Chapter 7: Entity-Relationship Model

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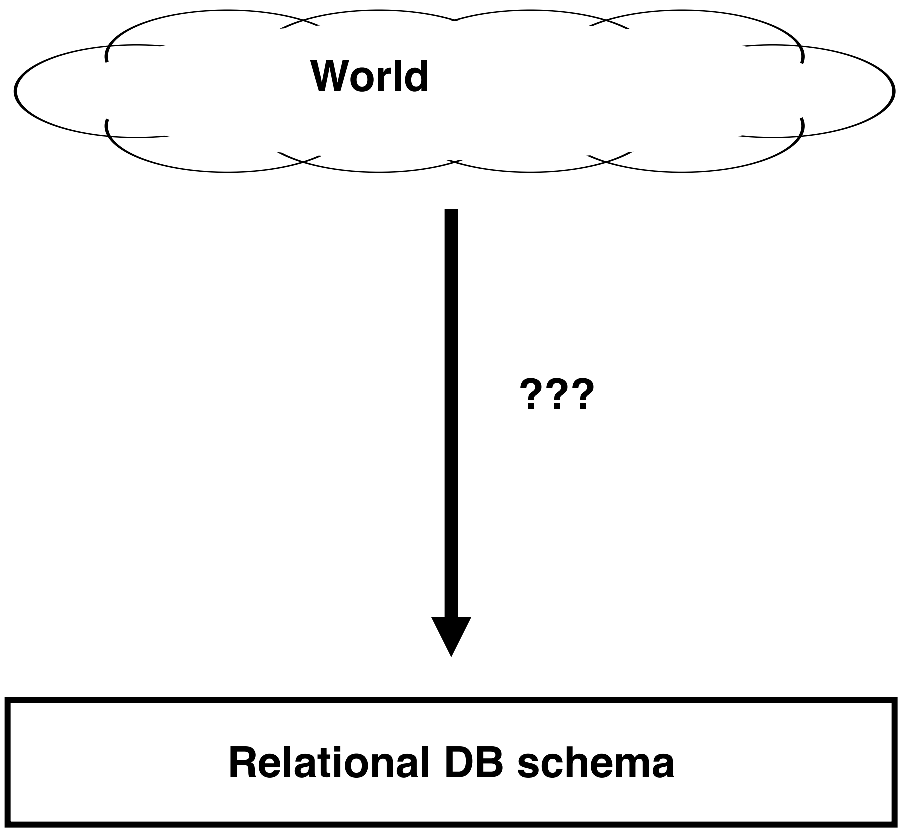
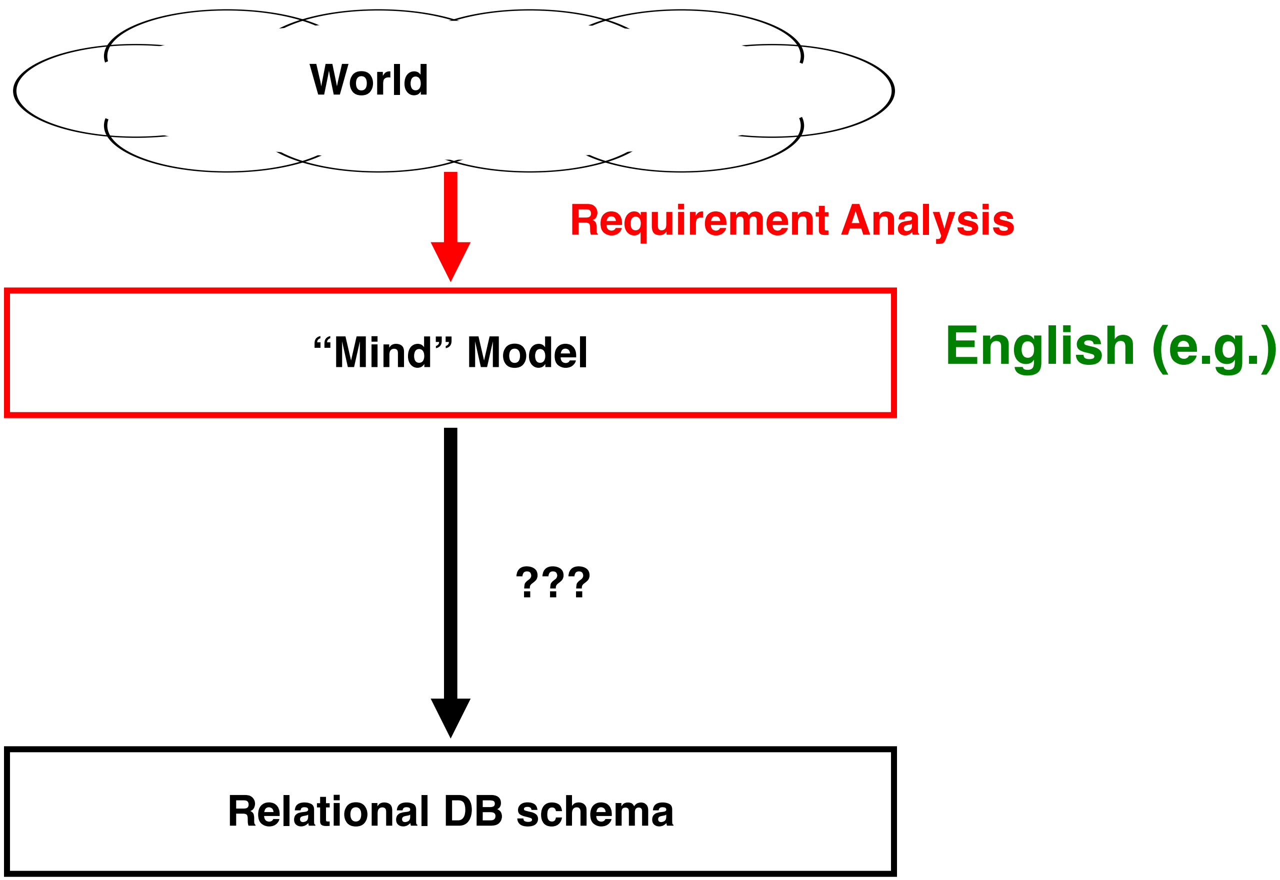
- Design Process
- Modeling
- Constraints
- E-R Diagram
- Design Issues
- Weak Entity Sets
- Extended E-R Features
- Design of the Bank Database
- Reduction to Relation Schemas
- Database Design
- UML

Database Design



Database Design

- First: need to develop a “mind”-model based on a requirement analysis



Requirement Analysis Example Zoo

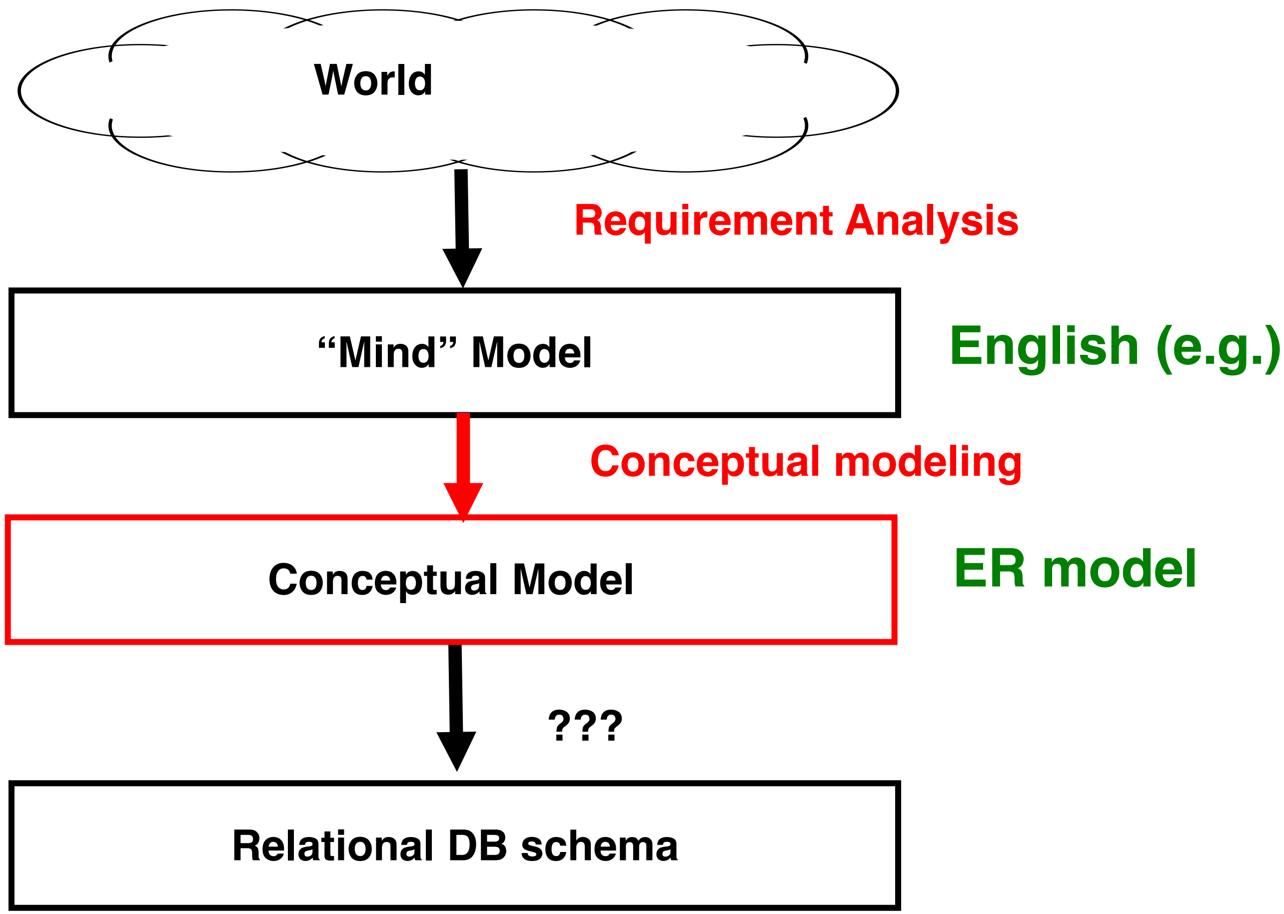
- The zoo stores information about animals, cages, and zoo keepers.
- Animals are of a certain species and have a name. For each animal we want to record its weight and age.
- Each cage is located in a section of the zoo. Cages can house animals, but there may be cages that are currently empty. Cages have a size in square meter.
- Zoo keepers are identified by their social security number. We store a first name, last name, and for each zoo keeper. Zoo keepers are assigned to cages they have to take care of (clean, …). Each cage that is not empty has a zoo keeper assigned to it. A zoo keeper can take care of several cages. Each zoo keeper takes care of at least one cage.

Requirement Analysis Example
Music Collection

- Let's do it!

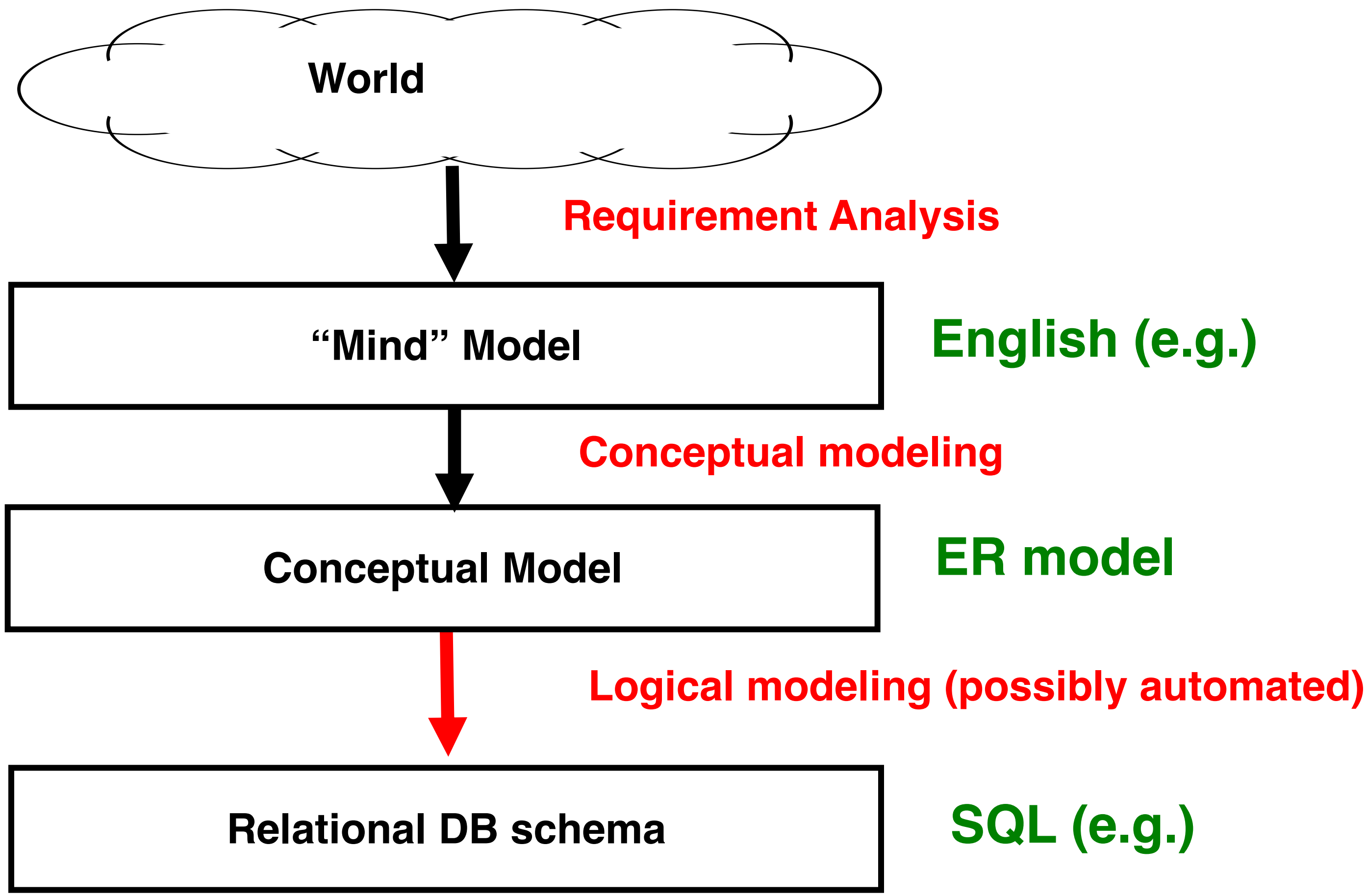
Database Design

- Second: Formalize this model by developing a conceptual model



Database Design

- Second: Formalize this model by developing a conceptual model



Modeling – ER model

- A *database* can be modeled as:
  - a collection of entities,
  - relationship among entities.
- An **entity** is an object that exists and is distinguishable from other objects.
  - Example: specific person, company, event, plant
- Entities have **attributes**
  - Example: people have *names* and *addresses*
- 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 *instructor* and *student*

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

instructor

student-ID	student_name
98988	Tanaka
12345	Shankar
00128	Zhang
76543	Brown
76653	Aoi
23121	Chavez
44553	Peltier

student

Relationship Sets

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

  Example:

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

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

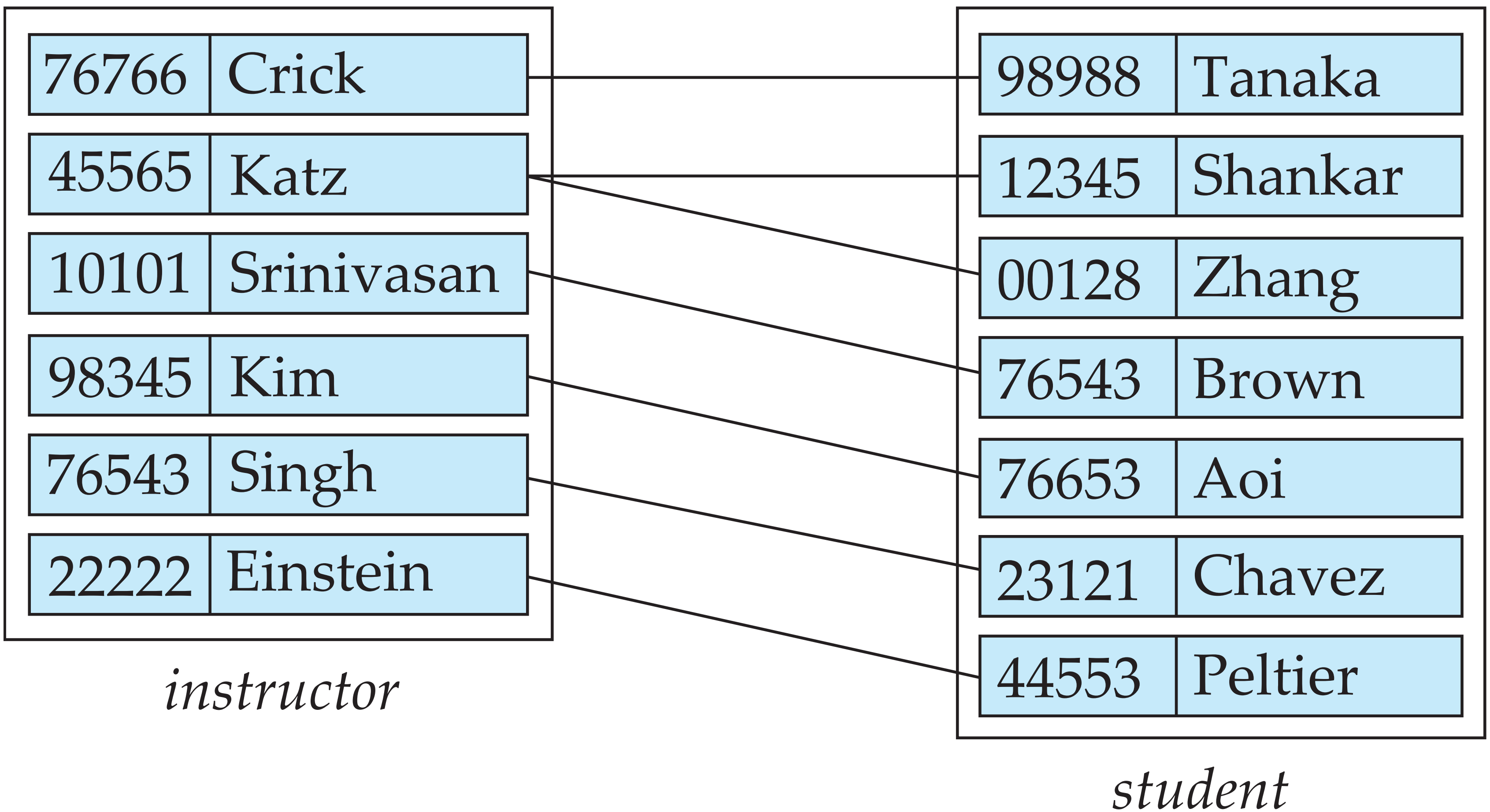
  $$\{(e_1, e_2, \ldots e_n) \mid e_1 \in E_1, e_2 \in E_2, \ldots, e_n \in E_n\}$$

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

  - Example:

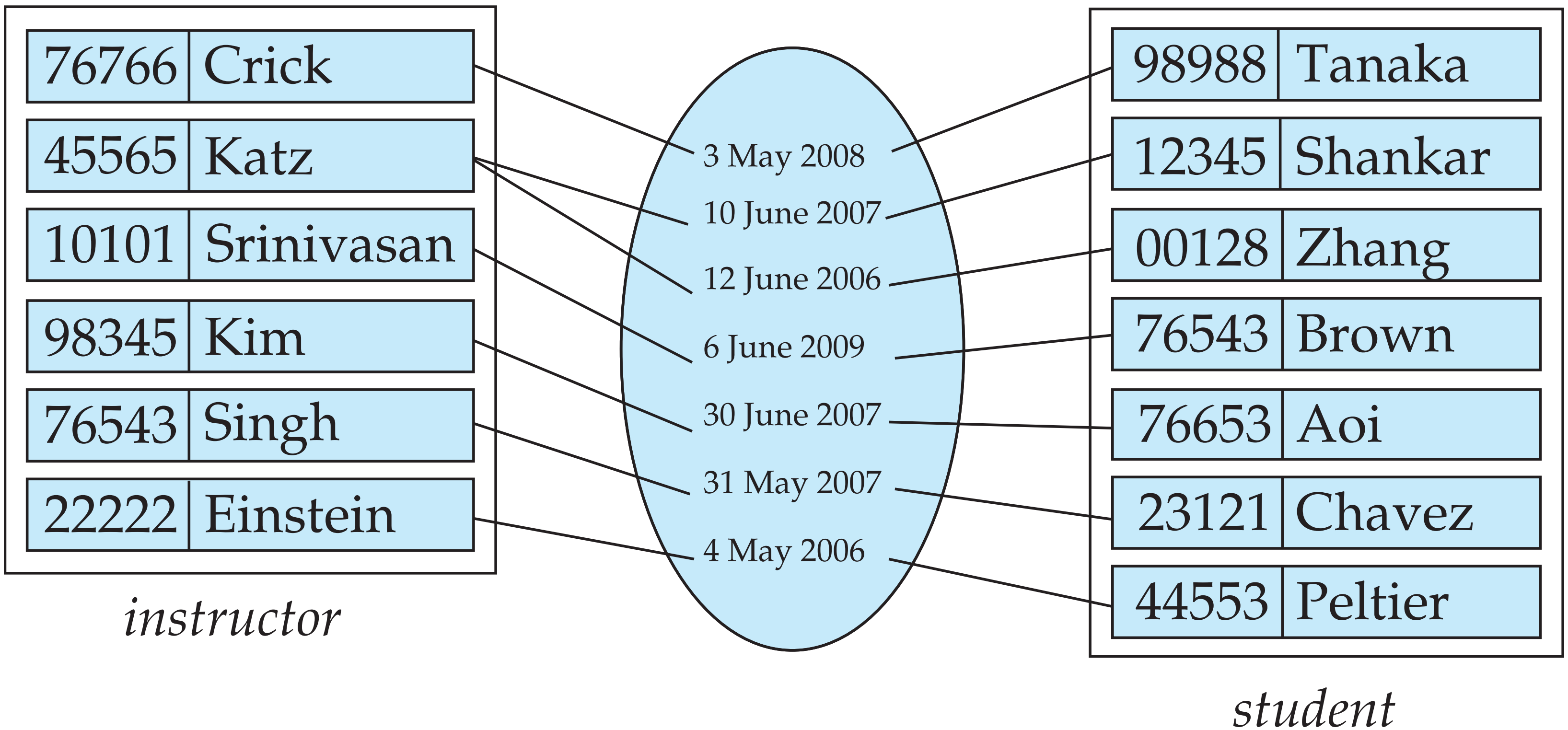
    (44553,22222) $\in$ *advisor*

Relationship Set *advisor*



Relationship Sets (Cont.)

- An **attribute** can also be property of 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



Degree of a Relationship Set

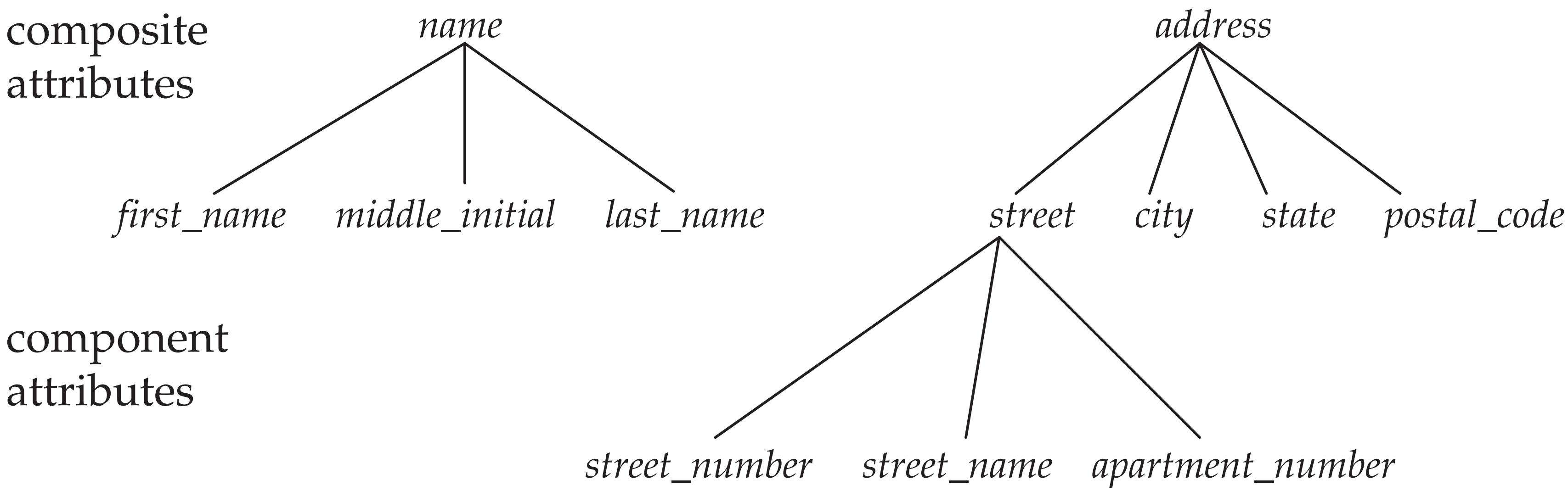
- **binary relationship**
  - involve two entity sets (or degree two).
- Relationships between more than two entity sets are rare. Most relationships are binary. (More on this later.)
  - Example: *students* work on research *projects* under the guidance of an *instructor*.
  - relationship *proj_guide*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

Attributes

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

    instructor = (*ID*, *name*, *street*, *city*, *salary*)
    course= (*course_id*, *title*, *credits*)
- **Domain** – the set of permitted values for each attribute
- Attribute types:
  - **Simple** and **composite** attributes.
  - **Single-valued** and **multivalued** attributes
    - Example: multivalued attribute: *phone_numbers*
  - **Derived** attributes
    - Can be computed from other attributes
    - Example: age, given date_of_birth

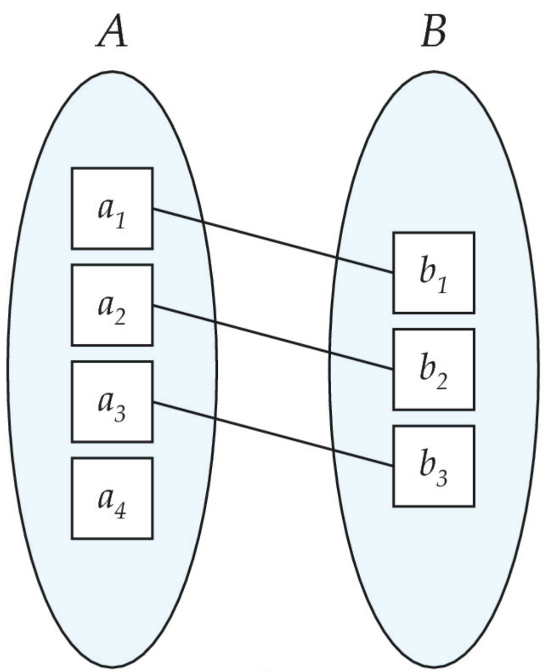
Composite Attributes



Mapping Cardinality Constraints

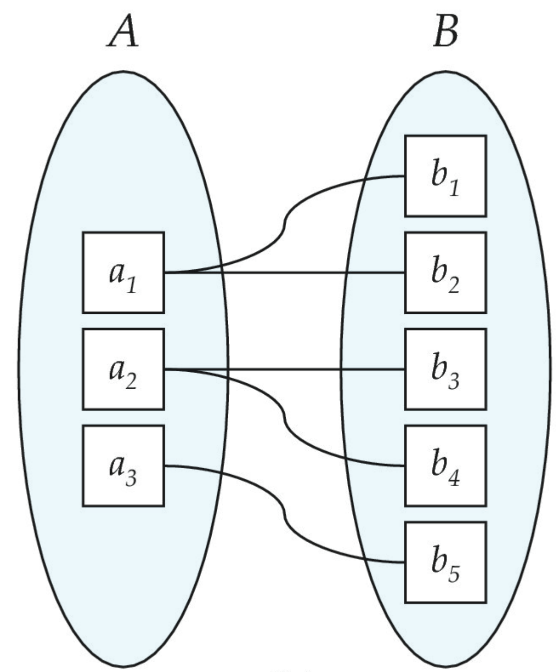
- Express the number of entities to which another entity can be associated via a relationship set.
- For a binary relationship set the mapping cardinality must be one of the following types:
  - One to one (1-1)
  - One to many (1-N)
  - Many to one (N-1)
  - Many to many (N-M)

