Chapter 7

Entity Relationship Model

Slides by Silbershatz, Modifications by Rogers and Brown

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

Modeling

- 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

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

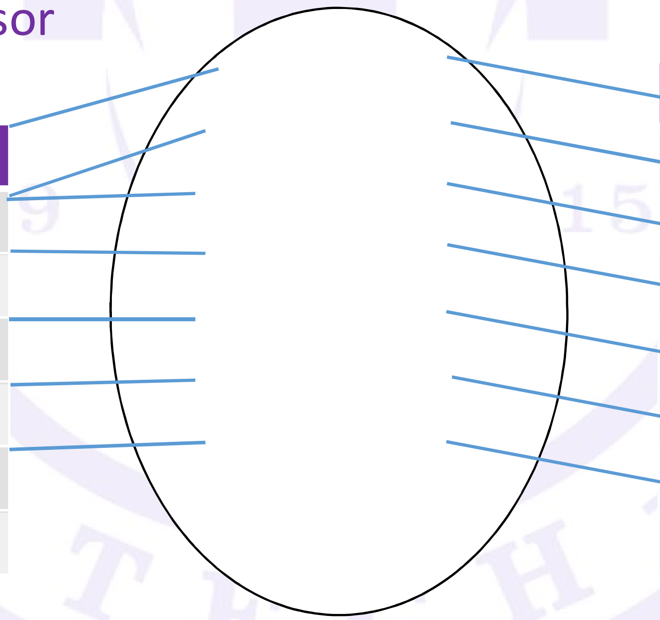
student

Relationship Sets (cont)

- At attribute can also be a 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

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

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*

Attributes

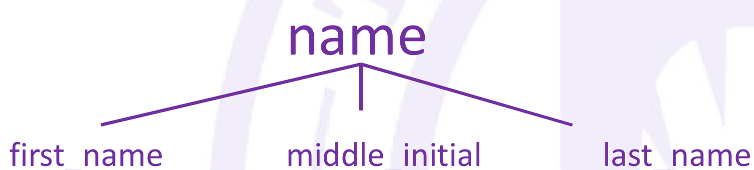
- An entity is represented by a set of attributes, that is descriptive properties possessed by all members of an entity set.
- Example:

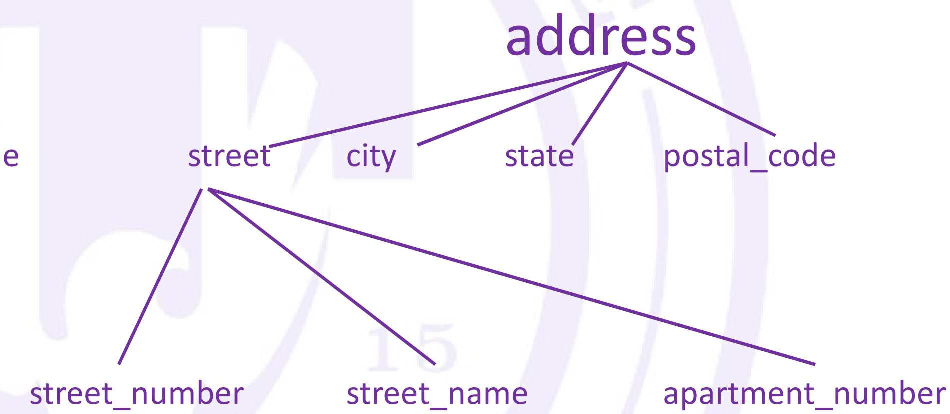
  instructor = (ID, name, street, city, salary)
  course= (course_id, title, credits)

- 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





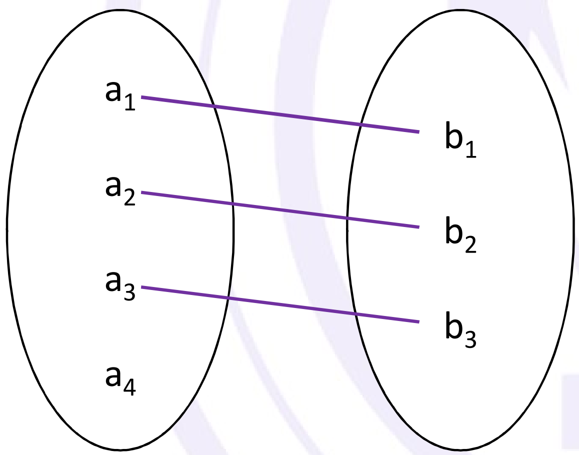
Component Attributes

Mapping Cardinality Constraints

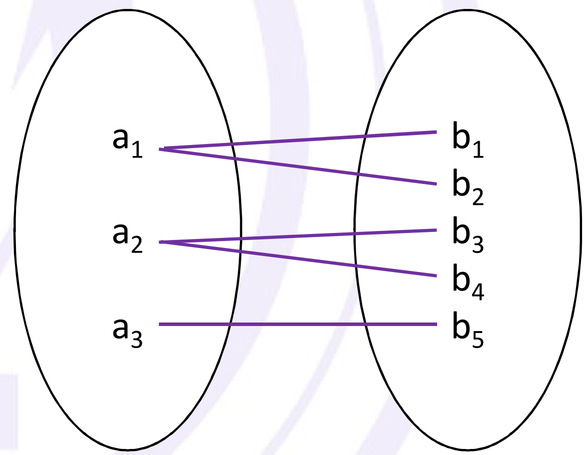
- Express the number of entities to which another entity can be associated via a relationship set.
- Most useful in describing binary relationship sets.
- For a binary relationship set the mapping cardinality must be one of the following types:
  - One to one
  - One to many
  - Many to one
  - Many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

Mapping Cardinalities

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



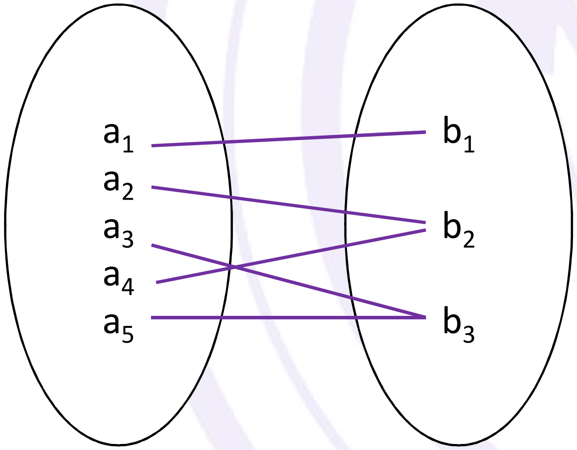
(a)
One to One



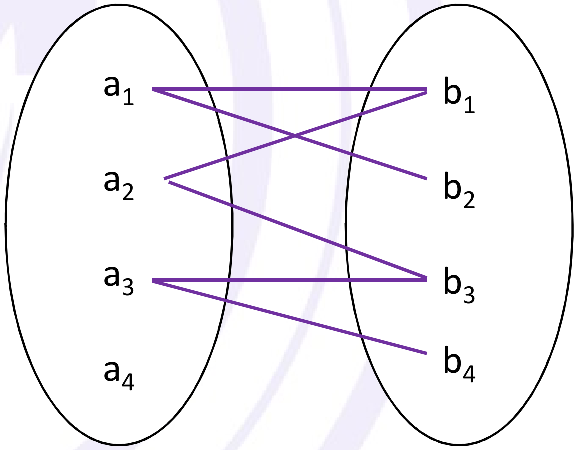
(b)
One to Many

Mapping Cardinalities

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



(a)
Many to One



(b)
Many to Many

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.

