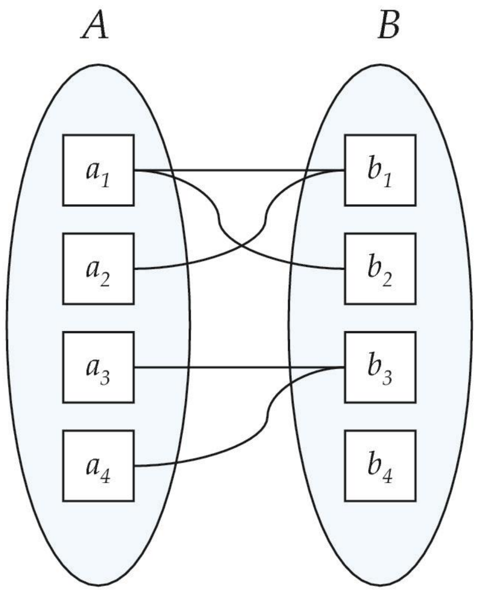
Note: Some elements in *A* and *B* may not be mapped to any elements in the other set

Mapping Cardinalities (Cont.)



(a)

Many to one



(b)

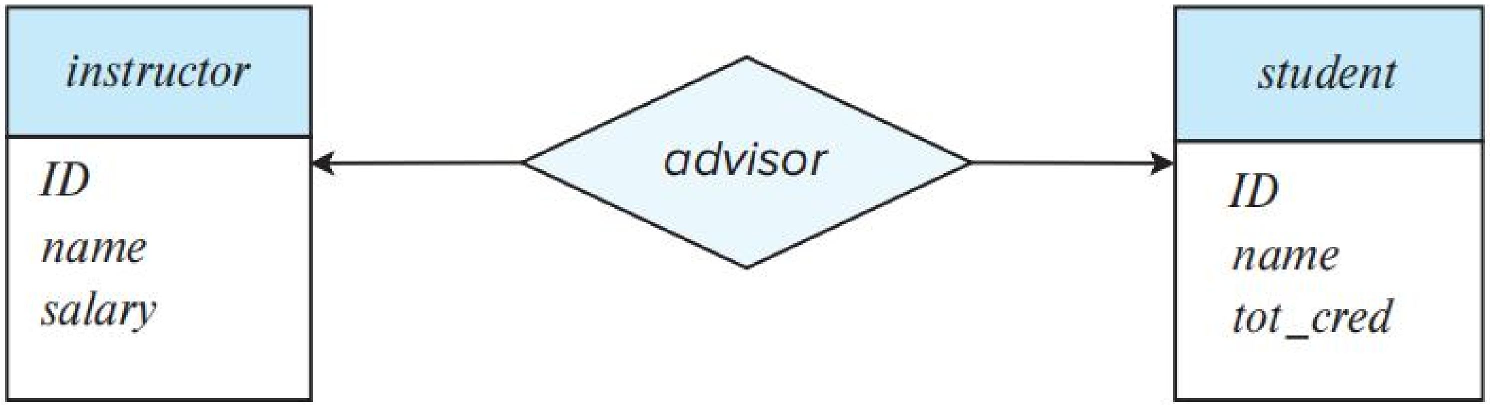
Many to many

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

Representing Cardinality Constraints in ER Diagram

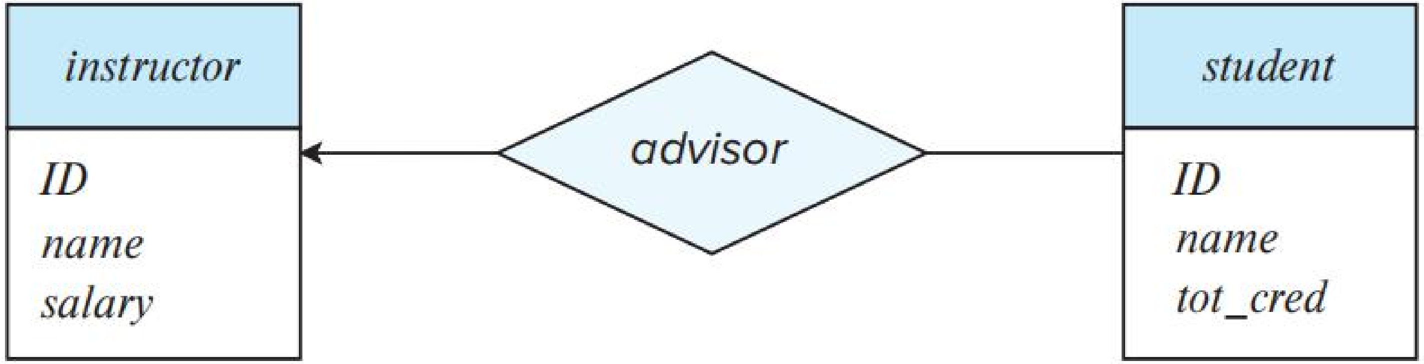
- We express cardinality constraints by drawing either a directed line (→), signifying "one," or an undirected line (—), signifying "many," between the relationship set and the entity set.

- One-to-one relationship between an *instructor* and a *student* :
  - A student is associated with at most one *instructor* via the relationship *advisor*
  - A *student* is associated with at most one *department* via *stud_dept*



One-to-Many Relationship

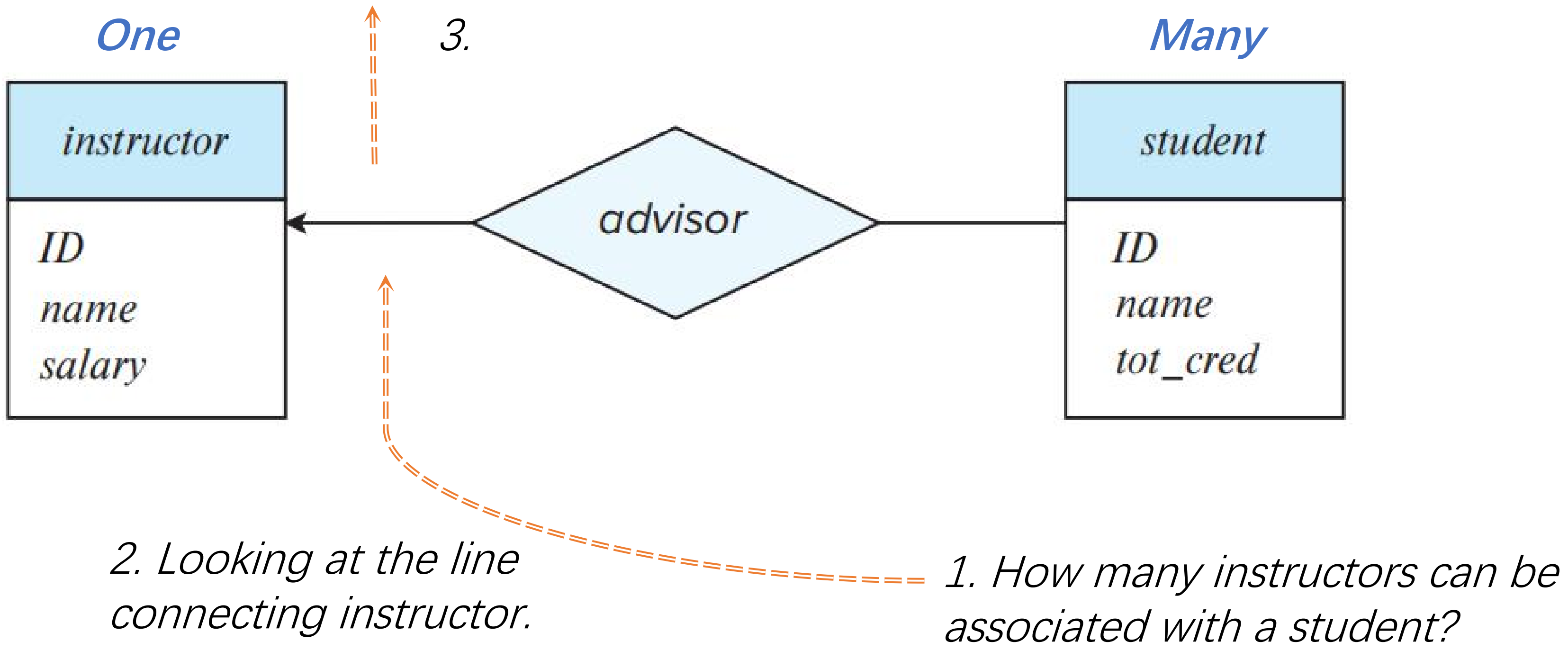
- One-to-many relationship between an *instructor* and a *student*
  - An instructor is associated with several (including 0) students via *advisor*
  - A student is associated with at most one instructor via *advisor*,



One-to-Many Relationship

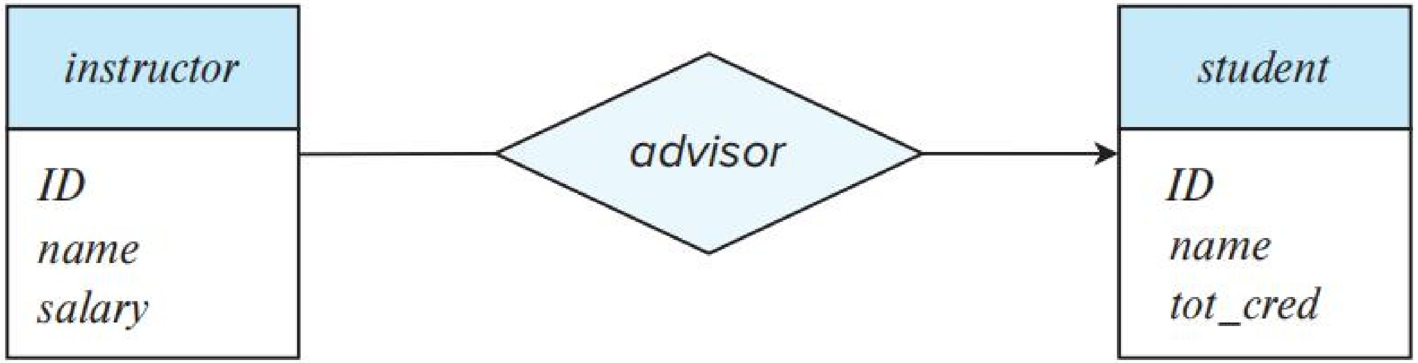
- One-to-many relationship between an *instructor* and a *student*
  - An instructor is associated with several (including 0) students via *advisor*
  - A student is associated with at most one instructor via *advisor*,

We draw a directed line from the relationship set to the "***one***" side of the relationship.



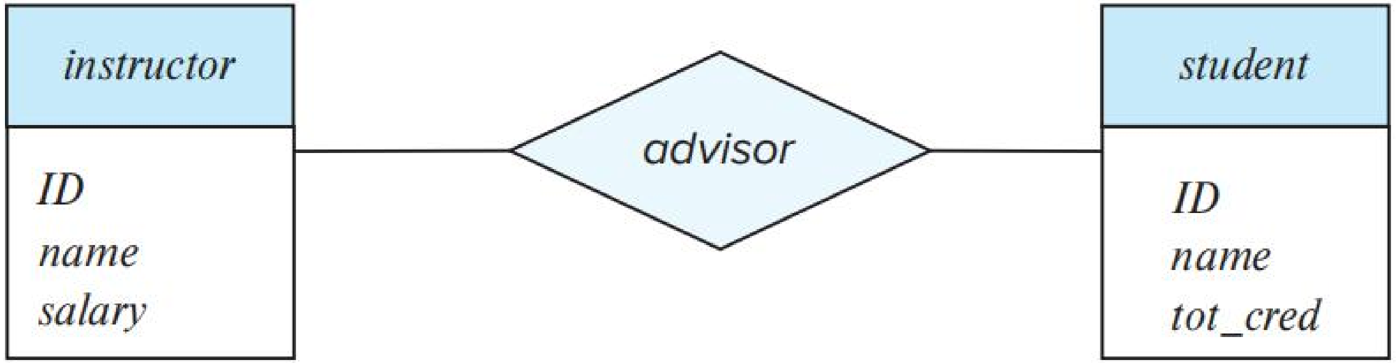
Many-to-One Relationships

- 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*



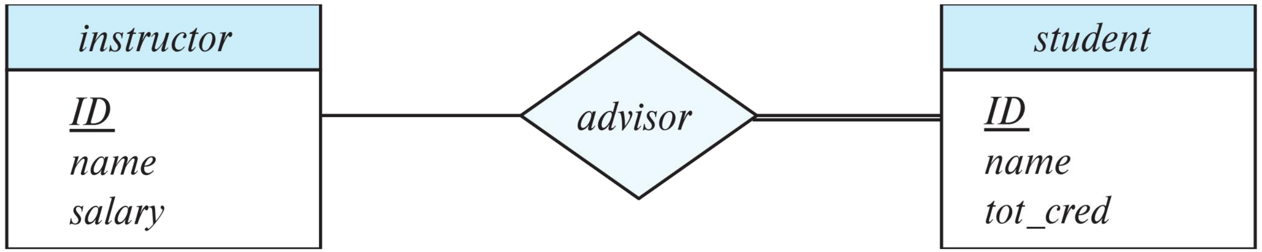
Many-to-Many Relationship

- 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

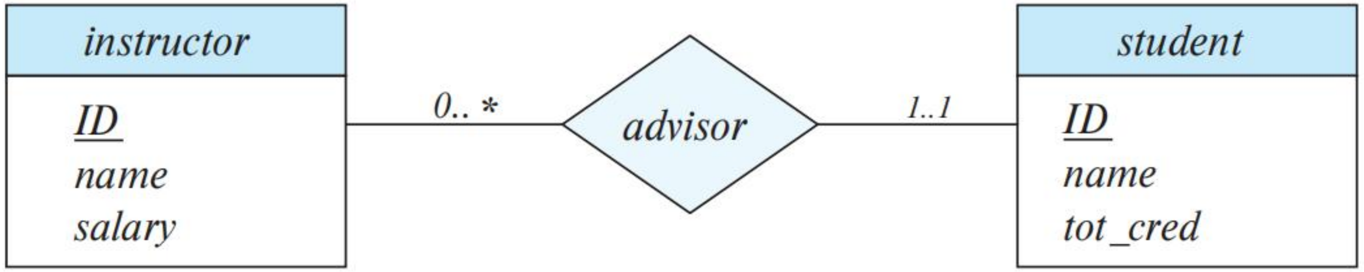


  - E.g., participation of *student* in *advisor* relation is total
    - i.e., every *student* must have an associated *instructor*