Mapping Cardinalities



(a)

One to one

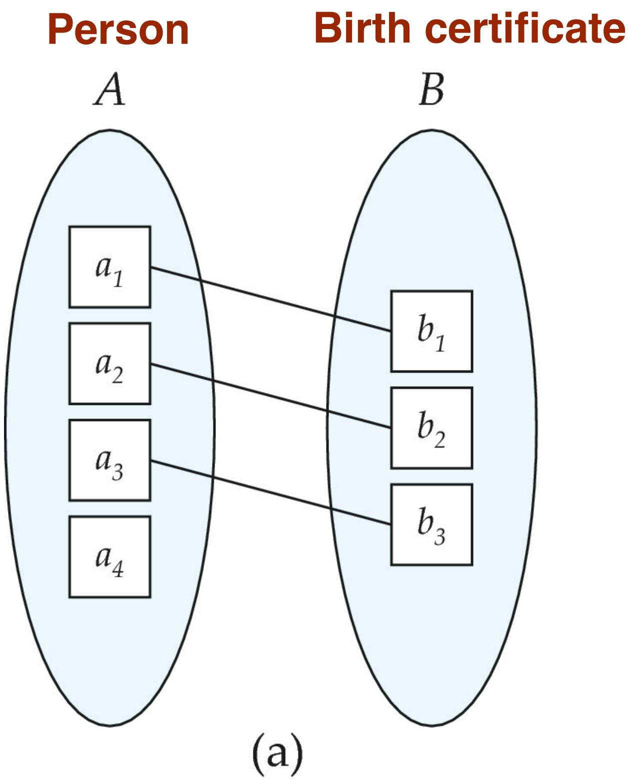


(b)

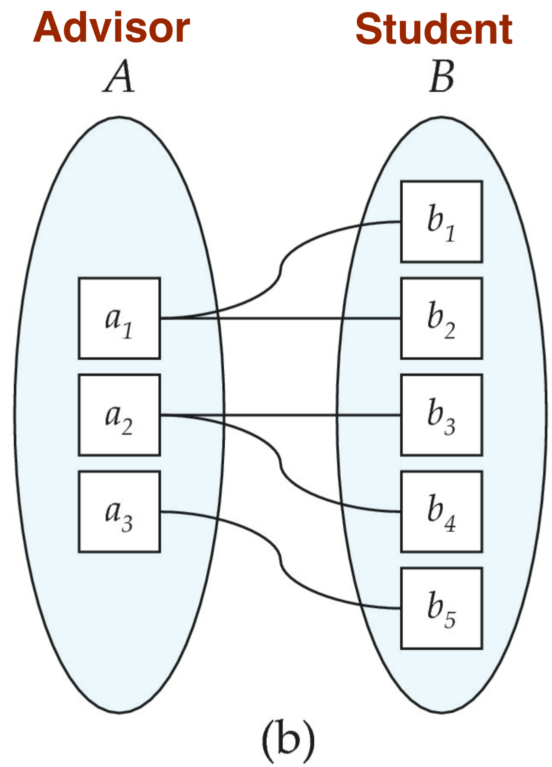
One to many

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

Mapping Cardinalities Example



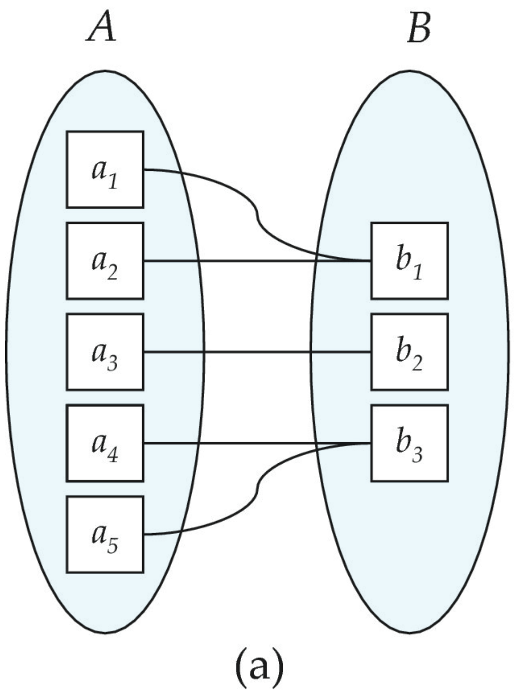
One to one



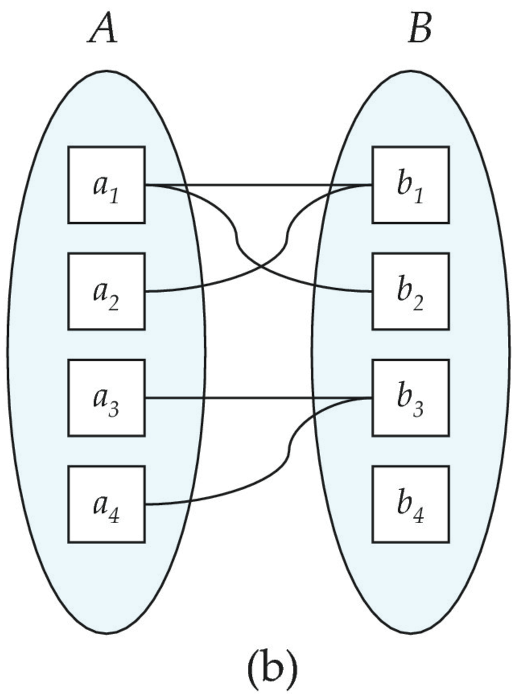
One to many

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

Mapping Cardinalities



Many to one

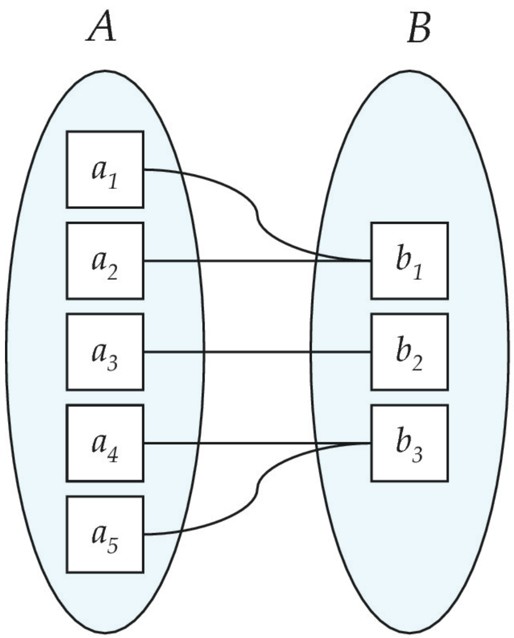


Many to many

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

Mapping Cardinalities Example

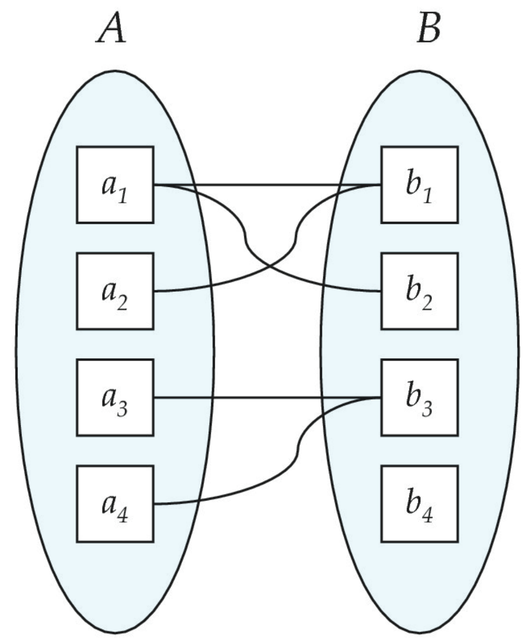
Employee **Department**



(a)

Many to one

Student **Course**



(b)

Many to many

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

Mapping Cardinality Constraints Cont.

- What if we allow some elements to not be mapped to another element?
  - E.g., 0:1 – 1
- For a binary relationship set the mapping cardinality must be one of the following types:

- **1-1**
  - 1-1
  - 0:1-1
  - 1-0:1
  - 0:1-0:1
- **1-N**
  - 0:1-N
  - 0:1-0:N
  - 1-N
  - 1-0:N
- **N-1**
  - N-1
  - N-0:1
  - 0:N-1
  - 0:N-0:1
- **N-M**
  - N-M
  - N-0:M
  - 0:N-M
  - 0:N-0:M

Keys

- A **super key** of an entity set is a set of one or more attributes whose values uniquely determine each entity.
- A **candidate key** of an entity set is a minimal super key
  - *ID* is candidate key of *instructor*
  - *course_id* is candidate key of *course*
- Although several candidate keys may exist, one of the candidate keys is selected to be the **primary key**.

- **Note: Basically the same as for relational model**

Keys for Relationship Sets

- The combination of primary keys of the participating entity sets forms a super key of a relationship set.
  - (*s_id, i_id*) is the super key of *advisor*
  - *NOTE: this means* ***a pair of entities can have at most one relationship in a particular relationship set.***
    - Example: if we wish to track multiple meeting dates between a student and her advisor, we cannot assume a relationship for each meeting. We can use a multivalued attribute though or model meeting as a separate entity
- Must consider the mapping cardinality of the relationship set when deciding what are the candidate keys
- Need to consider semantics of relationship set in selecting the *primary key* in case of more than one candidate key

Keys for Relationship Sets Cont.

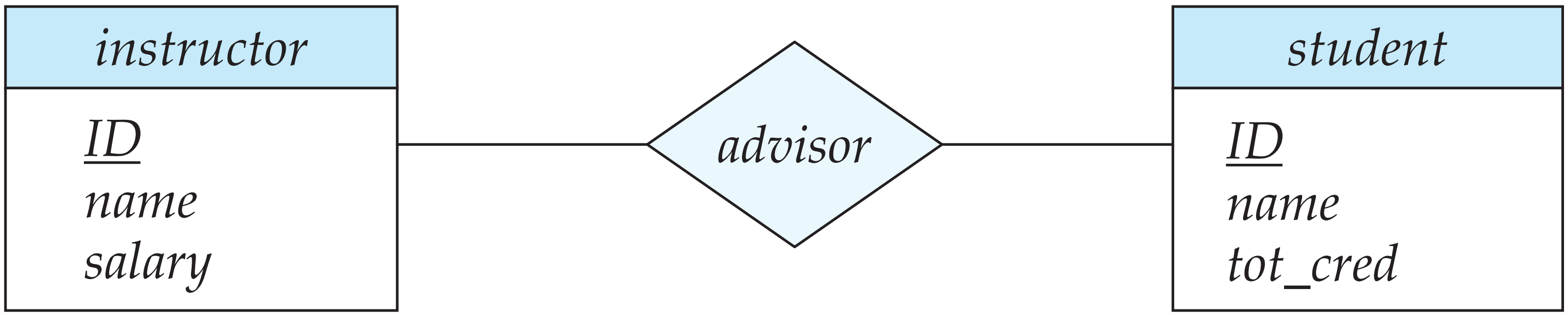
- Must consider the mapping cardinality of the relationship set when deciding what are the candidate keys
  - 1-1: both primary keys are candidate keys
    - Example: **hasBc**: (Person-Birthcertificate)
  - N-1: the N side is the candidate key
    - Example: **worksFor**: (Instructor-Department)
  - N-M: the combination of both primary keys
    - Example: **takes**: (Student-Course)

Redundant Attributes

- Suppose we have entity sets
  - *instructor*, with attributes including *dept_name*
  - *department*

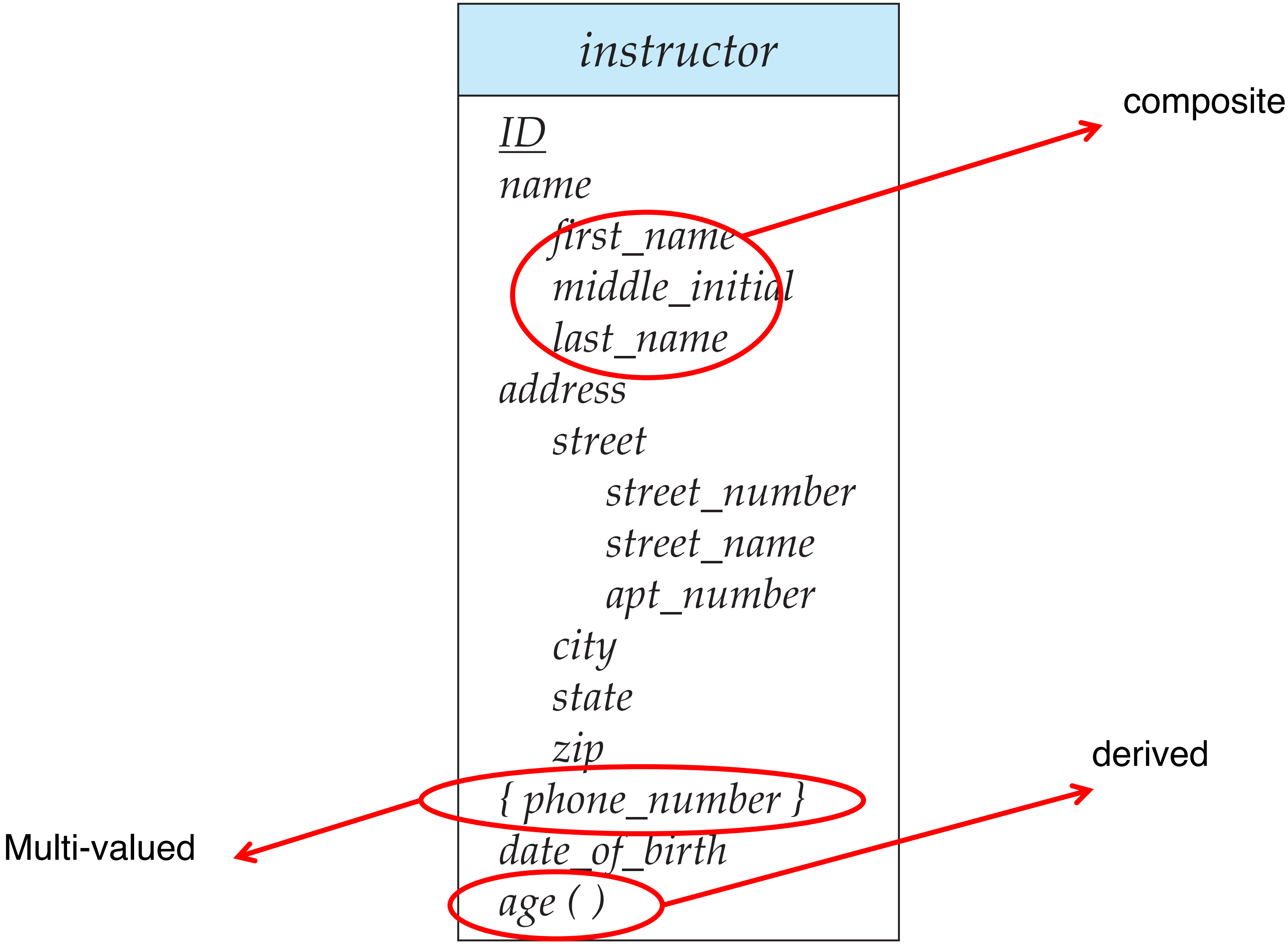
  and a relationship
  - *inst_dept* relating *instructor* and *department*
- Attribute *dept_name* in entity *instructor* is redundant since there is an explicit relationship *inst_dept* which relates instructors to departments
  - The attribute replicates information present in the relationship, and should be removed from *instructor*
  - BUT: when converting back to tables, in some cases the attribute gets reintroduced, as we will see.

E-R Diagrams

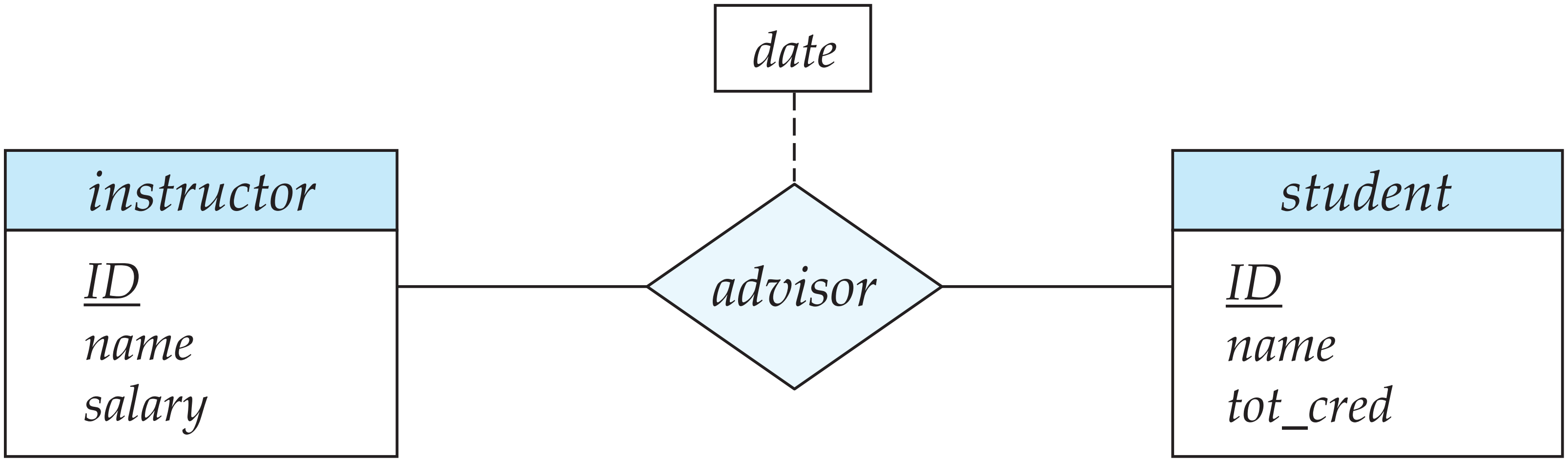


- Rectangles represent entity sets.
- Diamonds represent relationship sets.
- Attributes listed inside entity rectangle
- Underline indicates primary key attributes

Entity With Composite, Multivalued, and Derived Attributes

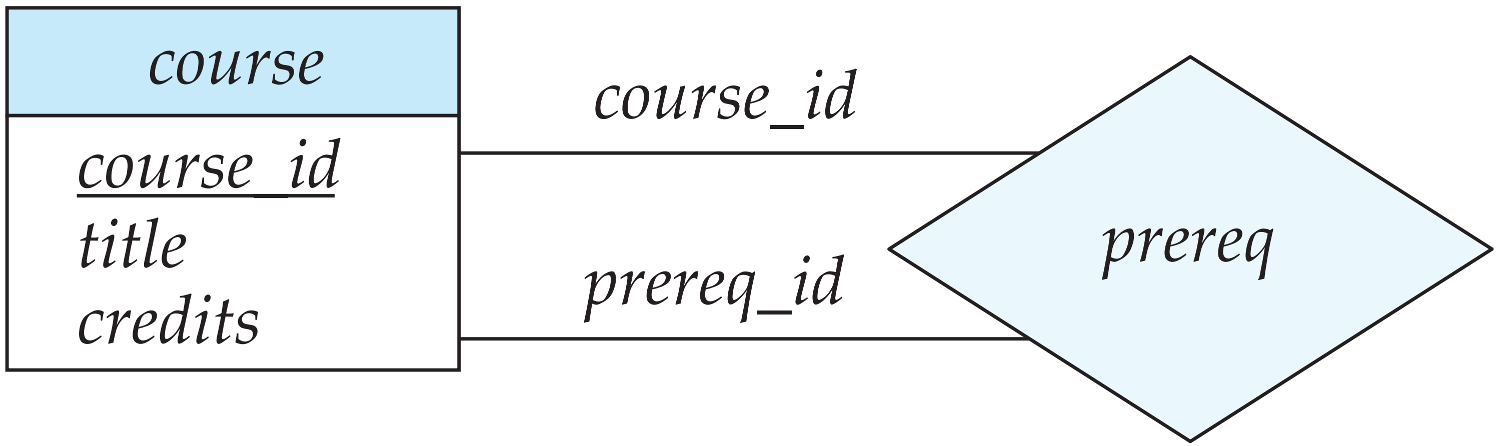


Relationship Sets with Attributes



Roles

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

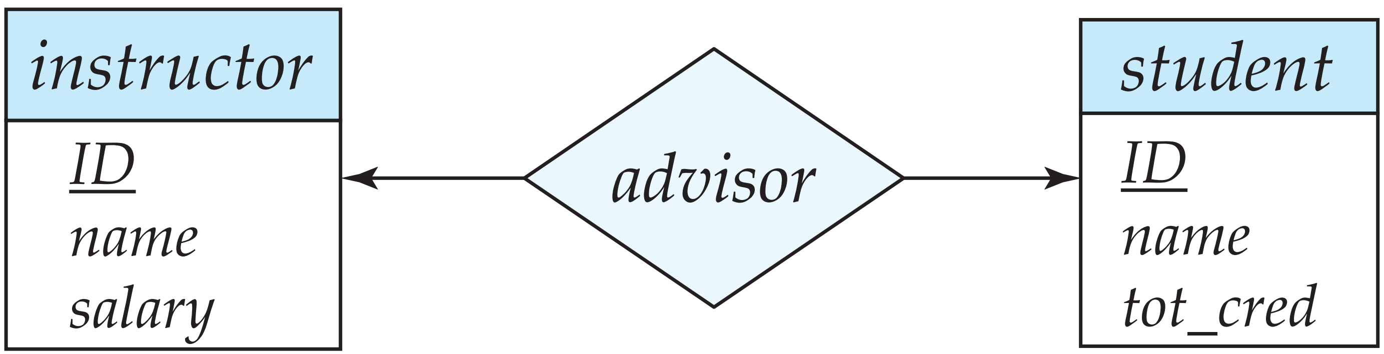


Cardinality Constraints

- 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:
  - 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*

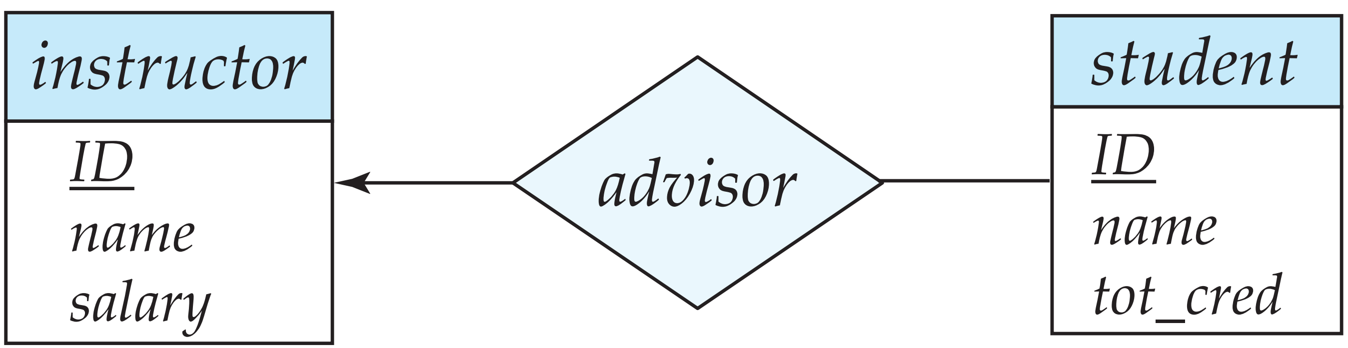
One-to-One Relationship

- one-to-one relationship between an *instructor* and a *student*
  - an instructor is associated with at most one student via *advisor*
  - and a student is associated with at most one instructor via *advisor*



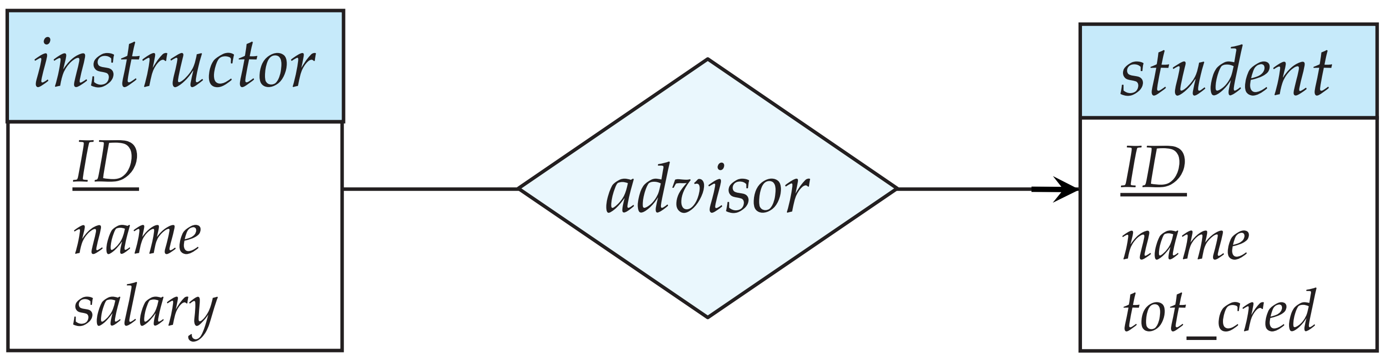
One-to-Many Relationship

- 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,



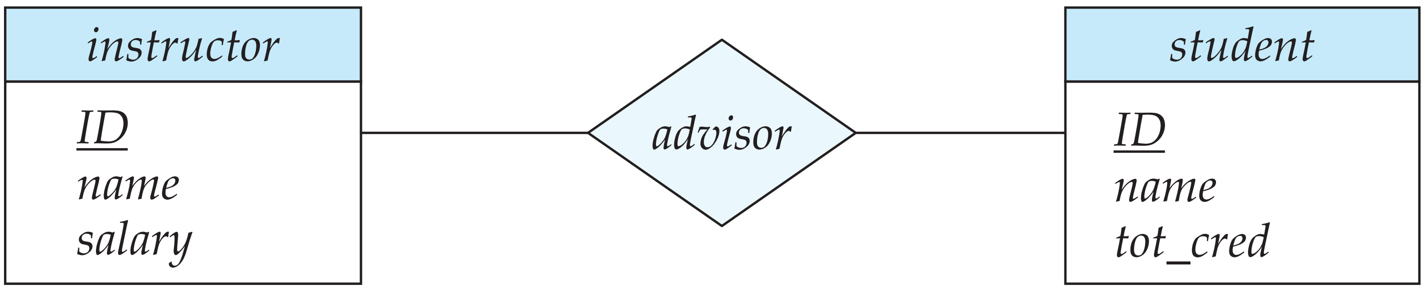
Many-to-One Relationships

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



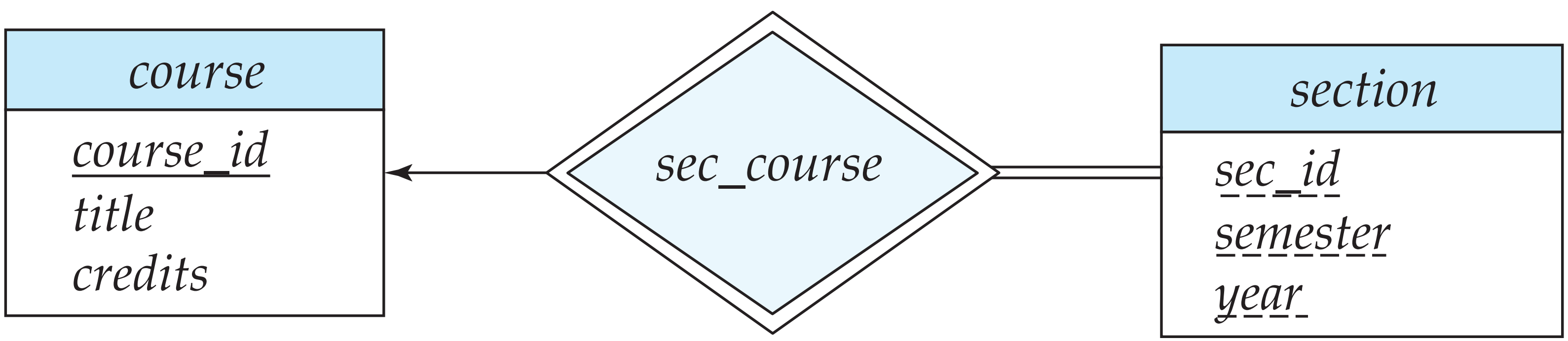
Many-to-Many Relationship

- An instructor is associated with several (possibly 0) students via *advisor*
- A student is associated with several (possibly 0) instructors via *advisor*