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

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

instructor
ID
name

first_name
  middle_initial
  last_name

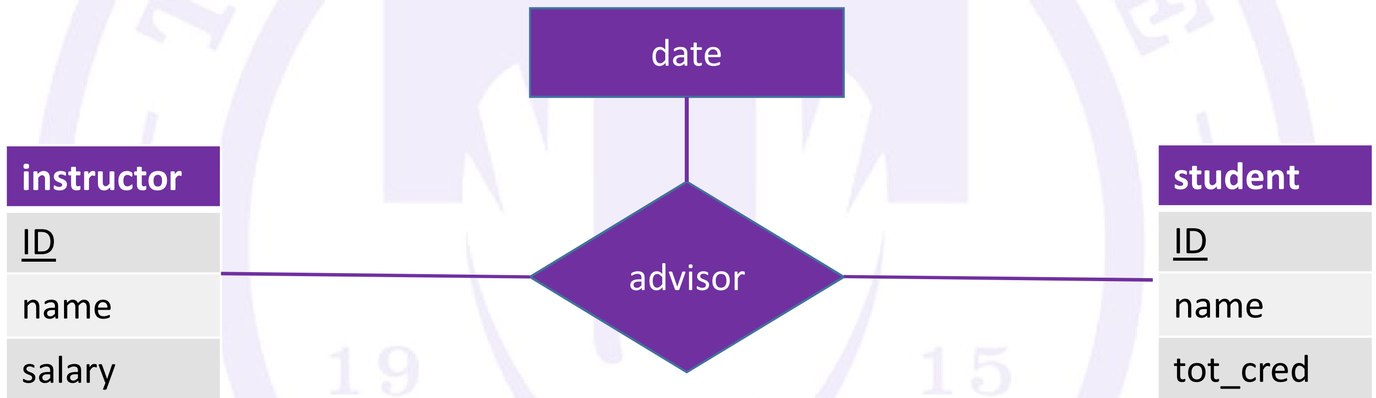
address
street

street_number
    street_name
    apt_number

city
  state
  zip

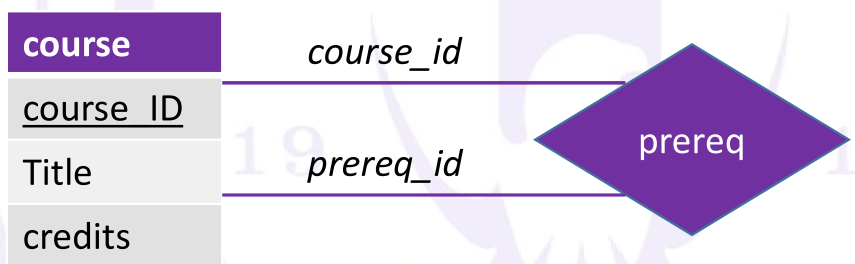
{ phone_number }
date_of_birth
age ( )

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
  - 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 Relationship

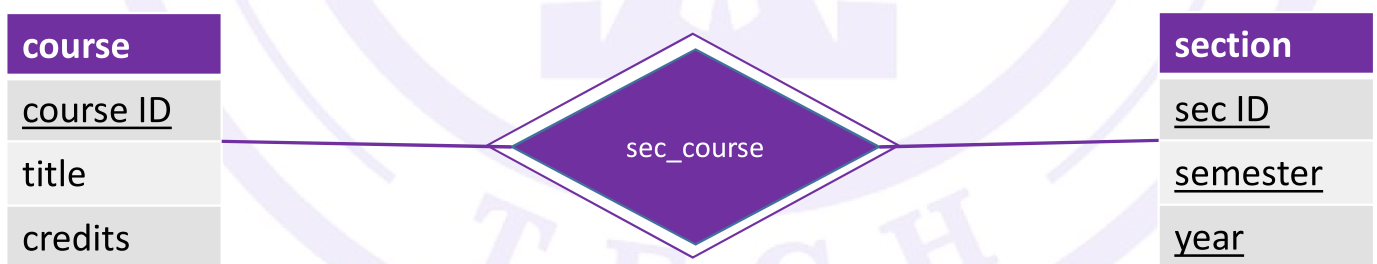
- Many-to-one relationship between an instructor and a student
  - An instructor is associated with at most one students via advisor
  - A student is associated with several (including 0) instructor via advisor

Many-to-Many Relationship

- Many-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 several (including 0) instructor via advisor

Participation of an Entity Set in a Relationship Set

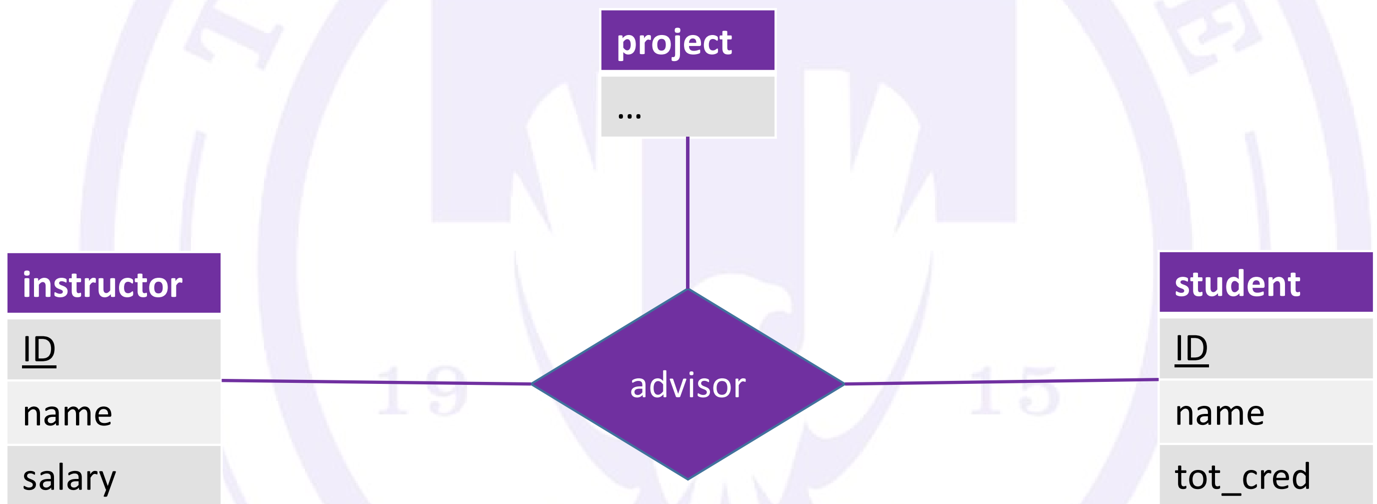
- Total participation (indicated by double line): every entity in the entity set participates in at least one relationship in the relationship set
  - E.g., participation of section in sec_course is total
    - every section must have an associated course
- Partial participation: some entities may not 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

