Entity Relationship Models

CS460 Databases for Data Scientists

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Previously on
Databases for Data Scientists

- Introduction to Relational Databases
  - A standard model for storing data
  - Using relations/tables
- Introduction to SQL
  - Creating and changing tables
  - Reading and writing data into tables

Today

- Designing databases
  - i.e., how to get from your customer's requirements...
  - ... to a set of tables and attributes

Outline

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- Design Process
- Cardinality Constraints
- ER Diagrams
- Reduction to Relation Schemas
- Design Decisions
- Comparison UML

Database Design

- Initial phase: requirements engineering
  - characterize fully the data needs of the prospective database users
  - which data needs to be stored?
    - ... and in which volumes?
  - which queries should be answered?
- Conceptual schema
  - which types of entities and relations exist?
  - what attributes do they have?

Database Design

- Final phase: from a conceptual to physical data model
  - Logical Design: 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

Database Design Approaches

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- **<u>Today</u>**
  Entity Relationship Model
  - 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

- **Next lecture**
  Normalization Theory
  - Formalize what designs are bad, and test for them

Entity Relationship Model

- Dates back to the 1970s
  - Chen, Peter Pin-Shan: *The Entity–Relationship Model – Toward A Unified View of Data*.
    ACM Transactions on Database Systems. 1(1): 9–36, 1976
  - Developed to facilitate database design by allowing the specification of an enterprise schema that represents the overall logical structure of a database

- Toolkit for mapping the meanings and interactions of real-world enterprises onto a conceptual schema
- The ER data model employs three basic concepts:
  - Entity sets,
  - Relationship sets,
  - Attributes
- Associated diagrammatic representation (ER diagram)
  - Graphic expression of the overall logical structure of a database

Entity Sets

- An entity is an object that exists and is distinguishable from other objects
  - Example: Peter Chen, Mannheim, Star Wars
- An entity set is a set of entities of the same type that share the same properties
  - Example: set of all persons, cities, movies
- Each entity is represented by a *set of attributes*
  - 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 identifying each member of the set

Entity Sets – Example

- instructor (instructor_id, instructor_name)
- student (student_id, student_name)

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

instructor

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

student

Relationship Sets

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

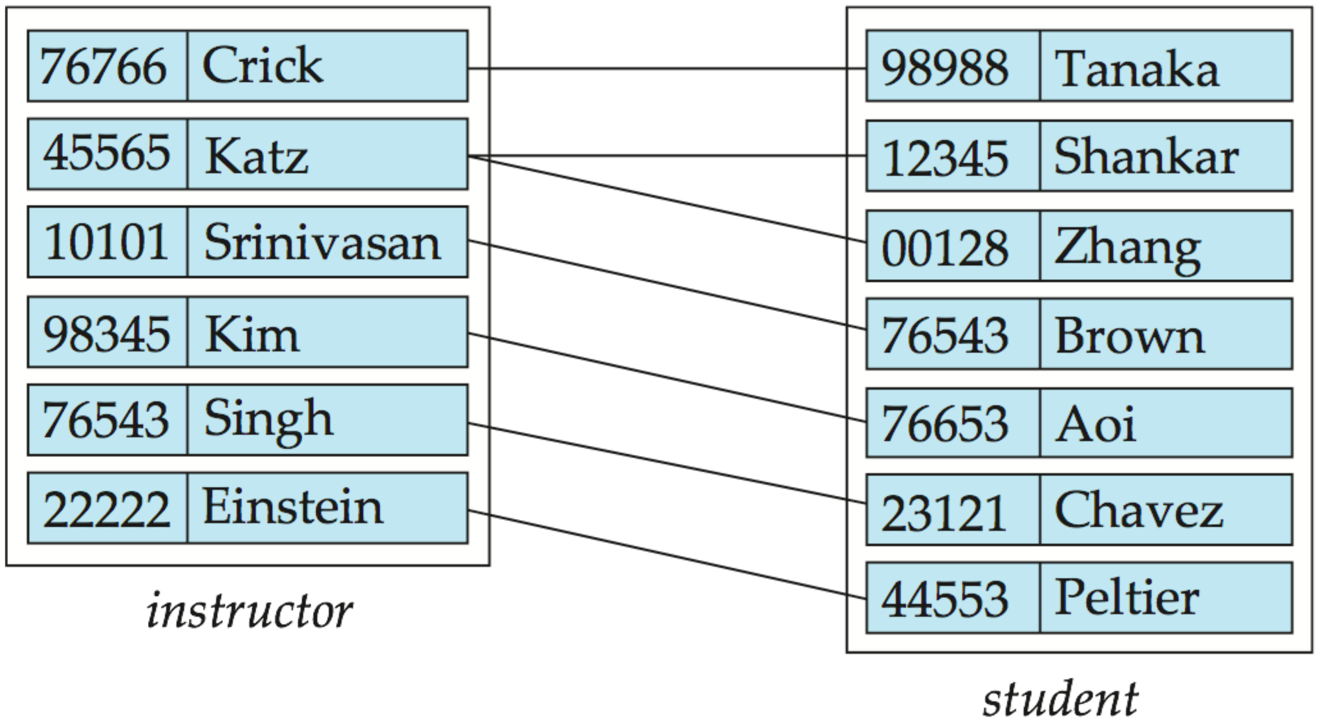
  Example:

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
  $\{(e_1, e_2, \dots e_n) \mid e_1 \in E_1, e_2 \in E_2, \dots, e_n \in E_n\}$
  where $(e_1, e_2, \dots, e_n)$ is a relationship
- Example:

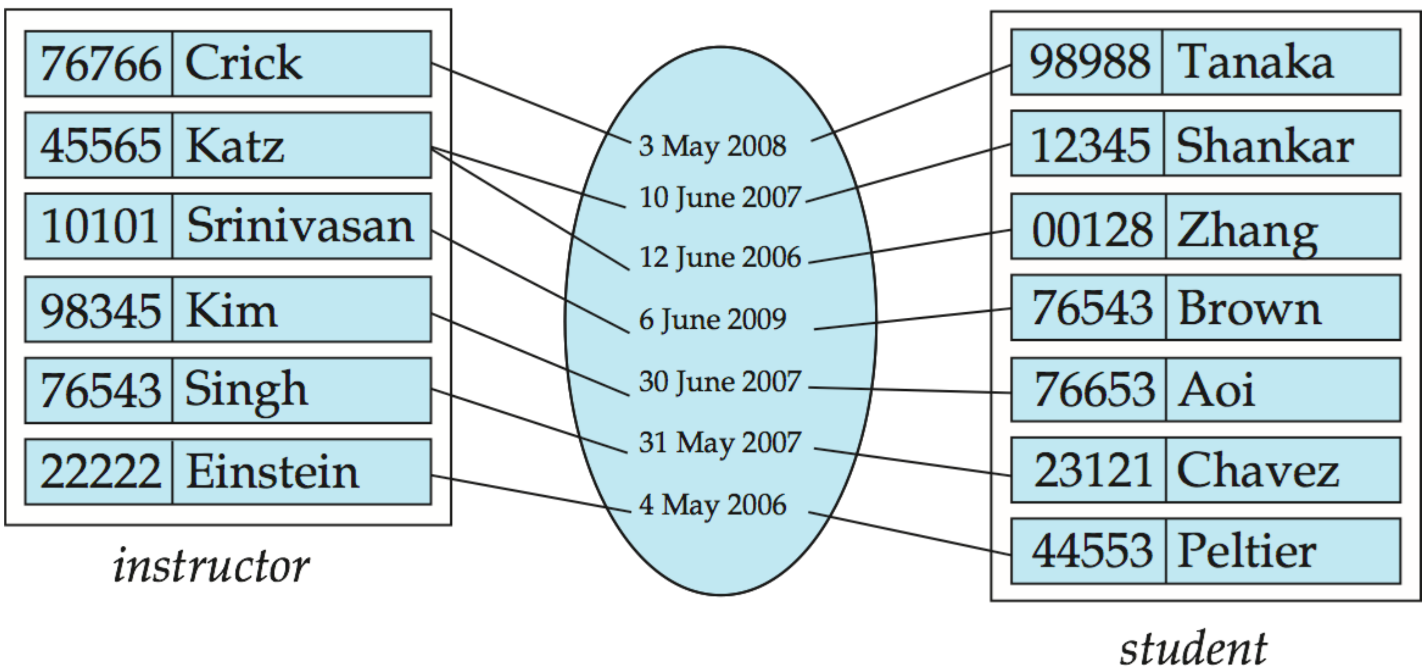
  (44553,22222) $\in$ *advisor*

Relationship Sets



Relationship Sets

- An attribute can also be associated with a relationship set
- E.g., *advisor* relationship set:
  - date which captures the start of the supervision



Degree of a Relationship

- Definition: degree of a relationship
  i.e., number of entity sets that are involved in relation set
- Binary relationship (degree two)
  - Involve two entity sets
  - The by far most frequent case
- Relationships between more than two entity sets (degree >2)
  - e.g.: students work on projects under the guidance of an instructor
  - Relationship proj_guide is a *ternary relationship* between instructor, student, and project
  - Those are rather rare

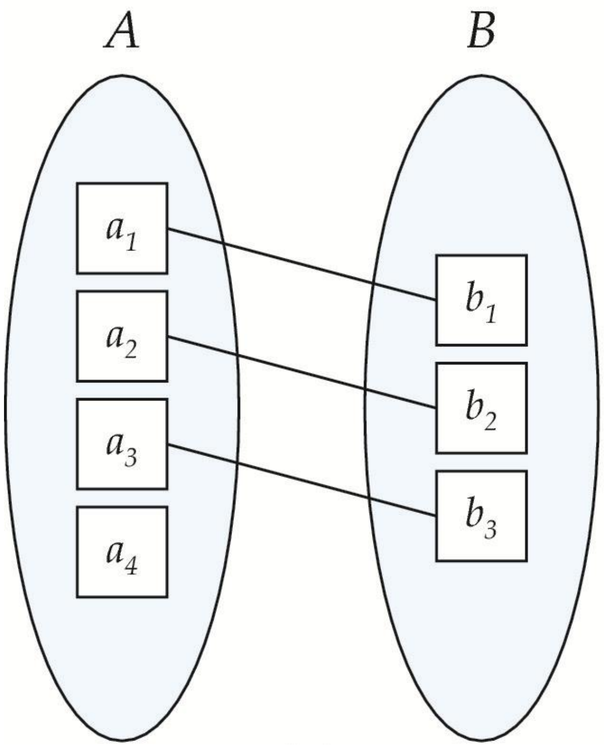
Cardinality Constraints

- 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:
  - 1:1 (one to one)
  - 1:n (one to many)
  - n:1 (many to one)
  - n:m (many to many)

Mapping Cardinalities – One to One

- One to one (1:1)
  - Note: Some elements in A and B may not be mapped to any elements in the other set

- Examples
  - student_works_on_thesis
  - department_has_dean



Mapping Cardinalities – One to Many

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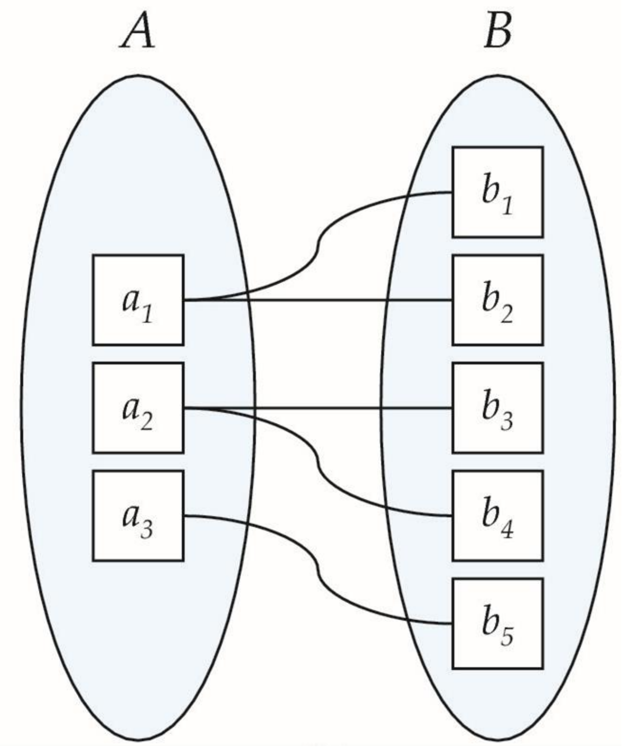
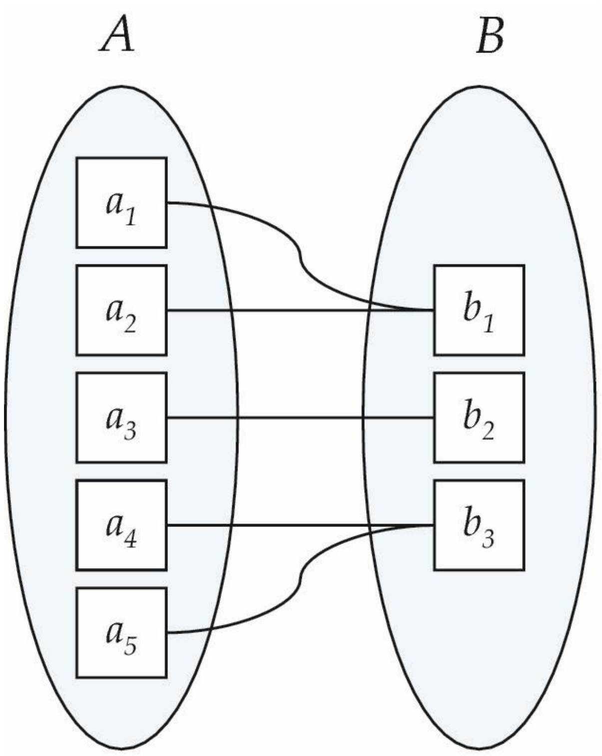
- One to many (1:n)
  - Note: Some elements in A and B may not be mapped to any elements in the other set
- Examples
  - building_has_room
  - faculty_has_member



