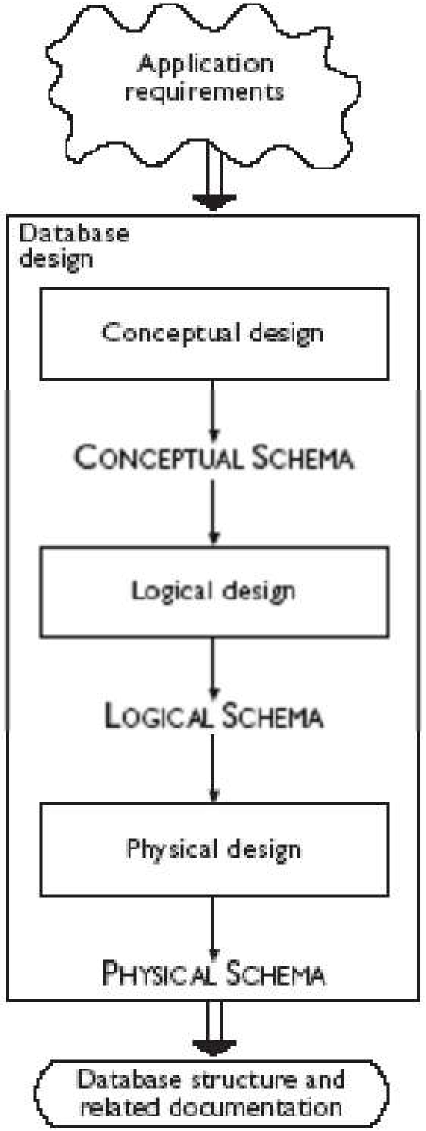
Chapter 7: Entity-Relationship Model

Database System Concepts, 6th Ed.

Overview of the Design Process

- Creating a database application
  - **Design of the database schema**
  - Design of the programs that access and update the data
  - Design of a security scheme to control access to data
- Two major pitfalls to avoid in designing a database schema
  - Redundancy
    - repeating information ➔ data inconsistency
  - Incompleteness
    - difficult or impossible to model certain aspects of the enterprise

Main Phases of Database Design



- Requirements collection and analysis
  - Understanding the needs of users and enterprises
- Conceptual design
  - Choosing an abstract model like E-R Model
  - **Conceptual schema**: descriptions of the data requirements, entities, relationships, and constraints
- Logical design
  - Converting the abstract model to implementation model
    - E-R model to relational model
- Physical design
  - Specifying physical features of the database
    - File organization, index structures (Ch. 10 & 11)

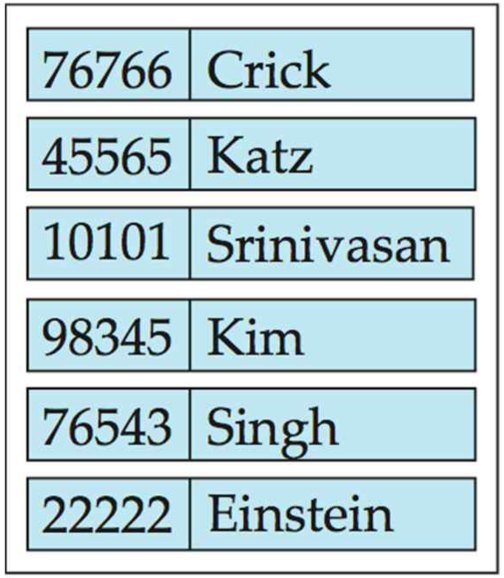
E-R Model

- Proposed by P. Chen in 1976
- Simple and powerful tool for the database design
  - Many database design tools draw on concepts from the E-R model
- A *database* can be modeled as:
  - a collection of **entities**
  - **relationships** among entities

Entity Sets

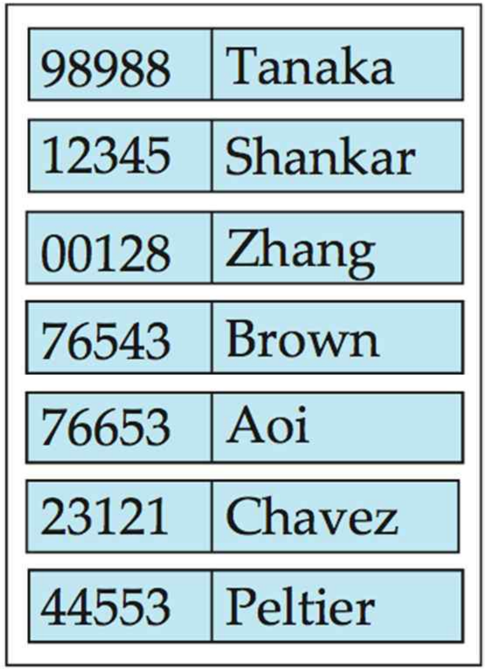
- **Entity** – an object that exists and is distinguishable from other objects
  - Example: specific person, company, event, plant
- **Entity set** – a set of entities of the same type that share the same properties
  - Example: set of all persons, companies, trees, holidays
- **Attribute** – descriptive properties possessed by all members of an entity set
  - Example: people have *names* and *addresses*

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

- **Relationship** – an association among several entities

  Example:

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

- **Relationship set** – a mathematical relation among $n \geq 2$ entities, each taken from entity sets

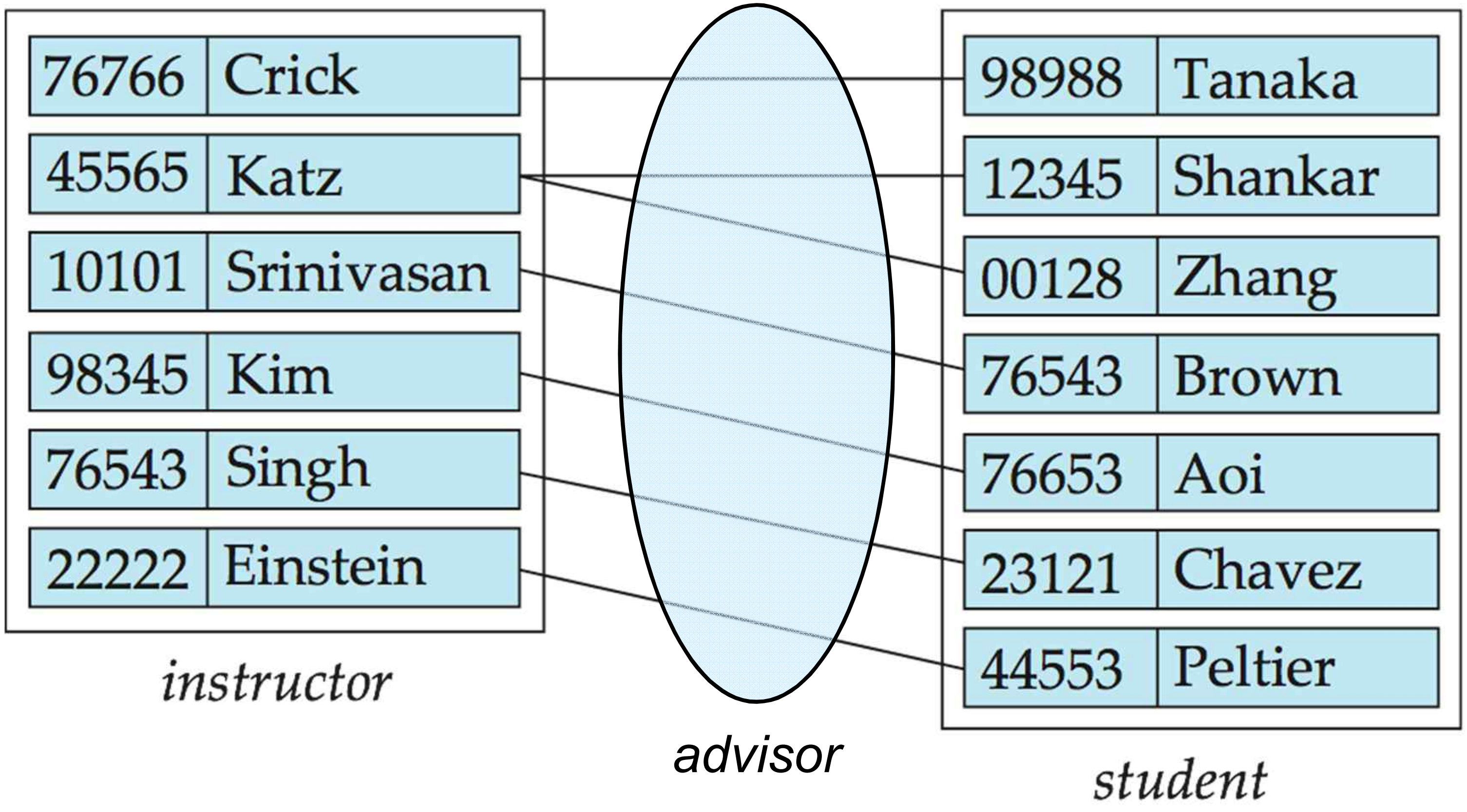
$$\{(e_1, e_2, \ldots e_n) \mid e_1 \in E_1, e_2 \in E_2, \ldots, e_n \in E_n\}$$

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

  - Example:

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

Relationship Set – *advisor*



76766	Crick
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22222	Einstein

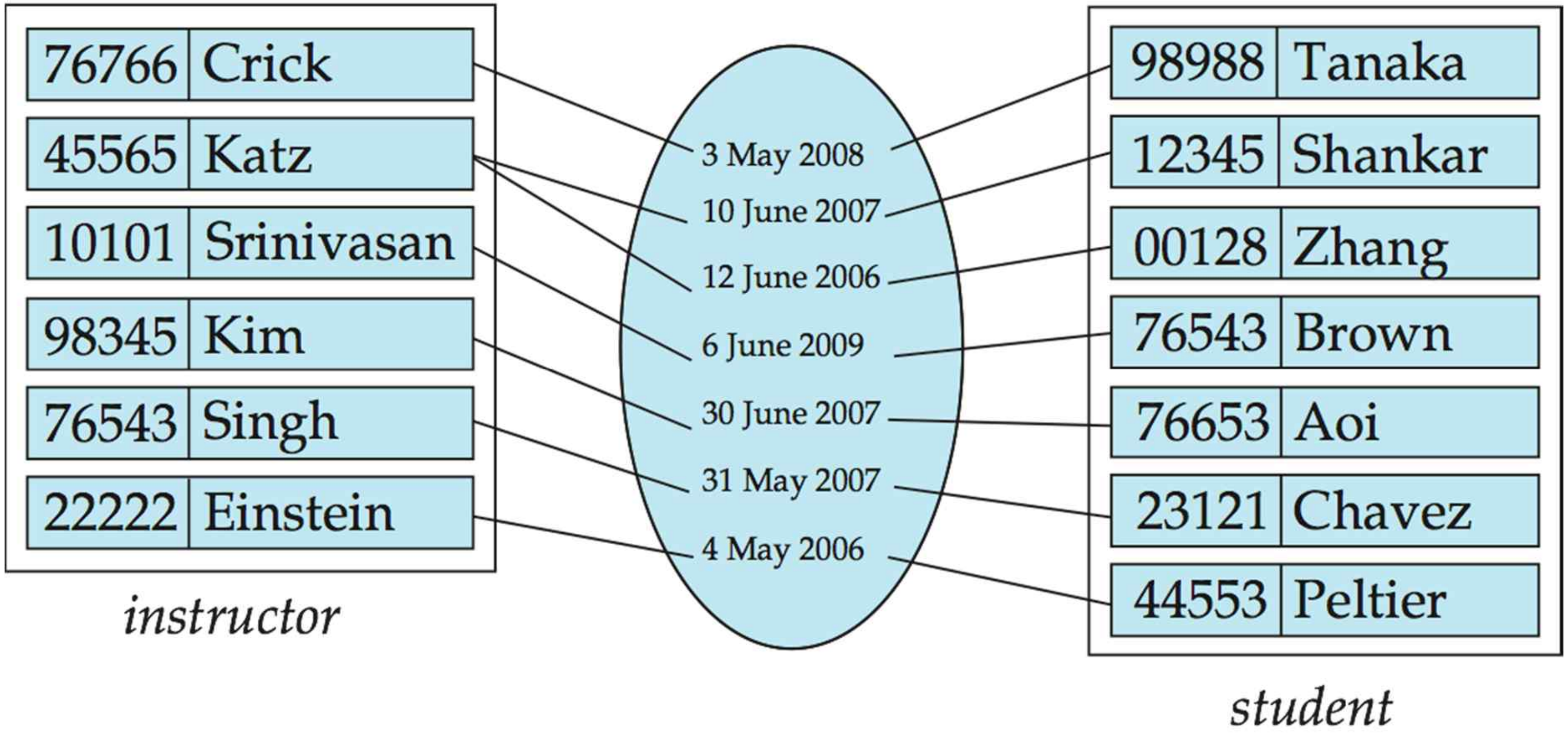
instructor

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

student

Attribute of Relationship Set

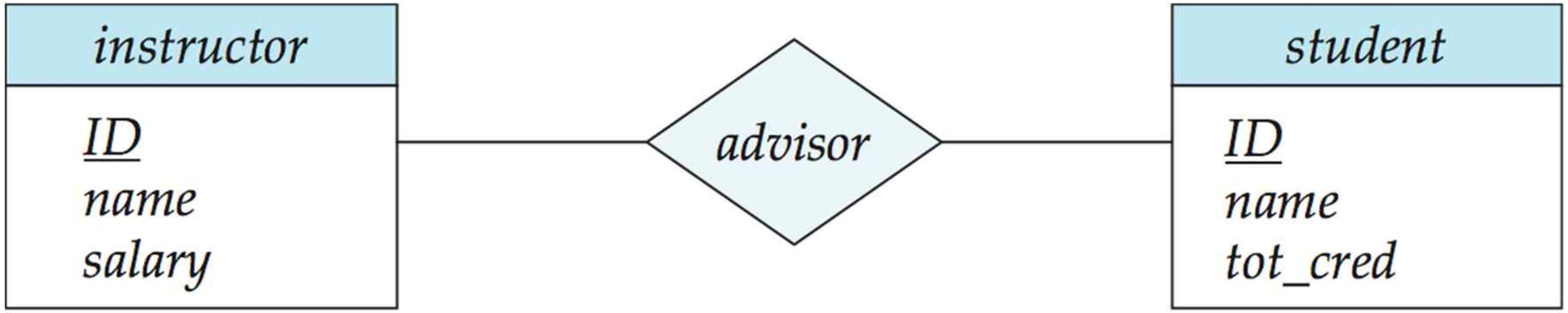
- An **attribute** can also be property of a relationship set



Natural Language Sentences to E-R Model

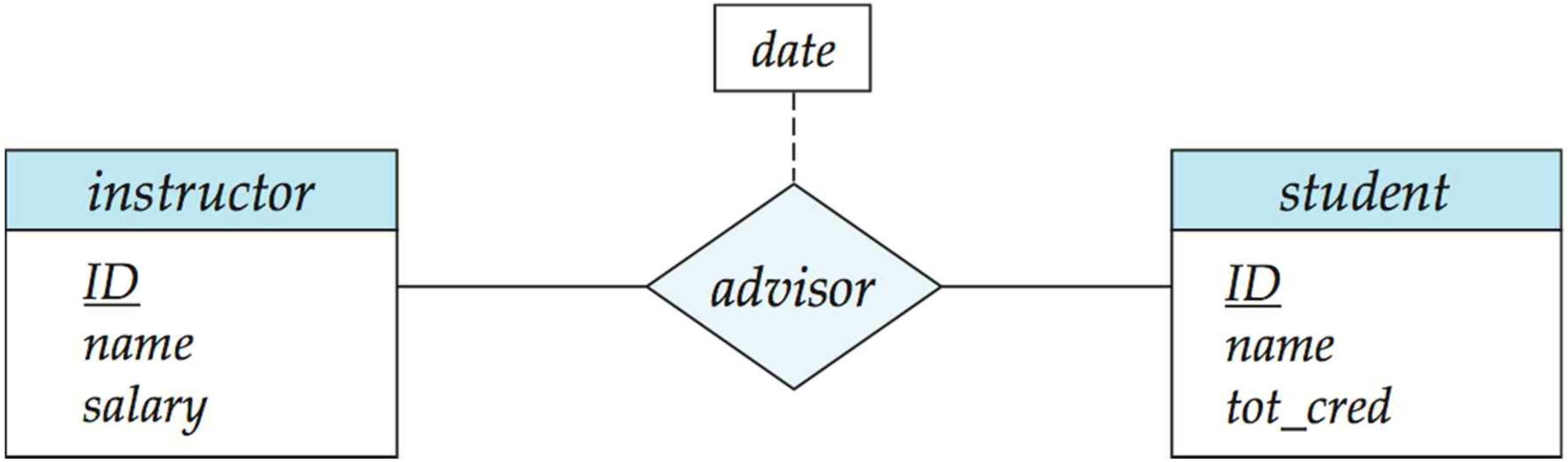
- Rules of thumb for mapping natural language descriptions into E-R model:
- Noun
  - Common noun ➔ entity set
  - Proper noun ➔ entity
- Verb
  - Transitive verb ➔ relationship set
  - Intransitive verb ➔ attribute for entity
- Adjective ➔ attribute for entity
- Adverb ➔ attribute for relationship

E-R Diagrams



- Rectangles represent entity sets
- Diamonds represent relationship sets
- Lines link entity sets to relationship sets
- Attributes are listed inside entity rectangles
- Underline indicates primary key attributes