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

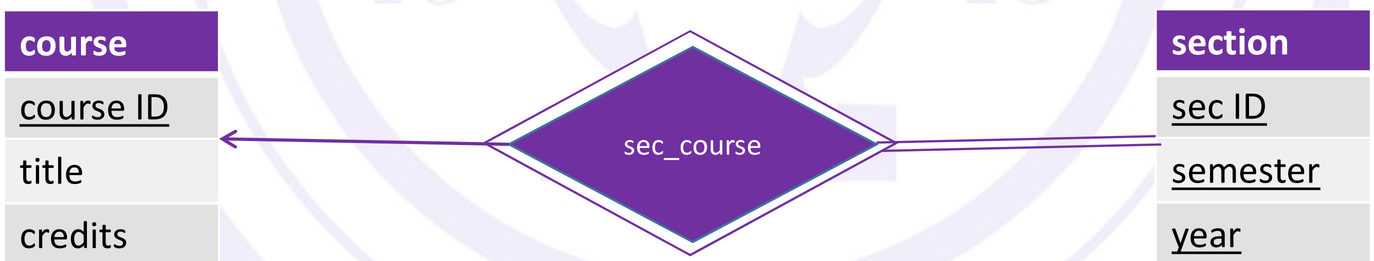
    1. each A entity is associated with a unique entity from B and C or
    2. each pair of entities from (A, B) is associated with a unique C entity, and each pair (A, C) is associated with a unique B
  - Each alternative has been used in different formalisms
  - To avoid confusion we outlaw more than one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

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.

Weak Entity Sets

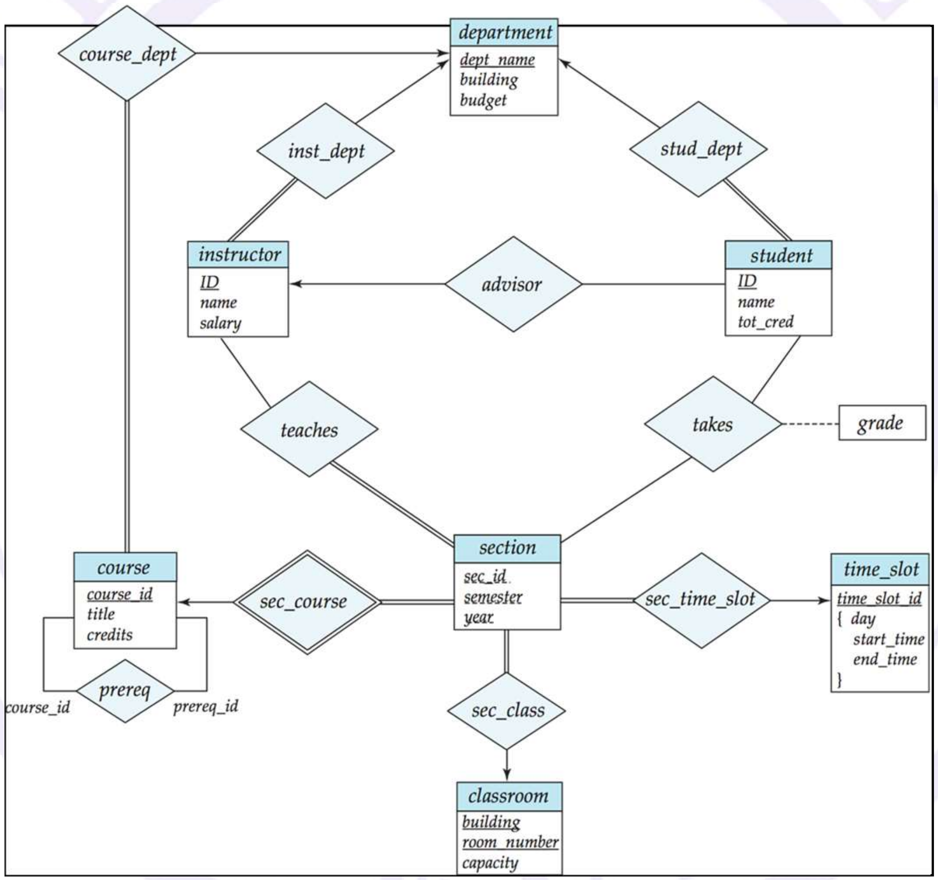
- We underline the discriminator of a weak entity set with a dashed line.
- We put the identifying relationship of a weak entity in a double diamond.
- Primary key for *section* – (*course_id, sec_id, semester, year*)



Weak Entity Sets

- 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

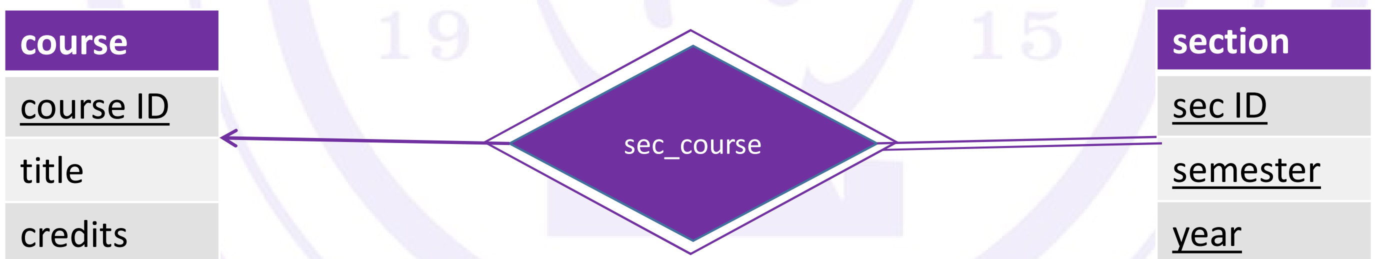


Reduction to Relation Schemas

- 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(<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>)