Mapping Cardinalities – Many to One

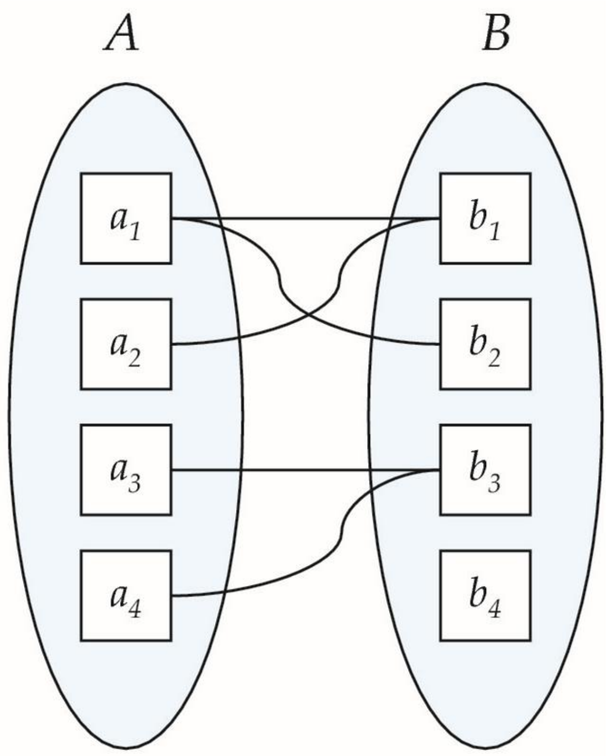
- Many to one (n:1)
  - Note: Some elements in A and B may not be mapped to any elements in the other set
- Examples
  - room_located_in_building
  - member_of_faculty
- Note:
  - the inverse of a 1:n relation is a n:1 relation
  - and vice versa



Mapping Cardinalities – Many to Many

- Many to many (n:m)
  - Note: Some elements in A and B may not be mapped to any elements in the other set

- Examples
  - student_takes_course
  - student_has_advisor



Distinguishing 1:n/n:1 Cardinalities and n:m Cardinalities

- Rule of thumb
  - Always ask for the cardinality the other way around

- "A building may have multiple rooms..."
  - "...but can a room be in multiple buildings?"
  - No → building_has_room is 1:n

- "A department can be located in multiple buildings..."
  - "...but can a building host multiple departments?"
  - Yes → department_located_in_building is n:m

Relation Sets from the Same Entity Set

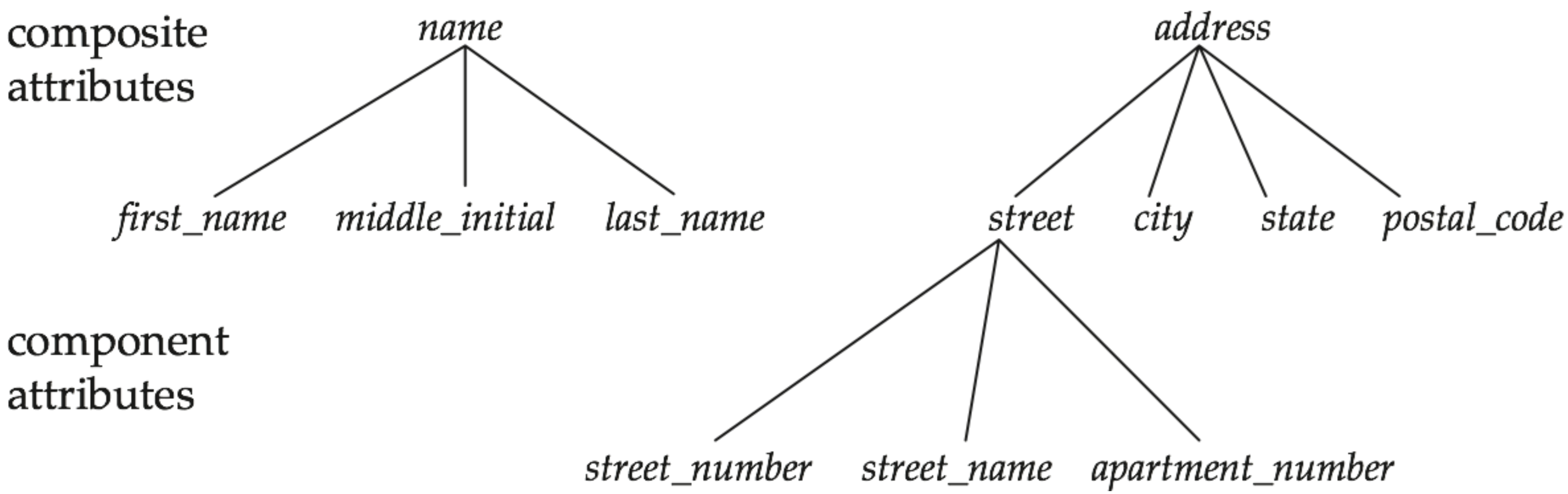
- The two entity sets in a relation set may be the same
- This holds independently from the cardinality!

- person_married_to_person
  - 1:1
- person_is_father_of_person
  - 1:n
- person_has_father
  - n:1
- person_is_parent_of_person
  - n:m

Attribute Types & Domains

- Attribute types:
  - Simple and composite attributes
  - Single-valued and multi-valued attributes
    - Example: multi-valued attribute: phone_numbers
- Derived attributes
  - Can be computed from other attributes
  - Example: age (given date_of_birth)
- Domain – the set of permitted values for each attribute

Composite Attributes



Redundant Attributes

- Suppose we have entity sets:
  - instructor, with attributes: ID, name, dept_name, salary
  - department, with attributes: dept_name, building, budget
- In ERM, instructors and departments are connected by a relation set
  - e.g., instructor_belongs_to_department (ID,dept_name)
- Now, dept_name is no longer needed in the instructor entity set
  - It is redundant there
  - Hence, we will remove it
- *Note:* sometimes, removed redundant attributes are reintroduced when converting the conceptual model into a logical model

Weak Entity Sets

- Consider the set of buildings and rooms
  - Entity set building(building_name,address)
  - Entity set room(number,capacity)
  - Relation set room_in_building (number,building_name)
- Note:
  - As in the previous example, we have removed the redundant attribute *building_name* from the entity set *room*
- Question:
  - What is the primary key of the the entity set *room*?

Weak Entity Sets

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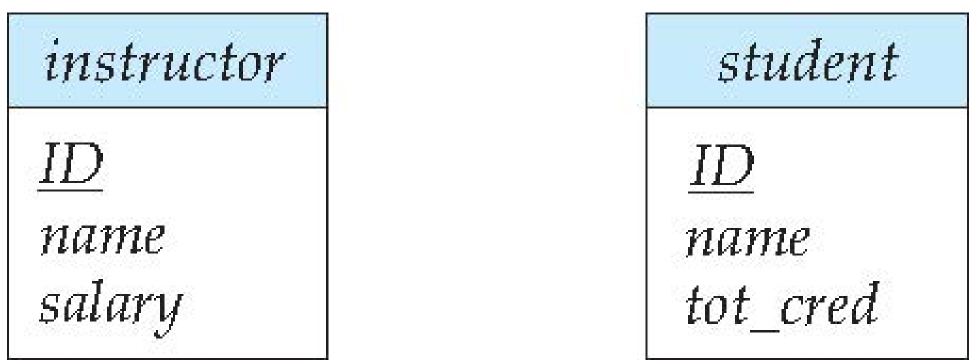
- Weak entity sets are entity sets that
  - Do no not have a set of attributes sufficient to identify each entity uniquely
  - Require an additional relation set to identify each entity uniquely
- Those relation sets are called *identifying relation set*
- Weak entities do not have primary keys
  - A weak entity set has an *identifying entity* and a *discriminator*
  - Example: room(number, capacity)
    - *Building* is the identifying entity
    - *Number* is the discriminator
- A weak entity cannot exist without the identifying entity
  - e.g., a room cannot exist without the building

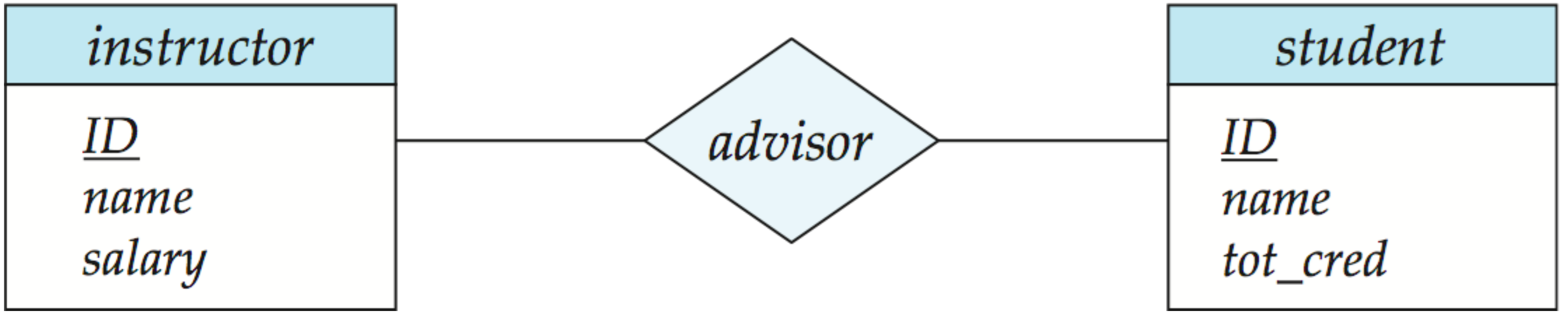
ER Diagrams

- Entity Relationship Diagrams (ER diagrams)
  - Are the graphical notation of entity relationship models
- Notation of entity sets:
  - Rectangles represent entity sets
  - Attributes listed inside entity rectangle
  - Underlining indicates primary key attributes



ER Diagrams

- Diamonds represent relationship sets



ER Diagrams

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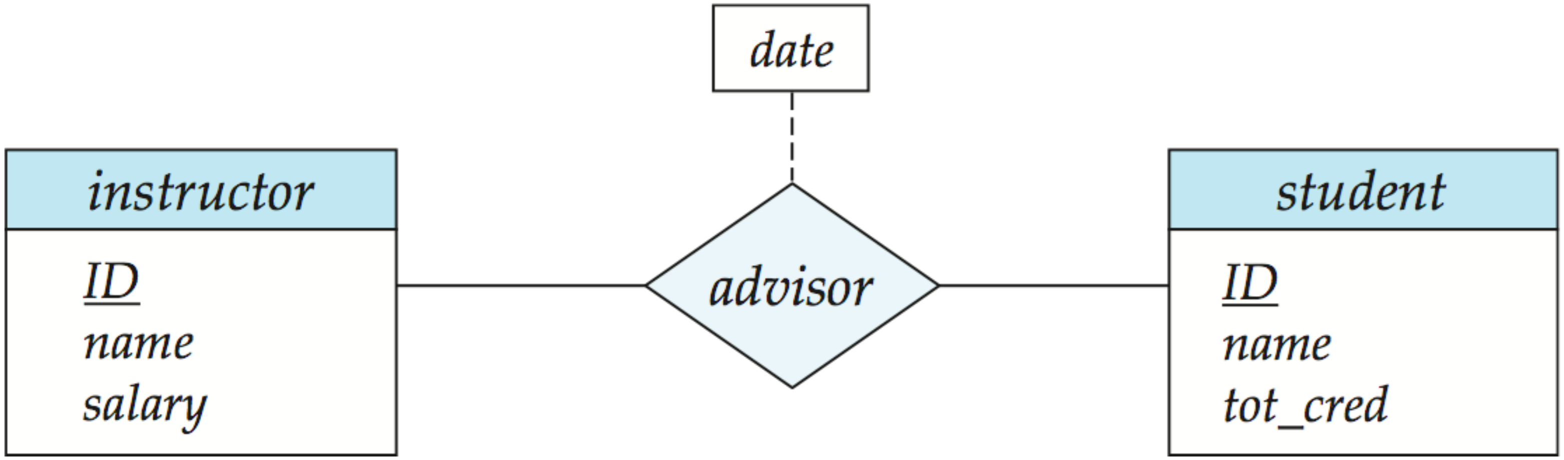
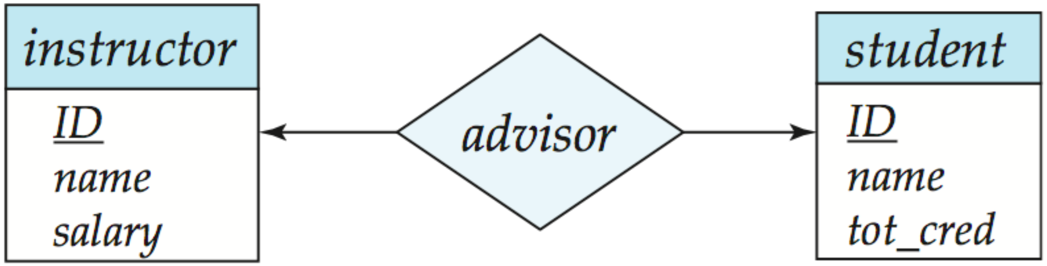
- Diamonds represent relationship sets
  - Attributes can be attached to relationship sets



