COMP9120

Week 2: Conceptual Database Design

Semester 1, 2025

Remember to form group and put that information in Canvas

68% have already formed a group

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School of Computer Science

THE UNIVERSITY OF SYDNEY

Contents developed by Dr Lijun Chang

Warming up!

Let’s menti!

Acknowledgement of Country

I would like to acknowledge the Traditional Owners of Australia and recognise their continuing connection to land, water and culture. I am currently on the land of the Gadigal people of the Eora nation and pay my respects to their Elders, past, present and emerging.

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BREAKING NEWS!!

LIVE HELP ON ED: *STARTING NEXT WEEK!*

To access the **weekly schedule**, please go to Canvas:

https://canvas.sydney.edu.au/courses/63042/modules

under Modules, under NEW! LIVE ED SCHEDULE S1 2025

How: The indicated tutor (e.g., Dipankar) will be on Ed during the hours mentioned in the schedule to answer your questions **live**!

Week	Weekday	FROM	TO	Name
3	TUE	6:00 pm	8:00 pm	Dipankar
3	THUR	11:00 am	1:00 pm	Dipankar
4	TUE	6:00 pm	8:00 pm	Dipankar
4	THUR	11:00 am	1:00 pm	Dipankar
5	TUE	6:00 pm	8:00 pm	Dipankar
5	WED	6:00 pm	8:00 pm	Dipankar
5	THUR	11:00 am	1:00 pm	Dipankar
6	TUE	6:00 pm	8:00 pm	Dipankar
6	WED	6:00 pm	8:00 pm	Dipankar
6	THUR	11:00 am	1:00 pm	Dipankar
6	WED	6:00 pm	8:00 pm	Abbey
6	THUR	11:00 am	12:00 pm	Abbey
7	TUE	6:00 pm	8:00 pm	Dipankar
7	THUR	11:00 am	1:00 pm	Dipankar
8	TUE	6:00 pm	8:00 pm	Dipankar
8	THUR	11:00 am	1:00 pm	Dipankar
9	TUE	6:00 pm	8:00 pm	Dipankar
9	WED	6:00 pm	8:00 pm	Dipankar
9	THUR	11:00 am	1:00 pm	Dipankar
10	TUE	6:00 pm	8:00 pm	Dipankar
10	WED	6:00 pm	8:00 pm	Dipankar
10	THUR	11:00 am	1:00 pm	Dipankar
10	WED	6:00 pm	8:00 pm	Abbey
11	THUR	11:00 am	12:00 pm	Abbey
11	TUE	6:00 pm	8:00 pm	Dipankar
11	WED	6:00 pm	8:00 pm	Dipankar
11	THUR	11:00 am	1:00 pm	Dipankar
11	WED	6:00 pm	8:00 pm	Abbey
11	THUR	11:00 am	12:00 pm	Abbey
12	TUE	6:00 pm	8:00 pm	Dipankar
12	THUR	11:00 am	1:00 pm	Dipankar
13	TUE	6:00 pm	8:00 pm	Dipankar
13	WED	6:00 pm	8:00 pm	Dipankar
13	THUR	11:00 am	1:00 pm	Dipankar

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Outline

- Introduction to Conceptual Database Design

- Entity Relationship Model
  - Notation and usage
  - Entity and Relationship types, attributes
  - Key, participation and cardinality constraints
  - Weak entities, IsA hierarchies, aggregation

Conceptual Database Design

- **Purpose** of conceptual database design
  - **Agree** on the **structure of the database** before deciding on a particular implementation: Let us look at Tree swing example to see the issues that may arise:

How the customer explained it

https://medium.com/@thx2001r/the-project-cartoon-root-cause-5e82e404ec8a

Database Design Sequence

1. Requirements Analysis

- Understand…
  - what data needs to be stored
  - what applications must be built
  - what operations are most frequent

2. Conceptual Design

- Develop…
  - high-level description of the data closely matching how users think of the data
  - Works as communication vehicle

Today

3. Logical Design

- Convert…
  - conceptual design into a logical database schema

4. Schema Refinement

- Refine…
  - Identify problems in current schema & refine

5. Physical Design

- Convert…
  - logical schema into a physical schema for a specific DBMS and tuned for app.

6. App & Security Design

- Determine who plays what roles, in what workflows, with security settings …
  - What roles are played by different system entities in system processes, and what permissions should be given to these roles?

Conceptual Database Design

- What is our goal?
  - Specification of the database schema
- **Conceptual Database Design**: A framework for understanding and capturing business information requirements *graphically*
- It does *not* include how data is implemented, created, modified, used, or deleted.
  - Works as communication vehicle *between* technical people *and* non-technical people
  - Facilitates planning, operation & maintenance of various data resources
- Usually, this is the role of the *System Analyst*

Entity Relationship Model

- First designed by **Peter Chen** in 1976
  - Several variations/versions have since appeared
  - The *conceptual database model* we will use in this class**: Enhanced** or **Extended E-R model (EER)**

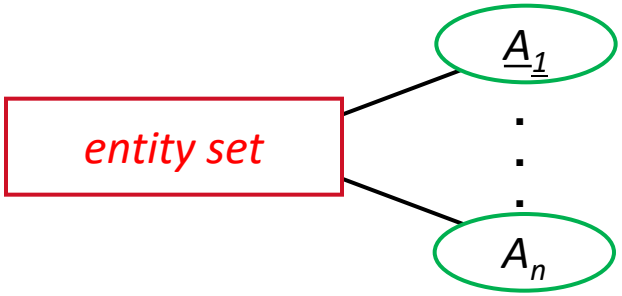
- Definition: A (conceptual) *data modelling* approach is a *visual representation* that depicts the *associations* among different *categories of data* within a Universe of Discourse – UoD (e.g., enterprise).
  - What are the ***entities*** and ***relationships*** in the UoD (e.g., enterprise)?
  - What information do we need to store in the database about these entities and relationships?
  - What are the *business rules* (represented by *integrity constraints)* that should always hold (i.e., be *true*)?

- A database 'schema' in the ER Model is represented pictorially (***ER Diagrams – ERD*** as a shorthand).
  - We can always convert an ER diagram (ERD) into a logical (e.g., relational) schema.

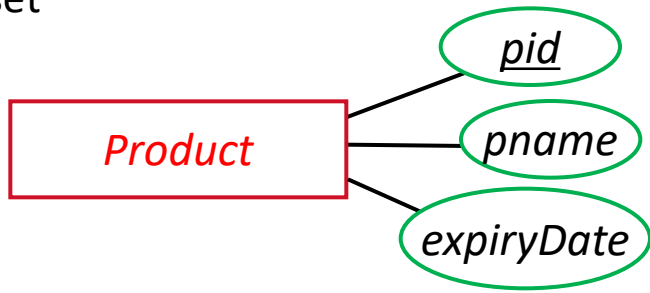
Entities & Entity set

- **Entity**: represents an *individual* object from the UoD (such as a University): a specific person, place, object, event, etc.
  - it must be *distinguishable* from *other entities*
  - Example: *John Doe*, unit *COMP9120*, bank account *4711*

- **Entity Type** (also called **entity set**): a *collection* of entities that share *common properties* or characteristics
  - Example: *students*, *courses*, *bank accounts*
  - In E-R, a *Rectangle* represents an entity set



- **Attribute**: describes one *aspect* (i.e., a description) of an entity set
  - Descriptive *properties* possessed *by all* members of an entity set
  - Example: product have *pid*, *name* and *expiryDate*
  - Depicted by an *ellipse*



Entity Schema

- ***Domain***: all possible *values* of an attribute
  - Values may be *complex / set-oriented which is,* as we will see, contrary to the relational model.
    - **Simple** and **composite** attributes. E.g. (color vs. date)
    - **Single-valued** and **multi-valued** attributes (studentID vs spokenLanguages)

- ***Key***: *minimal* set of attributes, called a *candidate key*, that *uniquely* identifies an entity in the set (may have more than one candidate key)
  - Example: each student is *uniquely* identified by the student *ID*.
  - The *selected key* among *candidate keys* is called **Primary Key** (PK) => depicted by underlining the attributes forming the key. **Only** *one primary key* at all times!

