Chapter 7: Entity-Relationship Model

- 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

Design Phases

- The initial phase of database design is to characterize fully the data needs of the prospective database users.
- Next, the designer chooses a data model and, by applying the concepts of the chosen data model, translates these requirements into a conceptual schema of the database.
- A fully developed conceptual schema also indicates the functional requirements of the enterprise. In a "specification of functional requirements", users describe the kinds of operations (or transactions) that will be performed on the data.

Design Phases (Cont.)

The process of moving from an abstract data model to the implementation of the database proceeds in two final design phases.

- 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

Design Approaches

- Entity Relationship Model (covered in this chapter)
  - Models an enterprise as a collection of *entities* and *relationships*
    - Entity: a “thing” or “object” in the enterprise that is distinguishable from other objects
      - Described by a set of *attributes*
    - Relationship: an association among several entities
  - Represented diagrammatically by an *entity-relationship diagram:*
- Normalization Theory (Chapter 8)
  - Formalize what designs are bad, and test for them

Outline of the ER Model

ER model -- Database Modeling

- The ER data mode was developed to facilitate database design by allowing specification of an enterprise schema that represents the overall logical structure of a database.
- The ER model is very useful in mapping the meanings and interactions of real-world enterprises onto a conceptual schema. Because of this usefulness, many database-design tools draw on concepts from the ER model.

- The ER data model employs three basic concepts:
  - entity sets,
  - relationship sets,
  - attributes.
- The ER model also has an associated diagrammatic representation, the ER diagram, which can express the overall logical structure of a database graphically.

Entity Sets

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

    instructor = (*ID, name, street, city, salary*)
    course= (*course_id, title, credits*)
- A subset of the attributes form a primary key of the entity set; i.e., uniquely identifiying each member of the set.

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

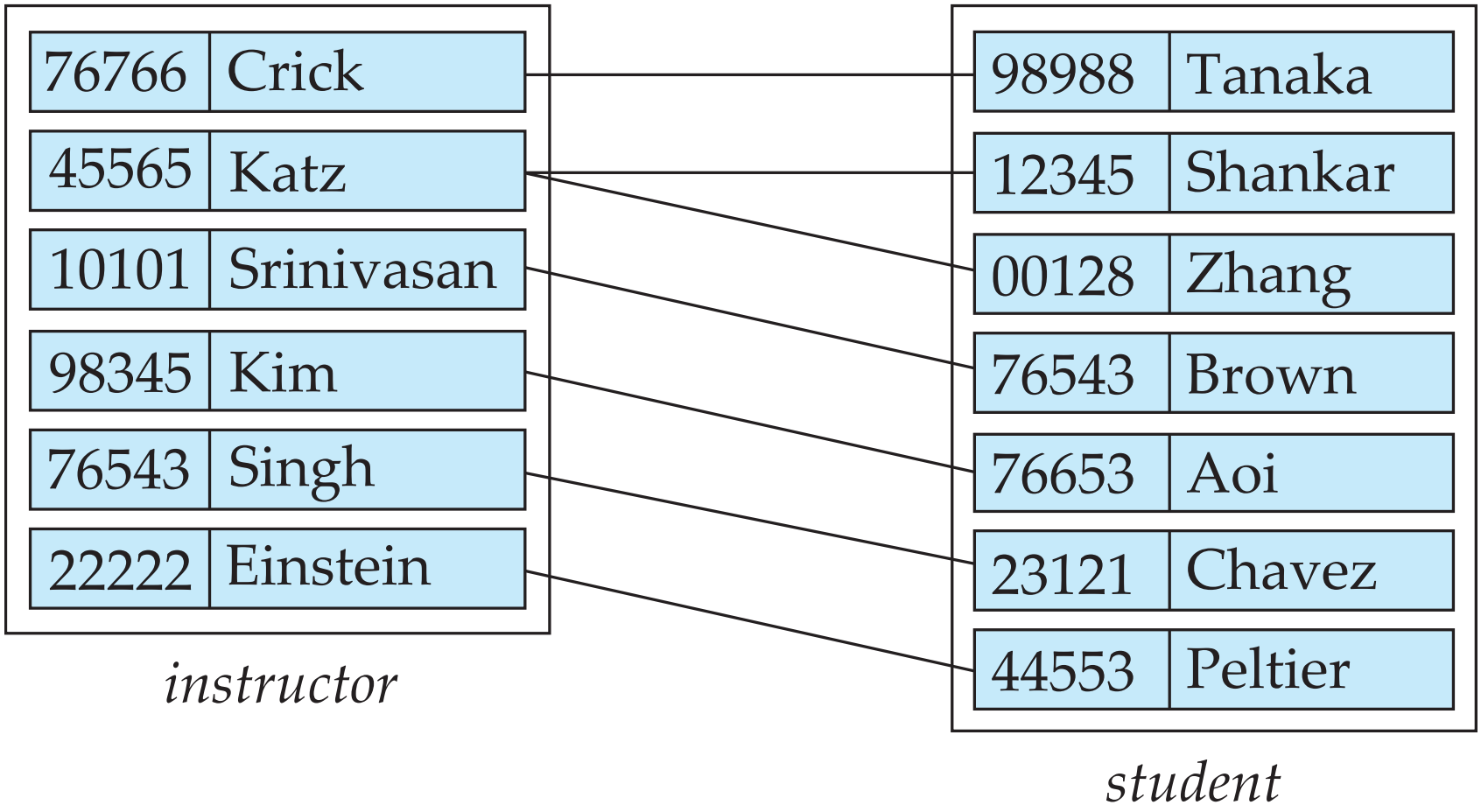
$$\{(e_1, e_2, \ldots e_n) \mid e_1 \in E_1, e_2 \in E_2, \ldots, e_n \in E_n\}$$

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

  - Example:

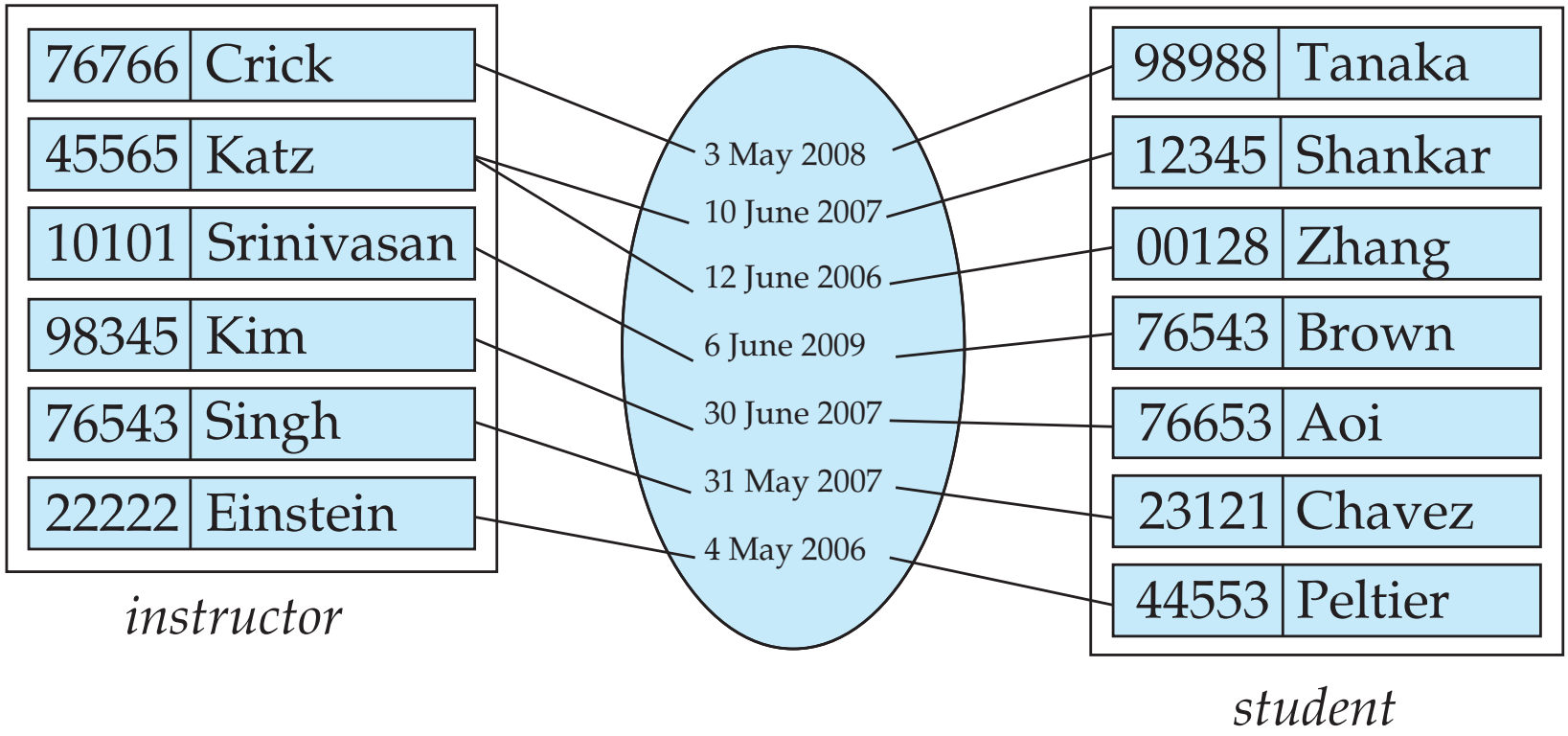
$$(44553,22222) \in advisor$$

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

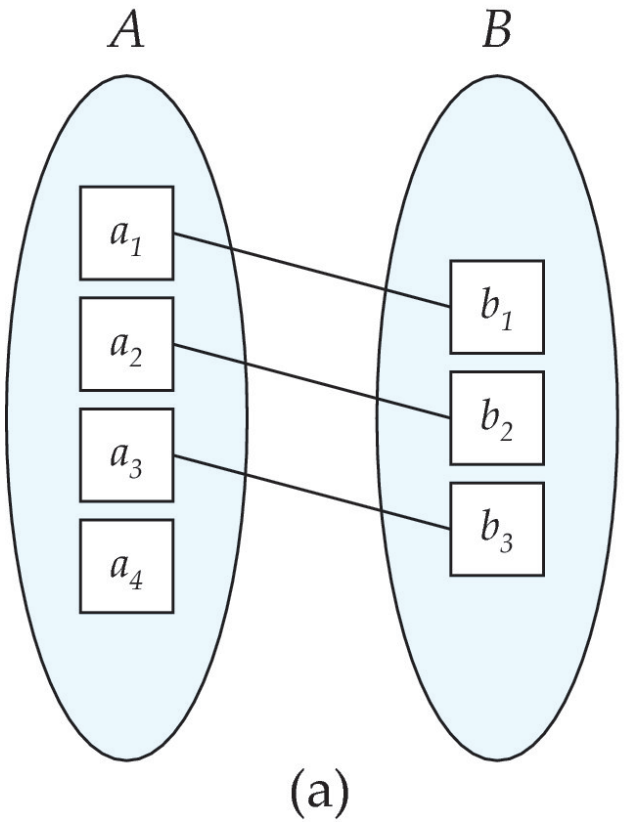
- **binary relationship**
  - involve two entity sets (or degree two).
  - most relationship sets in a database system are binary.

