Principles of Database Systems (CS307)

Lecture 8: Database Design using E-R Model

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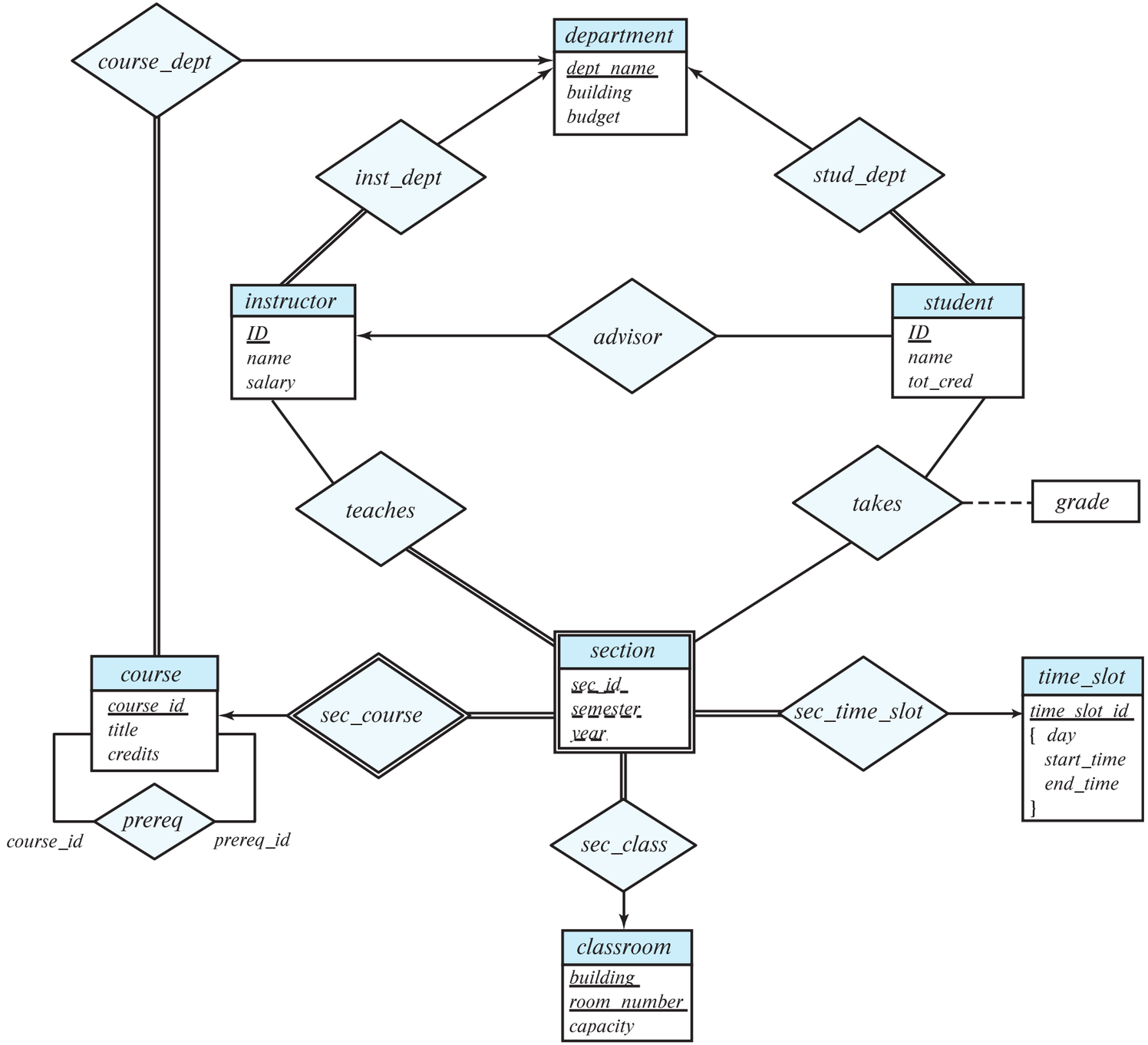
- Most contents are from slides made by Stéphane Faroult and the authors of Database System Concepts (7th Edition).
- Their original slides have been modified to adapt to the schedule of CS307 at SUSTech.
- The slides are largely based on the slides provided by Dr. Yuxin Ma

Announcements

- Project I, due date: 23:59 on November 10th 2024, Beijing Time
  - Only accept project report in English
    - The class is designed as an English class
    - Can avoid potential unfairness when grading Chinese and English reports

Entity-Relationship Model (E-R Model)
Entity-Relationship Diagram (E-R Diagram)

The New Running Example



Design Phases

- Initial phase: characterize fully the data needs of the prospective database users
  - Interact extensively with domain experts
  - The outcome is a specification of user requirements

Design Phases

- Second phase: choosing a data model
  - E.g., relational model, entity-relationship model, semi-structured data model, and object-oriented data model
  - Applying the concepts of the chosen data model
  - Translating these requirements into a conceptual schema of the database
    - Detailed overview of the enterprise
  - A fully developed conceptual schema indicates the functional requirements of the enterprise
    - Describes operations (e.g., update, retrieval, delete) that will be performed on the data
- Entity-relationship model is typically used
  - Outcome is an E-R diagram that provides a graphic representation of the schema
    - Entities that are represented in the database
    - Attributes of the entities
    - Relationships among entities
    - Constraints on the entities and relationship

Design Phases

- 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 decision
      - 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
    - E.g., the form of file organization and choice of index structures
  - Physical schema is easy to change after application is built
    - But logical schema is not, because changes may affect a number of queries and updates scattered across application code

Design Alternatives

- In designing a database schema, we must ensure that we avoid two major pitfalls
  - **Redundancy**: a bad design may result in repeated information
    - E.g., store course identifier and title of a course for each course offering
      - Only store course identifier is sufficient
    - Redundant representation of information may lead to data inconsistency among the various copies of information
      - E.g., update is not performed on all the copies
  - **Incompleteness**: a bad design may make certain aspects of the enterprise difficult or impossible to model
    - E.g., only have entity for course offering, but without entity for courses
      - Impossible to model new courses that are not offered yet

Design Alternatives

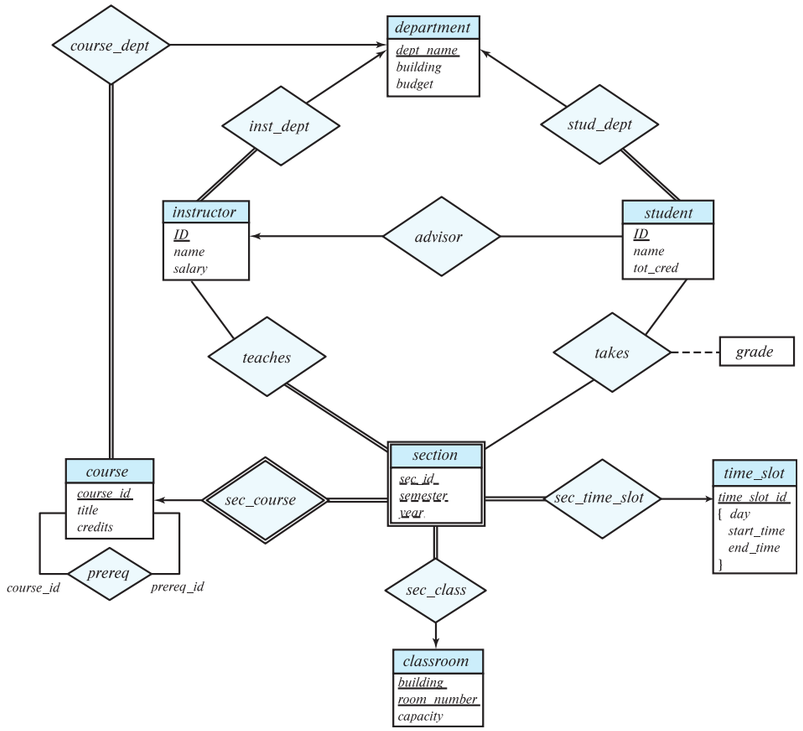
- Avoiding bad designs is not enough
  - There may be many good designs from which we must choose

- For example, a customer who buys a product
  - The sale activity is a relationship between the customer and the product?
  - The sale activity is a relationship among the customer, the product, and the sale itself?
    - i.e., the sale can be considered as an entity

- Database design can be difficult
  - When #entities and #relationships are large

Design Approaches

- Entity-Relationship Model (covered in this chapter)
  - Specifies an enterprise schema representing overall logical structure of a database
  - Models an enterprise as a collection of entities and relationships
  - Represented diagrammatically by an entity-relationship diagram (E-R diagram)
    - Express overall logical structure of a database graphically



- Normalization Theory (coming in the next few weeks)
  - Formalize what designs are bad, and test for them

Entity and Entity Sets

- An entity is an object that exists and is distinguishable from other objects
  - Concrete entity: specific person, company, plant, book
  - Abstract entity: flight reservation, course, course offering

- 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
  - Entity sets may not be disjoint (e.g., person vs. instructor and student)