- ***Entity Schema***: *entity set name*, *attributes*, their *domains*, and *PK*

Identify Keys

- Which one would you choose as a primary key?
  - Staff(staff_id, name, email, phone_number, address, dateOfBirth)

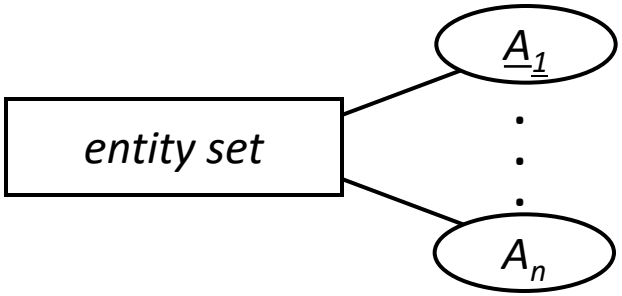
- Which one would you choose as a primary key?
  - House(house_number, street_name, city, state, build_in_year, selling_price)

Graphical Representation in E-R Diagram

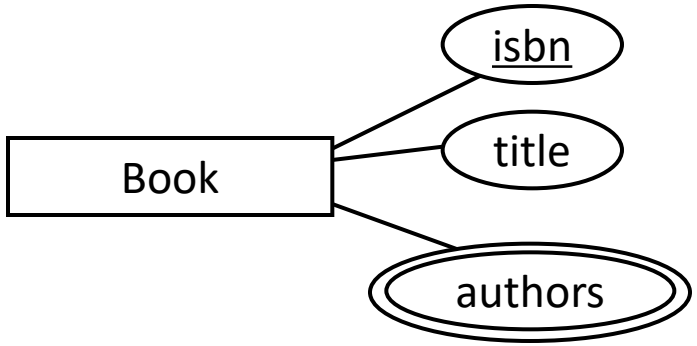
Symbols:

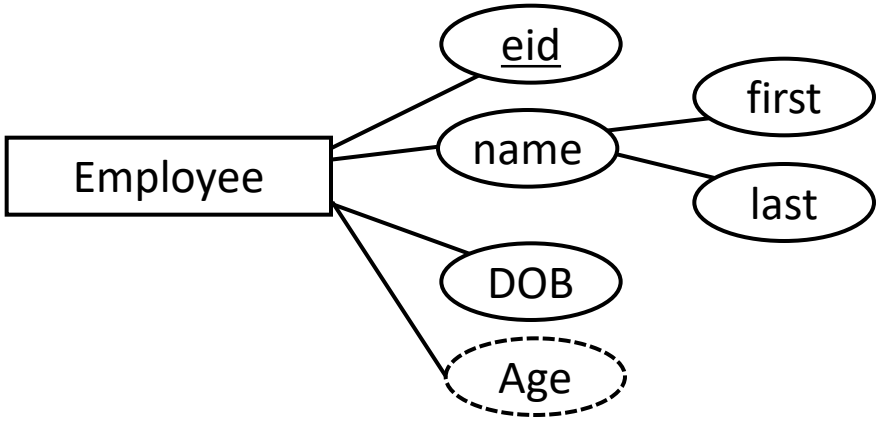
- Entity Sets represented by a rectangle

- Attributes depicted by ellipses
  - Keys are underlined
  - Double ellipses for multi-valued attributes



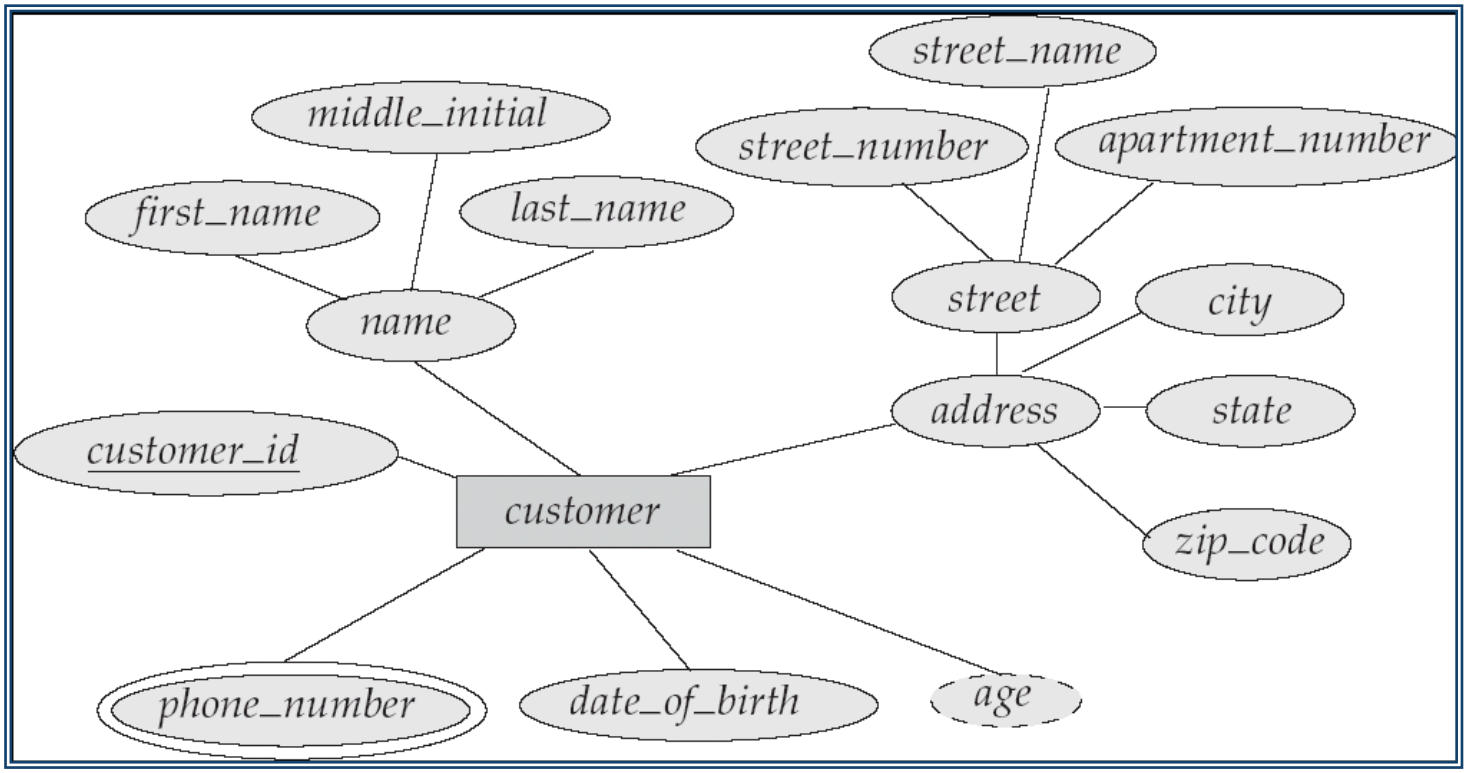
Examples:





Note:
Book.authors is a *multi-valued attribute*;
Employee.name is a *composite attribute*.
Employee.Age is a *derived attribute*

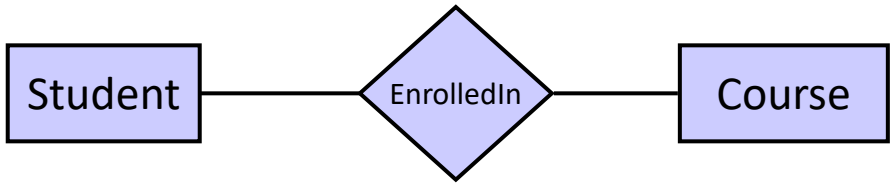
Entity Set


street_name
middle_initial
street_number
apartment_number
first_name
last_name
street
city
name
address
state
customer_id
customer
zip_code
phone_number
date_of_birth
age

Relationships

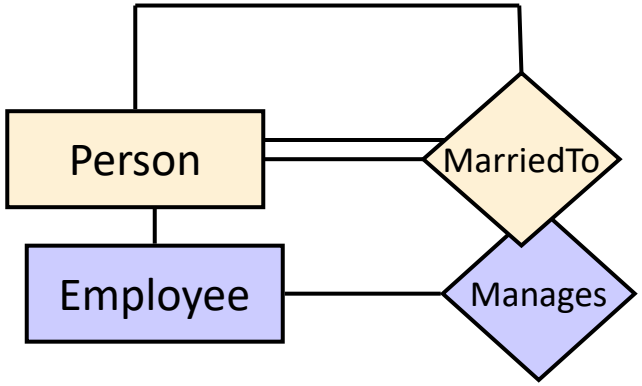
- **Relationship**: relates *two* or *more* entities
  - Example: John *is enrolled in* COMP9120

- **Relationship Type** (also called **Relationship Set**): set of similar relationships
  - Formally: a relation among $n \geq 2$ entities, each entity from an entity set is defined as:
    $\{(e_1, e_2, \ldots e_n) \mid e_1 \in E_1, e_2 \in E_2, \ldots, e_n \in E_n\}$
  - Example: **Student** (entity set) is related to **Course** (entity set) by **EnrolledIn** (relationship type).
  - *Diamond* shape represents the *relationship type*

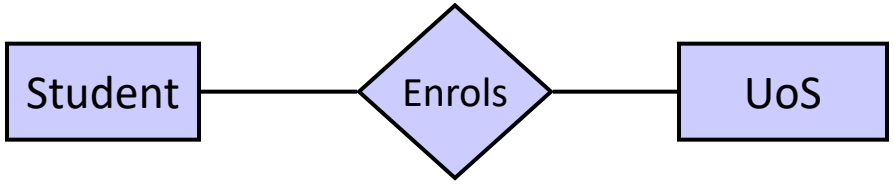


Relationship Degree

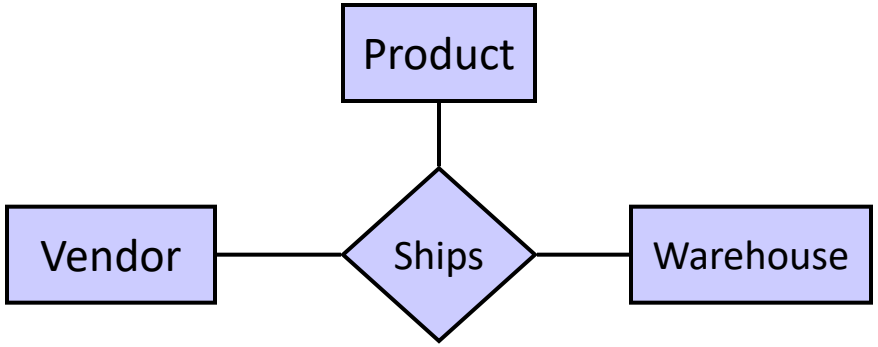
- *Degree* of a Relationship: *number* of entity types involved



- Unary Relationship (Recursive)



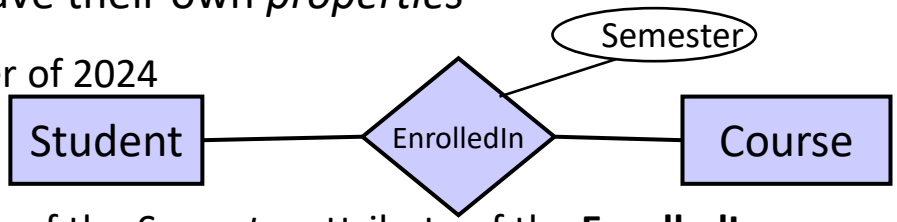
- Binary Relationship



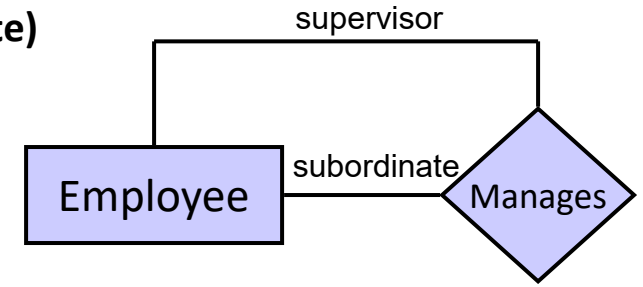
- Ternary Relationship

Relationship Attributes and Roles

- **Relationship Attributes:** *Relationships* can also have their own *properties*
  - E.g., John enrols in COMP9120 *in* the second semester of 2024
  - John and COMP9120 are related *for a limited time*
  - 2024sem2 describes this *temporal* relationship - value of the *Semester* attribute of the **EnrolledIn** relationship set



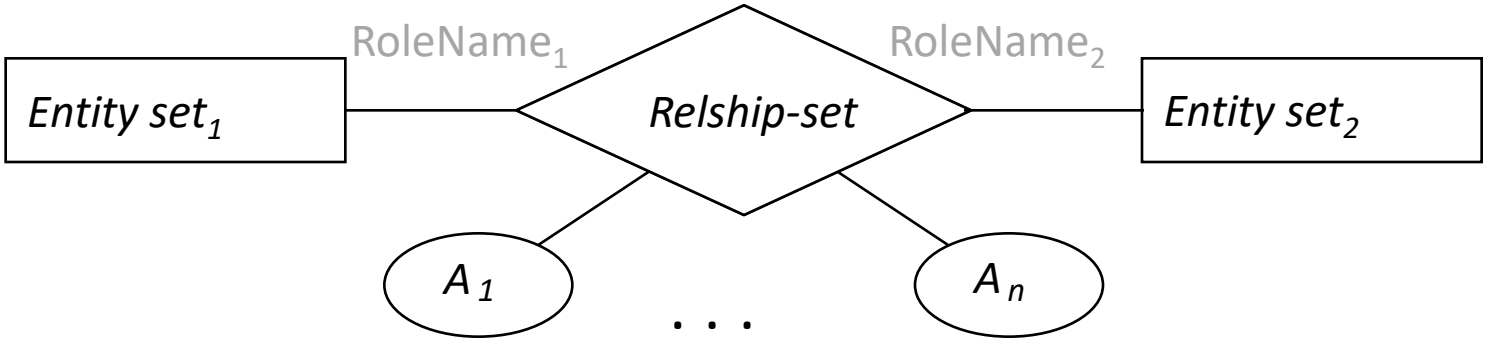
- **Relationship Role:** Each participating entity can be named with an explicit *role*
  - The "supervisor" and "subordinate" labels are called *roles*. They indicate how Employee entities interact via the *Manages* relationship
  - Useful for relationships that relate elements of the same entity type
  - Example: **Manages(Employee: supervisor, Employee: subordinate)**