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

Mapping Cardinality Constraints

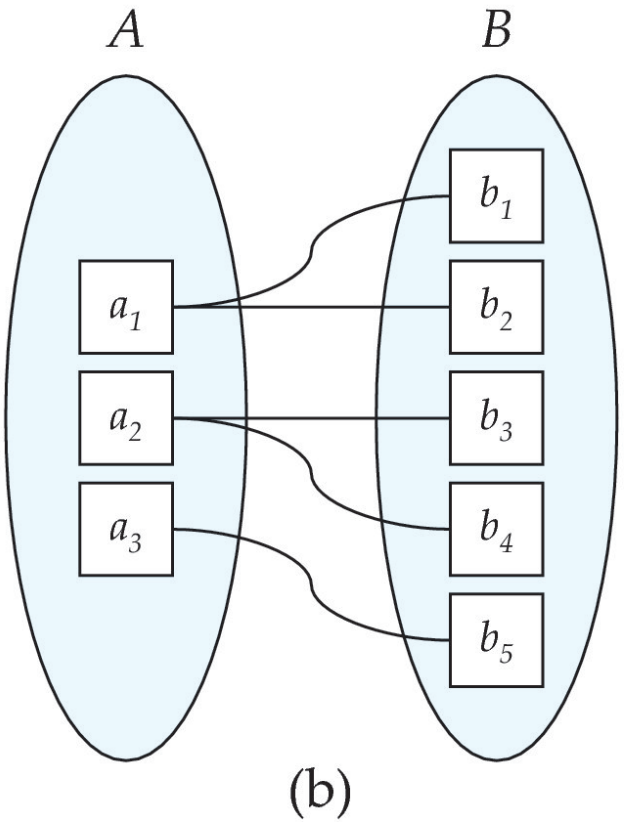
- Express the number of entities to which another entity can be associated via a relationship set.
- Most useful in describing binary relationship sets.
- For a binary relationship set the mapping cardinality must be one of the following types:
  - One to one
  - One to many
  - Many to one
  - Many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

Mapping Cardinalities



(a)

One to one



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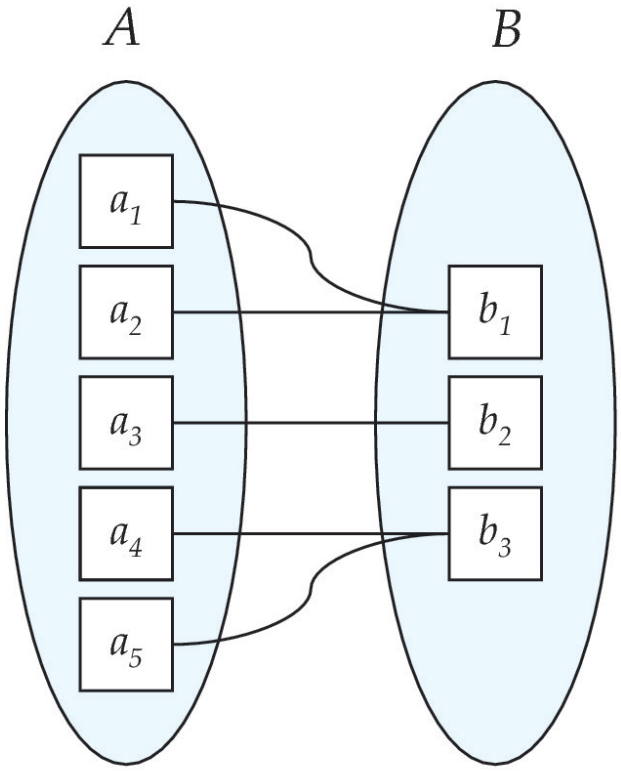
One to many

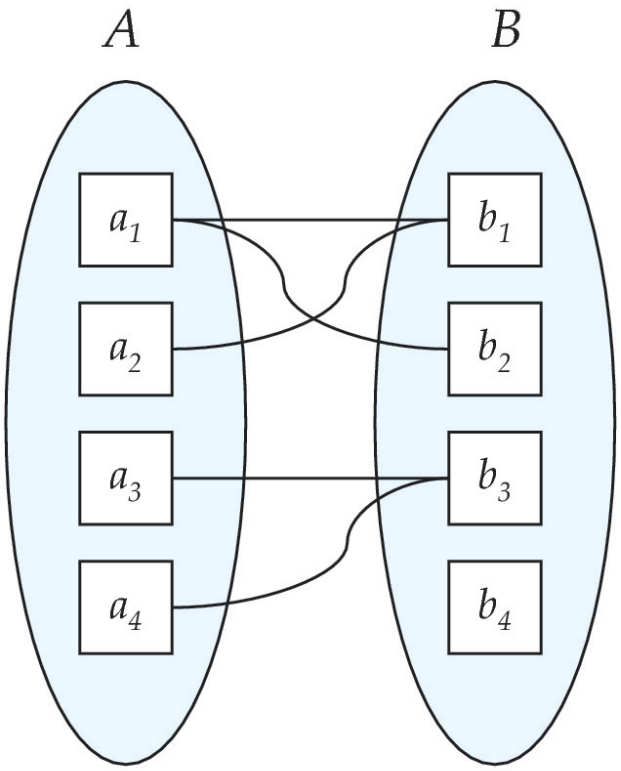
Note: Some elements in *A* and *B* may not be mapped to any elements in the other set

Mapping Cardinalities



(a)

Many to one



(b)

Many to many

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

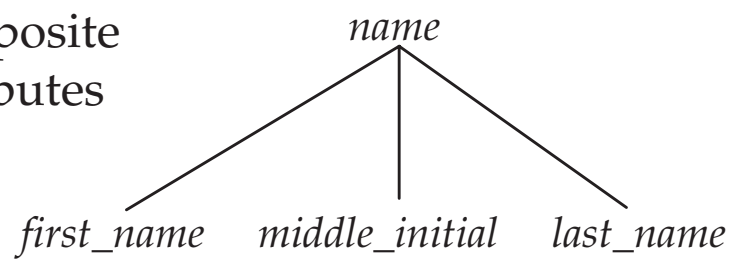
Attributes

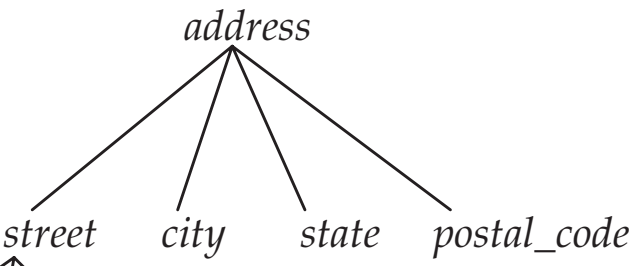
- An entity is represented by a set of attributes, that is descriptive properties possessed by all members of an entity set.
  - Example:

    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

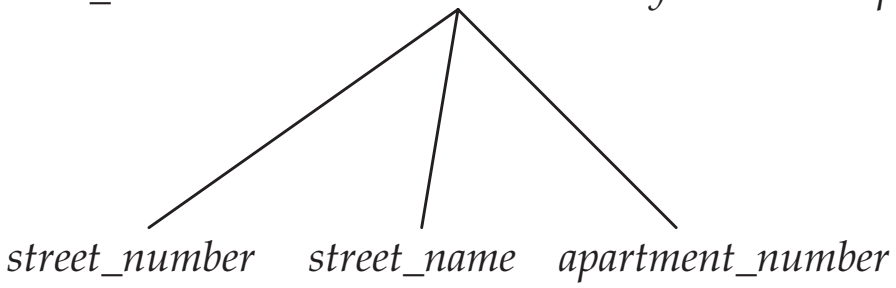
Composite Attributes

composite attributes





component attributes



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**.

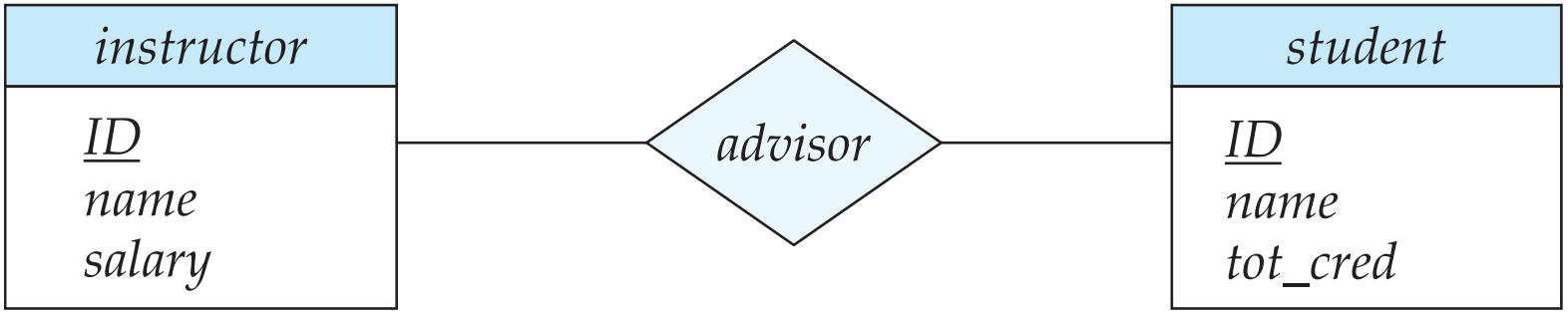
Weak Entity Sets

- 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.
- 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.