Entity and Entity Sets

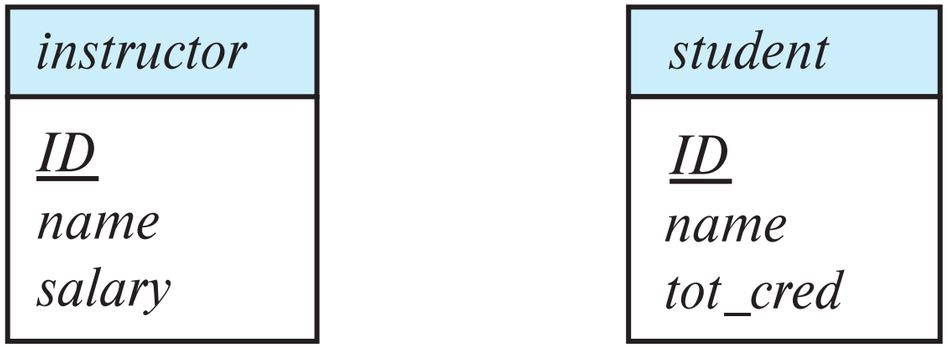
- An entity is represented by a set of attributes; i.e., descriptive properties possessed by all members of an entity set
- Example:

```
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
  - Government-issued ID number as the primary key
    - May have privacy and security issues
  - Enterprise-issued ID number

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

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

- A relationship set is a set of relationships of the same type (e.g., advising)
  - A mathematical relation among n ≥ 2 (possibly non-distinct) entities, each taken from entity sets

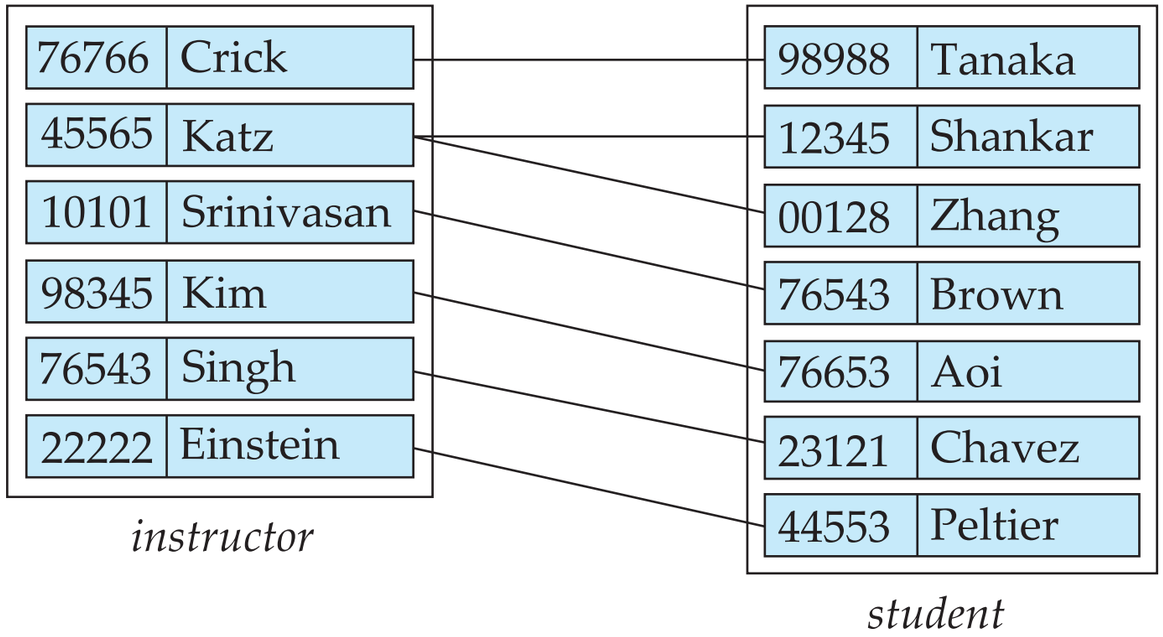
$$\{(e_1, e_2, \ldots e_n) \mid e_1 \in E_1, e_2 \in E_2, \ldots, e_n \in E_n\}$$

where (e_1, e_2, ..., e_n) is a relationship, or relationship instance

  - Example: (44553,22222) ∈ advisor
  - The association between entity sets is referred to as participation
    - Entity sets E_1, E_2, … , E_n participate in relationship set R

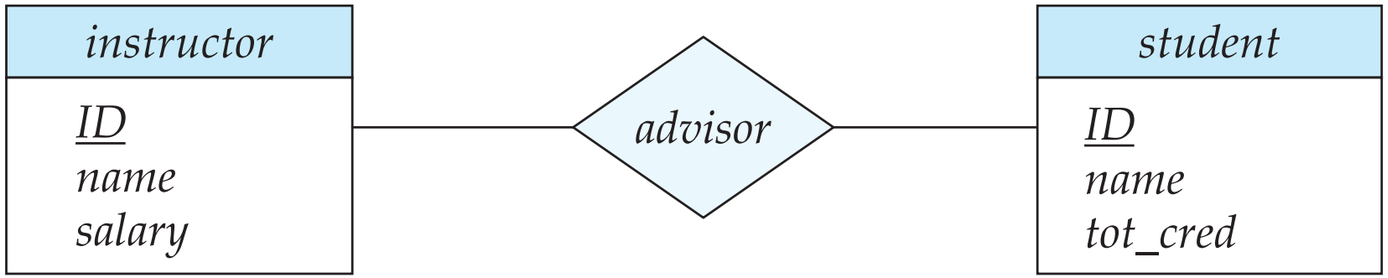
Relationship Sets

- 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



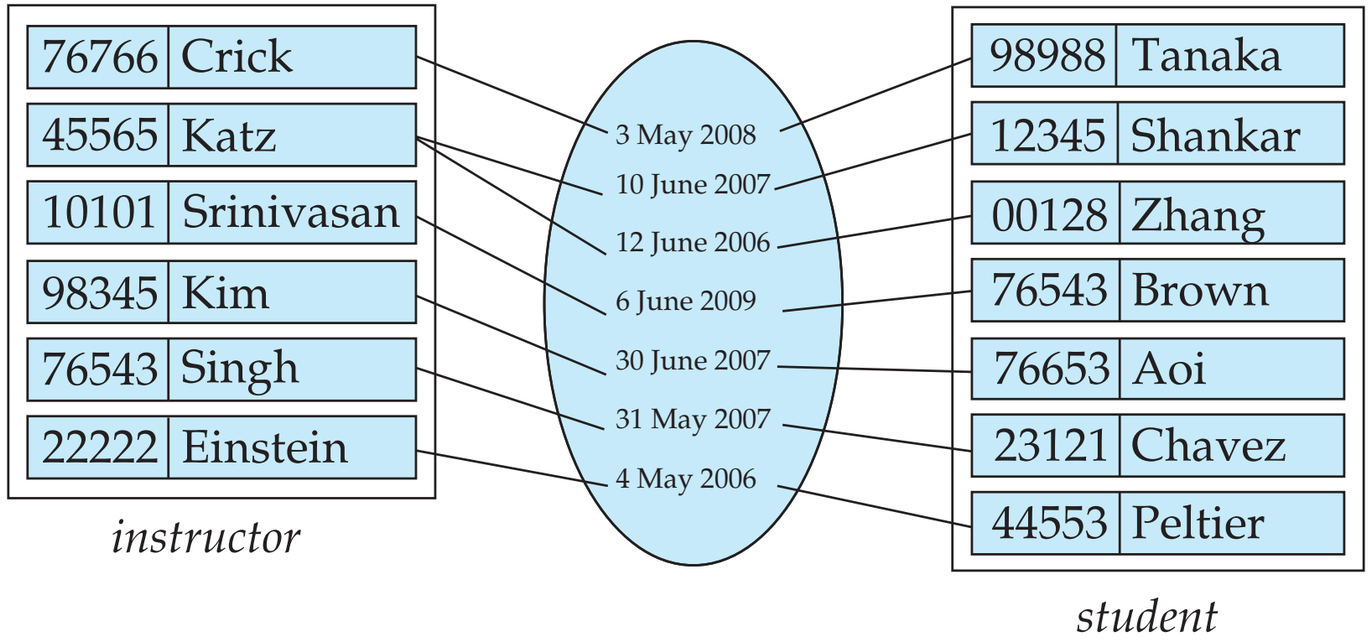
Representing Relationship Sets via E-R Diagrams

- Use diamonds to represent relationship sets



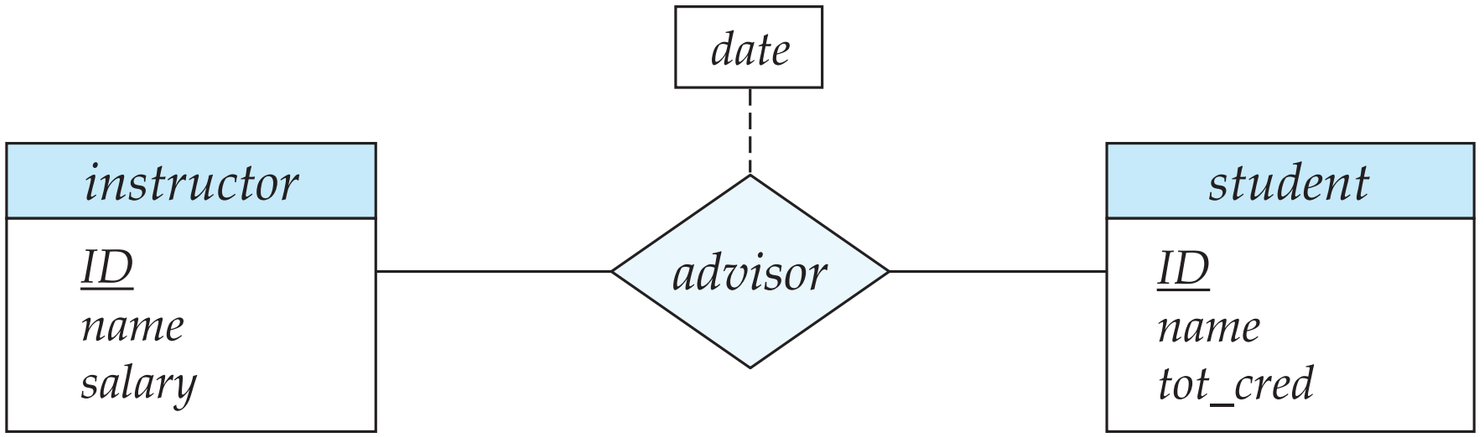
Relationship Sets (Cont.)

- A descriptive attribute can be associated with a relationship set.
  - E.g., 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



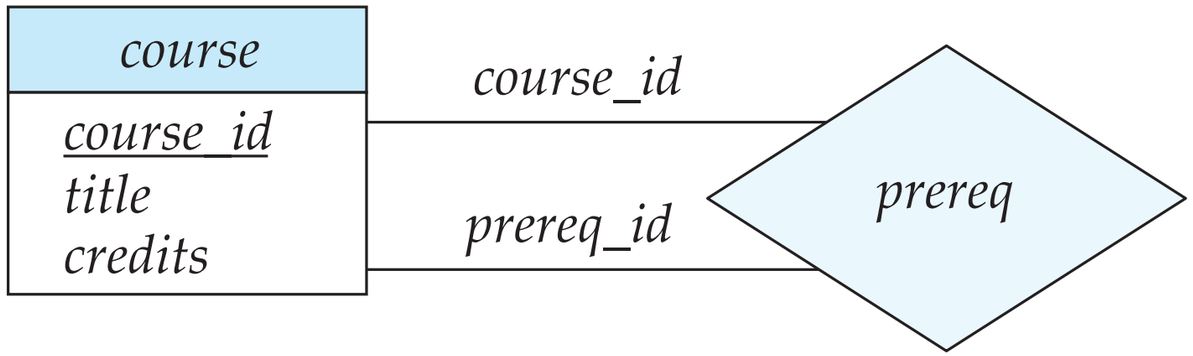
Relationship Sets with Attributes

- Represented by using an undivided rectangle
- Linked to the diamond representing the relationship set via a dashed line



Roles

- Entity sets of a relationship need not be distinct (i.e., can be the same entity set)
  - We can create self-pointing relationships for an entity set
  - Each occurrence of an entity set plays a "role" in the relationship
  - Example: A relationship set to represent the prerequisites of a course
    - E.g., Data Structure depends on Introduction to Programming
    - The labels `course_id` and `prereq_id` are called roles



- If the entity sets participating in a relationship are distinct,
  - Their roles are implicit and usually are not specified

Degree of a Relationship Set

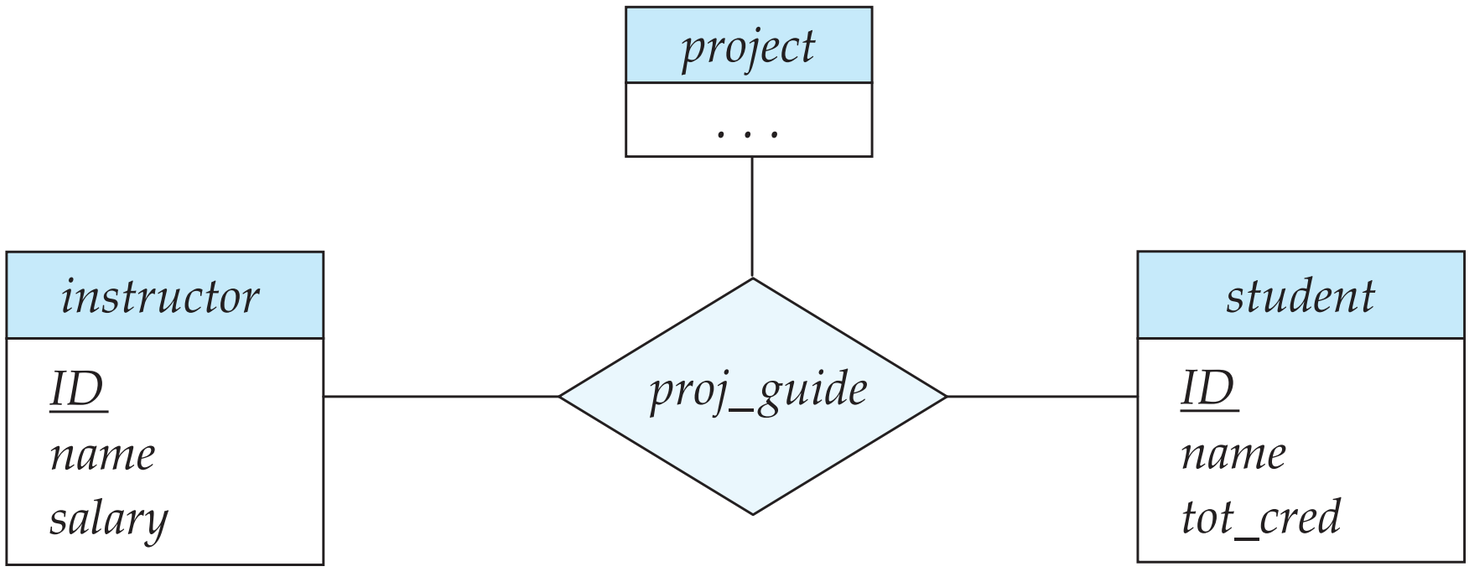
- Defined as the number of entity sets participating in a relationship set

- 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
  - E.g., students work on research projects under the guidance of an instructor
    - relationship `proj_guide` is a ternary relationship among instructor, student, and project
      - A particular student is guided by a particular instructor on a particular project

Non-binary Relationship Sets

- Although 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

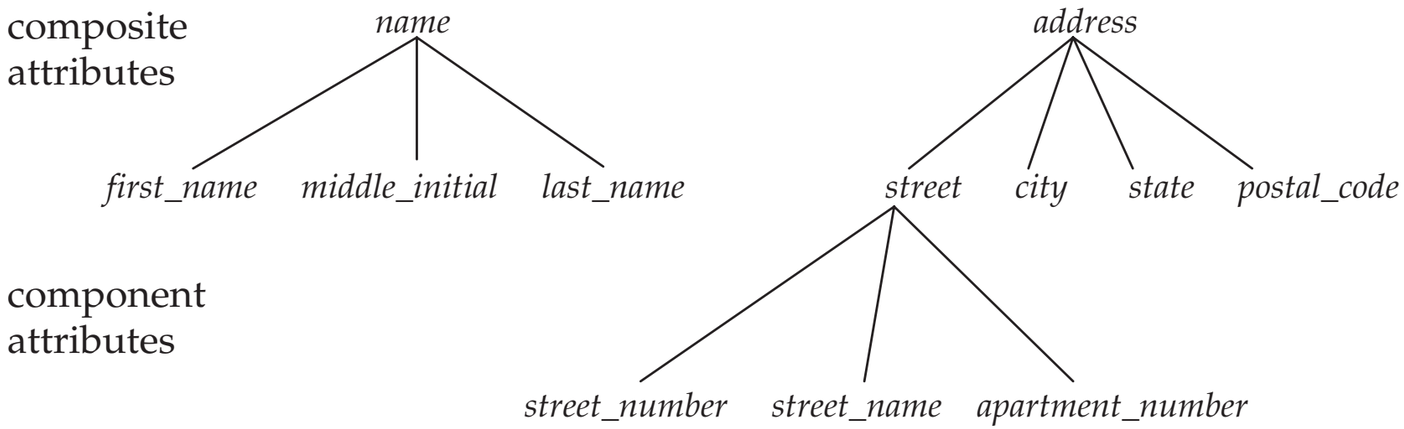


Complex Attributes

- Attribute types
  - Simple (i.e., not divided into subparts) and composite (i.e., divided into subparts) attributes

Composite Attributes

- Composite attributes allow us to divided attributes into subparts
  - Sometimes we may only use part of the attributes
  - In this case, composite attribute is a good design choice
- Allow us to group together related attributes, making the modeling cleaner
- A composite attribute may appear as a hierarchy



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 ( )

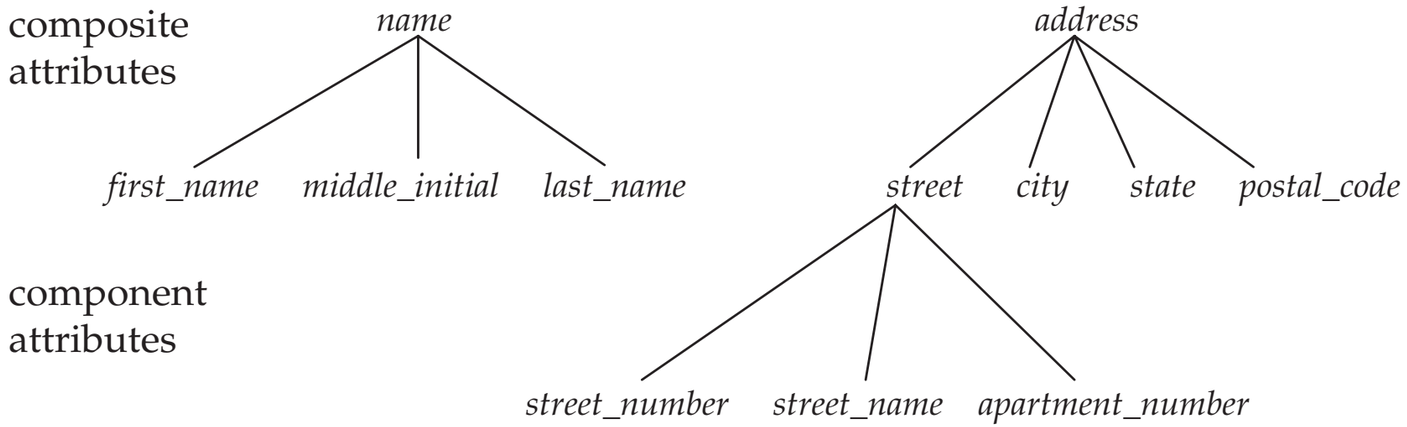
E-R notation

Complex Attributes

- Attribute types
  - Simple (i.e., not divided into subparts) and composite (i.e., divided into subparts) attributes
  - Single-valued and multivalued attributes
    - Single-valued attribute: e.g., for a student, only one *student_id*
    - Multivalued attribute
      - *phone_numbers*: a person can have 0, 1, or multiple phone numbers at the same time
      - *grades*: each student may have multiples grades in a course
      - *dependent_name*: an instructor may be hired by 0, 1, or multiple departments
  - Derived attributes
    - Can be computed from other attributes
    - Example: *age* computed based on *date_of_birth*, #students advised by an instructor
- **Domain**: set of permitted values for each attribute
  - *course_id* might be the set of all text strings of a certain length
  - *semester* might be strings from the set {Fall, Winter, Spring, Summer}

E-R notation of Composite Attributes

- E-R notations for
  - Composite attributes
  - Multivalued attributes
  - Derived attributes

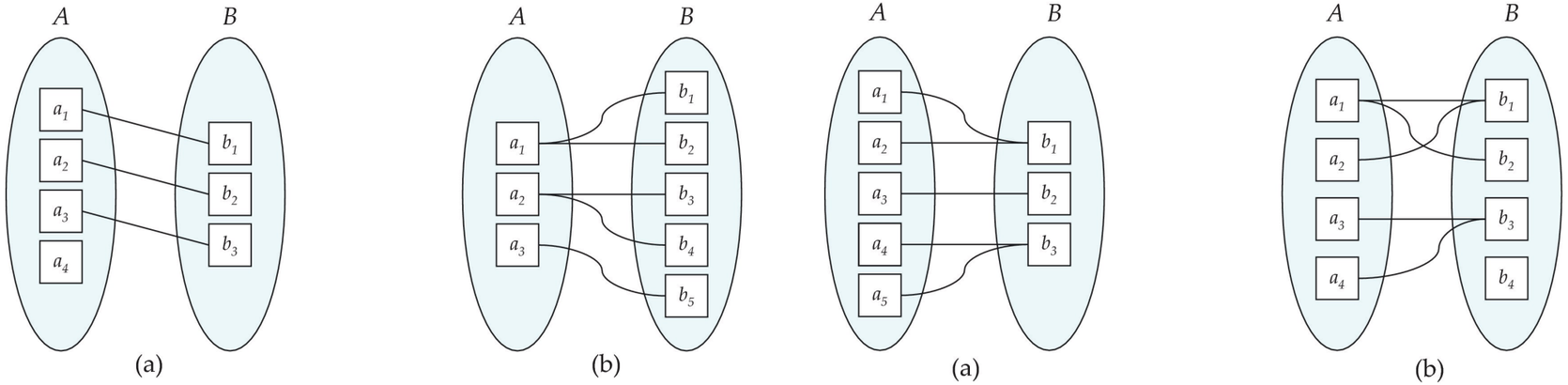


instructor

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 ( )

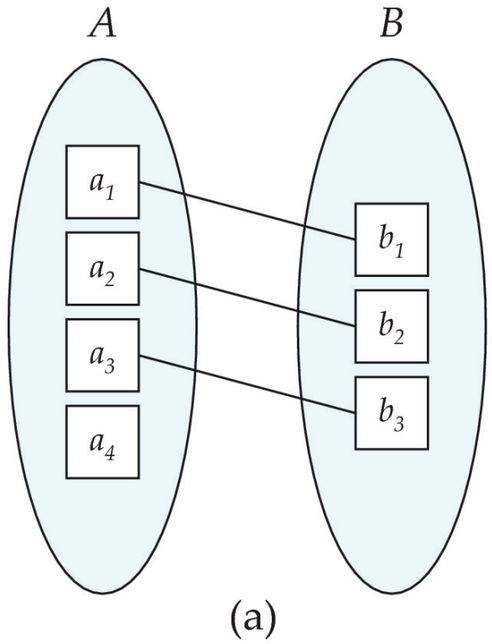
Mapping Cardinality Constraints

- Mapping Cardinality（映射基数）
  - Express the number of entities to which another entity can be associated via a relationship set
    - Most useful in describing binary relationship sets
    - Can also help describe non-binary relationship sets
- For a binary relationship set, the mapping cardinality must be one of the following
  - One to one, one to many, many to one, many to many

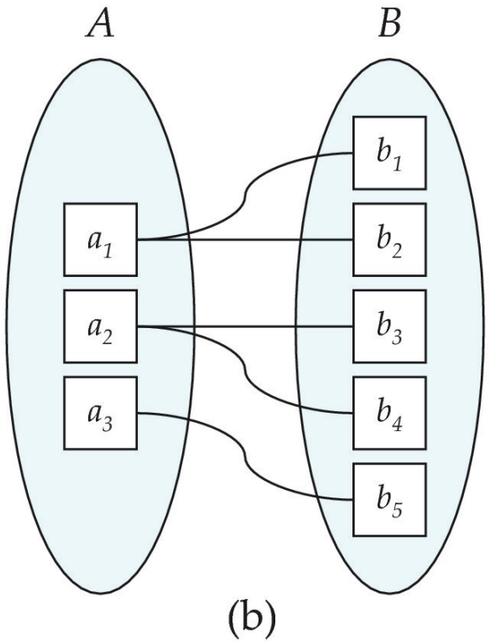


Mapping Cardinalities

- Every entity in A is associated with at most one entity in B
- Same for entity set B



One to one



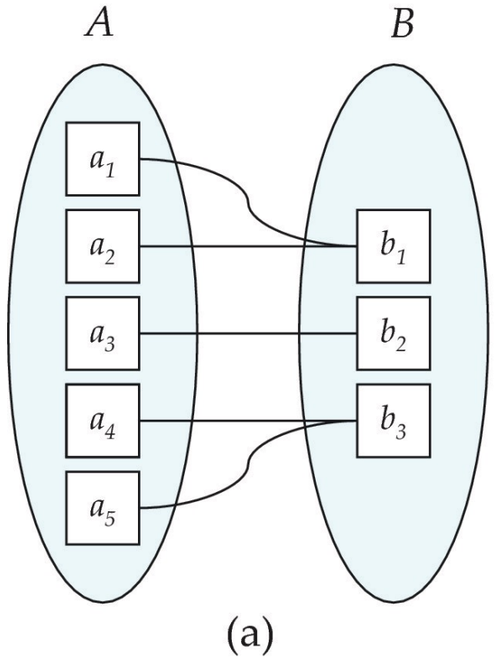
One to many

- Every entity in A is associated with 0, 1, or more entities in B
- Every entity in B is associated with at most one entity in A

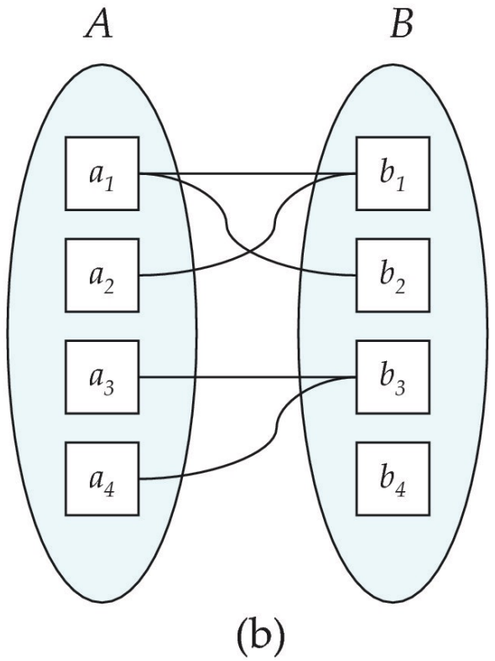
