Principles of Database Systems (CS307)

Lecture 7-8: Application Development; Database Design Using the E-R Model

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- Most contents are from slides made by Stéphane Faroult and the authors of Database System Concepts (7th Edition).
- Their original slides have been modified to adapt to the schedule of CS307 at SUSTech.

Application Development

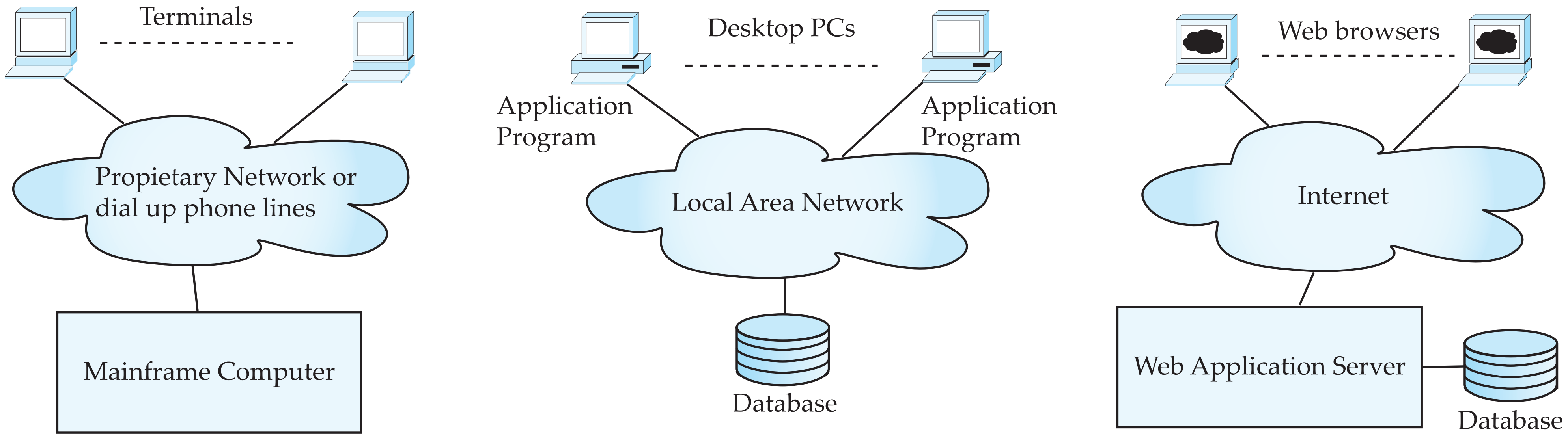
Application Programs and User Interfaces

- Most database users do *not* use a query language like SQL
- An application program acts as the intermediary between users and the database
  - Applications split into
    - front-end
    - middle layer
    - backend
- Front-end: user interface
  - Forms
  - Graphical user interfaces
  - Many interfaces are Web-based

Application Architecture Evolution

- Three distinct era's of application architecture
  - Mainframe (1960' s and 70' s)
  - Personal computer era (1980' s)
  - Web era (mid 1990' s onwards)
  - Web and Smartphone era (2010 onwards)

Next generation?



(a) Mainframe Era (b) Personal Computer Era (c) Web era

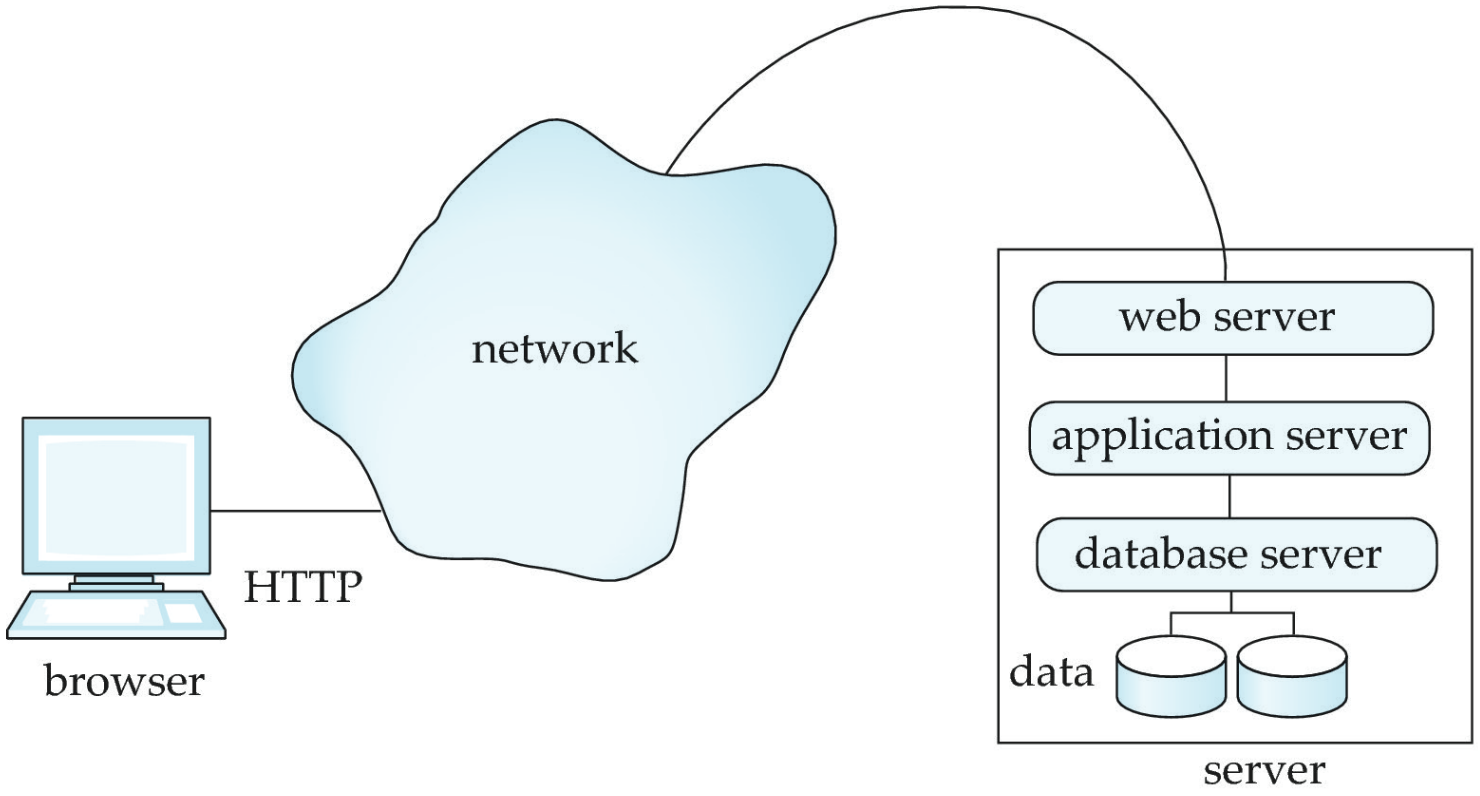
Web Interface

- Web browsers have become the de-facto standard user interface to databases
  - Enable large numbers of users to access databases from anywhere
  - Avoid the need for downloading/installing specialized code, while providing a good graphical user interface
    - JavaScript and other scripting languages run in browser, but are downloaded transparently
  - Examples: banks, airline and rental car reservations, university course registration and grading, and so on.