Keys for Relationship Sets

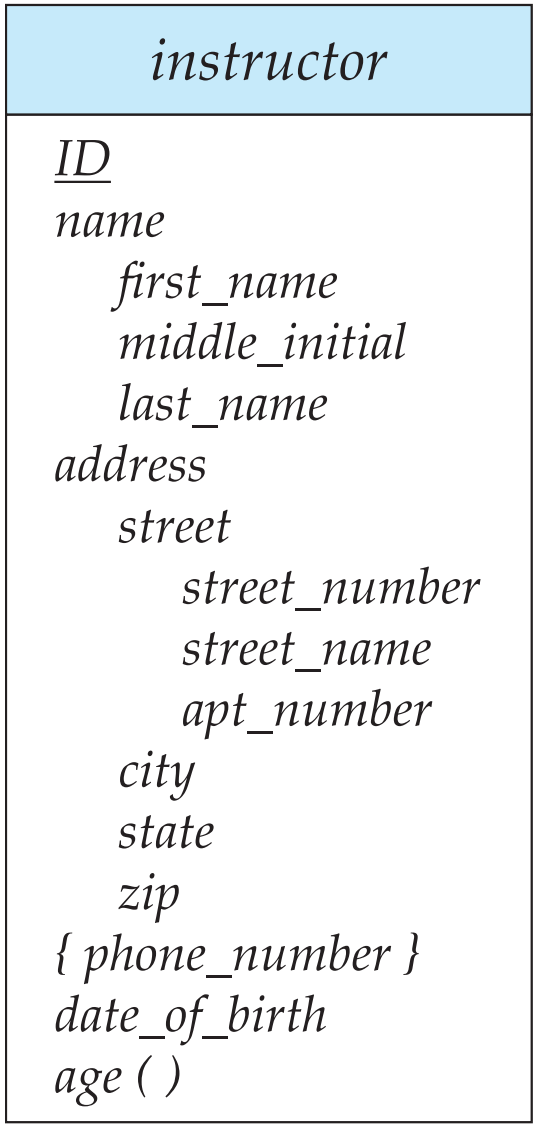
- The combination of primary keys of the participating entity sets forms a super key of a relationship set.
  - (*s_id, i_id*) is the super key of *advisor*
  - *NOTE: this means* ***a pair of entity sets can have at most one relationship in a particular relationship set.***
    - Example: if we wish 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
- 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

E-R Diagrams

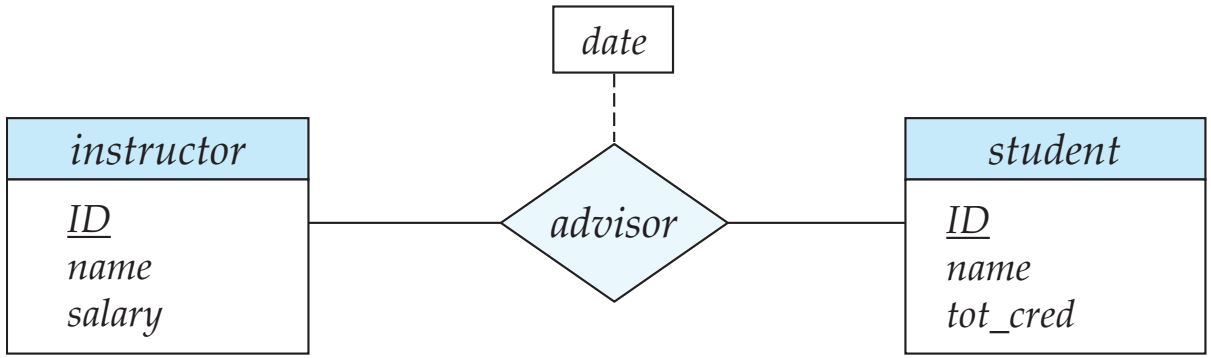


- Rectangles represent entity sets.
- Diamonds represent relationship sets.
- Attributes listed inside entity rectangle
- Underline indicates primary key attributes

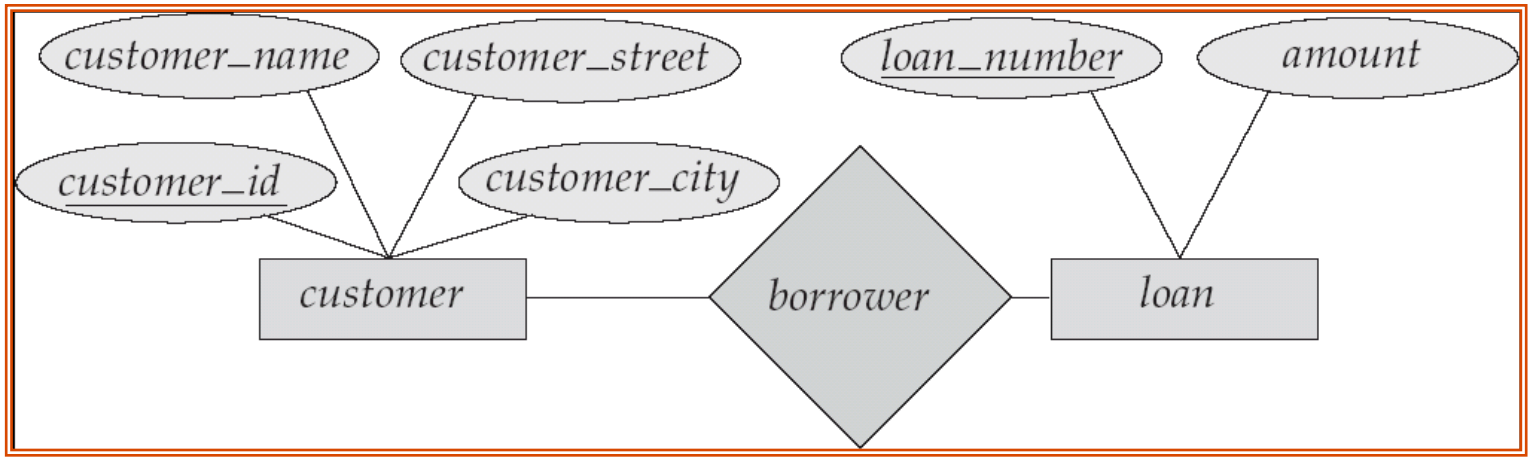
Entity With Composite, Multivalued, and Derived Attributes



Relationship Sets with Attributes



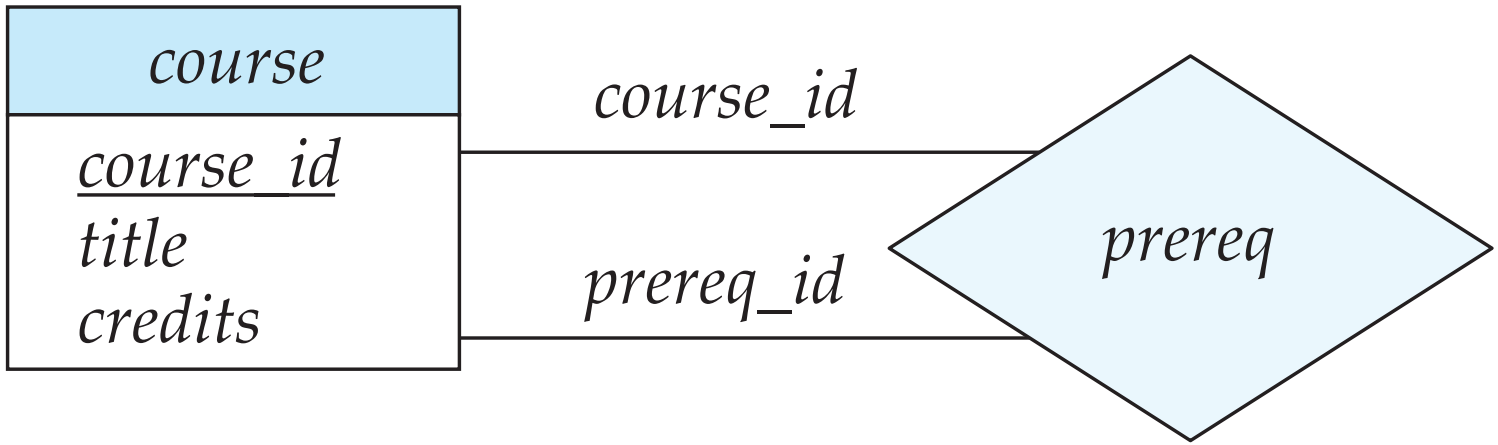
Alternative Notation: E-R Diagrams



- Used in previous edition of the book
- Same thing otherwise

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 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

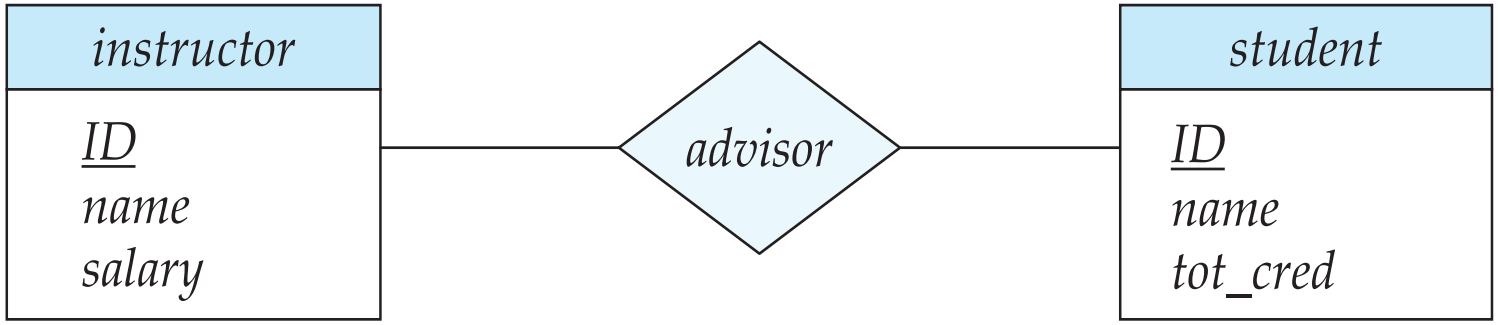
- one-to-many relationship between an *instructor* and a *student*
  - an instructor is associated with several (including 0) students via *advisor*
  - a student is associated with at most one instructor via advisor,