Cardinalities in ER Diagrams

- We express cardinality constraints by drawing either a directed line (→), signifying "one", or an undirected line (—), signifying "many", between the relationship set and the entity set.
- One-to-one relationship between an instructor and a student:
  - A student is associated with at most one instructor via the relationship advisor
  - An instructor is associated with at most one student via the relationship advisor

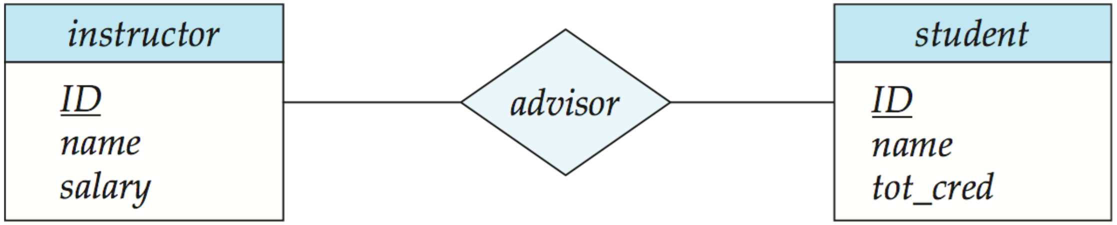


Cardinalities in ER Diagrams

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

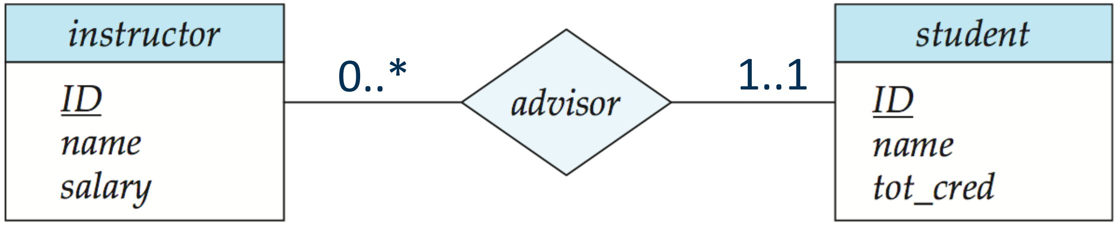
Cardinalities in ER Diagrams

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



Complex Cardinality Constraints

- Notation for minimum/maximum cardinality of a relation
  - Each student has *exactly one* advisor (i.e., min=max=1)
  - Each instructor can be the advisor of multiple students, but needs not be (i.e., min=0,max=∞)
- Notation:
  - min..max
  - * indicates no limit



Roles

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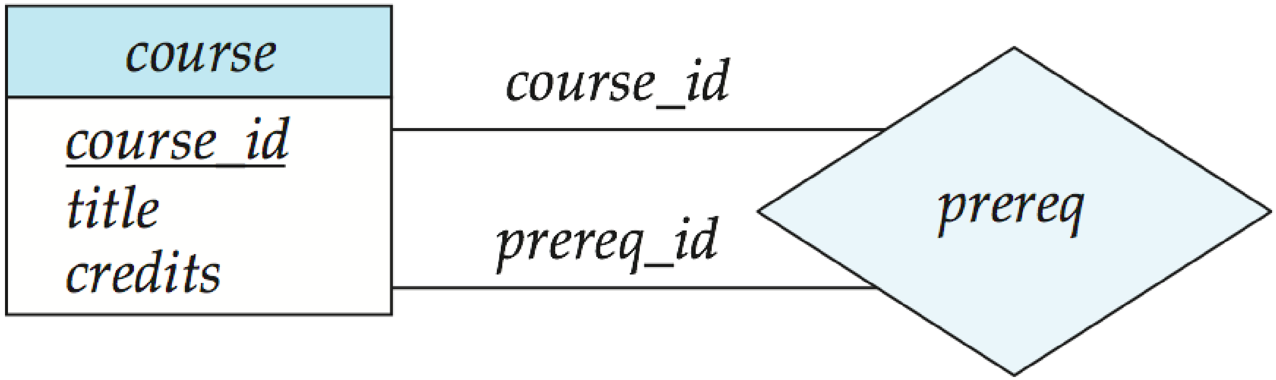
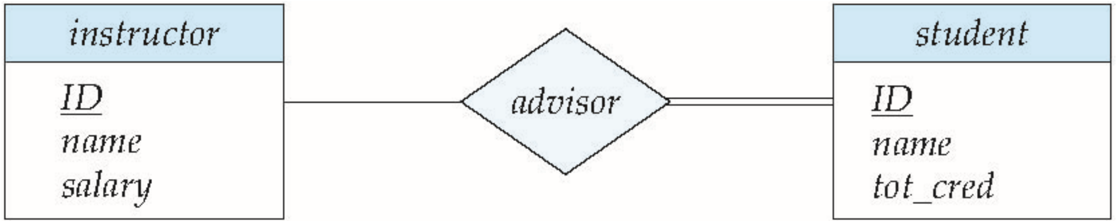
- Entity sets of a relationship need not be distinct
  - i.e., there may be a relationship set involving the same entity set twice
- Each occurrence of an entity set plays a "role" in the relationship
  - The labels "*course_id*" and "*prereq_id*" are called **roles**

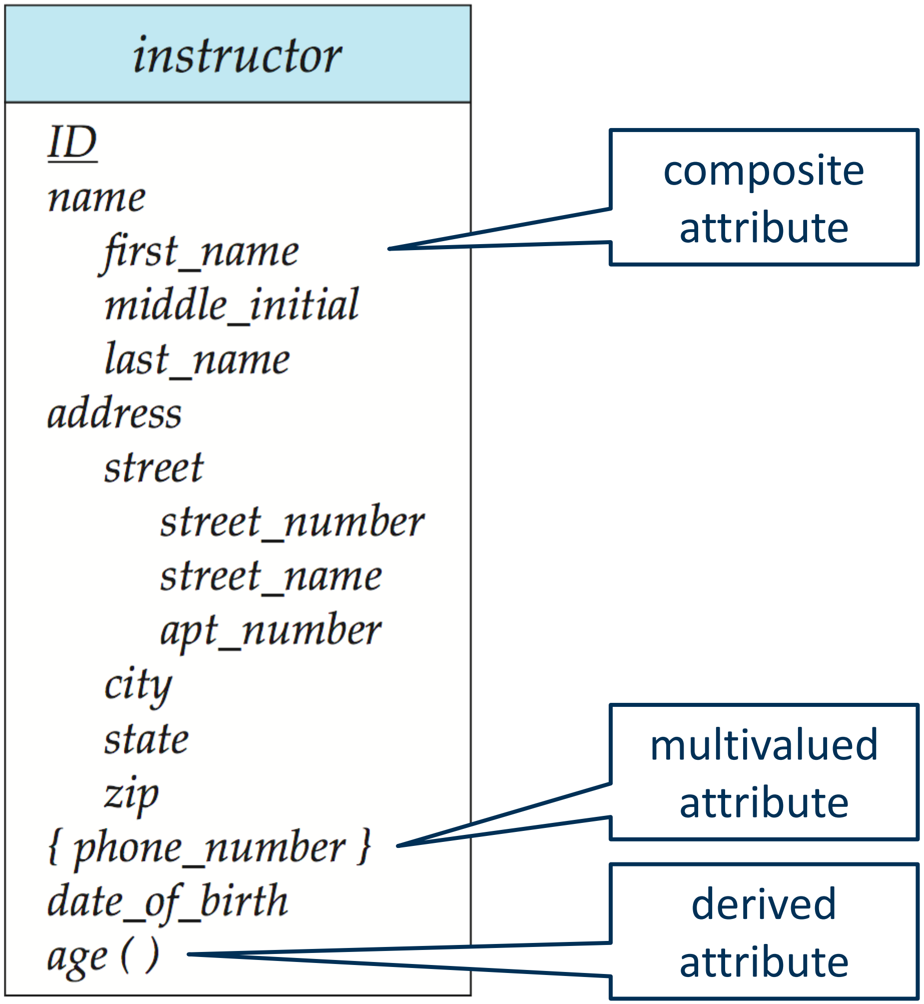


Total and Partial Participation

- Total participation (double line)
  - Every entity in the entity set participates in at least one relationship in the relationship set
  - i.e., every student *must* have an advisor
    - recap: think of *not null* constraints
- Partial participation (single line)
  - Some entities may not participate in the relationship
  - e.g., not every instructor has to supervise a student

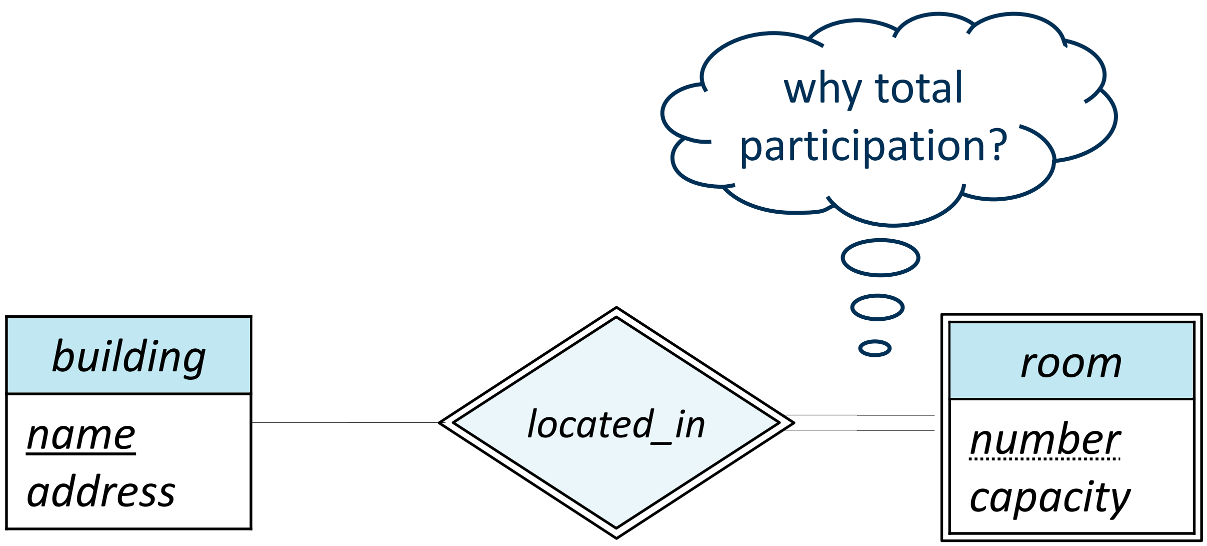


Notation of Attribute Types



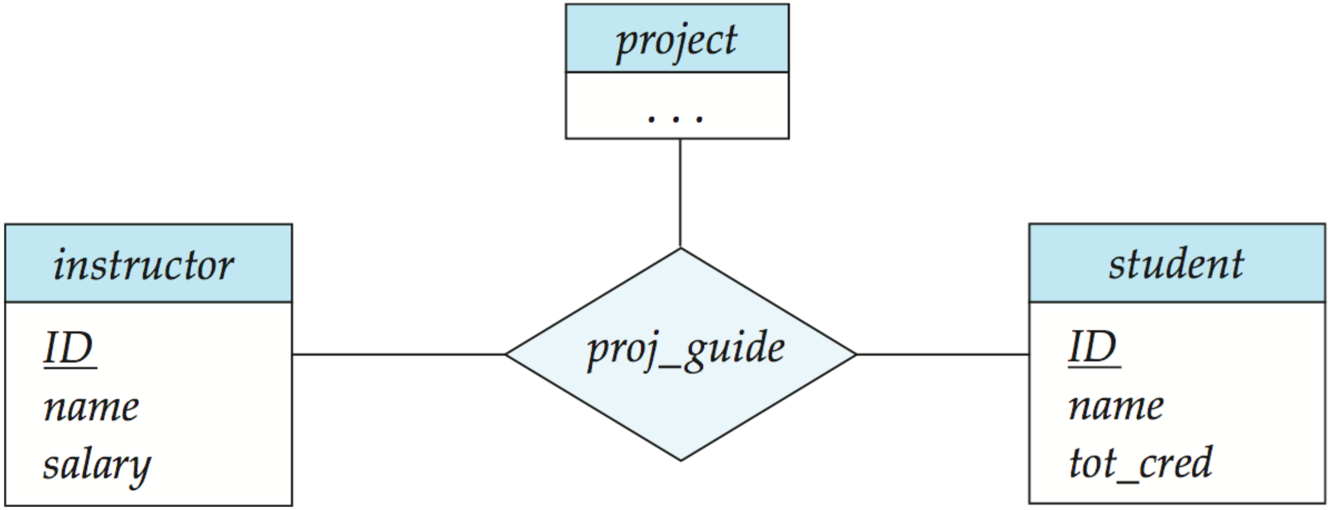
Expressing Weak Entity Sets

- A weak entity set is depicted via a double rectangle
  - The identifying relationship set is depicted by a double diamond
- The *discriminator* is underlined with a dashed line
  - Identifier for room: (number, building.name)