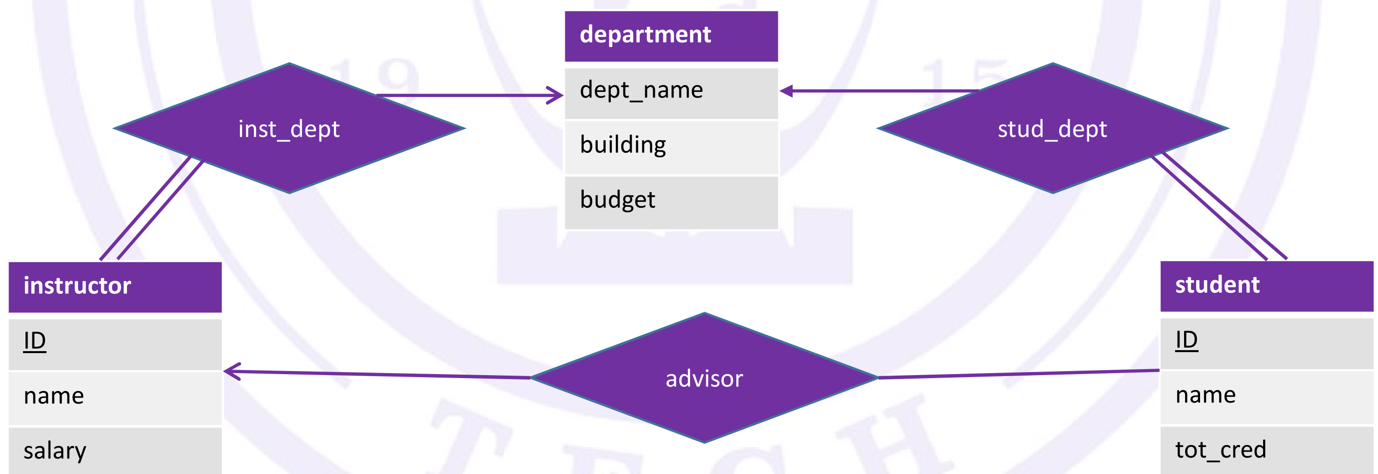


Representing Relationship Sets

- 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

- 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 ( )

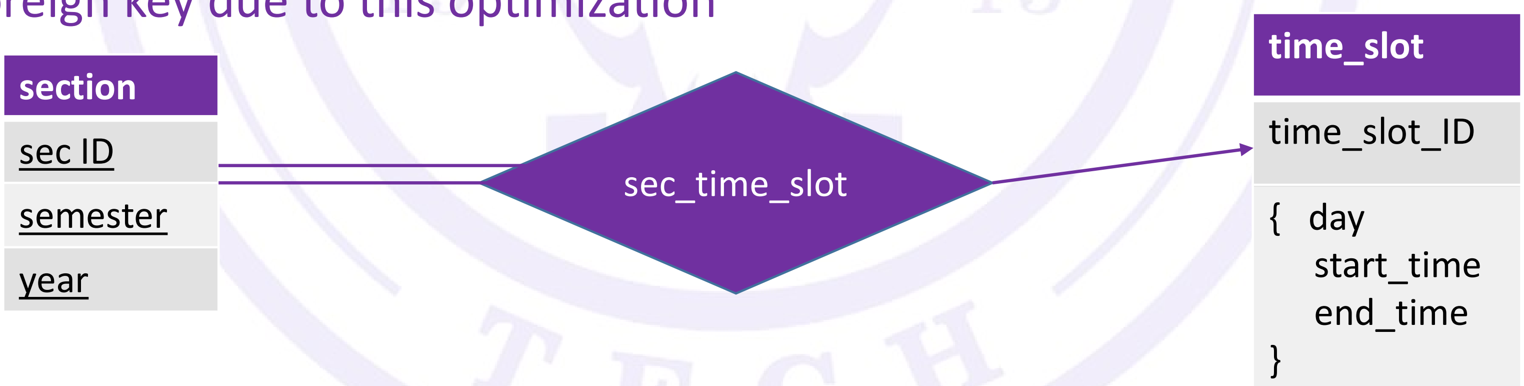
- Composite attributes are flattened out by creating a separate attribute for each component attribute
  - Example: given entity set instructor with composite attribute name with component attributes first_name and last_name the schema corresponding to the entity set has two attributes name_first_name 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