Note: Some entities in *A* and *B* may not be mapped to any entities in the other set

Mapping Cardinalities

- Every entity in A is associated with at most one entity in B
- Every entity in B is associated with 0, 1 or more entities in A



Many to one



Many to many

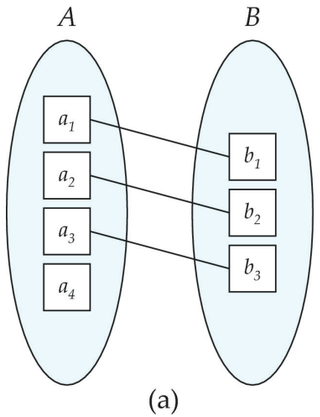
- Every entity in A is associated with 0, 1, or more entities in B
- Same for B

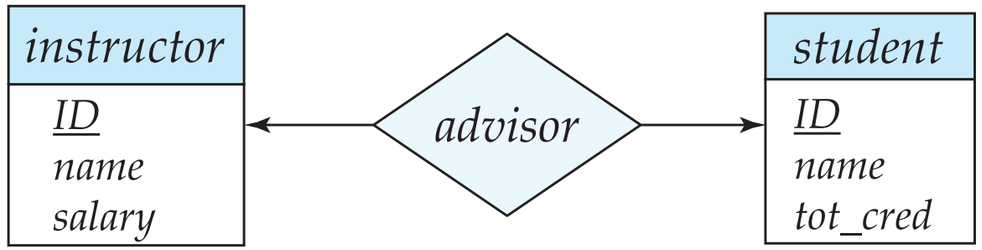
Note: Some entities in *A* and *B* may not be mapped to any entities in the other set

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

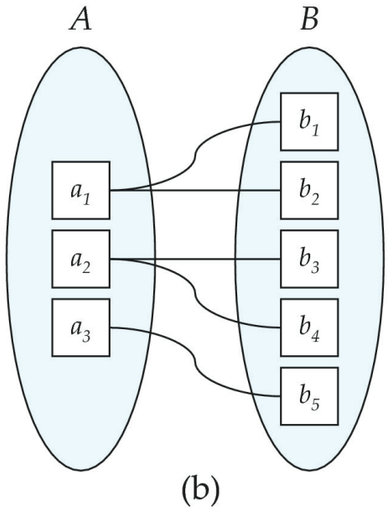
- One-to-one relationship between an instructor and a student :
  - A student is associated with at most one instructor via the relationship advisor





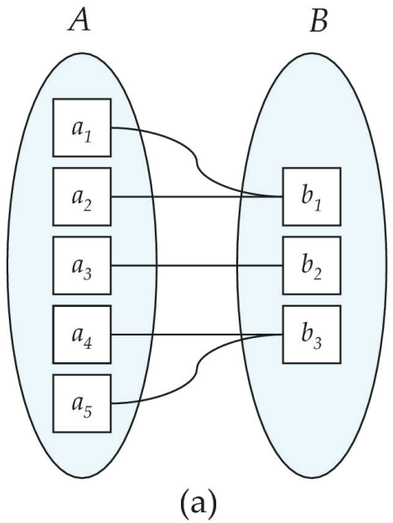
Representing Cardinality Constraints in ER Diagram

- 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



Representing Cardinality Constraints in ER Diagram

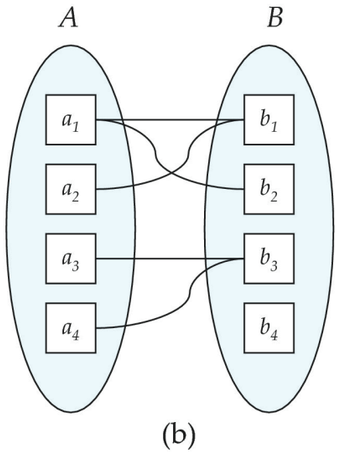
- In a many-to-one relationship between an instructor and a student,
  - An instructor is associated with at most one student via advisor
  - A student is associated with several (including 0) instructors via advisor



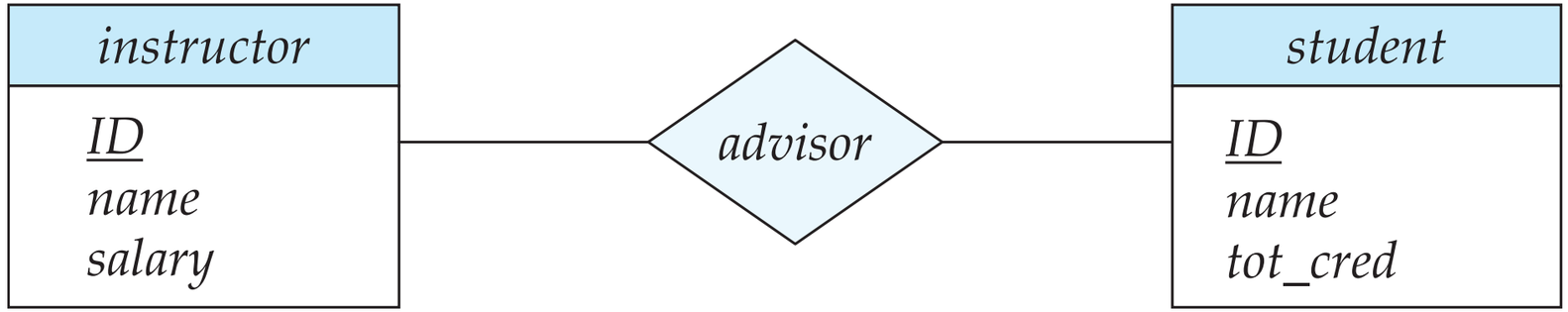
(a)

Representing Cardinality Constraints in ER Diagram

- Many-to-many relationship:
  - An instructor is associated with several (possibly 0) students via advisor
  - A student is associated with several (possibly 0) instructors via advisor

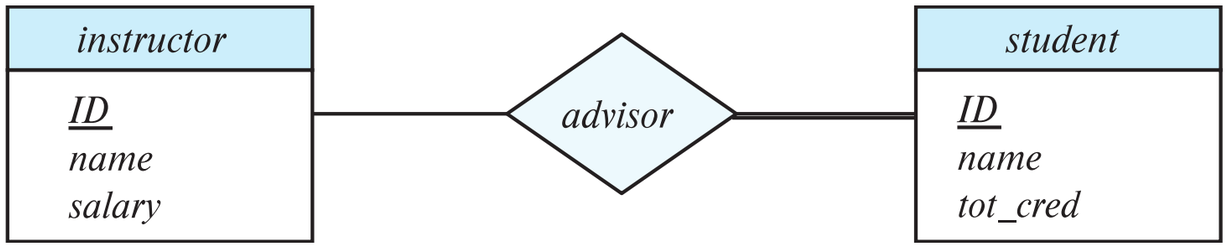


(b)



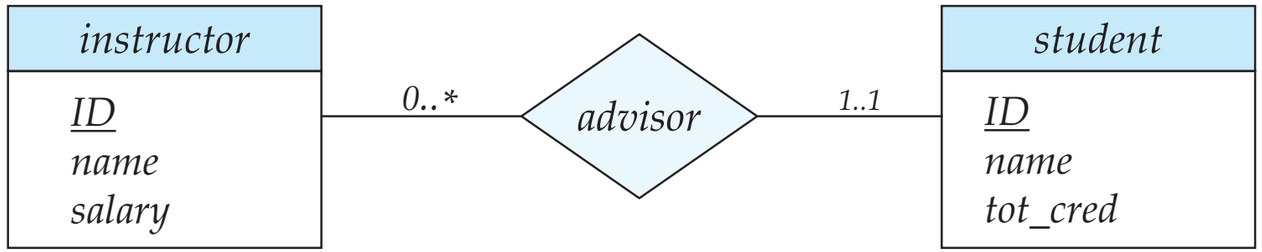
Total and Partial Participation

- Total participation (indicated by *undirected double line, i.e., =*)
  - 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 (undirected line, i.e., —)
  - Some entities may not participate in any relationship in the relationship set
    - E.g., participation of instructor in advisor is partial

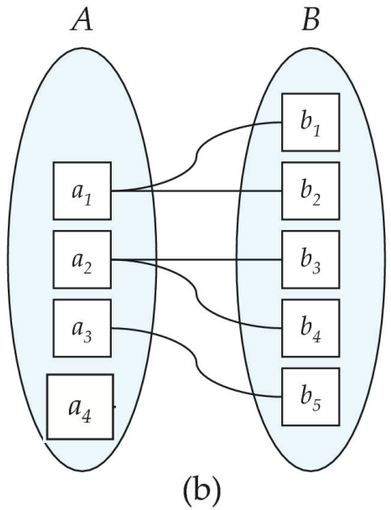


Notation for Expressing More Complex Constraints

- 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
  - An entity can participate in at minimum l and at maximum h relationships
  - 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



one to many,
not many to one

Primary Key

- Superkey, candidate key, and primary key apply to entity and relationship sets (like in relation schemas)
- Primary key provides a way to specify how entities and relations are distinguished

Primary Key for Entity Sets

- By definition, individual entities are distinct
  - From database perspective, their differences must be expressed in terms of their attributes

- The values of the 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

Primary Key for Relationship Sets

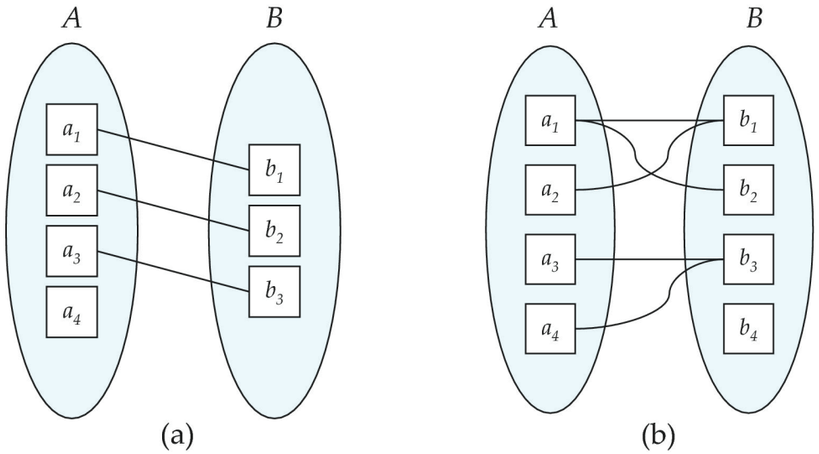
- To distinguish among the various relationships of a relationship set, we use the **individual primary keys** of the entities in the relationship set.
  - Let R be a relationship set involving entity sets E1, E2, .. En
  - The primary key for R consists of the union of the primary keys of entity sets E1, E2, ..En
    - Form a superkey
  - If the relationship set R has attributes $a_1, a_2, .., a_m$ associated with it, the primary key of R also includes the attributes $a_1, a_2, .., a_m$

- 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 union of the primary keys is a minimal superkey and is chosen 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.

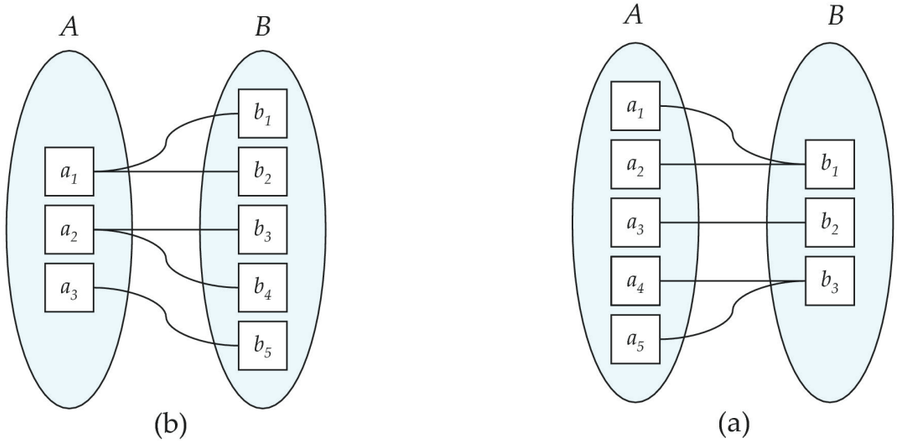


* *K* is a **superkey** of *R* if values for *K* are sufficient to identify a unique tuple of each possible relation *r(R)*

- Example: {*ID*} and {ID,name} are both superkeys of *instructor*.

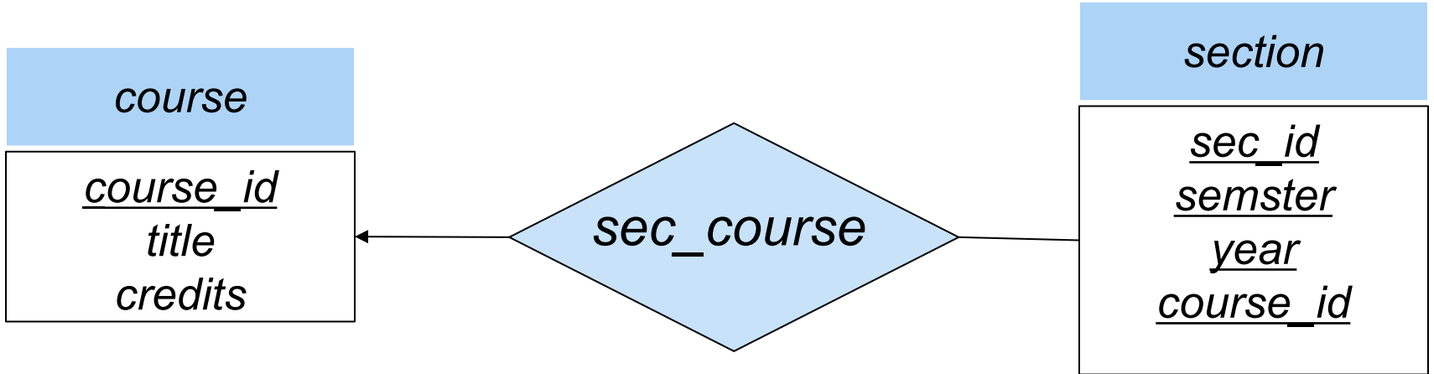
Choice of Primary key for Binary Relationship

- One-to-Many relationships
  - The primary key of the “Many” side is a minimal superkey and is used as the primary key
    - E.g., each student can have at most one advisor → then the primary key of advisor is simply the primary key of student.
- Many-to-one relationships
  - The primary key of the “Many” side is a minimal superkey and is used as the primary key



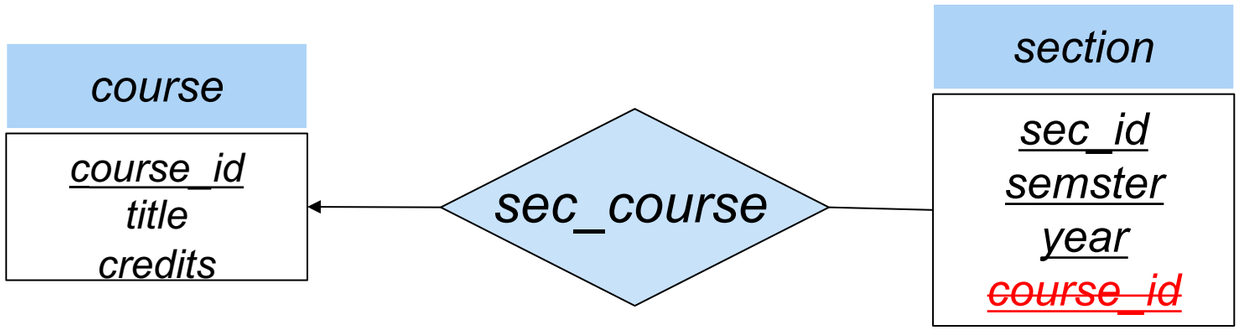
Weak Entity Sets (弱实体集)

- Consider a *section* entity, which is uniquely identified by *course_id*, *semester*, *year*, and *sec_id*
  - Clearly, *section* entities are related to *course* entities
  - Suppose we create a relationship set *sec_course* between *section* and *course*
    - 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 （弱实体集）

- 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, *section* then does not have enough attributes to identify a particular section entity uniquely
  - Although each section entity is distinct, sections for different courses may share the same sec id, year, and semester



Weak Entity Sets （弱实体集）

- To deal with this problem, we treat the relationship *sec_course* as a special relationship that provides extra information, in this case, *course_id*, to identify section entities uniquely

- A weak entity set is one whose existence is dependent on another entity, called its identifying entity
  - Entity set that does not have sufficient attributes to form a primary key

- Instead of associating a primary key with a weak entity, we use the identifying entity, along with extra attributes called discriminator to uniquely identify a weak entity

Weak Entity Sets （弱实体集）