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*

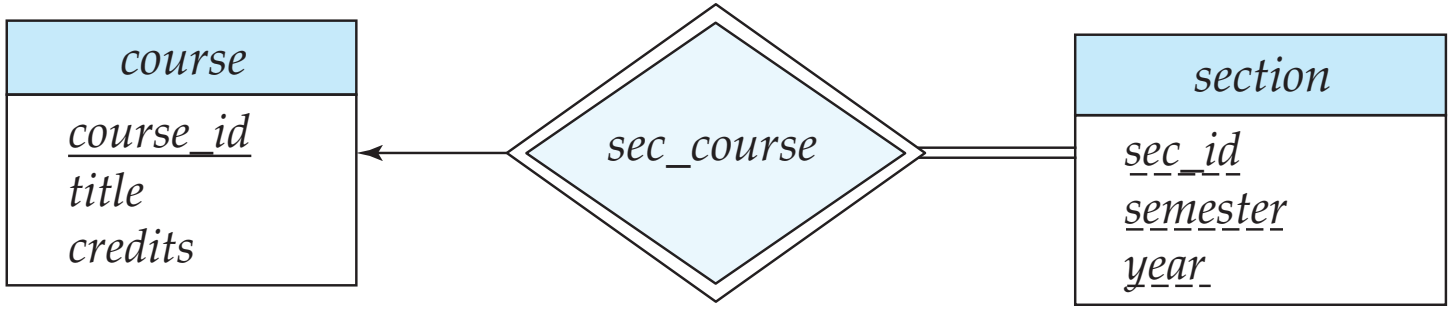
Many-to-Many Relationship

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



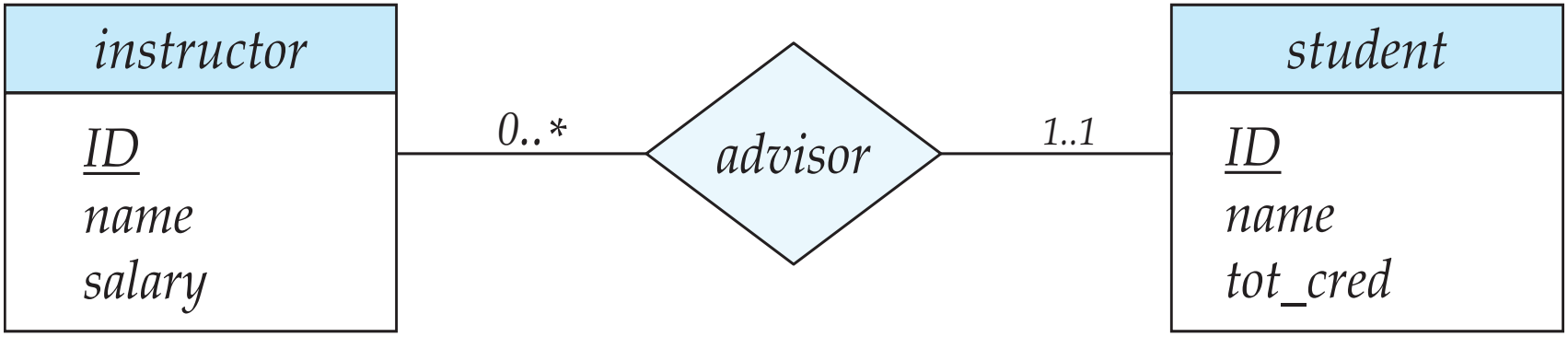
Participation of an Entity Set in a Relationship Set

- 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
- Note: double box means *weak entity* – more about that later
- Partial participation: some entities may not participate in any relationship in the relationship set
  - Example: participation of *instructor* in *advisor* is partial

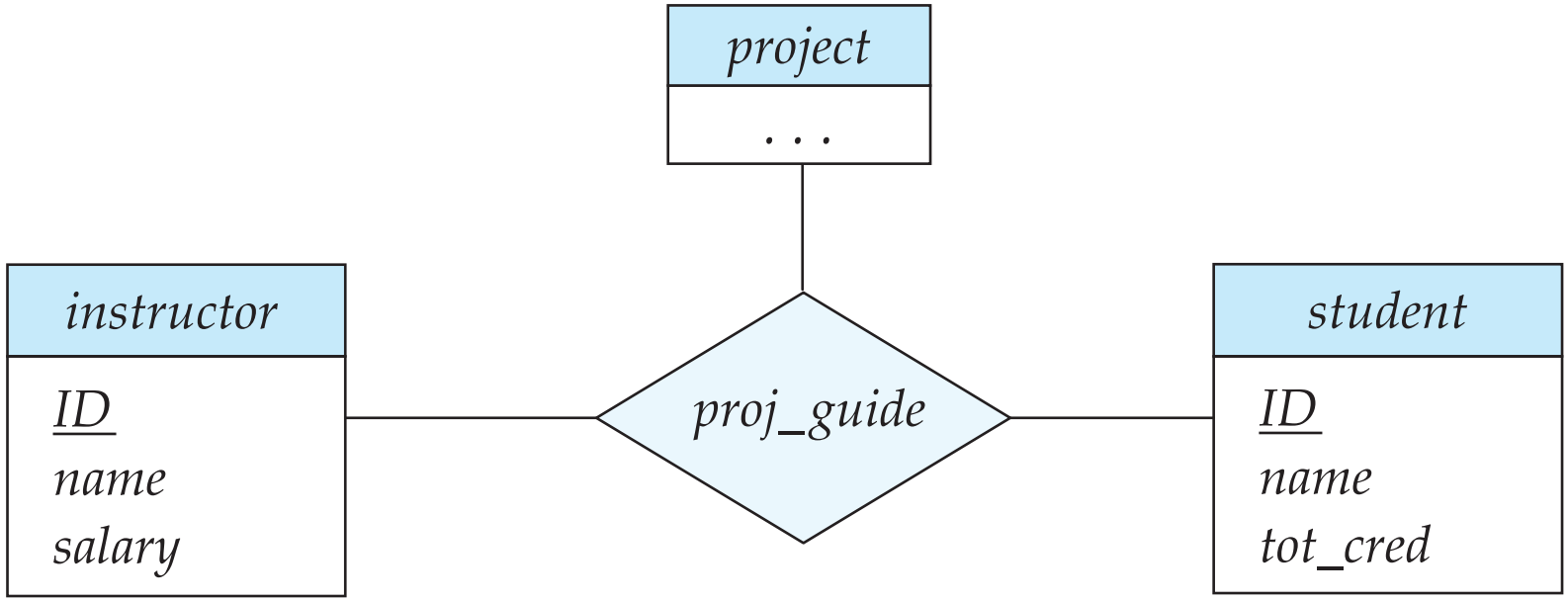


Alternative Notation for Cardinality Limits

- Cardinality limits can also express participation constraints



E-R Diagram with a Ternary Relationship



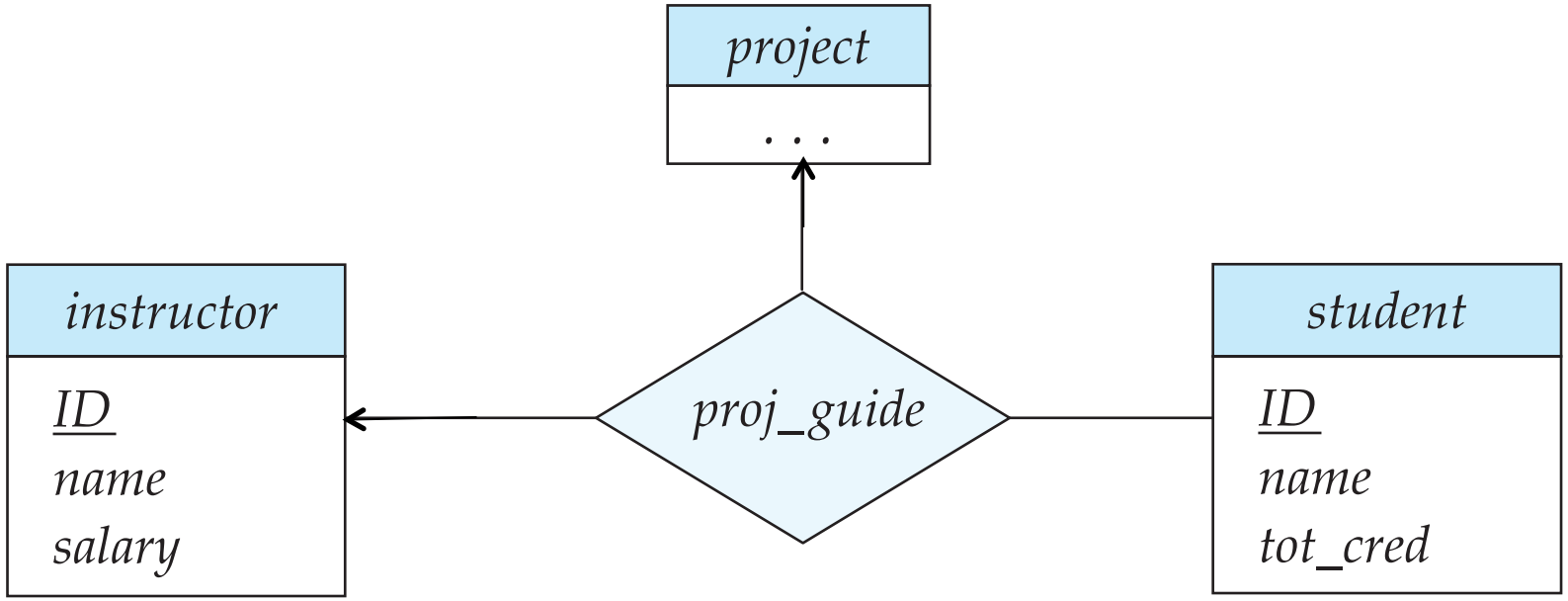
Cardinality Constraints on Ternary Relationship