- **Relationship Type Schema**:
  - Relationship name
  - Role names (or names of participating entity sets) – this is optional
  - Relationship attributes and their domains

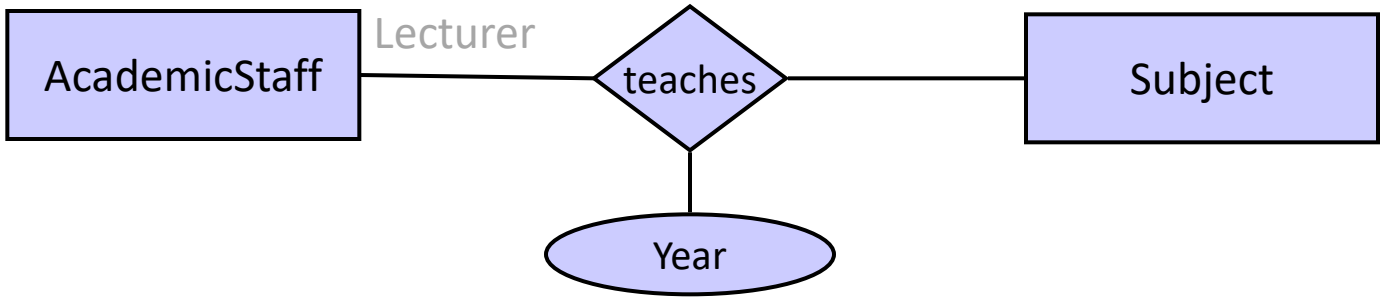
Graphical Representation of Relationships in ERD

Symbol:



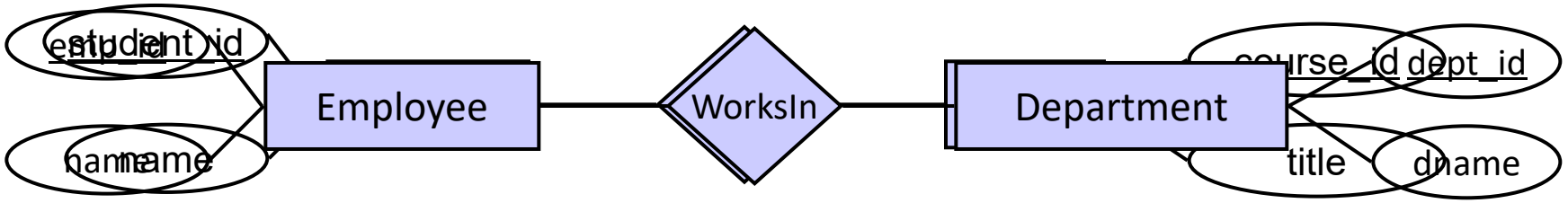
- *Diamonds* represent relationship set
- *Lines* link attributes to entity/relationship sets and entity sets to relationship set.
- *Roles* are labels over edges (lines), labelled with role names

Example



Key of Relationship Set

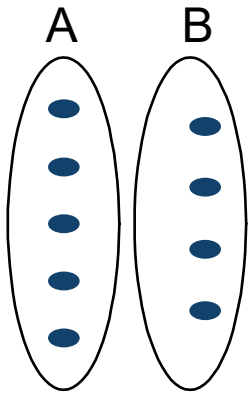
- The combination of the primary keys of the participating entity sets forms a **superkey** (superset of a key) of an (entity) relationship.
  - Example: (student_id, course_id) is the superkey of *Enrols*

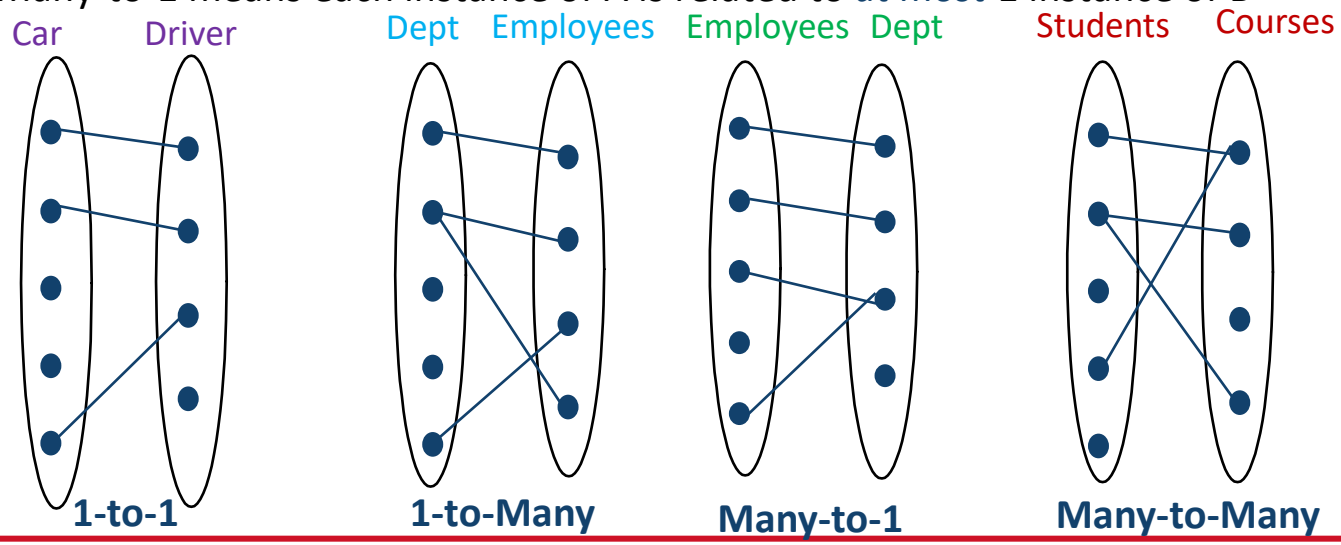


  - We must consider the ***mapping cardinality of the relationship*** when deciding what the ***candidate key*** *(minimal set* of attributes*)* is:
    - Consider **WorksIn**: *An employee* can work in *many* departments; *a department* can have *many* employees.
    - In contrast, *each department* has at *most one* manager
  - **We do <u>not</u> represent the *keys* of the *relationship set* in E-R diagram**

Mapping Cardinality of Relationships

- We present examples of each style of relationship.
  - Given a relationship between two entity sets **A** and **B**, we need to consider *both directions* of the relationship:
  - How many instances of **B** can a given instance of **A** be related to?
  - How many instances of **A** can a given instance of B be related to?
- Answer: ***1 to 1, 1 to N, N to 1, N to M*** are the possible **cardinalities** of a relationship between entities
- Beware: the natural language formulation may confuse you!
  - Many-to-1 means each instance of A is related to *at most* 1 instance of B