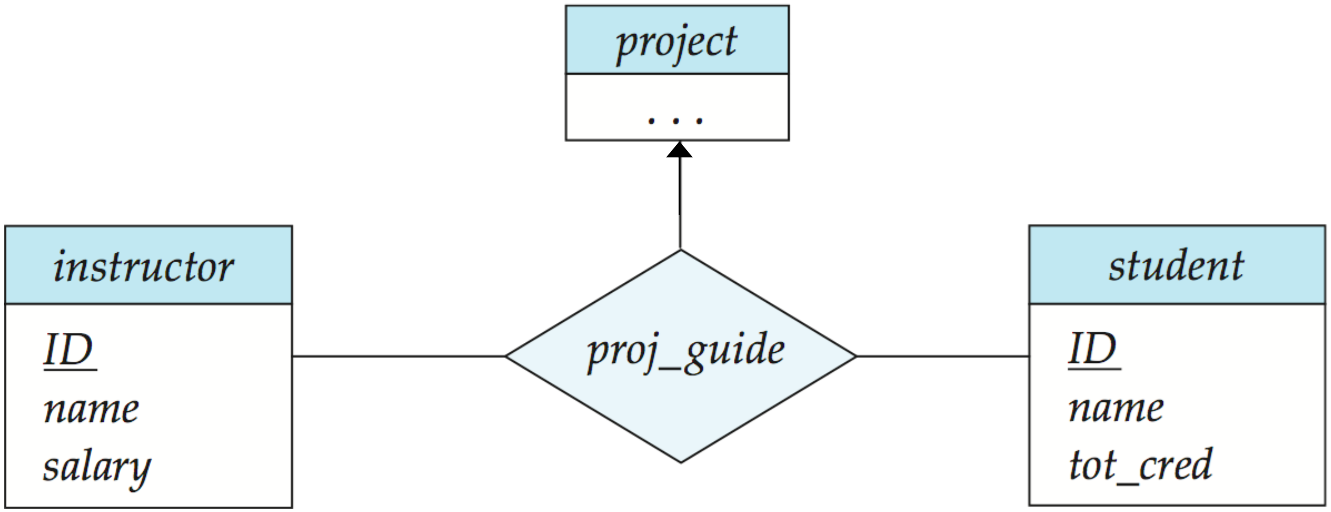
Higher Arity Relationship Sets

- Most relationship sets are binary
- Sometimes, ternary (or higher arity) relations occur
  - ER models support that
- Example:
  - Students work on projects under supervision of an instructor



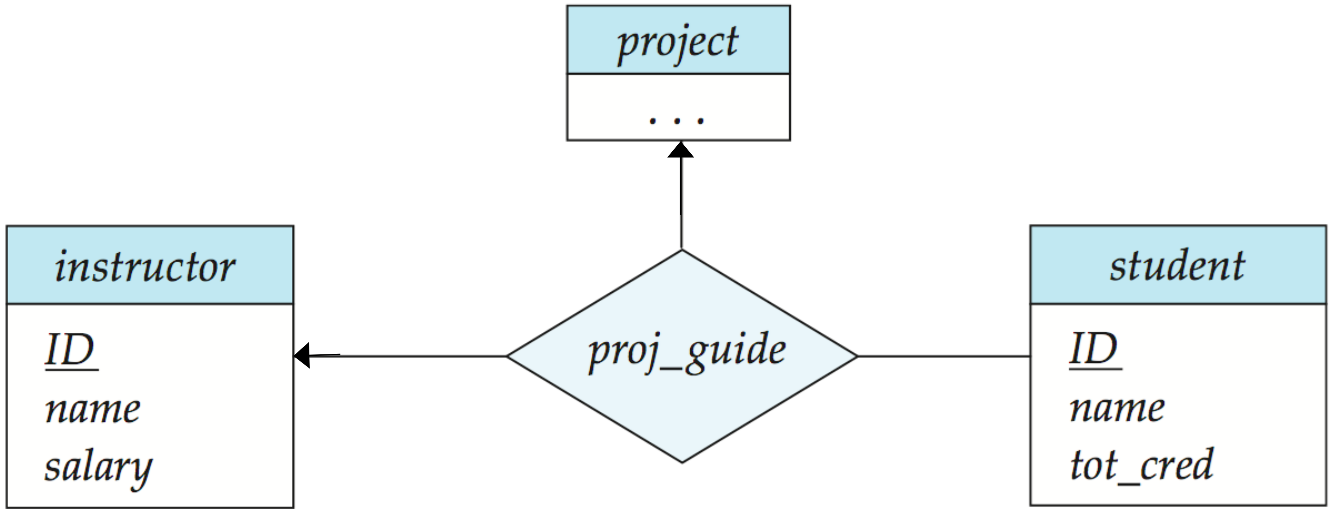
Cardinality Constraints for Ternary Relations

- Only one single arrow (i.e., cardinality restriction) is allowed for a ternary relation
  - Example: each student can work in at most one project under the supervision of some instructor(s)



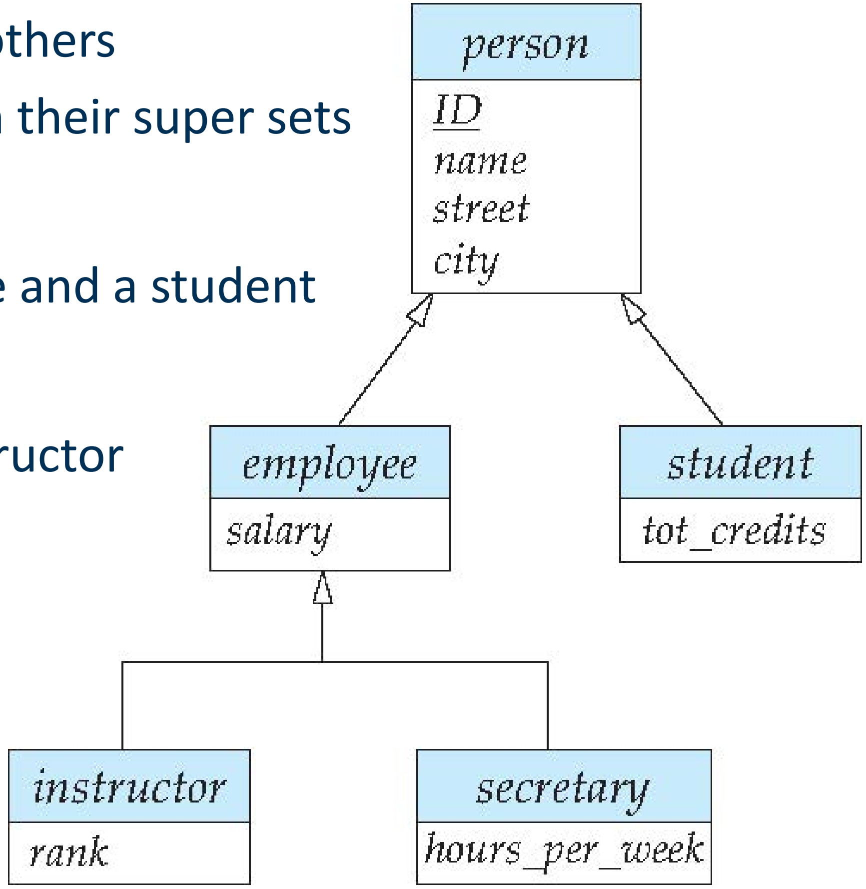
Cardinality Constraints for Ternary Relations

- Multiple single arrows (i.e., cardinality restrictions) would lead to different possible interpretations
  - Each student works on at most one project under at most one instructor
  - For each project a student works on, there is at most one instructor
  - For each instructor supervising a student, there is at most one project
- Hence, we do not allow for them



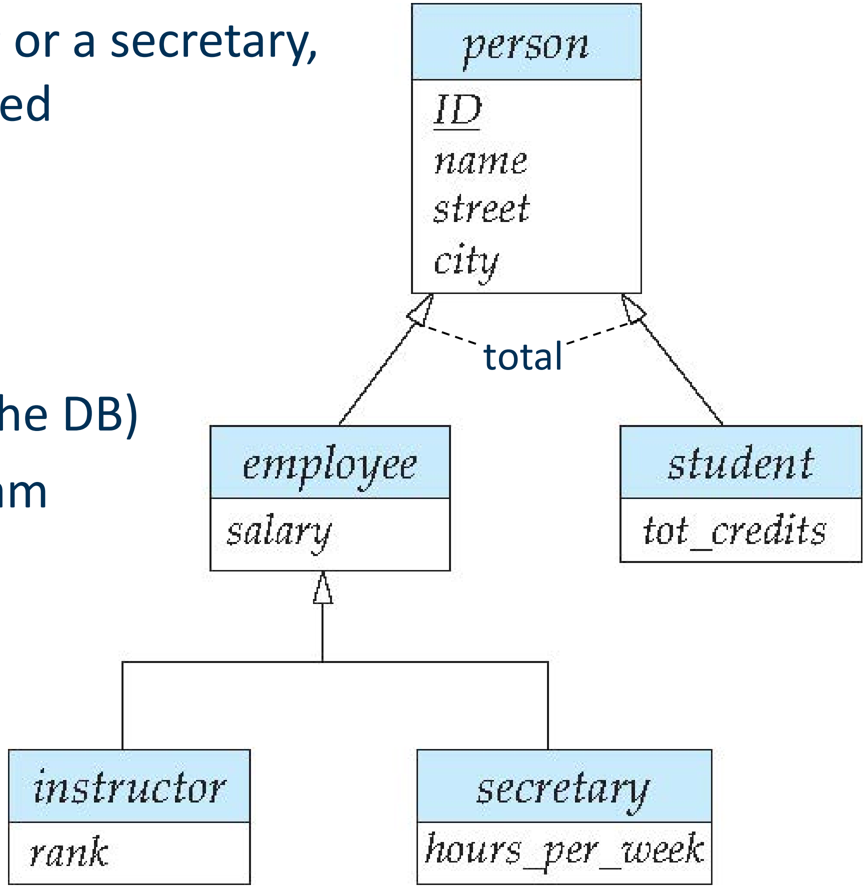
Specialization

- A concept very common in (object oriented) programming
  - Entity sets are sub-/super sets of others
  - They inherit all the attributes from their super sets
- Overlapping
  - A person can be *both* an employee and a student
- Disjoint
  - An employee can be *either* an instructor *or* a secretary



Partial vs. Total Specialization

- Partial specialization
  - An employee may be an instructor or a secretary, or an employee not further specified
  - the default case
- Total specialization
  - There are no other persons than employees and students (in the DB)
  - Needs to be specified in the diagram
  - Analogy in OOP: abstract classes



A Full Example

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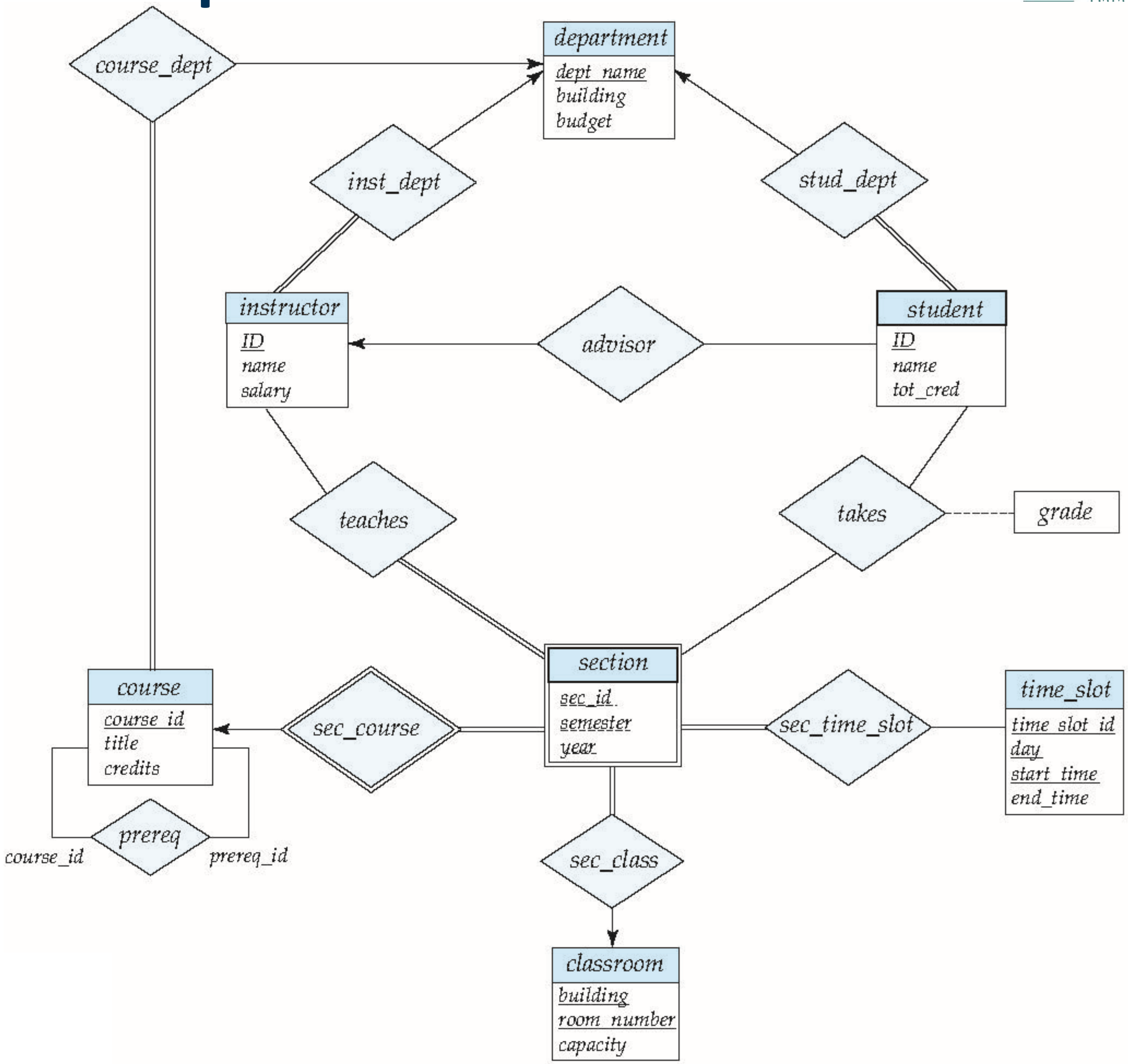