The World Wide Web

- The Web is a distributed information system based on hypertext.
- Most Web documents are hypertext documents formatted via the HyperText Markup Language (HTML)
- HTML documents contain
  - text along with font specifications, and other formatting instructions
  - hypertext links to other documents, which can be associated with regions of the text.
  - forms, enabling users to enter data which can then be sent back to the Web server

Three-Layer Web Architecture



HTML and HTTP

- HTML provides formatting, hypertext link, and multimedia display features
  - including tables, stylesheets (to alter default formatting), etc.
- HTML also provides input features
  - Select from a set of options
    - Pop-up menus, radio buttons, check lists
  - Enter values
    - Text boxes
  - Filled in input sent back to the server, to be acted upon by an executable at the server
- HyperText Transfer Protocol (HTTP) used for communication with the Web server

HTML and HTTP

HTML Demo.html

```html
<label for="role">Select Role:</label>
<select id="role">
    <option value="admin">Admin</option>
    <option value="user">User</option>
</select>
<p>Enter Username:</p>
<input type="text" placeholder="Enter username">
```

```html
<p>This is an example of <a href="#">hypertext link</a> in HTML.</p>
<img src="https://via.placeholder.com/150" alt="Placeholder Image">
```

```html
<table>
    <thead>
        <tr>
            <th>Name</th>
            <th>Email</th>
        </tr>
    </thead>
    <tbody>
        <tr>
            <td>John Doe</td>
            <td>john@example.com</td>
        </tr>
        <tr>
            <td>Jane Smith</td>
            <td>jane@example.com</td>
        </tr>
    </tbody>
</table>
```

JavaScript

- JavaScript very widely used
  - Forms basis of new generation of Web applications (called Web 2.0 applications) offering rich user interfaces
- JavaScript functions can
  - Check input for validity
  - Modify the displayed Web page, by altering the underling document object model (DOM) tree representation of the displayed HTML text
    - Communicate with a Web server to fetch data and modify the current page using fetched data, without needing to reload/refresh the page
    - Forms basis of AJAX technology used widely in Web 2.0 applications
    - E.g. on selecting a country in a drop-down menu, the list of states in that country is automatically populated in a linked drop-down menu

JavaScript

JS Demo.html

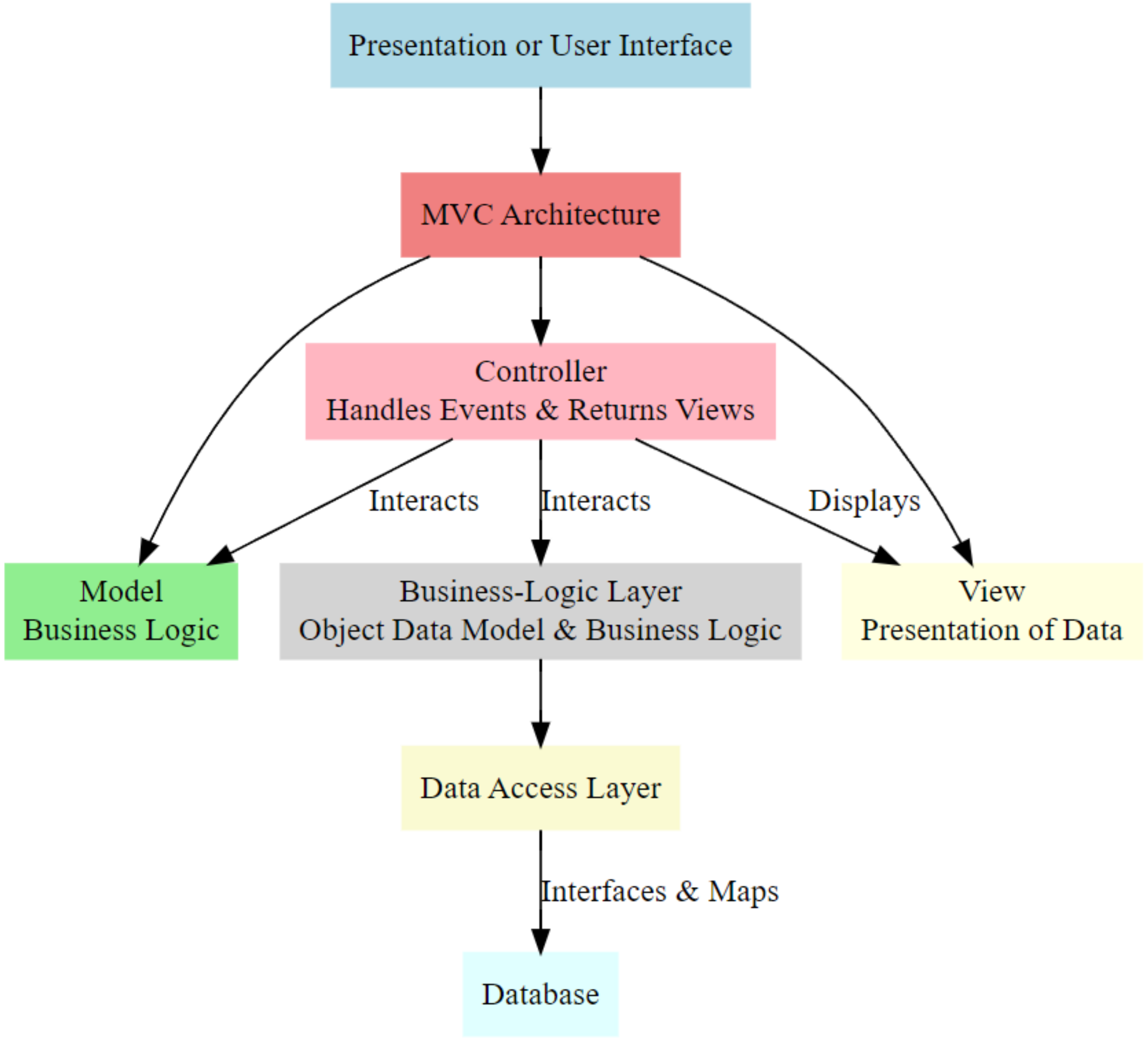
```
function showAlert() {
    alert('This is an alert!');
}

function getConfirmation() {
    let response = confirm('Do you confirm?');
    if (response) {
        alert('You clicked OK');
    } else {
        alert('You clicked Cancel');
    }
}
```

```
function buttonClicked() {
    alert('Button was clicked!');
}
```

```
function changeText() {
    document.getElementById('domText').textContent = 'Text changed by JavaScript!';
}
```

Application Architectures

- Application layers
  - Presentation or user interface
    - model-view-controller (MVC) architecture
      - model: business logic
      - view: presentation of data, depends on display device
      - controller: receives events, executes actions, and returns a view to the user
  - business-logic layer
    - provides high level view of data and actions on data
    - hides details of data storage schema
  - data access layer
    - interfaces between business logic layer and the underlying database



Business Logic Layer

- Provides abstractions of entities
- Enforces business rules for carrying out actions
- Supports workflows which define how a task involving multiple participants is to be carried out
  - Sequence of steps to carry out task
  - Error handling
  - …

Business Logic Layer

- **Scenario:** 📚 Library system allowing users to borrow books.