- 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

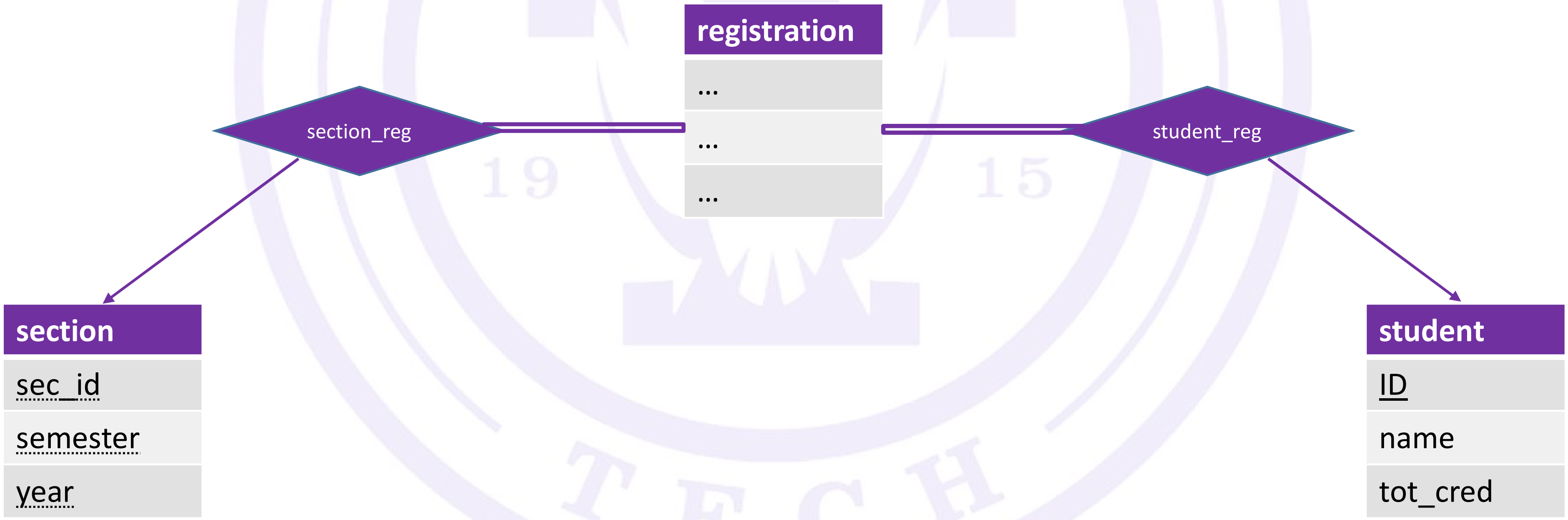
- Use of entity sets v attributes

instructor
<u>ID</u>
name
salary
phone_num

- 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



Design Issues

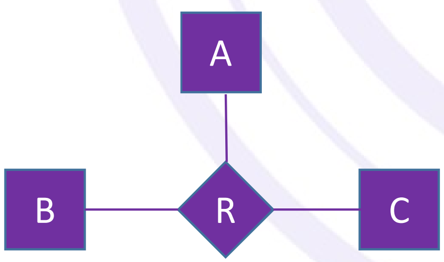
- Binary versus n-ary relationship sets
  - Although it is possible to replace any nonbinary (*n*-ary, for $n > 2$) relationship set by a number of distinct binary relationship sets, a *n*-ary relationship set shows more clearly that several entities participate in a single relationship.
- Placement of relationship attributes
  e.g., attribute date as attribute of advisor or as attribute of student

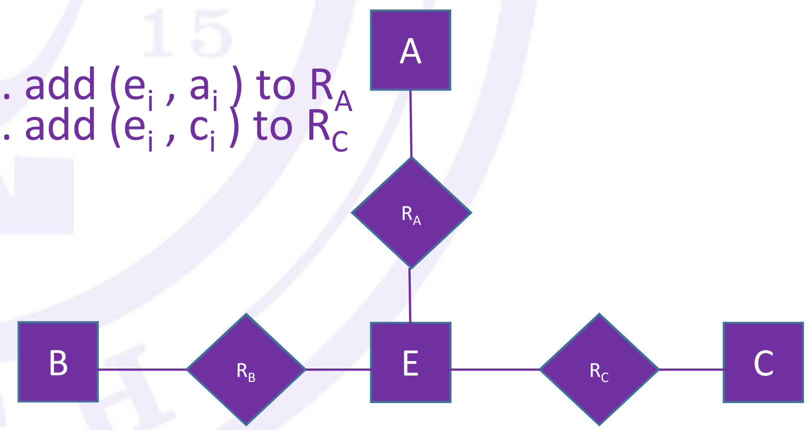
Binary v Non-Binary Relationships

- 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





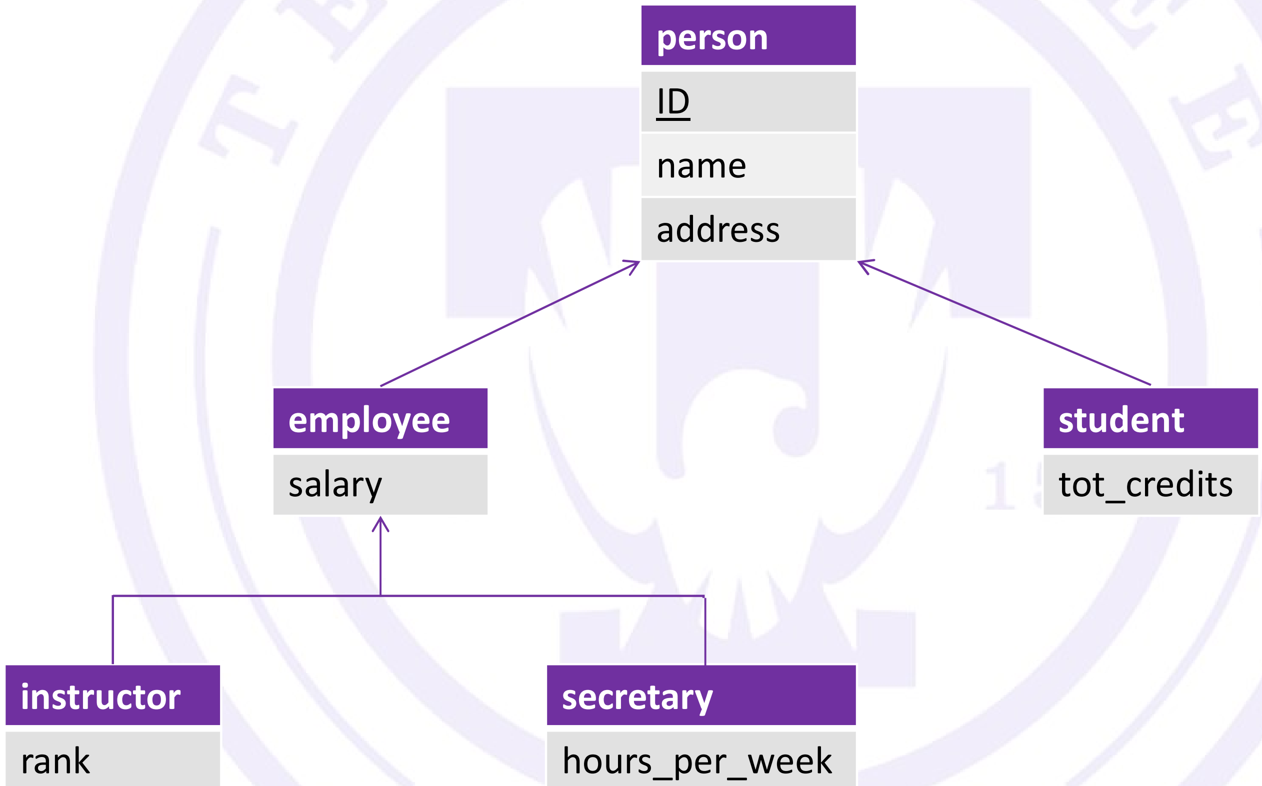
Converting Non-Binary Relationships

- 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



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

- 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 Specialization and Generalization