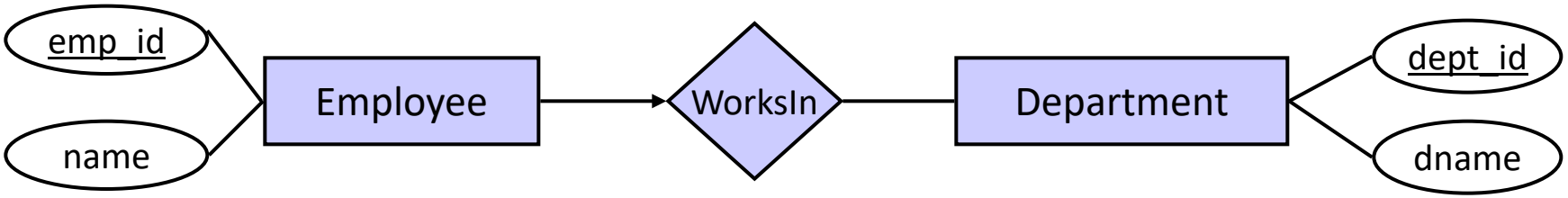




Cardinalities are depicted in E-R diagrams (ERD) as *constraints.*

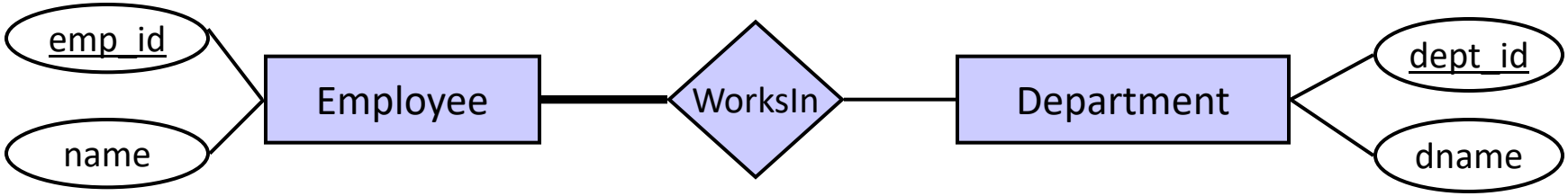
Key Constraints

- If for a particular entity set, each entity participates in *at most one* instance of a relationship, the *key* of the entity set is the (candidate) key of the relationship type
  - E.g., *Employee* key (emp_id) is also *unique* in *WorksIn*
    - called: **many-to-one, also** denoted **N:1 relationship**
- Representation in E-R diagram: ***arrow***
- Example: *An employee* works in at *most one* department.



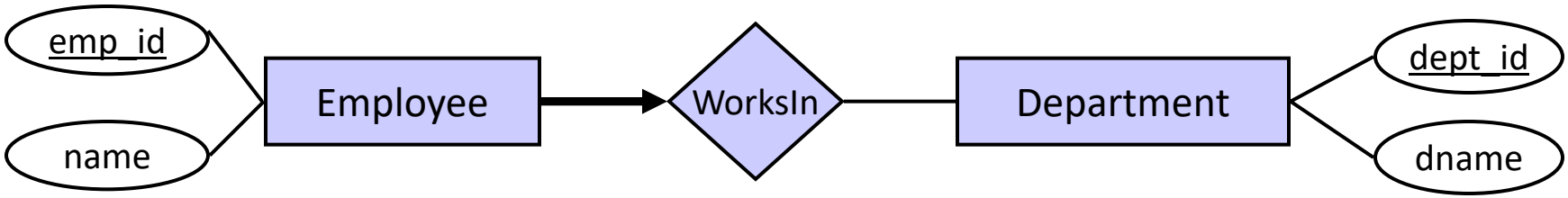
Participation Constraint

- If *every* entity of an entity type participates in *at least one* instance of a relationship, a ***participation*** *constraint* holds, i.e., it is true:
  - also called a **total participation** of entity *E* in *R*
    - A participation that is *not total* is said to be **partial**
- Representation in E-R diagram: ***thick line***
- Example: *Every* employee works in at *least* one department



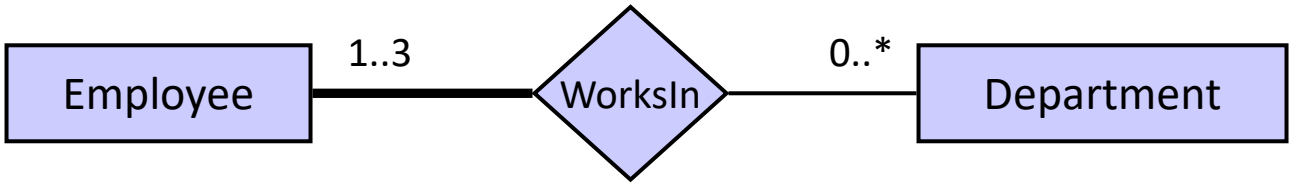
Participation and Key Constraint

- If every entity participates in *exactly one* relationship, then both a **participation** and a **key constraint** hold.
- Representation in E-R diagrams: ***thick arrow***
- Example: Every employee works in exactly one department
  - Again: N:1 relationship



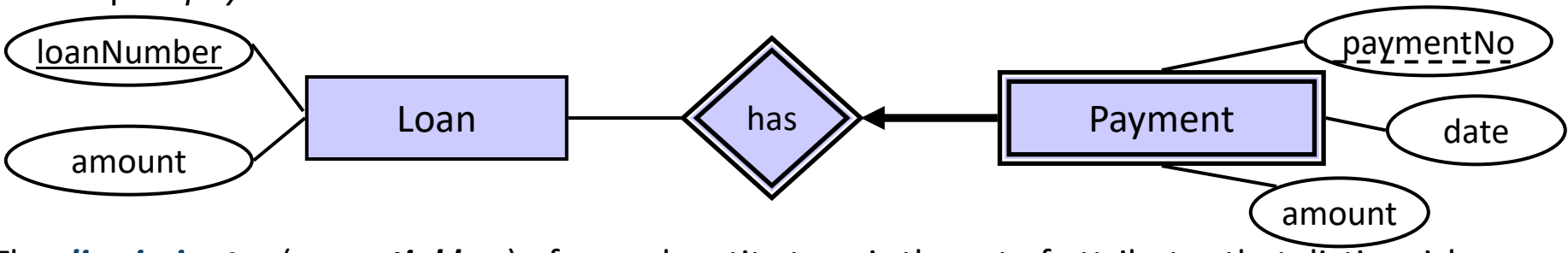
Cardinality Constraints

- ***Generalisation*** of ***key*** and ***participation*** constraints
- A **cardinality constraint** for the participation of an entity set E in a relationship R specifies **how often** an entity of set E participates in R: **at least** (*minimum* cardinality) and **at most** (*maximum* cardinality).
  - In an ER-diagram, we annotate the edge between an entity set E and relationship R with min..max, where *min* is the minimum cardinality and *max* the maximum cardinality. If no maximal cardinality is specified, we set '*' as *max* number ("don't care" or no upper limit).
- Example: Every employee works in *at least* 1 department and *at most* 3 departments.