- An entity set that is not a weak entity set is termed a strong entity set （强实体集）
- Every weak entity must be associated with an identifying entity
  - 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
- The relational schema, eventually created for *section*, does have the attribute *course_id*,
  - Even though we have dropped the attribute *course_id* from *section* in E-R diagram

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
  - The identifying relationship is many-to-one from the weak entity set to the identifying entity set
  - The participation of the weak entity set in the relationship is total
  - The identifying relationship set should not have any descriptive attributes, since any such attributes can instead be associated with the weak entity set

Expressing Weak Entity Sets

- Primary key for *section*: (*course_id*, *sec_id*, *semester*, *year*)
  - Primary key of identifying (strong) entity set, plus discriminators of weak entity set
  - We have constraints on the *section* schema, with the attribute *course_id* referencing the primary key of the *course* schema

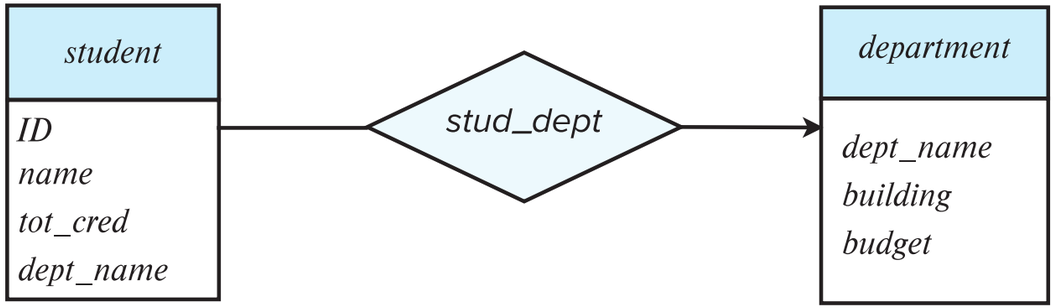
Removing Redundant Attributes in Entity Sets

Redundant Attributes

- Database usually starts with
  - Identifying entity sets that should be included
    - E.g., in university organization, we have instructors and students
  - Choosing appropriate attributes
    - Represent the various values we want to capture in the database
    - Depending on the designer, who has a good understanding of the enterprise
    - E.g., for instructor, we can record
      - ID, name, dept name, and salary
      - phone number, office number, home page, and others
- Once entities and attributes are chosen, relationship sets among the entities are formed
  - The relationship sets may lead some attributes to be redundant, and need to be removed

Redundant Attributes

- Suppose we have entity sets:
  - student = {ID, name, tot_cred, dept_name}
  - department = {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 replicates the one in the relationship and is redundant
  - and needs to be removed

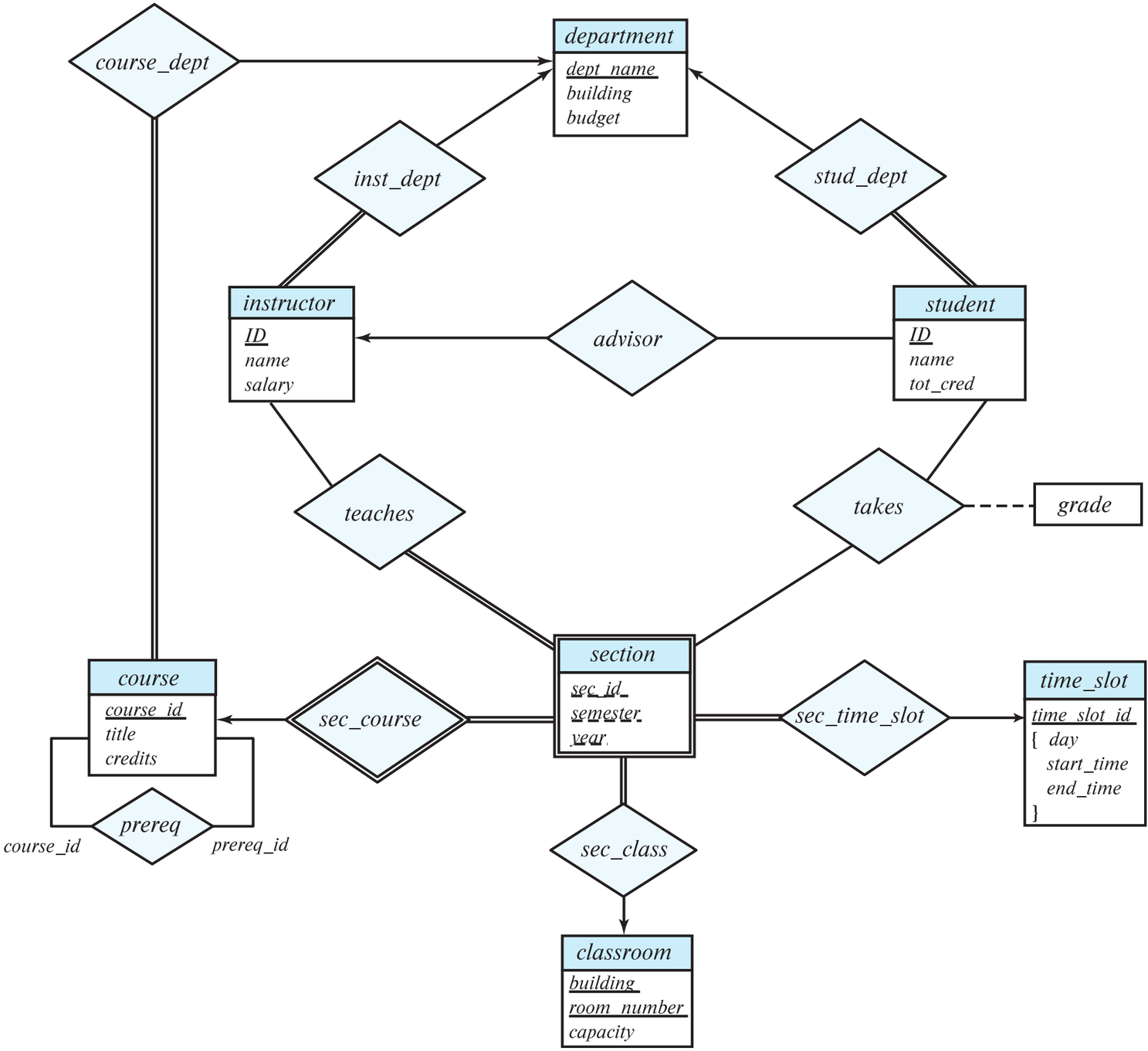


(a) Incorrect use of attribute

  - BUT: when converting back to tables from E-R diagrams, in some cases the attribute gets reintroduced
    - Depending on the mapping cardinality (e.g., when each student has at most one department)
- A good entity-relationship design does not contain redundant attributes

Quick Example

- Each instructor must have exactly one associated department
- Each instructor can have at most one associated department
- Every course must be in some department
- Every student must be majoring in some department
- A course (and a student) can be related to only one department
- Relationship set *takes* has a descriptive attribute grade
- Each student has at most one advisor
- *section* is a weak entity set, with attributes sec_id, semester, and year forming the discriminator
- *sec_course* is the identifying relationship set relating weak entity set *section* to the strong entity set *course*



Reduction to Relation Schemas

Reduction to Relation Schemas

- Both E-R model and relational database model are abstract, logical representations of real-world enterprises
  - We can convert an E-R design into a relational design

- 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 attributes, with unique names

Representing Entity Sets

- A strong entity set reduces to a schema with the same attributes
  - Each tuple in a relation on this schema corresponds to one entity of the entity set

student(<u>ID</u>, name, tot_cred)

- A weak entity set becomes a table that includes a column for the primary key of the identifying strong entity set

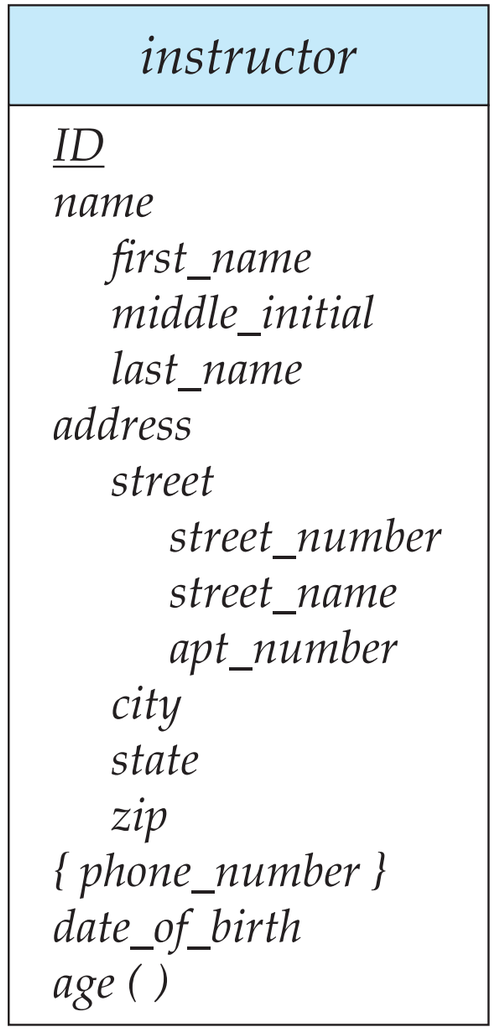
section (<u>course_id, sec_id, sem, year</u>)

- Example

Representation of Entity Sets with Composite 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 (e.g., 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
    - E.g., multivalued attribute phone_number of instructor is represented by a schema
    - Foreign-key constraint on *inst_phone*: ID references the instructor relation

inst_phone= (ID, phone_number)

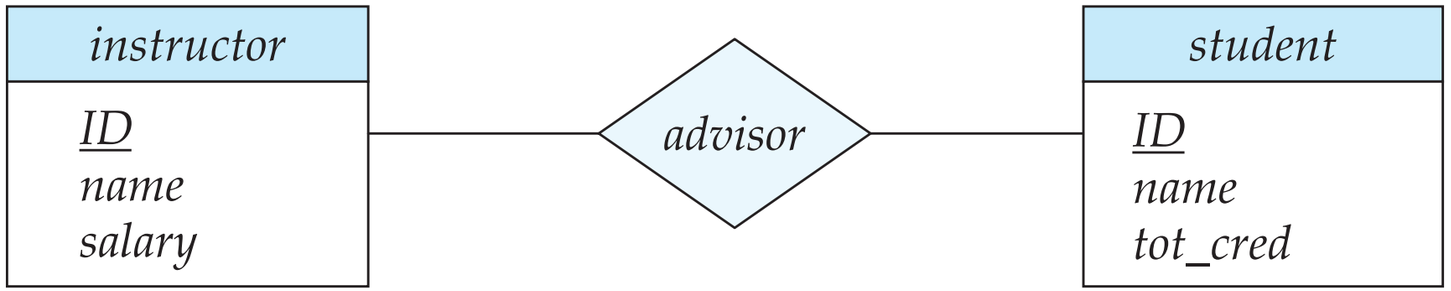
  - Each value of the multivalued attribute maps to a separate tuple of the relation schema EM
    - E.g., an instructor entity with primary key 22222 and phone numbers 456-7890 and 123-4567 maps to two tuples:

(22222, 456-7890) and *(22222, 123-4567)*

Representing Relationship Sets

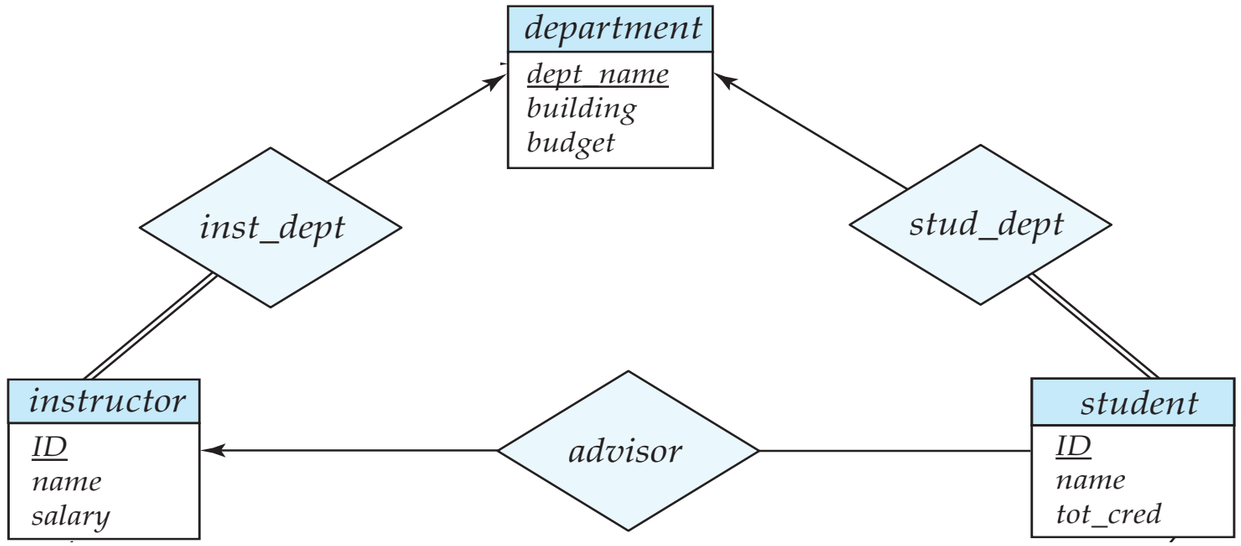
- A many-to-many relationship set is represented as a schema with
  - Attributes consisted of the primary keys of the two participating entity sets
  - Descriptive attributes of the relationship set
- Example: schema for relationship set advisor
  - With two foreign keys created

$$advisor = (\underline{s\_id}, \underline{i\_id})$$



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

- 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 nulls

Redundancy of Schemas

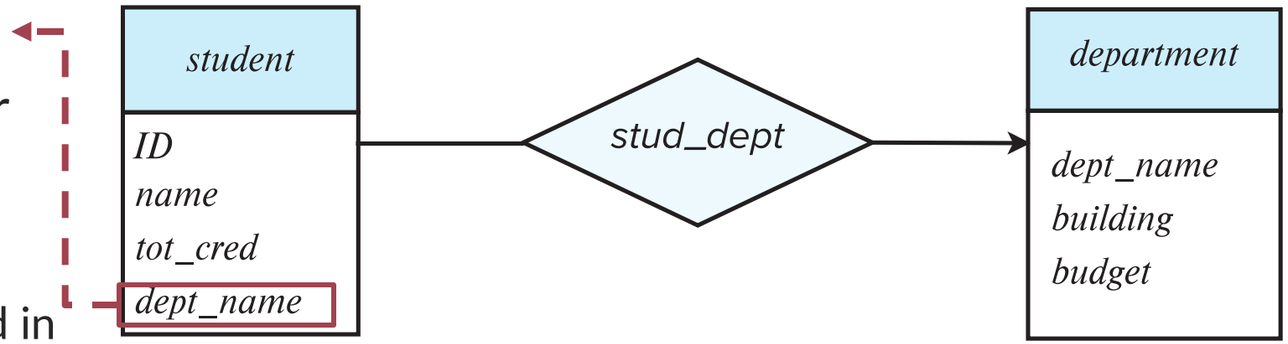
- The schema corresponding to a relationship set linking a weak entity set to its identifying strong entity set is **redundant**
  - Example: The *section* schema already contains the attributes that would appear in the *sec_course* schema

- Primary key for *section*: (*course_id*, *sec_id*, *semester*, *year*)
  - Primary key of identifying (strong) entity set, plus discriminators of weak entity set