- 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

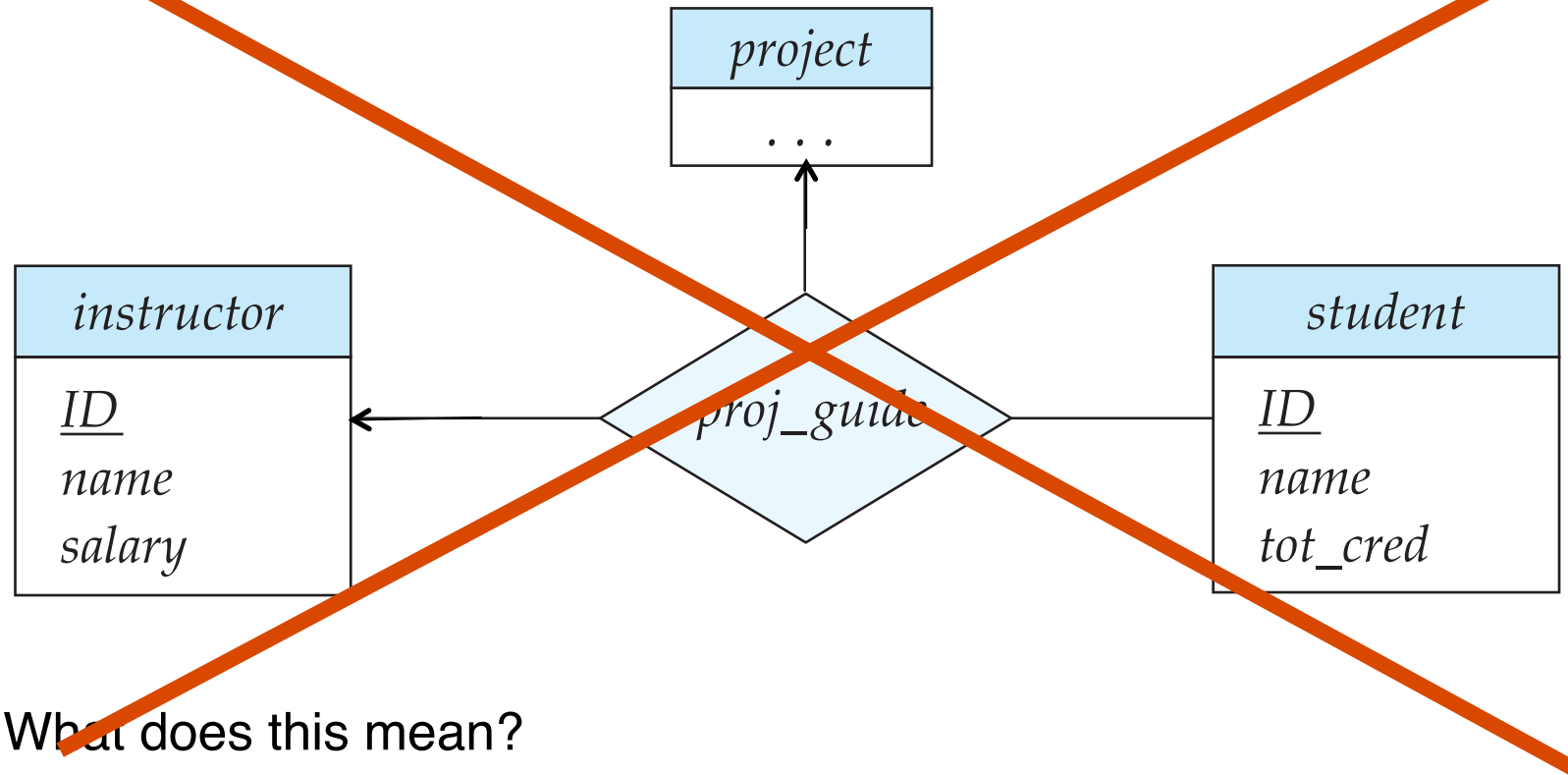
    2. each pair of entities from (*A, B*) is associated with a unique *C* entity, and each pair (*A, C*) is associated with a unique *B*
  - Each alternative has been used in different formalisms
  - To avoid confusion we outlaw more than one arrow

E-R Diagram with a Ternary Relationship



- What does this mean?
  - A student can have only one project, and only one instructor?
  - For each student and project, there can be only one instructor, and for each student and instructor, there can be only one project?

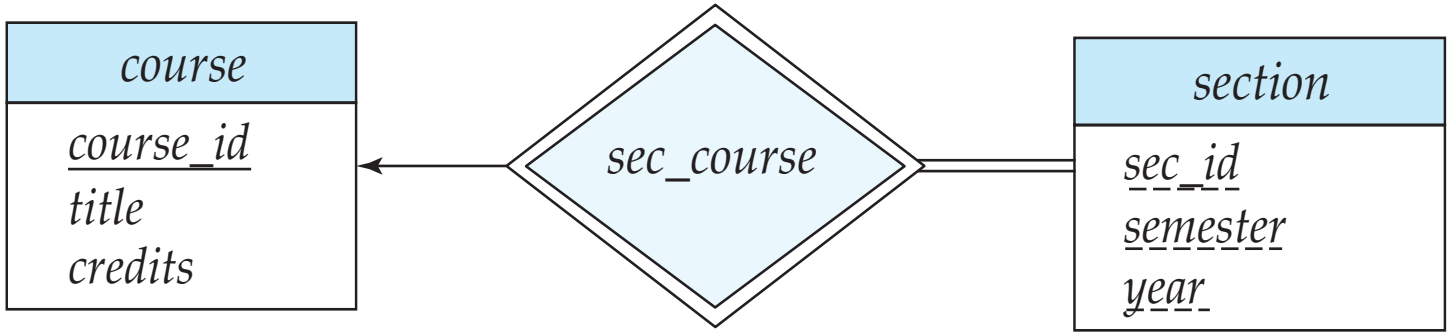
E-R Diagram with a Ternary Relationship



- What does this mean?
  - A student can have only one project, and only one instructor?
  - For each student and project, there can be only one instructor, and for each student and instructor, there can be only one project?

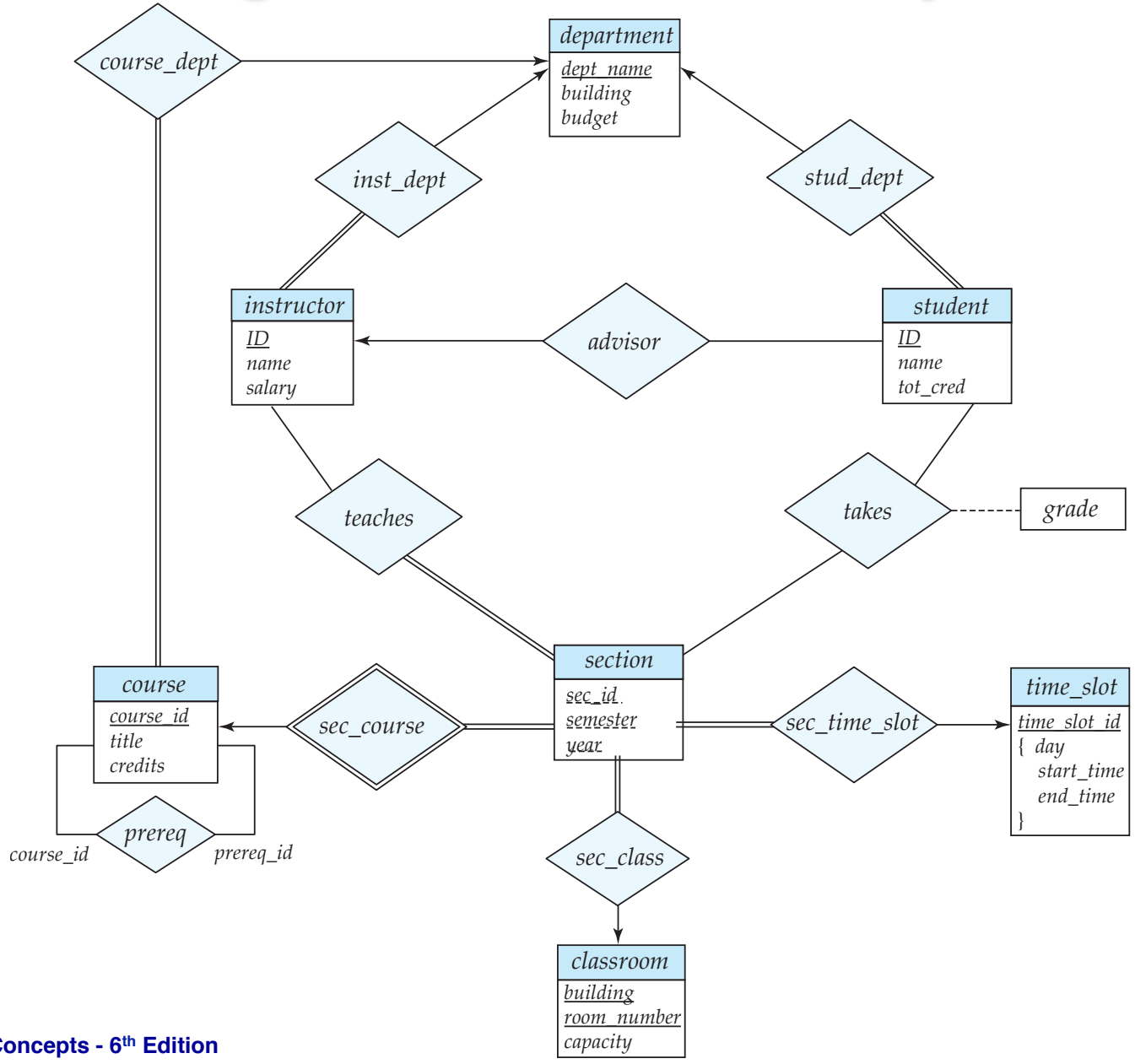
Weak Entity Sets (Cont.)