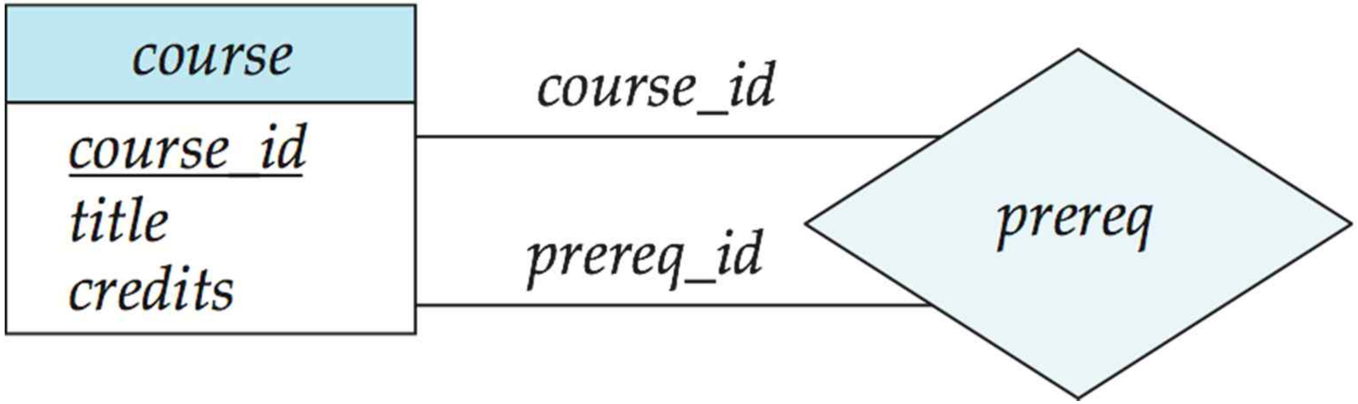
Relationship Sets with Attributes



- Dashed lines link attributes to the relationship sets

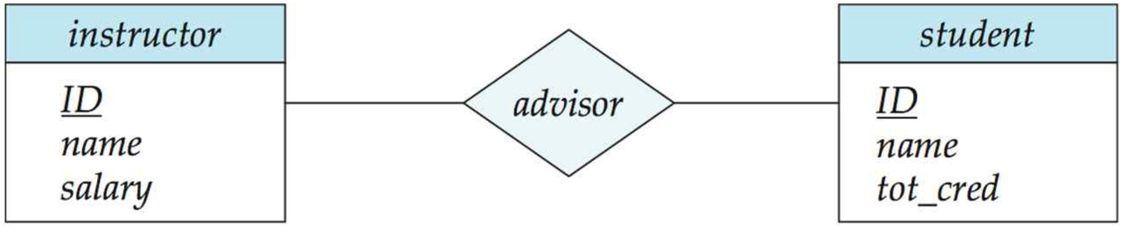
Roles

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

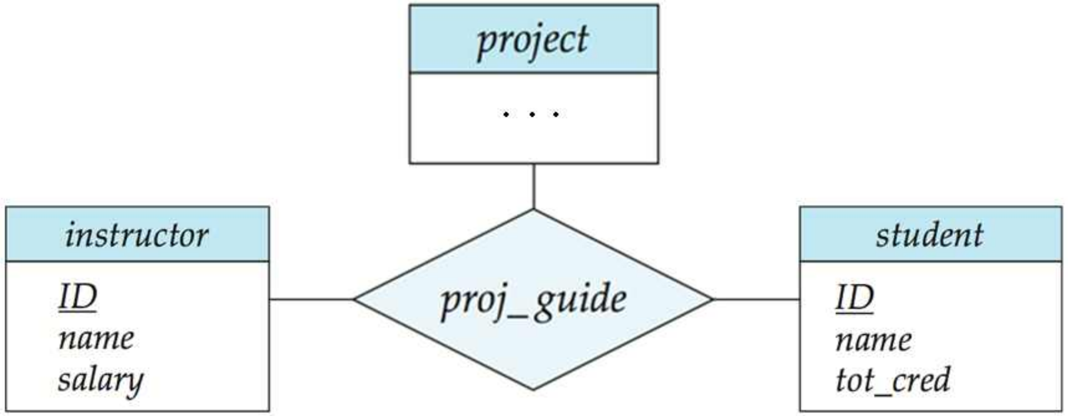


Degree of a Relationship Set

- **Degree** of a relationship set
  - The number of entity sets that participate in the relationship
- Most relationship sets in a database system are binary



- You can define non-binary relationships

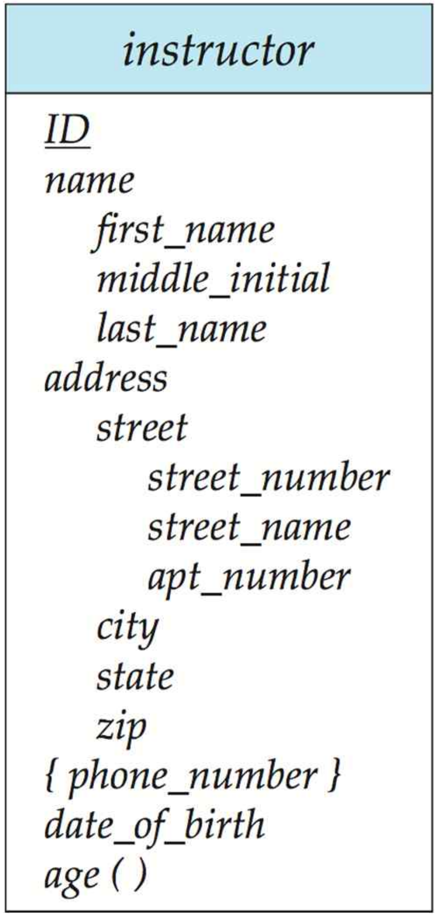


Attribute Types

- **Simple** and **composite** attributes
  - Simple attribute: can not be divided into subparts
  - Composite attribute: composed of multiple subparts
    - Example: name = (first_name, middle_initial, last_name)
      address = (street, city, state, zip_code)
- **Domain** – the set of permitted values for each attribute
  - Null value: a special value meaning “missing” or “unknown”
    - Some attributes are not allowed to have null values

Attribute Types

- **Single-valued** and **multivalued** attributes
  - Single-valued attribute
    - Each attribute has a single value for an entity
    - Example: *ID, name, address*
  - Multivalued attribute
    - An attribute may have more than one value for an instance
    - Example: *phone_number = {7287, 7288}*
- **Derived** attributes
  - Can be computed from other attributes
  - Example: *age*, given *date_of_birth*



instructor

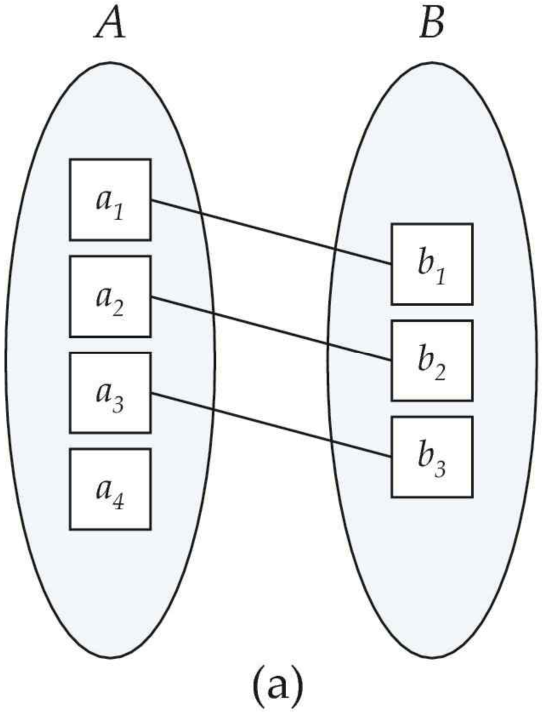
- *ID*
- *name*
  - *first_name*
  - *middle_initial*
  - *last_name*
- *address*
  - *street*
    - *street_number*
    - *street_name*
    - *apt_number*
  - *city*
  - *state*
  - *zip*
- *{ phone_number }*
- *date_of_birth*
- *age ( )*

Mapping Cardinality Constraints

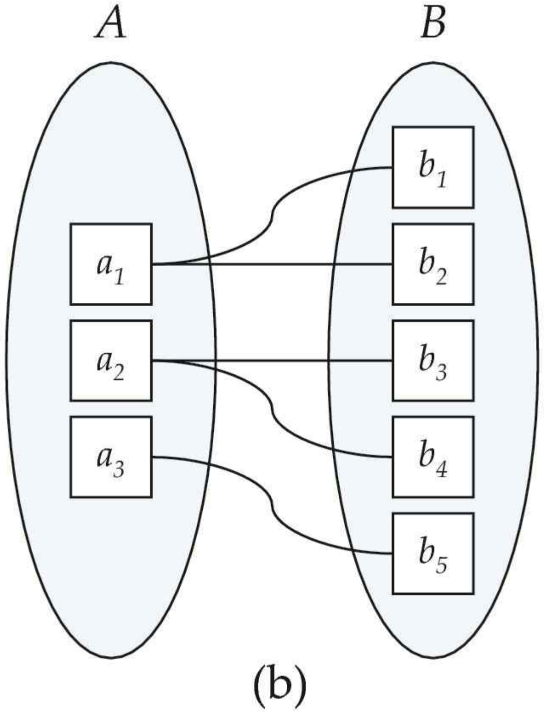
- Express the number of entities to which another entity can be associated via a relationship set

- 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



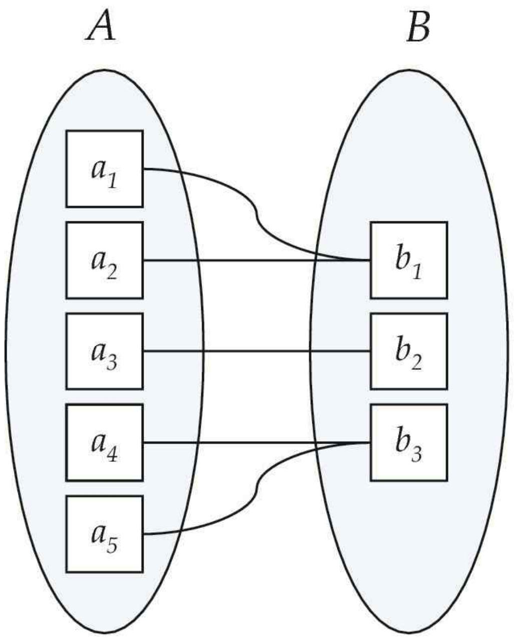
One-to-one



One-to-many

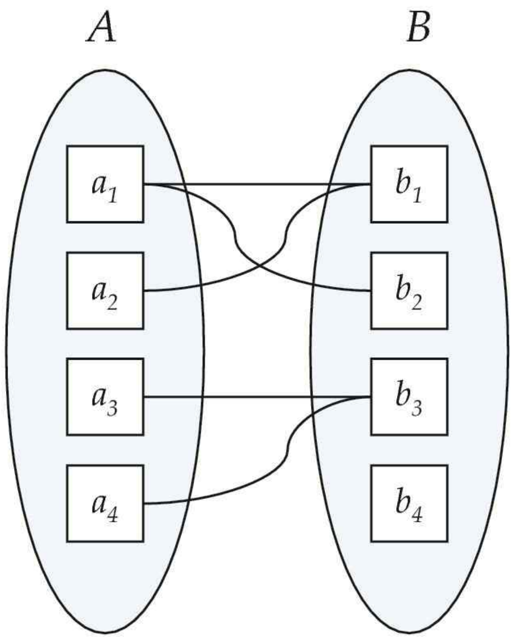
Note: Some elements in *A* and *B* may not be mapped to any elements in the other set

Mapping Cardinalities



(a)