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

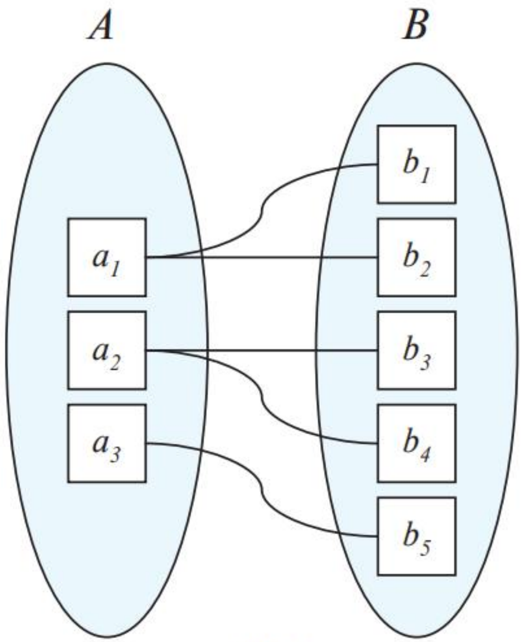
Notation for Expressing More Complex Constraints

- 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
  - Note: The relationship *advisor* is one-to-many from *instructor* to *student*

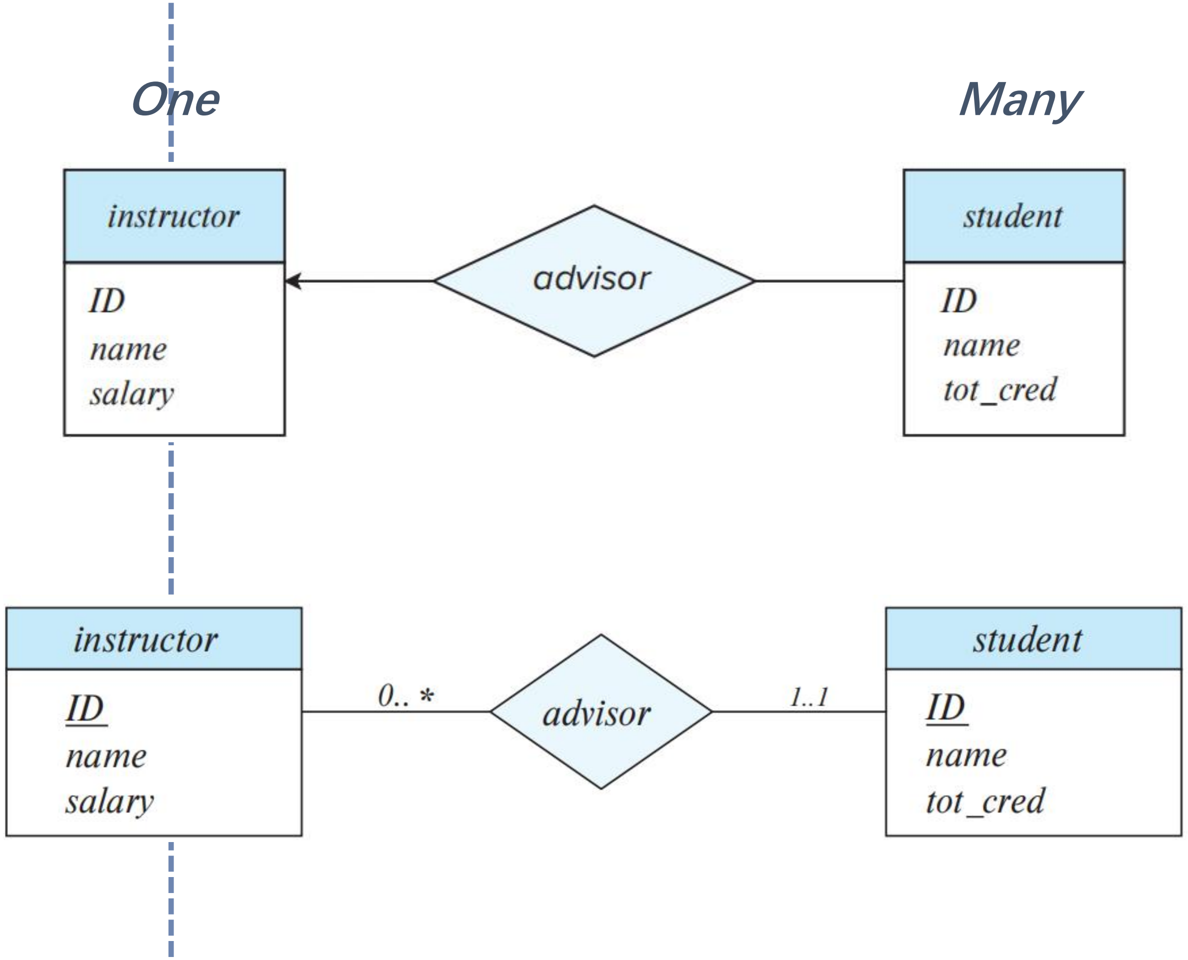
Different Representations in ER Digram



(b)

One to many

Note: Some elements in *A* and *B* may not be mapped to any elements in the other set



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*

Primary Key

- Primary keys provide a way to specify how entities and relationships are distinguished.

- We will consider:
  - Entity sets
  - Relationship sets.
  - Weak entity sets

Primary key for Entity Sets

- Conceptually, individual entities are distinct.
- From database perspective, the differences among them must be expressed in terms of their attributes.
- The values of attributes 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.
  - The same concepts apply as keys (superkeys, candidate keys and primary keys) for relational schemas

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, .. E_n
  - The primary key for *R* is consists of the union of the primary keys of entity sets E_1, E_2, ..E_n
- 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
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- 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
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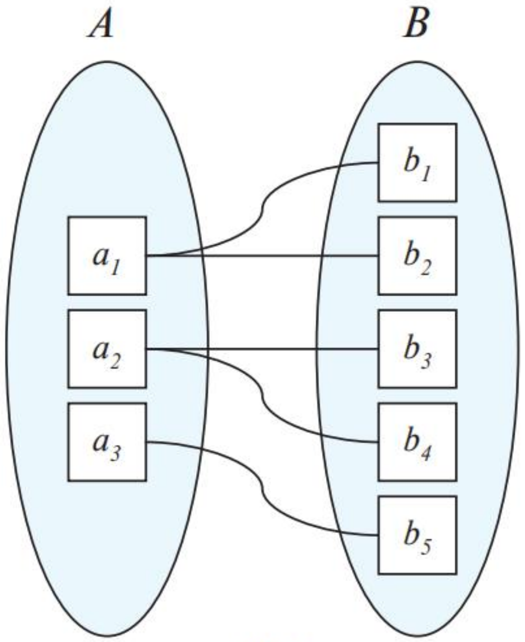
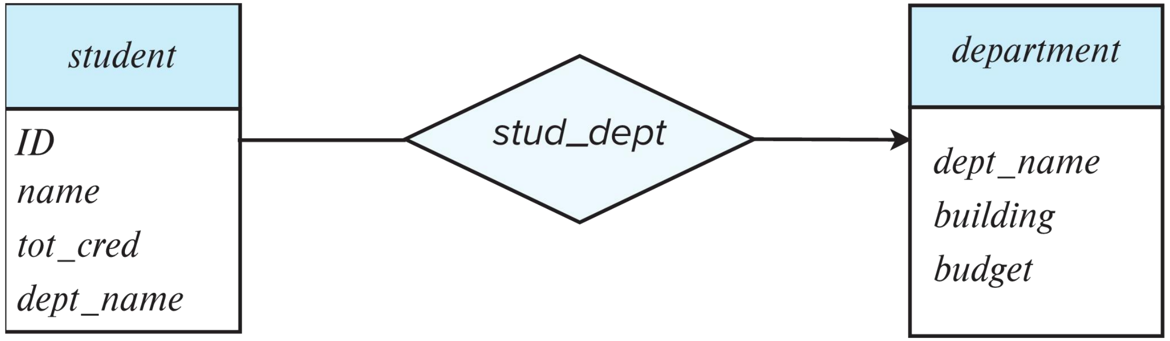
    One to many
- One-to-one relationships
  - The primary key of either one of the participating entity sets forms a minimal superkey, and either one can be chosen as the primary key.



(b)

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

Redundant Attributes

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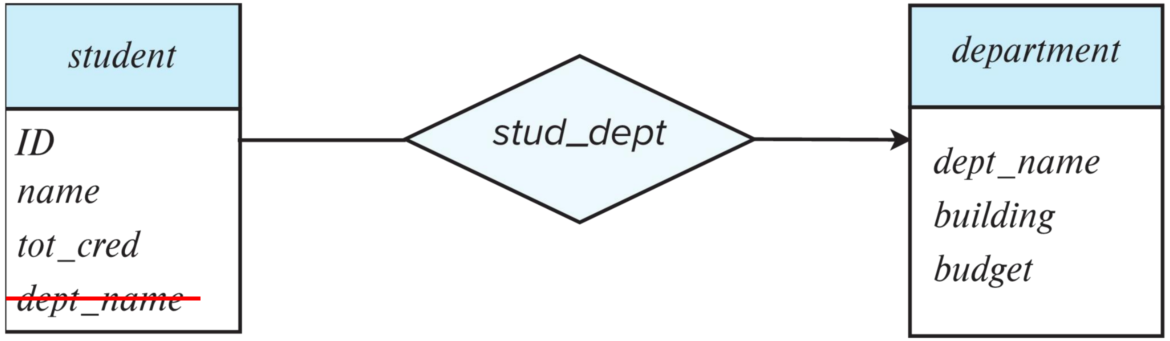
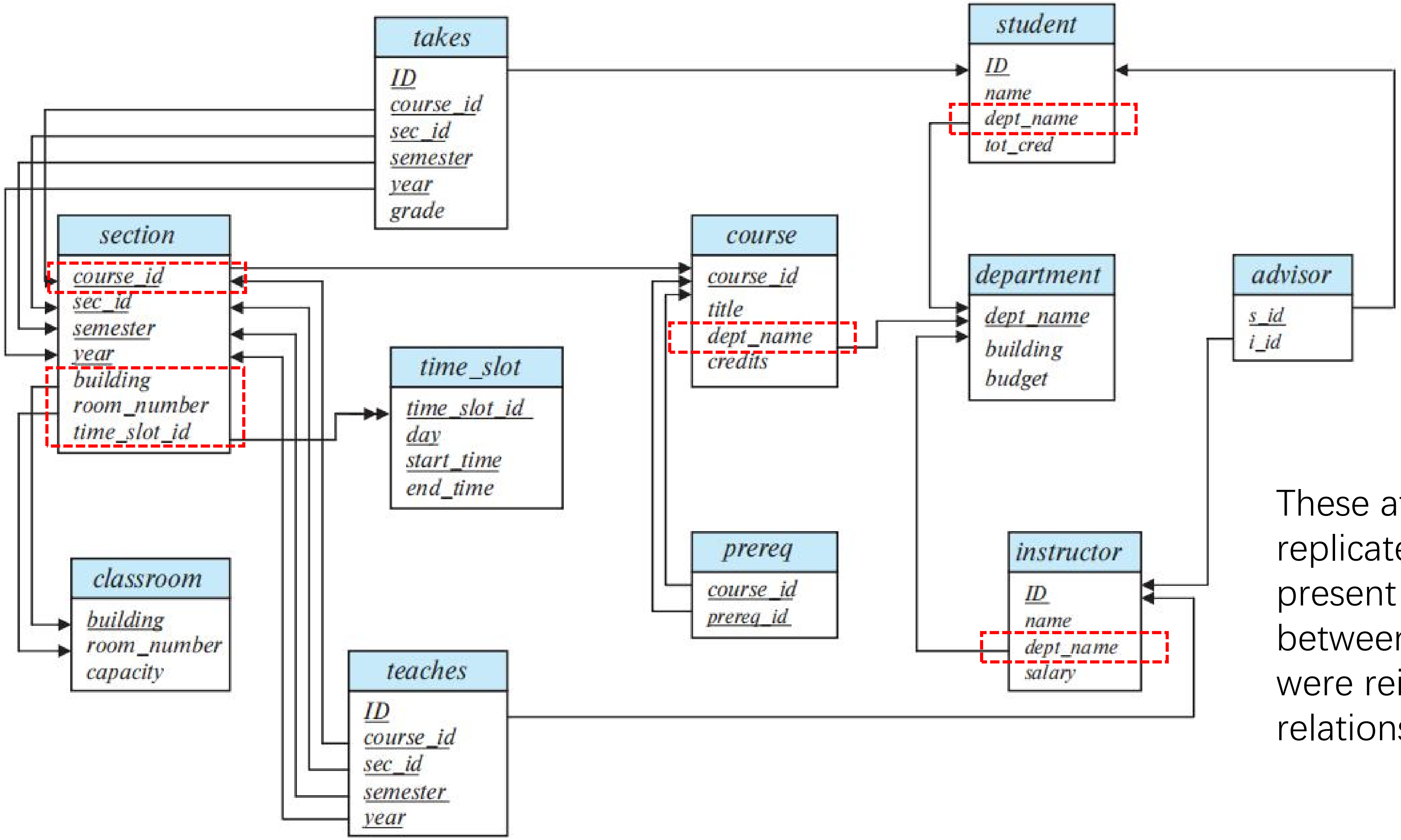


(a) Incorrect use of attribute

More Examples of Redundant Attributes

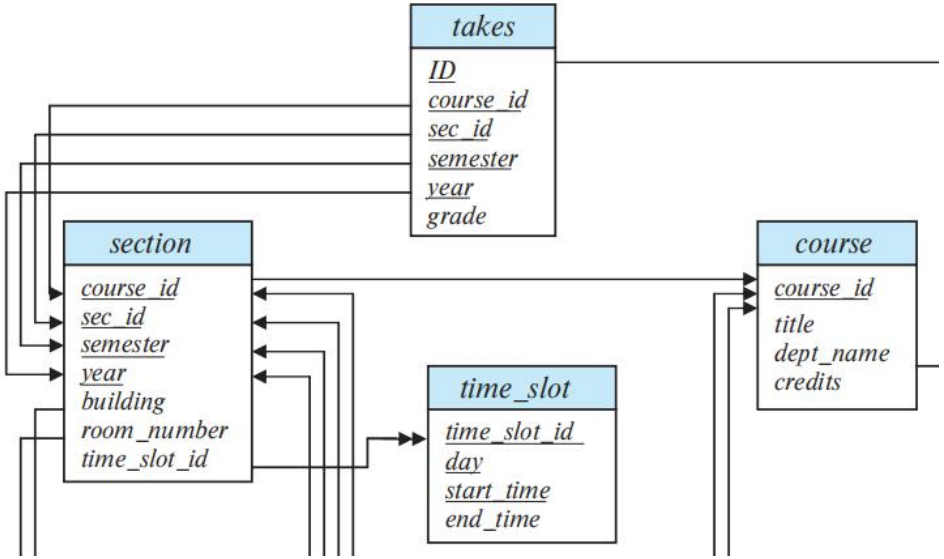


These attributes replicates information present in relationships between entities, but were reintroduced into relations.

Weak Entity Sets

- Consider a *section* entity, which is uniquely identified by a *course_id*, *semester, year*, and *sec_id*.