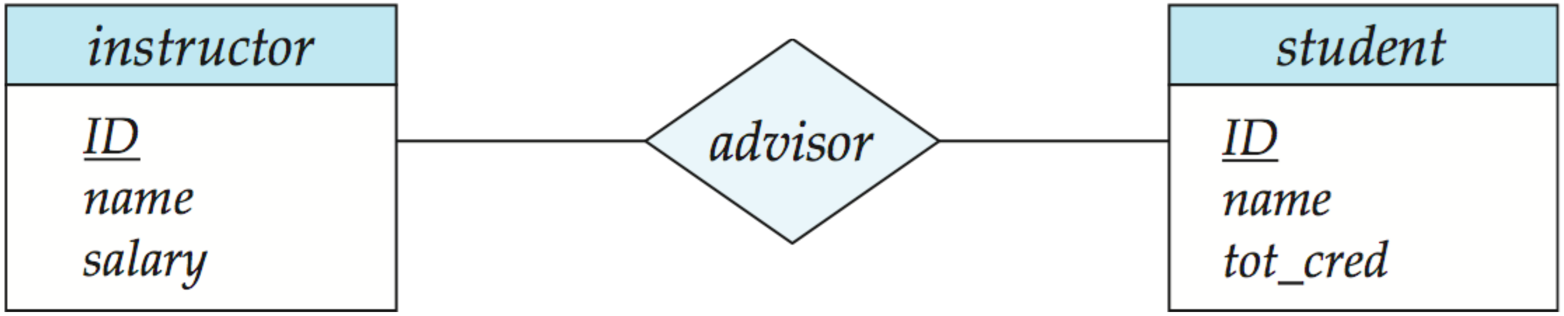
Reduction to Relation Schemas

- How to get to from an ER model to a relational database model?
  - Recap: relational database models consists of relations
- We have
  - Entity sets and relationship sets
- Goal
  - Translate entity and relationship sets uniformly to *relation schemas*
- Mechanism:
  - For each entity set and relationship set there is a unique relation that is assigned the name of the corresponding entity set or relationship set
  - Each relation has a number of columns (generally corresponding to attributes), which have unique names

Representing Relationship Sets

- Many-to-many relationship sets
  - Represented as a relation with attributes for the primary keys of the two participating entity sets
  - They are foreign keys to the individual tables as well
- Example: schema for relationship set *advisor*

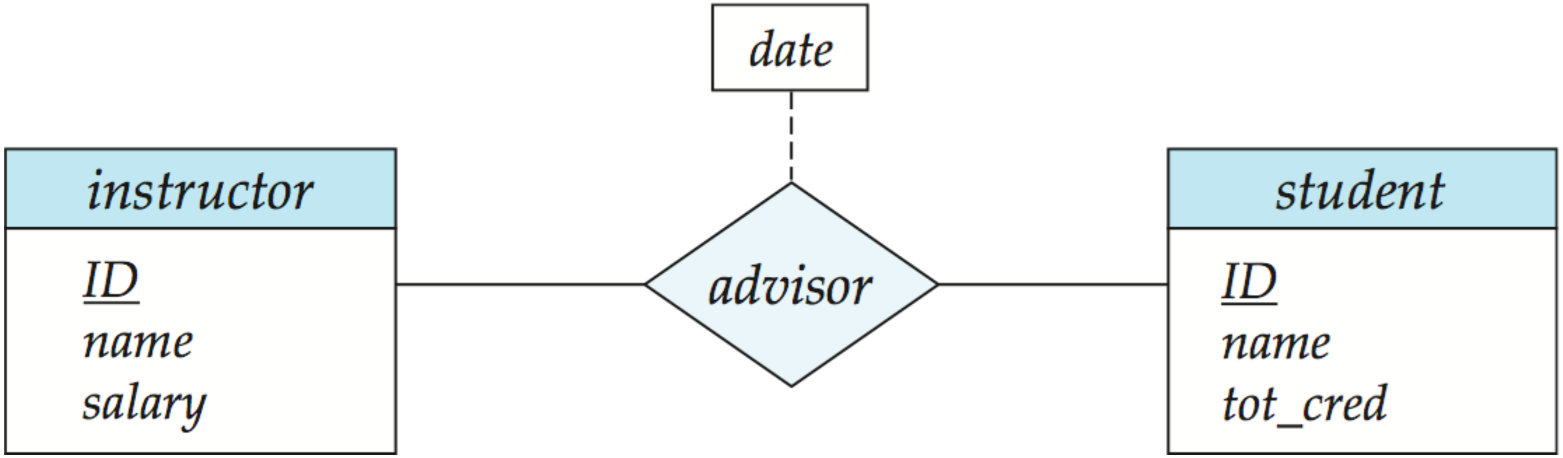
advisor = (*student_ID*, *instructor_ID*)



Representing Relationship Sets

- Many-to-many relationship sets
  - Additional attributes of the relationship set become attributes of the representing relation
- Example: schema for relationship set *advisor*

advisor = (*<u>student_ID</u>*, *<u>instructor_ID</u>*, *date*)

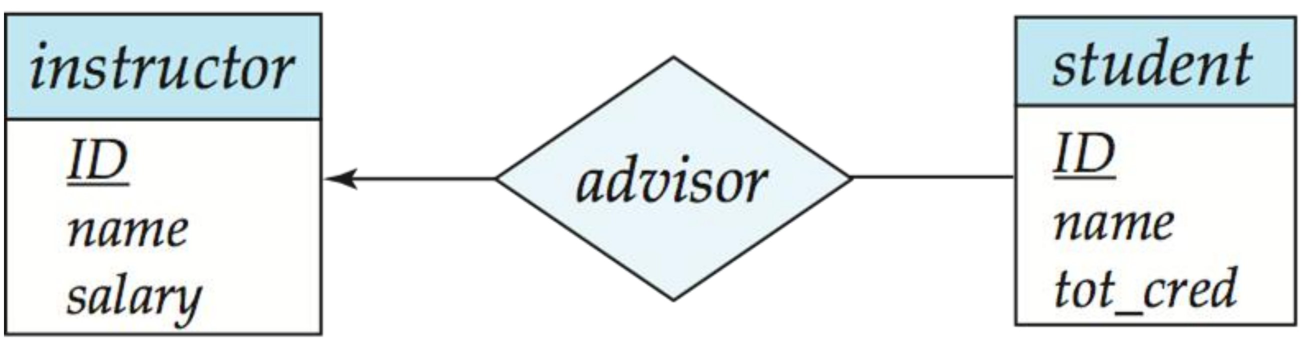


Representing Relationship Sets

- One-to-many relationship sets
  - The primary key of the “one” side can become a foreign key attribute on the “many” side

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

- In case of partial participation, this may cause **null** values



Representing Relationship Sets

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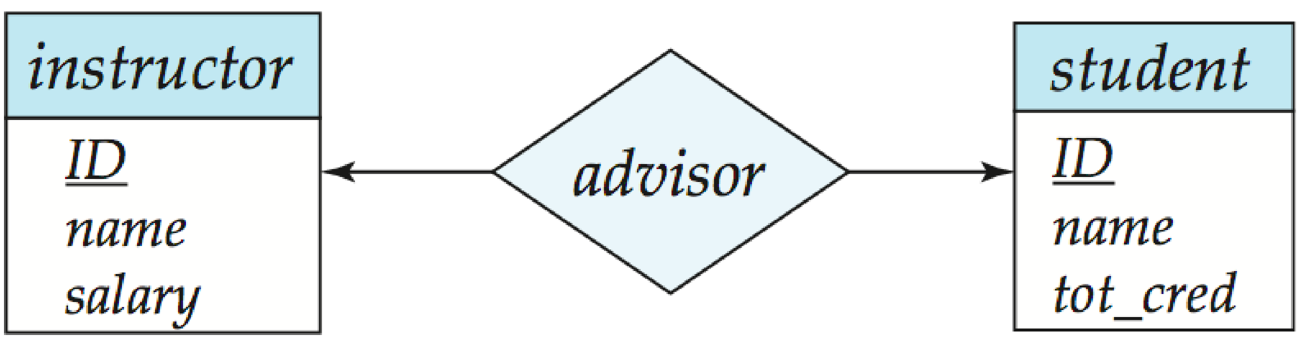
- Special case for one-to-one relationship sets
  - The primary key on one side can be included on the other side

student = (ID, name, tot_cred, instructor_ID) **or**
instructor = (ID, name, salary, student_id)

why not on both sides?

- In case of partial participation, this may cause **null** values



Representing Attributes

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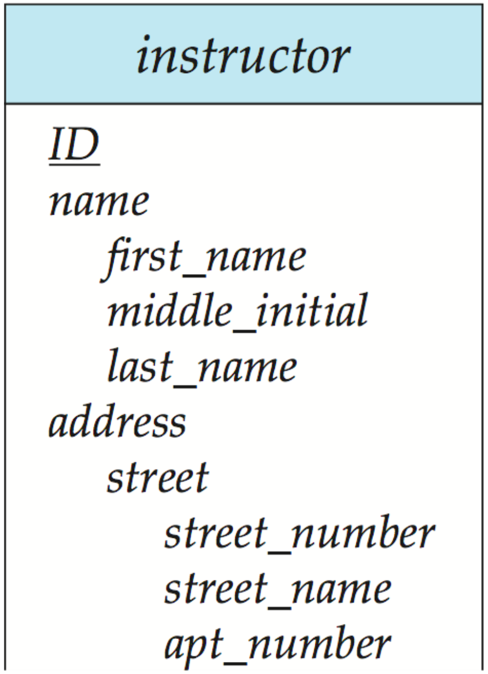
- **Composite attributes** are flattened out by creating a separate attribute for each component attribute
- Add prefix of super attribute in case ambiguous names occur
  - e.g., street_number, phone_number

instructor(ID,
first_name, middle_initial, last_name,
street_number, street_name,
apt_number)



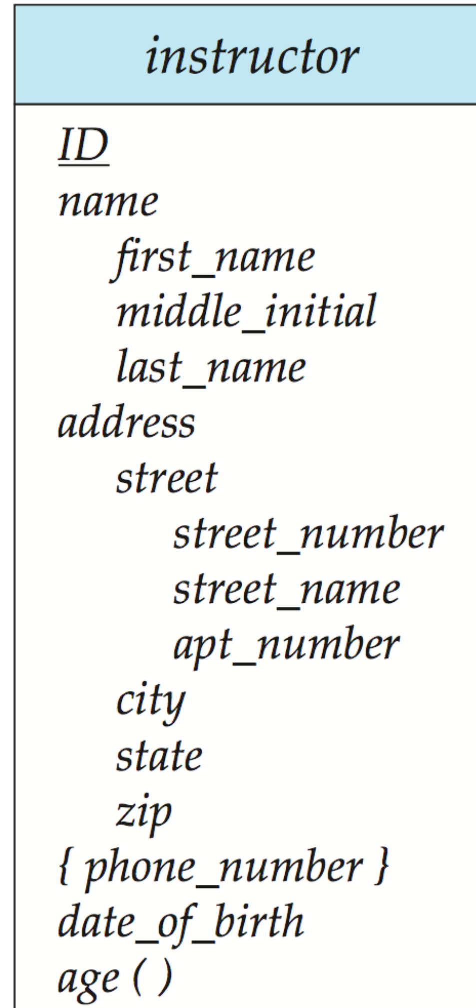
Representing Multi-valued Attributes

- **A multivalued attribute** *M* of an entity *E* is represented by a separate schema *EM*
- Schema *EM* has attributes corresponding to the primary key of *E* and an attribute corresponding to multivalued attribute *M*
  - Example: Multivalued attribute *phone_number* of *instructor* is represented by a schema:
    inst_phone= (*<u>ID</u>*, *<u>phone_number</u>*)
- Each value of the multivalued attribute maps to a separate tuple of the relation on schema *EM*
  - 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)

Representing Derived Attributes

- Derived attributes can be represented as a view
  – Example: age()

```
CREATE VIEW instructor_age AS
    SELECT ID,NOW()-date_of_birth AS age
    FROM instructor
```



Representing Weak Entities

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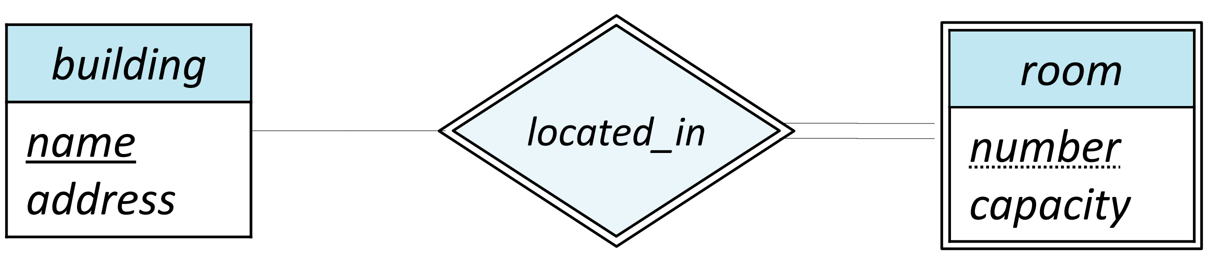
- A strong entity set becomes a relation with the same attributes

  building(<u>name</u>, address)

- A weak entity set becomes a relation that includes
  - the column(s) of the primary key of the identifying strong entity set:
  - room (<u>name</u>, <u>number</u>, capacity)
- At the same time, name is a foreign key
  - which integrity constraints should we use?