- 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*)



- 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

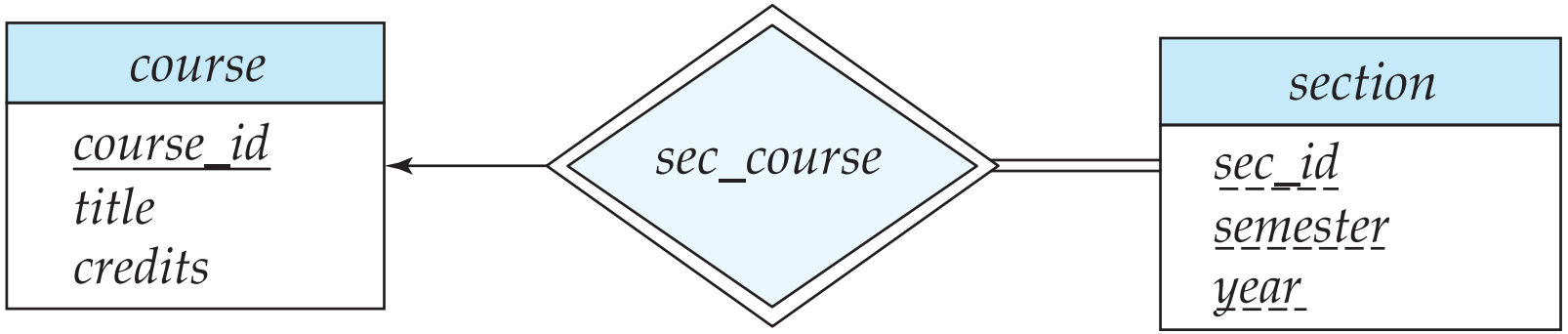


Reduction to Relation Schemas

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

Representing Entity Sets With Simple Attributes

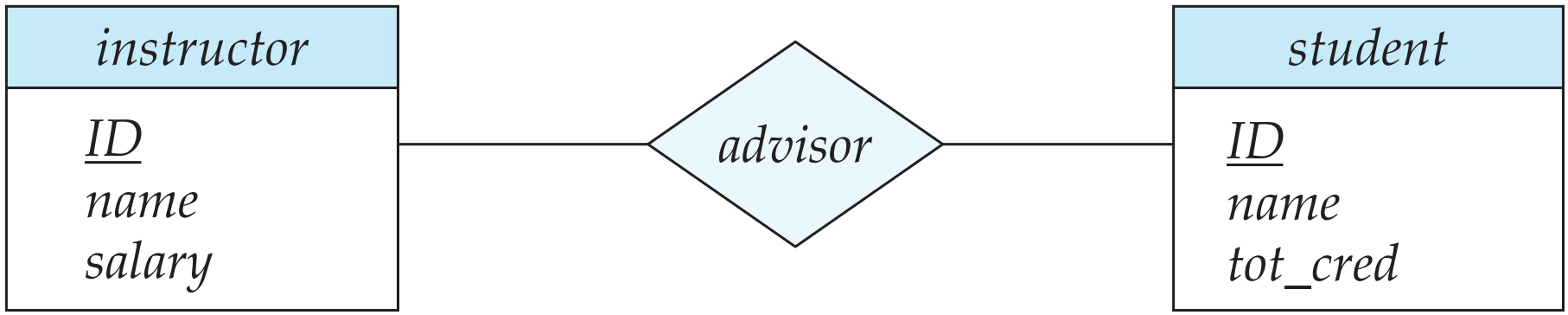
- A strong entity set reduces to a schema with the same attributes
  student(ID, name, tot_cred)
- A weak entity set becomes a table that includes a column for the primary key of the identifying strong entity set
  section (course_id, sec_id, sem, year)



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*)



Composite and Multivalued 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 ( )

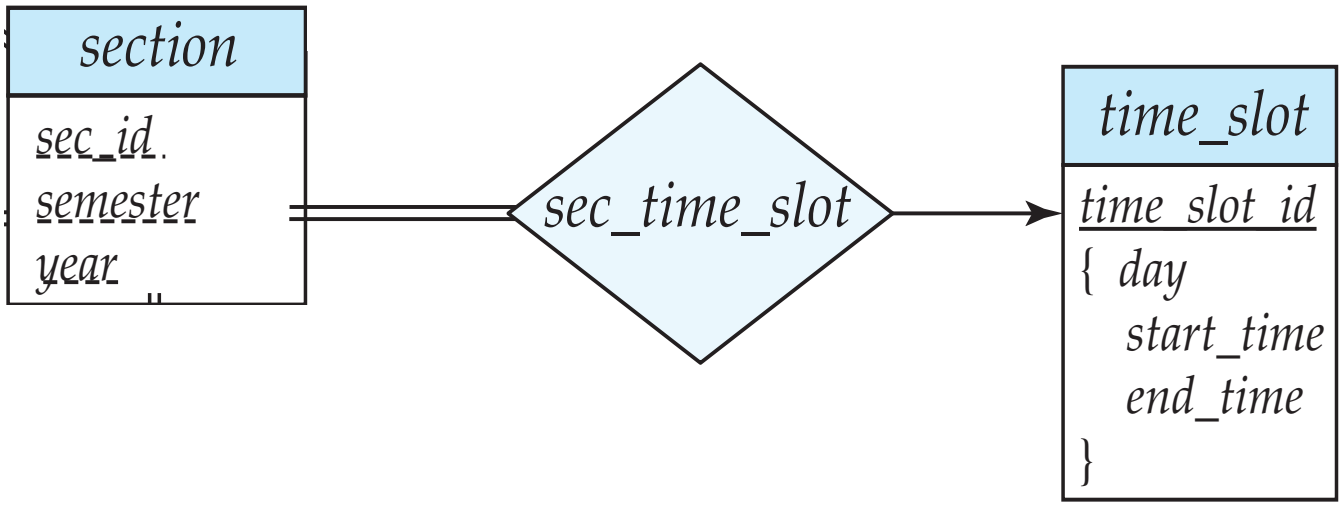
- Composite attributes are flattened out by creating a separate attribute for each component attribute
  - Example: given entity set *instructor* with composite attribute *name* with component attributes *first_name* and *last_name* the schema corresponding to the entity set has two attributes *name_first_name* 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= (*ID*, *phone_number*)
  - Each value of the multivalued attribute maps to a separate tuple of the relation on schema *EM*
    - For example, an *instructor* entity with primary key 22222 and phone numbers 456-7890 and 123-4567 maps to two tuples:
      (22222, 456-7890) and (22222, 123-4567)

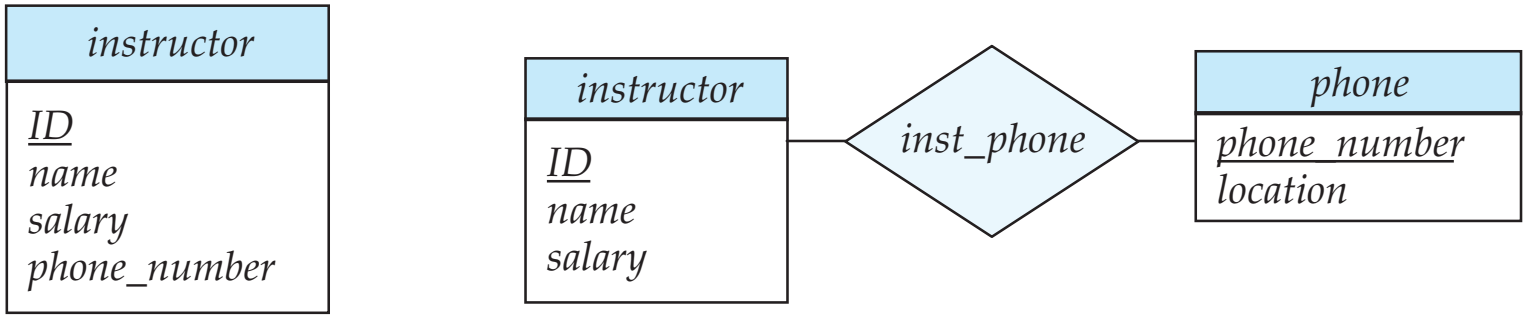
Multivalued Attributes (Cont.)

- 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*(*time_slot_id, day, start_time*, *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**

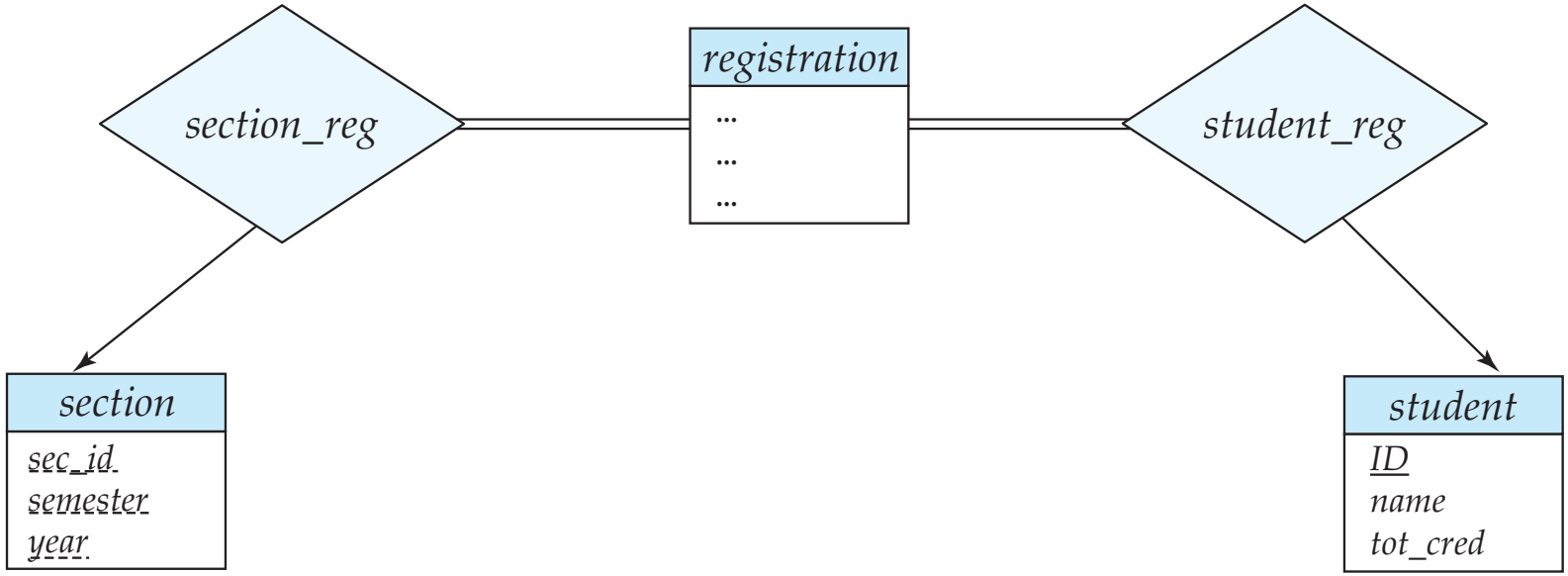


- Use of phone as an entity allows extra information about phone numbers (plus multiple phone numbers)

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

  Unless that action can happen multiple times between same entities!



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, a n-ary relationship set shows more clearly that several entities participate in a single relationship.