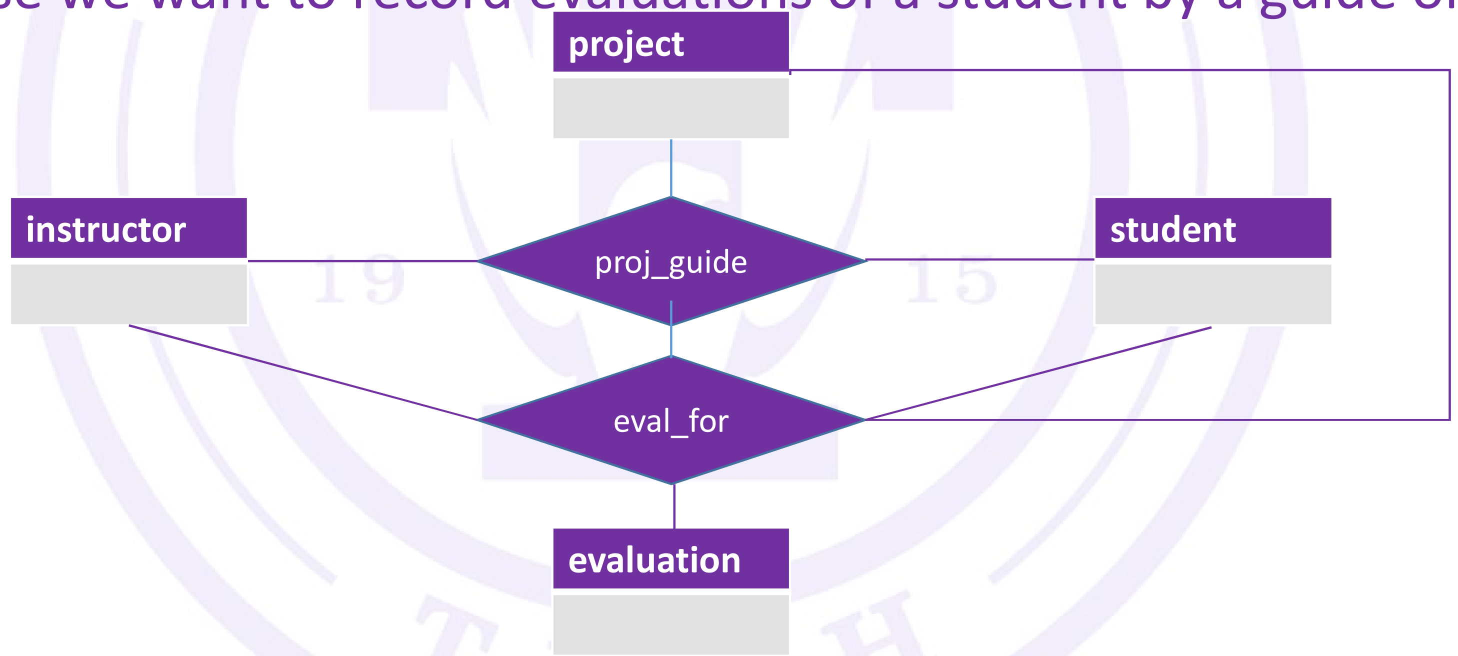
- Constraint on which entities can be members of a given lower-level entity set.
  - Condition-defined
    - Example: all customers over 65 years are members of senior-citizen entity set; senior-citizen ISA person.
  - User-defined
- Constraint on whether or not entities may belong to more than one lower-level 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

Design Constraints on Specialization and 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

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

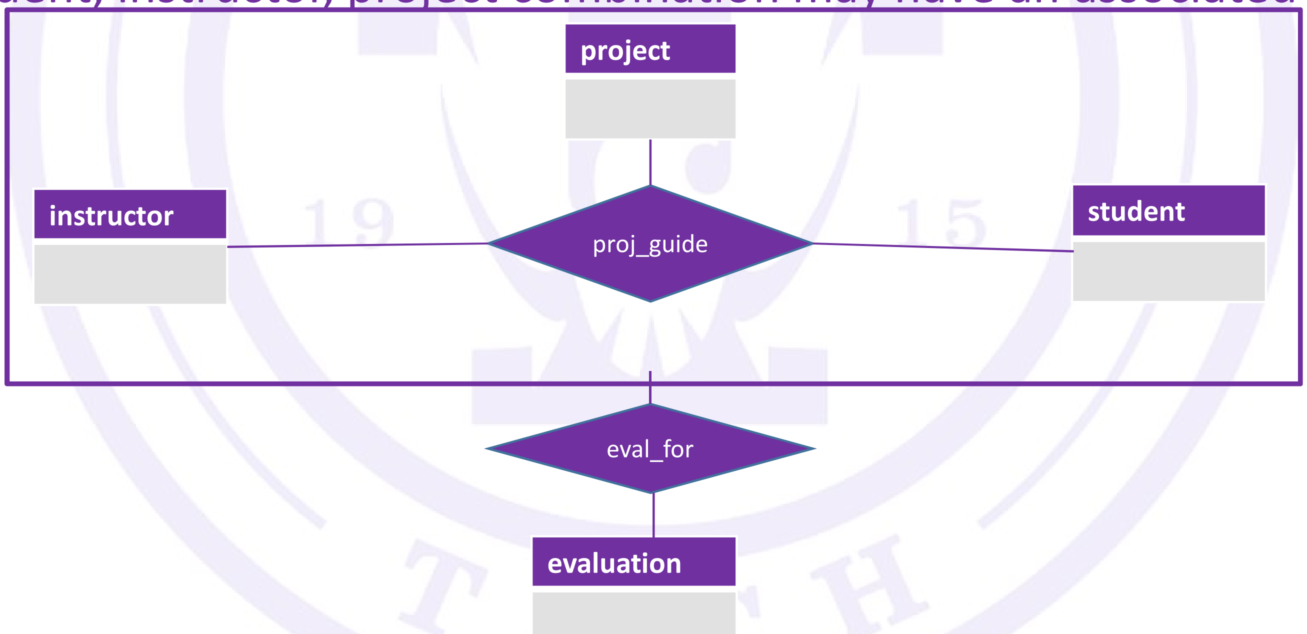


Aggregation

- 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

- 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 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, name, street, city, tot_cred
employee	ID, name, street, city, 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

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

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

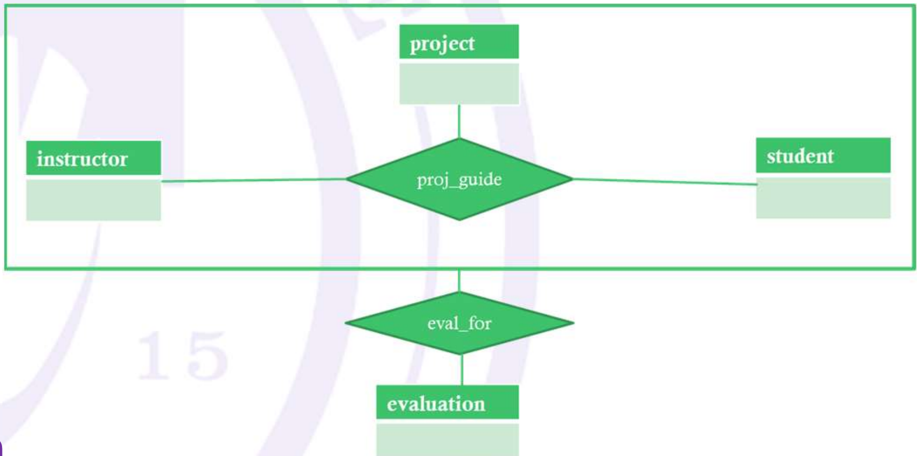
  - If specialization is total, the schema for the generalized entity set (*person*) not required to store information
    - Can be defined as a "view" relation containing union of specialization relations
    - But explicit schema may still be needed for foreign key constraints
  - Drawback: *name, street*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

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

- 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)
- Schema proj_guide is redundant provided we are willing to store null values for attribute manager_name in relation on schema manages



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.