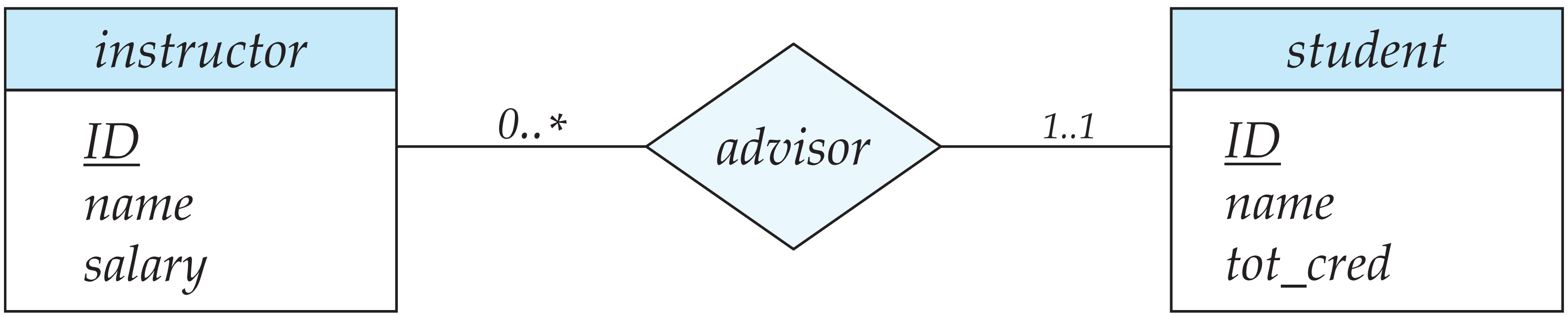
Participation of an Entity Set in a Relationship Set

- 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 *section* in *sec_course* is total
    - every *section* must have an associated course
- Partial participation: some entities may not participate in any relationship in the relationship set
  - Example: participation of *instructor* in *advisor* is partial



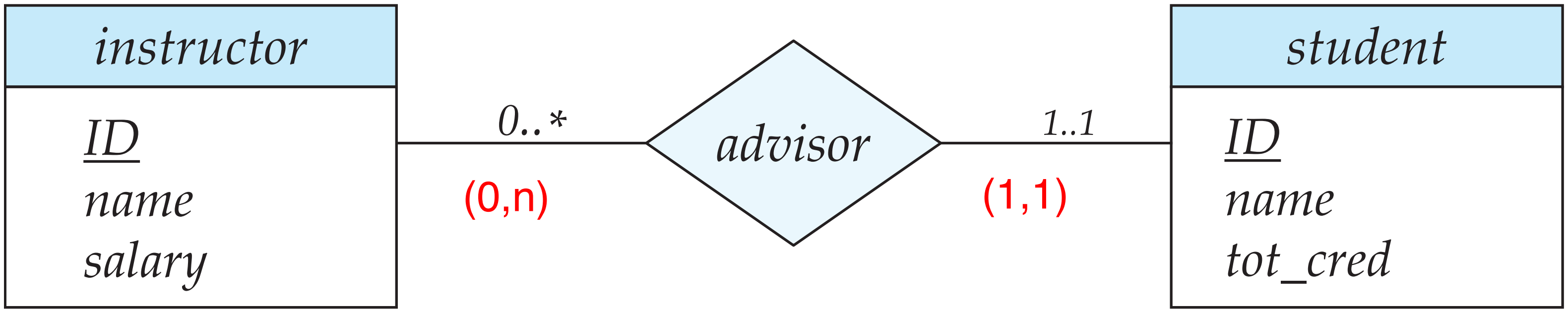
Alternative Notation for Cardinality Limits

- Cardinality limits can also express participation constraints

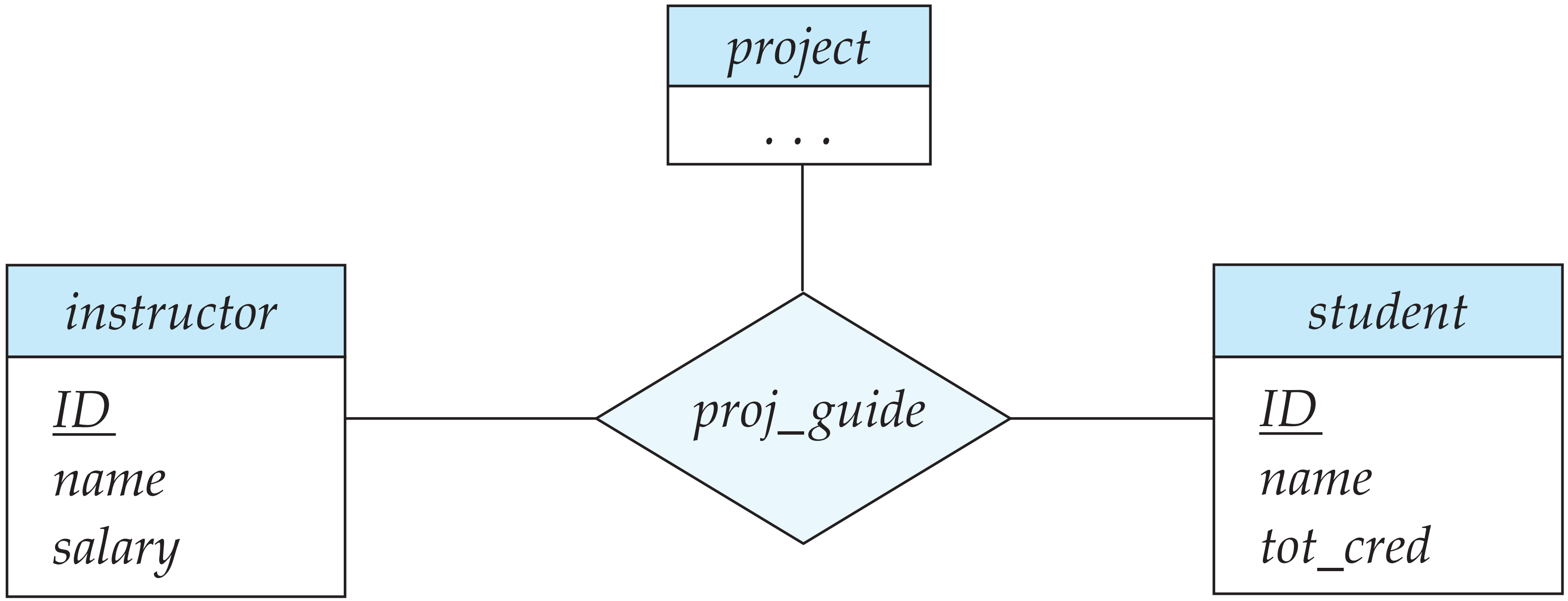


Alternative Notation for Cardinality Limits

- Alternative Notation



E-R Diagram with a Ternary Relationship



Cardinality Constraints on Ternary Relationship

- We allow at most one arrow out of a ternary (or greater degree) relationship to indicate a cardinality constraint
- E.g., 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.
  - E.g., 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
- Better to use cardinality constraints such as (0,n)

Let's design an ER-model for parts of the university database

Lets design an ER-model for parts of the university database

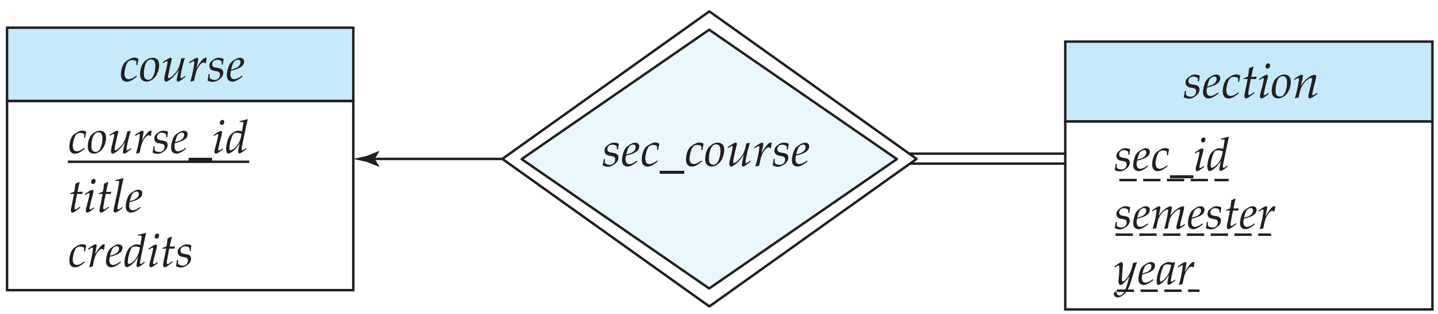
1) Identify Entities
2) Identify Relationship
3) Determine Attributes
4) Determine Cardinality Constraints

Weak Entity Sets

- An entity set that does not have a primary key is referred to as a **weak entity set**.
- The existence of a weak entity set depends on the existence of a **identifying entity set**
  - It must relate to the identifying entity set via a total, one-to-many relationship set from the identifying to the weak entity set
  - **Identifying relationship** depicted using a double diamond
- The **discriminator** (*or partial key)* of a weak entity set is the set of attributes that distinguishes among all the entities of a weak entity set that are associated with the same entity of the identifying entity set
- The primary key of a weak entity set is formed by the primary key of the strong entity set on which the weak entity set is existence dependent, plus the weak entity set's discriminator.

Weak Entity Sets (Cont.)

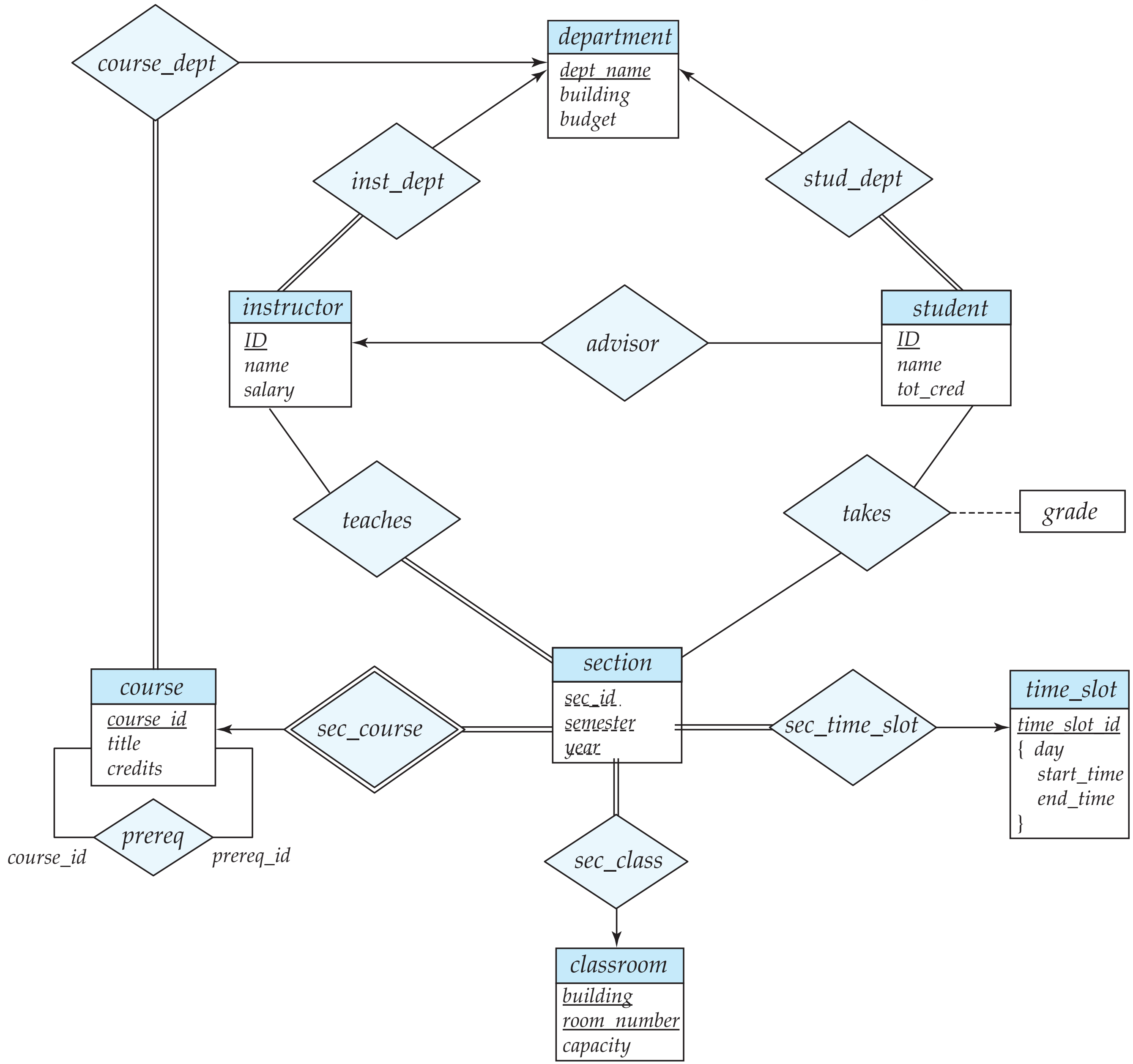
- We underline the discriminator of a weak entity set with a dashed line.
- We put the identifying relationship of a weak entity in a double diamond.
- Primary key for *section* – (*course_id, sec_id, semester, year*)



Weak Entity Sets (Cont.)

- Note: the primary key of the strong entity set is not explicitly stored with the weak entity set, since it is implicit in the identifying relationship.
- If *course_id* were explicitly stored, *section* could be made a strong entity, but then the relationship between *section* and *course* would be duplicated by an implicit relationship defined by the attribute *course_id* common to *course* and *section*

E-R Diagram for a University Enterprise



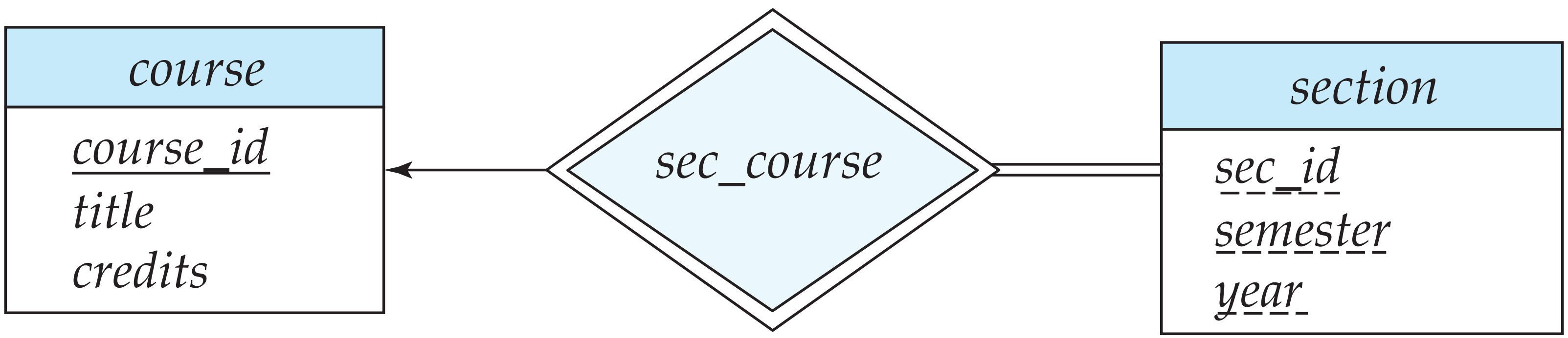
Reduction to Relational Schemas

Reduction to Relation Schemas

- Entity sets and relationship sets can be expressed uniformly as *relation schemas* that represent the contents of the database.
- A database which conforms to an E-R diagram can be represented by a collection of relation schemas.
- For each entity set and relationship set there is a unique relation schema that is assigned the name of the corresponding entity set or relationship set.

Representing Entity Sets With Simple Attributes

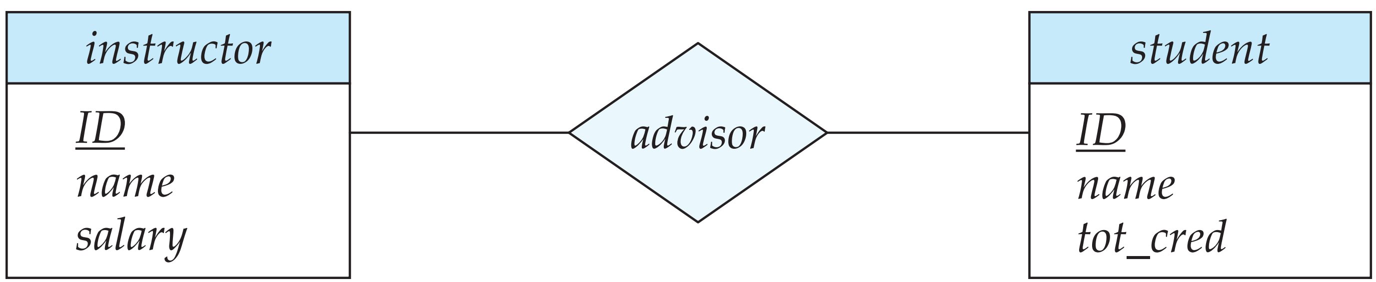
- A strong entity set reduces to a schema with the same attributes
  student(<u>ID</u>, name, tot_cred)
- A weak entity set becomes a table that includes a column for the primary key of the identifying strong entity set
  section (<u>course_id, sec_id, sem, year</u>)



Representing Relationship Sets

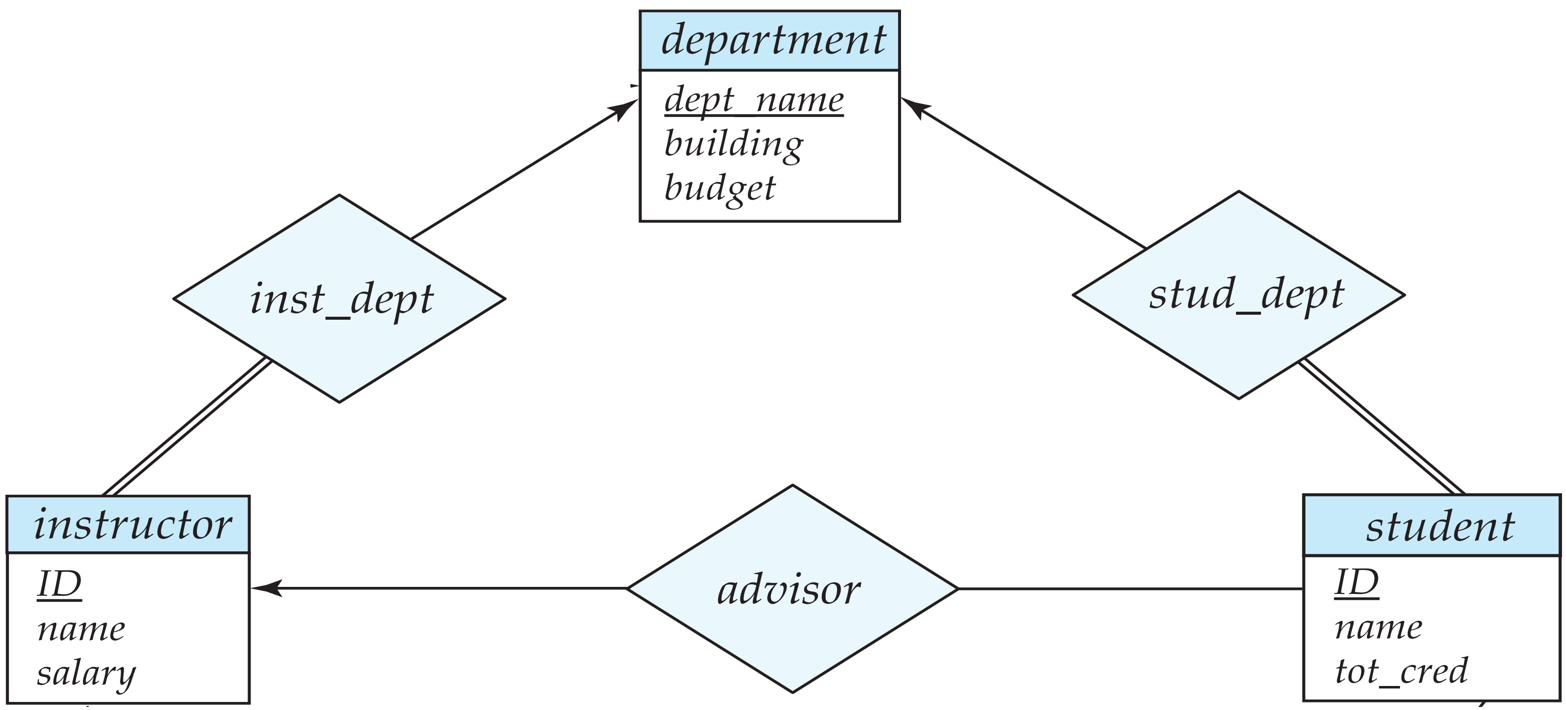
- A many-to-many relationship set is represented as a schema with attributes for the primary keys of the two participating entity sets, and any descriptive attributes of the relationship set.
- Example: schema for relationship set *advisor*

  advisor = (*s_id, i_id*)



Redundancy of Schemas

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



Redundancy of Schemas (Cont.)

- For one-to-one relationship sets, either side can be chosen to act as the "many" side
  - That is, extra attribute can be added to either of the tables corresponding to the two entity sets
  - If the relationship is total in both sides, the relation schemas from the two sides can be merged into one schema
- 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
- 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

Composite and Multivalued Attributes

instructor
<u>ID</u> *name*   *first_name*   *middle_initial*   *last_name* *address*   *street*   *street_number*   *street_name*   *apt_number*   *city*   *state*   *zip* *{ phone_number }* *date_of_birth* *age ( )*

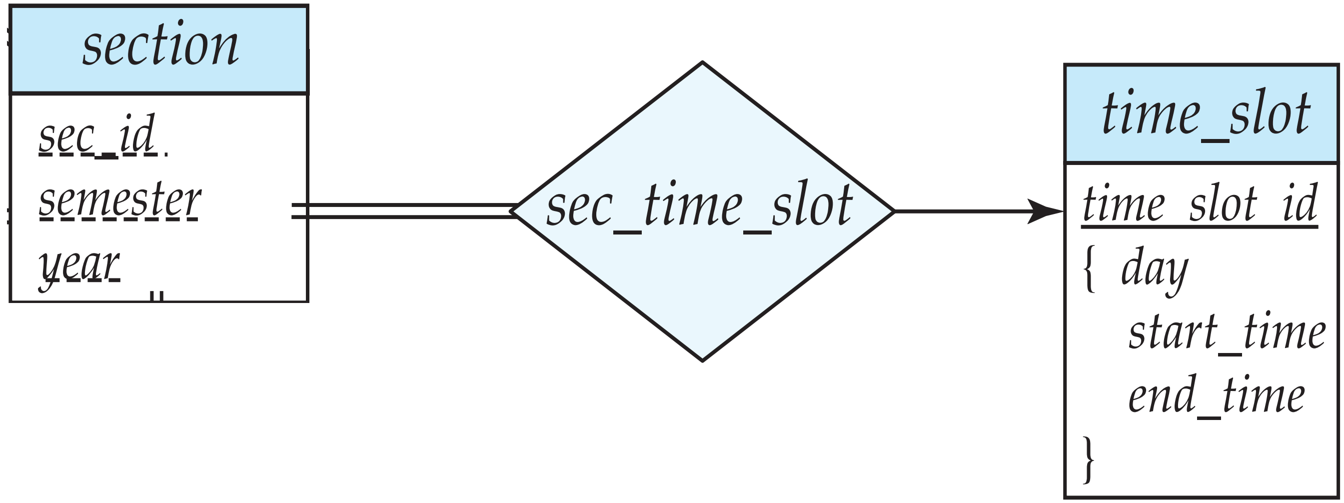
- Composite attributes are flattened out by creating a separate attribute for each component attribute
  - Example: given entity set *instructor* with composite attribute *name* with component attributes *first_name* and *last_name* the schema corresponding to the entity set has two attributes *name_first_name* and *name_last_name*
    - *Prefix omitted if there is no ambiguity*
- 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)

Composite and Multivalued Attributes

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

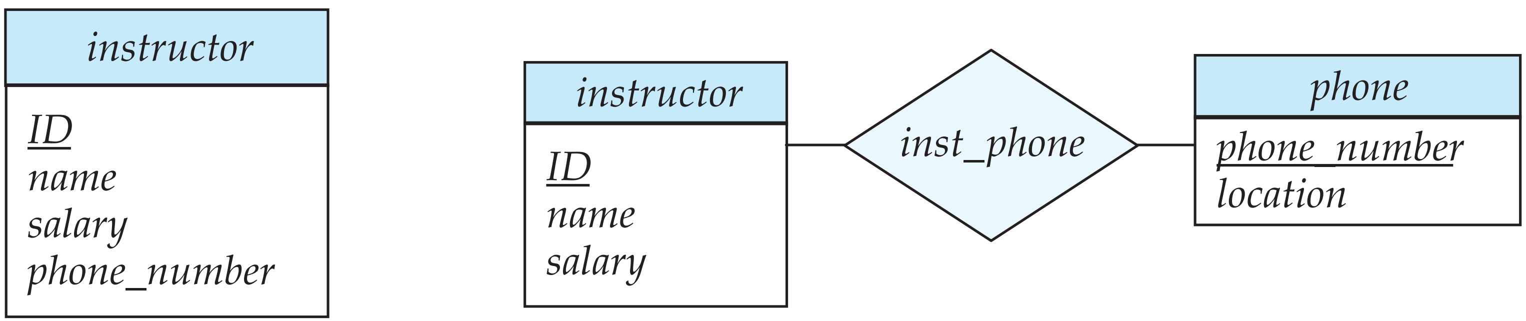
Multivalued Attributes (Cont.)