  - We have constraints on the *section* schema, with the attribute *course_id* referencing the primary key of the *course* schema

Design Issues

Common Mistakes in E-R Diagrams

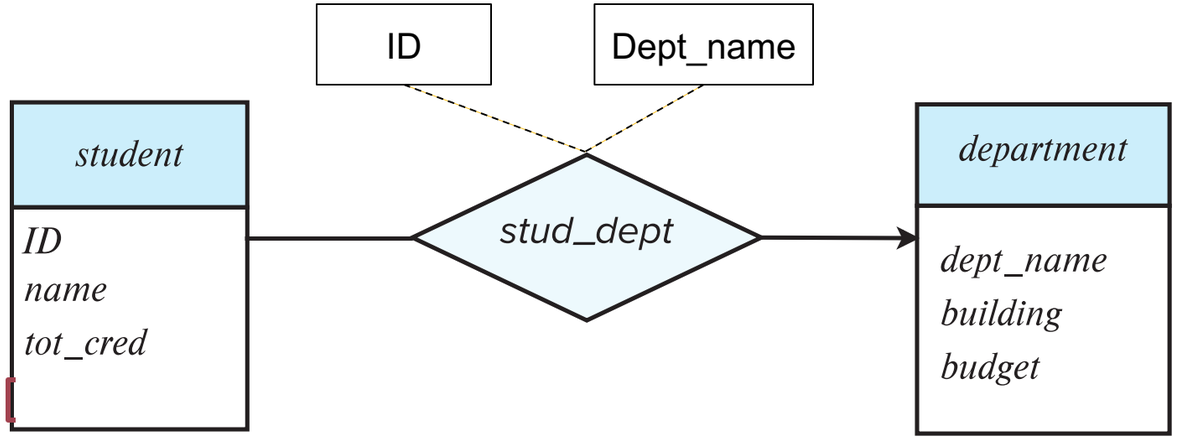
- Examples of erroneous E-R diagrams
  - (a) Unnecessary attribute in entity set
    - … which is the primary key of another entity
    - Problem: data redundancy
      - The relationships are already presented in the relationship set *stud_dept*



(a) Incorrect use of attribute

Common Mistakes in E-R Diagrams

- Examples of erroneous E-R diagrams
  - (b) Unnecessary attribute in relationship set
    - Designate the primary-key attributes of the related entity sets as attributes of the relationship set
    - Problem: data redundancy
      - primary-key attributes are already implicit in the relationship set*

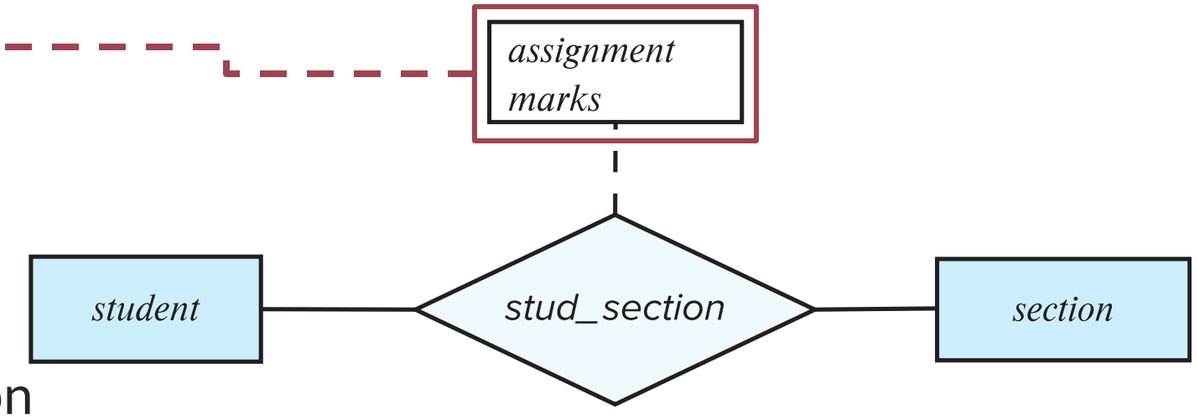


(a) Incorrect use of attribute

* When we create a relation schema from the E-R schema, the attributes may appear in a schema created from the stud_dept relationship set; however, they should not appear in the stud_dept relationship set in the E-R diagram

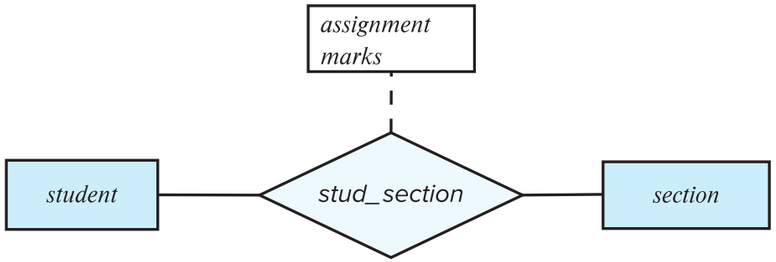
Common Mistakes in E-R Diagrams

- Examples of erroneous E-R diagrams
  - (c) Erroneous relationship attributes
    - Use a relationship with a single-valued attribute in a situation that requires a multivalued attribute
    - Problem: cannot represent multiple assignments released in the same section for a given student-section pair



(b) Erroneous use of relationship attributes

Common Mistakes in E-R Diagrams



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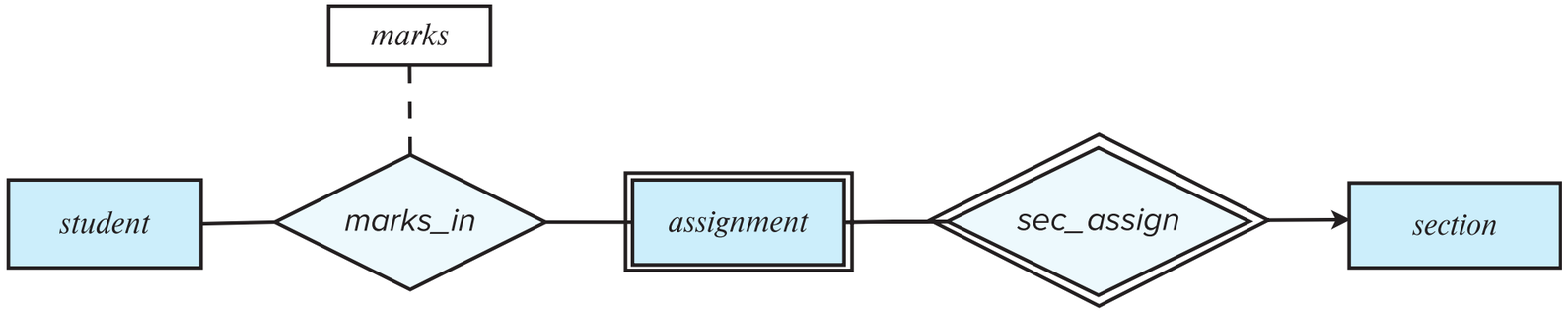
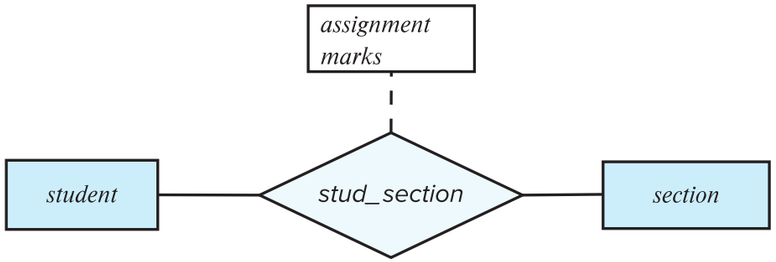
  - (c) Erroneous relationship attributes
    - Use a relationship with a single-valued attribute in a situation that requires a multivalued attribute
    - Problem: cannot represent multiple assignments released in the same section for a given student-section pair

- Solutions:
  - **1) Weak entity set**
    - model *assignment* as a weak entity identified by *section*
    - add a relationship *marks_in* between *assignment* and *student*
    - *marks_in* has an attribute *marks*



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

Common Mistakes in E-R Diagrams



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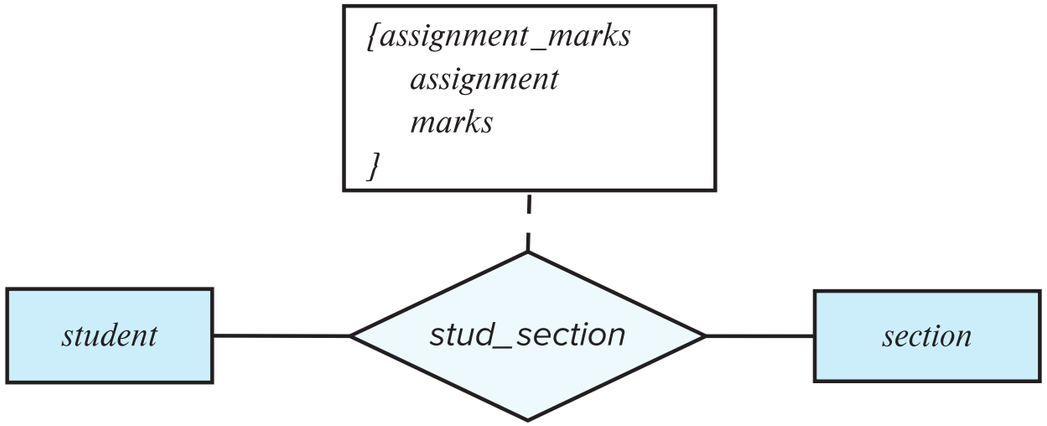
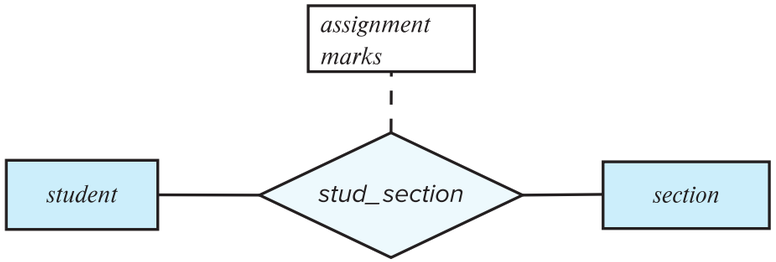


(d) Correct alternative to erroneous E-R diagram (b)

- Solutions:
  - 1) Weak entity set
  - **2) Composite attributes**
    - use a multivalued composite attribute *{assignment marks}*, where *assignment_marks* has component attributes *assignment* and *marks*

Common Mistakes in E-R Diagrams



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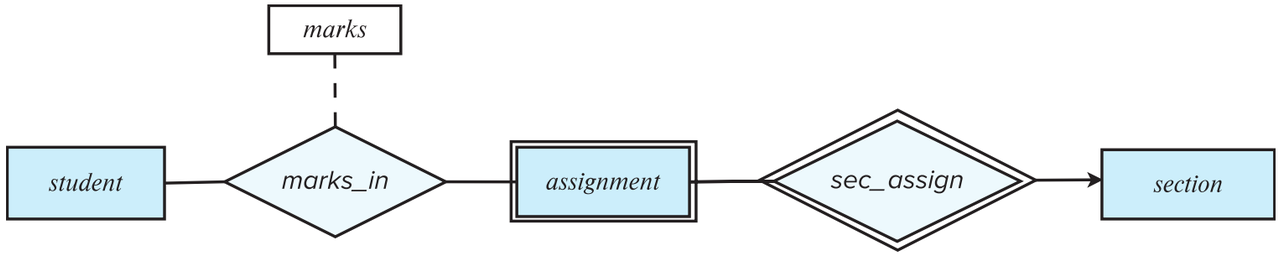

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- Solutions:
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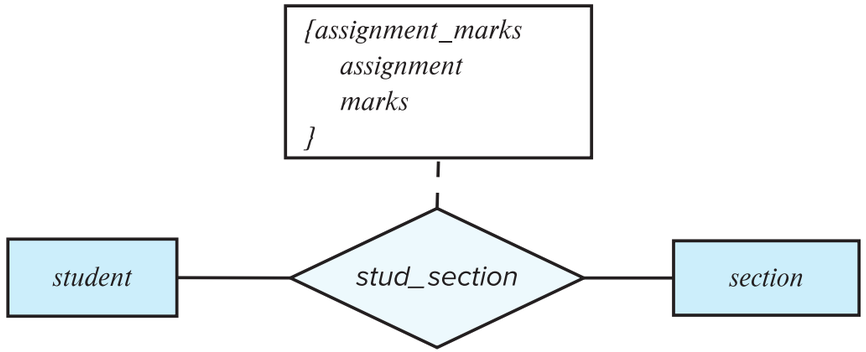
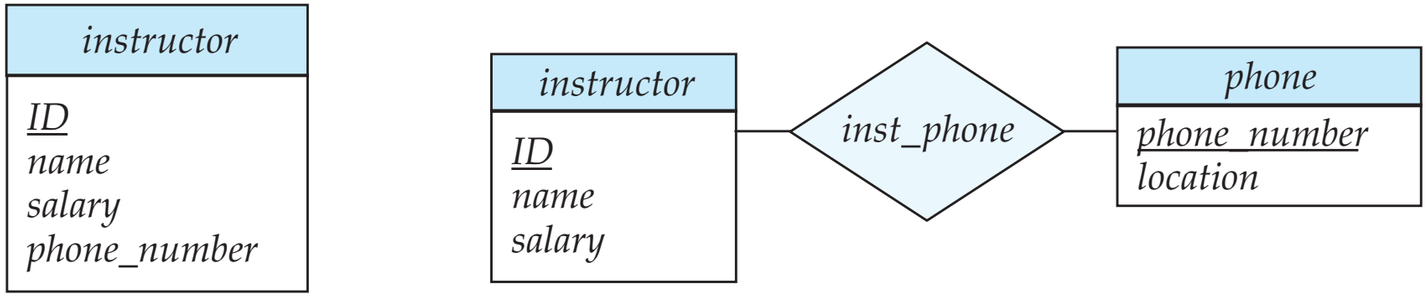


(d) Correct alternative to erroneous E-R diagram (b)

Using weak entity set is better, since it allows recording other information about the assignment, such as maximum marks or deadlines

Use of Entity Sets vs. Attributes

- Use entity sets or attributes?



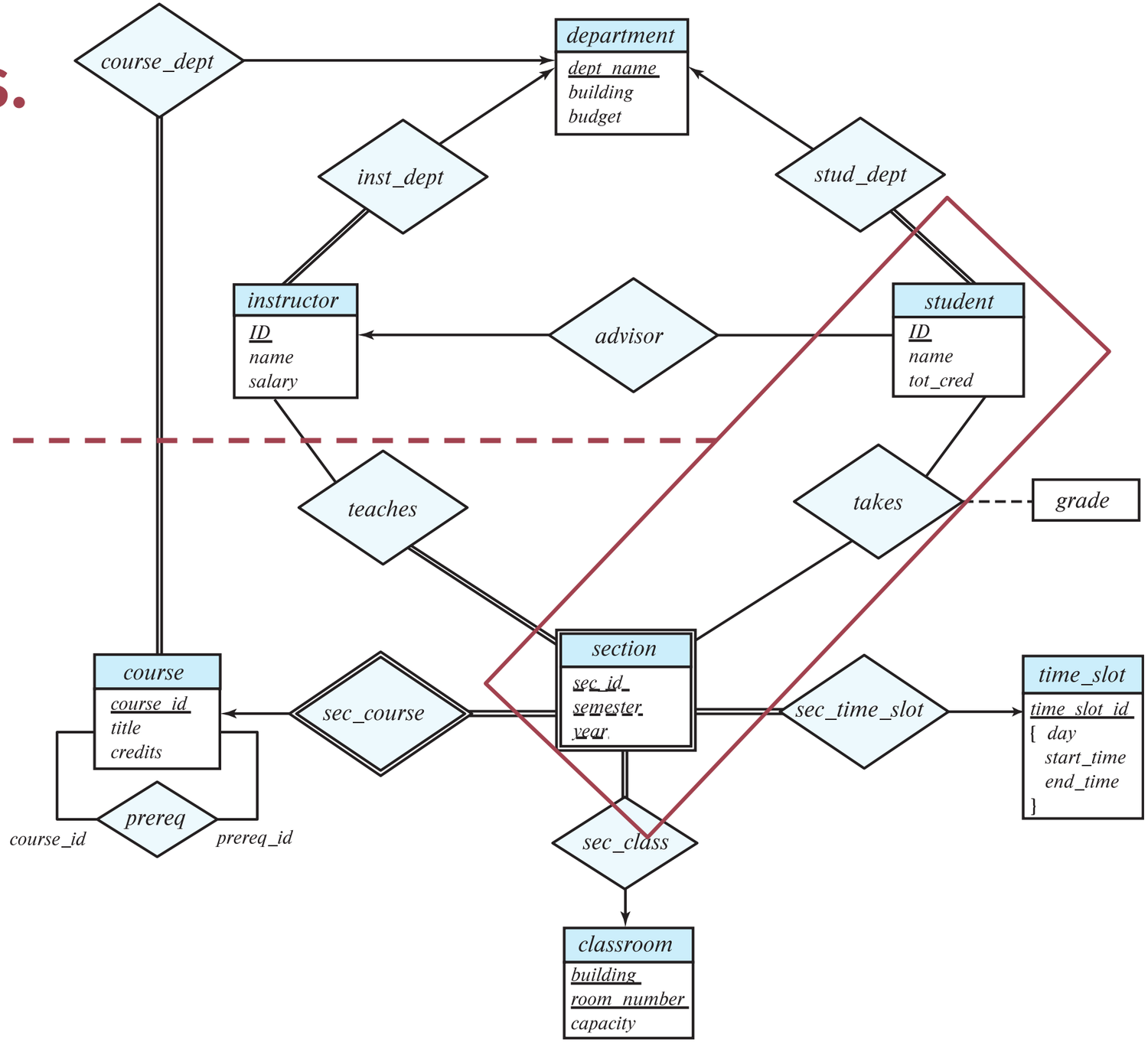
  - Use of *phone* as an entity allows extra information about phone numbers
    - E.g. location (Home phone, mobile (cell) phone, office phone), phone type / brand
    - Allow each instructor to have multiple (including zero) phone numbers
  - Treating *phone_number* as an attribute implies that instructors have precisely one phone number each
    - But this can be avoided by configuring *phone_number* as a multi-valued attribute
  - Treating phone as an entity is more general than treating it as an attribute
    - We can keep extra information about a phone

Use of Entity Sets vs. Relationship Sets

- Use entity sets or relationship sets? sometimes it is difficult to answer
  - **A possible guideline**: Use a relationship set to describe an action that occurs between entities

Use of Entity Sets vs. Relationship Sets

- Example: *takes*



Use of Entity Sets vs. Relationship Sets

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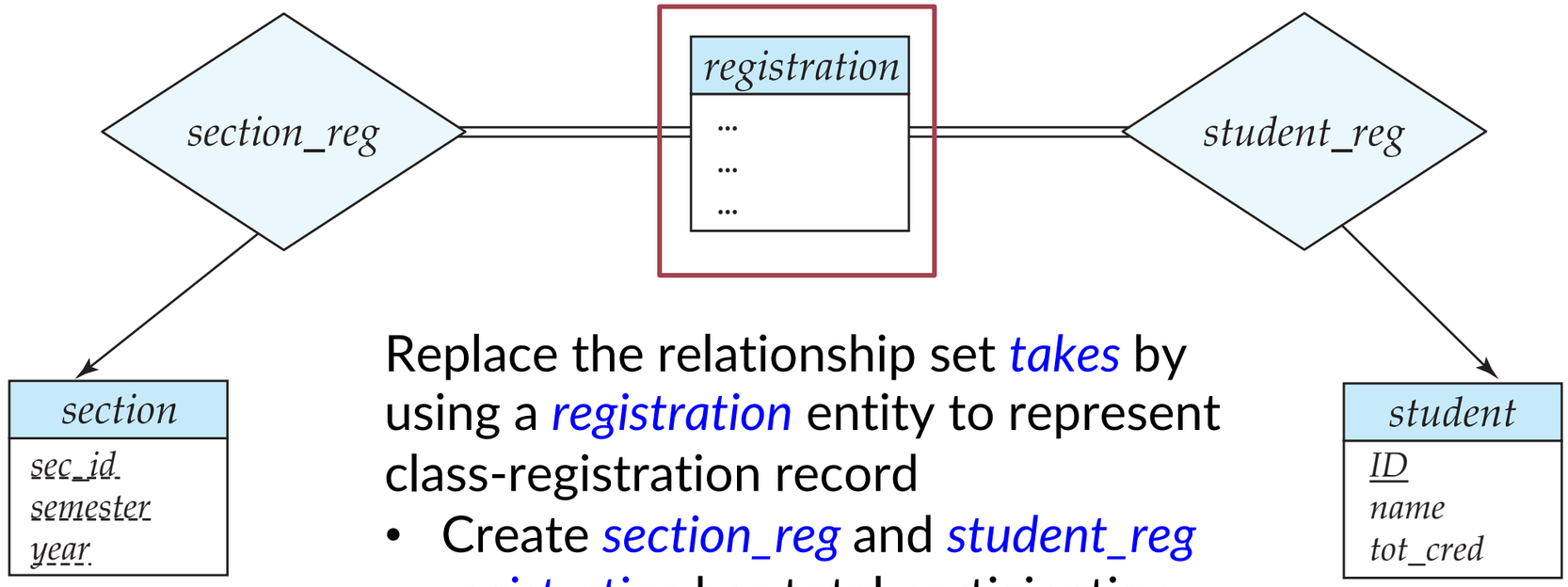
  - **A possible guideline**: Use a relationship set to describe an action that occurs between entities



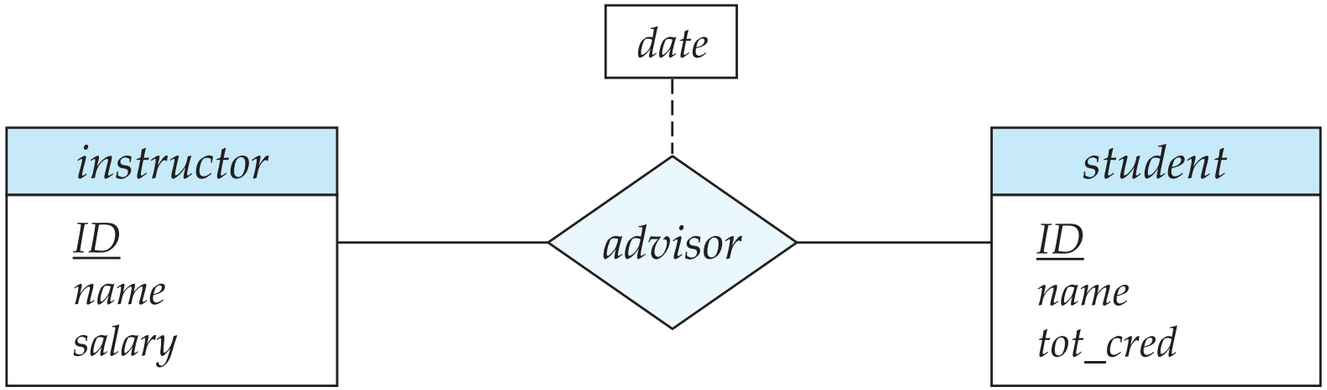
Replace the relationship set *takes* by using a *registration* entity to represent class-registration record

- Create *section_reg* and *student_reg*
- *registration* has total participation

  - Using *take* could be more compact and probably preferable
  - But by using a *registration* entity, we can associate other info with a course-registration record

Use of Entity Sets vs. Relationship Sets

- Use entity sets or relationship sets? sometimes it is difficult to answer
  - **A possible guideline**: Use a relationship set to describe an action that occurs between entities
    - This guideline can be used for designing relationship attributes
      - For example, attribute *date* as attribute of advisor or as attribute of student



Binary vs. Non-Binary Relationships

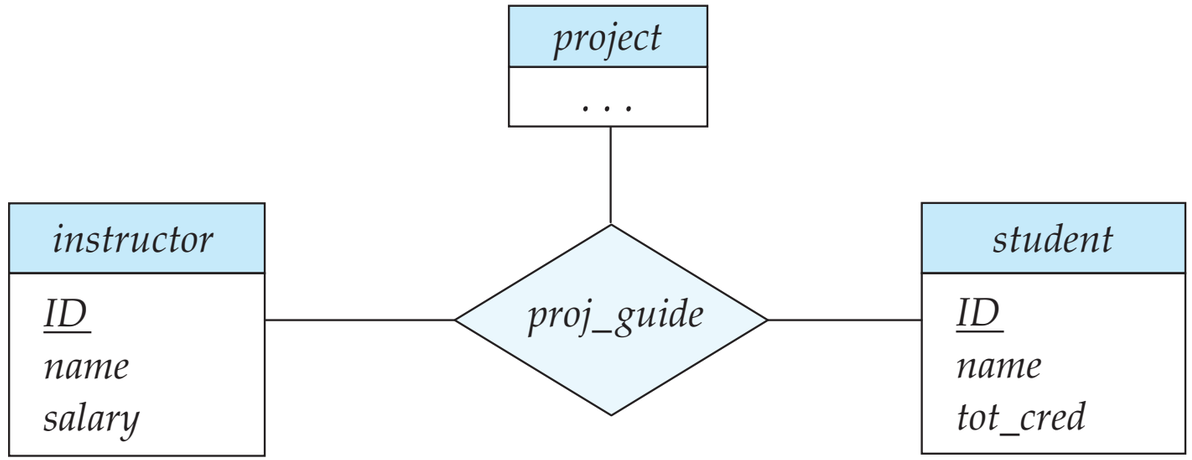