Weak Entities

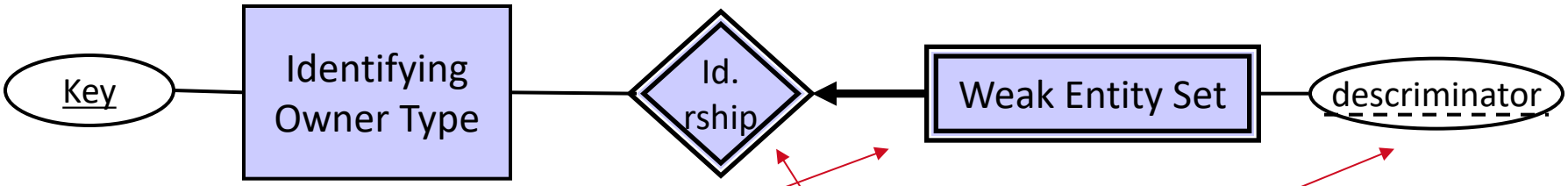
- ***Weak entity type***: An entity type that does ***not*** have a self-contained *primary key*.
  - Its existence **depends** on the existence of an ***identifying owner*** entity
  - The weak entity ***must***:
    - relate to the identifying owner entity set via a **one-to-many** *identifying relationship type* **from** the *identifying owner* entity set to the *weak* entity set
    - have **total** participation in the identifying relationship type
  - Can be seen as an **exclusive 'part-of' relationship**
  - Example: *payment* of a loan



- The ***discriminator*** (or ***partial key***) of a weak entity type is the set of attributes that distinguishes them among all the entities of a weak entity type related to the *same owning entity*.
- The *primary key* of a *weak entity type* is formed by the ***primary key*** of the strong entity type(s) on which the weak entity type is existence dependent, ***plus*** the weak entity type's ***discriminator***.

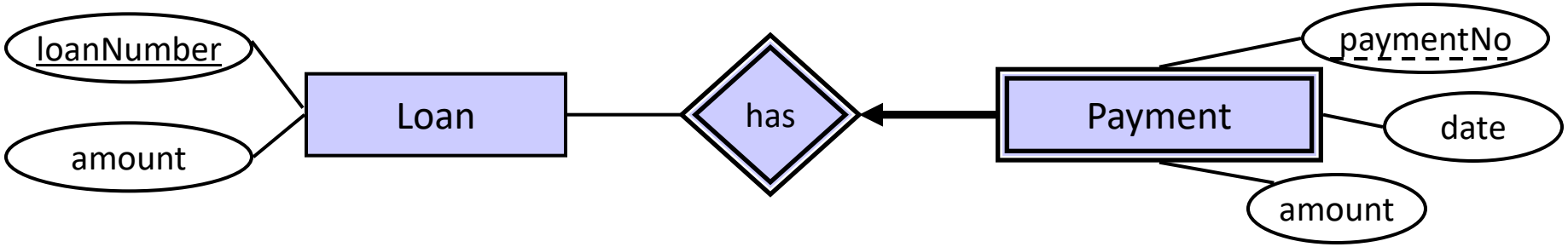
Representation of Weak Entity Types

Symbols:



- We depict a weak entity set by double rectangles.
- Identifying relationship depicted using a double diamond
- underline the discriminator of a weak entity set with a dashed line

Example:



- paymentNumber: discriminator of the Payment entity set
- Primary key for Payment: (loanNumber, paymentNumber)

Let’s take a break!

It’s time to play our menti game!

Enhanced E-R Model

- ER model in its original form did not support
  - SPECIALIZATION/ GENERALIZATION
  - ABSTRACTIONS ('aggregation')

- This led to the development of an 'Enhanced' ER model:
  - Includes all modelling concepts of basic ER
  - Some additional object-oriented concepts: subclasses/superclasses, specialization/generalization, categories, attribute inheritance
  - The resulting model is called the Enhanced-ER or Extended ER (E2R or EER) model
    - used to model applications more completely and accurately

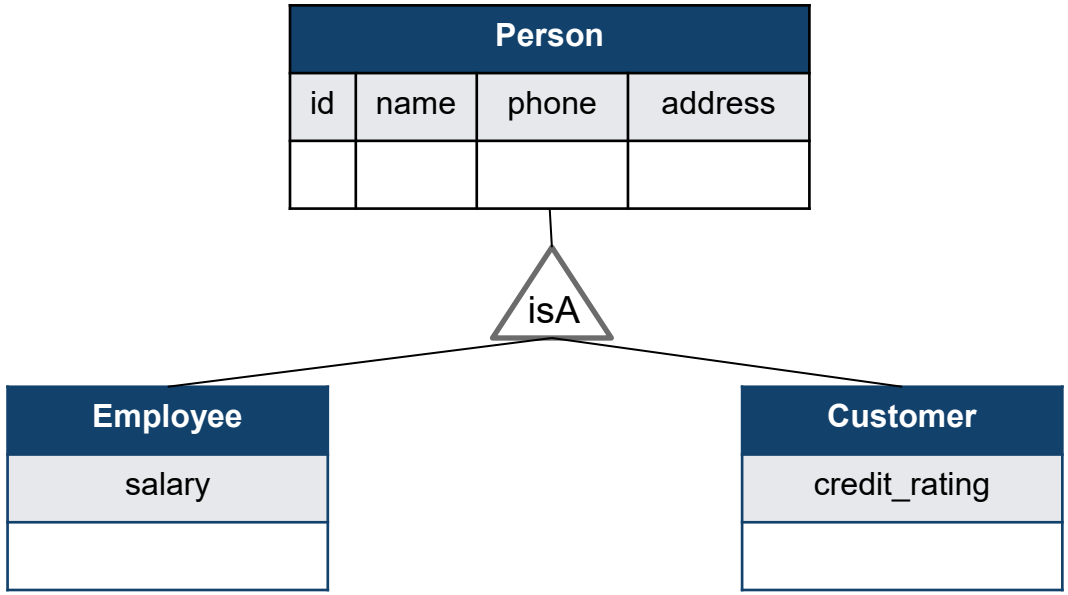
- When we talk about E-R model, we always mean EER model

Generalisation/ Specialisation

- Arranging entity sets in a type hierarchy.
  - Determine entity sets whose set of *properties* are a **subset** of another entity set

Employee				
id	name	phone	address	salary

Customer				
id	name	phone	address	credit_rating



Generalisation/ Specialisation

- Arranging entity sets in a type hierarchy.
  - Determine entity sets whose set of properties are a subset of another entity set

- Definition of **Generalisation** / **Specialisation** / **Inheritance**:
  Two entity types *E* and *F* are in an **IsA-relationship** ("*F* is a *E*"), if