- There is a relationship set *sec_course* between entity sets *section* and *course*.
  - Clearly, section entities are related to course entities.
  - The attribute *course_id* replicates information present in the relationship sec_course and is therefore **redundant.**
  - ***Or:*** The information in *sec_course* seems **redundant**, since *section* already has an attribute *course_id*



- 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.

The *Section* Relation

- Each course in a university may be offered multiple times, across different semesters, or even within a semester.
- *Section* - a relation to describe each individual offering, or section, of the class.
- Instance

course_id	*sec_id*	*semester*	*year*	*building*	*room_number*	*time_slot_id*
BIO-101	1	Summer	2017	Painter	514	B
BIO-301	1	Summer	2018	Painter	514	A
CS-101	1	Fall	2017	Packard	101	H
CS-101	1	Spring	2018	Packard	101	F
CS-190	1	Spring	2017	Taylor	3128	E
CS-190	2	Spring	2017	Taylor	3128	A
CS-315	1	Spring	2018	Watson	120	D
CS-319	1	Spring	2018	Watson	100	B
CS-319	2	Spring	2018	Taylor	3128	C
CS-347	1	Fall	2017	Taylor	3128	A
EE-181	1	Spring	2017	Taylor	3128	C
FIN-201	1	Spring	2018	Packard	101	B
HIS-351	1	Spring	2018	Painter	514	C
MU-199	1	Spring	2018	Packard	101	D
PHY-101	1	Fall	2017	Watson	100	A

Schema
section (<u>course_id</u>, <u>sec_id</u>, <u>semester</u>, <u>year</u>, building, room number, time slot id)

Weak Entity Sets (Cont.)

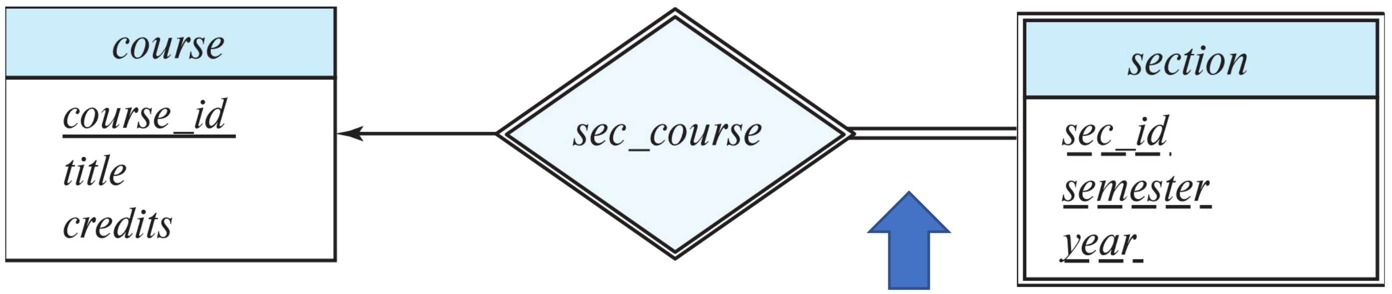
- An entity set that is not a weak entity set is termed a **strong entity set**.
- Every weak entity must be associated with an identifying entity; that is, the weak entity set is said to be **existence dependent** on the identifying entity set.
- The identifying entity set is said to **own** the weak 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.

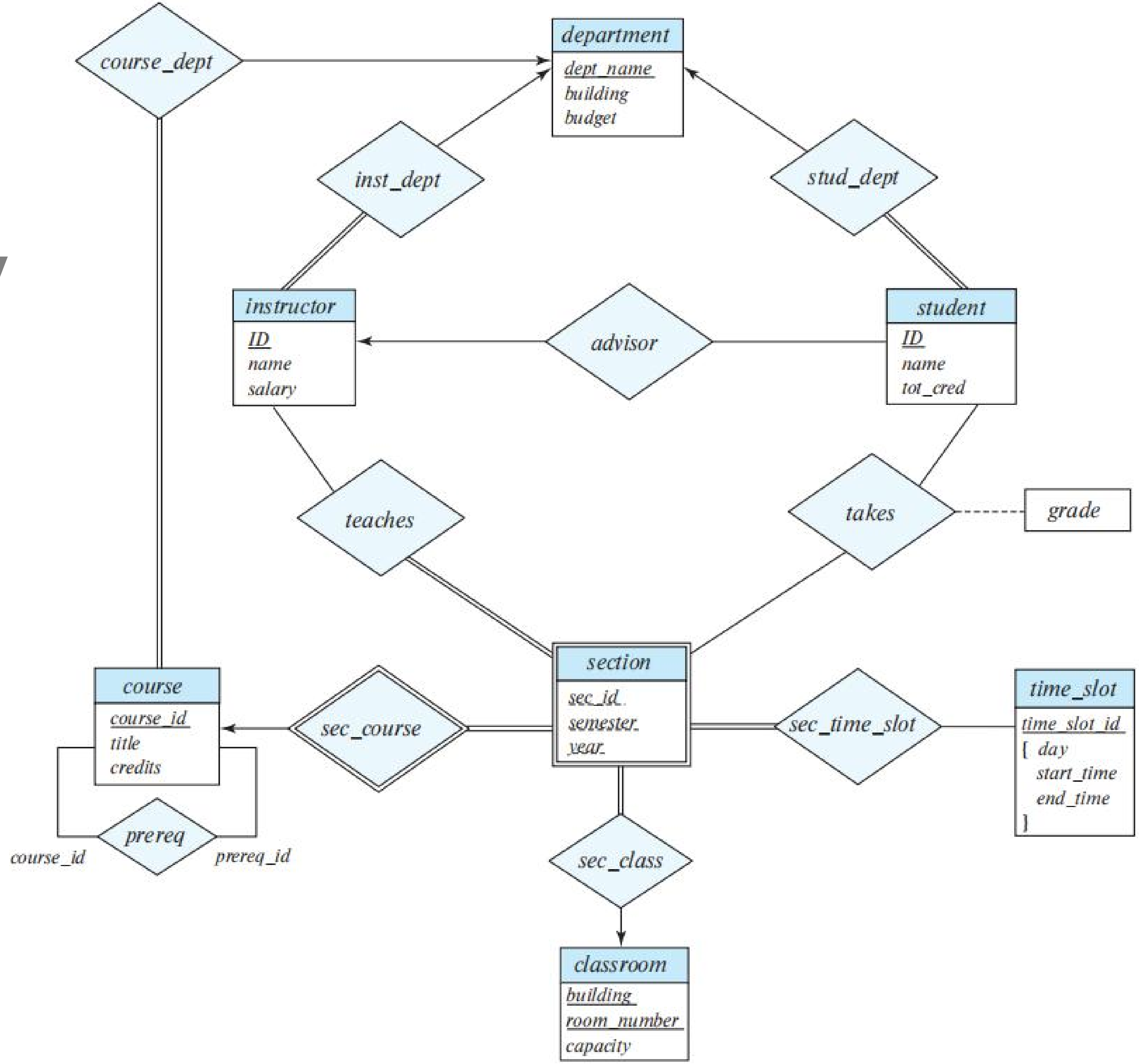
- The relationship set connecting the weak entity set to the identifying strong entity set is depicted by a double diamond.

- Primary key for *section* – (*course_id, sec_id, semester, year*)



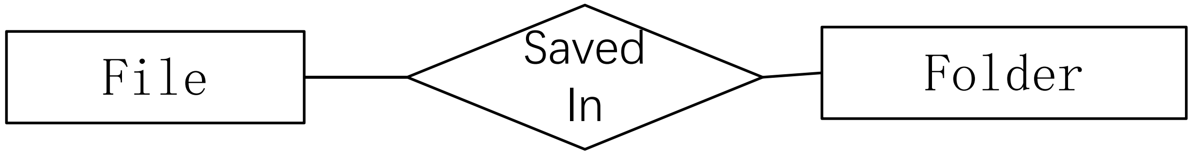
Double line → Total participation
i.e., every section must be related with some course

ER Diagram for a University Enterprise



Quick Check

- What do we change below to label the weak entity?



Steps in Database Design

- **Requirements Analysis**
  - User needs; what must database do?
- **Conceptual Design**
  - High level description (often done w/ER model)
- **Logical Design**
  - Translate ER into DBMS data model
- **Schema Refinement**
  - Consistency, normalization
- **Physical Design** - Indexes, disk layout
- **Security Design** - Who accesses what, and how

Reduction to Relational Schemas

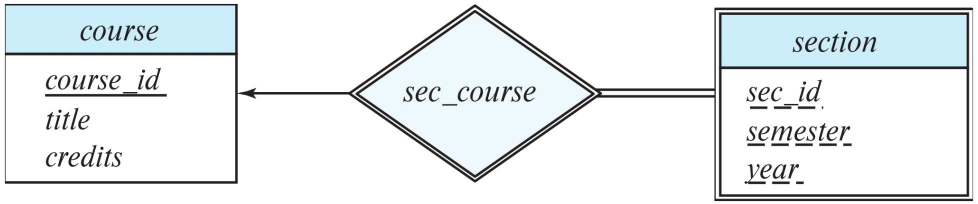
Reduction to Relational Schemas

- Entity-Relationship Model & Relational Model
  - Abstract, logical representations of real-world enterprises
  - Employ similar design principles
- Entity-Relationship Model → Relational Model
  - 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.

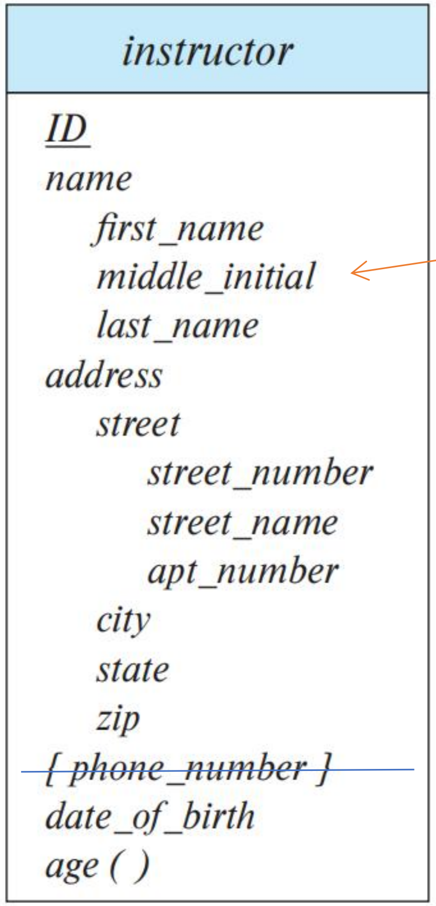
Representing Entity Sets

- A **strong** entity set reduces to a relation with the same attributes
  - Entity → Tuple
  - Attribute → Attribute
  - E.g., *student (<u>ID</u>, name, tot cred)*

- A **weak** entity set becomes a table that includes columns for the primary key of the identifying strong entity set
  - *section (<u>course_id</u>, <u>sec_id</u>, <u>sem</u>, <u>year</u>)*
    - The primary key consists of the primary key of the entity set *course*, along with the discriminator of *section*, which is *sec_id, semester*, and *year*.
    - A foreign-key constraint is created on the *section* schema, with *course_id* referencing the primary key of the *course* schema



Representation of Entity Sets with Complex Attributes



- Composite attributes are flattened out by creating a separate attribute for each component attribute
  - E.g., 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 relation schema *EM*

- Schema *EM* has attributes corresponding to the primary key of *E* and an attribute corresponding to multivalued attribute *M*
  - The primary key of EM consists of all attributes of the relation schema
  - Example: Multivalued attribute *phone_number* of *instructor* is represented by a schema:

    inst_phone= (<u>*ID*</u>, <u>*phone_number*</u>)
  - A foreign-key constraint is created on *EM* referencing the primary key of *E,*
  - Example: *inst_phone.ID* → *instructor.ID*

- Each value of the multivalued attribute maps to a separate tuple of the relation on schema *EM*
  - 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

- Let *R* be a relationship set, let $a_1, a_2, \ldots, a_m$ be the set of attributes formed by the union of the primary keys of each of the entity sets participating in *R*, and let the descriptive attributes (if any) of *R* be $b_1, b_2, \ldots, b_n$. We represent this relationship set by a relation schema called *R* with one attribute for each member of the set:

$$\{a_1, a_2, \ldots, a_m\} \cup \{b_1, b_2, \ldots, b_n\}$$

- Example: schema for relationship set *takes*

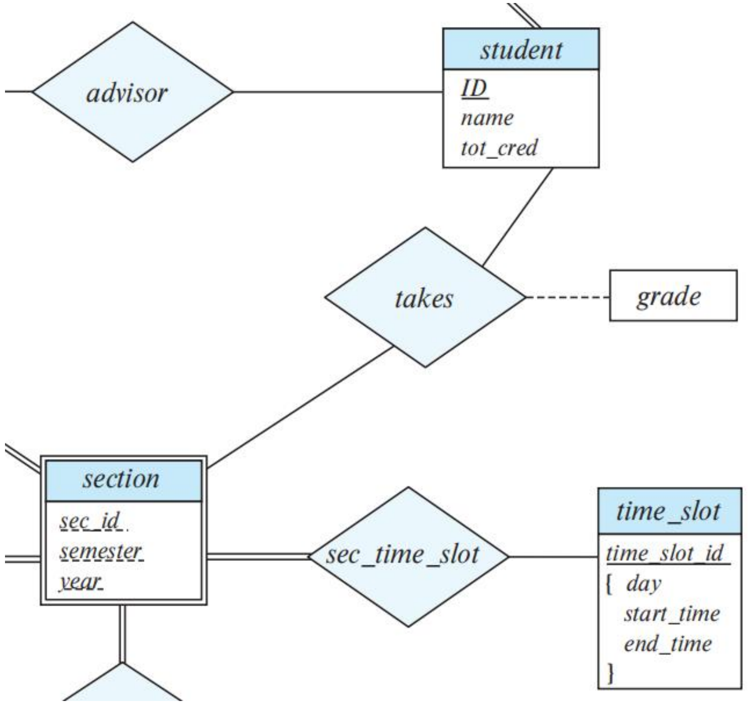
    takes (ID, course id, sec id, semester, year, grade)

  given:

    section (<u>course_id</u>, <u>sec_id</u>, <u>sem</u>, <u>year</u>)

    student(<u>ID</u>, name, tot cred)

- What is the the primary key for this relation *R*?