Representing Higher Arity Relations

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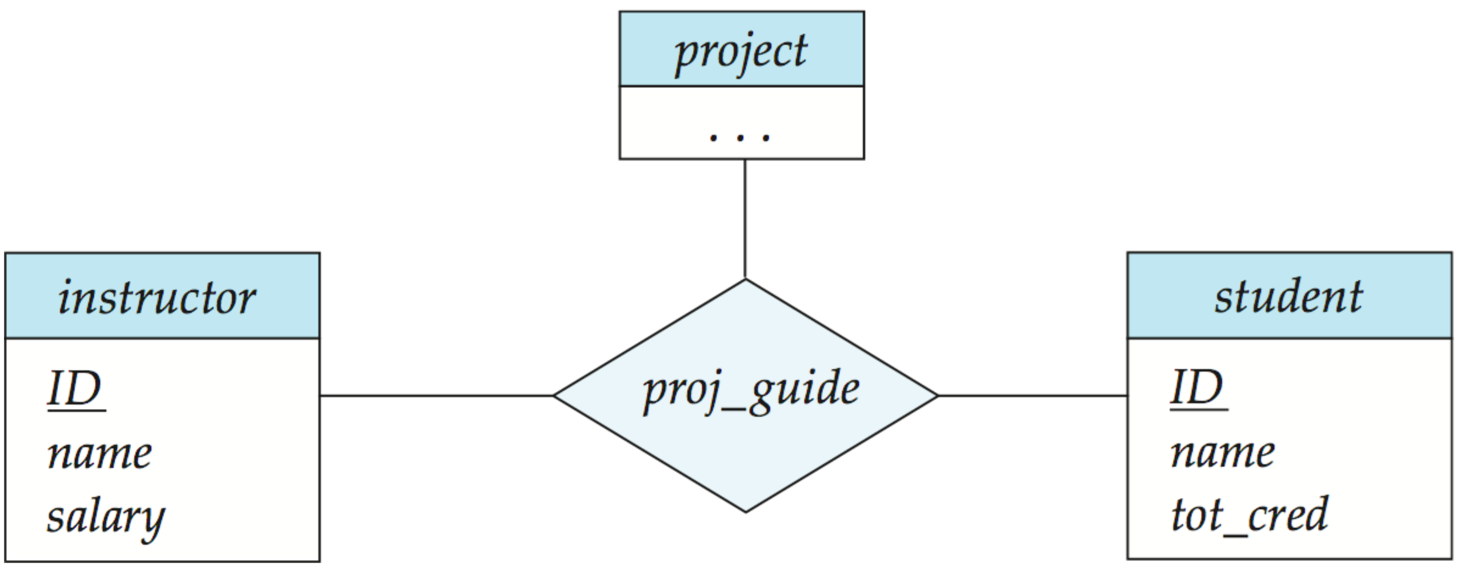
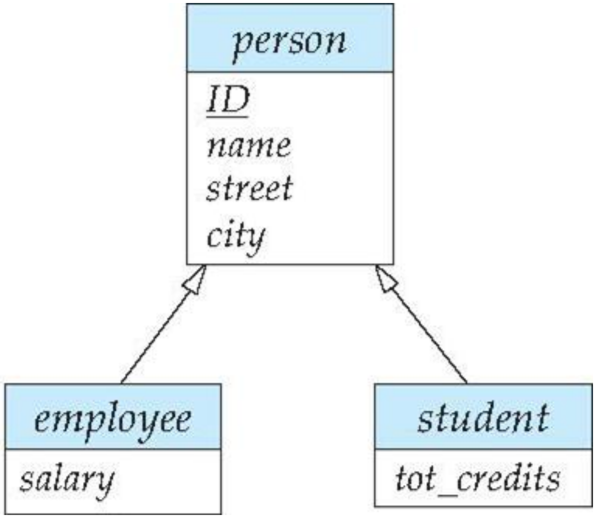
- Higher arity relationship sets are represented just like binary ones
  - i.e., as one relation with the primary keys of the related entity sets
  - proj_guide(instructor_ID, student_ID, project_ID)



Representing Specialization

- **Method 1**
  - All three relations become relations
    - primary key is shared
  - Shared attributes are only represented in the higher level entity

  person(<u>ID</u>, name, street, city)
  employee(<u>ID</u>, salary)
  student(<u>ID</u>, tot_credits)



- Drawback:
  - Accessing person information for employees and students requires access to two relations

Representing Specialization

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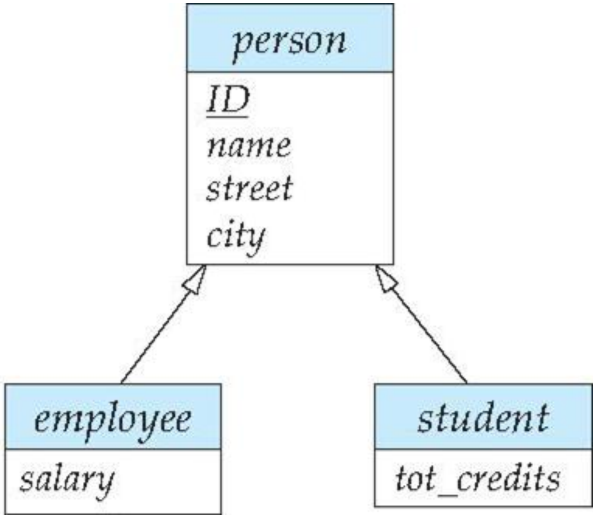
- **Method 2**
  - All three relations become relations
    - primary key is shared
  - Shared attributes are only represented in each entity

    person(<u>ID</u>, name, street, city)

    employee(<u>ID</u>, name, street, city, salary)

    student(<u>ID</u>, name, street, city, tot_credits)
  - Super relation can be omitted for total specialization



- Drawback:
  - Redundant storage for overlapping specialization
    - i.e., for persons that are both employees and students

Design Decisions in ER Modeling

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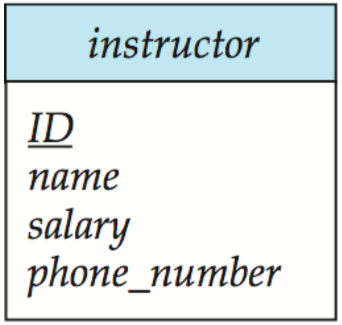
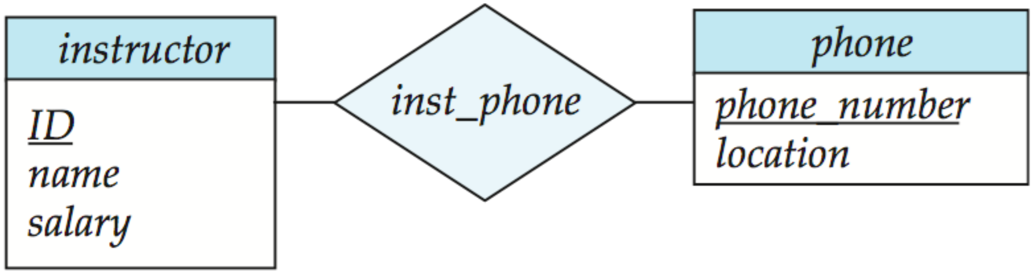
- Entity sets vs. attributes

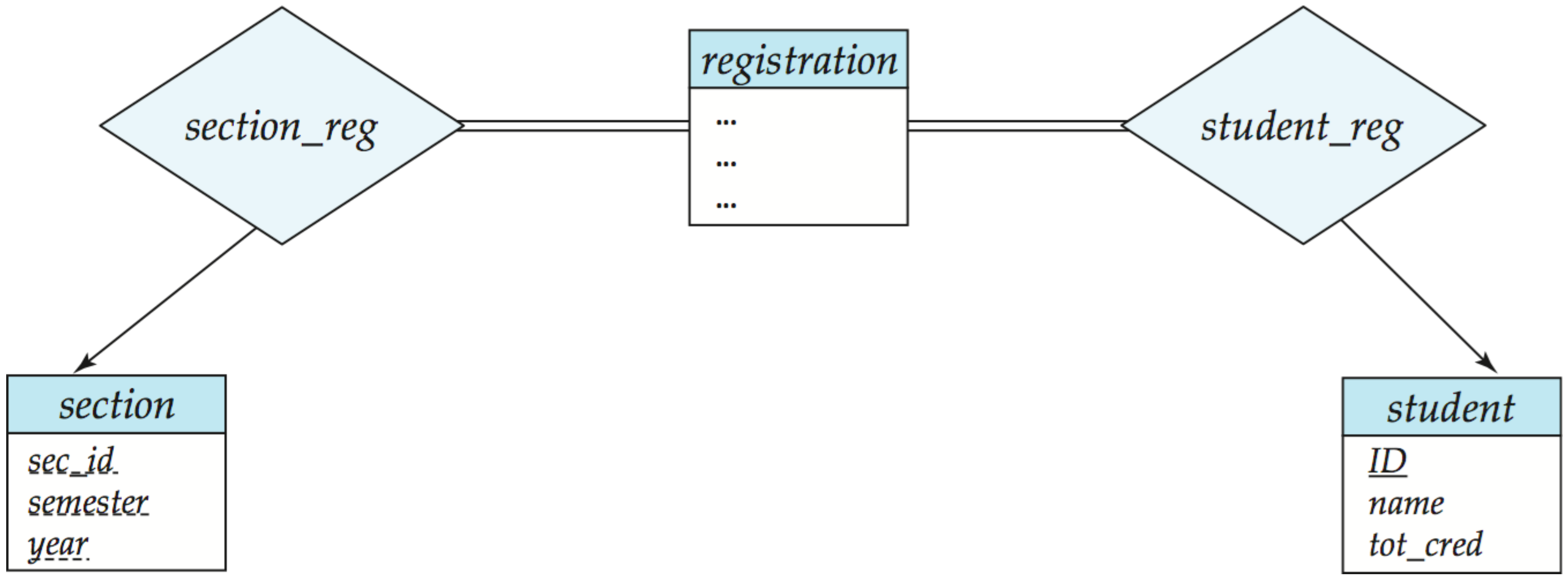




- Entity set
  - Allows for additional information
  - Supports multi-valued attributes
    - in that case, the attribute would end as a relation in the DB anyways

Entity Sets vs. Relationship Sets

- Students register for course sections
  - This could be a simple relationship set as well
- Entity set can store additional information, e.g.
  - Date of registration

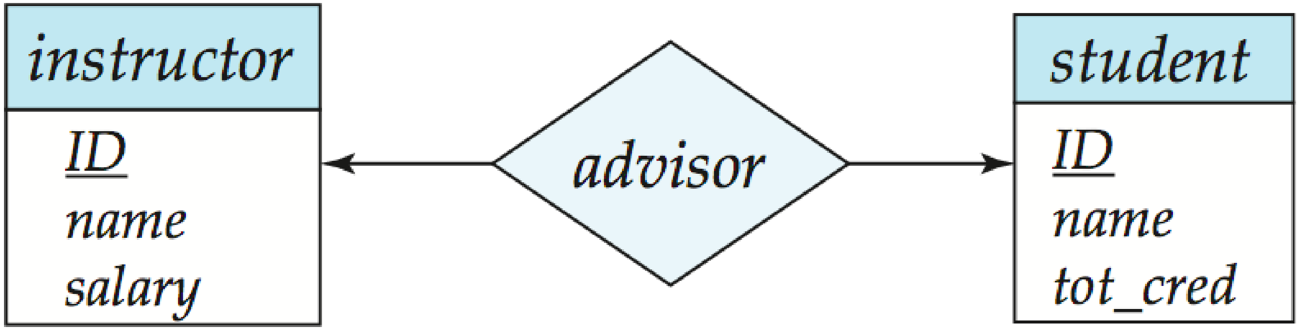


Placement of Attributes for 1:1 Relationships

- The primary key on one side can be included on the other side

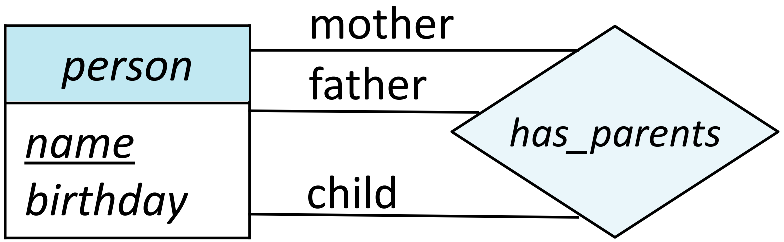
  student = (<u>ID</u>, name, tot_cred, instructor_ID) **or**
  instructor = (<u>ID</u>, name, salary, student_id)

- Which one?