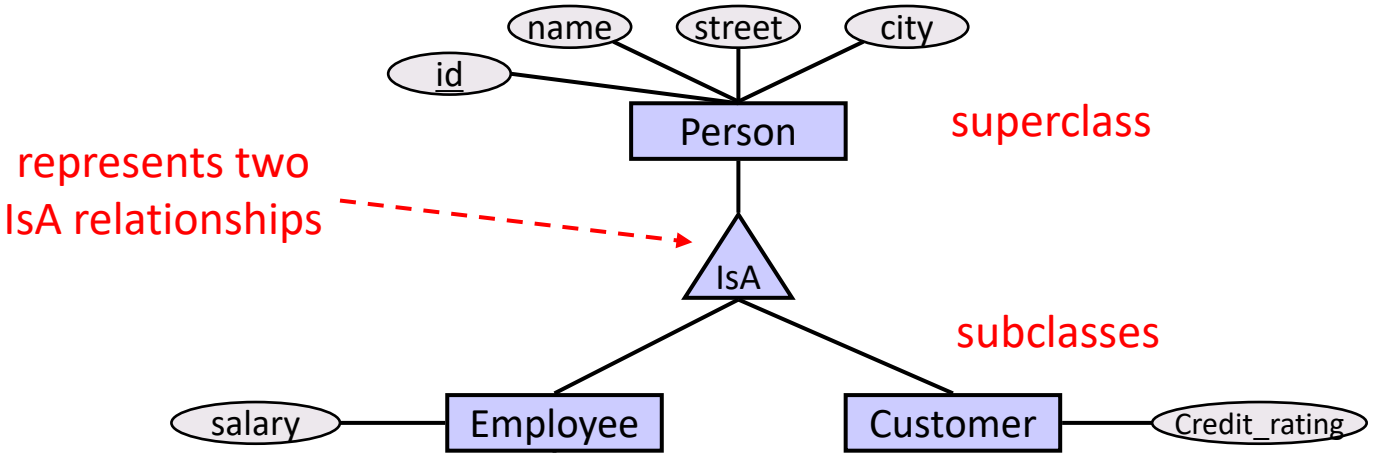
  (1) the set of attributes of *F* is a *superset* of the set of attributes of *E*, and

  (2) the entity set *F* is a *subset* of the entity set of *E* ("each *f* is an *e*")

- We say that *F* is a *specialisation* of *E* (*F* is **subclass**) and *E* is a *generalisation* of *F* (*E* is **superclass**).
  - Example: **Student** is a subclass of **Person**
- **Attribute inheritance** – a lower-level (subclass) entity type *inherits* all the attributes and relationship participations of its supertype.

- Depicted by a *triangle* component labelled *IsA*

Superclass / Subclass Example



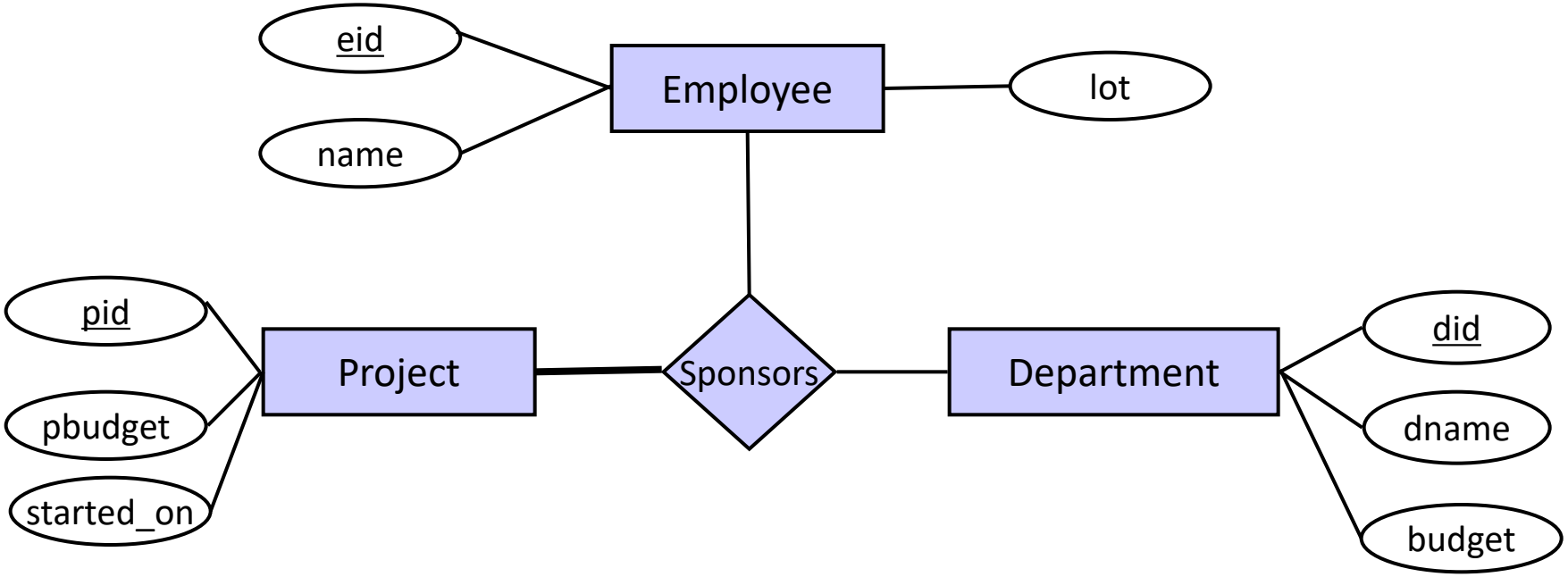
- Specialisation stems from a single entity set. It emphasizes differences among entities within the set by creating distinct lower-level entities
- Generalization proceeds from the recognition that a number of entity sets share some common features

Constraints on IsA Hierarchies

- We can specify *overlap* and *covering* constraints for ISA hierarchies:
- ***Overlap Constraints***
  - **Disjoint**
    - an entity can belong to *only one* lower-level entity set
    - Noted in E-R diagram by writing *disjoint* next to the IsA triangle
  - **Overlapping** (the default - *opposite to Ramakrishnan/Gehrke book*)
    - an entity can belong to *more than one* lower-level entity set
- ***Covering Constraints***
  - **Total**
    - an entity must belong to one of the lower-level entity sets
    - Denoted with a thick line between the IsA-triangle and the superclass
  - **Partial** (the default)
    - an entity need not belong to one of the lower-level entity sets