- **Core Business Rules**:
  1. 📖 Users can borrow up to 5 books at a time.
  2. 🚫 Cannot borrow a book already checked out.
  3. ❗ Cannot borrow with overdue books.

```java
public class LibraryBusinessLayer {

    private DataAccessLayer dataAccess;

    public LibraryBusinessLayer(DataAccessLayer dataAccess) {
        this.dataAccess = dataAccess;
    }

    public String borrowBook(User user, int bookId) {
        if (dataAccess.getBorrowedBooksCount(user) >= 5) {
            return "Limit reached.";
        }
        if (dataAccess.isBookBorrowed(bookId)) {
            return "Book is already borrowed.";
        }
        if (dataAccess.hasOverdueBooks(user)) {
            return "You have overdue books.";
        }
        dataAccess.borrowBook(user, bookId);
        return "Book borrowed successfully!";
    }
}
```

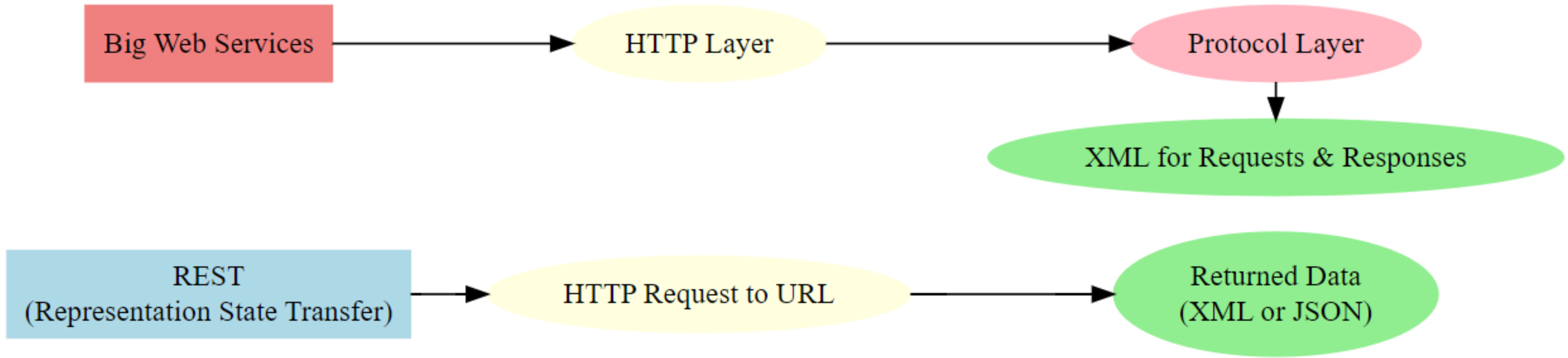
Object-Relational Mapping (ORM)

ORM allows using object-oriented models in applications while storing data in relational databases.

- Benefits:
  - Seamless integration of object and relational models.
  - Write application code using objects, store data as relational tables.
- Challenges:
  - Object-oriented databases are NOT widely adopted commercially.
  - Need to map object data to relational schema.
    - Example: A Student class in Java maps to a student table.
- How ORM Works:
  - Open a database session.
  - Use the session to save or query objects.
    - E.g.: *session.save(object)* converts the object to table rows.

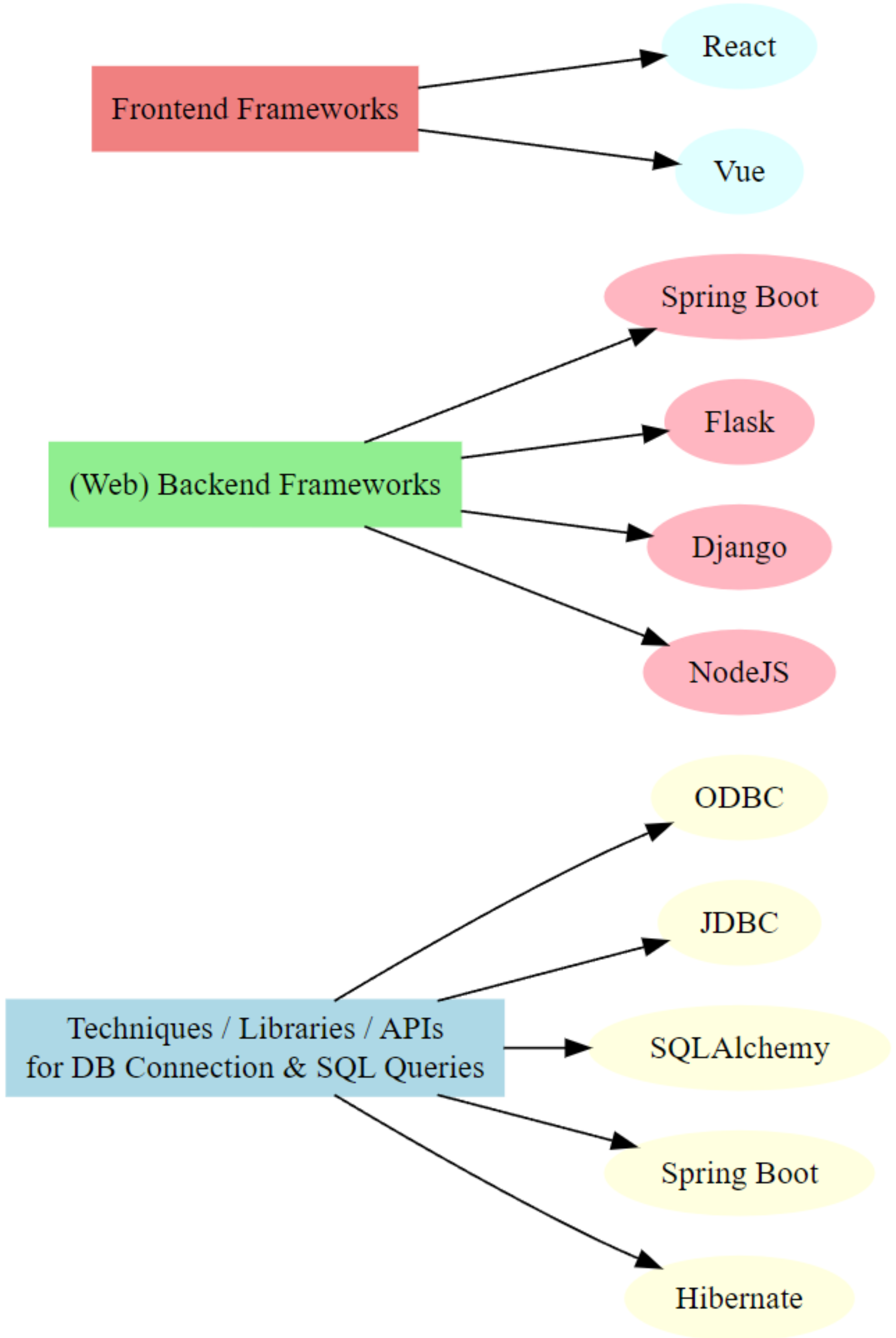
Web Services

- Allow data on Web to be accessed using remote procedure call mechanism
- Two approaches are widely used
  - Representation State Transfer (REST): allows use of standard HTTP request to a URL to execute a request and return data
    - Returned data is encoded either in XML, or in JavaScript Object Notation (JSON)
  - Big Web Services:
    - Uses XML representation for sending request data, as well as for returning results
    - Standard protocol layer built on top of HTTP