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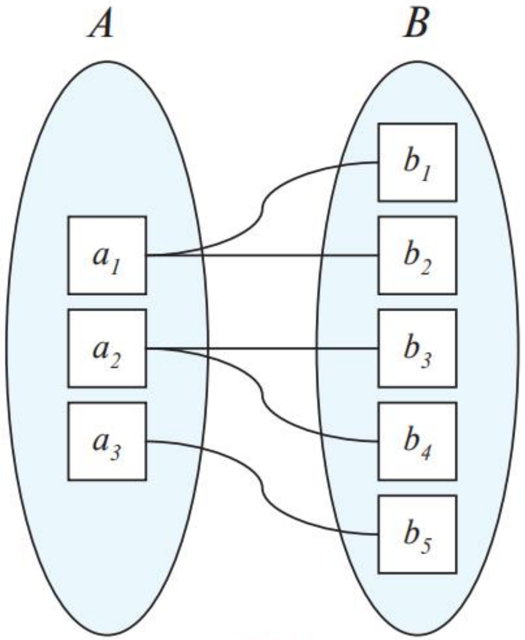

(b)

Representing Relationship Sets

- Let R be a relationship set, let $a_1, a_2, \ldots, a_m$ be the set of attributes formed by the union of the primary keys of each of the entity sets participating in R, and let the descriptive attributes (if any) of R be $b_1, b_2, \ldots, b_n$. We represent this relationship set by a relation schema called R with one attribute for each member of the set:

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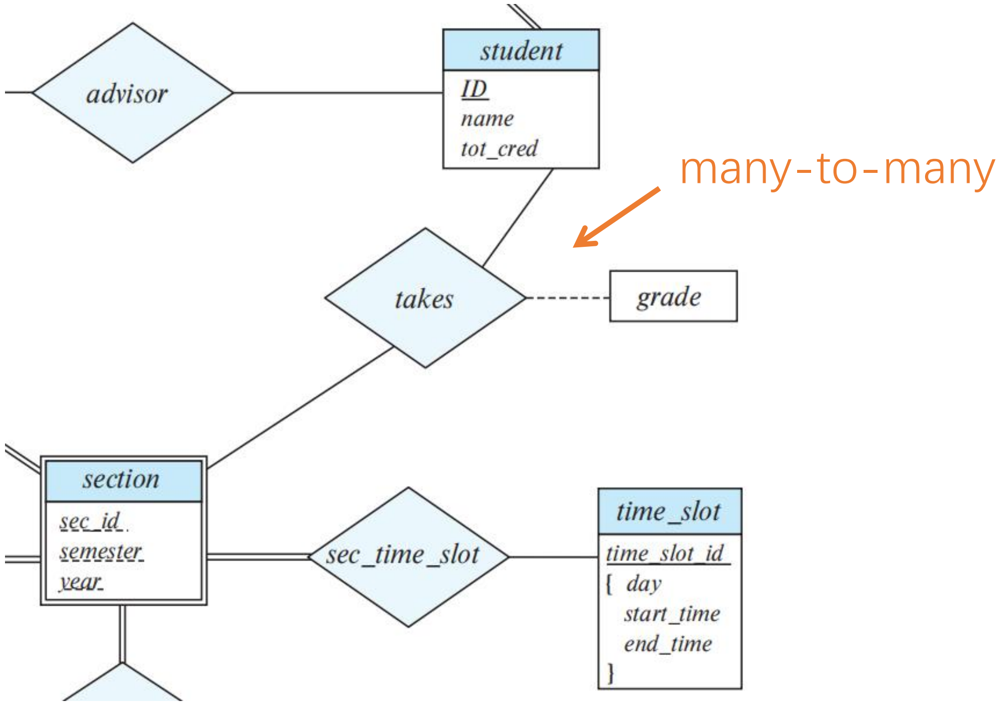
  student(<u>ID</u>, name, tot cred)

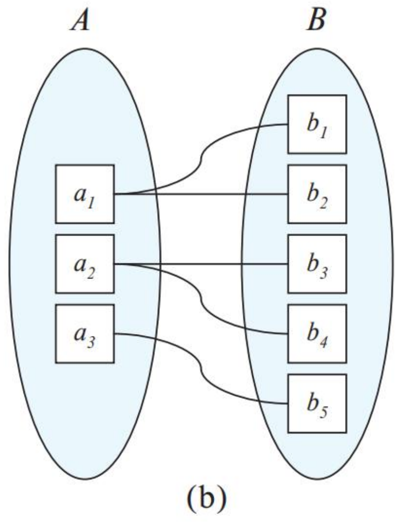


⑩ What is the the primary key for this relation R?

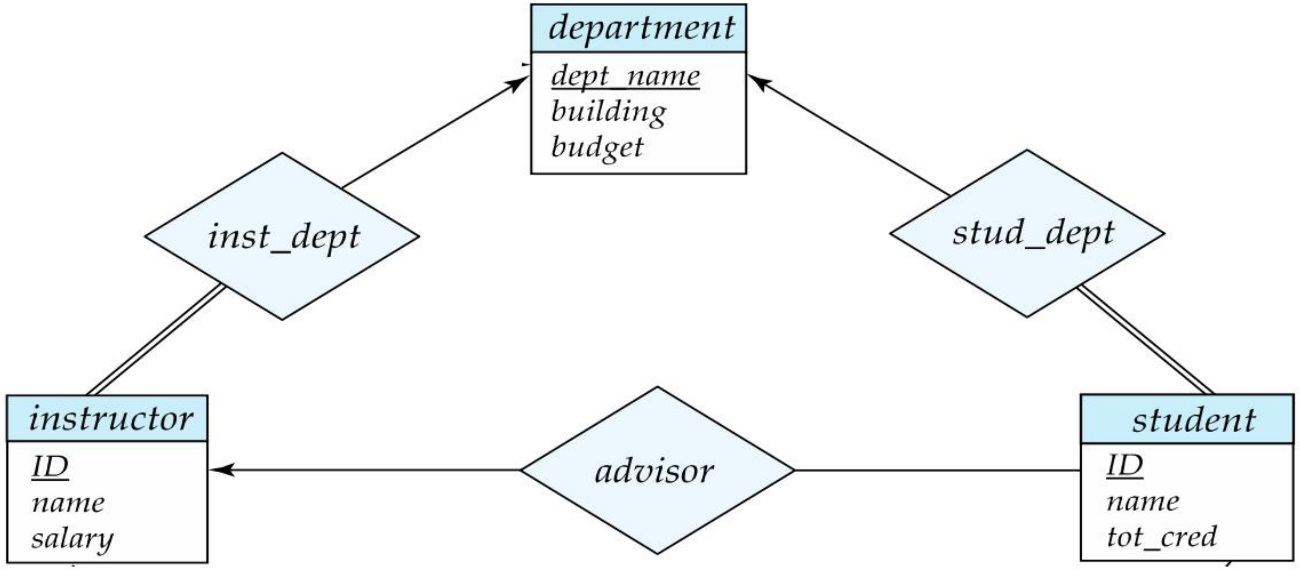
Redundancy of Schemas

- 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*



A = *department*
B = *instructor*



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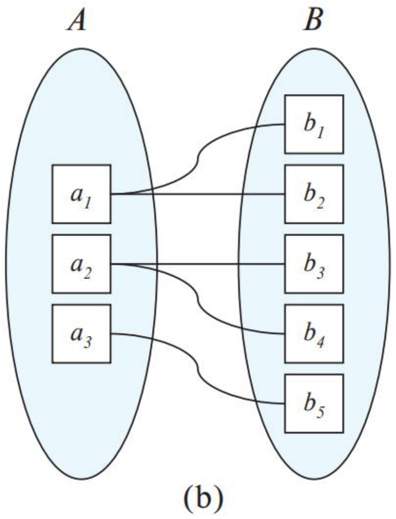

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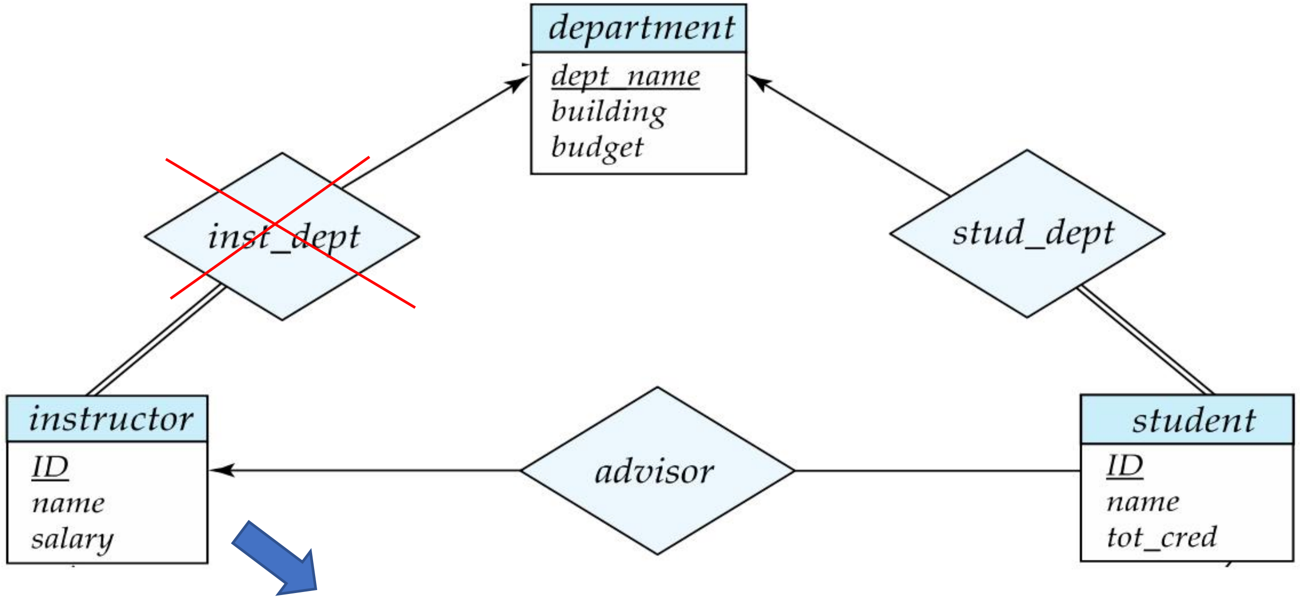
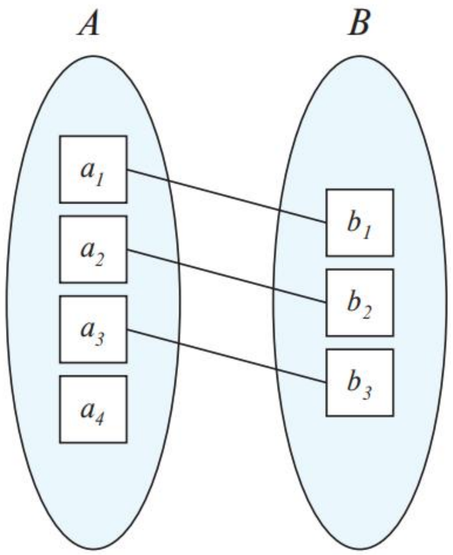


*instructor(<u>ID</u>, name, **dept_name**, salary)*

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



Example

- Entity a_4 does not participate in the binary relationship.
- If we add the PK of *B* to relation *A* to reprensent this relationship, the tuple corresponding to a_4 would have null value for this column.
- In this case, choose *B* as the “many” side to avoid 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

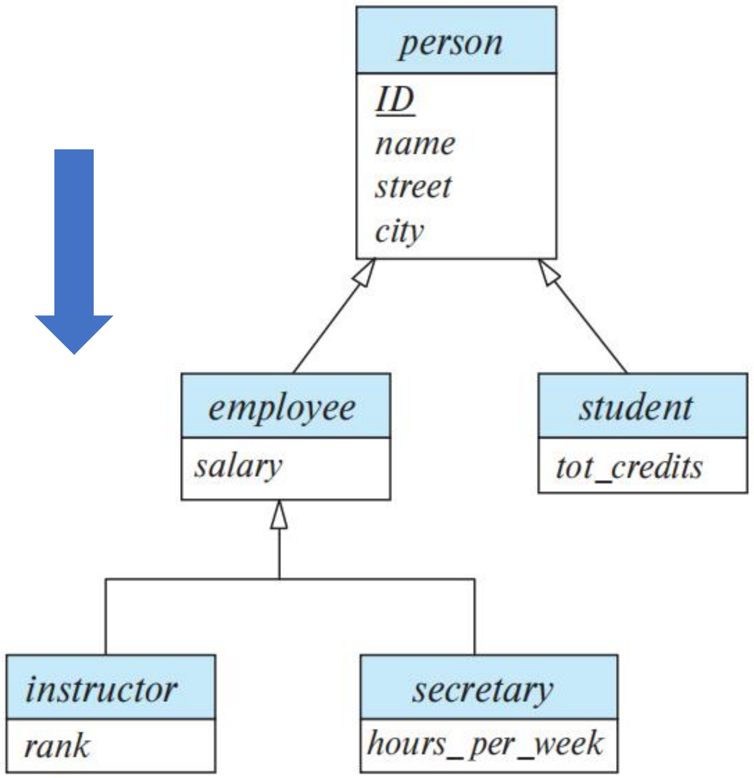
Extended ER Features

Specialization

- ***Top-down design process*** - 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 (e.g., *salary* of *employee*)

- **ER Diagram** - depicted by a *hollow arrow-head* pointing from the specialized entity to the other, referred as ISA relationship (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.



Constraint on specialization

- **Overlapping** – *employee* and *student*
- **Disjoint** – *instructor* and *secretary*

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, street, 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 as Schemas (Cont.)