Many-to-one



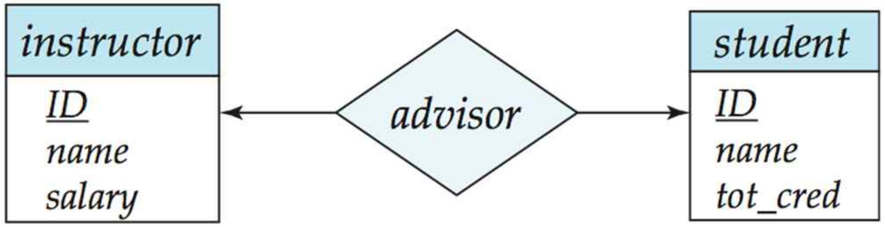
(b)

Many-to-many

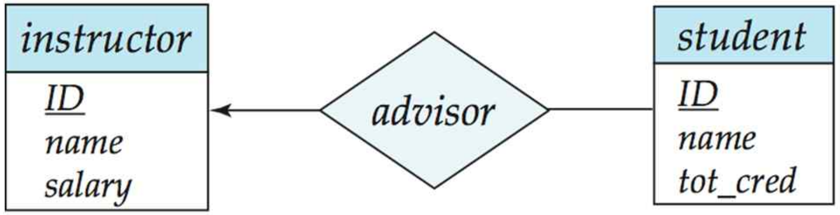
Note: Some elements in *A* and *B* may not be mapped to any elements in the other set

Mapping Cardinality Constraints in E-R diagram

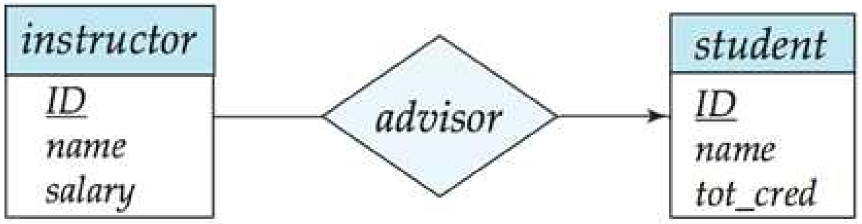
- Line types between the relationship set and the entity set
  - Directed line (→): at most “one” (including 0)
  - Undirected line (—): “many” (including 0)



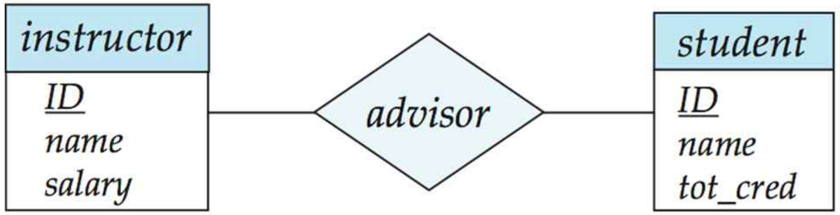
One-to-one



One-to-many



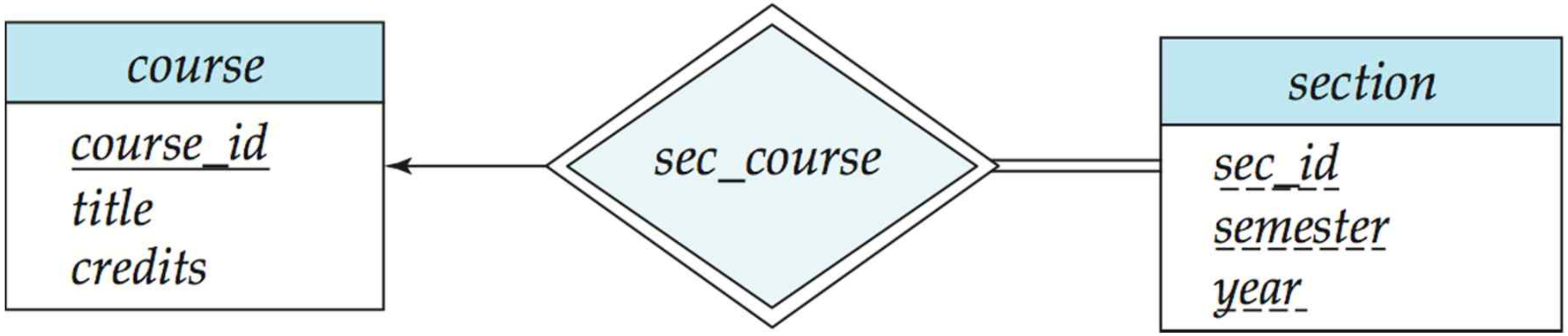
Many-to-one



Many-to-many

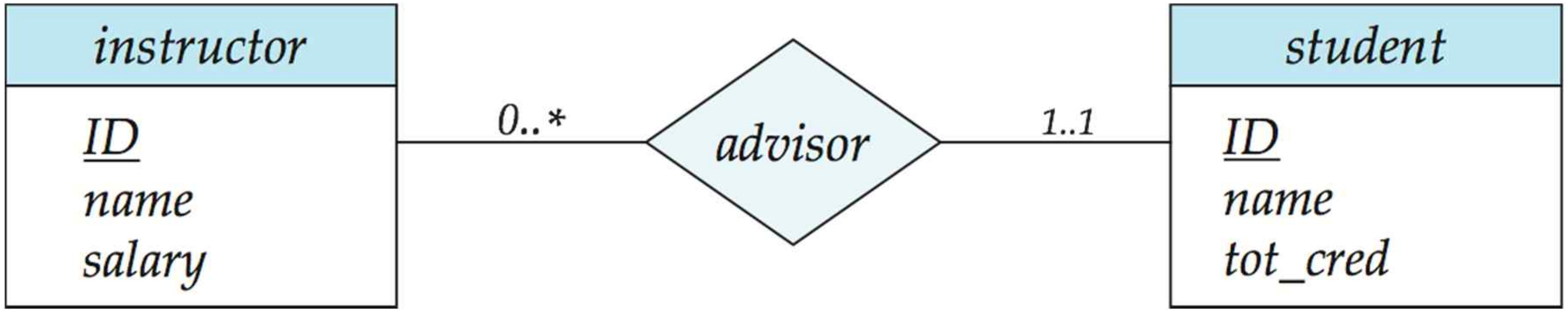
Participation Constraints

- Total participation (indicated by double line): every entity in the entity set participates in at least one relationship in the relationship set
  - Example: 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



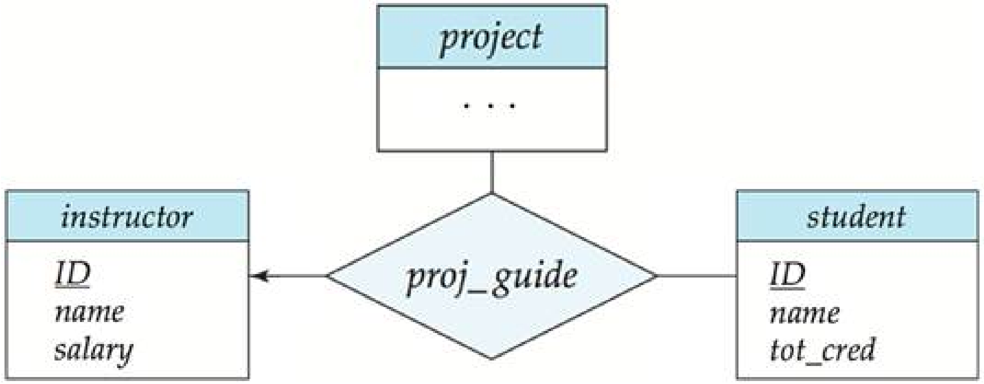
Cardinality Limits on Relationship Sets

- Cardinality limits can indicate more complex participation constraints



Cardinality Constraints on *n*-ary Relationship

- We allow at most one arrow out of a ternary (or greater degree) relationship
  - E.g., an arrow from *proj_guide* to *instructor* indicates each student has at most one guide for a project



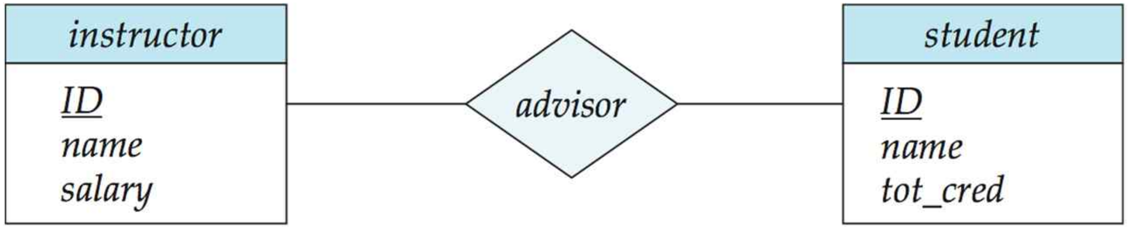
- If there is more than one arrow, there are two ways of defining the meaning.
  - E.g., a ternary relationship *R* between *A*, *B* and *C* with arrows to *B* and *C* could mean

    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*
  - To avoid confusion we outlaw more than one arrow

Keys

- Keys for entity sets
  - 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*
  - Although several candidate keys may exist, one of the candidate keys is selected to be the **primary key**.
- 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*



Keys for Relationship Sets

- Must consider the mapping cardinality of the relationship set when deciding what are the candidate keys (primary keys)

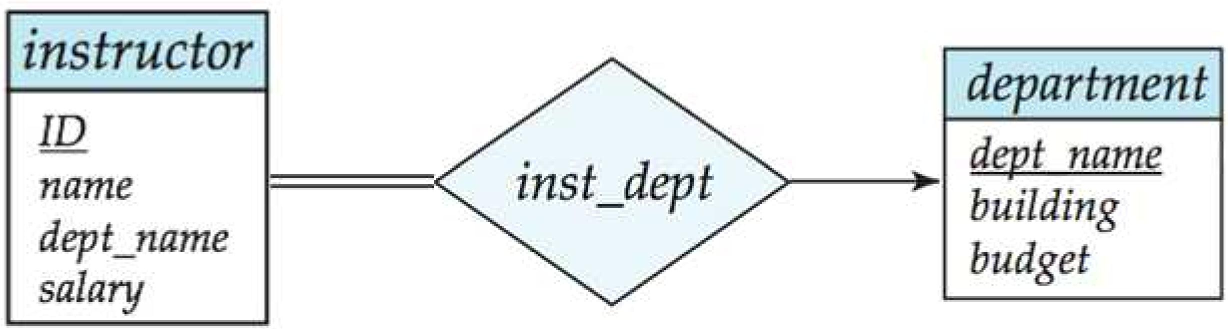
Let R be a relationship set involving entity sets E_1, E_2, …, E_n.