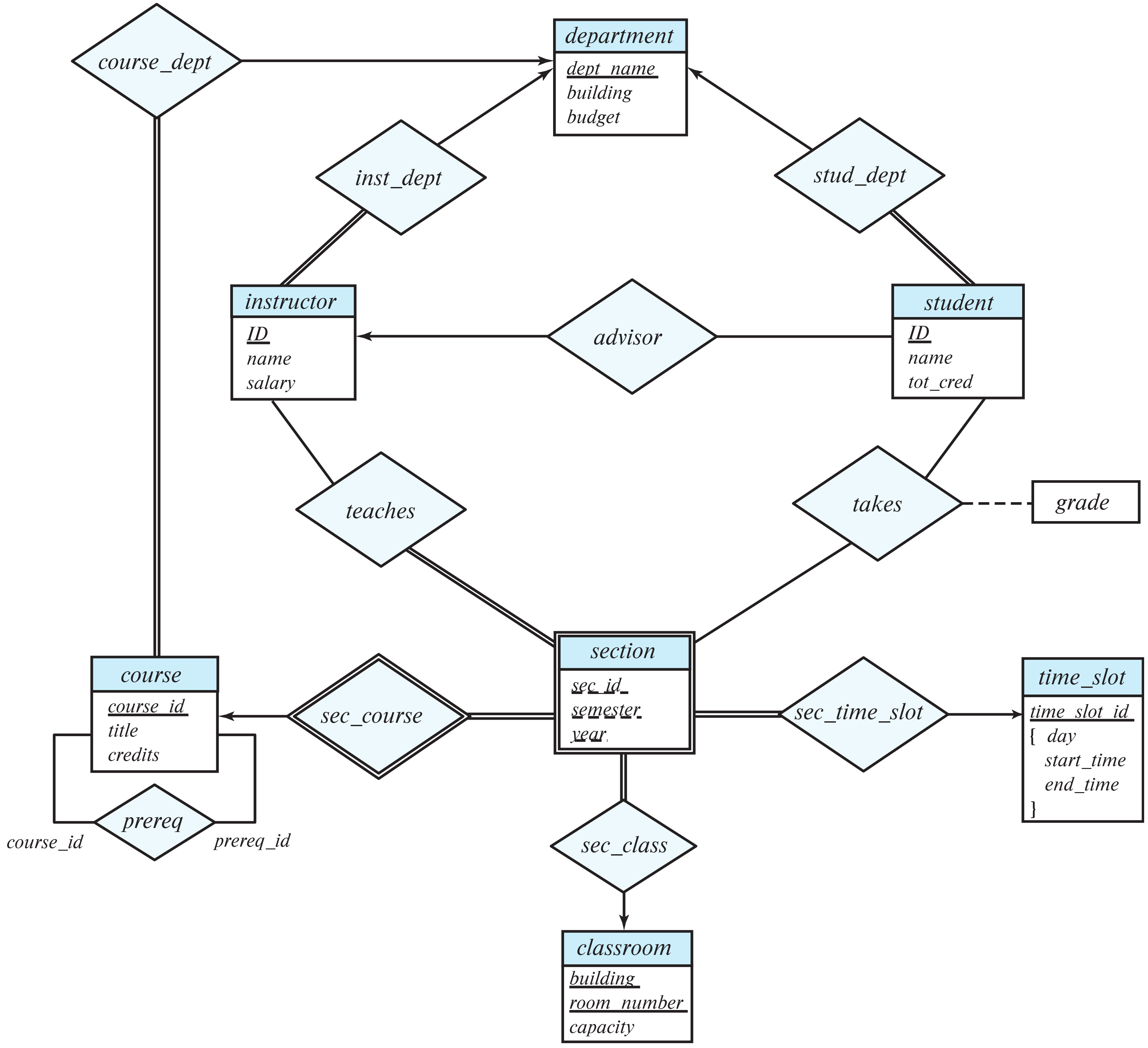
Self Study

- Key points:
  - Techniques / libraries / APIs to connect to a database (e.g. PostgreSQL) and run SQL querys in a program
    - ODBC, JDBC?
    - SQLAlchemy? Spring Boot? Hibernate?
  - (Web) Backend Frameworks
    - Spring Boot, Flask, Django
    - NodeJS
  - Frontend Frameworks
    - React, Vue



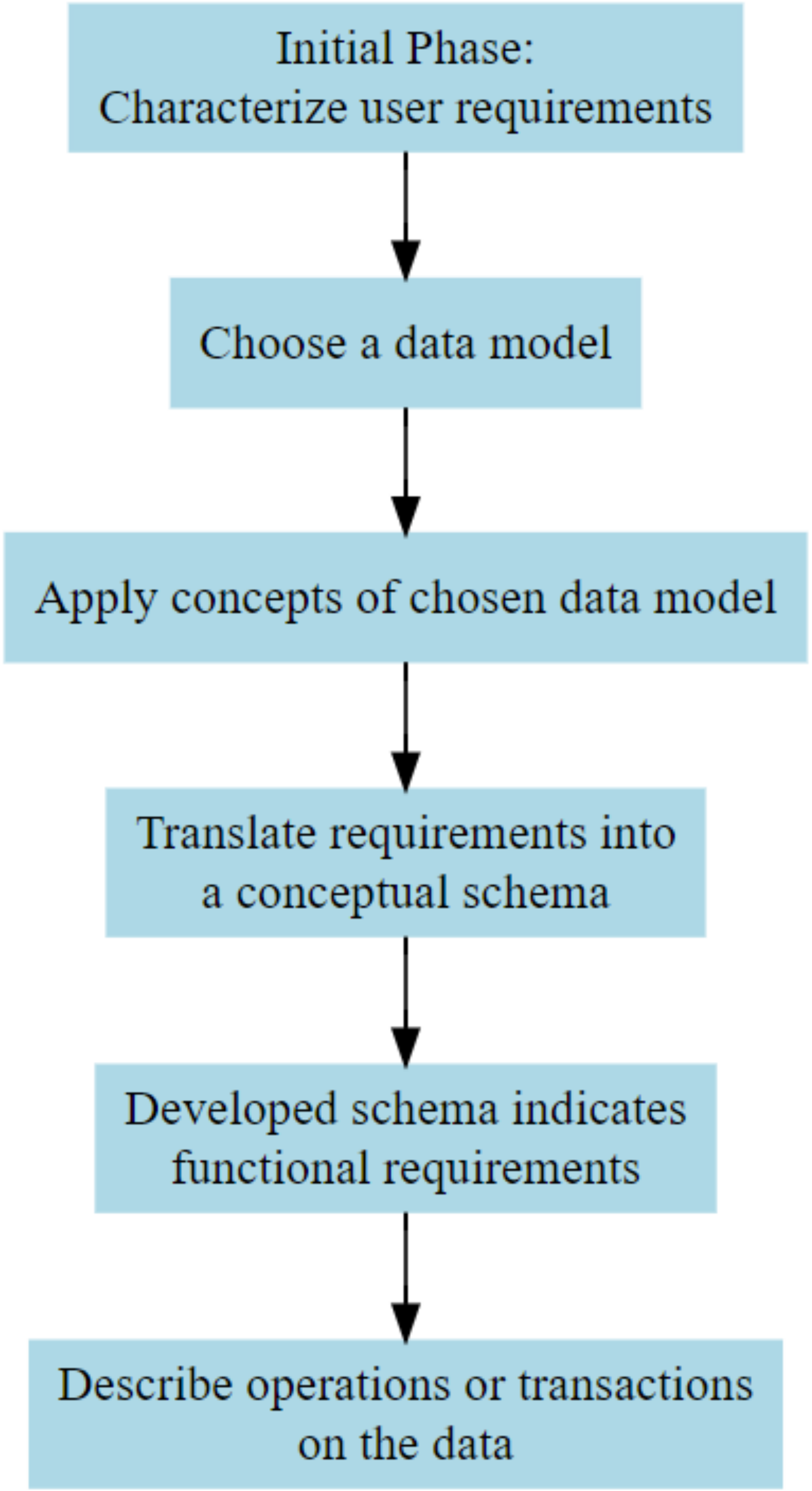
Entity-Relationship Model (E-R Model)
Entity-Relationship Diagram (E-R Diagram)