Aggregation

› Consider a *ternary* relationship *Sponsors*

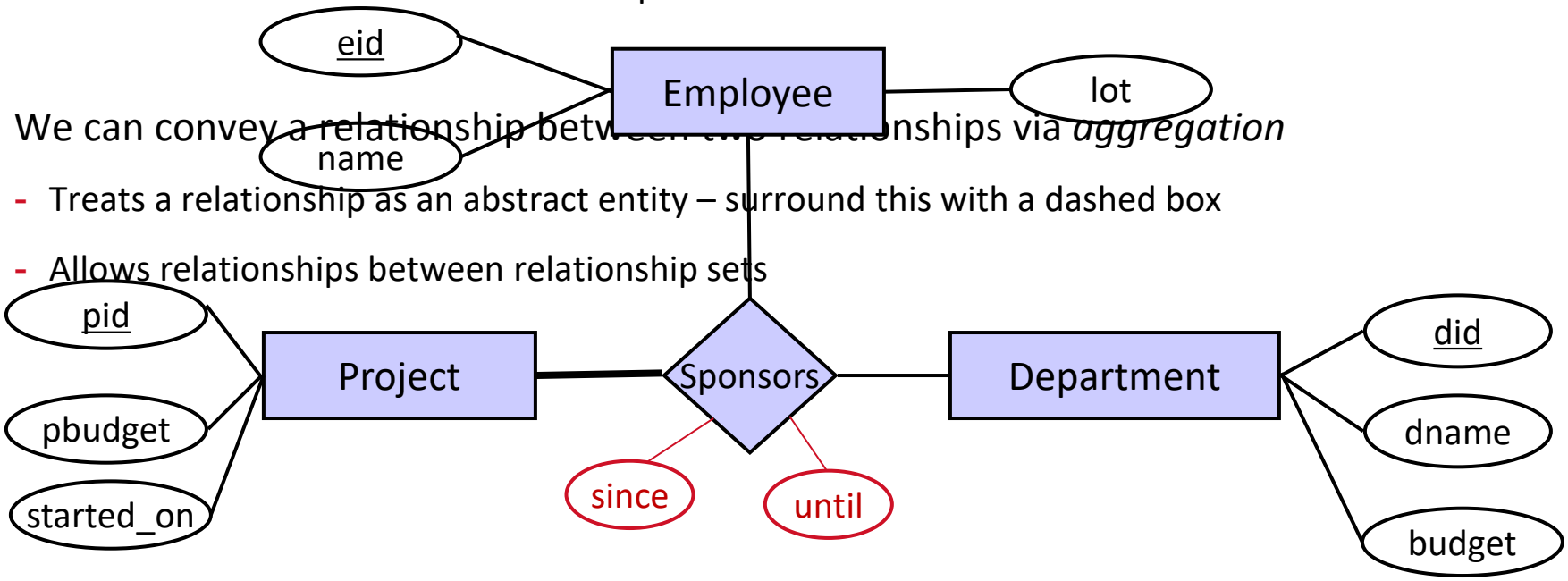


- Each project can be sponsored by one or more departments
- A department can appoint one or more employees to monitor a sponsorship
- What are the issues with this representation?

(Example adapted from Ramakrishnan & Gherke, DBMS, 3rd edition)

Aggregation (Cont'd)

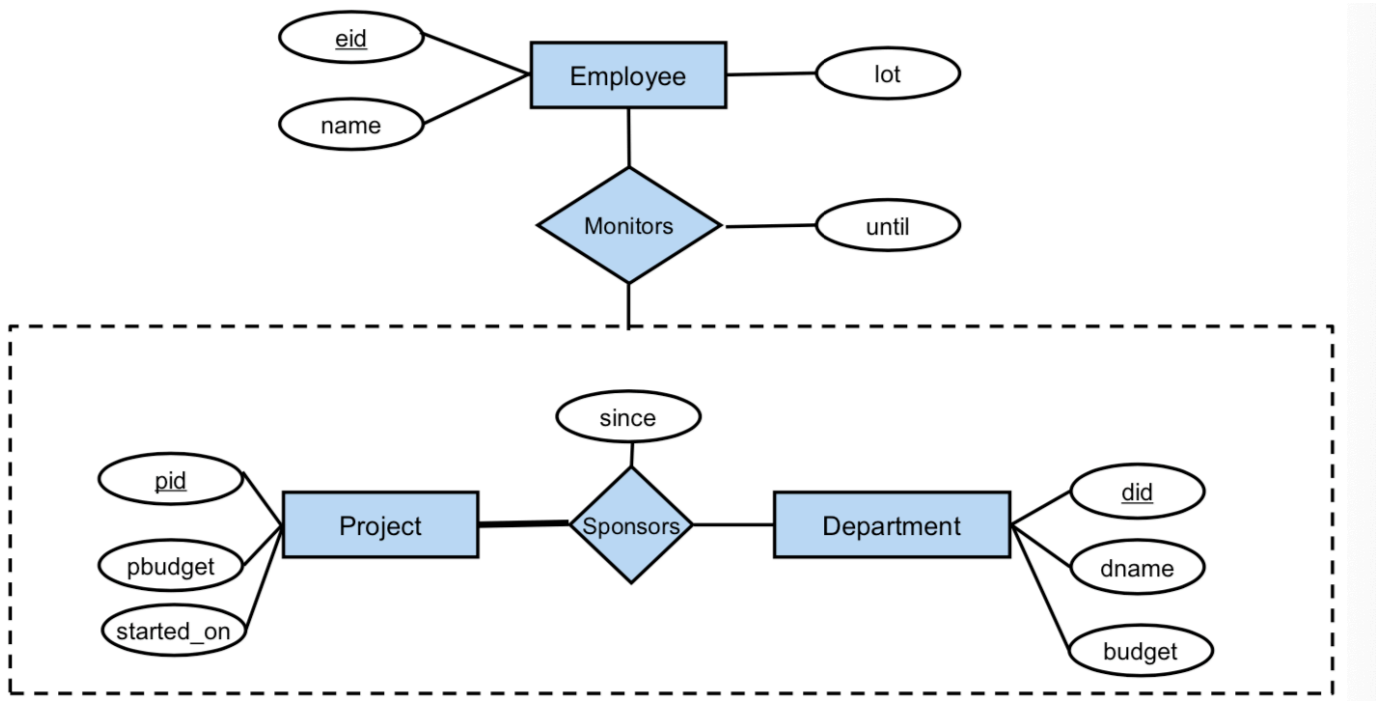
- Relationship set *Sponsors is* really trying to model *two relationships*
  - It is trying to model the fact that departments *sponsor* projects, but also these sponsorships are *monitored.*
  - What if we want to add different attributes for each of these relationships, e.g., attribute "*since*" to the sponsorship and until attribute "*until*" to the monitoring?
    - It would be more meaningful. However, we need to ensure our model adds such required attributes on the correct relationship.



- We can convey a relationship between two relationships via *aggregation*
  - Treats a relationship as an abstract entity – surround this with a dashed box
  - Allows relationships between relationship sets

E-R Diagram With Aggregation

- **Aggregation:** It conveys a **relationship between two relationships**: in our example, it conveys a relationship between the *sponsors* relationship type and the Employee entity type: we introduce aggregation via a *Monitors* relationship type.
  - Allows us to model that *sponsorships* start at a given time and that employees are assigned to *monitor* a *sponsorship* until a given time.



(Example from Ramakrishnan & Gherke, DBMS, 3rd edition)

This Week We Have Learned…

- **Conceptual database design using the E-R Model**
  - Understanding and experience with conceptual database design using the entity-relationship model:
    - Basic Constructs: Entity, Attributes (single, composite, multivalued, derived), Relationships, Cardinality Constraints
    - Advanced Concepts: Weak Entities, Inheritance, Aggregation

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IMPORTANT

- Many variations of ER diagrams are in use, and there is no widely accepted standard.

- **Which notation should I use for assessments like quiz, final exam etc?**
  - **Must use** the notation just outlined in this lecture

References

- Ramakrishnan/Gehrke (3rd edition)
  - **Chapter 2**

- Kifer/Bernstein/Lewis (2nd edition)
  - Chapter 4
- Ullman/Widom (3rd edition)
  - Chapter 4
- Silberschatz/Korth/Sudarshan (5th edition - ‘sailing boat’)
  - Chapter 6
- Elmasri/Navathe (5th edition)
  - Chapters 3 and 4

Next Week: Relational Model

- Readings:
  - **Ramakrishnan/Gehrke, Chapter 3 plus Chapter 1.5**
  - Kifer/Bernstein/Lewis, Chapter 3
  - Ullman/Widom, Chapter 2.1 - 2.3, Section 7.1 and Chapter 8.1-8.2

See you next week!

Remember to form group and put that information in Canvas

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