- Primary keys for binary relationship set (n = 2)
  - Many-to-many: PK(R) = PK(E_1) U PK(E_2)
  - Many-to-one/one-to-many: PK(R) = PK("many"-side entity)
  - One-to-one: PK(R) = PK(E_1) or PK(E_2)
- Primary keys for n-ary relationship set
  - No arrow edges: PK(R) = PK(E_1) U PK(E_2) U … U PK(E_n)
  - With an arrow edge: PK(R) = PKs of the entity sets not on the "arrow"-side

- If the relationship set R' is the relationship R with attributes {a_1, …, a_m}
  - PK(R') = PK(R) U {a_1, …, a_m}

Removing Redundant Attributes

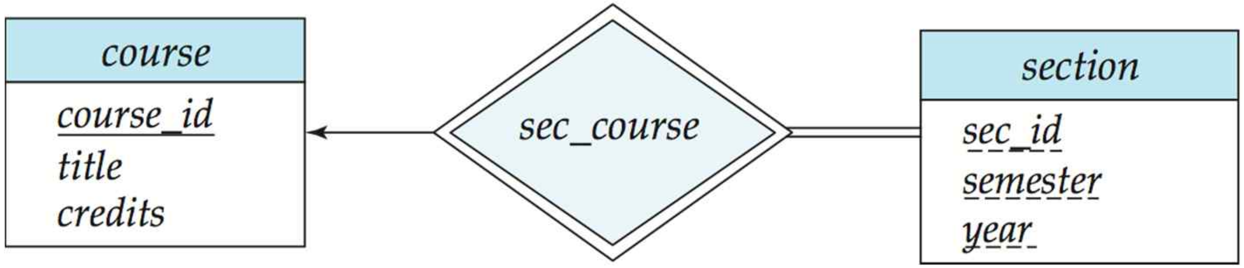
- Suppose we have entity sets



- Attribute *dept_name* in entity *instructor* is redundant
  - The attribute replicates information present in the relationship *inst_dept*, and should be removed from *instructor*
  - BUT: when converting back to tables, in some cases the attribute gets reintroduced, as we will see.

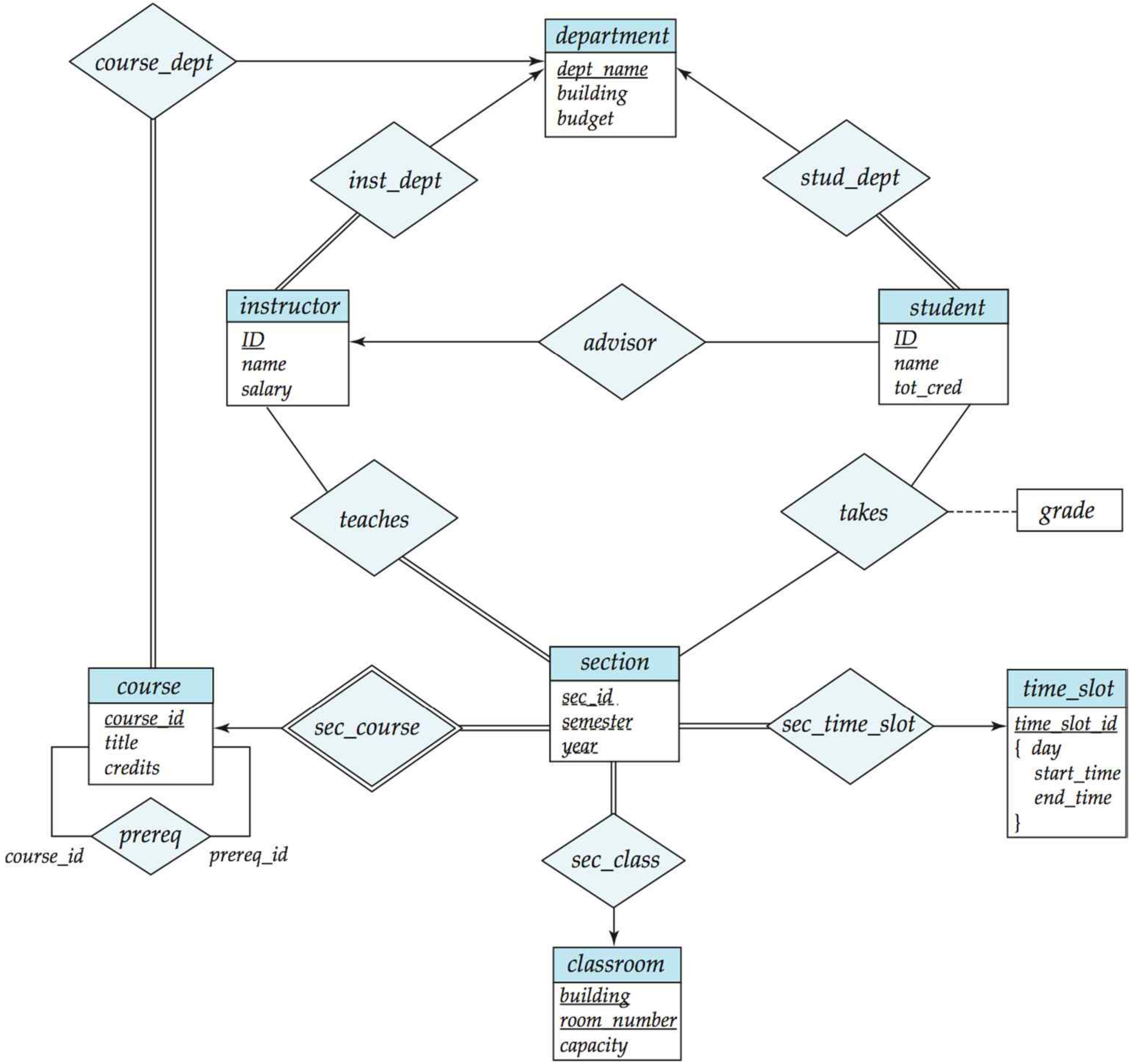
Weak Entity Sets

- **Weak entity set**: an entity set that does not have a primary key



- The existence of a weak entity set depends on the existence of an **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.
  - We underline the discriminator of a weak entity set with a dashed line.
- The primary key of a weak entity set = (the primary key of identifying strong entity set)+ (the weak entity set's discriminator)

E-R Diagram for a University Enterprise



Exercise

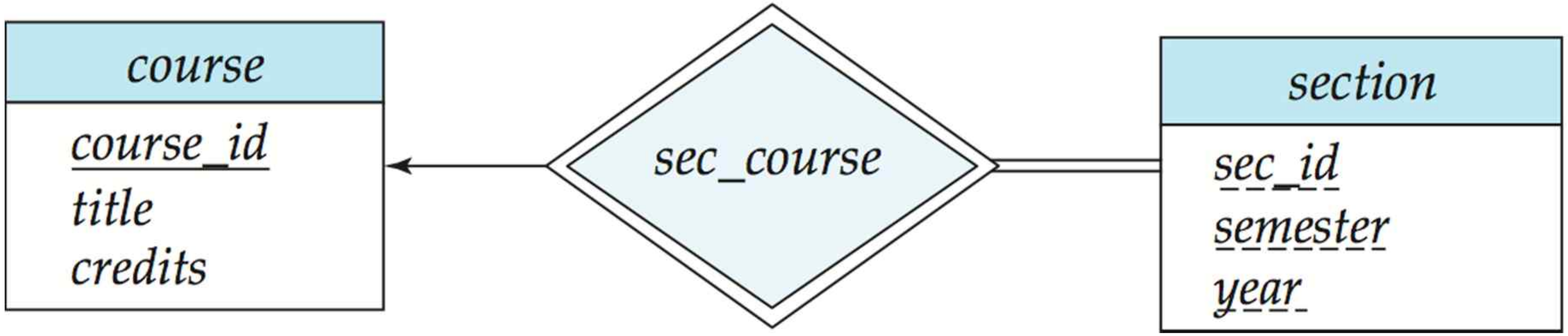
- Construct an E-R diagram for the following company enterprise.
  - A company has many employees. We store each employee’s name, SSN, address, salary, gender, and birth date.
  - The company is organized into departments. Each department has a unique name, a unique number, and a particular employee who manages the department. The department may have several locations.
  - An employee works for one department, and we keep track of the employee assignments. We also keep track of the direct supervisor of each employee.
  - Also, we want to keep track of the dependents of each employee for insurance purposes. We keep each dependent’s name, gender, birth date, and relationship to the employee.