The New Running Example



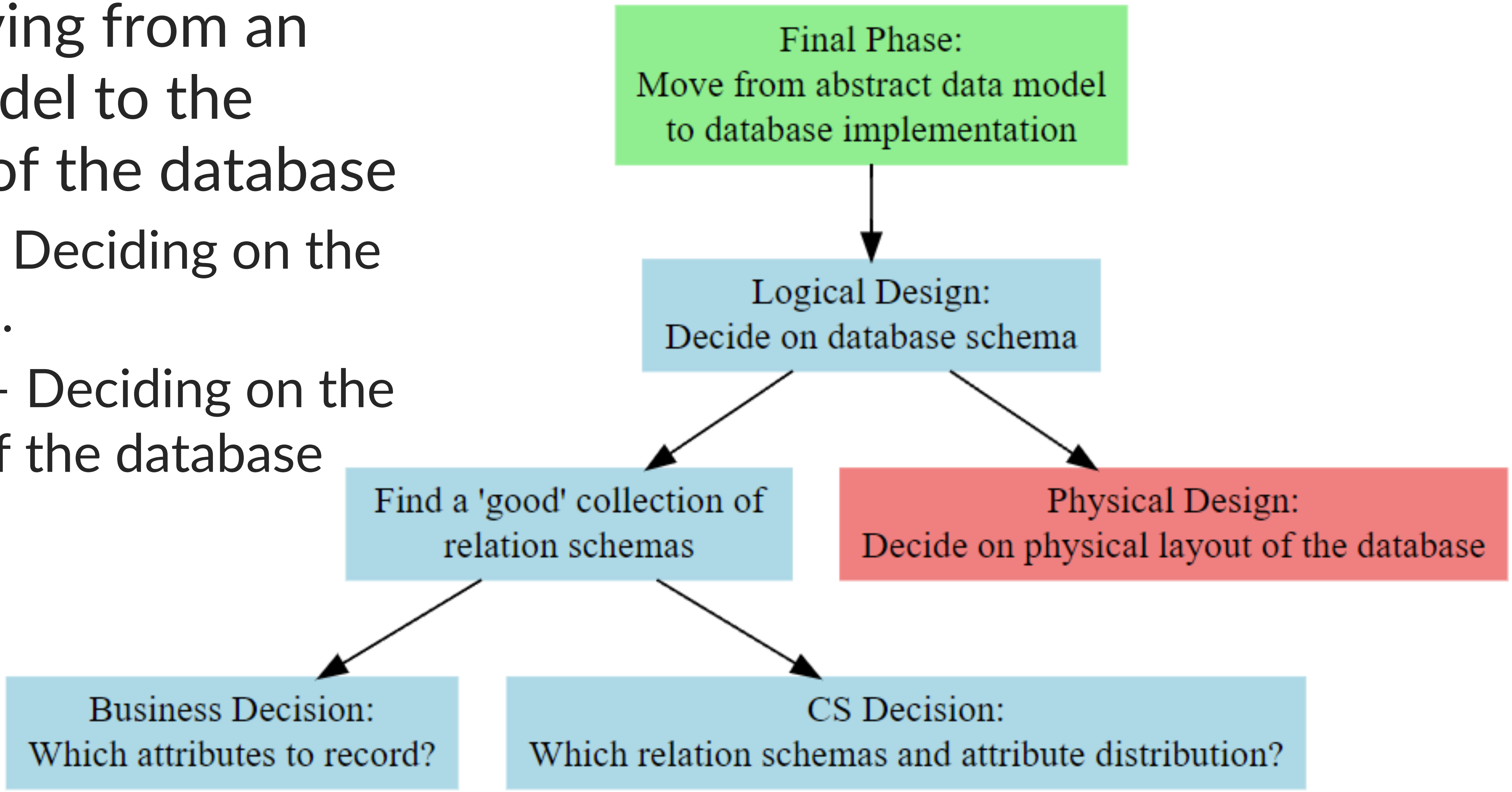
Design Phases

- Initial phase: characterize fully the requirements of the prospective database users.
- Second phase: choosing a data model
  - Applying the concepts of the chosen data model
  - Translating these requirements into a conceptual schema of the database
  - A fully developed conceptual schema indicates the functional requirements of the enterprise
    - Describe the kinds of operations (or transactions) that will be performed on the data



Design Phases

- Final Phase: Moving from an abstract data model to the implementation of the database
  - Logical Design – Deciding on the database schema.
  - Physical Design – Deciding on the physical layout of the database



Design Phases – Physical Design

- File Organization: How data is stored and organized.
- Indexing: Mechanisms to speed up data retrieval.
- Data Partitioning: Distributing data across storage.
- Storage Structures: Data structures for data storage, e.g., B-trees.
- Backup & Recovery: Mechanisms to restore data post failures.
- ...

Design Alternatives

- In designing a database schema, we must ensure that we avoid two major pitfalls:
  - **Redundancy**: a bad design may result in <u>repeat information</u>
    - Redundant representation of information may lead to data inconsistency among the various copies of information
  - **Incompleteness**: a bad design may <u>make certain aspects</u> of the enterprise <u>difficult or impossible to model</u>
- Avoiding bad designs is not enough
  - There may be many good designs from which we must choose

Design Approaches

- Entity Relationship Model (covered in this chapter)
  - Models an enterprise as <u>a collection of</u> 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 (E-R diagram)

- Normalization Theory (coming in the next few weeks)
  - Formalize what designs are bad, and test for them

Entity Sets

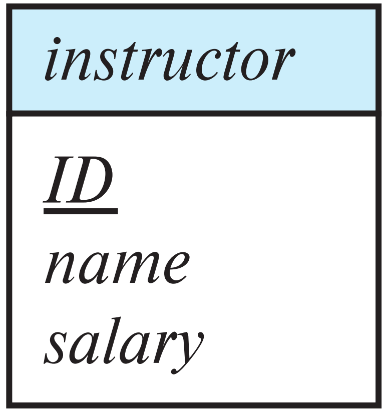
- An entity is an object that exists and is distinguishable from other objects
  - Example: specific person, company, event, plant
- An entity set is a set of entities of the same type that share the same properties
  - Example: set of all persons, companies, trees, holidays
- An entity is represented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

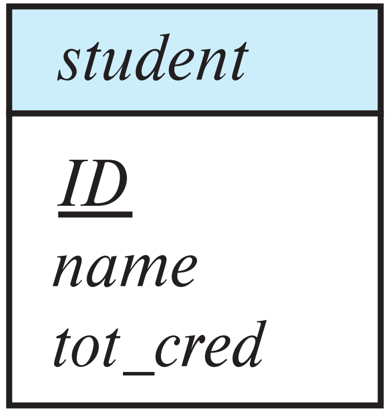
```
instructor = (ID, name, salary)
course = (course_id, title, credits)
```

- A subset of the attributes form a primary key of the entity set; i.e., uniquely identifying each member of the set.