- Special case:entity *time_slot* has only one attribute other than the primary-key attribute, and that attribute is multivalued
  - Optimization: Don't create the relation corresponding to the entity, just create the one corresponding to the multivalued attribute
  - *time_slot*(<u>*time_slot_id, day, start_time*</u>, *end_time*)
  - Caveat: *time_slot* attribute of *section* (from *sec_time_slot*) cannot be a foreign key due to this optimization



Design Issues

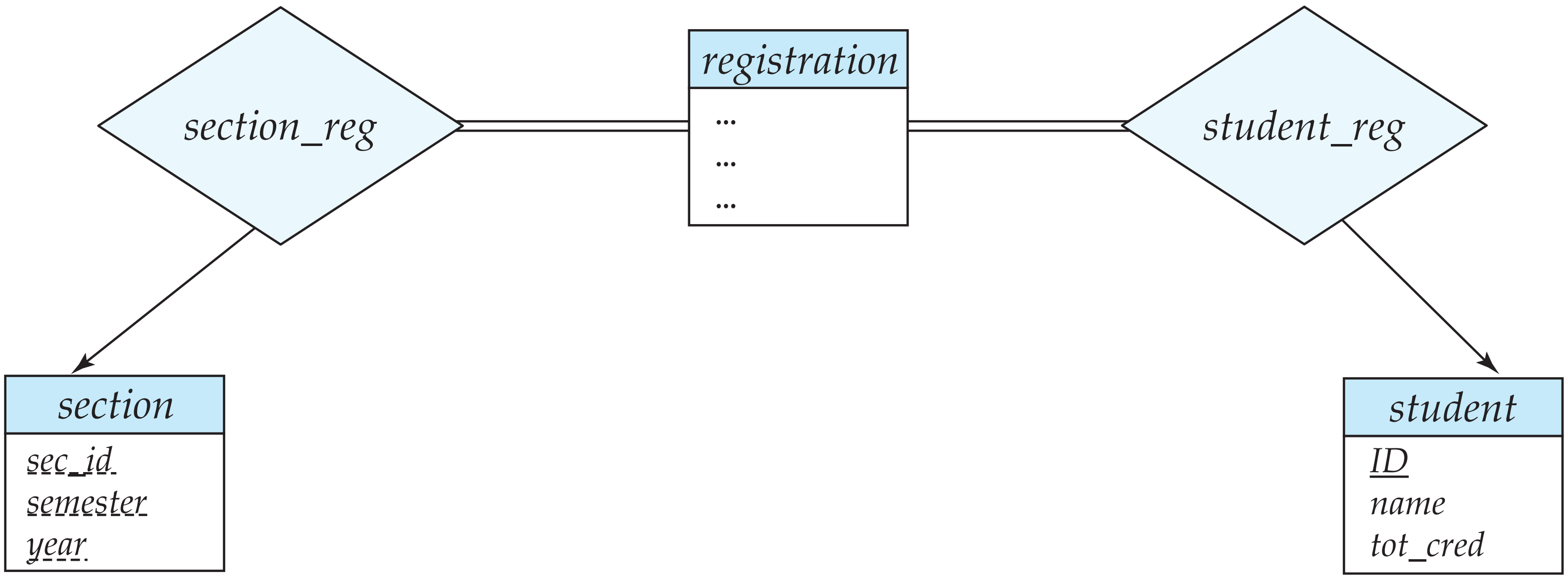
- **Use of entity sets vs. attributes**



- Designing phone as an entity allow for primary key constraints for phone
- Designing phone as an entity allow phone numbers to be used in relationships with other entities (e.g., student)
- Use of phone as an entity allows extra information about phone numbers

Design Issues

- **Use of entity sets vs. relationship sets**
  - Possible guideline is to designate a relationship set to describe an action that occurs between entities
  - Possible hint: the relationship only relates entities, but does not have an existence by itself. E.g., hasAddress: (department-address)



Design Issues

- **Binary versus n-ary relationship sets**
  - Although it is possible to replace any nonbinary (*n*-ary, for *n* > 2) relationship set by a number of distinct binary relationship sets + an aritifical entity set, a *n*-ary relationship set shows more clearly that several entities participate in a single relationship.
- **Placement of relationship attributes**
  - e.g., attribute *date* as attribute of *advisor* or as attribute of *student*
  - Does not work for *N-M relationships!*

Binary Vs. Non-Binary Relationships

- 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 know)
  - But there are some relationships that are naturally non-binary
    - Example: *proj_guide*

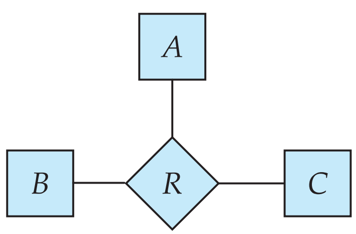
Converting Non-Binary Relationships to Binary Form

- 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:

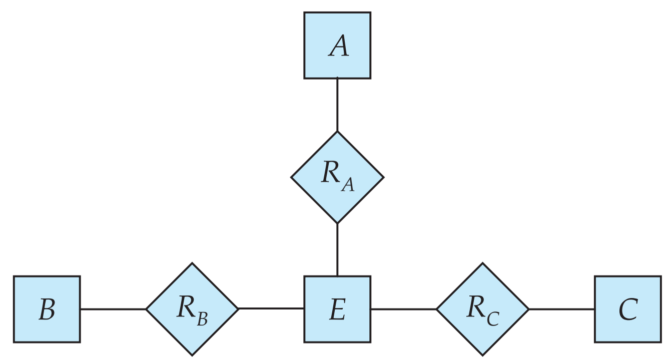
    1. R_A, relating *E* and *A* 2. R_B, relating *E* and *B*
    3. R_C, relating *E* and *C*

  - Create a special identifying attribute for *E*
  - 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.)

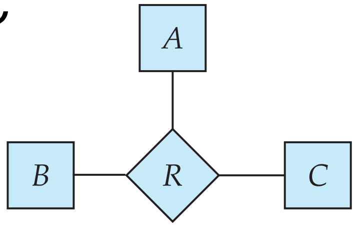
- Also need to translate constraints
  - Translating all constraints may not be possible
  - There may be instances in the translated schema that cannot correspond to any instance of *R*
    - Exercise: *add constraints to the relationships R_A, R_B and R_C* to ensure that a newly created entity corresponds 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

Converting Non-Binary Relationships: Is the New Entity Set E Necessary?

- Yes, because a non-binary relationship stores more information that any number of binary relationships
  - Consider again the example (a) below
  - Replace R with three binary relationships:

    1. R_{AB}, relating A and B   2. R_{BC}, relating B and C
    3. R_{AC}, relating A and C

  - For each relationship (a_i , b_i , c_i) in R, create
    - 1. add (a_i , b_i) to R_{AB}
    - 2. add (b_i , c_i) to R_{BC}
    - 3. add (a_i , c_i) to R_{AC}
  - *Consider R = order, A = supplier, B = item, C = customer*



(a)

(Gunnar, chainsaw, Bob) – Bob ordered a chainsaw from Gunnar

->

(Gunnar, chainsaw), (chainsaw, Bob), (Gunnar, Bob)

Gunnar supplies chainsaws, Bob ordered a chainsaw, Bob ordered something from Gunnar. E.g., we do not know what Bob ordered from Gunnar.

ER-model to Relational Summary

- ***Rule 1)*** *Strong entity E*
  - *Create relation with attributes of E*
  - *Primary key is equal to the PK of E*
- ***Rule 2)*** *Weak entity W identified by E through relationship R*
  - *Create relation with attributes of W and R and PK(E).*
  - *Set PK to discriminator attributes combined with PK(E). PK(E) is a foreign key to E.*
- ***Rule 3)*** *Binary relationship R between A and B: one-to-one*
  - *If no side is total add PK of A to as foreign key in B or the other way around. Add any attributes of the relationship R to A respective B.*
  - *If one side is total add PK of the other-side as foreign key. Add any attributes of the relationship R to the total side.*
  - *If both sides are total merge the two relation into a new relation E and choose either PK(A) as PK(B) as the new PK. Add any attributes of the relationship R to the new relation E.*

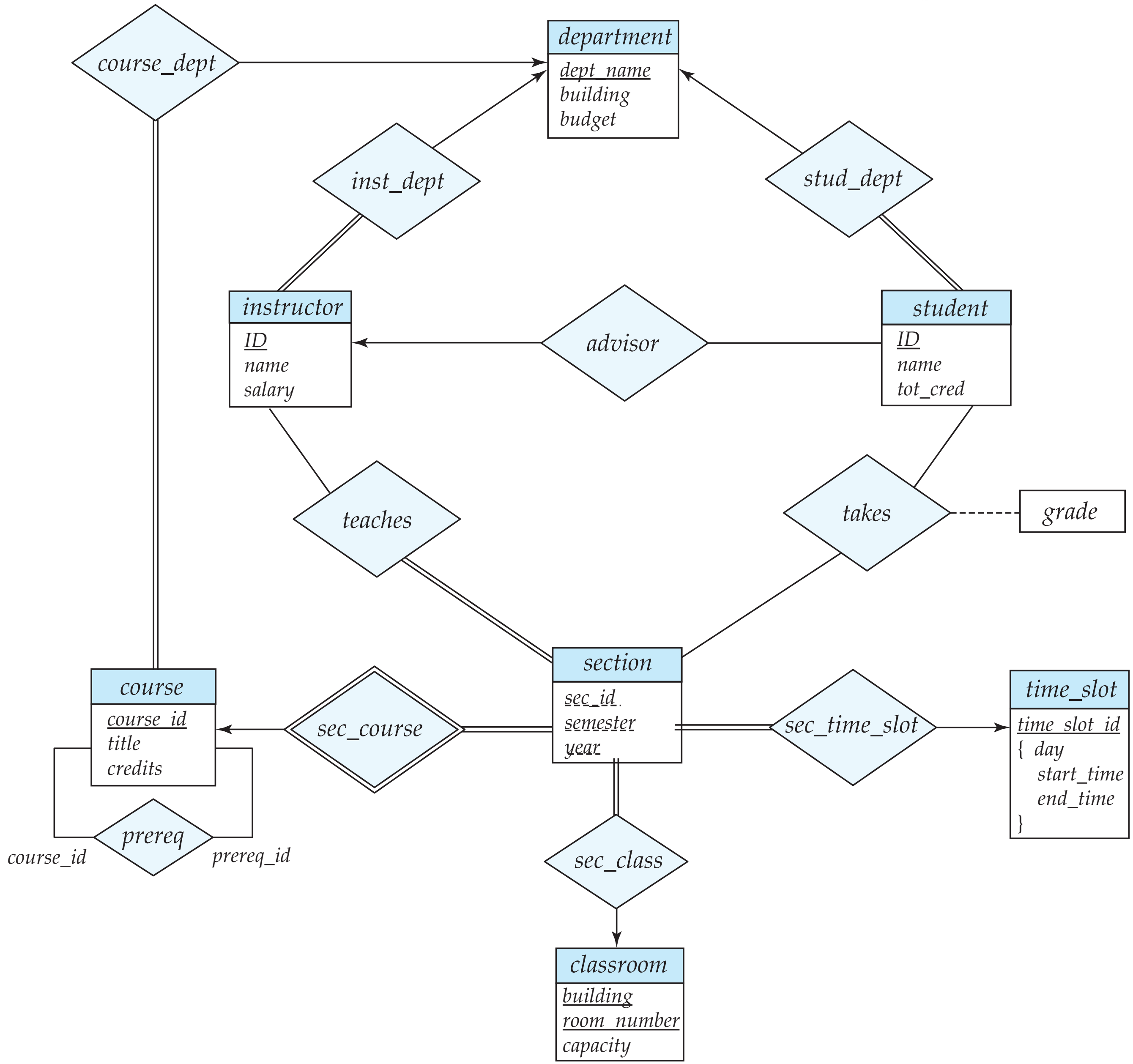
ER-model to Relational Summary (Cont.)

- ***Rule 4)*** *Binary relationship R between A and B: one-to-many/many-to-one*
  - *Add PK of the "one" side as foreign key to the "many" side.*
  - *Add any attributes of the relationship R to the "many" side.*
- ***Rule 5)*** *Binary relationship R between A and B: many-to-many*
  - *Create a new relation R.*
  - *Add PK's of A and B as attributes + plus all attributes of R.*
  - *The primary key of the relationship is PK(A) + PK(B). The PK attributes of A/B form a foreign key to A/B*
- ***Rule 6)*** *N-ary relationship R between* $E_1 \ldots E_n$
  - *Create a new relation.*
  - *Add all the PK's of* $E_1 \ldots E_n$*. Add all attributes of R to the new relation.*
  - *The primary key or R is* $PK(E_1) \ldots PK(E_n)$*. Each* $PK(E_i)$ *is a foreign key to the corresponding relation.*

ER-model to Relational Summary (Cont.)

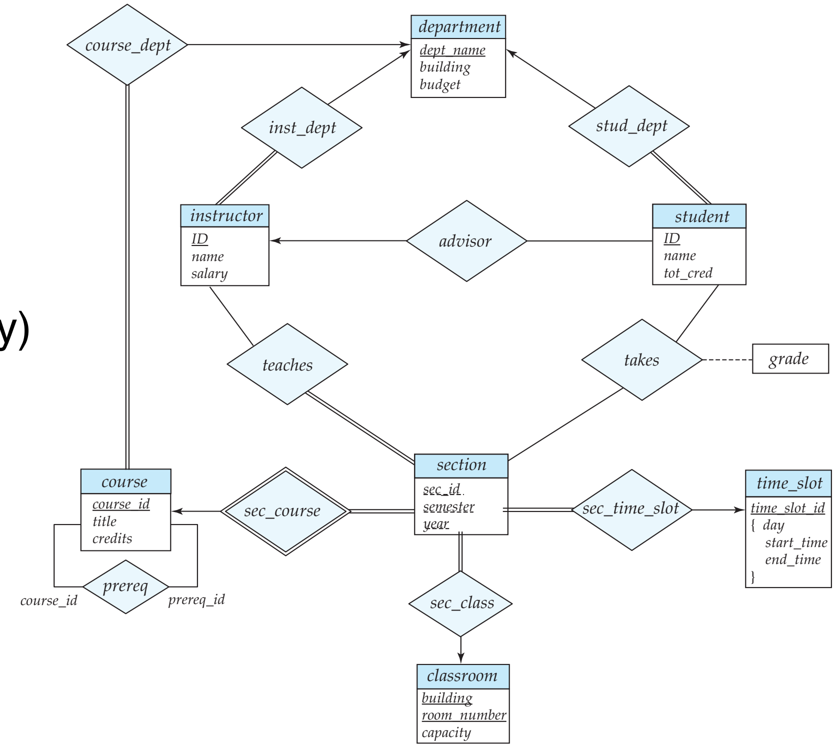
- ***Rule 7)*** *Entity E with multi-valued attribute A*
  - *Create new relation. Add A and PK(E) as attributes.*
  - *PK is all attributes. PK(E) is a foreign key.*

E-R Diagram for a University Enterprise



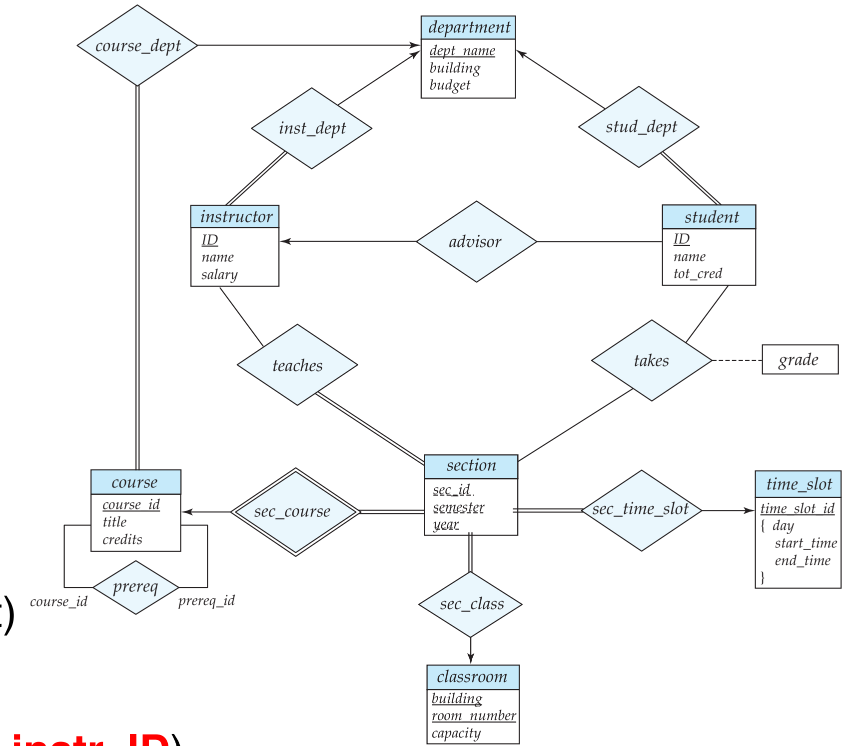
Translate the University ER-Model

- **Rule 1) Strong Entities**
  - **department**(dept_name, building, budget)
  - **instructor**(ID, name, salary)
  - **student**(ID, name, tot_cred)
  - **course**(course_id, title, credits)
  - **time_slot**(time_slot_id)
  - **classroom**(building,room_number, capacity)
- **Rule 2) Weak Entities**
  - **section**(course_id, sec_id, semester, year)



Translate the University ER-Model

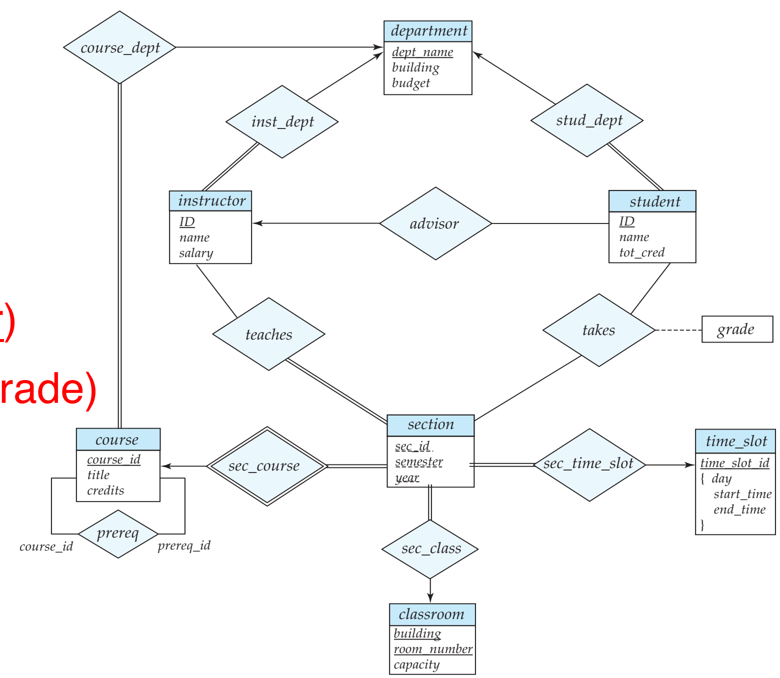
- **Rule 3) Relationships one-to-one**
  - None exist



- **Rule 4) Relationships one-to-many**
  - **department**(dept_name, building, budget)
  - **instructor**(ID, name, salary, **dept_name**)
  - **student**(ID, name, tot_cred, **dept_name**, **instr_ID**)
  - **course**(course_id, title, credits, **dept_name**)
  - **time_slot**(time_slot_id)
  - **classroom**(building,room_number, capacity)
  - **section**(course_id, sec_id, semester, year, **room_building**, **room_number**, **time_slot_id**)

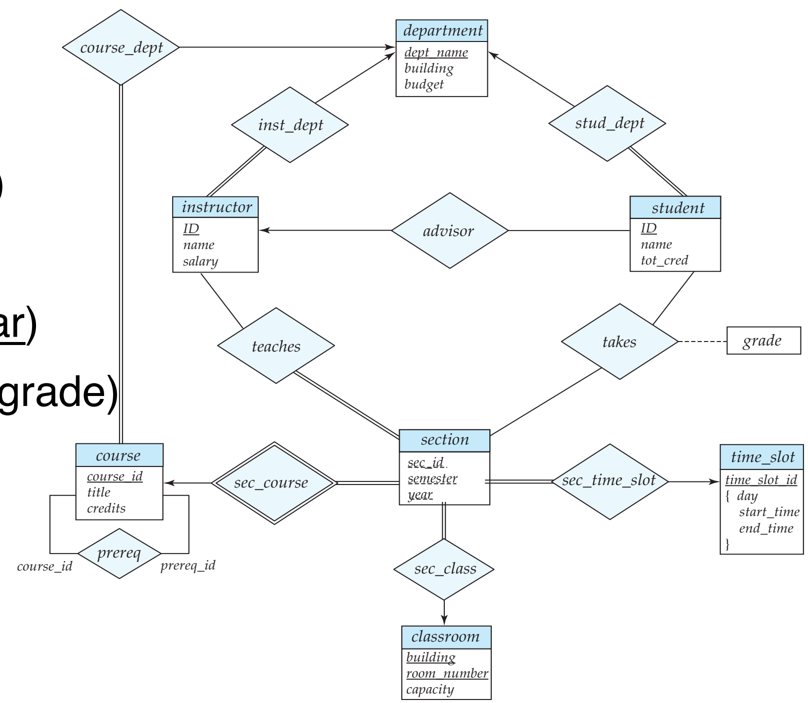
Translate the University ER-Model

- **Rule 5) Relationships many-to-many**
  - **department**(dept_name, building, budget)
  - **instructor**(ID, name, salary, dept_name)
  - **student**(ID, name, tot_cred, dept_name, instr_ID)
  - **course**(course_id, title, credits, dept_name)
  - **time_slot**(time_slot_id)
  - **classroom**(building,room_number, capacity)
  - **section**(course_id, sec_id, semester, year,
    room_building, room_number, time_slot_id)
  - **prereq**(course_id, prereq_id)
  - **teaches**(ID, course_id, sec_id, semester, year)
  - **takes**(ID, course_id, sec_id, semester, year, grade)
- **Rule 6) N-ary Relationships**
  - none exist



Translate the University ER-Model

- **Rule 7) Multivalued attributes**
  - **department**(dept_name, building, budget)
  - **instructor**(ID, name, salary, dept_name)
  - **student**(ID, name, tot_cred, dept_name, instr_ID)
  - **course**(course_id, title, credits, dept_name)
  - **time_slot**(time_slot_id)
  - **time_slot_day**(time_slot_id, start_time, end_time)
  - **classroom**(building,room_number, capacity)
  - **section**(course_id, sec_id, semester, year,
    room_building, room_number, time_slot_id)
  - **prereq**(course_id, prereq_id)
  - **teaches**(ID, course_id, sec_id, semester, year)
  - **takes**(ID, course_id, sec_id, semester, year, grade)

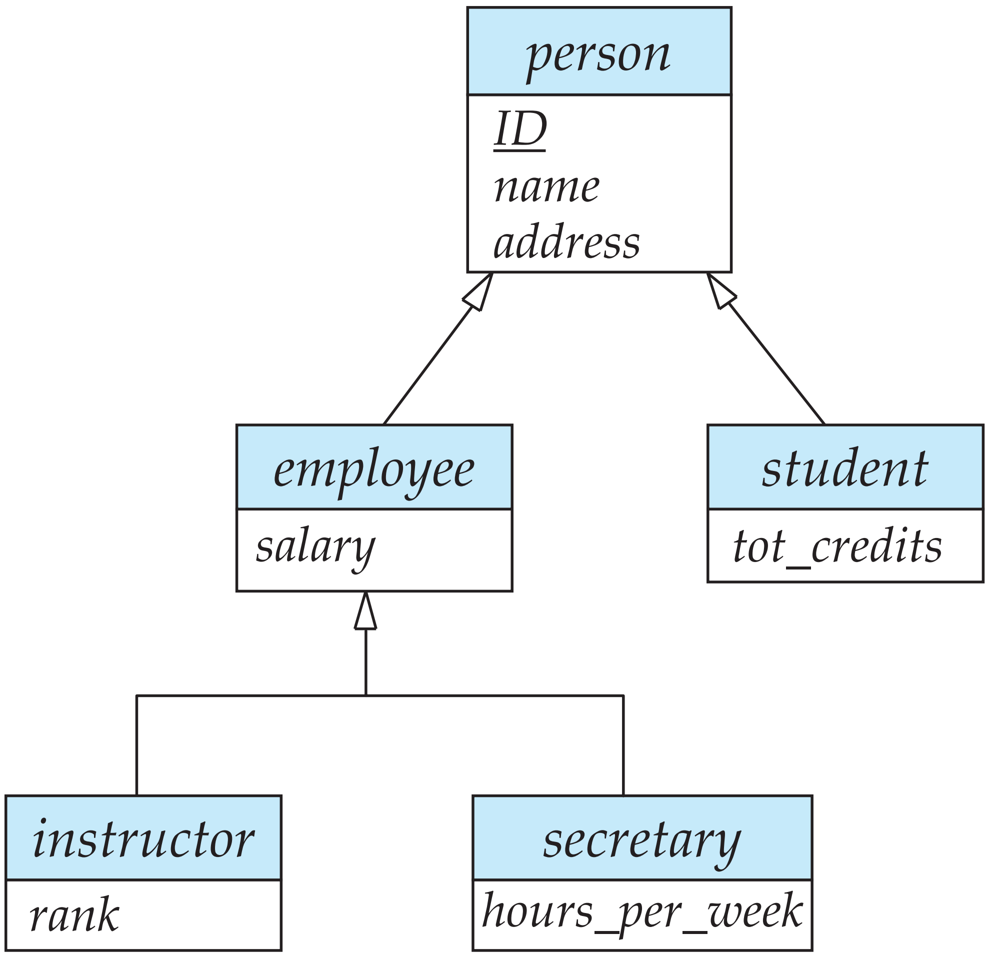


Extended ER Features

Extended E-R Features: Specialization

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

Specialization Example



Extended ER Features: Generalization

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

Specialization and Generalization (Cont.)

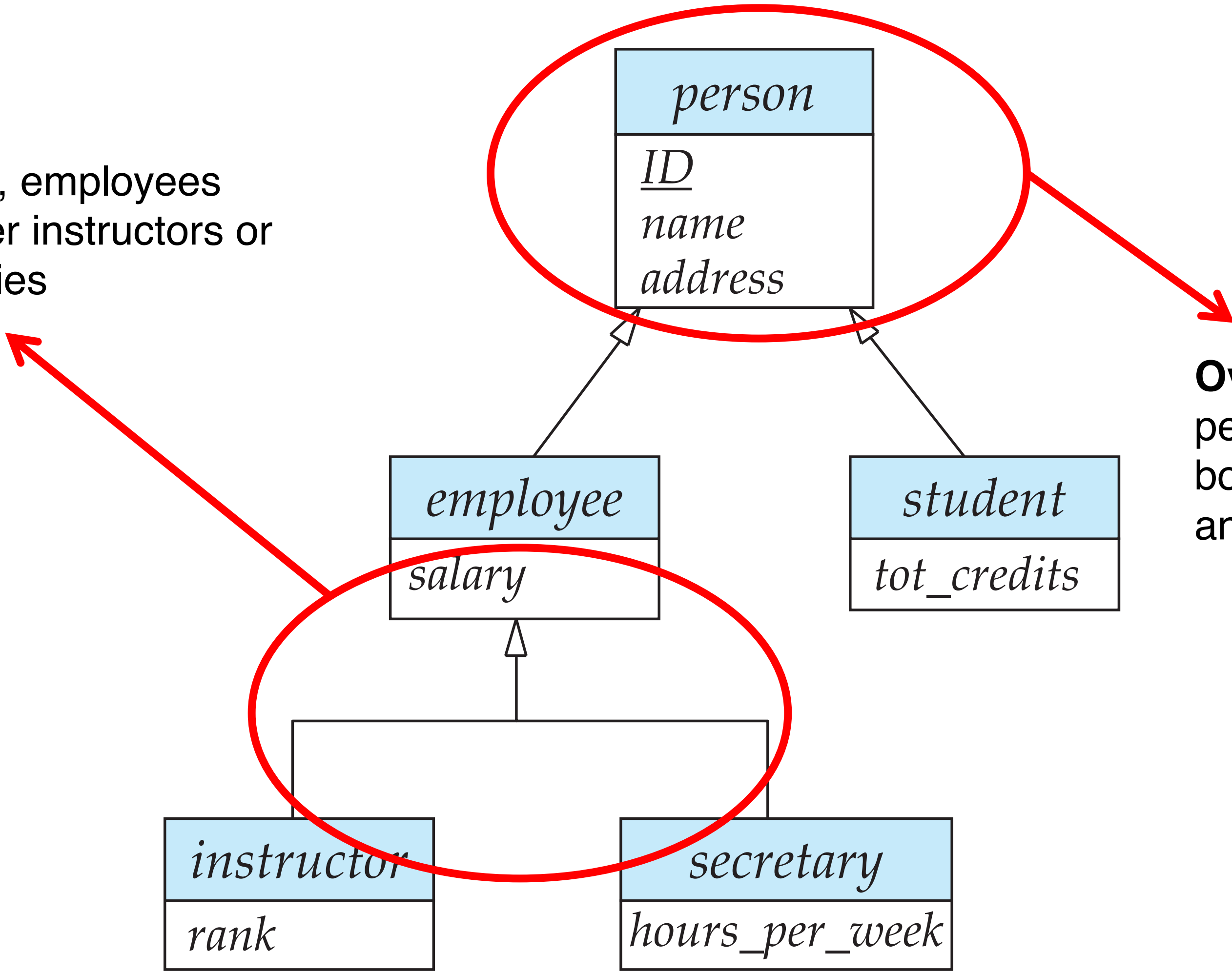
- Can have multiple specializations of an entity set based on different features.
- E.g., *permanent_employee* vs. *temporary_employee*, in addition to *instructor* vs. *secretary*
- Each particular employee would be
  - a member of one of *permanent_employee* or *temporary_employee*,
  - and also a member of one of *instructor*, *secretary*
- The ISA relationship also referred to as **superclass - subclass** relationship

Design Constraints on a Specialization/Generalization

- Constraint on which entities can be members of a given lower-level entity set.
  - condition-defined
    - Example: all customers over 65 years are members of *senior-citizen* entity set; *senior-citizen* ISA *person*.
  - user-defined
- Constraint on whether or not entities may belong to more than one lower-level entity set within a single generalization.
  - **Disjoint**
    - an entity can belong to only one lower-level entity set
    - Noted in E-R diagram by having multiple lower-level entity sets link to the same triangle
  - **Overlapping**
    - an entity can belong to more than one lower-level entity set

Specialization Example

Disjoint, employees are either instructors or secretaries



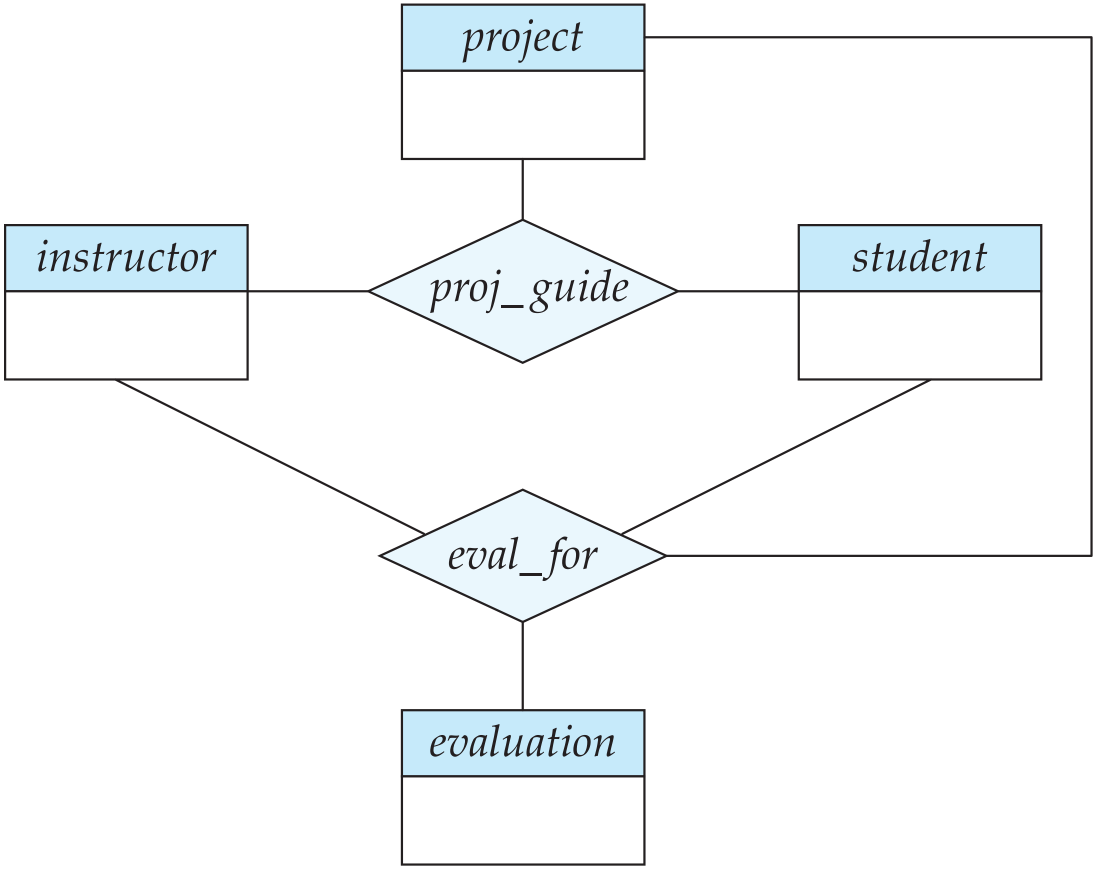
Overlapping, a person can be both an employee and a student

Design Constraints on a Specialization/Generalization (Cont.)