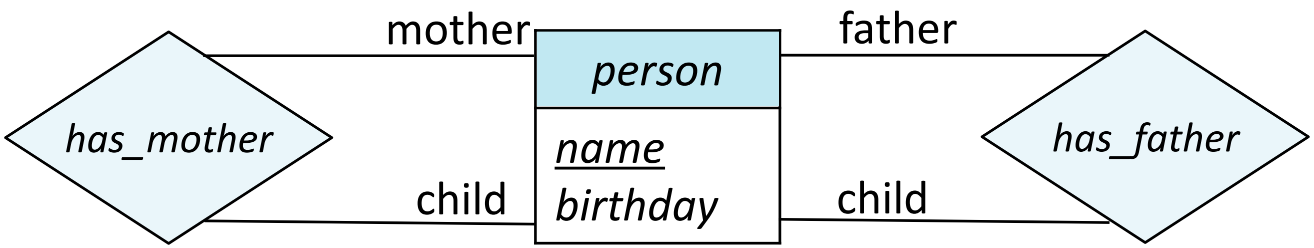
Binary vs. Non-Binary Relationships

- Sometimes, non-binary relationships can be replaced by binary ones



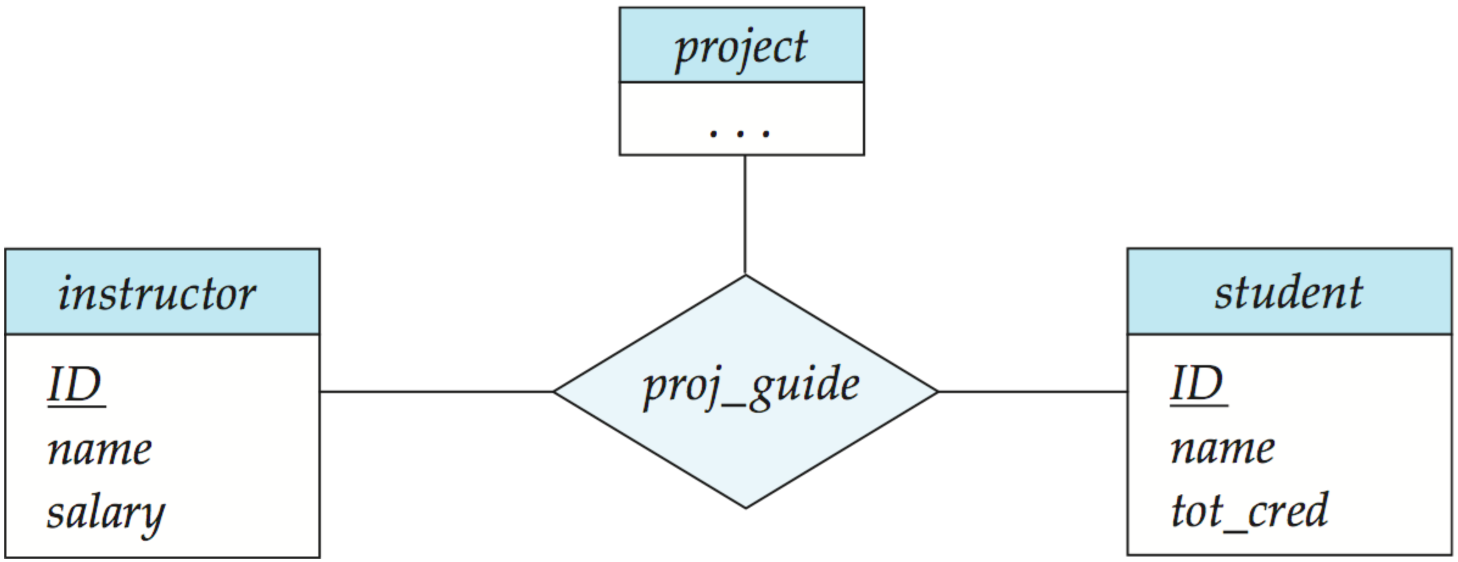
Binary vs. Non-Binary Relationships

- Sometimes, non-binary relationships can be replaced by binary ones
  - This is usually the preferred solution



Binary vs. Non-Binary Relationships

- Sometimes, non-binary relationships can be replaced by binary ones
  - but sometimes, they are n-ary by nature



Binary vs. Non-Binary Relationships

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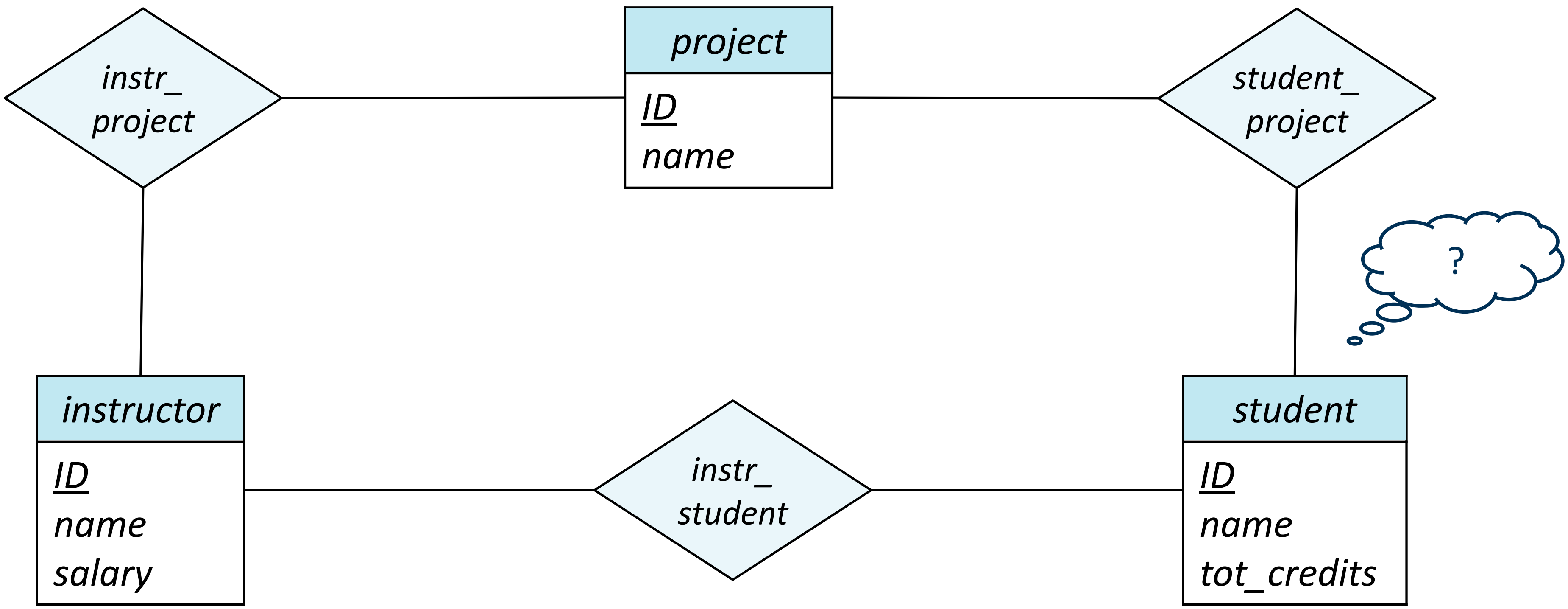
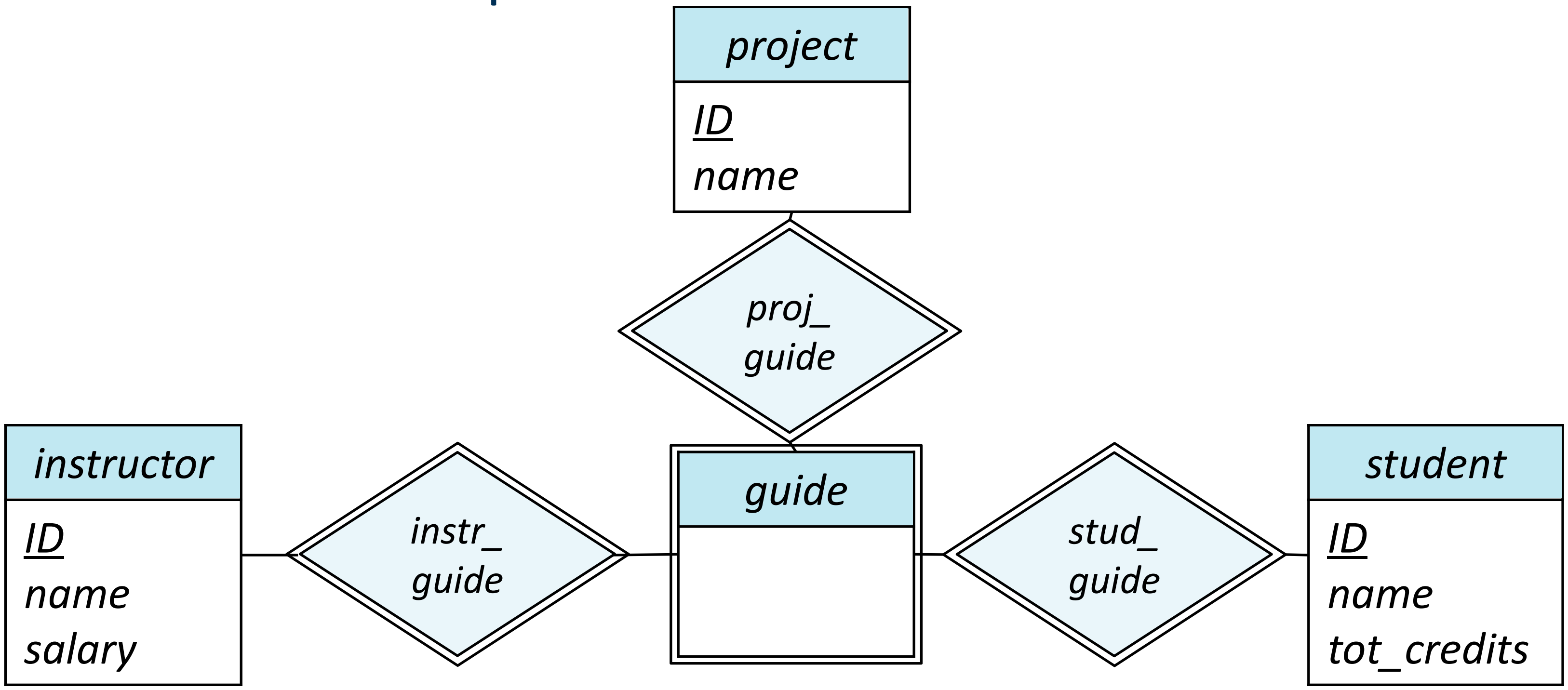


Binary vs. Non-Binary Relationships

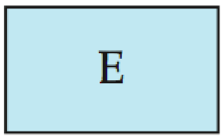
- Sometimes, non-binary relationships can be replaced by binary ones
- General decomposition schema:



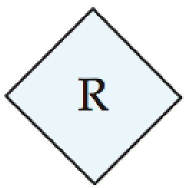
ER Design Decisions (Summary)

- 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 number of binary relationships
- The use of a strong or weak entity set
- The use of specialization/generalization – contributes to modularity in the design

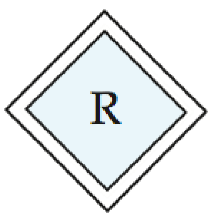
Summary of ER Notation



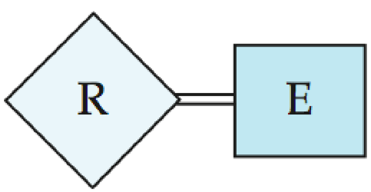
entity set



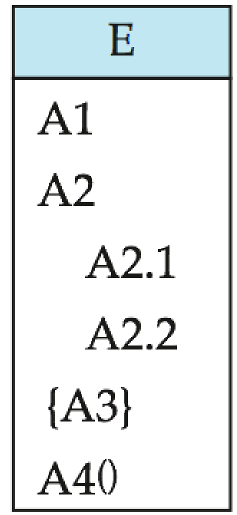
relationship set



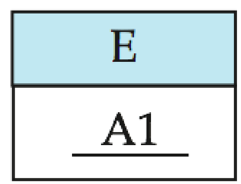
identifying relationship set for weak entity set



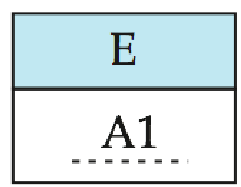
total participation of entity set in relationship