Representing Entity sets in ER Diagram

- Entity sets can be represented graphically as follows:
  - Rectangles represent entity sets.
  - Attributes listed inside entity rectangle
  - Underline indicates primary key attributes





Relationship Sets

- A relationship is an association among several entities

```
44553 (Tom) ──────→ advisor ←────── 22222 (Jack)
student entity    relationship set   instructor entity
```

- A relationship set is a mathematical relation among n $\geq$ 2 entities, each taken from entity sets

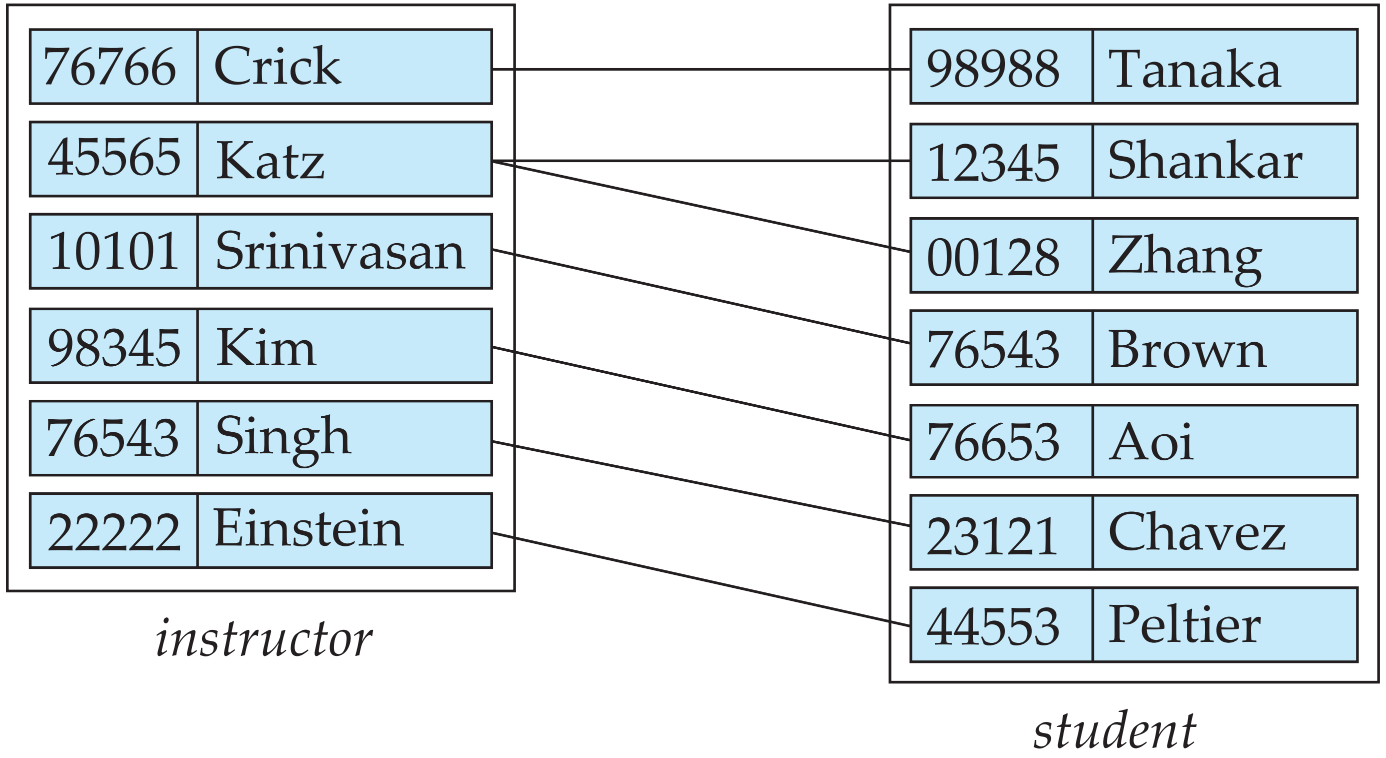
$$\{(e_1, e_2, \ldots e_n) \mid e_1 \in E_1, e_2 \in E_2, \ldots, e_n \in E_n\}$$

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

  - Example: (44553,22222) $\in$ advisor

Relationship Sets

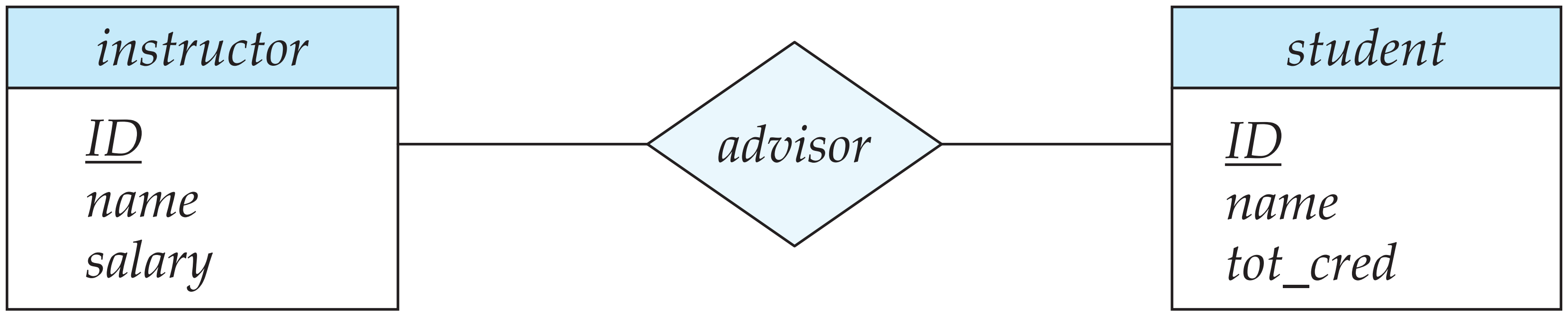
- Example: we define the relationship set `advisor` to denote the associations between students and the instructors who act as their advisors.
  - Pictorially, we draw a line between related entities



  - What is there are many relationships? Many lines?

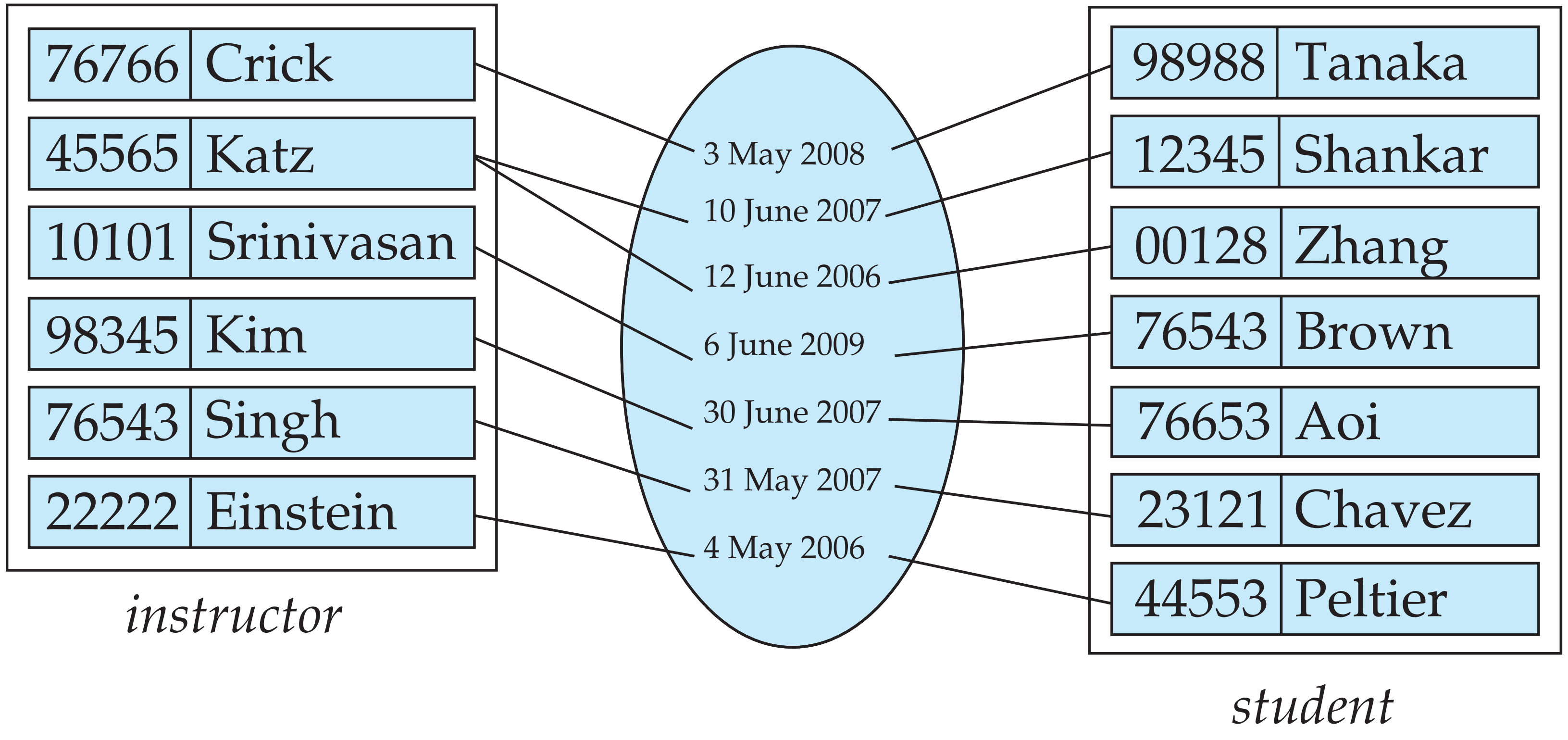
Representing Relationship Sets via E-R Diagrams