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

Aggregation

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

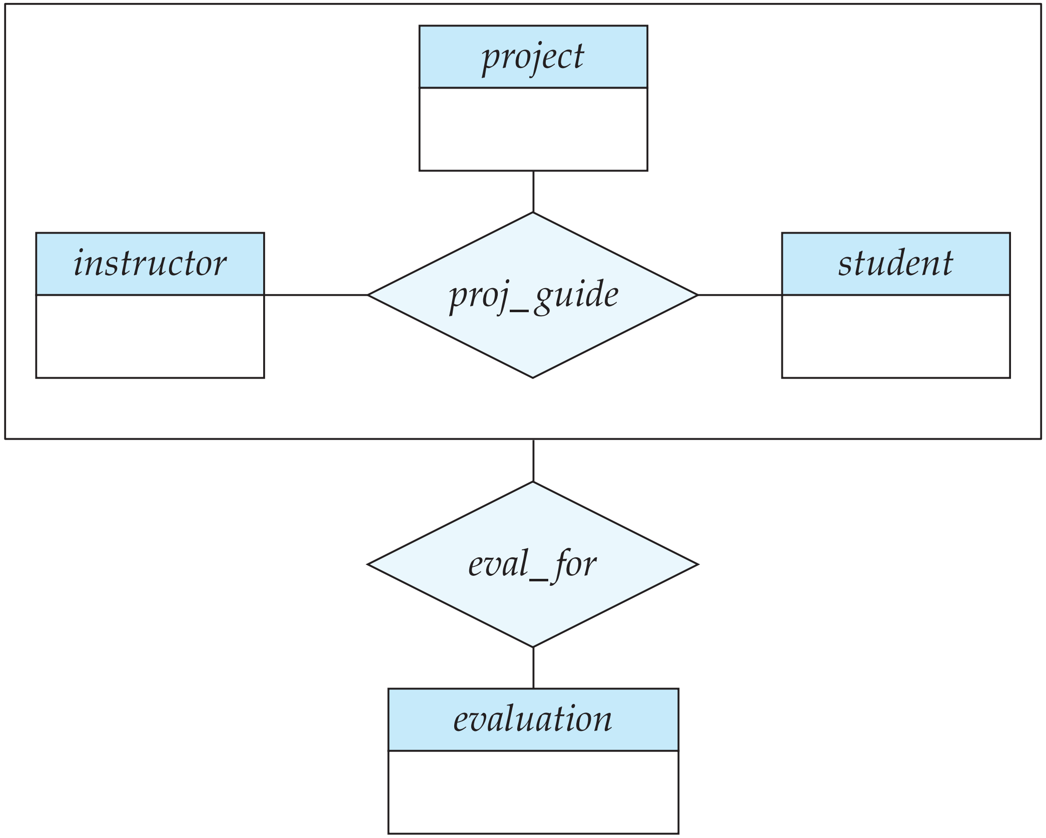


Aggregation (Cont.)

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

Aggregation (Cont.)

- 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



Representing Specialization via Schemas

- Method 1:
  - Form a relation schema for the higher-level entity
  - Form a relation 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 single relation 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*

  - If specialization is total, the schema for the generalized entity set (*person*) not required to store information
    - Can be defined as a "view" relation containing union of specialization relations
    - But explicit schema may still be needed for foreign key constraints
  - Drawback: *name, street* and *city* may be stored redundantly for people who are both students and employees

Representing Specialization as Schemas (Cont.)

- Method 3:
  - Form a single relation schema for each entity set with all local and inherited attributes
    - For total and disjoint specialization add a single "type" attribute that stores the type of an entity

schema	attributes
person	*ID*, ***type***, *name, street, city, tot_cred, salary*

    - For partial and/or overlapping specialization add multiple boolean "type" attributes

schema	attributes
person	*ID*, ***isEmployee, isStudent***, *name, street, city, tot_cred, salary*

  - Drawback: large number of NULL values, potentially large relation

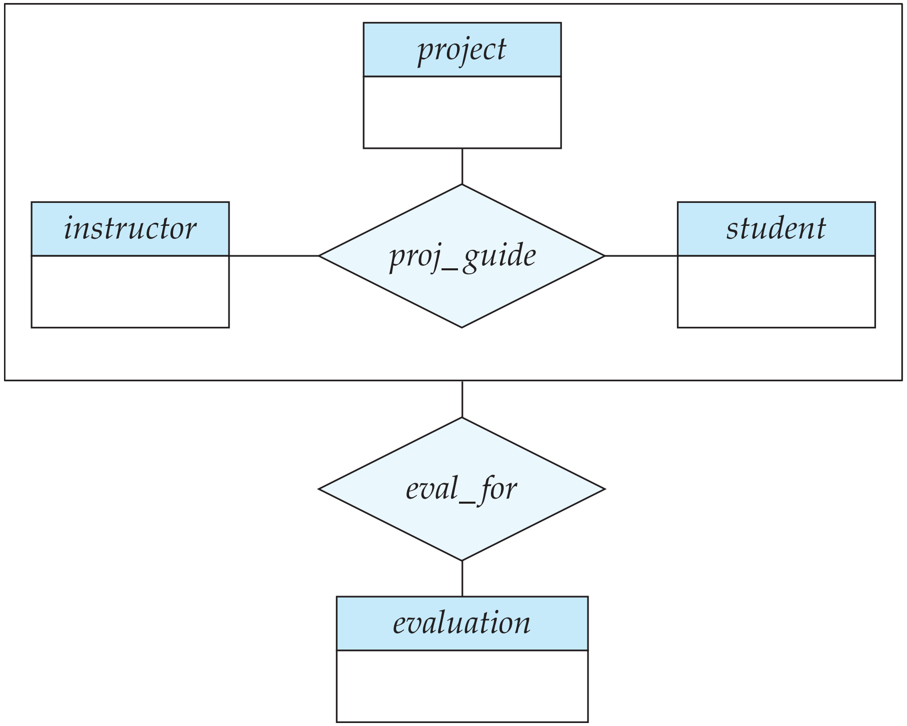
Schemas Corresponding to Aggregation

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

Schemas Corresponding to Aggregation (Cont.)

- For example, to represent aggregation manages between relationship works_on and entity set manager, create a schema

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



ER-model to Relational Summary (Cont.)

- ***Rule 8)*** *Specialization of E into S_1, … ,S_n (method 1)*
  - *Create a relation for E with all attributes of E. The PK of E is the PK.*
  - *For each S_i create a relation with PK(E) as PK and foreign key to relation for E. Add all attributes of S_i that do not exist in E.*
- ***Rule 9)*** *Specialization of E into S_1, … ,S_n (method 2)*
  - *Create a relation for E with all attributes of E. The PK of E is the PK.*
  - *For each S_i create a relation with PK(E) as PK and foreign key to relation for E. Add all attributes of S_i.*
- ***Rule 10)*** *Specialization of E into S_1, … ,S_n (method 3)*
  - *Create a new relation with all attributes from E and S_1, … ,$S_{n.}$*
  - *Add single attribute type or a boolean type attribute for each S_i*
  - *The primary key is PK(E)*

ER-model to Relational Summary (Cont.)

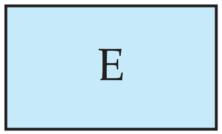
- ***Rule 11)*** *Aggregation: Relationship R_1 relates entity sets $E_1, \ldots, E_n$. This is related by relationship A to an entity set B*
  - *Create a relation for A with attributes $PK(E_1) \ldots PK(E_n)$ + all attributes from A + PK(B). PK are all attributes except the ones from A*

ER Design Decisions

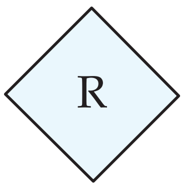
- The use of an attribute or entity set to represent an object.
- Whether a real-world concept is best expressed by an entity set or a relationship set.
- The use of a ternary relationship versus a pair of binary relationships.
- The use of a strong or weak entity set.
- The use of specialization/generalization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

How about doing another ER design interactively on the board?

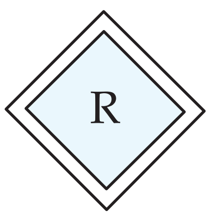
Summary of Symbols Used in E-R Notation



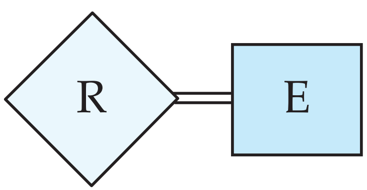
entity set



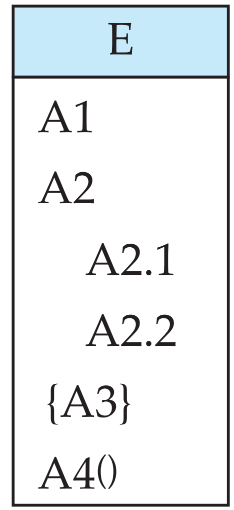
relationship set



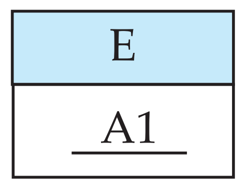
identifying
relationship set
for weak entity set



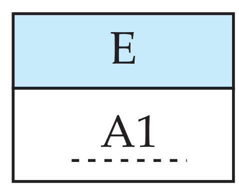
total participation
of entity set in
relationship



attributes:
simple (A1),
composite (A2) and
multivalued (A3)
derived (A4)

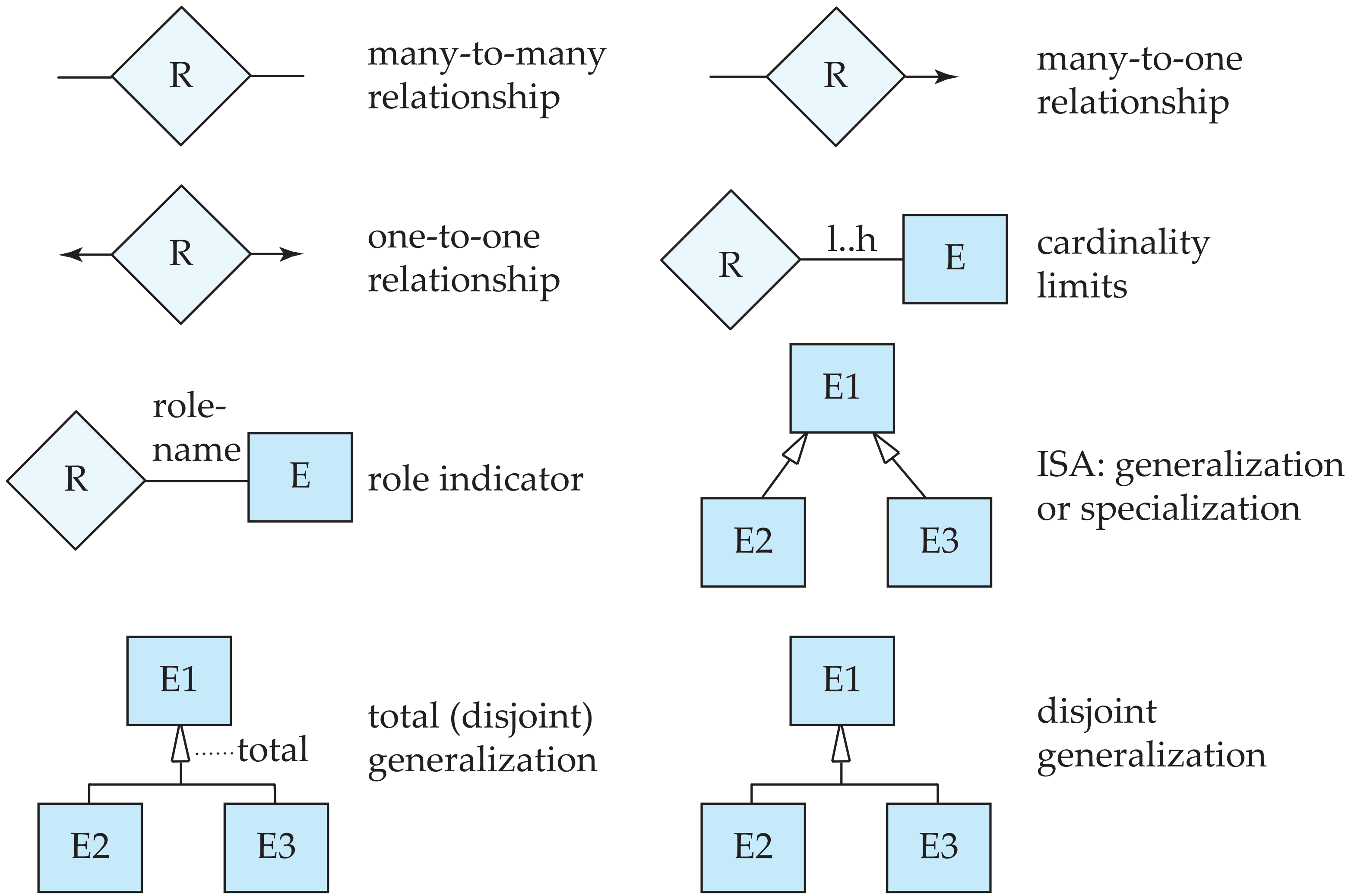


primary key



discriminating
attribute of
weak entity set

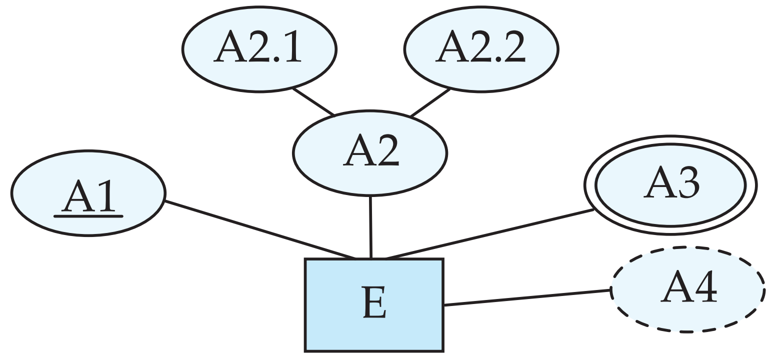
Symbols Used in ER Notation (Cont.)



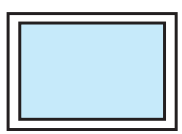
Alternative ER Notations

- Chen, IDE1FX, …

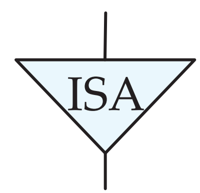
entity set E with
simple attribute A1,
composite attribute A2,
multivalued attribute A3,
derived attribute A4,
and primary key A1



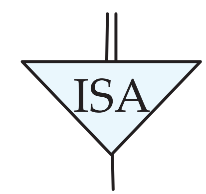
weak entity set



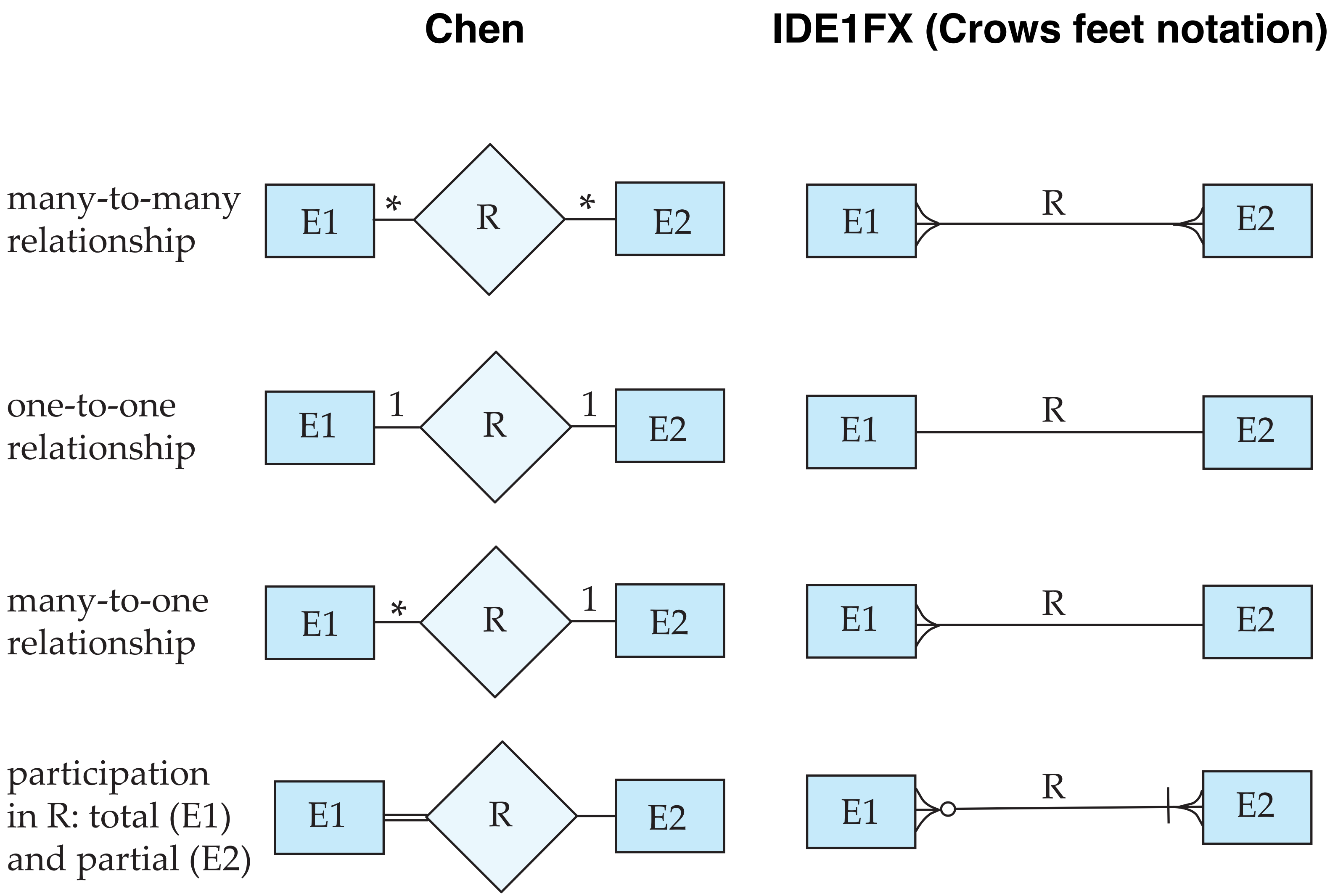
generalization



total
generalization



Alternative ER Notations

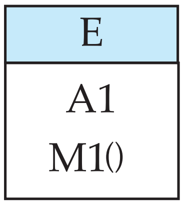


UML

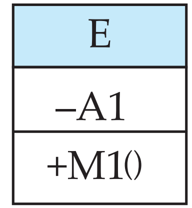
- **UML**: Unified Modeling Language
- UML has many components to graphically model different aspects of an entire software system
- UML Class Diagrams correspond to E-R Diagram, but several differences.

ER vs. UML Class Diagrams

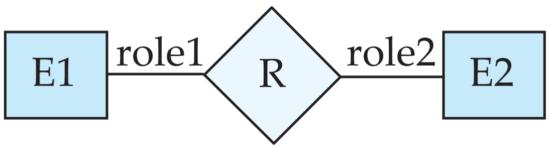
ER Diagram Notation | **Equivalent in UML**



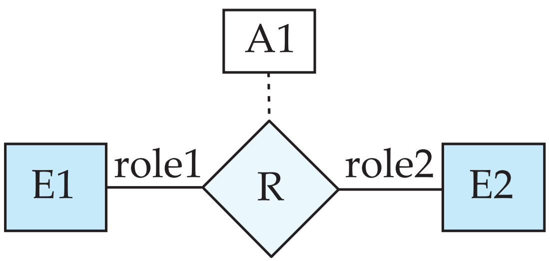
entity with attributes (simple, composite, multivalued, derived)



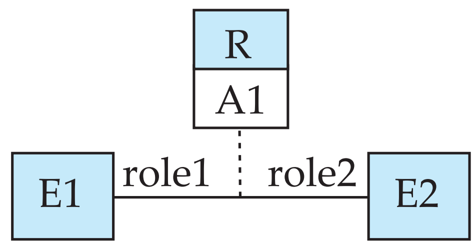
class with simple attributes and methods (attribute prefixes: + = public, – = private, # = protected)

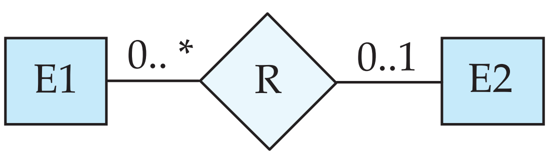


binary relationship

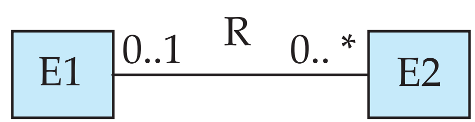


relationship attributes





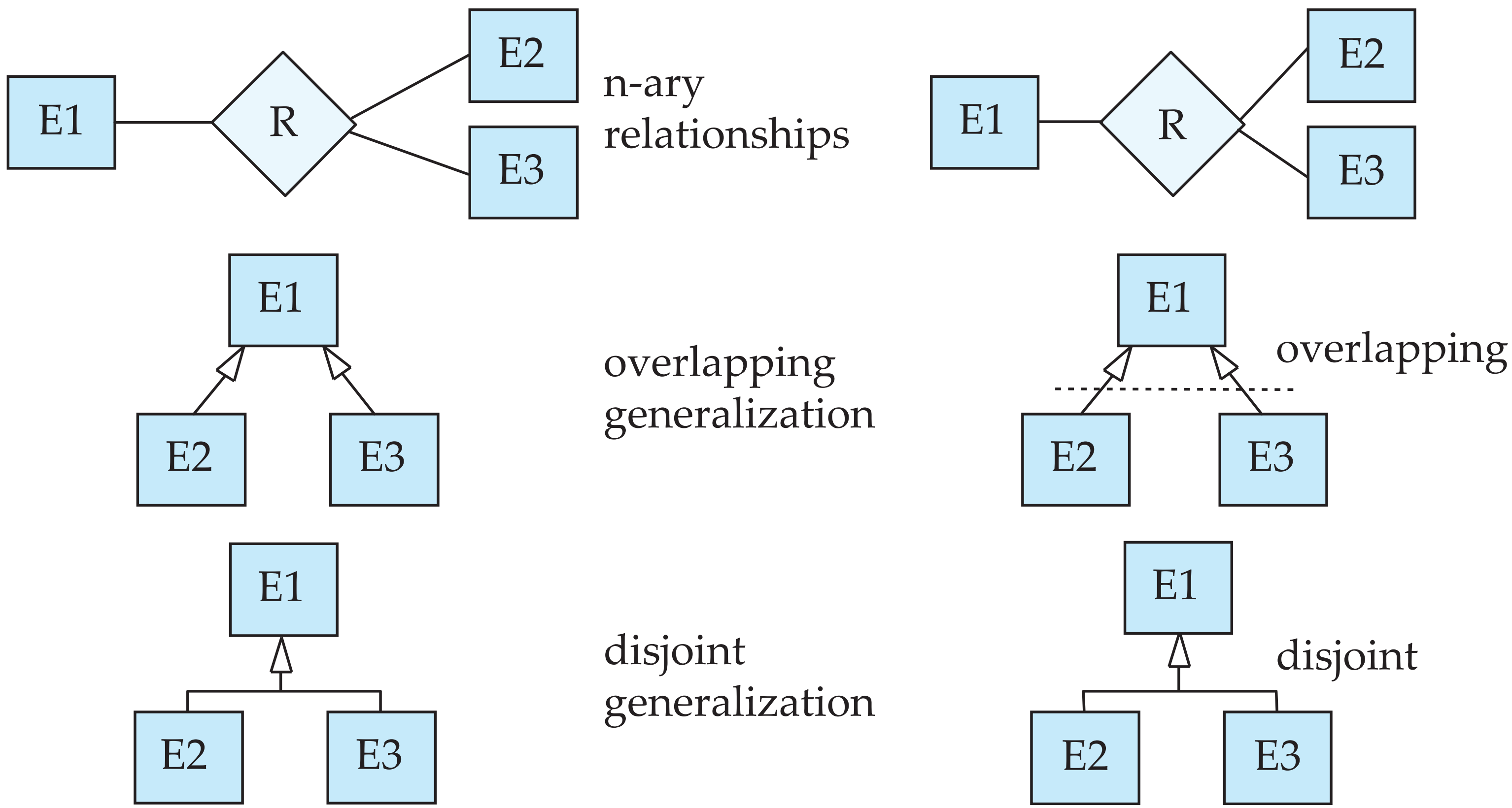
cardinality constraints



*Note reversal of position in cardinality constraint depiction

ER vs. UML Class Diagrams

ER Diagram Notation | **Equivalent in UML**



*Generalization can use merged or separate arrows independent of disjoint/overlapping

UML Class Diagrams (Cont.)