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(<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>)

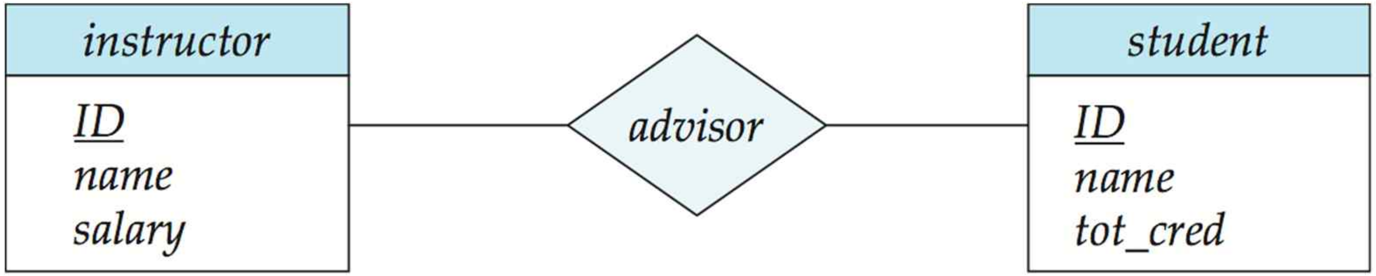


Representing Relationship Sets

- A relationship set is represented as a schema with attributes for the primary keys of the participating entity sets, and any descriptive attributes of the relationship set.

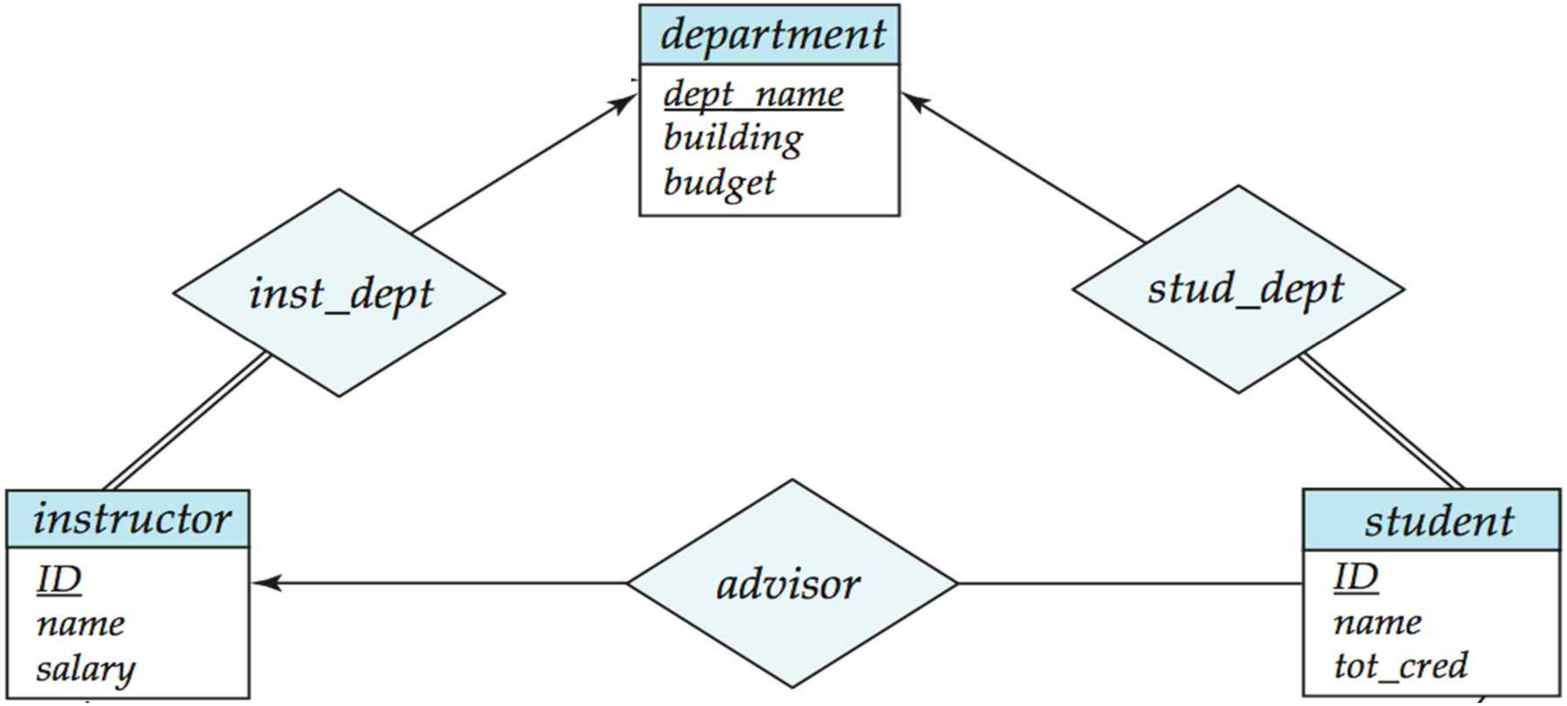
- Example: schema for relationship set *advisor*

  advisor = (*s_id, i_id*)



Redundancy of Schemas

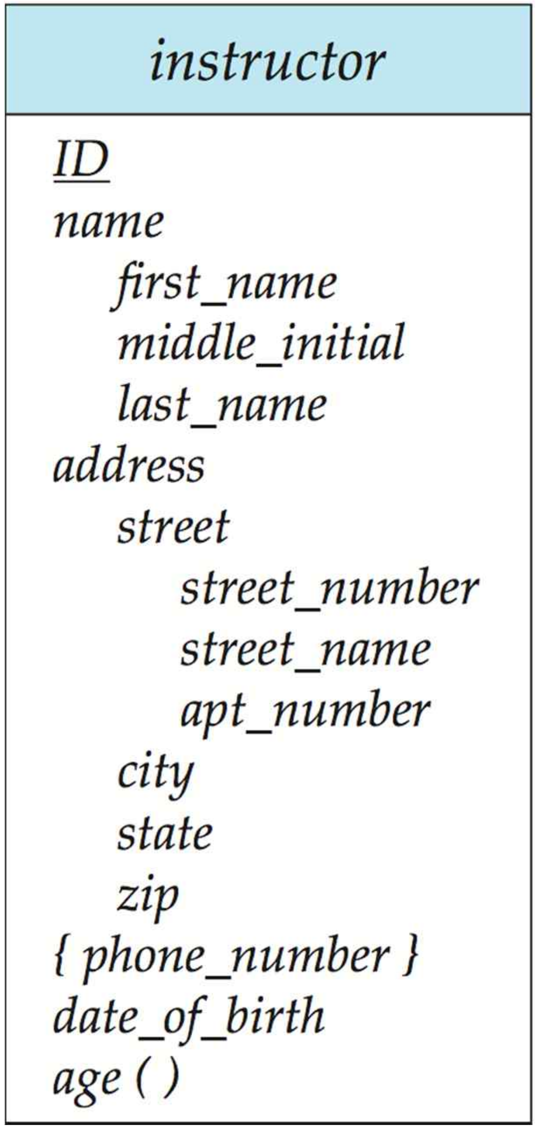
- Many-to-one and one-to-many relationship sets that are total on the many-side can be represented by adding an extra attribute to the "many" side, containing the primary key of the "one" side
- Example: Instead of creating a schema for relationship set *inst_dept*, add an attribute *dept_name* to the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

- *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 ( )*

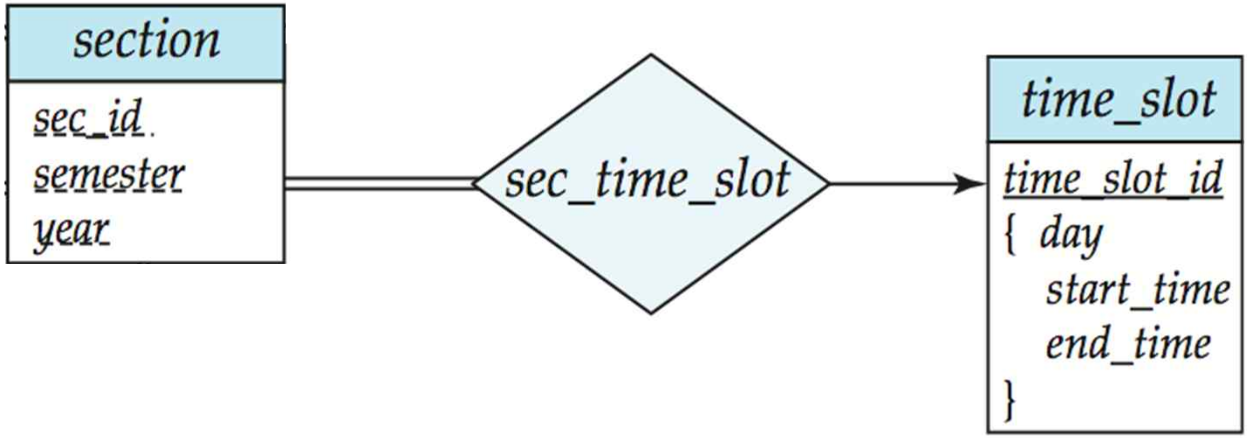
- Composite attributes are flattened out by creating a separate attribute for each component attribute
- Ignoring multivalued attributes, extended instructor schema is
  - *instructor(ID,*
    first_name, middle_initial, last_name,
    street_number, street_name, apt_number,
    city, state, zip_code,
    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)