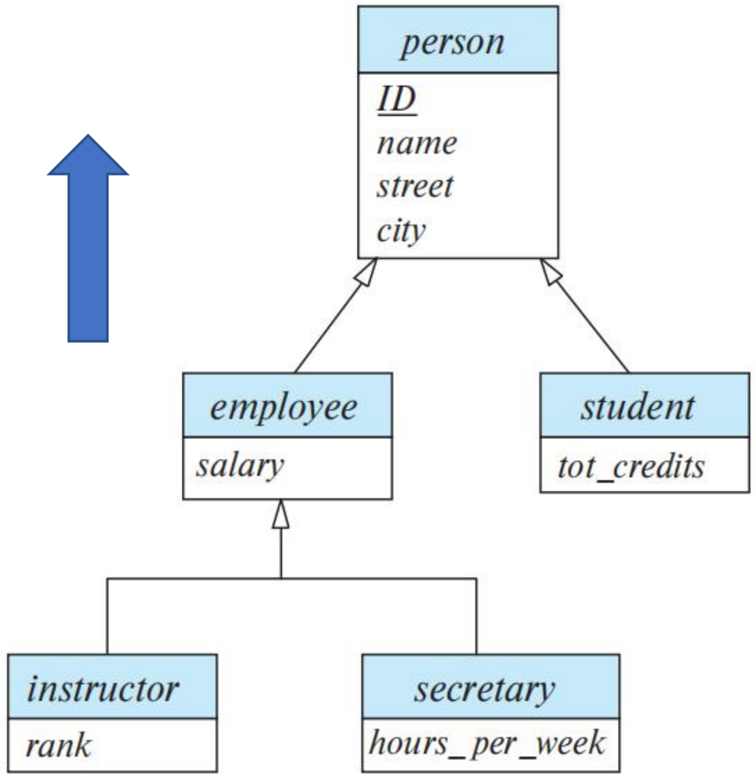
- Method 2:
  - Form a schema for each entity set with all local and inherited attributes

schema	attributes
person	ID, name, street, city
student	ID, name, street, city, tot_cred
employee	ID, name, street, city, salary

  - *Drawback*: *name, street* and *city* may be stored redundantly for people who are both students and employees
  - If the generalization is disjoint and complete, may remove the *person* relation
    - No FK constraints referencing *person.ID*

Generalization

- **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 ER diagram in the same way.
- In terms of the ER diagram, the terms specialization and generalization are used interchangeably.
- **Specialization** - focus on differences among entities within one set
- **Generalization** - focus on the similarities among lower-level entity sets
  - Hide difference
  - Economy of representation i.e., shared attributes are not repeated

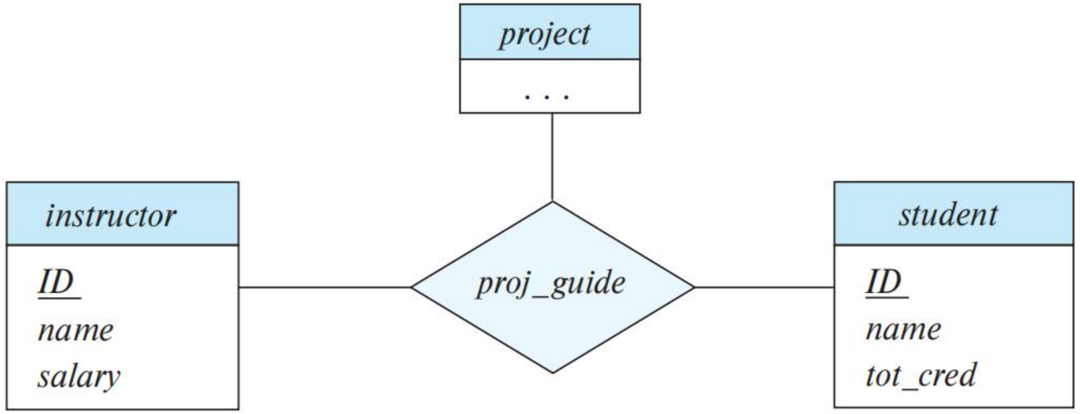


Completeness Constraint

- **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/specialization .
  - **Total**: an entity must belong to one of the lower-level entity sets
    - ER Diagram: We can specify total specialization by adding the keyword “total” and drawing a dashed line from the keyword to the corresponding hollow arrowhead to which it applies (for a disjoint specialization), or to the set of hollow arrowheads to which it applies (for an overlapping specialization).
  - **Partial**: an entity need not belong to one of the lower-level entity sets
    - Default

Aggregation

- One *limitation* of the E-R model is that it cannot express relationships among relationships.
- Consider the ternary relationship *proj_guide*, which we saw earlier
- Suppose we want to record evaluation report of a student by a guide on a project, once a month
  - Model the evaluation report as an entity *evaluation*



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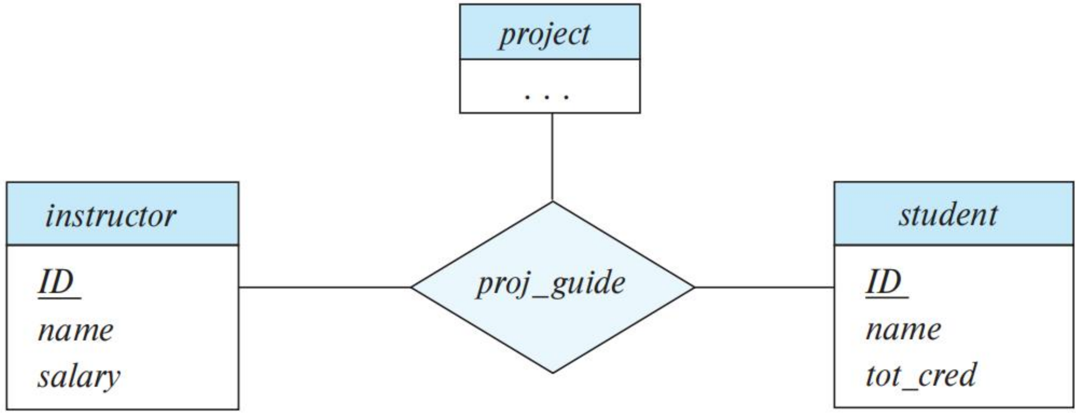
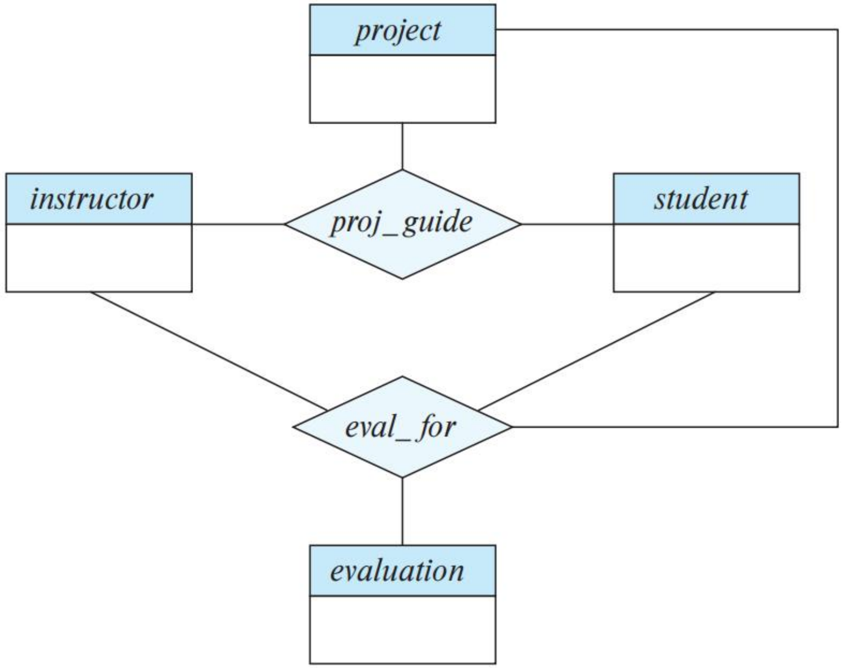
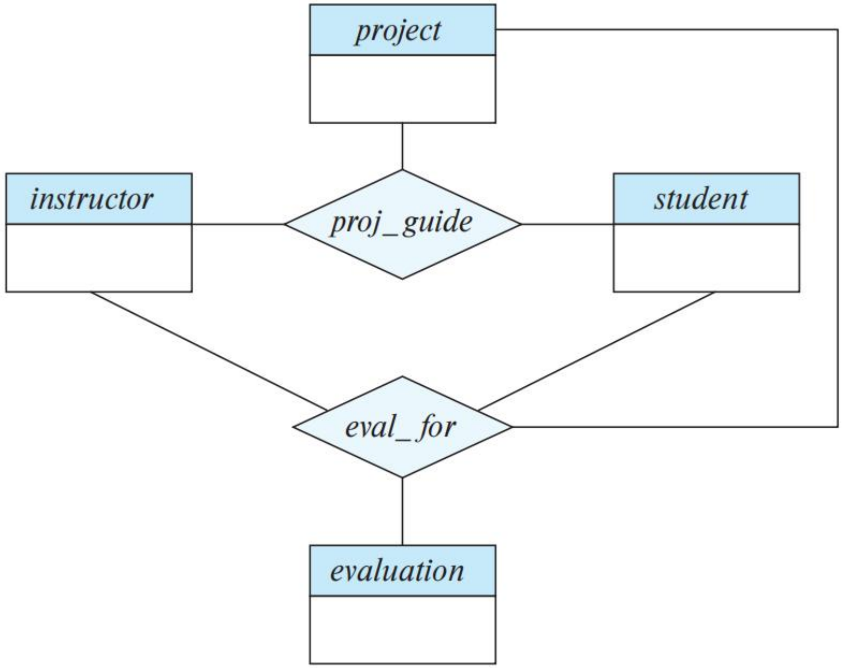
- Consider the ternary relationship *proj_guide*, which we saw earlier
- Suppose we want to record evaluation report of a student by a guide on a project, once a month
  - Model the evaluation report as an entity *evaluation*
  - Create a quaternary (4-way) relationship set *eval_for*





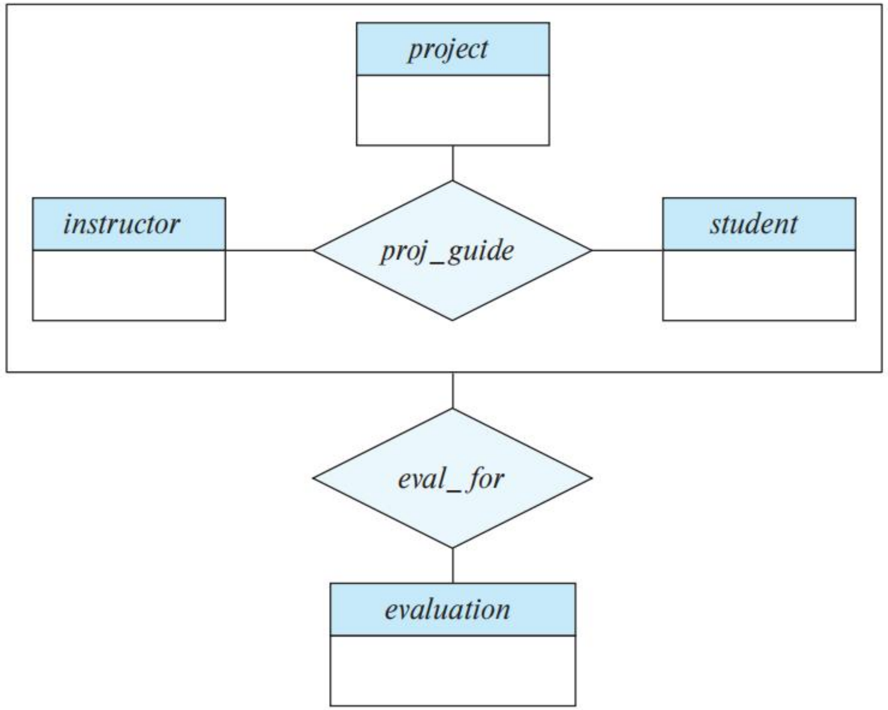
Aggregation (Cont.)

- 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 report

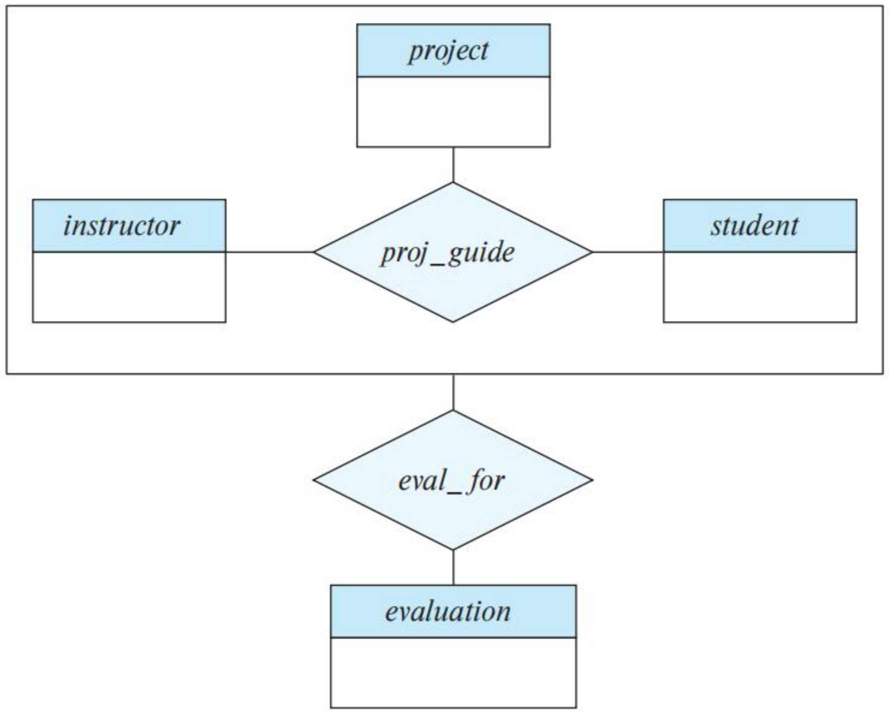


Reduction to Relational Schemas

- To represent aggregation, create a schema containing
  - Primary key of the aggregated relationship set
  - The primary key of the associated entity set
  - Any descriptive attributes

- In our example:
  - The schema *eval_for* is:

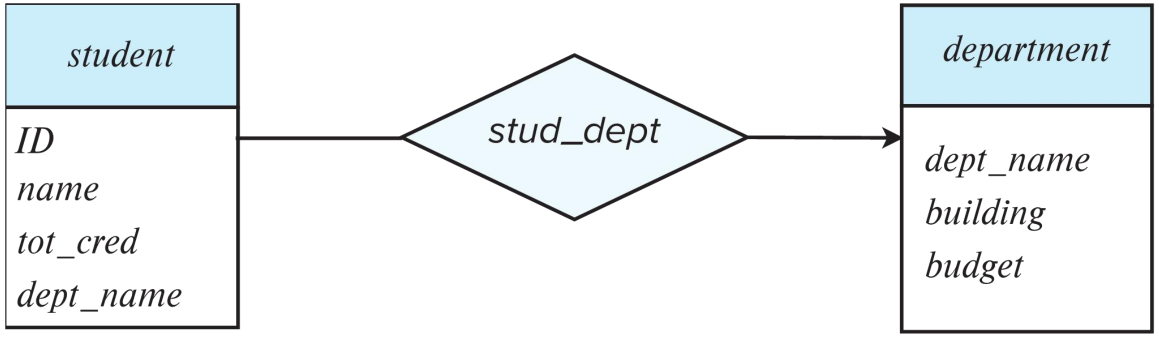
    eval_for (*s_ID, project_id, i_ID, evaluation_id*)