- Although it is possible to replace any non-binary (n-ary, for n > 2) relationship set by a number of distinct binary relationship sets, an n-ary relationship set shows more clearly that several entities participate in a single relationship.

Binary vs. Non-Binary Relationships

- Relationships in databases are often binary
- Some relationships that appear to be non-binary may be better represented using binary relationships
  - E.g., 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)
  - If *parent* is used, a null value would be required if only mother is known

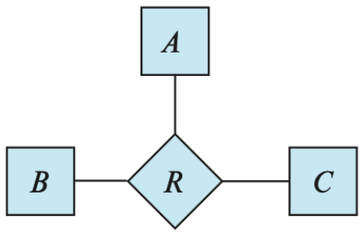
Binary vs. Non-Binary Relationships

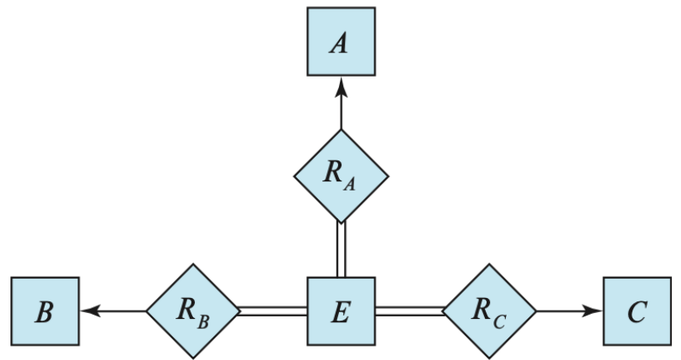
- Relationships in databases are often binary
- Some relationships that appear to be non-binary may be better represented using binary relationships
  - E.g., a ternary relationship *parents*, relating a child to his/her father and mother, is best replaced by two binary relationships, *father* and *mother*
    - 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*



Binary vs. Non-Binary Relationships

- It is possible to replace any non-binary (n-ary, for n > 2) relationship set by a number of distinct binary relationship sets
  - Replace relationship set R with entity set E, and relationship sets R_A, R_B and R_C
  - Participation of E in R_A, R_B and R_C is total
  - Any descriptive attributes in R are assigned to E; a special identifying attribute is created for E
    - This could make the design complicated and cost more storage
- n-ary relationship set shows more clearly several entities participate in a single relationship
- Some constraints on ternary relationship cannot be translated into constraints on binary relationships
  - E.g., R, which is many-to-one from A, B to C, cannot be easily satisfied by R_A, R_B and R_C
- Some relationships that are naturally non-binary
  - Better not using binary relationships to model





E-R Design Decisions

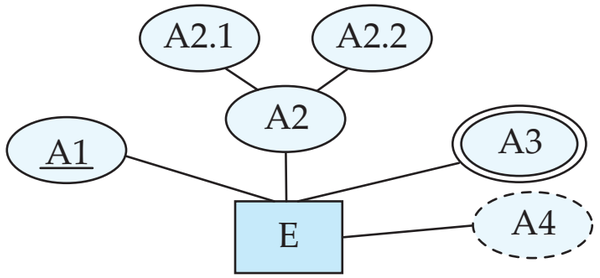
- The use of an attribute or entity set to represent an object
- Whether a real-world concept is best expressed by an entity set or a relationship set
- The use of a ternary relationship vs. a pair of binary relationships
- The use of a strong or weak entity set

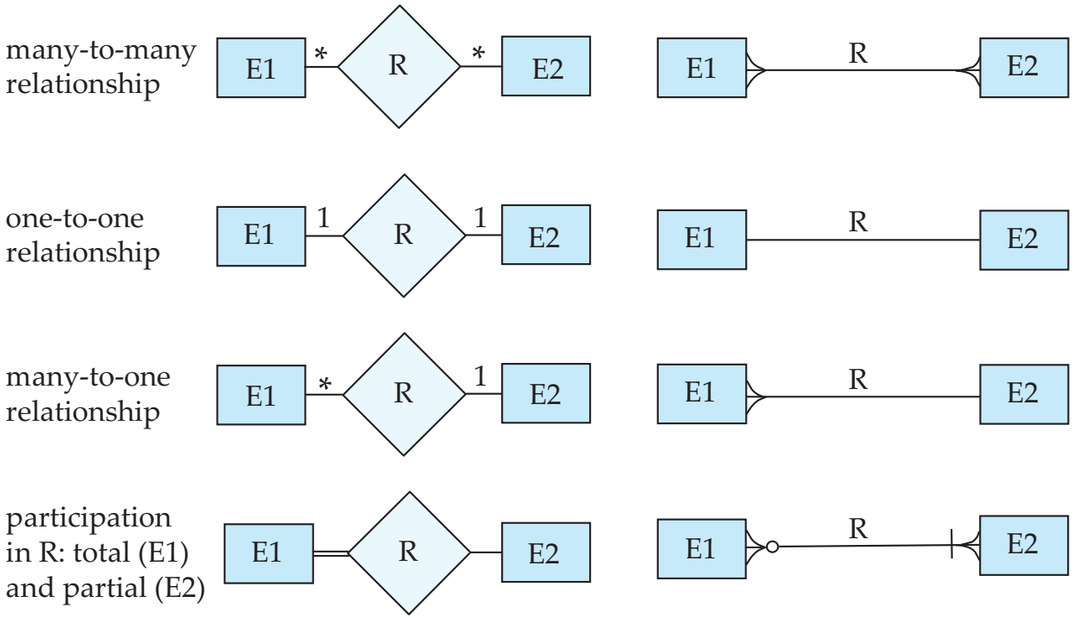
- ** Extra:*
  - ** The use of specialization/generalization – contributes to modularity in the design*
  - ** The use of aggregation – can treat the aggregate entity set as a single unit without concern for the details of its internal structure*

Self Study: Alternative ER Notations

- No universal standard for E-R diagram notation, and different books and E-R diagram software use different notations.
- Chapter 7.10, Database System Concepts (7th Edition)

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





Summary

- Database design mainly involves the design of the database schema
  - To represent overall logical structure of the database
- E-R model provides a convenient graphical representation to view data, relationships, and constraints
- Entity, entity set, relationship, relationship sets
- Superkey, candidate key, and primary key apply to entity and relationship sets (like in relation schemas)
  - Primary key of a relationship set is composed of attributes from one or more of the related entity sets
- Mapping cardinality: number of entities another entity can be associated to via a relationship set
- Weak entity set: entity set that does not have sufficient attributes to form a primary key
- Strong entity set: entity set with a primary key
- Concepts and objects may, in certain cases, be represented by entities, relationships, or attributes
- A database design based on an E-R diagram can be represented by a collection of relation schemas
- Common mistakes to avoid in E-R design

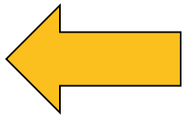
Normalization: A First Look

Design Alternatives

- In designing a database schema, we must ensure that we avoid two major pitfalls
  - **Redundancy**: a bad design may result in repeated information
    - E.g., store course identifier and title of a course for each course offering
      - Only store course identifier is sufficient
    - Redundant representation of information may lead to data inconsistency among the various copies of information
      - E.g., update is not performed on all the copies
  - **Incompleteness**: a bad design may make certain aspects of the enterprise difficult or impossible to model
    - E.g., only have entity for course offering, but without entity for courses
      - Impossible to model new courses that are not offered yet

Design Alternatives

- Avoiding bad designs is not enough
  - There may be many good designs from which we must choose
- For example, a customer who buys a product
  - The sale activity is a relationship between the customer and the product?
  - The sale activity is a relationship among the customer, the product, and the sale itself?
    - i.e., the sale can be considered as an entity
- Database design can be difficult
  - When #entities and #relationships are large
- Do we have any guidelines on how to get a good design?
  - Normal Forms (范式)!



Normalization （规范化）

- In practice, we usually just satisfy 1NF, 2NF and 3NF

	UNF (1970)	1NF (1970)	2NF (1971)	3NF (1971)	EKNF (1982)	BCNF (1974)	4NF (1977)	ETNF (2012)	5NF (1979)	DKNF (1981)	6NF (2003)