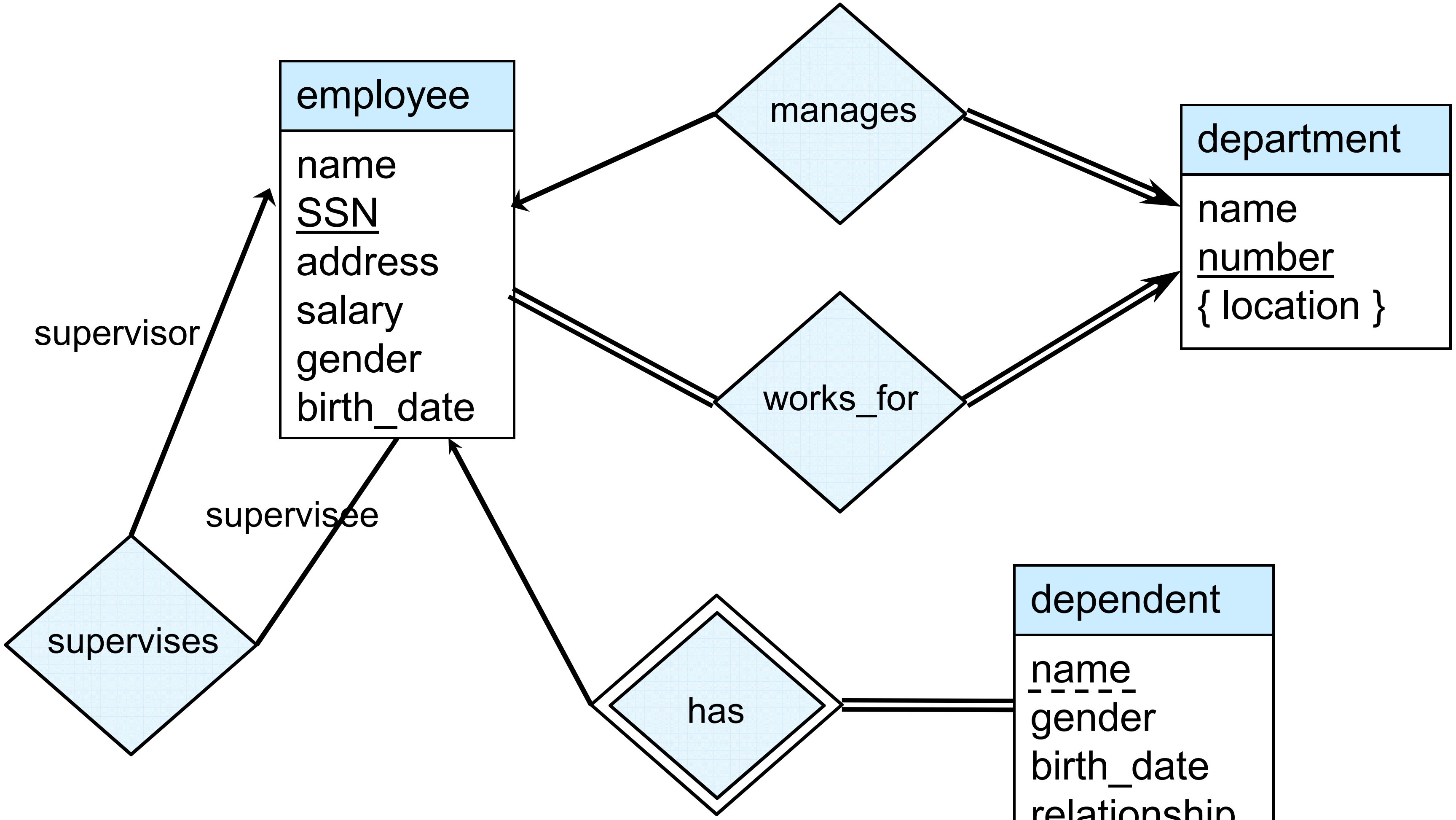
Multivalued Attributes (Cont.)

- 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



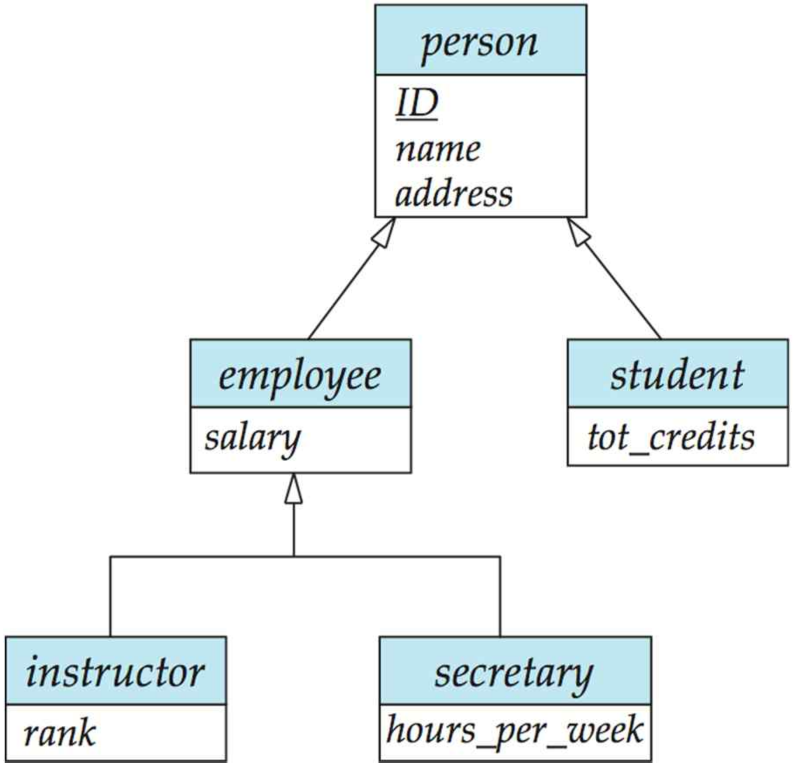
Exercise

- Convert the following E-R diagram into a set of relations.



Extended E-R Features: Specialization/Generalization

- **Specialization**
  - Designating subgroupings within an entity set
  - **Top-down** design process
- **Generalization**
  - Combining a number of entity sets that share the same features into a higher-level entity set
  - **Bottom-up** design process



- **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.
- Lower-level entity sets may have their own specific attributes or participate in relationships that do not apply to the higher-level entity set.

Constraints on Specialization/Generalization

- **Disjoint constraint** – specifies whether or not entities may belong to more than one lower-level entity set within a single generalization/specialization
  - **Disjoint** (denoted by a single arrow)
    - An entity can belong to only one lower-level entity set
  - **Overlapping** (denoted by separate arrows)
    - An entity can belong to more than one lower-level entity set

- **Completeness constraint** -- specifies whether or not an entity in the higher-level entity set must belong to at least one of the lower-level entity sets within a generalization/specialization
  - **Total** (denoted by a dashed line and the keyword "total")
    - an entity must belong to one of the lower-level entity sets
  - **Partial**(default)
    - an entity need not belong to one of the lower-level entity sets

Reduction to Relation 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

Reduction to Relation 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

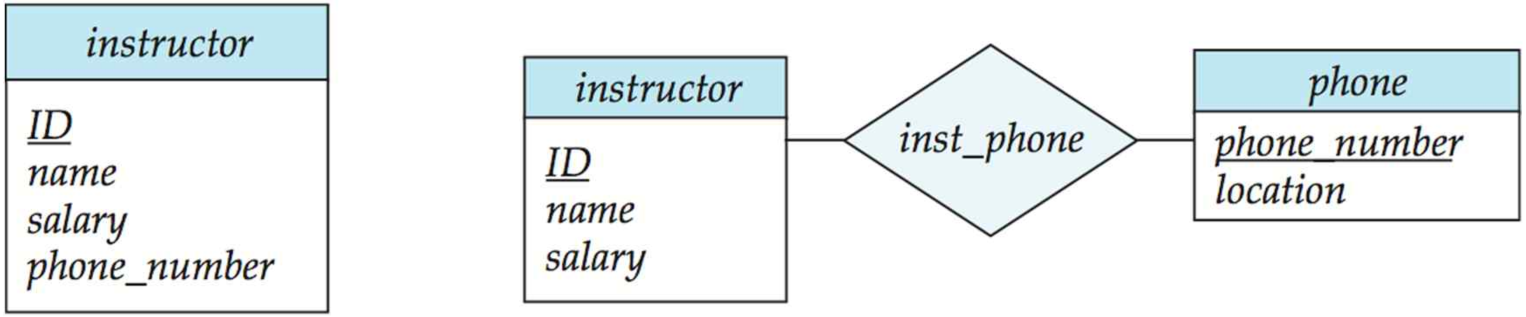
Entity-Relationship Design Issues

- The use of an attribute or an entity set to represent an object
- The use of an entity sets or an relationship sets to represent an object
- The use of a ternary relationship versus a pair of binary relationships

Use of Attributes vs. Entity Sets

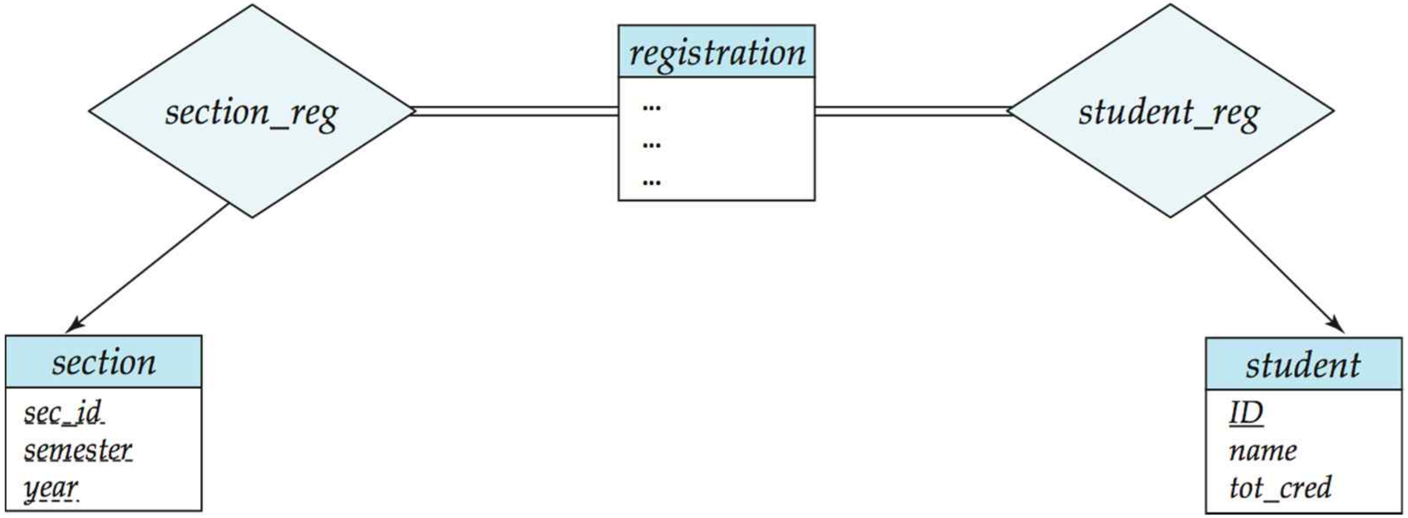
- Whether the entity must be treated as an independent entity
  - Whether to have multiple entities
  - Whether to keep extra information about the entity