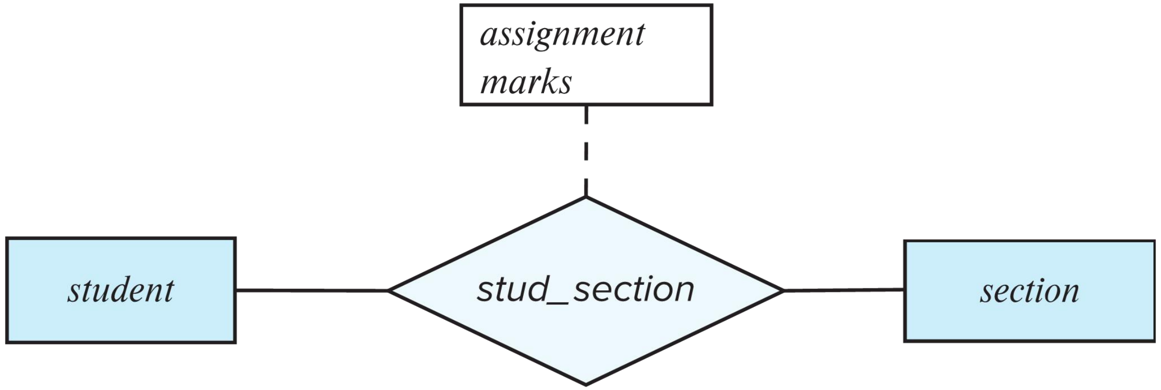
Design Issues

Common Mistakes in ER Diagrams

- Example of erroneous ER diagrams



(a) Incorrect use of attribute

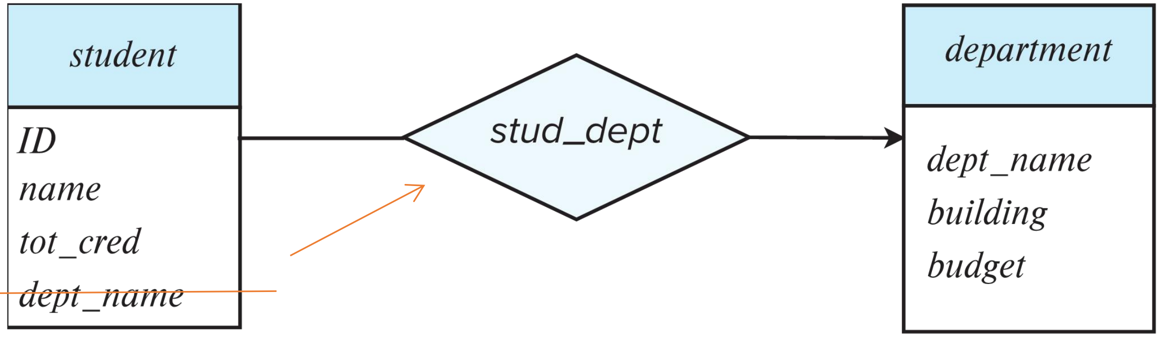


(b) Erroneous use of relationship attributes

Common Mistakes in ER Diagrams

- Example of erroneous ER diagrams

Duplicate information



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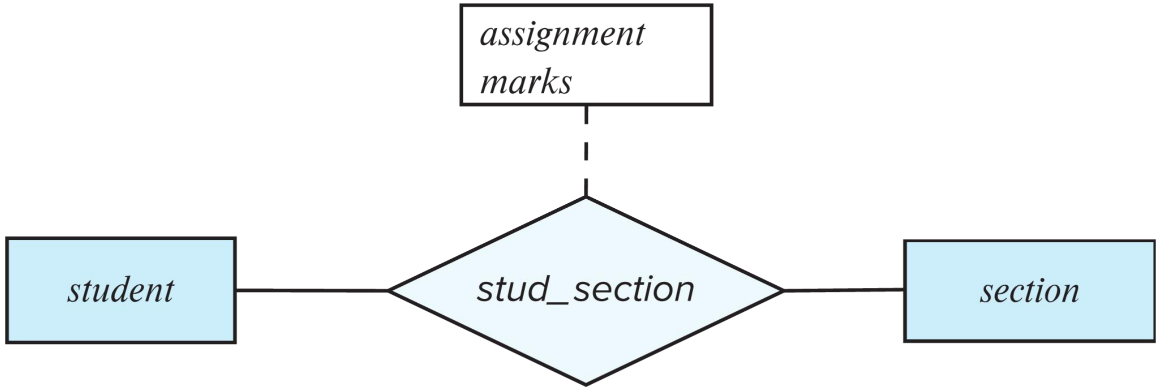

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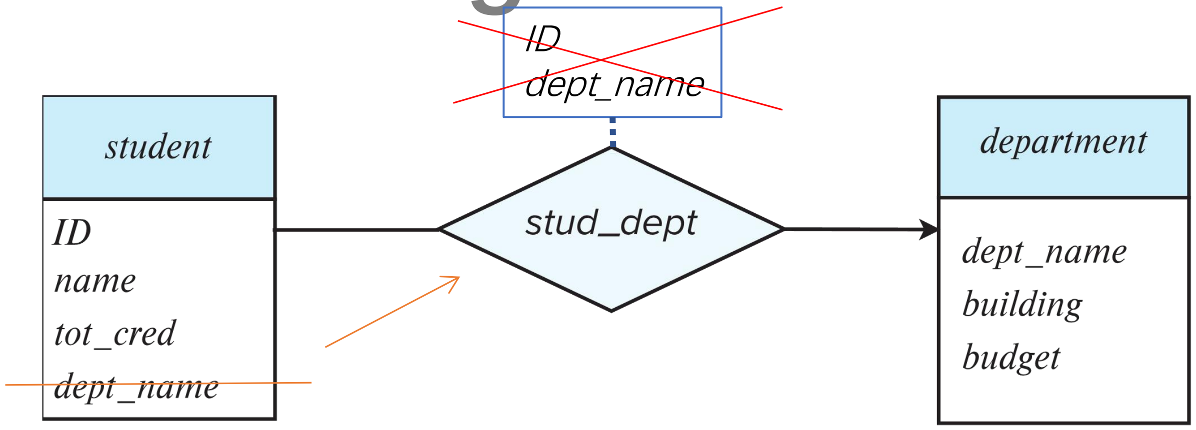
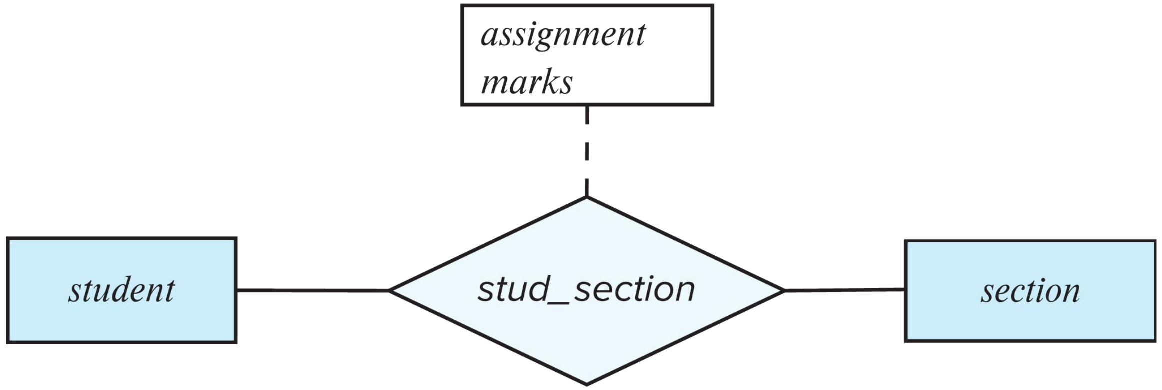
- Example of erroneous ER diagrams

Duplicate information



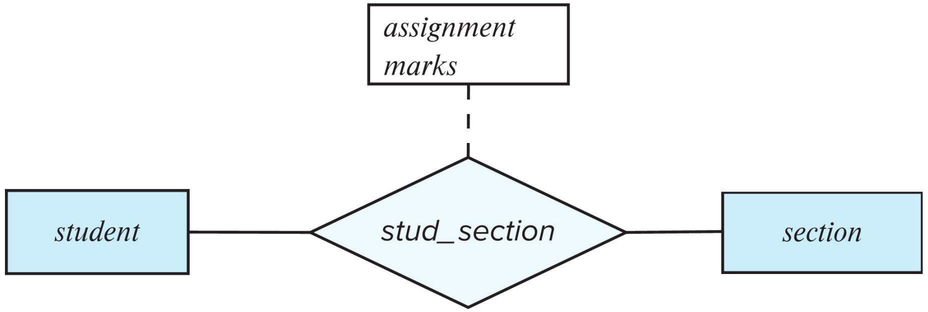
(a) Incorrect use of attribute

*These attributes may appear in the **relation schema** created from the relationship set, but they should not appear in the entity or relationship set in the ER diagram.*



(b) Erroneous use of relationship attributes

Common Mistakes in ER Diagrams (Cont.)

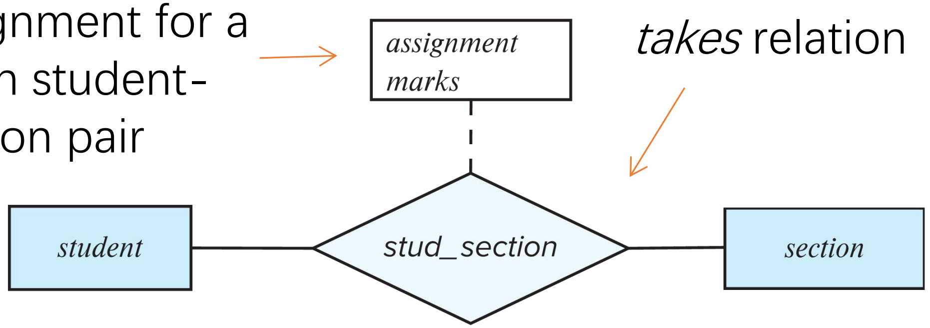


(b) Erroneous use of relationship attributes

E.g., We need to represent the marks a student gets in different assignments of a course offering (section).

Common Mistakes in ER Diagrams (Cont.)

we can only represent a single assignment for a given student-section pair



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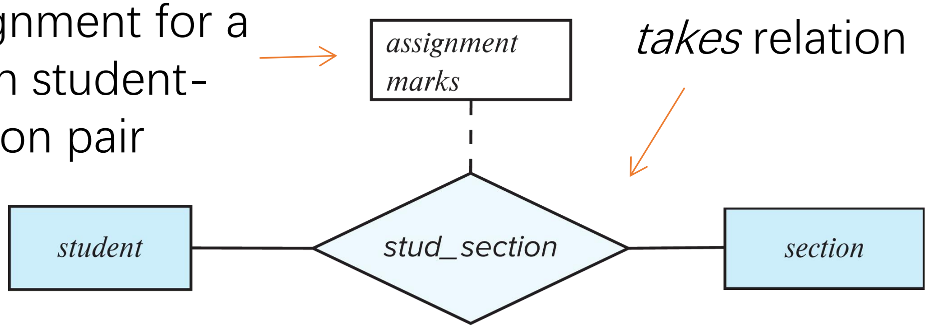
Common Mistakes in ER Diagrams (Cont.)

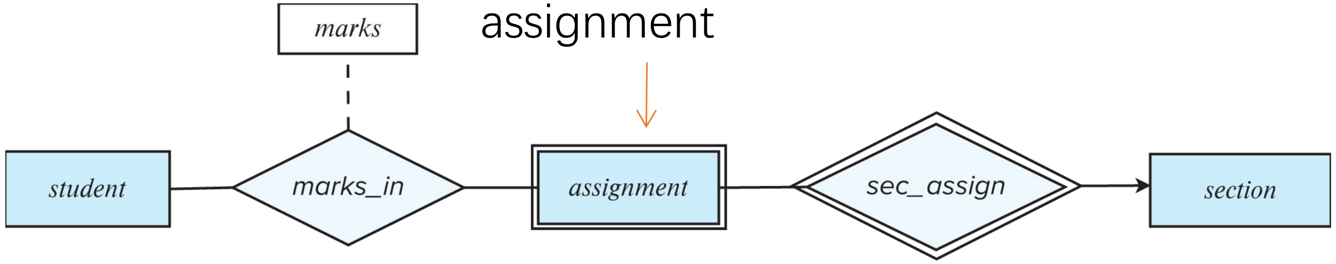
we can only represent a single assignment for a given student-section pair

takes relation



(b) Erroneous use of relationship attributes

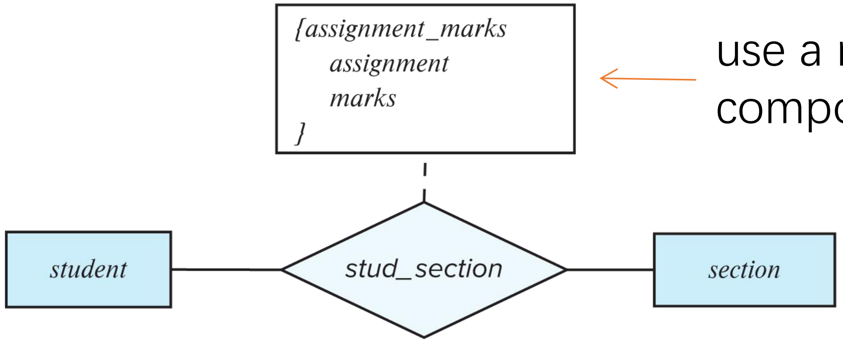
Introduce weak entity set assignment



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

E.g., We need to represent the marks a student gets in different assignments of a course offering (section).

use a multivalued composite attribute



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Common Mistakes in ER Diagrams (Cont.)