- Diamonds represent relationship sets

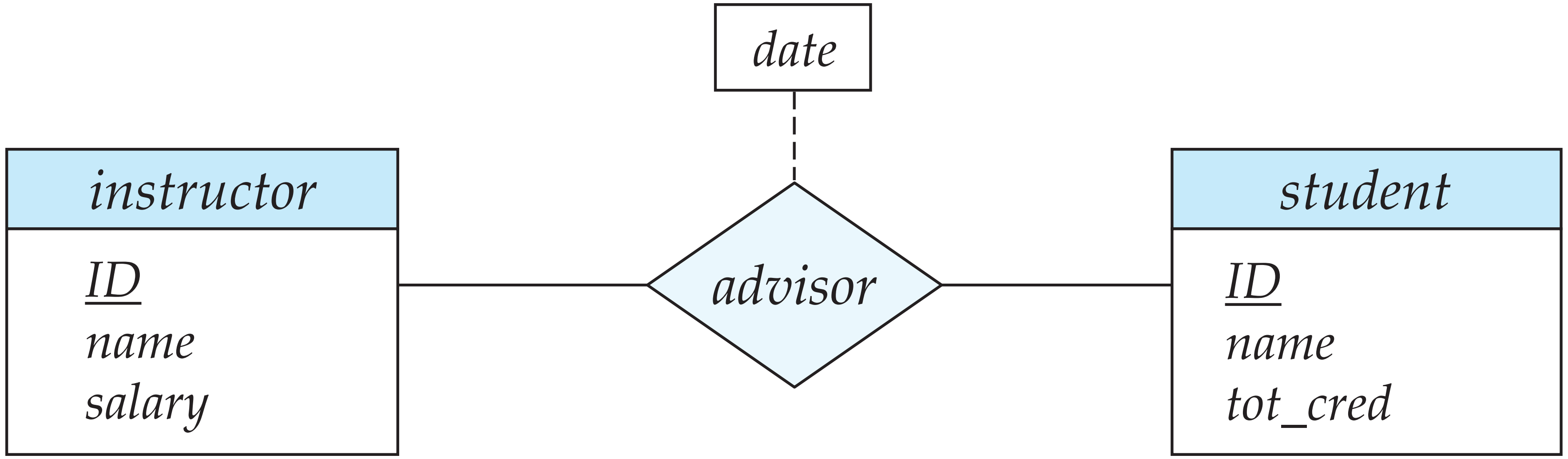


Relationship Sets (Cont.)

- An attribute can also be associated with 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



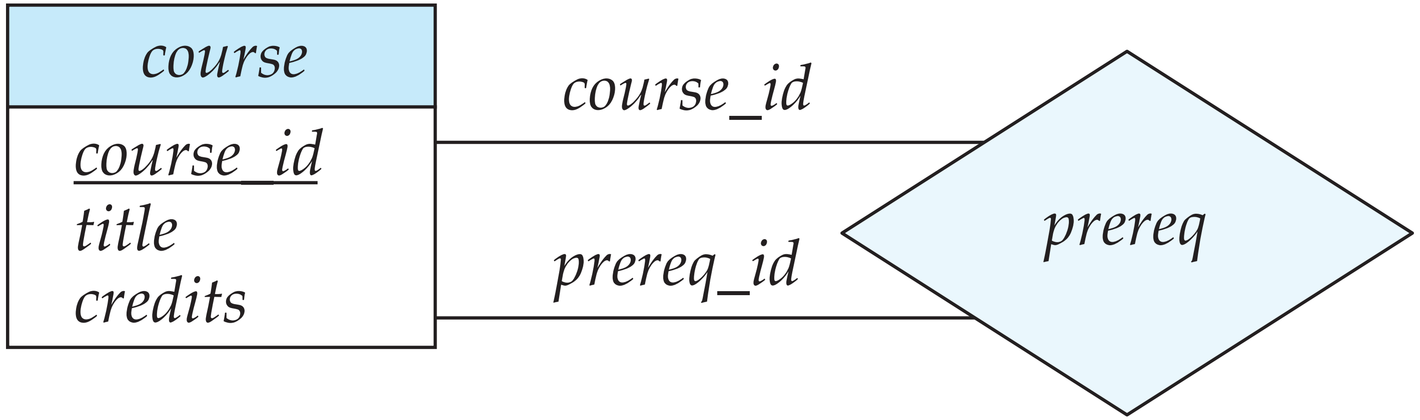
Relationship Sets with Attributes



Roles

- Entity sets of a relationship need not be distinct
  - That is to say, we can create self-pointing relationships for an entity set
  - Each occurrence of an entity set plays a "role" in the relationship

  - Example: A relationship set to represent the prerequisites of a course
    - E.g., Data Structure depends on Introduction to Programming
    - The labels "`course_id`" and "`prereq_id`" are called roles
    - Self-related

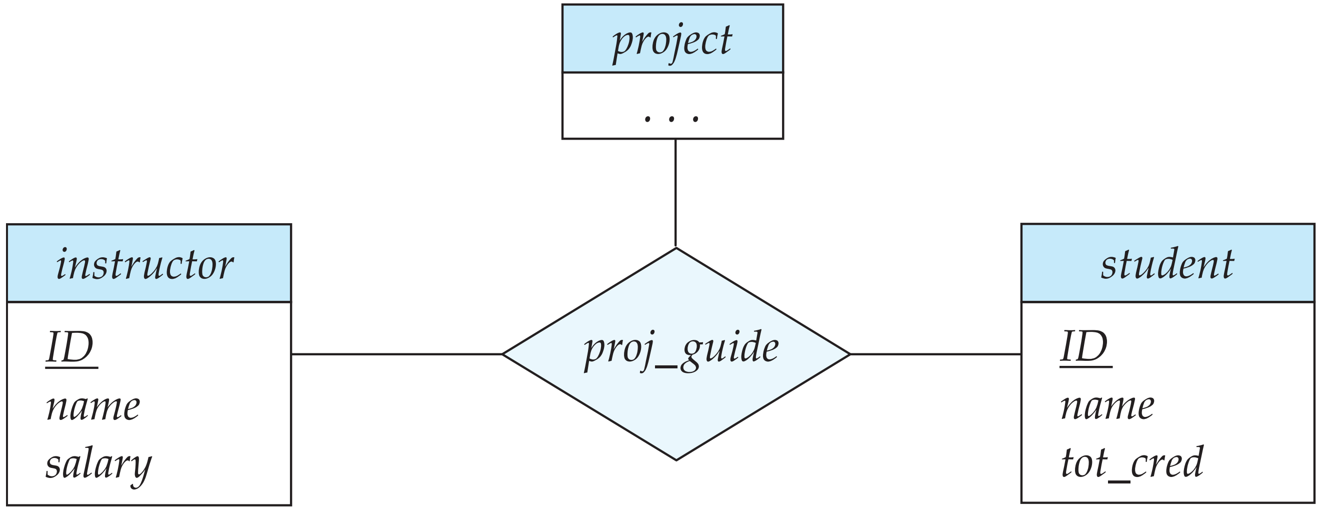


Degree of a Relationship Set

- 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 (why?)
  - Example: students work on research projects under the guidance of an instructor.
    - relationship `proj_guide` is a ternary (三重的) relationship between instructor, student, and project