- Example: use of phone as an entity allows extra information about phone numbers (plus multiple phone numbers)

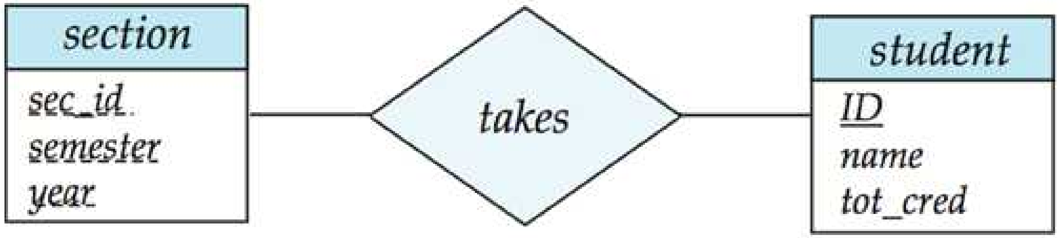


Use of Entity Sets vs. Relationship Sets

- Use of entity sets: keeping other information about the entity



- Use of relationship sets: more compact



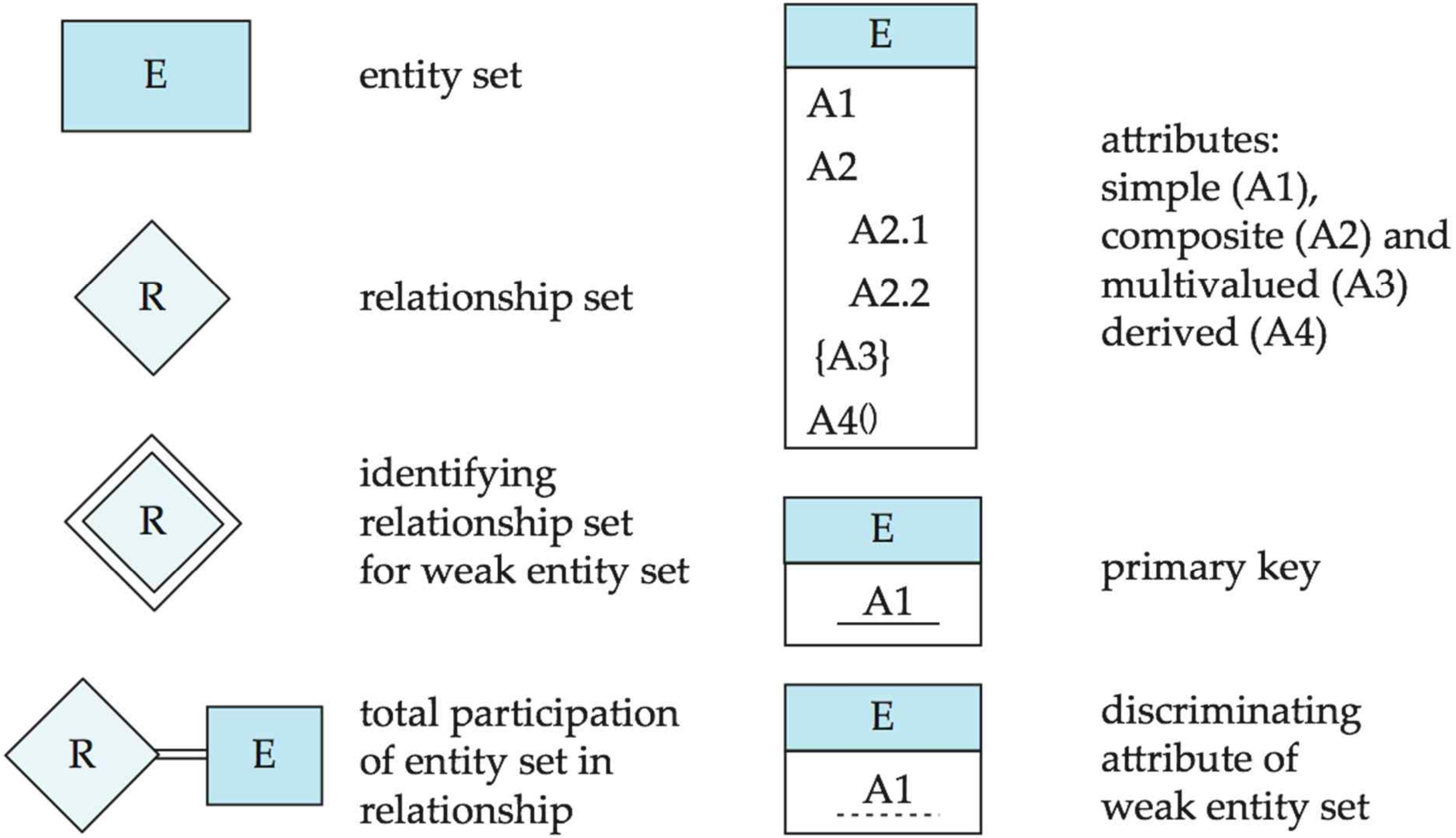
- It is not always clear – possible guideline is to designate a relationship set to describe an action that occurs between entities

Binary vs. Non-Binary Relationships

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

- 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*

Summary of Symbols Used in E-R Notation



entity set

relationship set

identifying
relationship set
for weak entity set

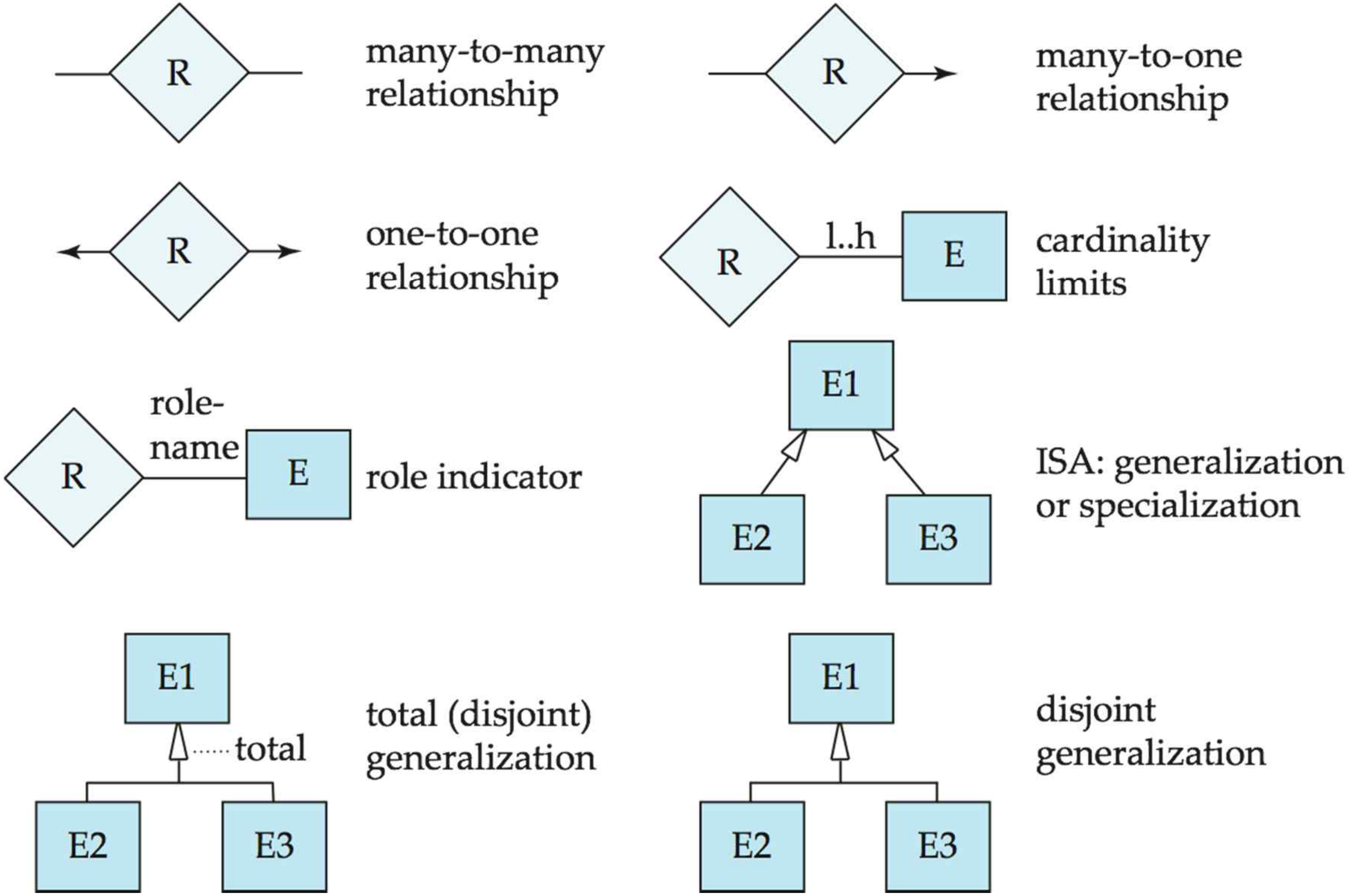
total participation
of entity set in
relationship

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

End of Chapter 7

Database System Concepts, 6th Ed.