- **Placement of relationship attributes**

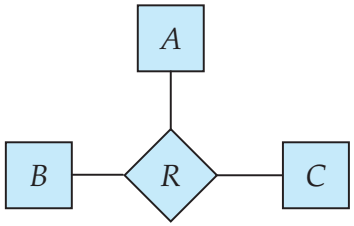
  e.g., attribute *date* as attribute of *advisor* or as attribute of *student*

Binary Vs. Non-Binary Relationships

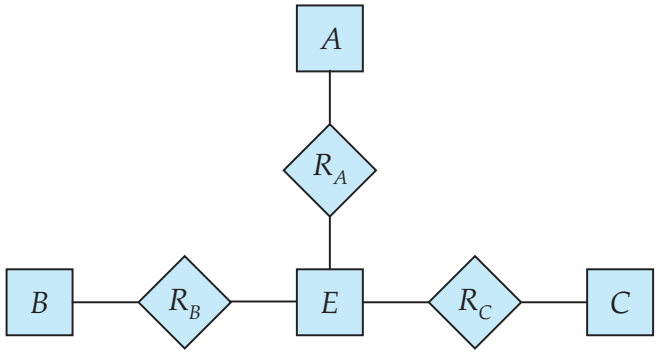
- Some relationships that appear to be non-binary may be better represented using binary relationships
  - E.g., A ternary relationship *parents*, relating a child to his/her father and mother, is best replaced by two binary relationships, *father* and *mother*
    - Using two binary relationships allows 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.)

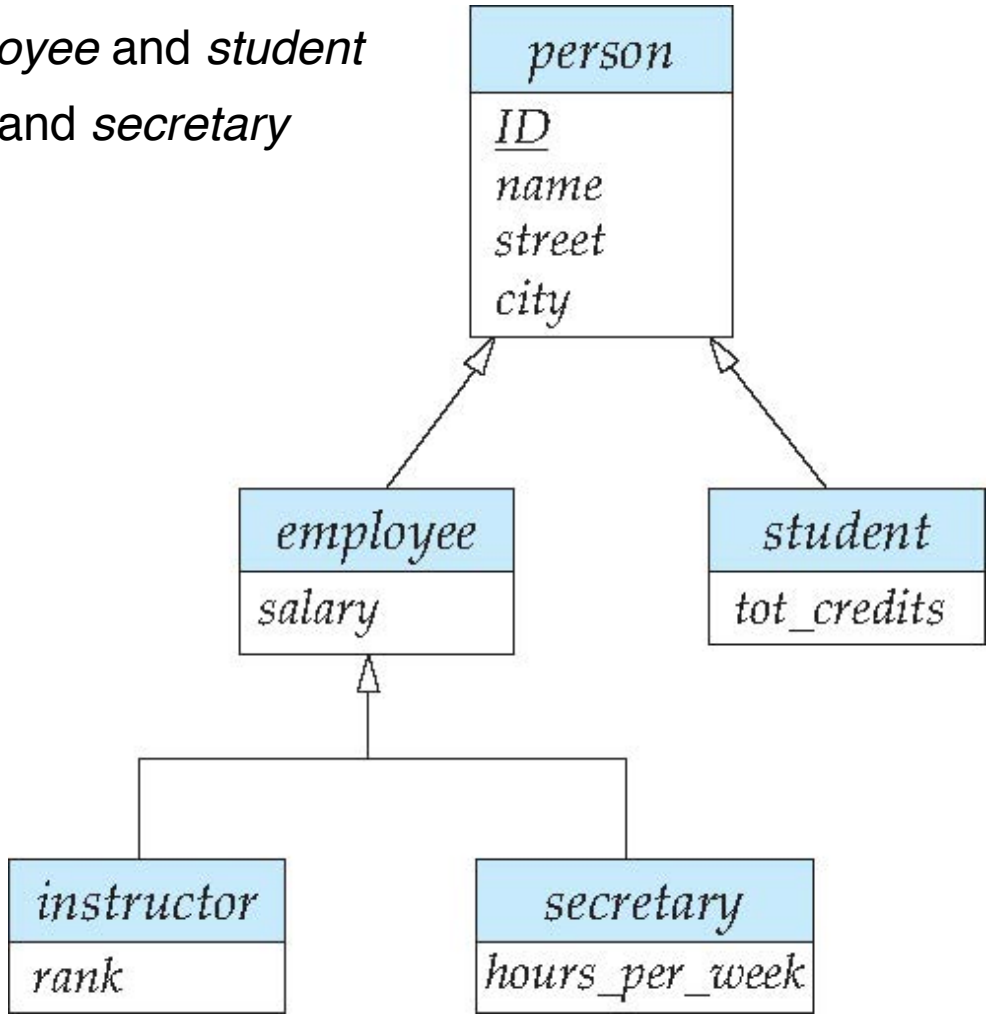
- Also need to translate constraints
  - Translating all constraints may not be possible
  - There may be instances in the translated schema that cannot correspond to any instance of *R*
    - Exercise: *add constraints to the relationships* R_A, R_B *and* R_C to ensure that a newly created entity corresponds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

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

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



Representing Specialization via Schemas

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

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

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

Representing Specialization as Schemas (Cont.)

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

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

  - 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

Generalization

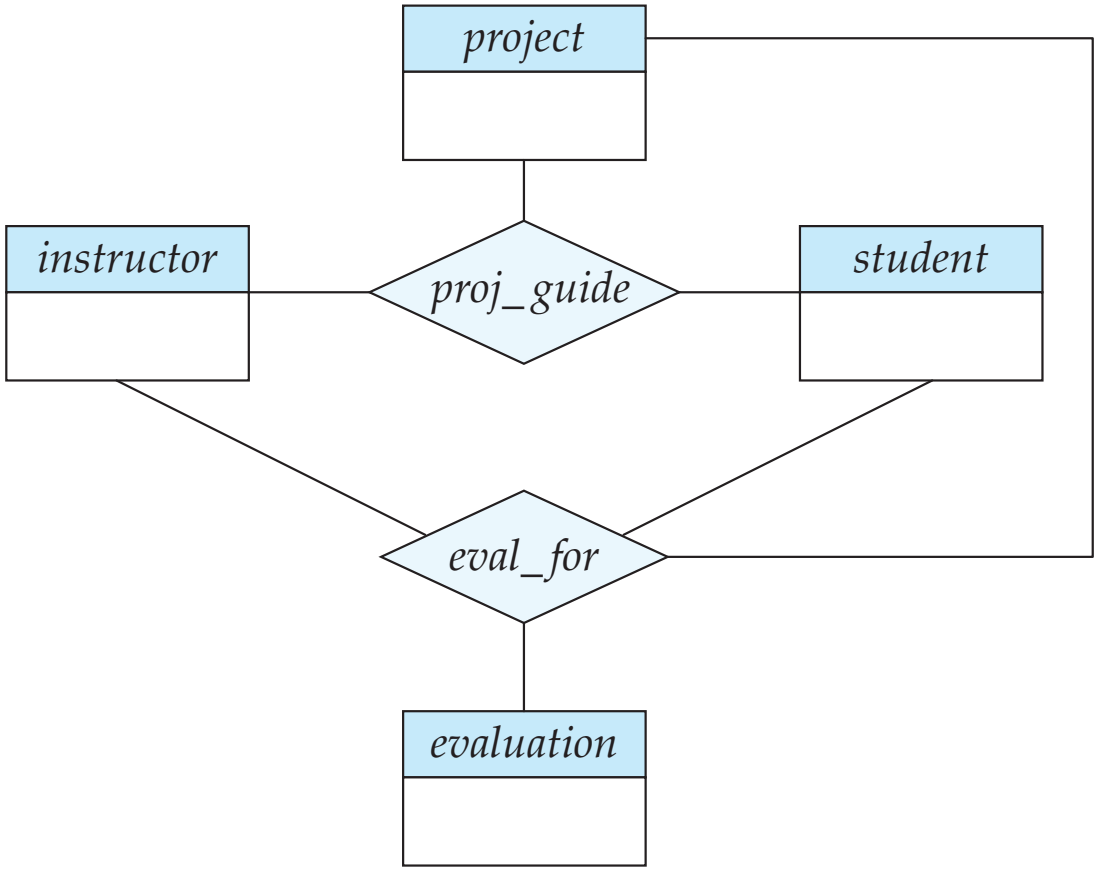
- **A bottom-up design process** – combine a number of entity sets that share the same features into a higher-level entity set.
- Specialization and generalization are simple inversions of each other; they are represented in an E-R diagram in the same way.
- The terms specialization and generalization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

Design Constraints on a Specialization/Generalization

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

Aggregation

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

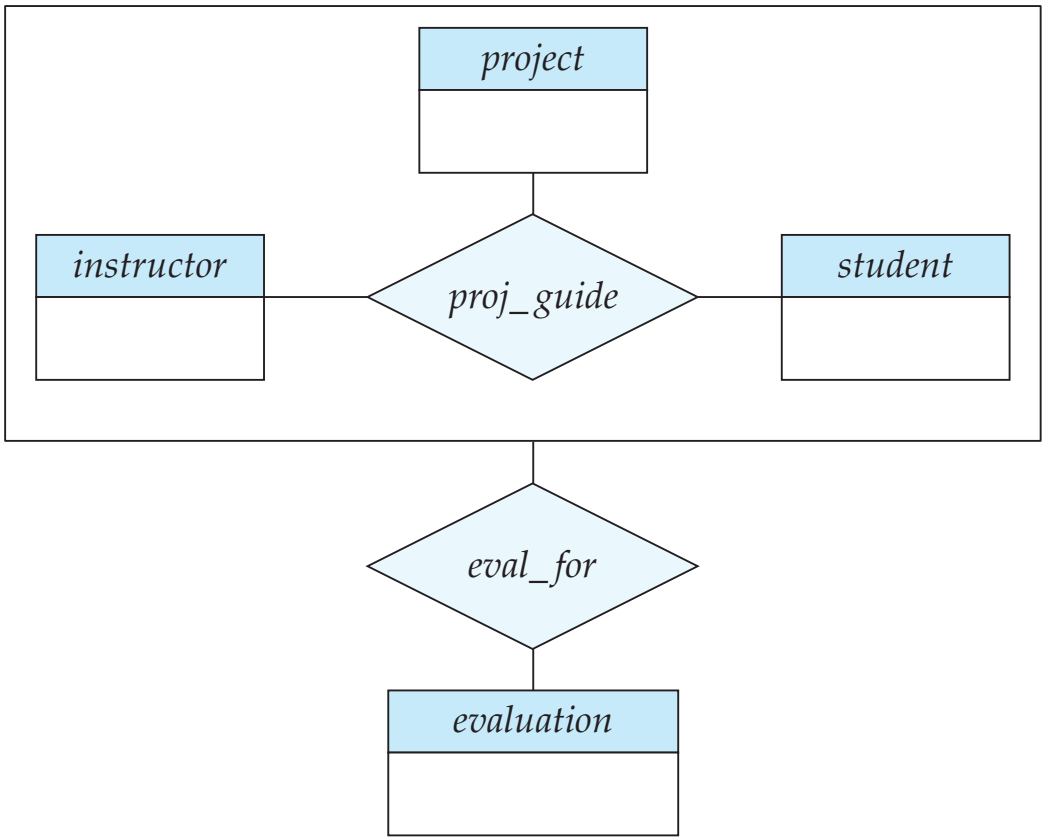


Aggregation (Cont.)