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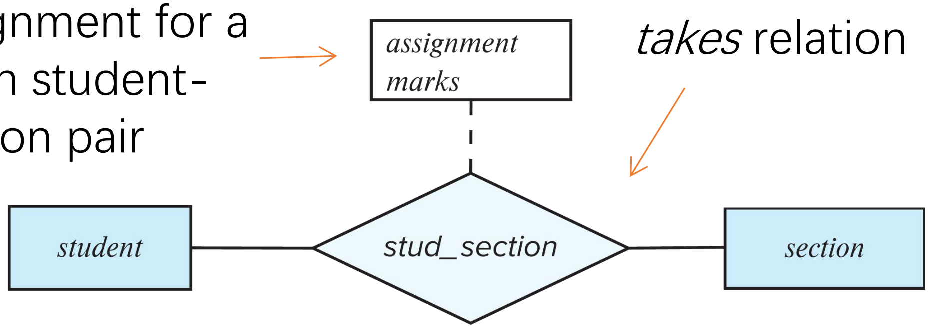
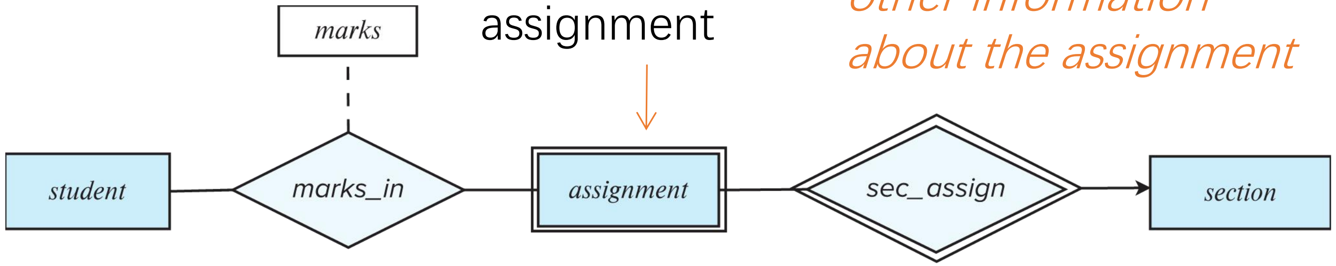


(b) Erroneous use of relationship attributes

Introduce weak entity set assignment

(c) is better than (d) as it allows recording other information about the assignment



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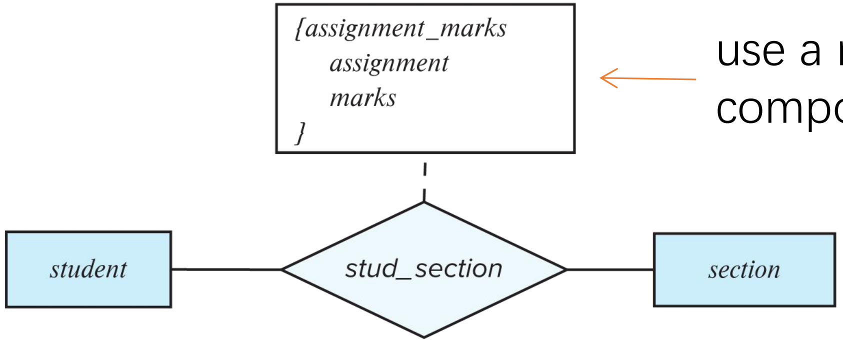

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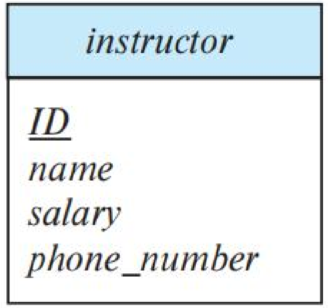
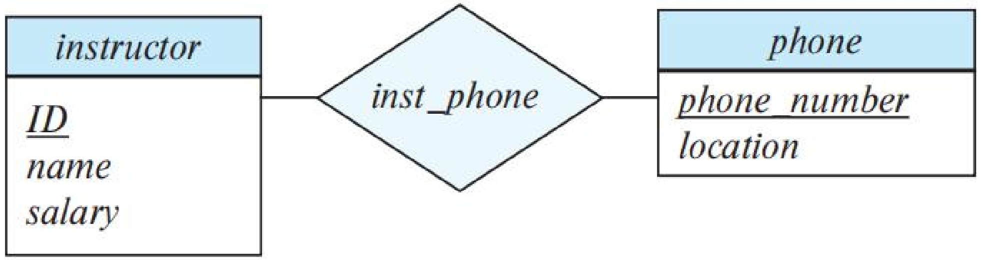
Entities vs. Attributes

- Use of entity sets vs. attributes



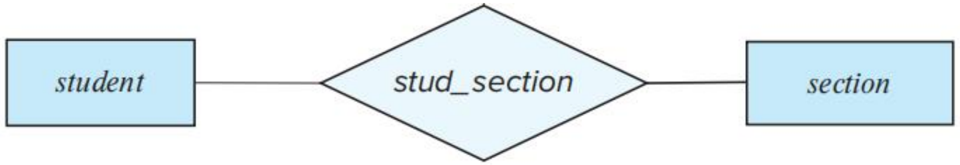


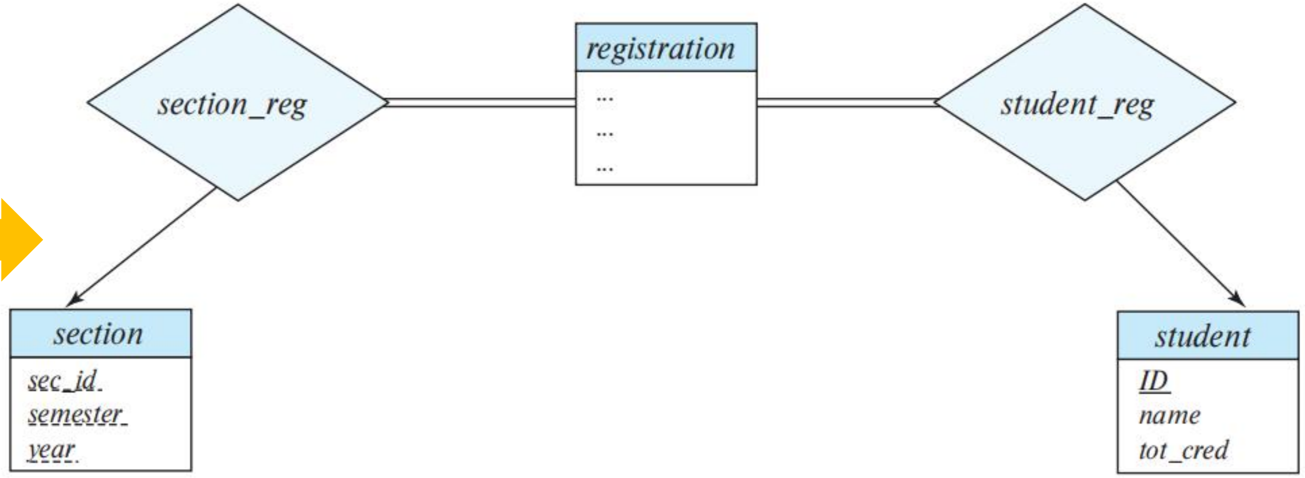
- Use of *phone* as an entity allows extra information about phone numbers (plus multiple phone numbers)
  - It would not be appropriate to treat the attribute name as an entity

- *What constitutes an attribute, and what constitutes an entity set?*

Entities vs. Relationship sets

- **Use of entity sets vs. relationship sets**





- The use of *takes* (*stud_section*) is more compact and probably preferable
- If the registrar's office associates other information with a course-registration record, it might be best to make it an entity in its own right

Possible guideline is to designate a relationship set to describe an action that occurs between entities

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*-ary relationship 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*

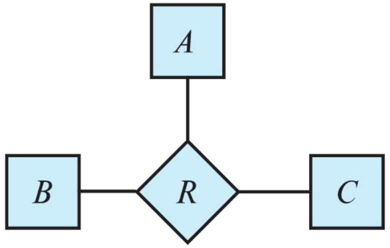
Converting Non-Binary Relationships to Binary Form

- 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:

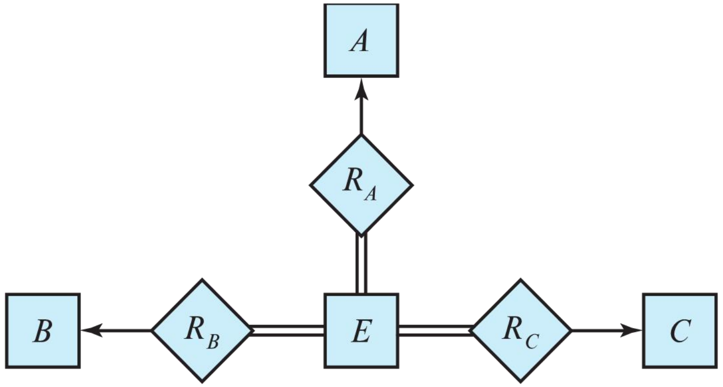
    1. R_A, relating *E* and *A* 2. R_B, relating *E* and *B* 3. R_C, relating *E* and *C*
  - Create an identifying attribute for *E and* add any attributes of *R* to *E*
  - For each relationship (a_i , b_i , c_i) in *R,* create

    1. a new entity e_i in the entity set *E* 2. add (e_i , a_i) to R_A

    3. add (e_i , b_i) to R_B 4. add (e_i , c_i) to R_C



(a)



(b)

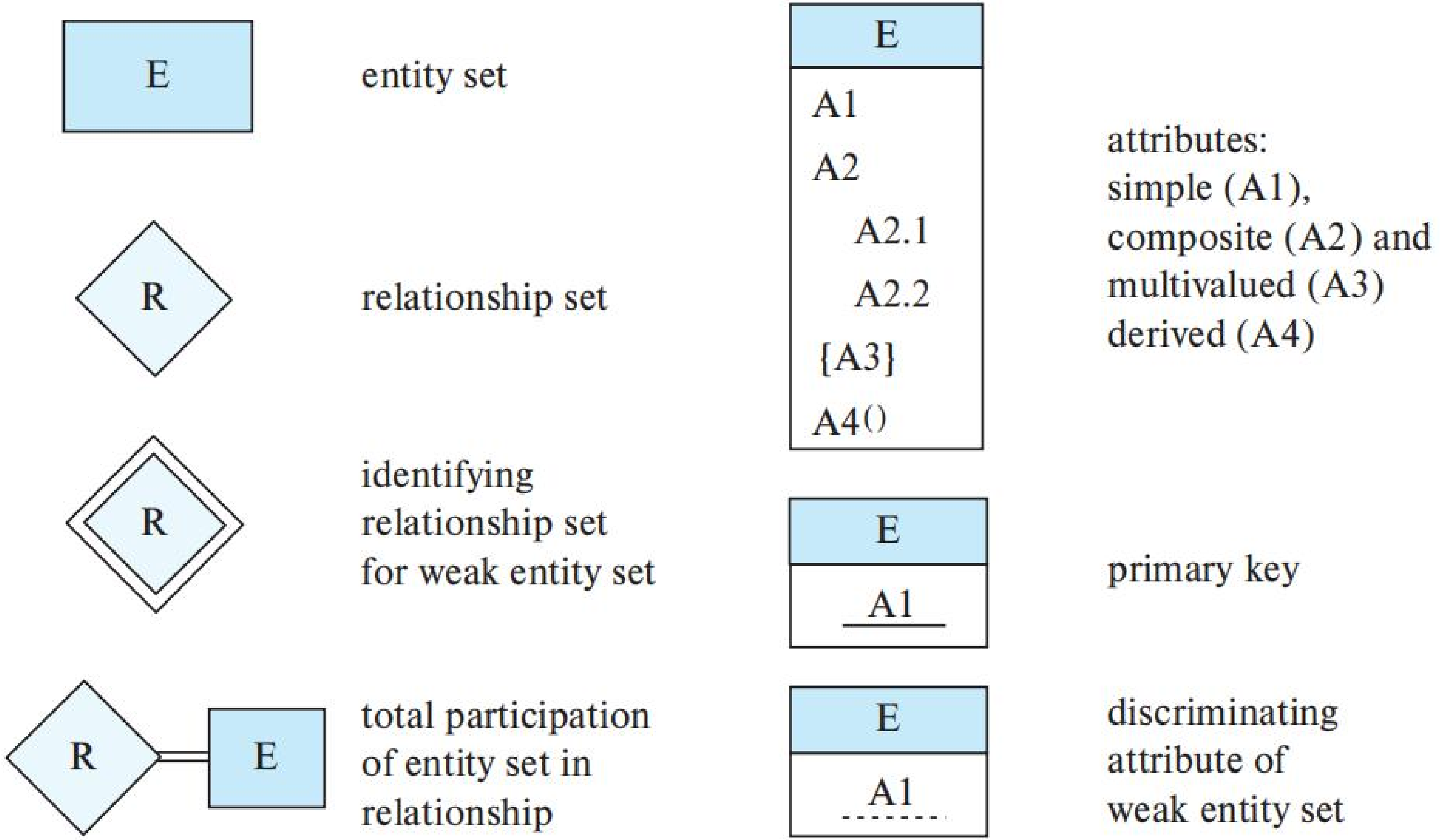
Converting Non-Binary Relationships (Cont.)

- Also need to translate constraints
  - Translating all constraints may not be possible
  - There may be instances in the translated schema that cannot correspond to any instance of *R*
    - Exercise: *add constraints to the relationships* R_A*,* R_B *and* R_C to ensure that a newly created entity corresponds to exactly one entity in each of entity sets *A, B* and *C*
  - We can avoid creating an identifying attribute by making E a weak entity set (described shortly) identified by the three relationship sets

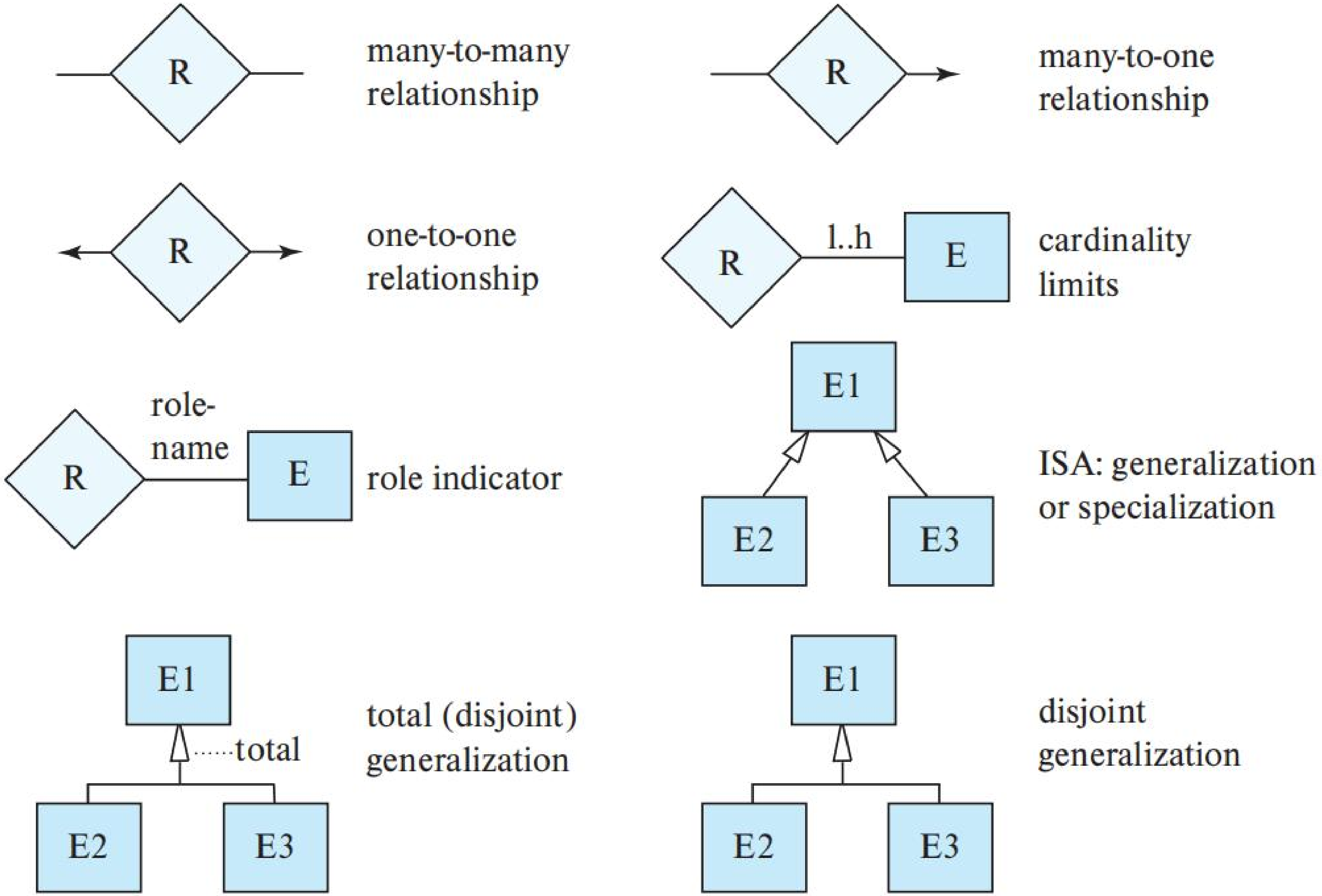
ER Design Decisions

- 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 ER Notation



Symbols Used in ER Notation (Cont.)