Primary key (no duplicate tuples)[4]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Atomic columns (cells cannot have tables as values)[5]	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Every non-trivial functional dependency either does not begin with a proper subset of a candidate key or ends with a prime attribute (no partial functional dependencies of non-prime attributes on candidate keys)[5]	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓
Every non-trivial functional dependency either begins with a superkey or ends with a prime attribute (no transitive functional dependencies of non-prime attributes on candidate keys)[5]	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓
Every non-trivial functional dependency either begins with a superkey or ends with an elementary prime attribute	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	N/A
Every non-trivial functional dependency begins with a superkey	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	N/A
Every non-trivial multivalued dependency begins with a superkey	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	N/A
Every join dependency has a superkey component[8]	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	N/A
Every join dependency has only superkey components	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	N/A
Every constraint is a consequence of domain constraints and key constraints	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗
Every join dependency is trivial	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓

https://en.wikipedia.org/wiki/Database_normalization

First Normal Form (1NF，第一范式)

- A relational schema *R* is in 1NF if the domains of all attributes of R are atomic
  - Domain is atomic if its elements are considered to be indivisible units
  - Examples of non-atomic domains:
    - Set of names, composite attributes
    - Identification numbers like CS307 that can be broken up into parts
      - However, in practice, we can also consider it atomic
  - Non-atomic values complicate storage and encourage redundant (repeated) storage of data

First Normal Form (1NF)

- Example: Non-atomic attribute

station_id	name	location
1	Luohu(罗湖)	114.11833 , 22.53111
2	Guomao(国贸)	114.11889 , 22.54
3	Laojie(老街)	114.11639 , 22.54444
4	Grand Theater(大剧院)	114.10333 , 22.54472
5	Science Museum(科学馆)	114.08972 , 22.54333
6	Huaqiang Rd(华强路)	114.07889 , 22.54306
7	Gangxia(岗厦)	114.06306 , 22.53778
8	Convention and Exhibition Center Station(会展中心)	114.05472 , 22.5375
9	Shopping Park(购物公园)	114.05472 , 22.53444
10	Xiangmihu(香蜜湖)	114.034 , 22.5417

First Normal Form (1NF)

- Fix it by splitting the names into two columns

station_id	english_name	chinese_name	longitude	latitude
1	Luohu	罗湖	114.11833	22.53111
2	Guomao	国贸	114.11889	22.54
3	Laojie	老街	114.11639	22.54444
4	Grand Theater	大剧院	114.10333	22.54472
5	Science Museum	科学馆	114.08972	22.54333
6	Huaqiang Rd	华强路	114.07889	22.54306
7	Gangxia	岗厦	114.06306	22.53778
8	Convention and Exhibition Cent…	会展中心	114.05472	22.5375
9	Shopping Park	购物公园	114.05472	22.53444
10	Xiangmihu	香蜜湖	114.034	22.5417

First Normal Form (1NF)

- Another example: Starring
  - Problems: 1) Redundant names; 2) difficulties in updating/deleting a specific person; 3) extra cost in splitting names; 4) difficulties in making statistics

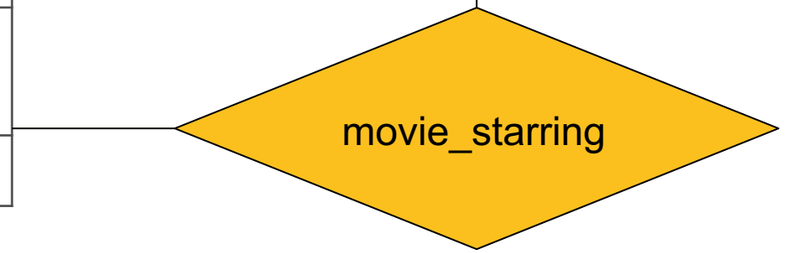
Movie ID	Movie Title	Country	Year	Director	Starring
0	Citizen Kane	US	1941	welles, o.	Orson Welles, Joseph Cotten
1	La règle du jeu	FR	1939	Renoir, J.	Roland Toutain, Nora Grégor, Marcel Dalio, Jean Renoir
2	North By Northwest	US	1959	HITCHCOCK, A.	Cary Grant, Eva Marie Saint, James Mason
3	Singin' in the Rain	US	1952	Donen/Kelly	Gene Kelly, Debbie Reynolds, Donald O'Connor
4	Rear Window	US	1954	Alfred Hitchcock	James Stewart, Grace Kelly

First Normal Form (1NF)

- Fix it by treating the column as a multi-valued attribute
  - *movie_starring* table has two foreign keys, *movid_id* and *star_id*

Movie ID	Movie Title	Country	Year	Director
0	Citizen Kane	US	1941	welles, o.
1	La règle du jeu	FR	1939	Renoir, J.
2	North By Northwest	US	1959	HITCHCOCK, A.
3	Singin' in the Rain	US	1952	Donen/Kelly
4	Rear Window	US	1954	Alfred Hitchcock

Star ID	Firstname	Lastname	Born	Died
1				
2				
3				



Second Normal Form (2NF，第二范式)

- A relation satisfying 2NF must:
  - be in 1NF
  - not have any non-prime attribute that is dependent on any proper subset of any candidate key of the relation
    - A non-prime attribute of a relation is an attribute that is not a part of any candidate key of the relation
  - 不 包含只依赖于 主键中部分属性 的非主属性
    - “非主属性”是指 不属于 任何候选键的属性

Second Normal Form (2NF)

- Example: consider this table with the composite primary key (*station_id*, *line_id*)

station_id	english_name	chinese_name	district	line_id	line_color	operator
1	Luohu	罗湖	Luohu	1	Green	Shenzhen Metro Corporation
2	Guomao	国贸	Luohu	1	Green	Shenzhen Metro Corporation
3	Laojie	老街	Luohu	1	Green	Shenzhen Metro Corporation
4	Grand Theater	大剧院	Luohu	1	Green	Shenzhen Metro Corporation
4	Grand Theater	大剧院	Luohu	11	Purple	Shenzhen Metro Corporation
4	Grand Theater	大剧院	Luohu	2	Orange	Shenzhen Metro Corporation
3	Laojie	老街	Luohu	3	DeepSkyBlue	Shenzhen Metro No.3 Line

  - The columns *line_color* and *operator* are not related to *station_id*
    - They are only related to *line_id*, which is only part of (a subset of) the primary key
  - Similarly, *english_name*, *chinese_name*, and *district* are not related to *line_id*
    - They are only related to *station_id*, which is only part of (a subset of) the primary key
  - 非主属性 *line_color*, *operator*, *english_name*, *chinese_name*, *district* 只依赖于主键中的部份属性