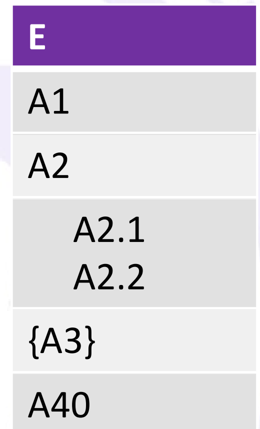
Summary of Symbols Used in E-R Notation

entity set

relationship set

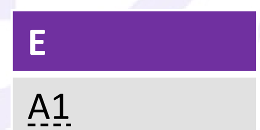
identifying relationship set
for weak entity set

total participation of entity
set in relationship



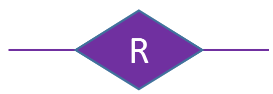
attributes:
simple (A1),
composite (A2) and
multivalued (A3)
derived (A4)

primary key

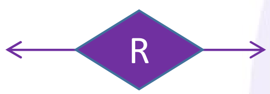


discriminating
attribute of weak
entity set

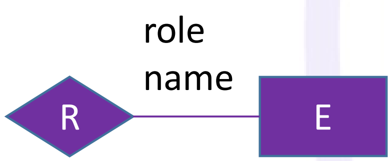
Summary of Symbols Used in E-R Notation



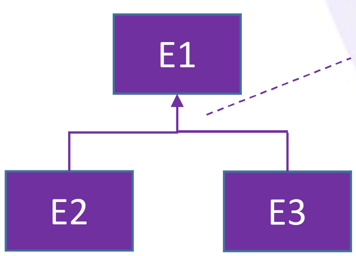
many-to-many relationship



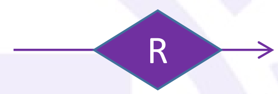
one-to-one relationship



role indicator

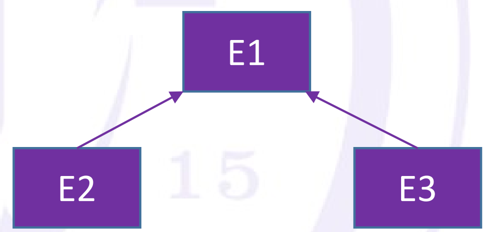


total (disjoint) generalization

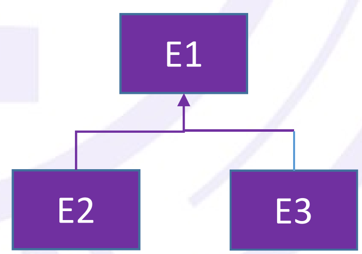


many-to-one relationship

cardinality limits



ISA: generalization or specialization

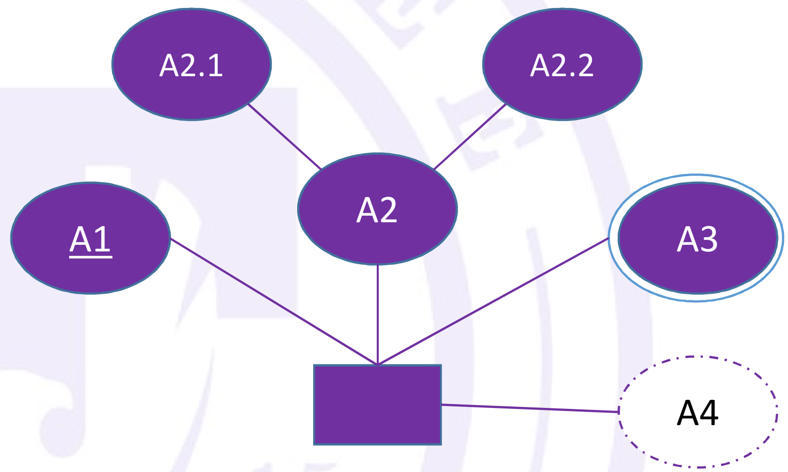


disjoint generalization

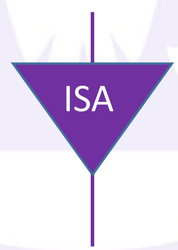
Alternative ER Notations

- Chen, IDE1FX, …

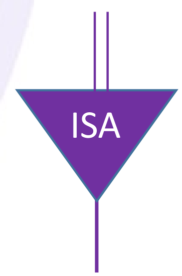
entity set E with simple attribute A1, composite attribute A2, multivalued attribute A3, derived attribute A4 and primary key A1