Steps in Database Design

- **Requirements Analysis**
  - User needs; what must database do?
- **Conceptual Design**
  - High level description (often done w/ER model)
- **Logical Design**
  - Translate ER into DBMS data model
- **Schema Refinement**
  - Consistency, normalization
- **Physical Design** - Indexes, disk layout
- **Security Design** - Who accesses what, and how

Schema Refinement

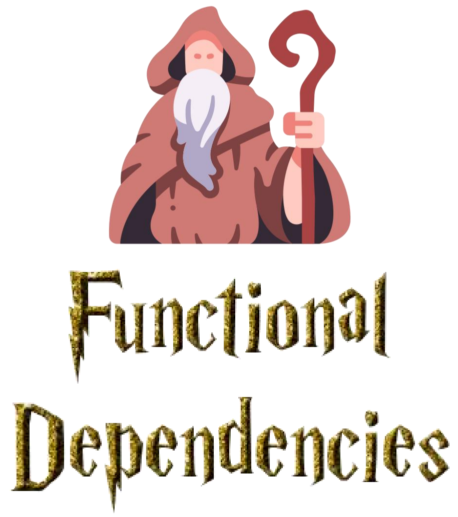
Overview of Schema Refinement

- The Evil to Avoid: Redundancy in your schema
  - i.e., replicated values
  - Leads to wasted storage
  - More important: insert/delete/update *anomalies*
    - *Replicated data + change = Trouble.*
    - *We'll see examples shortly*

Overview of Schema Refinement

- Solution: *Functional Dependencies*
  - A form of integrity constraints
  - Help identify *redundancy* in schemas
  - Help suggest refinements

- Main refinement technique: *Decomposition*
  - Split the columns of one table into two tables
  - Often good, but need to do this judiciously



Functional Dependencies (FDs)

- Idea: X →Y means
  - (Read "→" as "determines")
  - Given any two tuples in table r,
    if their X values are the same,
    then their Y values must be the same.
    (but not vice versa)

X	Y	Z
2	8	1
2	?	2
3	8	1

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X	Y	Z
2	8	1
2	8	2
3	8	1

Functional Dependencies (Cont.)

- Formally: An FD $\mathbf{X} \rightarrow \mathbf{Y}$ holds over relation schema R if, for every allowable instance r of R:

$$t1 \in r,\ t2 \in r,\ \pi_X(t1) = \pi_X(t2) \Rightarrow \pi_Y(t1) = \pi_Y(t2)$$

  - t1, t2 are tuples
  - X, Y are sets of attributes

- An FD is w.r.t. all allowable instances.
  - Declared based on application semantics
  - Not learned from data
    - (though you might learn suggestions for FDs)

Key Terminology (Important)

- Question: How are FDs related to keys?
  - Keys are special cases of FDs
  - K → {all attributes}
- Superkey: a set of columns in a table that determine all the columns in that table
  - K → {all attributes}
- Candidate Key: a **minimal** set of columns in a table that determine all the columns in the table
  - K → {all attributes}
  - For any L ⊂ K, L → {all attributes} (minimal)
- Primary Key: a single chosen candidate key

- Notice: Index/sort “key” – columns used in an index or sort.
  - Unrelated to FDs, dependencies.

Example - Constraints on Entity Set

- Consider relation *Hourly_Emps*:

  Hourly_Emps(ssn, name, lot, rating, wage_per_hr, hrs_per_wk)
- We can denote a relation schema by listing its attributes:
  - e.g., SNLRWH
  - This is really the set of attributes {S,N,L,R,W,H}.
- And we can use relation name to refer to the set of all its attributes
  - e.g., “Hourly_Emps” for SNLRWH

- What are some FDs on Hourly_Emps?
  - **ssn** is the primary key: S → SNLRWH
  - **rating** determines wage_per_hr: R → W
  - **lot** determines lot: L → L (“trivial” dependency)

Problem 1 - Due to R → W

- *Update anomaly*: Can we modify W in only the 1st tuple of SNLRWH?

S	N	L	R	W	H
123-22-3666	Attishoo	48	8	10	40
231-31-5368	Smiley	22	8	10	30
131-24-3650	Smethurst	35	5	7	30
434-26-3751	Guldu	35	5	7	32
612-67-4134	Madayan	35	8	10	40

Hourly_Emps

Then that tuple will be inconsistent with Smiley and Madayan!

Problem 2 - Due to R → W

- *Insertion anomaly*: What if we want to insert an employee and don't know the hourly wage for his or her rating? (or we get it wrong?) e.g., insert a new employee with rating 6

S	N	L	R	W	H
123-22-3666	Attishoo	48	8	10	40
231-31-5368	Smiley	22	8	10	30
131-24-3650	Smethurst	35	5	7	30
434-26-3751	Guldu	35	5	7	32
612-67-4134	Madayan	35	8	10	40

Hourly_Emps

Then you have to invent a value without reference to established truth!

Problem 3 - Due to R → W

- *Deletion anomaly*: If we delete all employees with rating 5, we lose the information about the wage for rating 5!

S	N	L	R	W	H
123-22-3666	Attishoo	48	8	10	40
231-31-5368	Smiley	22	8	10	30
131-24-3650	Smethurst	35	5	7	30
434-26-3751	Guldu	35	5	7	32
612-67-4134	Madayan	35	8	10	40

Hourly_Emps

Then you will forget established truth!

Detecting Redundancy

- Q: Why is R → W problematic, but S →W not?

S	N	L	R	W	H
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Hourly_Emps

Detecting Redundancy

- Q: Why is R → W problematic, but S →W not?
- A: R is not a key, so any pair, e.g.,(8,10), appears multiple times.
  S is a **candidate key**, so each pair like (123-22-3666,10) is stored exactly once.

S	N	L	R	W	H
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Hourly_Emps

Decomposing a Relation

- Redundancy can be removed by "chopping" the relation into pieces.
- FD's are used to drive this process.
  - R → W is causing the problems, so decompose SNLRWH into what relations?

S	N	L	R	H
123-22-3666	Attishoo	48	8	40
231-31-5368	Smiley	22	8	30
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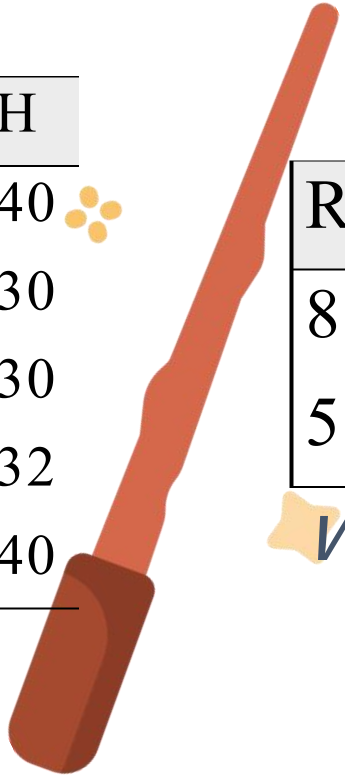
Hourly_Emps2



R	W
8	10
5	7

Wages

Reasoning About FDs

- Given some FDs, we can usually infer additional FDs:

bookID → (publisher, author)	implies	bookID → publisher
	and	bookID → author
bookID → publisher and bookID → author	implies	bookID → (publisher, author)
bookID → author and author → publisher	implies	bookID → publisher

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bookID → publisher and bookID → author	implies	bookID → (publisher,author)
bookID → author and author → publisher	implies	bookID → publisher

- But,

  (title, author) → publisher does **NOT** necessarily imply that
  title → publisher **NOR** that author → publisher

Reasoning About FDs - General

- Generally, an FD g is *implied by* a set of FDs F if g holds whenever all FDs in F hold.

- F+ = closure of F
  - The set of all FDs that are implied by F.
  - Includes "trivial dependencies"

  - How do we get F+ given F?

Rules of Inference

- Armstrong's Axioms (X, Y, Z are sets of attributes):
  - *Reflexivity*: If $X \supseteq Y$, then $X \rightarrow Y$
  - *Augmentation*: If $X \rightarrow Y$, then $XZ \rightarrow YZ$ for any Z
  - *Transitivity*: If $X \rightarrow Y$ and $Y \rightarrow Z$, then $X \rightarrow Z$

William Ward Armstrong

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William Ward Armstrong

- S*ound* and *complete* inference rules for FDs!
  - using AA you get *only* the FDs in F+ and *all* these FDs.

- Some additional rules (that follow from AA):
  - *Union*: If $X \to Y$ and $X \to Z$, then $X \to YZ$
  - *Decomposition*: If $X \to YZ$, then $X \to Y$ and $X \to Z$

Example

Given F

- Contracts(*<u>cid</u>, sid, jid, did, pid, qty, value*), and:
  - C is the key: C → CSJDPQV
  - Proj (J) purchases each part (P) using single contract (C): JP → C
  - Dept (D) purchases at most 1 part (P) from a supplier (S): SD → P

Attribute	Meaning
cid	contract
sid	supplier
jid	project
did	department
pid	part

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  - JP → C, C → CSJDPQV
    - Imply JP → CSJDPQV
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    - Implies SDJ → JP (by augmentation)

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A: NO!

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    X^+ = Set of all attributes A such that $X \rightarrow A$ is in F^+
    - $X^+ := X$
    - Repeat until no change (fixpoint):
      for $U \rightarrow V \subseteq F$,
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    - Repeat until no change (fixpoint):
      for $U \rightarrow V \subseteq F$,
      if $U \subseteq X^+$, then add V to X^+
  - Check if Y is in X^+
  - Approach can also be used to check for keys of a relation.
    - If $X^+ = R$, then X is a superkey for R.
    - Q: How to check if X is a "candidate key" (minimal)?
    - A: For each attribute A in X, check if $(X - A)^+ = R$

Attribute Closure - Example

- $R = \{A, B, C, D, E\}$
- $F = \{B \rightarrow CD, D \rightarrow E, B \rightarrow A, E \rightarrow C, AD \rightarrow B\}$

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  …Yep!

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  $A^+ = \ldots$ $D^+ = \ldots$

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  $AD^+ = \{A, D, E, C, B\}$
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  $A^+ = \{A\}$ $D^+ = \{D, E, C\}$
  …Yes!

- **Is ADE a candidate key for R?**

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  … Yep!

- **Is D a key for R?**
  D+ = {D, E, C}
  … Nope!

- **Is AD a key for R?**
  $AD^+ = \{A, D, E, C, B\}$
  …Yep!

- **Is AD a candidate key for R?**
  $A^+ = \{A\}$ $D^+ = \{D, E, C\}$
  …Yes!

- **Is ADE a candidate key for R?**
  No!

Thanks for that…

- So we know a lot about FDs

- Can they help with schema refinement?

The Notion of Normal Forms

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The Notion of Normal Forms

- Q1: given a schema and some FDs, is there any refinement needed?

- If relation is in a *normal form* (e.g. BCNF):
  - We know certain problems are avoided/minimized.
  - Helps decide whether decomposing relation is useful.

- Consider a relation R with 3 attributes, ABC.
  - No (non-trivial) FDs hold: No redundancy here.
  - Given $A \rightarrow B$: If A is not a key, then several tuples could have the same A value, and if so, they'll all have the same B value!

Redundancy

Basic Normal Forms

- 1st Normal Form – all attributes atomic
  - I.e. relational model
  - Violated by many common data models
    - Including XML, JSON, various OO models
  - Some of these "non-first-normal form" (NFNF) quite useful in various settings
    - Especially in update-never settings – e.g., data tranfer
    - If you never "unnest", then who cares!
      - Basically relational collection of structured objects

- 1st $\supset$ 2nd (of historical interest)
  $\supset$ 3rd
  $\supset$ Boyce-Codd …

Boyce-Codd Normal Form (BCNF)

- Relation R with FDs F is in BCNF if, for all $X \rightarrow A$ in F+
  - $A \subseteq X$ (called a trivial FD), or
  - X is a superkey for R.

- In other words: “R is in BCNF if the only non-trivial FDs over R are key constraints.”

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- Q: How to know if a set of attributes X is superkey of R?

Why is BCNF Useful?

- If R is in BCNF, every field of every tuple stores useful info that cannot be inferred via FDs alone.
  - Say we know FD $X \rightarrow A$ holds for this example relation:
  - Can you guess the value of the missing attribute?
  - Yes, so relation is not in BCNF

X	Y	A
x	y1	a
x	y2	?

Decomposition of a Relation Scheme

- How to normalize a relation?
  - *Decompose* into multiple normalized relations

- Suppose R contains attributes $A_1 \ldots A_n$.

- A *decomposition* of R consists of replacing R by two or more relations such that:
  - Each new relation scheme contains a subset of the attributes of R, and
  - Every attribute of R appears as an attribute of at least one of the new relations.

Example

- SNLRWH has FDs S → SNLRWH and R → W
- Q: Is this relation in BCNF?
  - No. The second FD causes a violation; R is not a superkey.
  - W values repeatedly associated with R values.

S	N	L	R	W	H
123-22-3666	Attishoo	48	8	10	40
231-31-5368	Smiley	22	8	10	30
131-24-3650	Smethurst	35	5	7	30
434-26-3751	Guldu	35	5	7	32
612-67-4134	Madayan	35	8	10	40

Hourly_Emps

Decomposing a Relation

- Easiest fix is to create a relation RW to store these associations, and to remove W from the main schema:

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Hourly_Emps2

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Wages

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- Q: Are both of these relations are now in BCNF?
- A: Yes. S → SNLRH is ok, as is R → W.

Problems with Decompositions

- There are three potential problems to consider:

1) May be ***impossible*** to reconstruct the original relation! (Lossiness)
   - Fortunately, not in the SNLRWH example.

2) Dependency checking may require joins.
   - Fortunately, not in the SNLRWH example.

3) Some queries become more expensive.
   - e.g., How much does Guldu earn?

Tradeoff: Must consider these 3 problems vs. redundancy.