Second Normal Form (2NF)

- Example: Consider this table with the composite primary key (*station_id, line_id*)

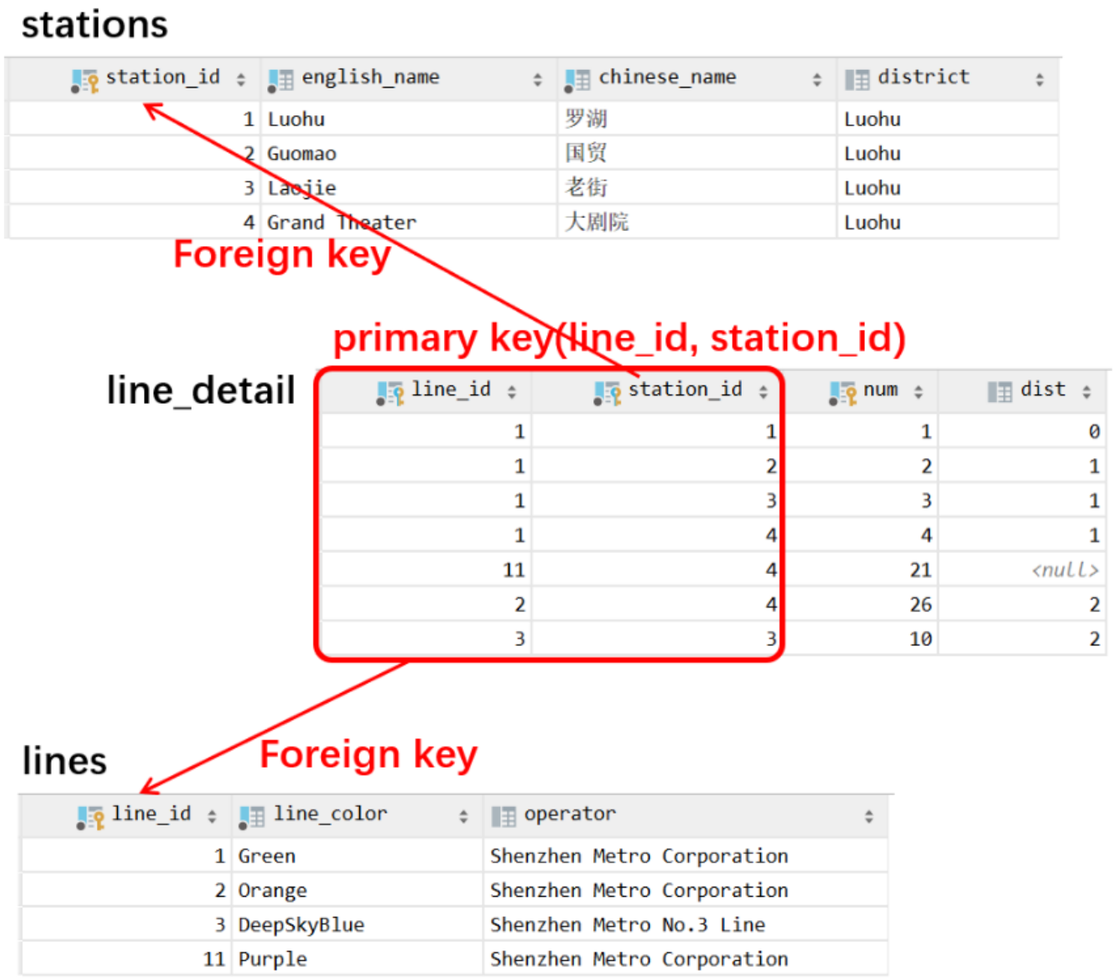
station_id	english_name	chinese_name	district	line_id	line_color	operator
1	Luohu	罗湖	Luohu	1	Green	Shenzhen Metro Corporation
2	Guomao	国贸	Luohu	1	Green	Shenzhen Metro Corporation
3	Laojie	老街	Luohu	1	Green	Shenzhen Metro Corporation
4	Grand Theater	大剧院	Luohu	1	Green	Shenzhen Metro Corporation
4	Grand Theater	大剧院	Luohu	11	Purple	Shenzhen Metro Corporation
4	Grand Theater	大剧院	Luohu	2	Orange	Shenzhen Metro Corporation
3	Laojie	老街	Luohu	3	DeepSkyBlue	Shenzhen Metro No.3 Line

  - Problem when not meeting 2NF: Insertion and deletion anomaly
    - We CANNOT insert a new station with no lines assigned yet (unless using NULLs)
    - If we delete a line, all stations associated with this line will be deleted as well

Second Normal Form (2NF)

- Fix it by
  - Splitting the two unrelated parts into two different tables of entities
  - And create a relationship set (if it is the many-to-many relationship between the two entities)

- By the way…
  - A relation with a single-attribute primary key is automatically in 2NF once it meets 1NF



Third Normal Form (3NF，第三范式)

- A relation satisfying 3NF must:
  - be in 2NF
  - all the attributes in a table are determined only by the candidate keys of that relation, not by any non-prime attributes
  - 所有属性 只依赖于主键，不依赖于任意非主属性

Third Normal Form (3NF)

- Example: Consider this table which describes the bus lines and their stops
  - Primary key (*bus_line*)

bus_line	station_id	chinese_name	english_name	district
B796	21	鲤鱼门	Liyumen	Nanshan
M343	21	鲤鱼门	Liyumen	Nanshan
M349	21	鲤鱼门	Liyumen	Nanshan
M250	26	坪洲	Pingzhou	Bao'an
374	61	安托山	Antuo Hill	Futian
B733	61	安托山	Antuo Hill	Futian
B828	120	临海	Linhai	Nanshan

  - *station_id* depends on the primary key (*bus_line*)
  - However, the columns *chinese_name*, *english_name*, and *district* depend on *station_id*, which is not the primary key.
    - They only have "indirect/transitive" dependence on the primary key
  - Problem: Data redundancy

Third Normal Form (3NF)

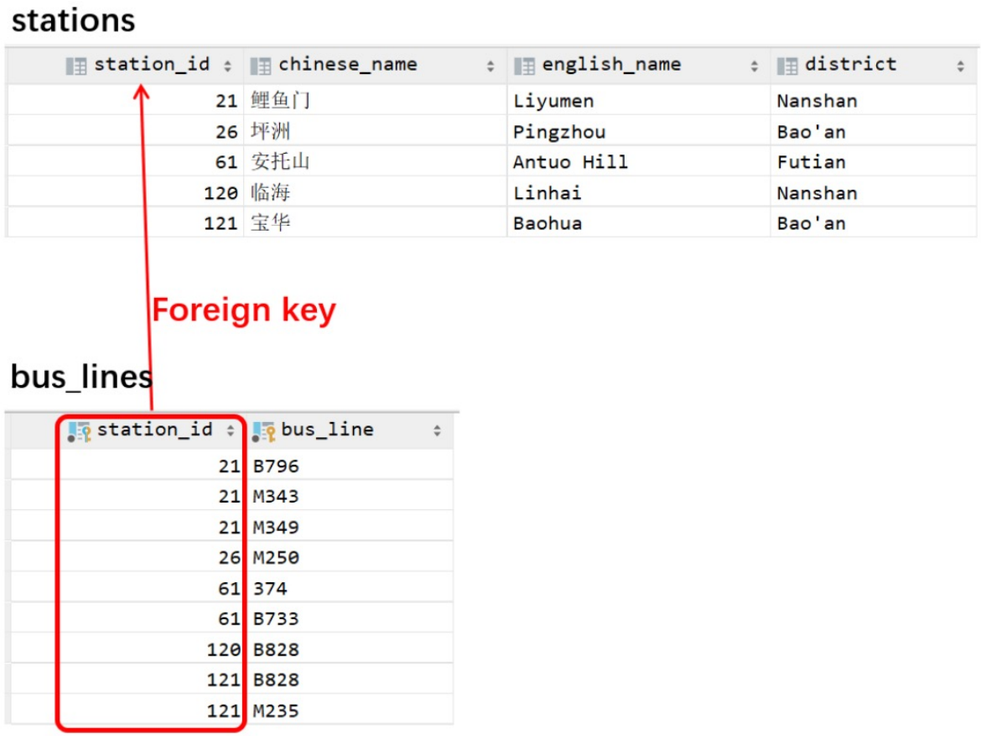
- Example: Consider this table which describes the bus lines and their stops
  - Primary key (*bus_line*)

bus_line	station_id	chinese_name	english_name	district
B796	21	鲤鱼门	Liyumen	Nanshan
M343	21	鲤鱼门	Liyumen	Nanshan
M349	21	鲤鱼门	Liyumen	Nanshan
M250	26	坪洲	Pingzhou	Bao'an
374	61	安托山	Antuo Hill	Futian
B733	61	安托山	Antuo Hill	Futian
B828	120	临海	Linhai	Nanshan

  - Problem when not meeting 3NF:
    - Data redundancy: as you can see in the table, the attributes for a station have been stored multiple times
    - Insertion and deletion anomaly: inserting a new bus line with no station becomes impossible without NULLs; deleting a station/bus line may also delete corresponding bus lines/stations.

Third Normal Form (3NF)

- Fix it by:
  - Create a new table with *station_id* as the primary key
    - i.e., the column which *chinese_name*, *english_name*, and *district* depend on
  - Move all columns which depend on the new primary key into the new table
    - … and, only leave the primary key of the new table (*station_id*) in the original table
  - (*In practice, if necessary) Add a foreign-key constraint
    - Not related to relational database modeling, only in implementations



Normalization

- In practice, we usually just satisfy 1NF, 2NF and 3NF

	UNF (1970)	1NF (1970)	2NF (1971)	3NF (1971)	EKNF (1982)	BCNF (1974)	4NF (1977)	ETNF (2012)	5NF (1979)	DKNF (1981)	6NF (2003)
Primary key (no duplicate tuples)[4]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Atomic columns (cells cannot have tables as values)[5]	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Every non-trivial functional dependency either does not begin with a proper subset of a candidate key or ends with a prime attribute (no partial functional dependencies of non-prime attributes on candidate keys)[5]	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓
Every non-trivial functional dependency either begins with a superkey or ends with a prime attribute (no transitive functional dependencies of non-prime attributes on candidate keys)[5]	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓
Every non-trivial functional dependency either begins with a superkey or ends with an elementary prime attribute	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	N/A
Every non-trivial functional dependency begins with a superkey	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	N/A
Every non-trivial multivalued dependency begins with a superkey	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	N/A
Every join dependency has a superkey component[8]	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	N/A
Every join dependency has only superkey components	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	N/A
Every constraint is a consequence of domain constraints and key constraints	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗
Every join dependency is trivial	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓

https://en.wikipedia.org/wiki/Database_normalization

Normalization

Every non key attribute must
provide a fact about the key,
the whole key,
and nothing but the key.

2NF

3NF

William Kent (1936 – 2005)

William Kent. "A Simple Guide to Five Normal Forms in Relational Database Theory", Communications of the ACM 26 (2), Feb. 1983, pp. 120–125.