- Binary relationship sets are represented in UML by just drawing a line connecting the entity sets. The relationship set name is written adjacent to the line.
- The role played by an entity set in a relationship set may also be specified by writing the role name on the line, adjacent to the entity set.
- The relationship set name may alternatively be written in a box, along with attributes of the relationship set, and the box is connected, using a dotted line, to the line depicting the relationship set.

Recap

- ER-model
  - Entities
    - Strong
    - Weak
  - Attributes
    - Simple vs. Composite
    - Single-valued vs. Multi-valued
  - Relationships
    - Degree (binary vs. N-ary)
  - Cardinality constraints
  - Specialization/Generalization
    - Total vs. partial
    - Disjoint vs. overlapping
  - Aggregation

Recap Cont.

- ER-Diagrams
  - Alternative notations
- UML-Diagrams
- Design decisions
  - Multi-valued attribute vs. entity
  - Entity vs. relationship
  - Binary vs. N-ary relationships
  - Placement of relationship attributes
  - Total 1-1 vs. single entity
- ER to relational model
  - Translation rules

End of Chapter 7

Figure 7.01

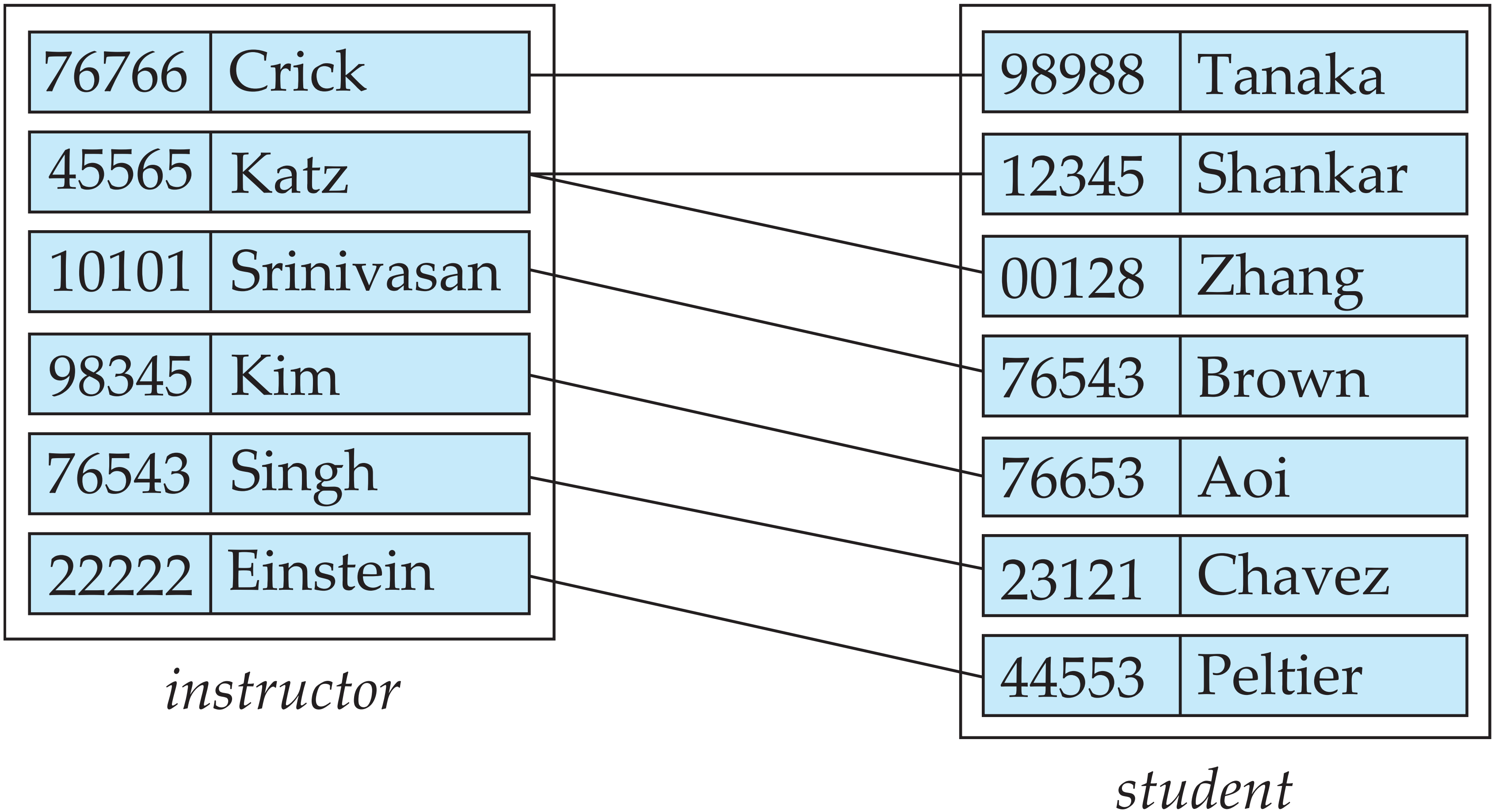
76766	Crick
45565	Katz
10101	Srinivasan
98345	Kim
76543	Singh
22222	Einstein

instructor

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

student

Figure 7.02



76766
Crick
45565
Katz
10101
Srinivasan
98345
Kim
76543
Singh
22222
Einstein
instructor
98988
Tanaka
12345
Shankar
00128
Zhang
76543
Brown
76653
Aoi
23121
Chavez
44553
Peltier
student

Figure 7.03

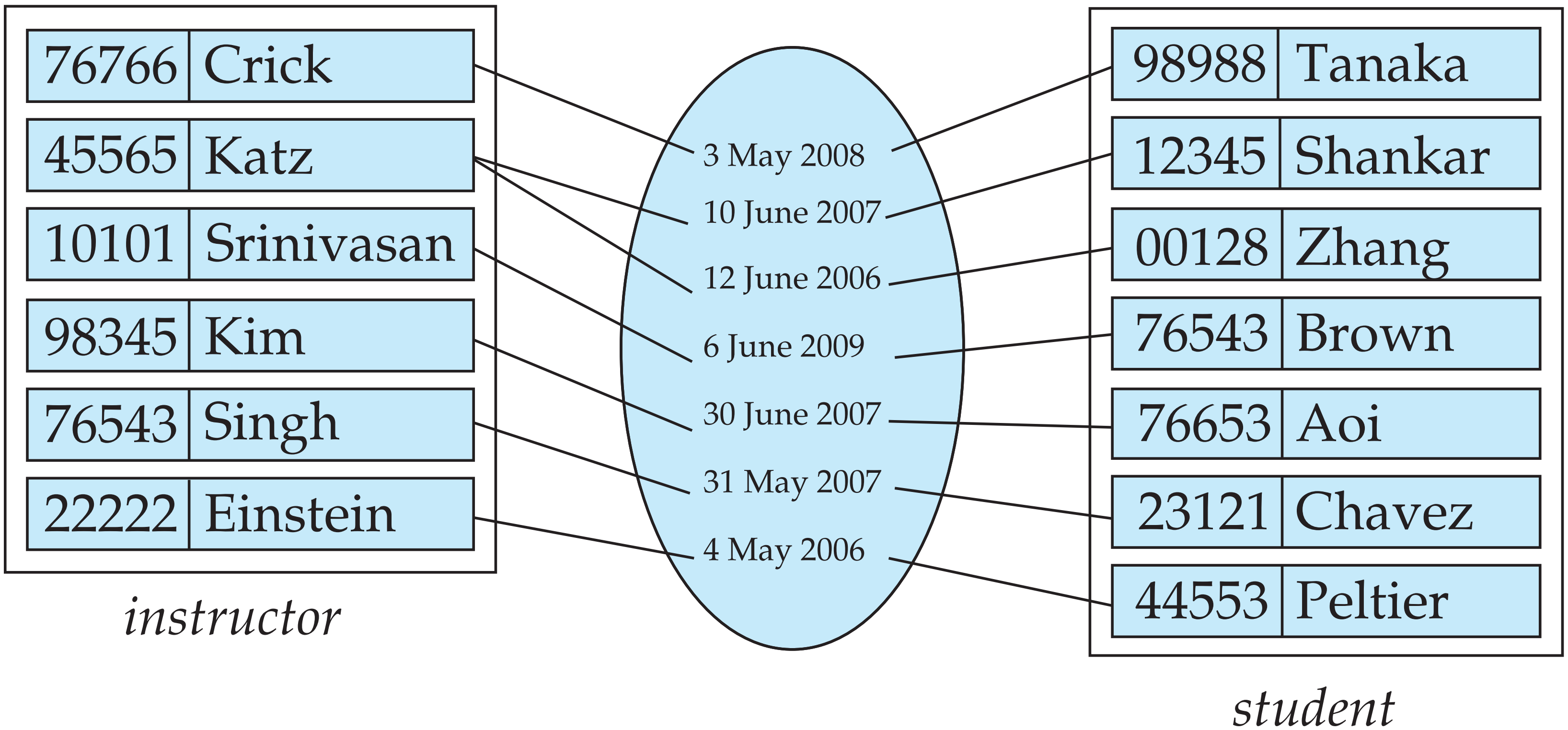

76766 Crick
45565 Katz
10101 Srinivasan
98345 Kim
76543 Singh
22222 Einstein
instructor
3 May 2008
10 June 2007
12 June 2006
6 June 2009
30 June 2007
31 May 2007
4 May 2006
98988 Tanaka
12345 Shankar
00128 Zhang
76543 Brown
76653 Aoi
23121 Chavez
44553 Peltier
student

Figure 7.04

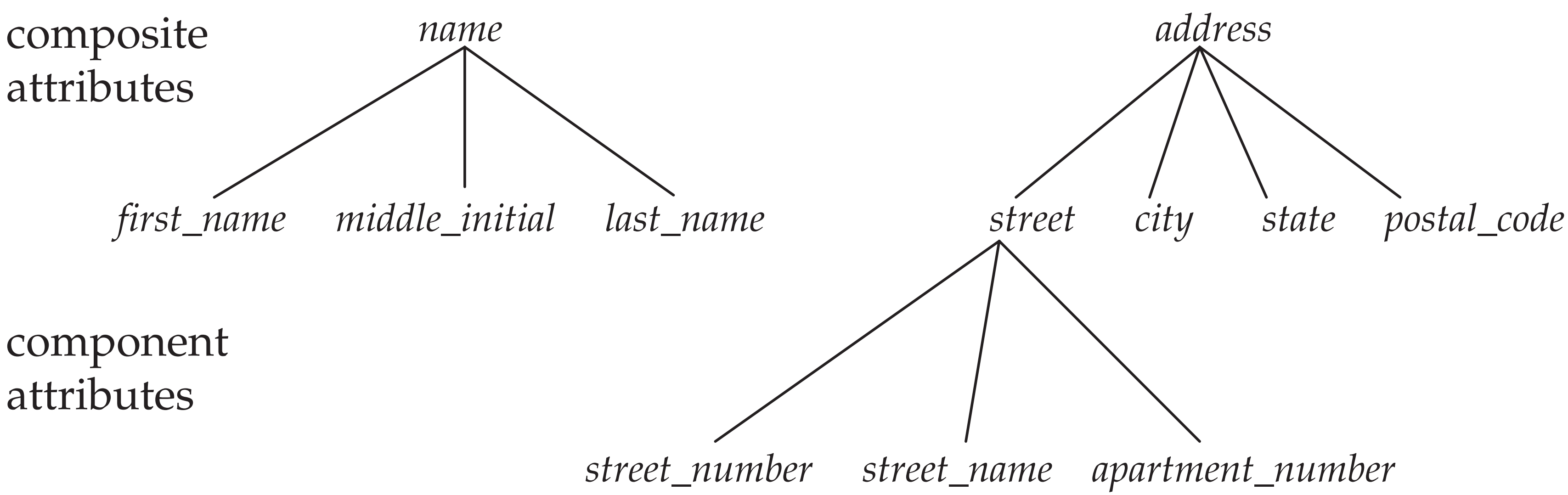

composite
attributes
component
attributes
name
first_name
middle_initial
last_name
address
street
city
state
postal_code
street_number
street_name
apartment_number

Figure 7.05

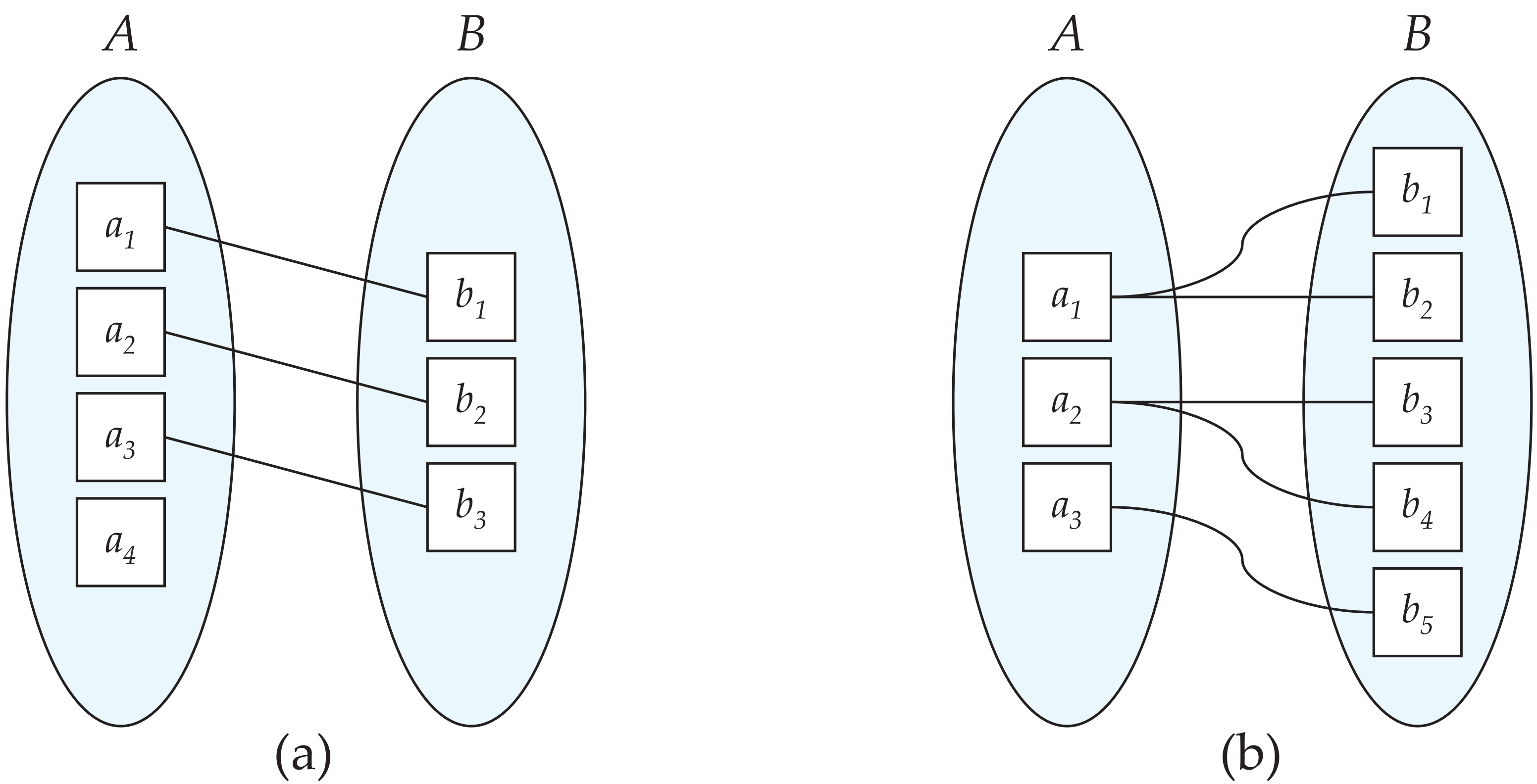
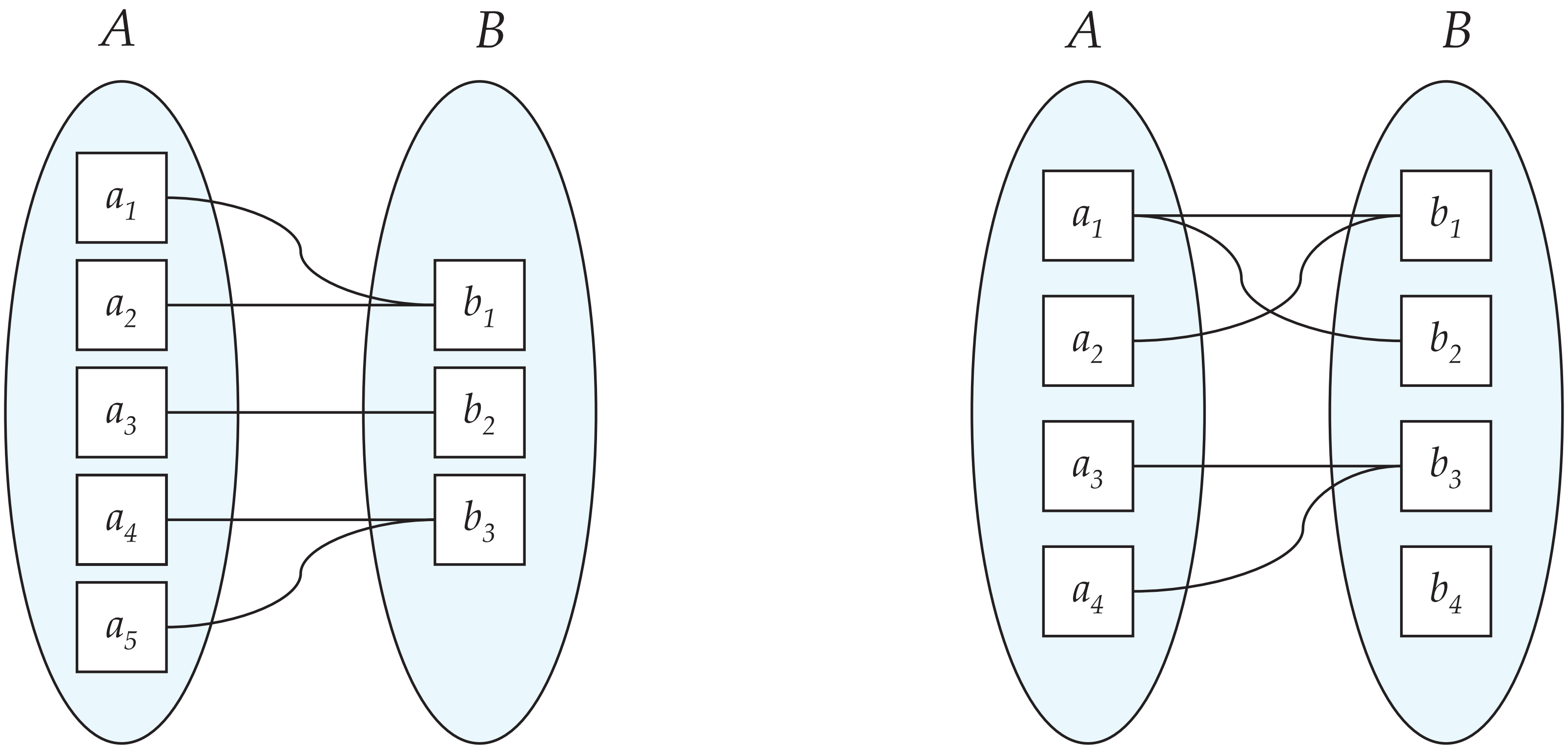


Figure 7.06



(a) (b)

Figure 7.07

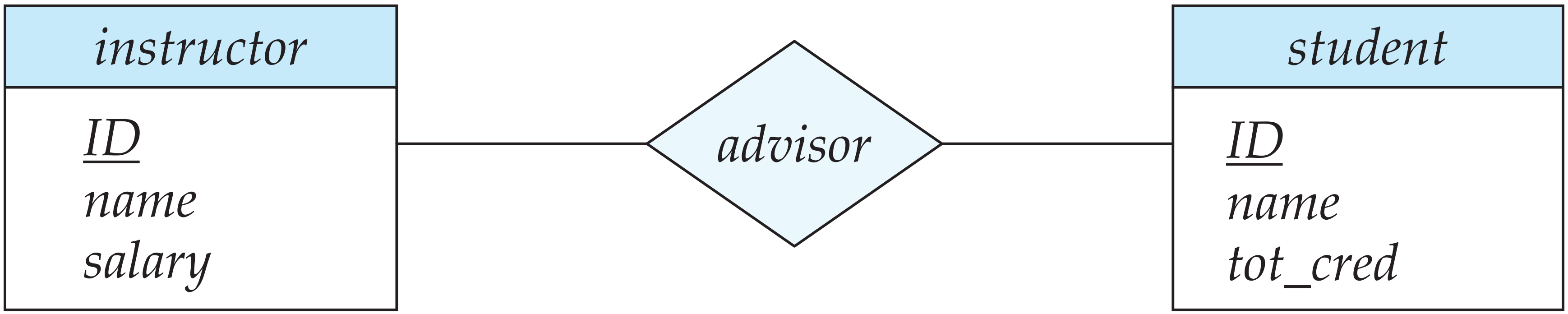


Figure 7.08

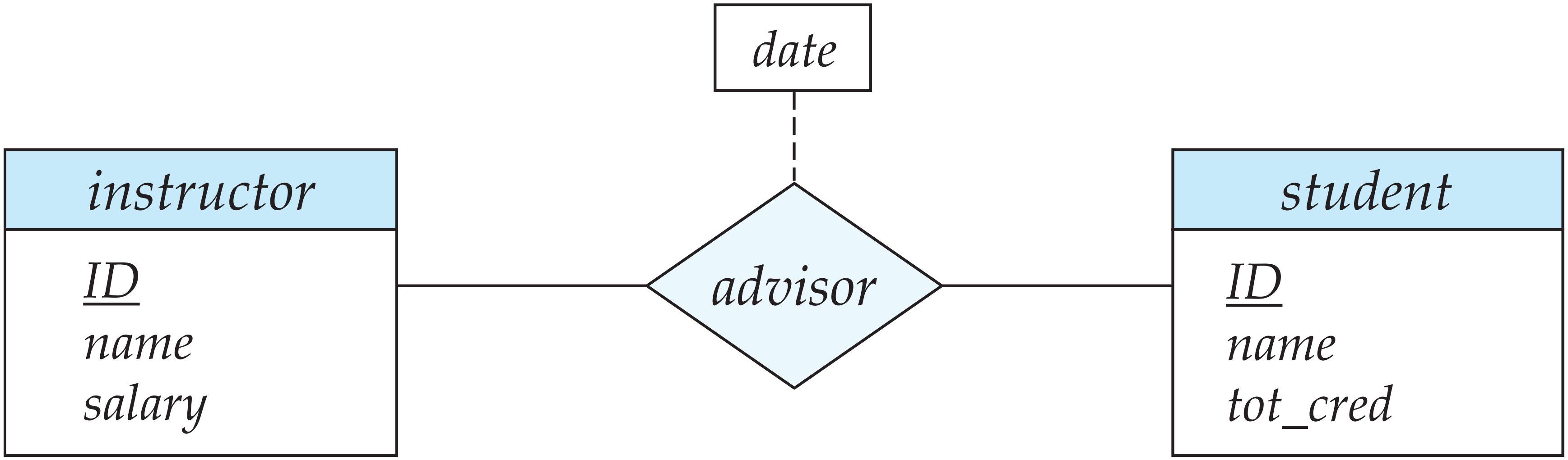

date
instructor
ID
name
salary
advisor
student
ID
name
tot_cred

Figure 7.09

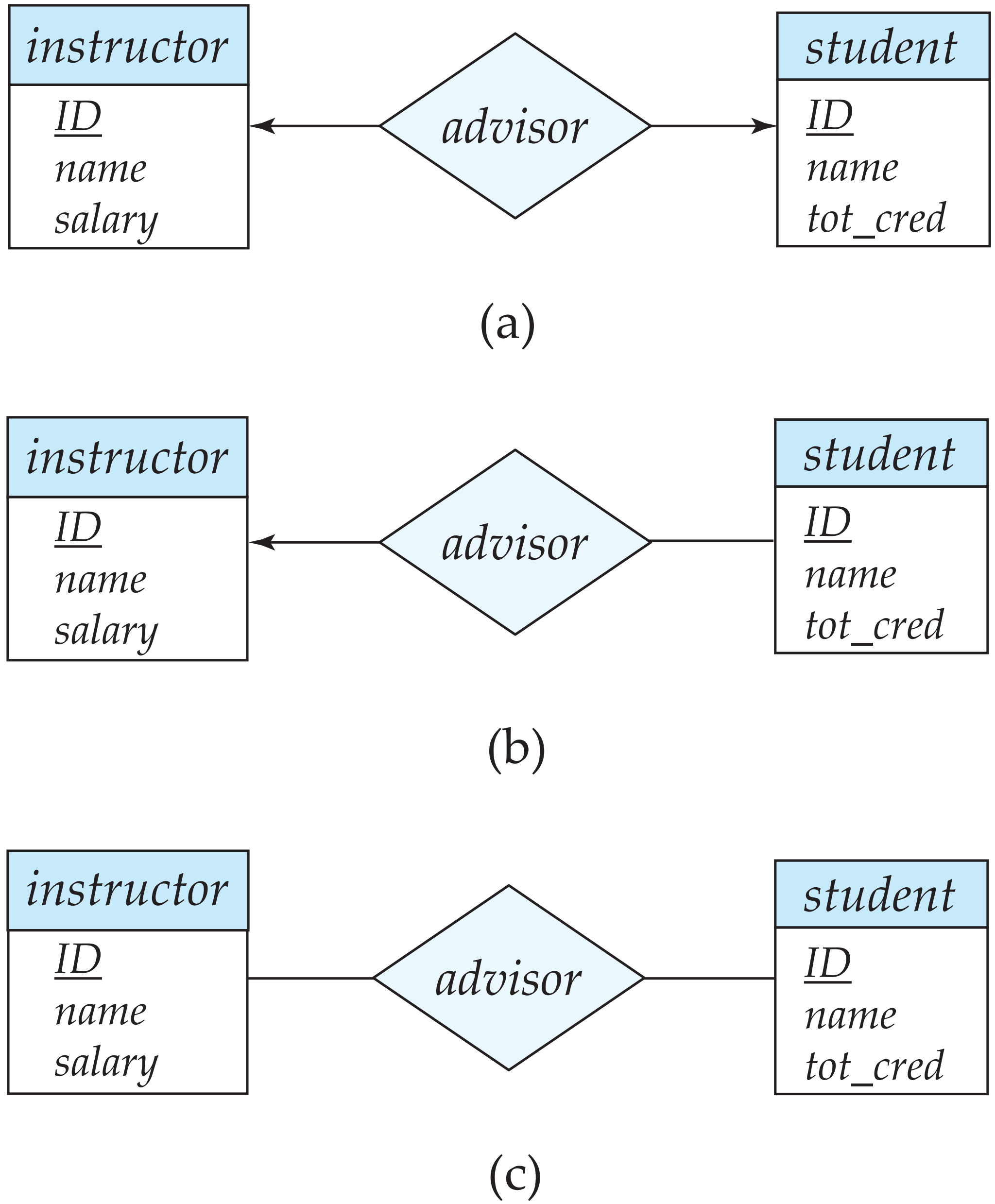

instructor
ID
name
salary
advisor
student
ID
name
tot_cred
(a)
instructor
ID
name
salary
advisor
student
ID
name
tot_cred
(b)
instructor
ID
name
salary
advisor
student
ID
name
tot_cred
(c)