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

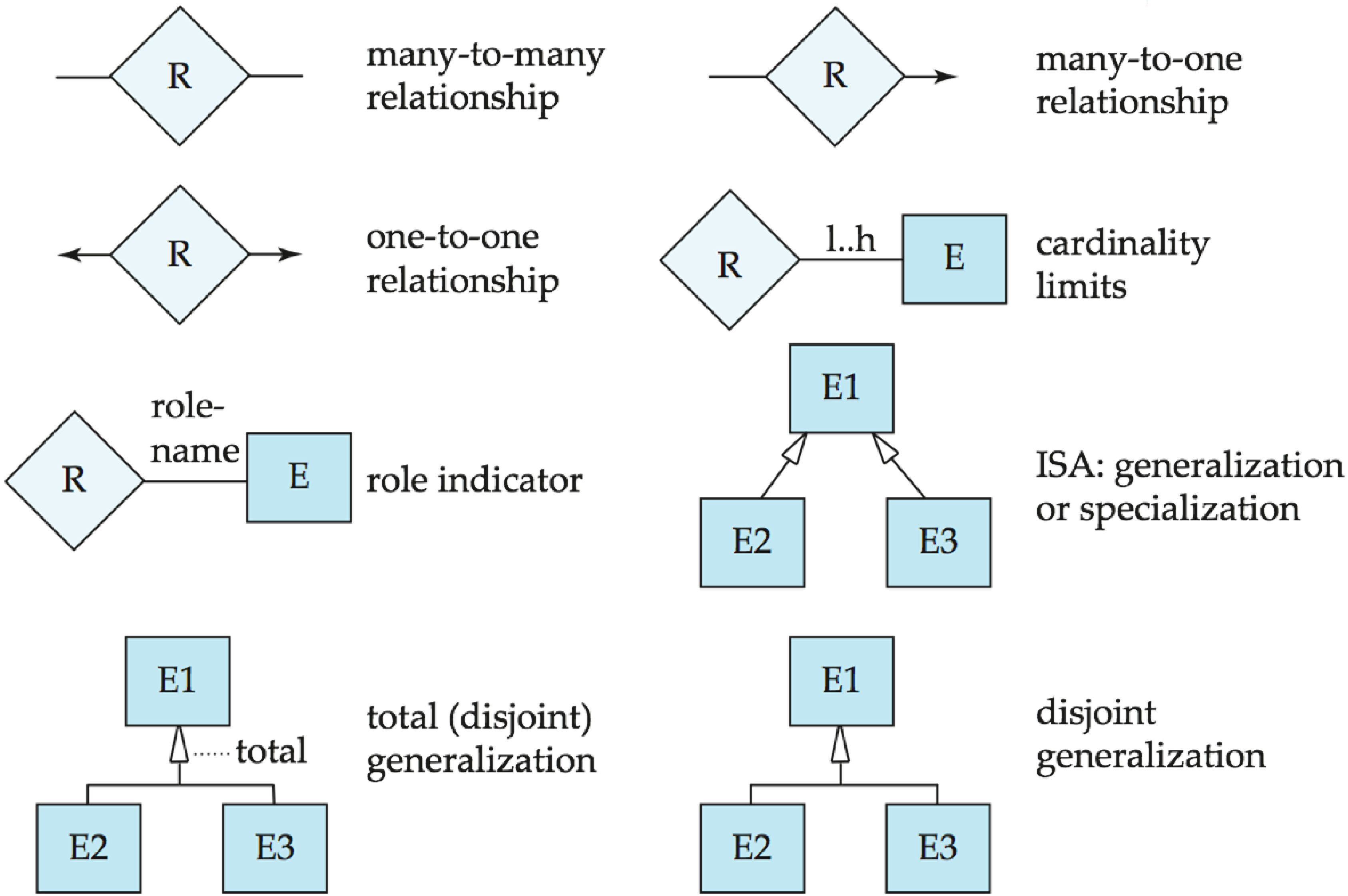


primary key



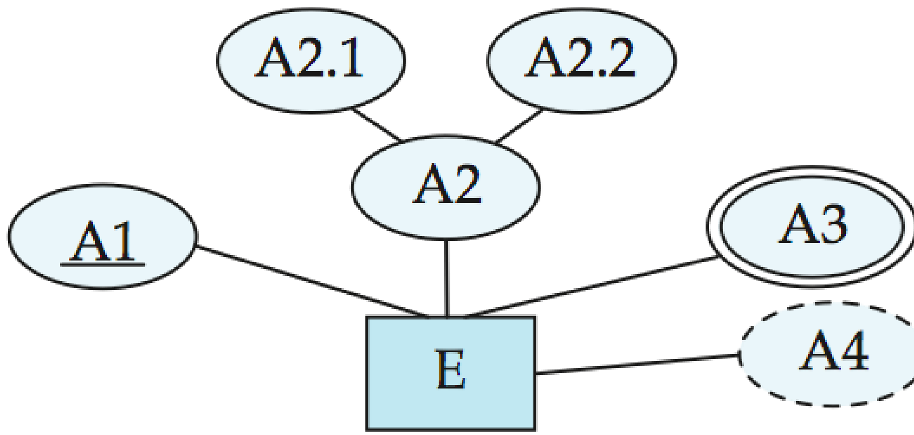
discriminating attribute of weak entity set

Summary of ER Notation (ctd.)



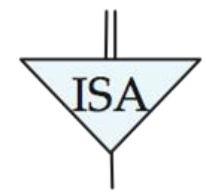
Alternative ER Notations

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 (ctd.)

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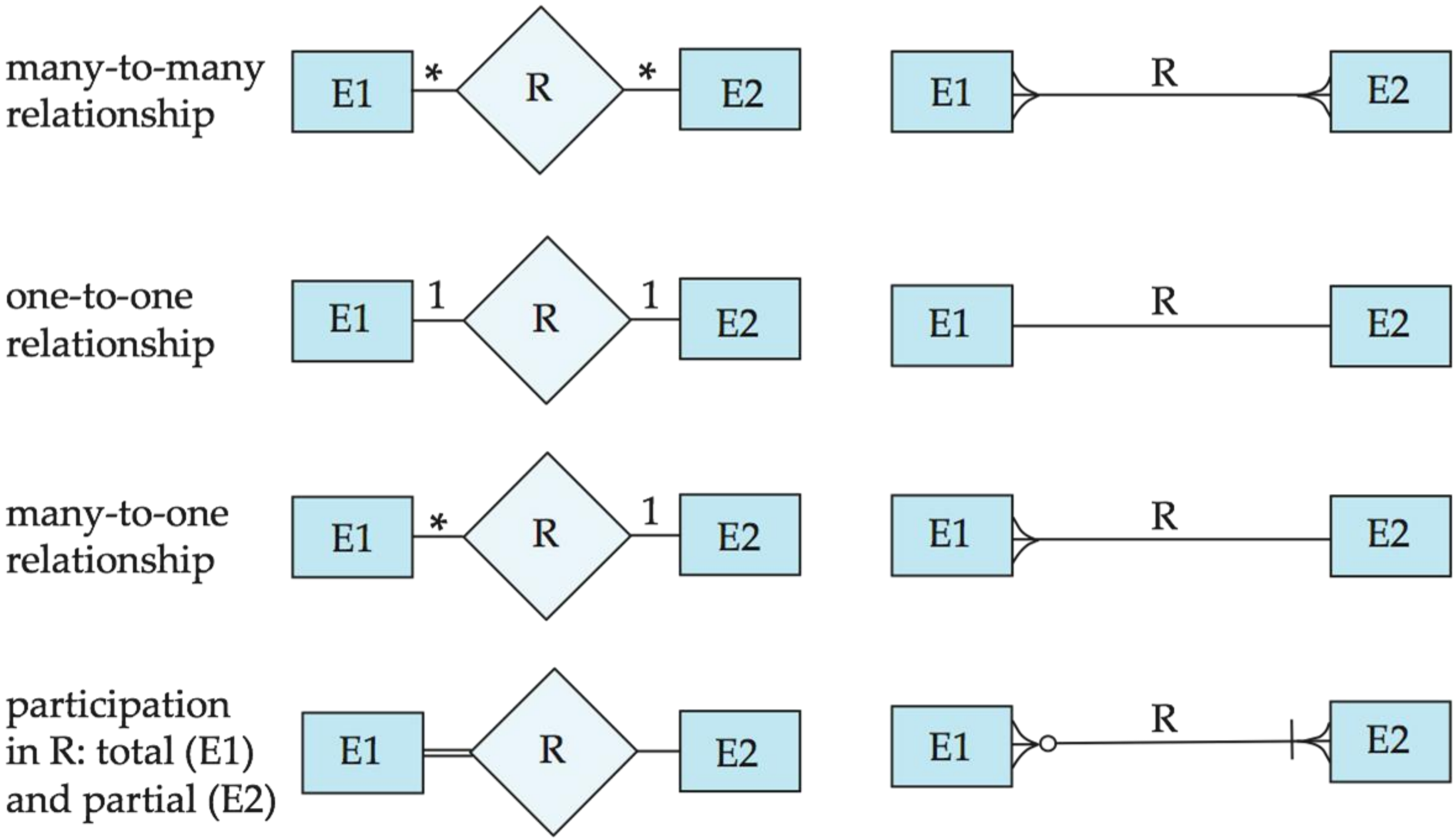


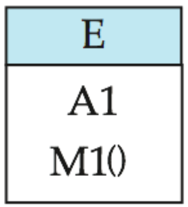
Alternative Modeling Paradigms: UML

- Unified Modeling Language
  - often used in software design
  - similar scope: objects and their relations
  - ISO standard since 2005

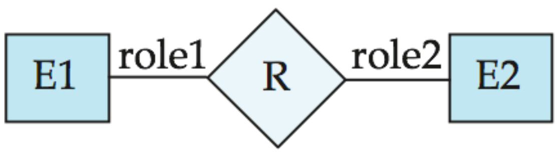
- ER models in RDBMS
  - Direct translation to SQL
- UML models in software engineering
  - Direct translation to source code

Alternative Modeling Paradigms: UML

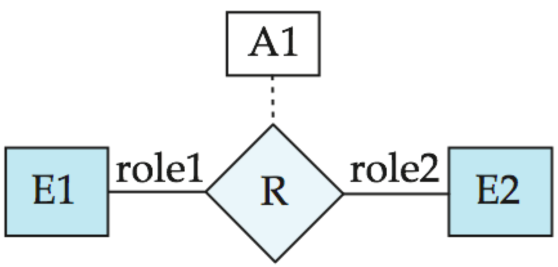
ER Diagram Notation



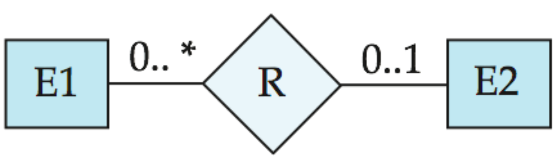
entity with attributes (simple, composite, multivalued, derived)



binary relationship

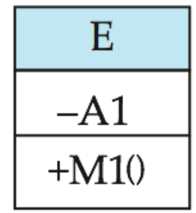


relationship attributes

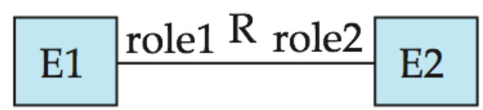


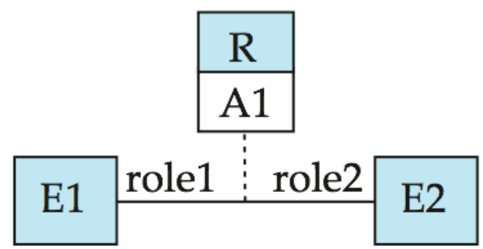
cardinality constraints

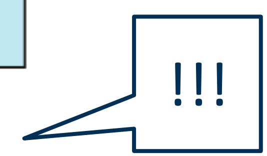
Equivalent in UML

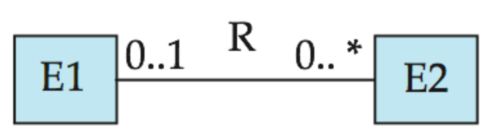


class with simple attributes and methods (attribute prefixes: + = public, – = private, # = protected)

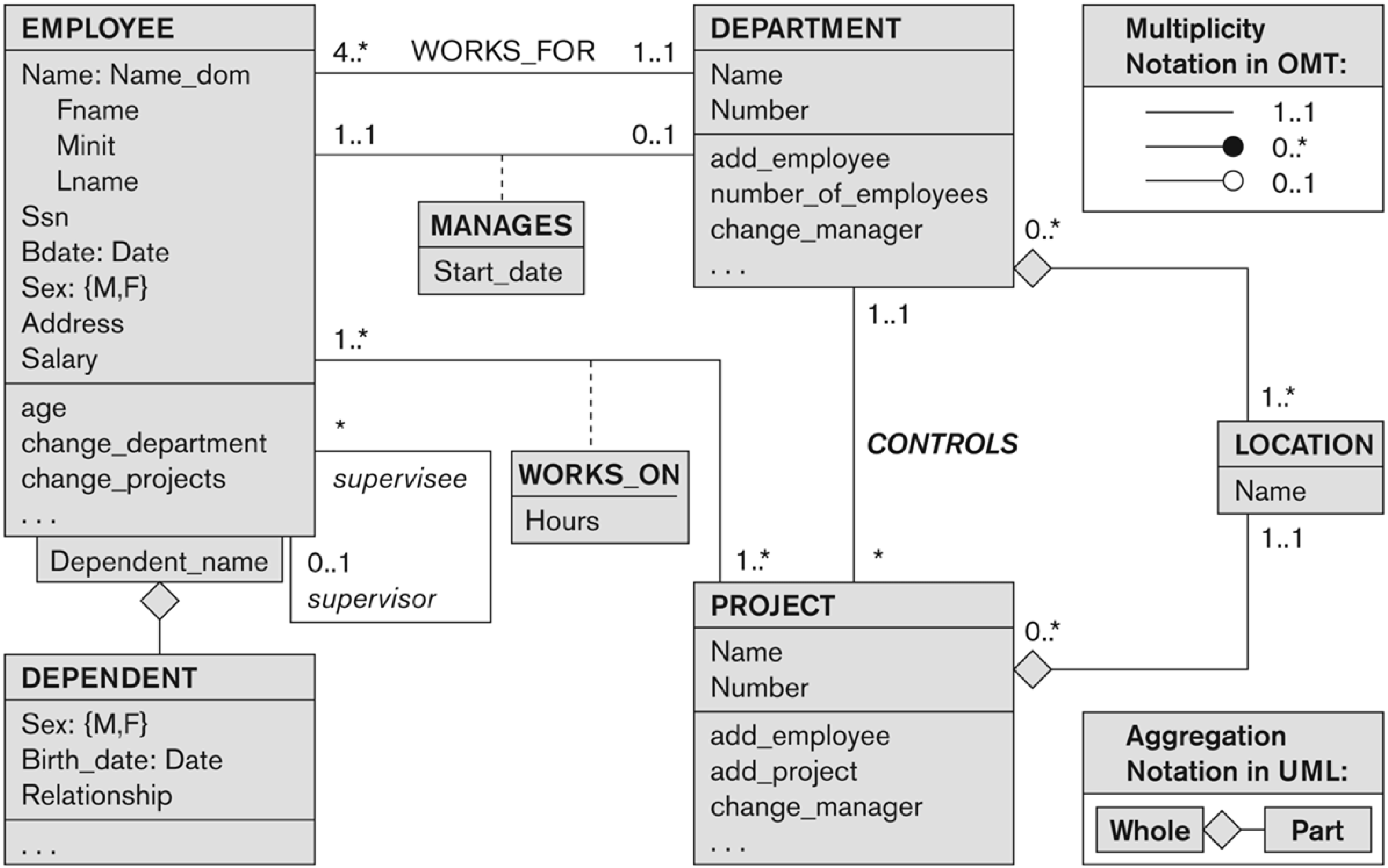








Alternative Modeling Paradigms: UML



http://pld.cs.luc.edu/database/ER.html

Summary

- Designing databases
  - i.e., how to get from your customer’s requirements…
  - ...to a set of tables and attributes
- ER Models are an intermediate step
  - Conceptual view on the database
  - Graphical notation
  - Can be used for discussion with customers
- Translation rules for ER to RDBMS
- Design decisions
  - For ER Models (mostly business decisions)
  - For translation to RDBMS (mostly computer science decisions)

Questions?

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