weak entity set

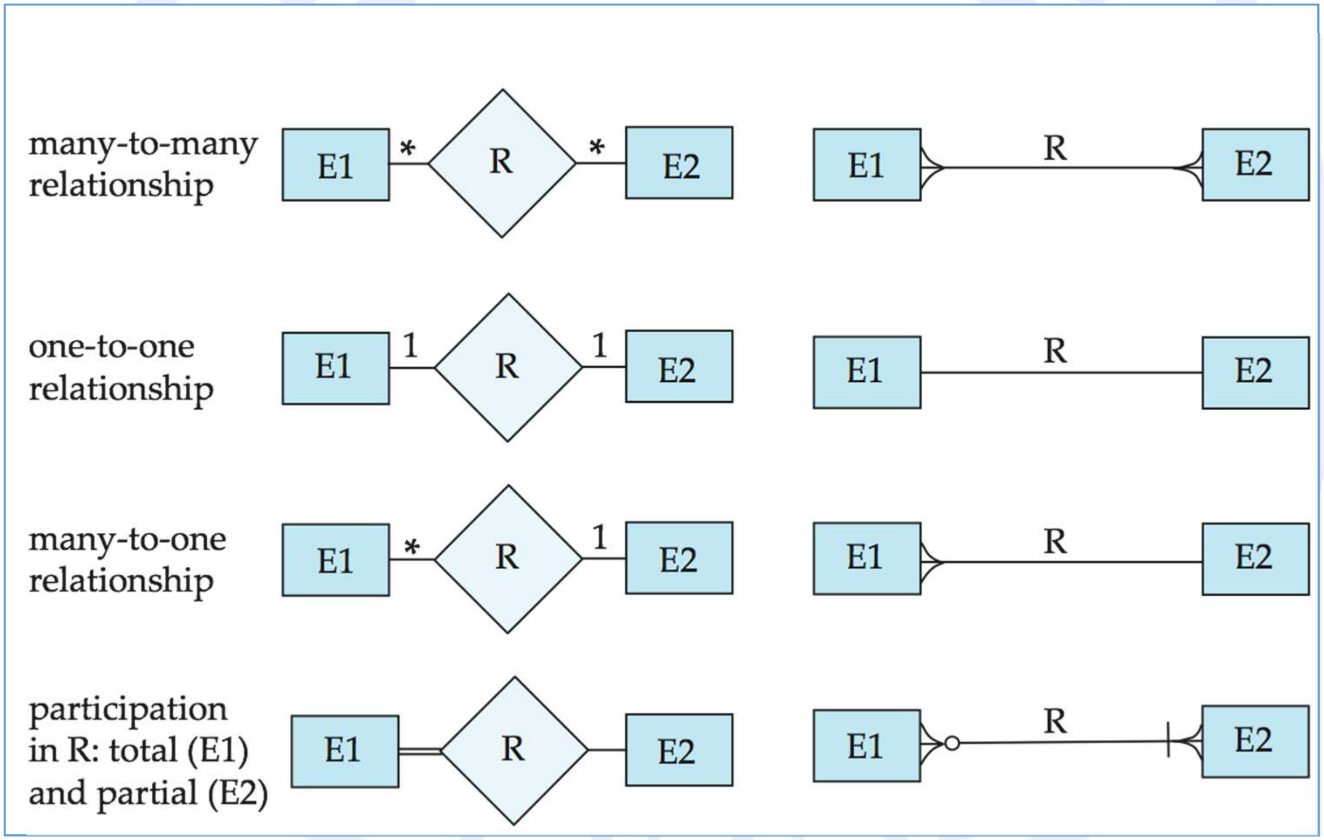


generalization



total generalization

Alternative ER Notations

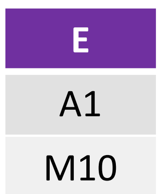


UML

- 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.

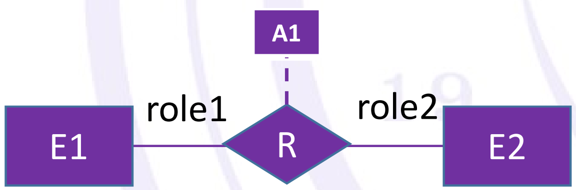
ER v UML Class Diagrams

ER Diagram Notation

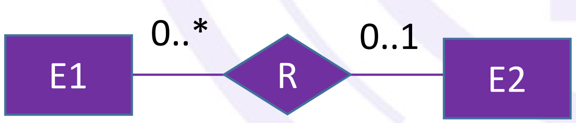


entity with attributes (simple, composite, multivalued, derived)

binary relationship



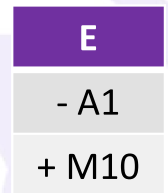
relationship attributes



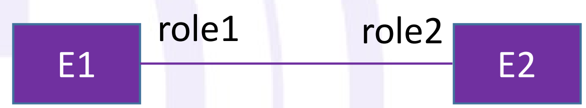
cardinality constraints

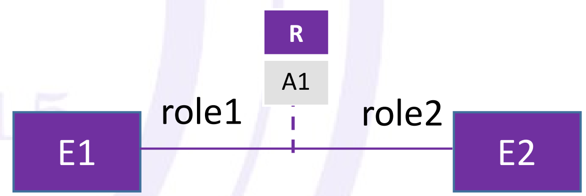
* Note the reversal of position in cardinality constraints depiction

Equivalent in UML



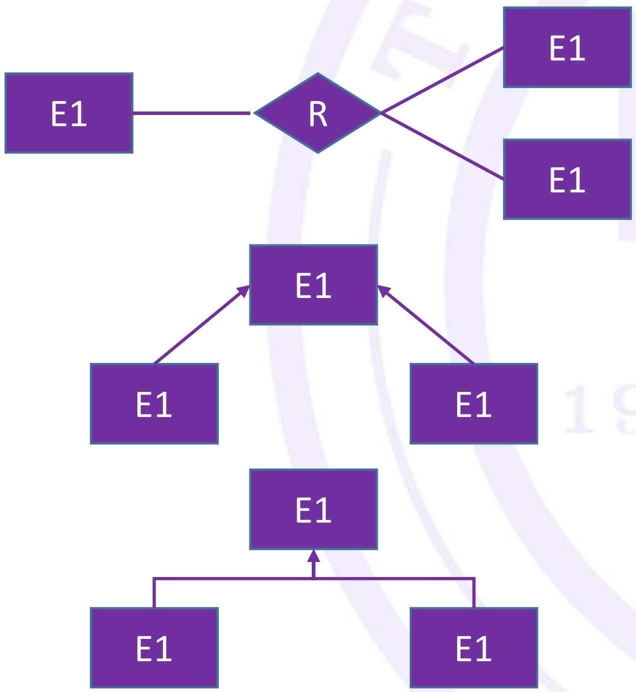
class with simple attributes and methods (attribute prefixes: + = public, - = private, # = protected)





ER v UML Class Diagrams

ER Diagram Notation

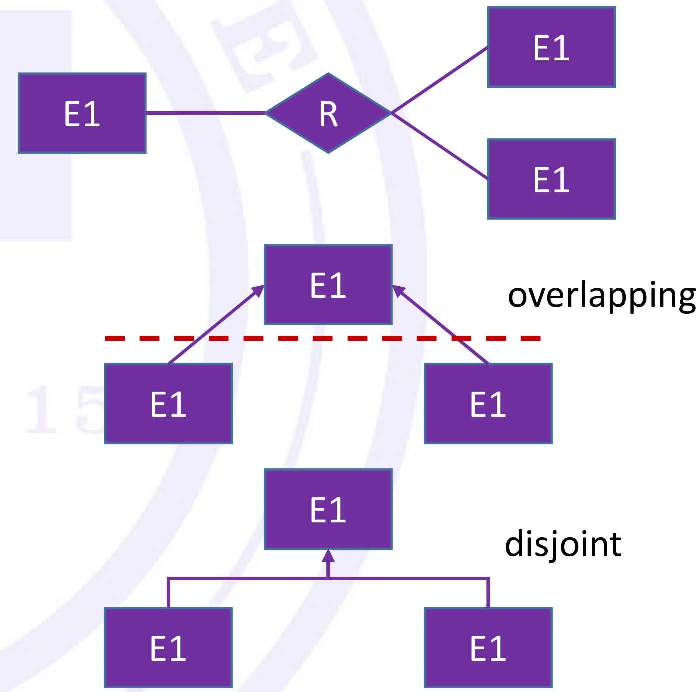


n-ary
relationships

overlapping
generalization

disjoint
generalization

Equivalent in UML



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

ER v UML Class Diagrams

- 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.

End of Chapter 7