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

Aggregation (Cont.)

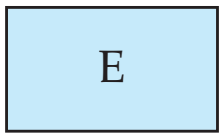
- Without introducing redundancy, the following diagram represents:
  - A student is guided by a particular instructor on a particular project
  - A student, instructor, project combination may have an associated evaluation



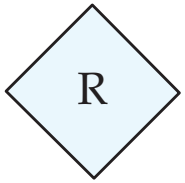
E-R Design Decisions

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

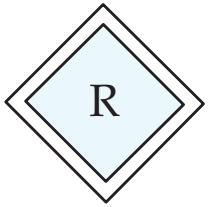
Summary of Symbols Used in E-R Notation



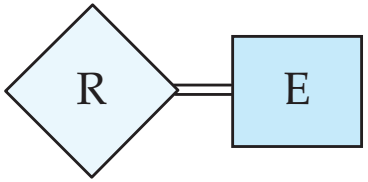
entity set



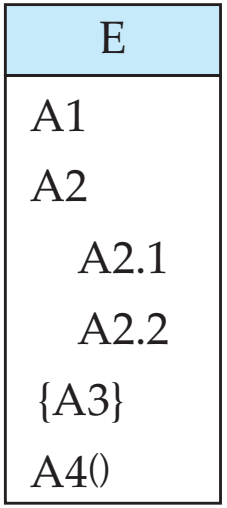
relationship set



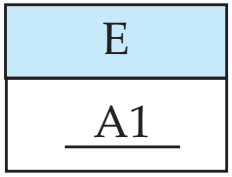
identifying relationship set for weak entity set



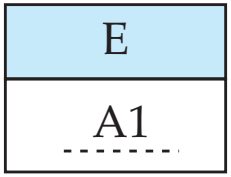
total participation of entity set in relationship



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

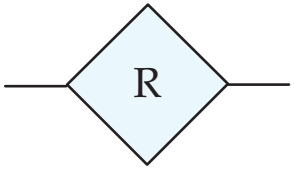


primary key

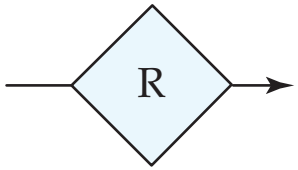


discriminating attribute of weak entity set

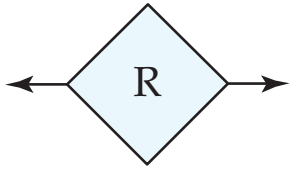
Symbols Used in E-R Notation (Cont.)



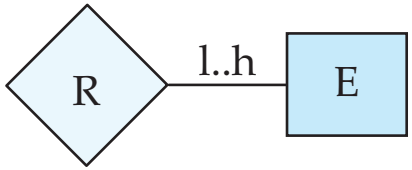
many-to-many relationship



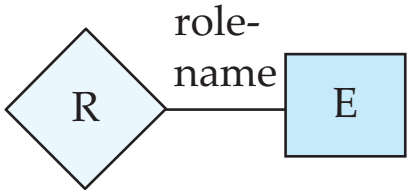
many-to-one relationship



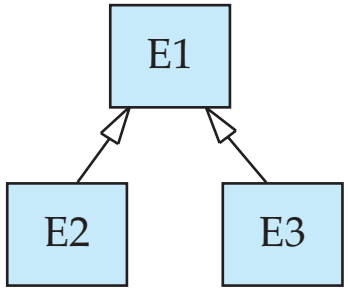
one-to-one relationship



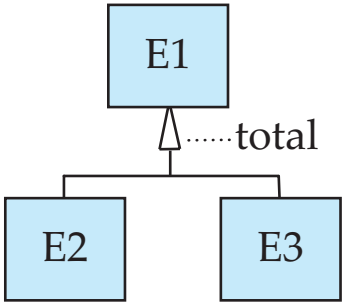
cardinality limits



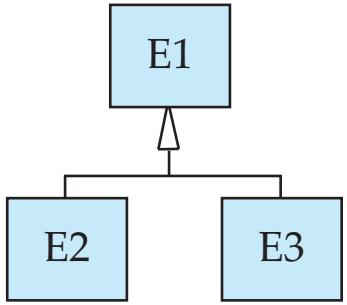
role indicator



ISA: generalization or specialization



total (disjoint) generalization

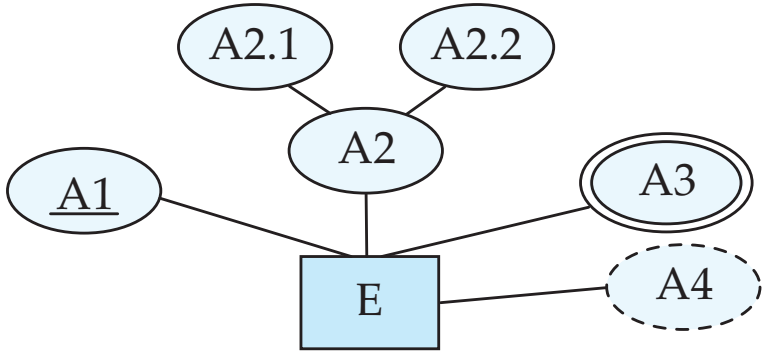


disjoint generalization

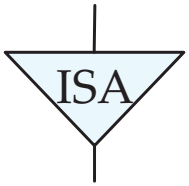
Alternative ER Notations

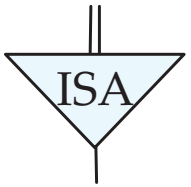
- Chen, IDE1FX, …

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

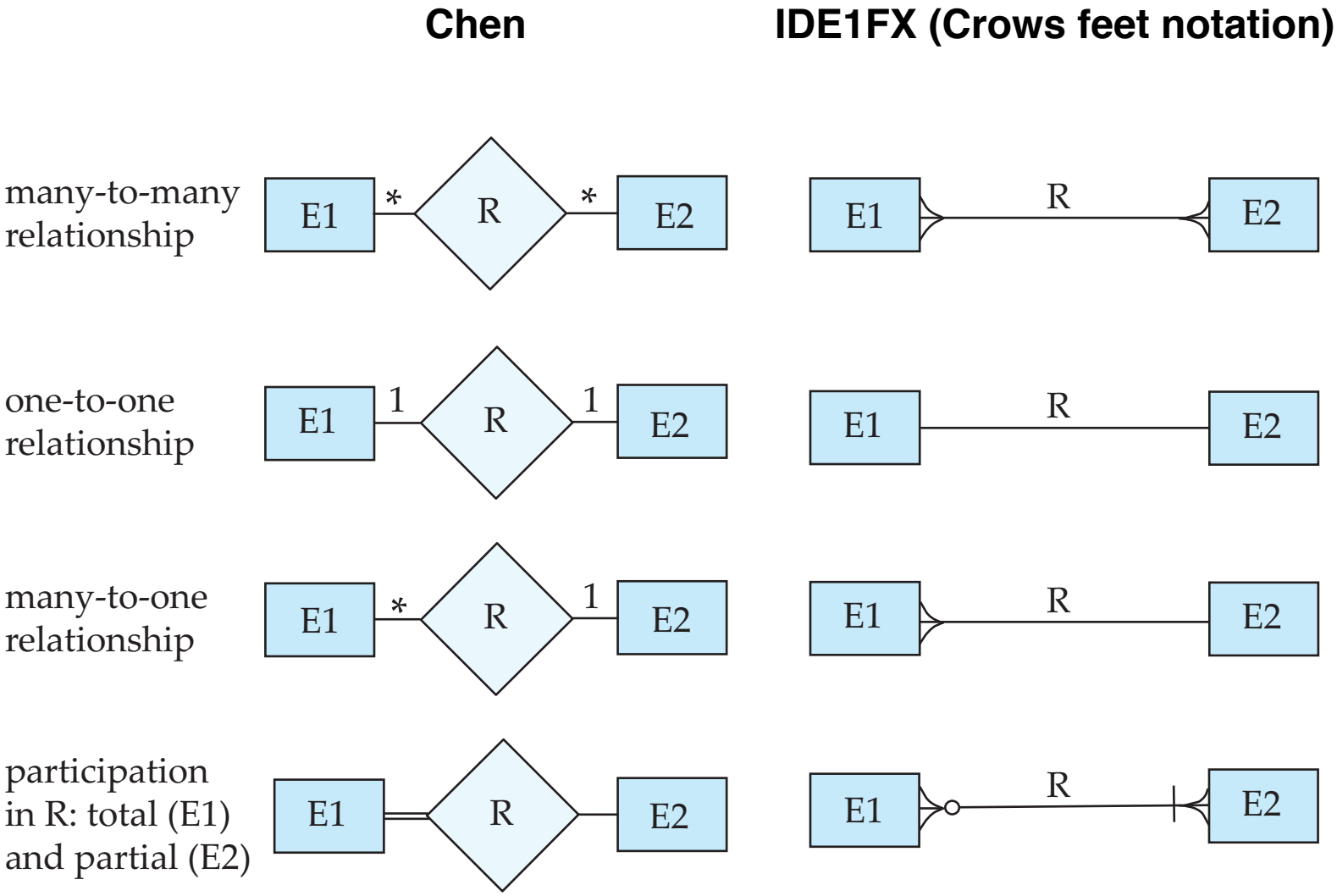


weak entity set 

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.