Figure 7.10

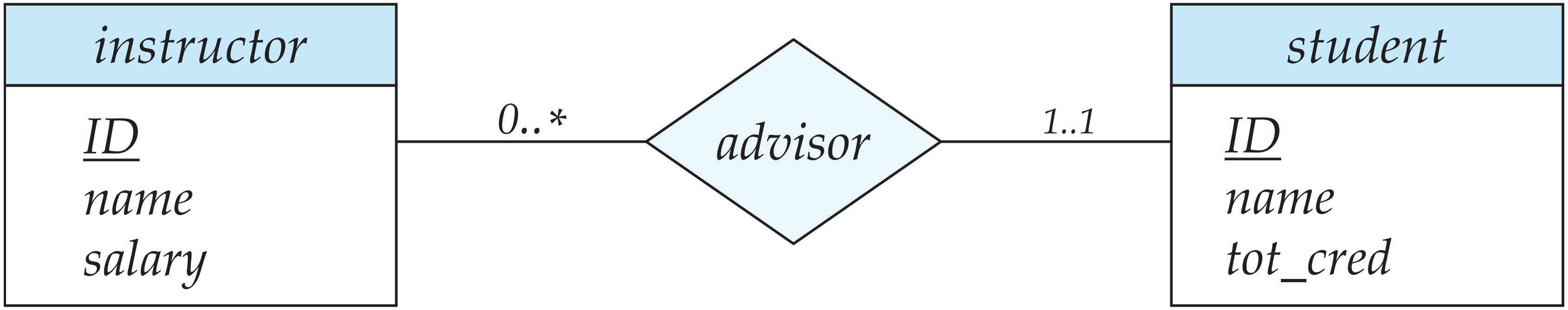

instructor
ID
name
salary
0..*
advisor
1..1
student
ID
name
tot_cred

Figure 7.11

instructor
<u>*ID*</u> *name*   *first_name*   *middle_initial*   *last_name* *address*   *street*   *street_number*   *street_name*   *apt_number*   *city*   *state*   *zip* *{ phone_number }* *date_of_birth* *age ( )*

Figure 7.12

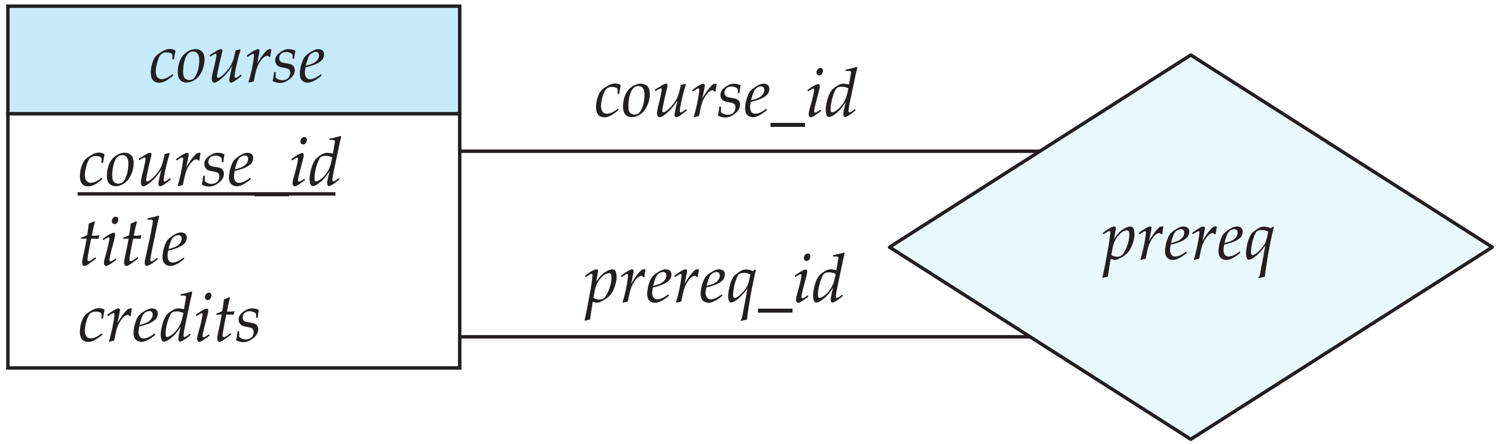


Figure 7.13

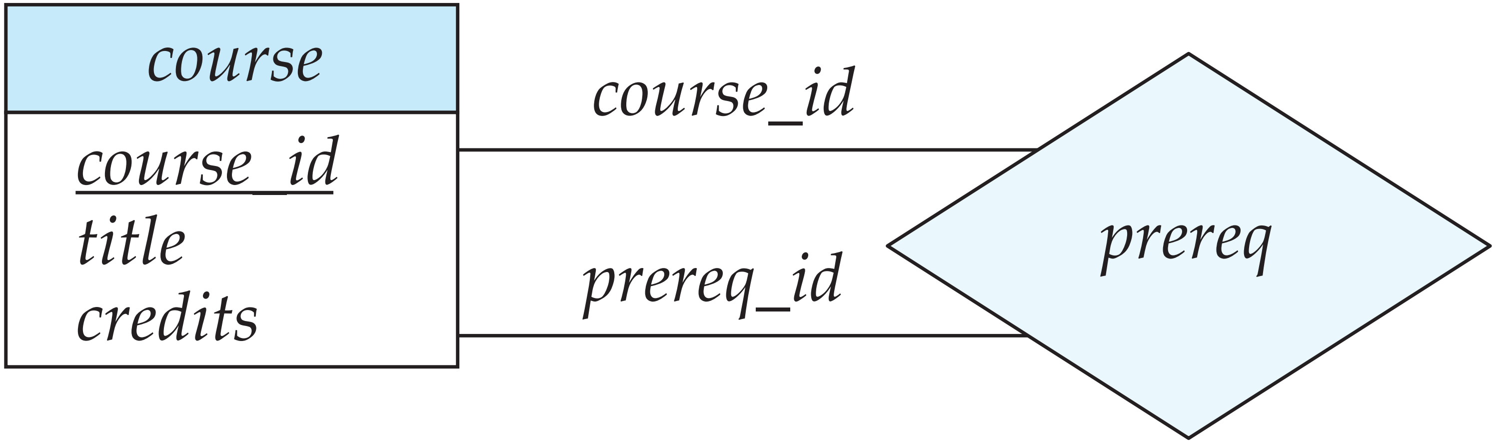


Figure 7.14

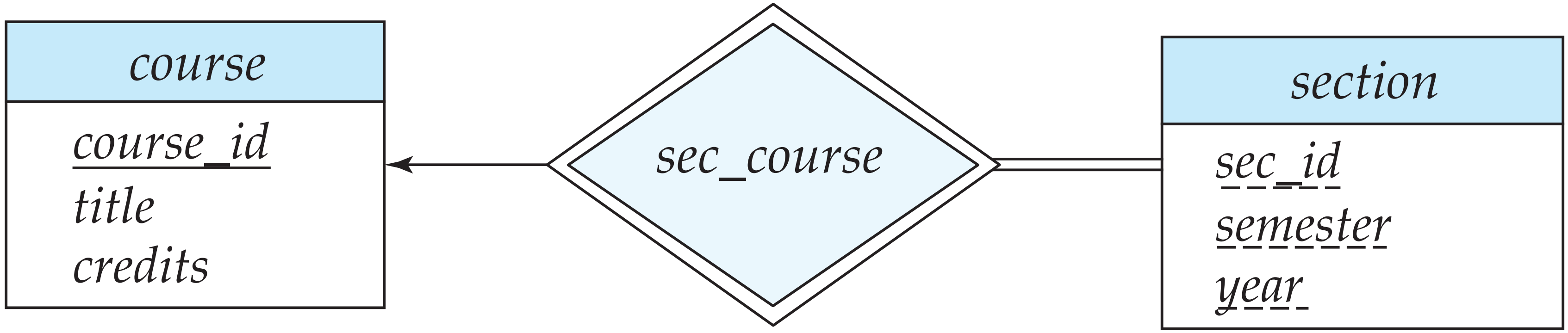

course
course_id
title
credits
sec_course
section
sec_id
semester
year

Figure 7.15

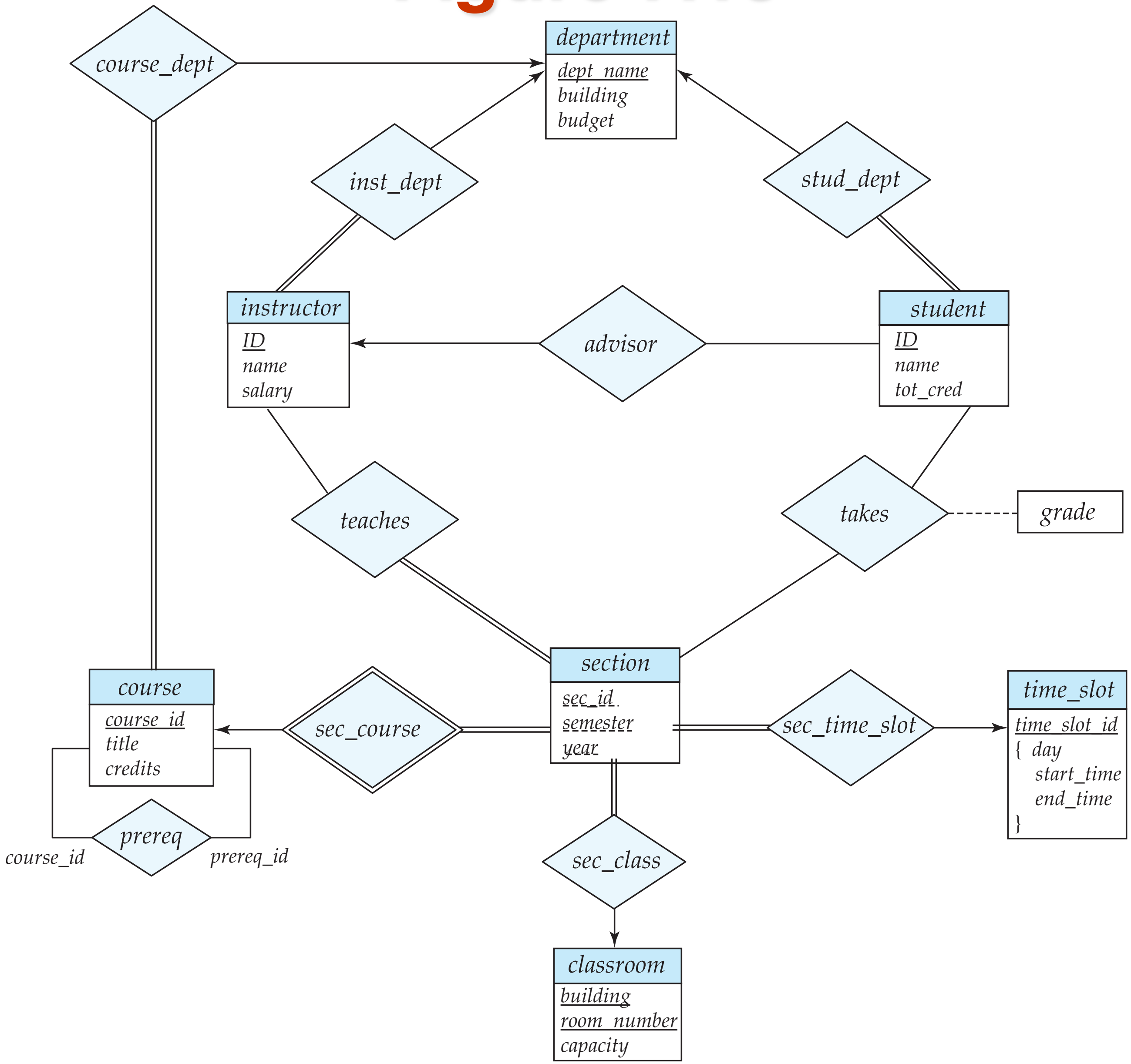

course_dept
department
dept_name
building
budget
inst_dept
stud_dept
instructor
ID
name
salary
advisor
student
ID
name
tot_cred
teaches
takes
grade
section
sec_id
semester
year
course
course_id
title
credits
sec_course
sec_time_slot
time_slot
time_slot_id
{ day
start_time
end_time
}
prereq
course_id
prereq_id
sec_class
classroom
building
room_number
capacity

Figure 7.17

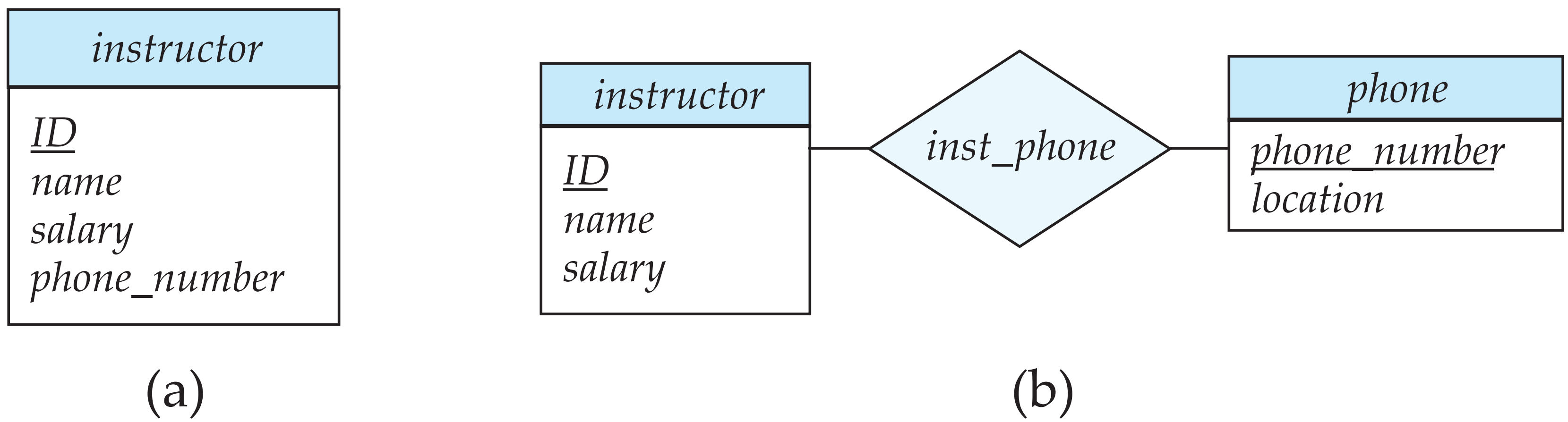

instructor
ID
name
salary
phone_number
(a)
instructor
ID
name
salary
inst_phone
phone
phone_number
location
(b)

Figure 7.18

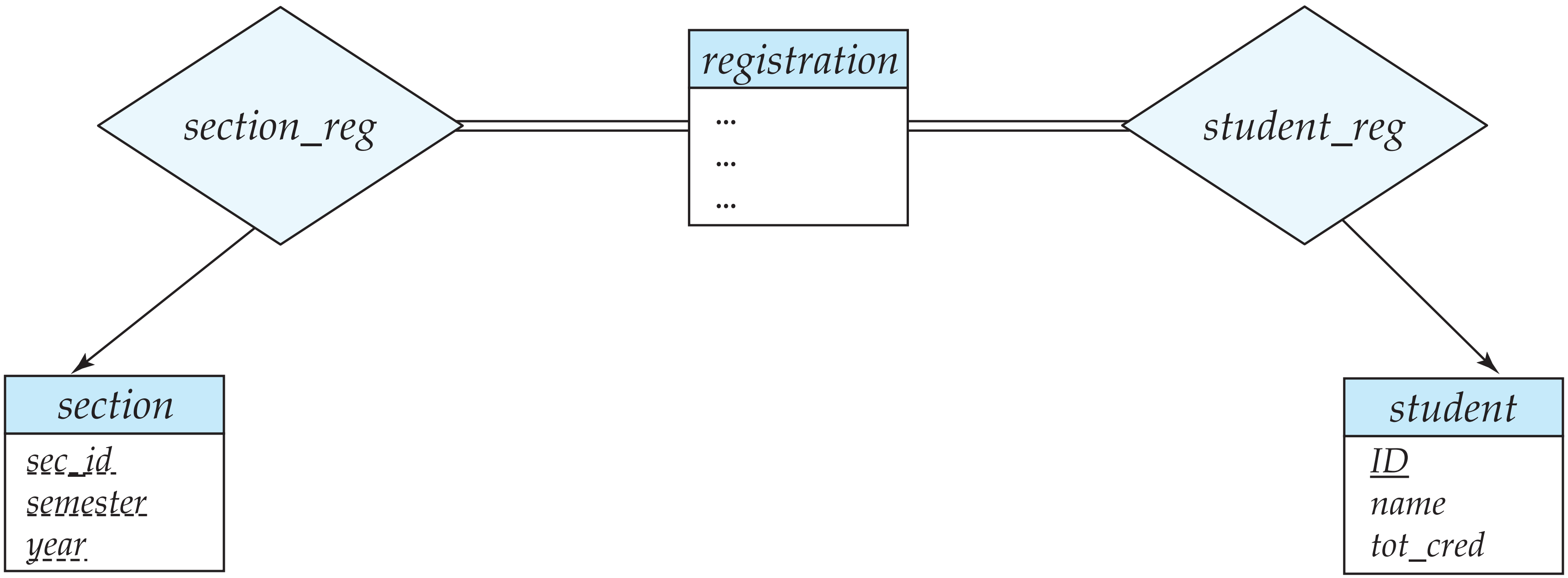

section_reg
registration
...
...
...
student_reg
section
sec_id
semester
year
student
ID
name
tot_cred

Figure 7.19

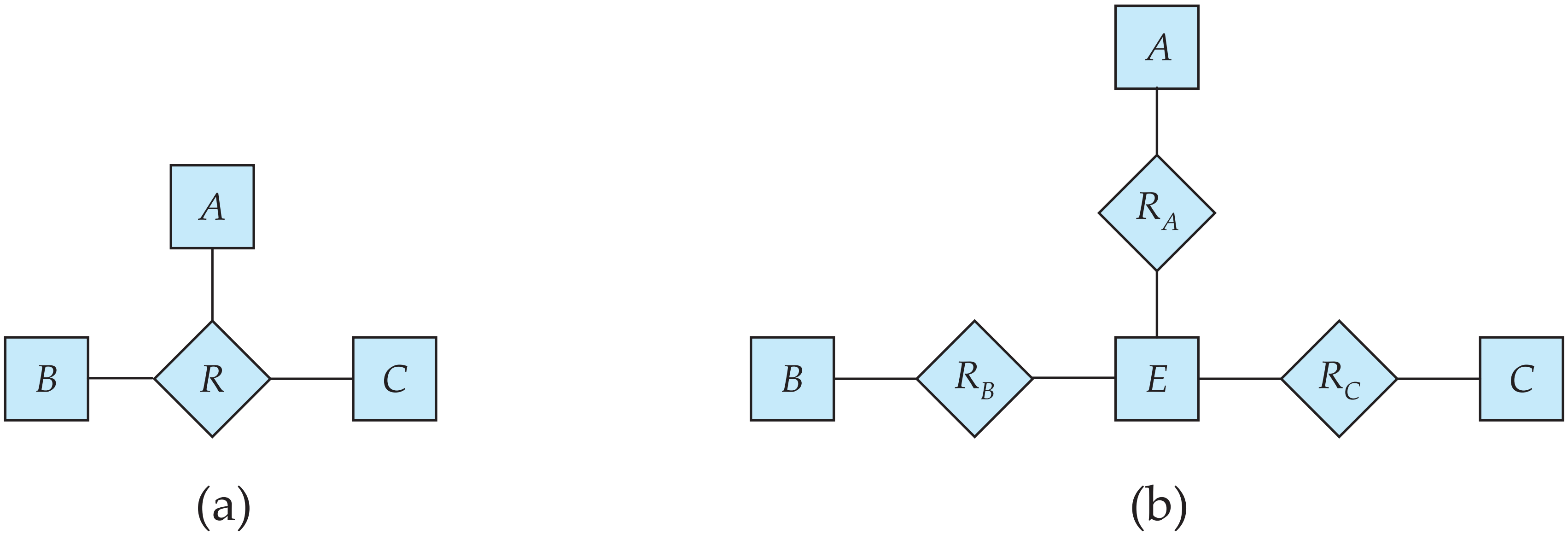
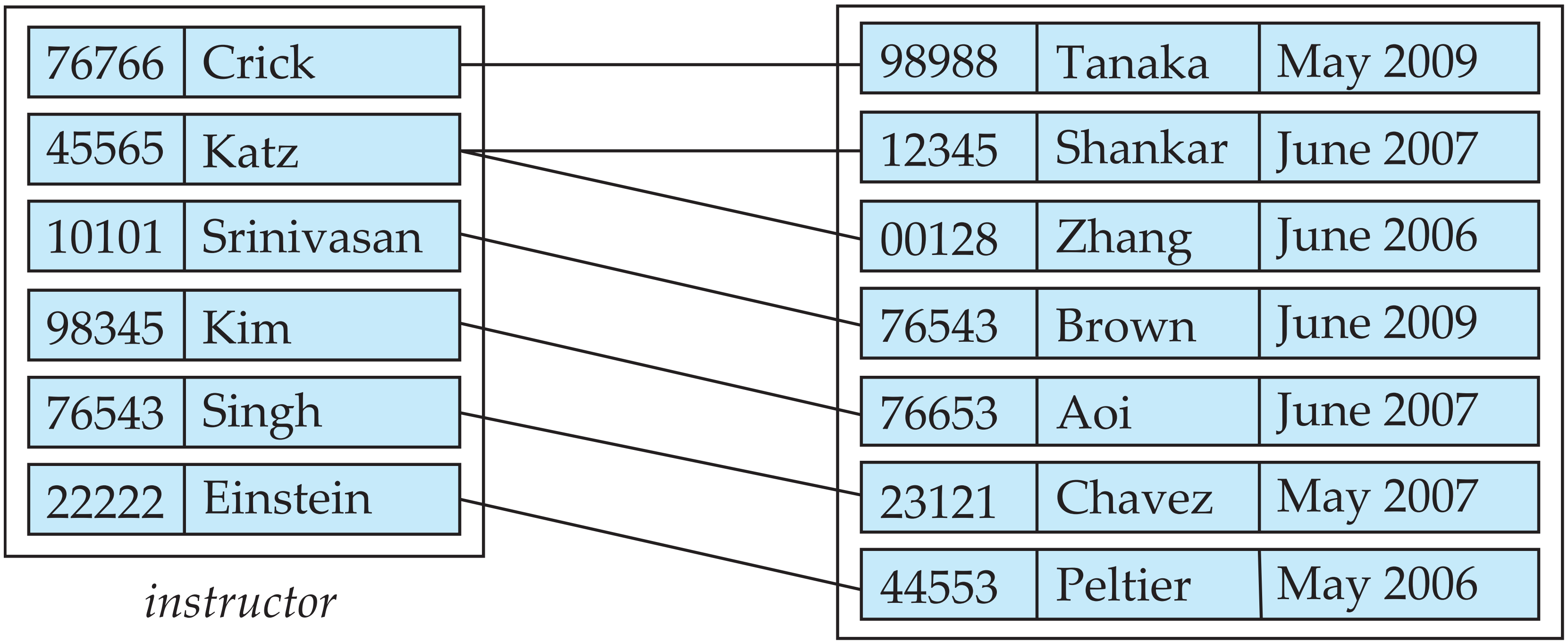


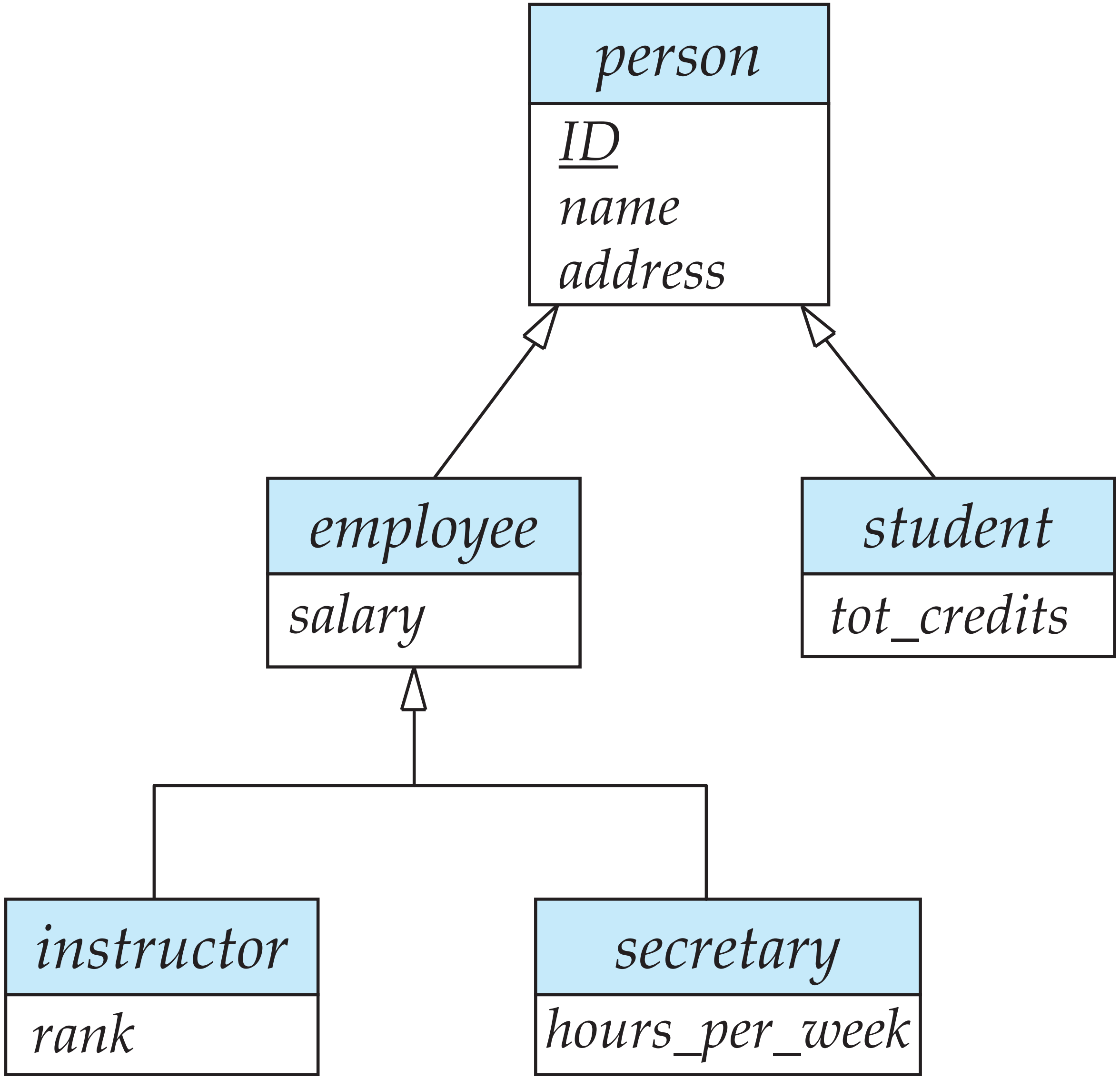
Figure 7.20



instructor

student

Figure 7.21



person
ID
name
address
employee
salary
student
tot_credits
instructor
rank
secretary
hours_per_week

Figure 7.22

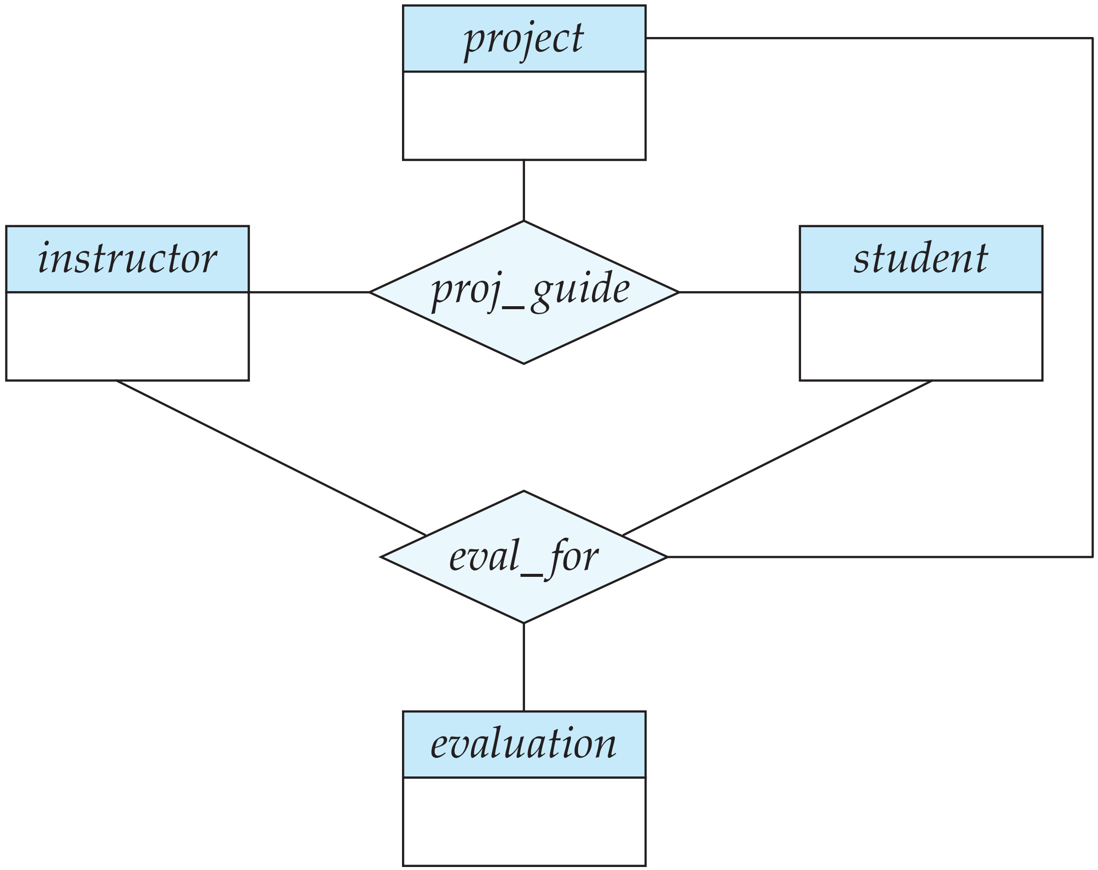

project
instructor
proj_guide
student
eval_for
evaluation

Figure 7.23

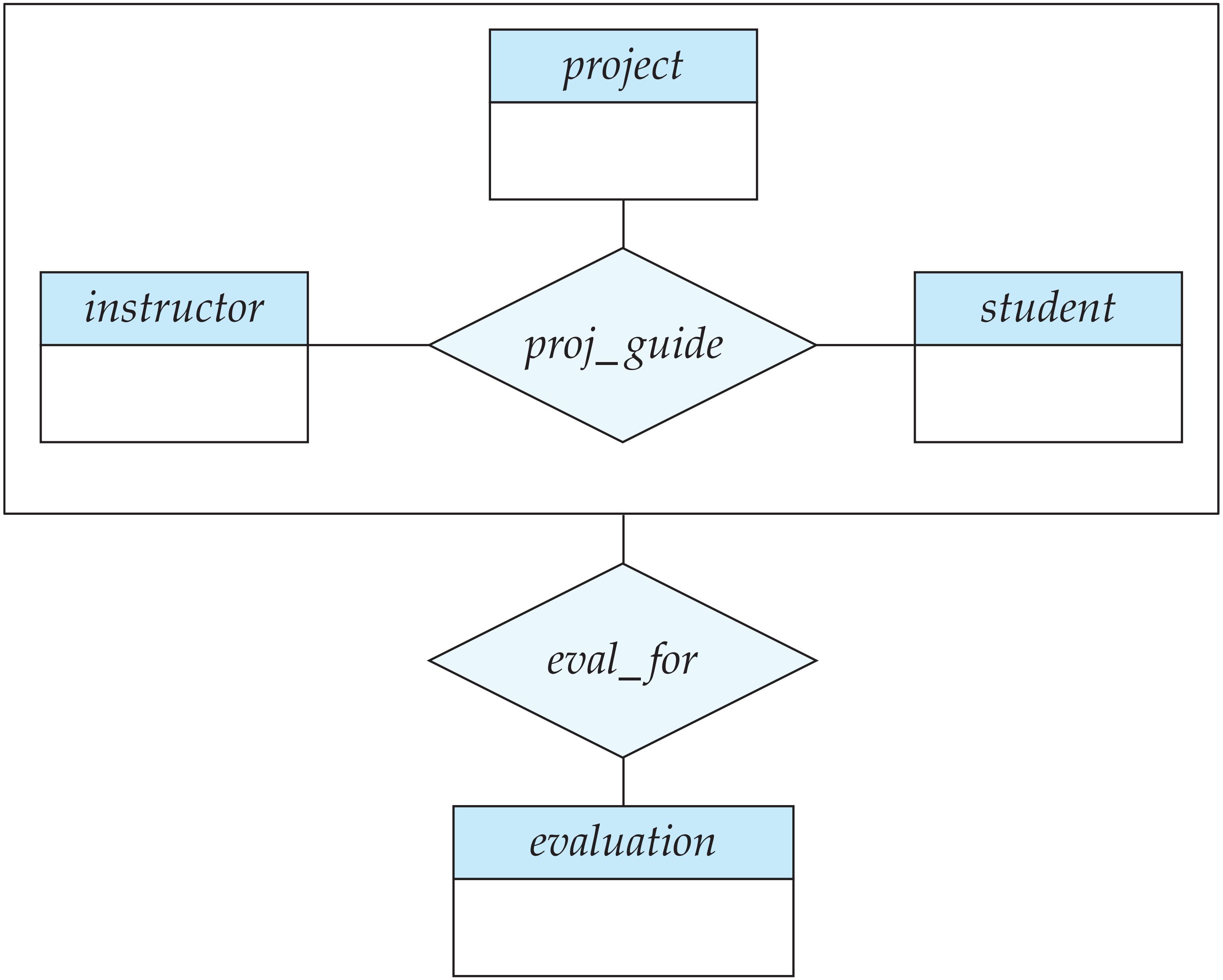

project
instructor
proj_guide
student
eval_for
evaluation

Figure 7.24

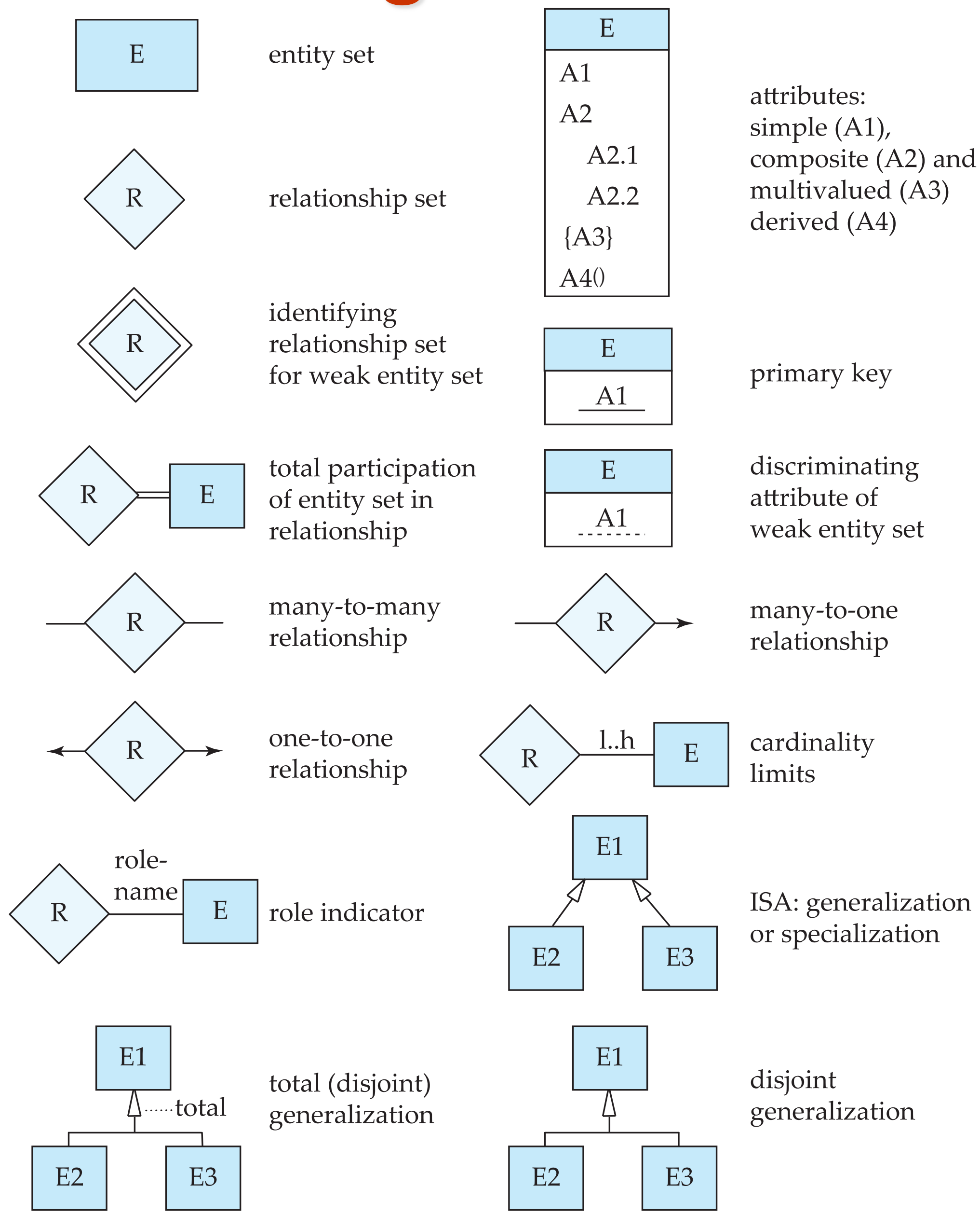

E
entity set
R
relationship set
R
identifying
relationship set
for weak entity set
R
E
total participation
of entity set in
relationship
R
many-to-many
relationship
R
one-to-one
relationship
R
role-
name
E
role indicator
E1
total
E2
E3
total (disjoint)
generalization
E
A1
A2
A2.1
A2.2
{A3}
A4()
attributes:
simple (A1),
composite (A2) and
multivalued (A3)
derived (A4)
E
A1
primary key
E
A1
discriminating
attribute of
weak entity set
R
many-to-one
relationship
R
l..h
E
cardinality
limits
E1
E2
E3
ISA: generalization
or specialization
E1
E2
E3
disjoint
generalization

Figure 7.25

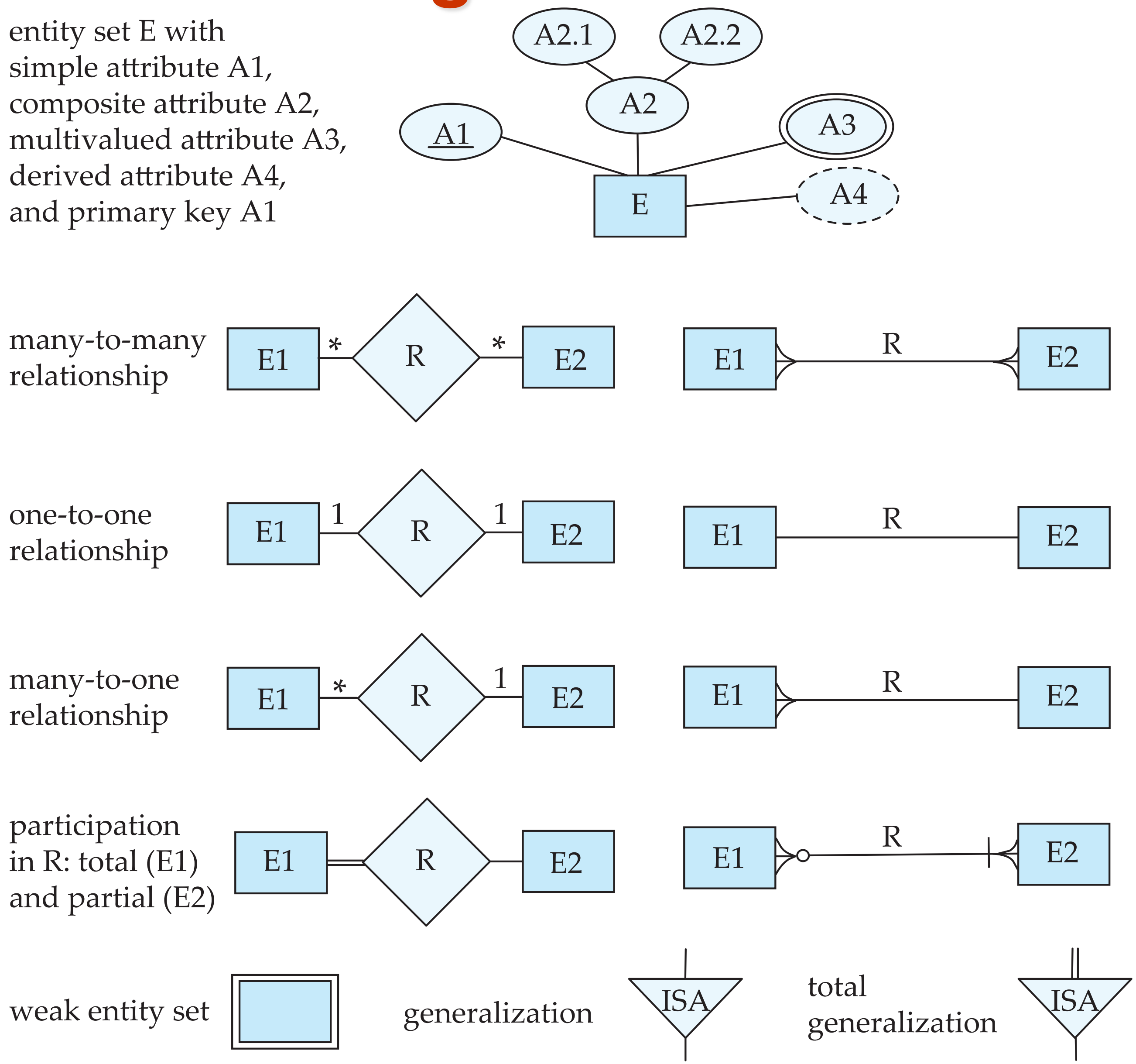
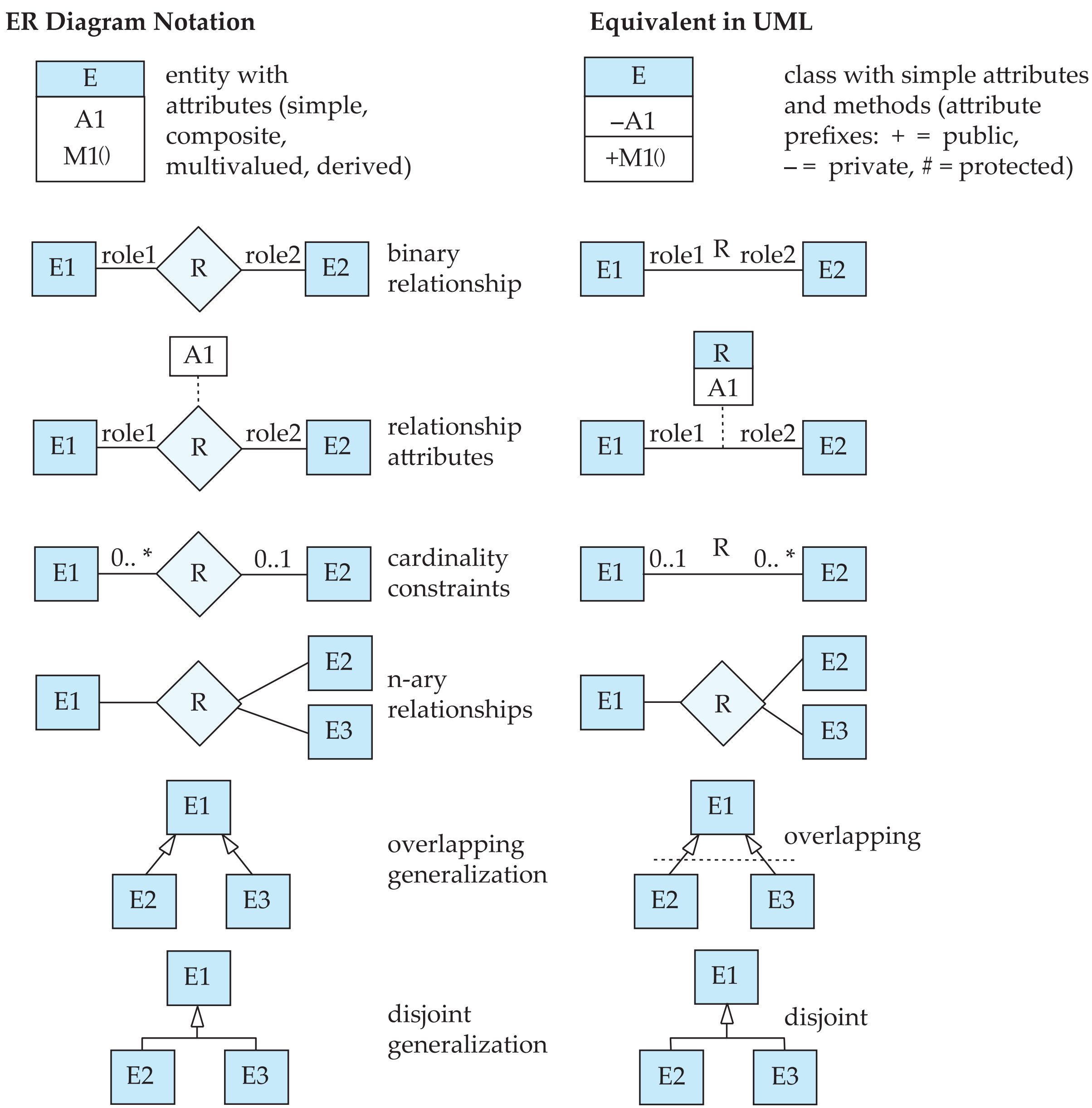

entity set E with
simple attribute A1,
composite attribute A2,
multivalued attribute A3,
derived attribute A4,
and primary key A1
A2.1
A2.2
A2
A1
A3
A4
E
many-to-many
relationship
E1
*
R
*
E2
E1
R
E2
one-to-one
relationship
E1
1
R
1
E2
E1
R
E2
many-to-one
relationship
E1
*
R
1
E2
E1
R
E2
participation
in R: total (E1)
and partial (E2)
E1
R
E2
E1
R
E2
weak entity set
generalization
ISA
total
generalization
ISA

Figure 7.26



ER Diagram Notation
Equivalent in UML
E
A1
M1()
entity with attributes (simple, composite, multivalued, derived)
E
–A1
+M1()
class with simple attributes and methods (attribute prefixes: + = public, – = private, # = protected)
E1
role1
R
role2
E2
binary relationship
E1
role1
R
role2
E2
A1
E1
role1
R
role2
E2
relationship attributes
R
A1
E1
role1
role2
E2
E1
0.. *
R
0..1
E2
cardinality constraints
E1
0..1
R
0.. *
E2
E1
R
E2
E3
n-ary relationships
E1
R
E2
E3
E1
E2
E3
overlapping generalization
E1
E2
E3
overlapping
E1
E2
E3
disjoint generalization
E1
E2
E3
disjoint

Figure 7.27

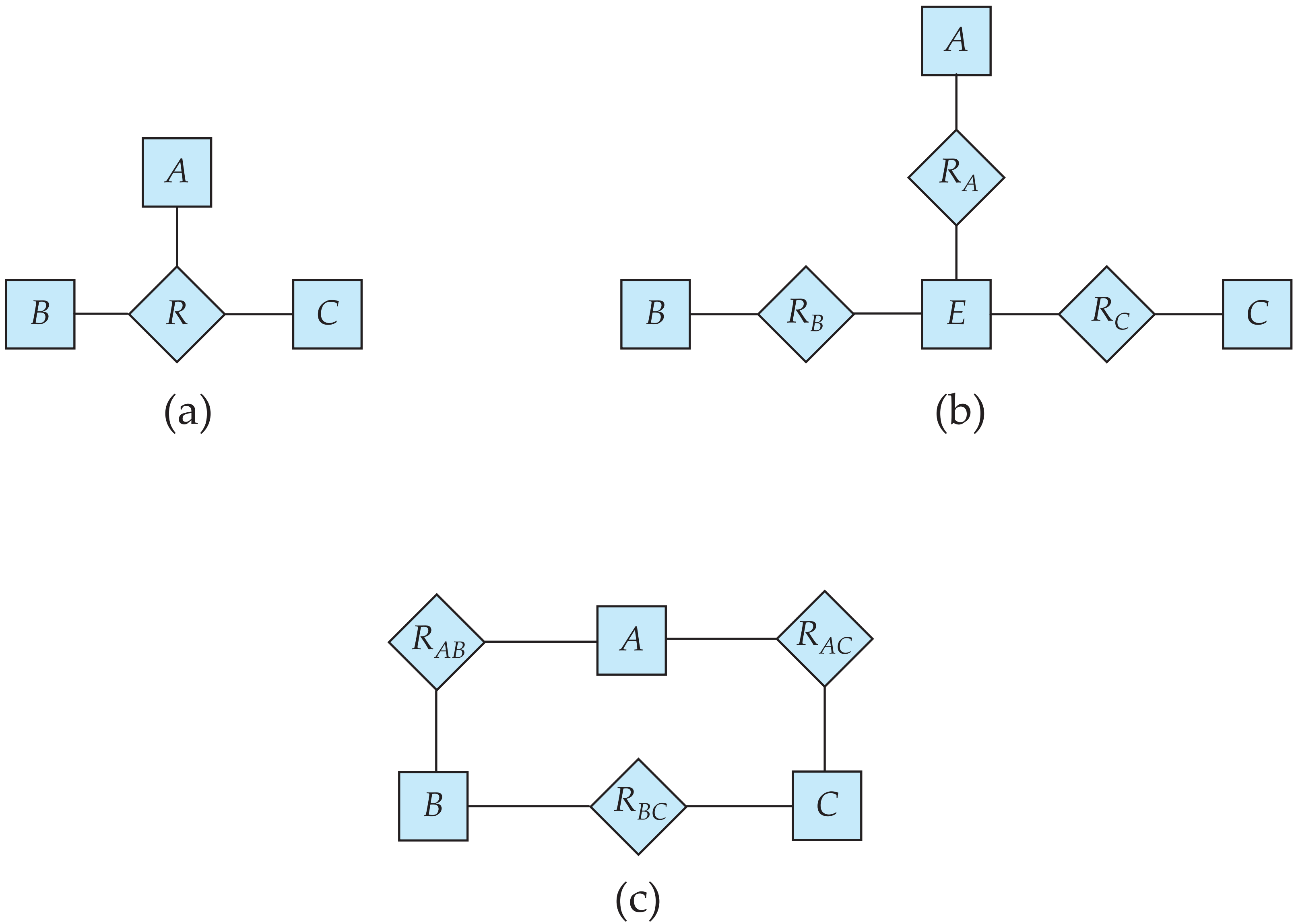


Figure 7.28

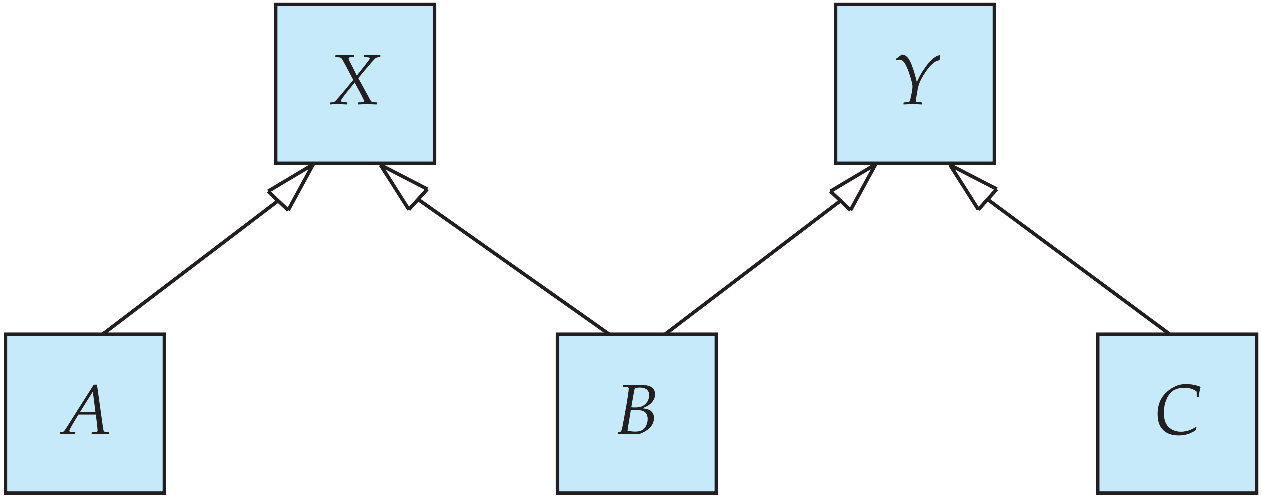
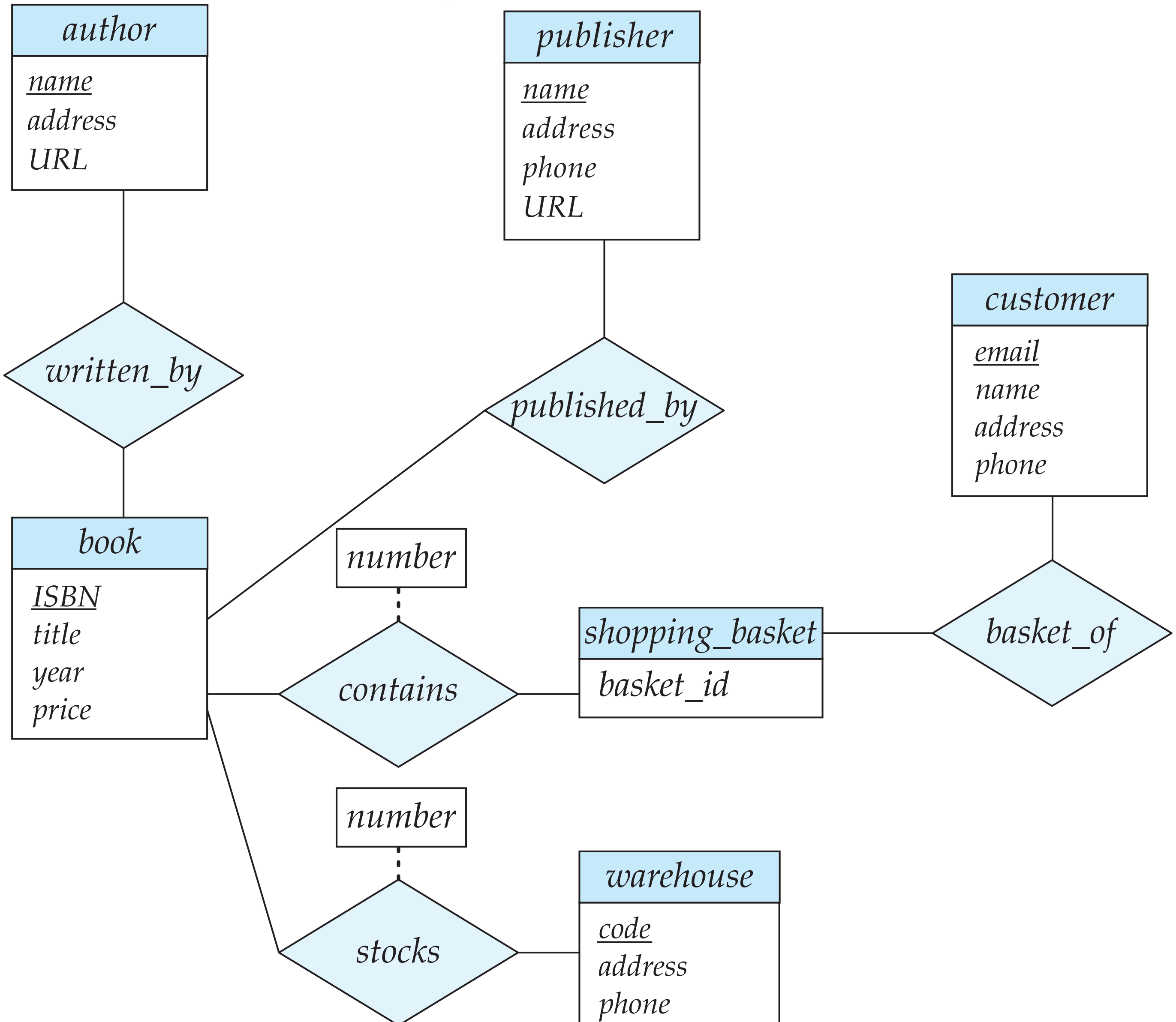


Figure 7.29


author
name
address
URL
publisher
name
address
phone
URL
customer
email
name
address
phone
written_by
published_by
book
ISBN
title
year
price
number
contains
shopping_basket
basket_id
basket_of
number
stocks
warehouse
code
address
phone