Non-binary Relationship Sets

- Most relationship sets are binary
  - There are occasions when it is more convenient to represent relationships as non-binary
- E-R Diagram with a Ternary Relationship



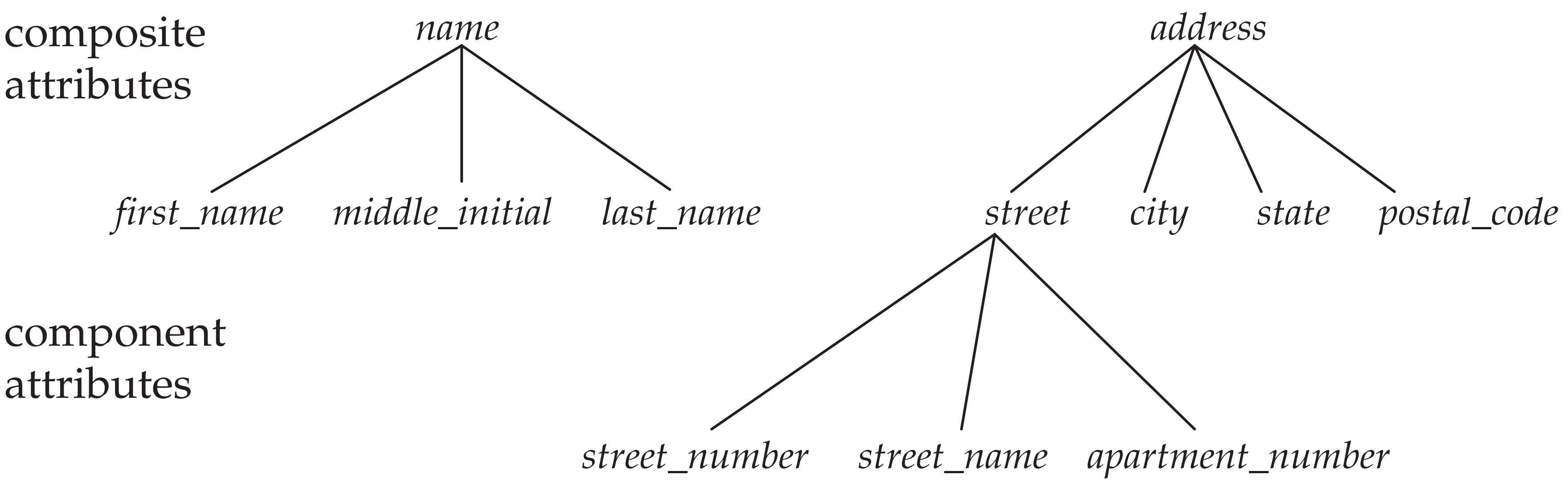
Complex Attributes – Tree Structure

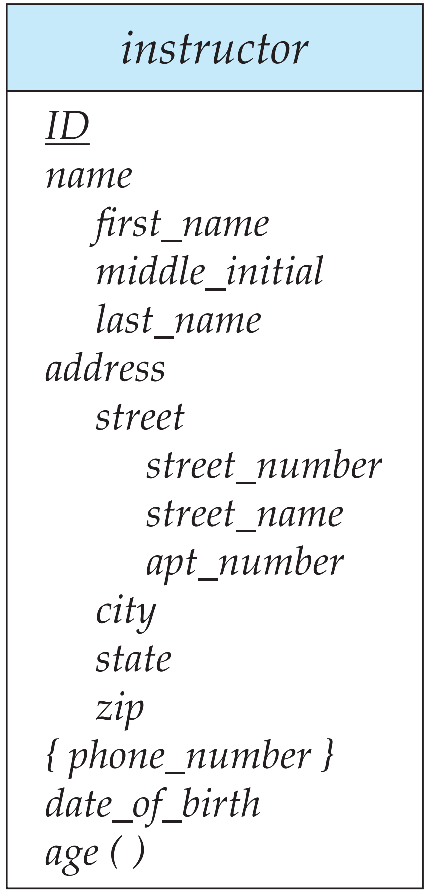
- Attribute types:
  - Simple and composite attributes.
  - Single-valued and multivalued attributes
    - Example: multivalued attribute: phone_numbers
      - A person can have 1 or more phone numbers at the same time
  - Derived attributes
    - Can be computed from other attributes
    - Example: age, given date_of_birth

- **Domain**: The set of permitted values for each attribute

Composite Attributes – Tree Structure

- Composite attributes allow us to divided attributes into subparts (other attributes)
  - Sometimes we may only use part of the attributes, where the composite attribute is a good design choice





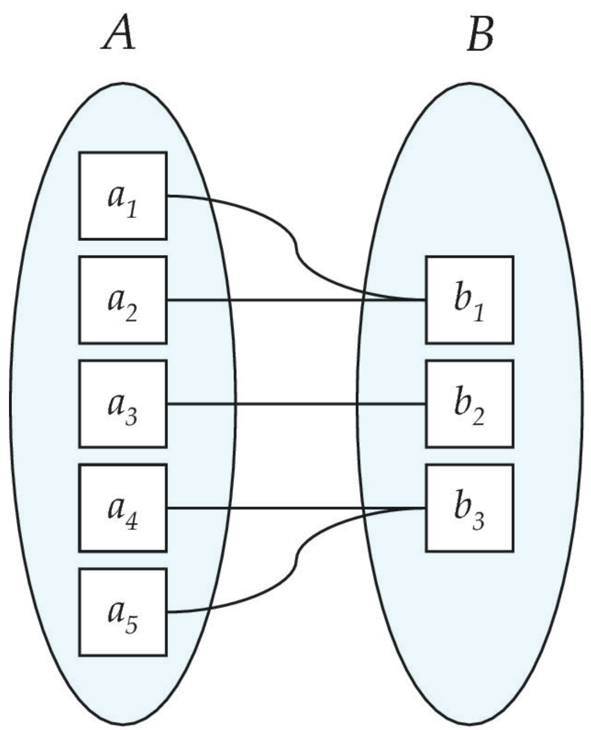
Cardinality (基数) in Database

- Definition:
  - Cardinality refers to the uniqueness of data values contained in a column.
  - In the context of databases, it denotes the number of distinct values in a column.
- Types:
  - Low Cardinality: Column has a limited set of unique values (e.g., Gender with values 'Male' or 'Female').
  - High Cardinality: Column has a large set of unique values (e.g., EmployeeID).
- Relevance:
  - Affects database design, query performance, and indexing strategies.
  - Essential in understanding relationships between tables in relational databases.

Mapping Cardinality Constraints

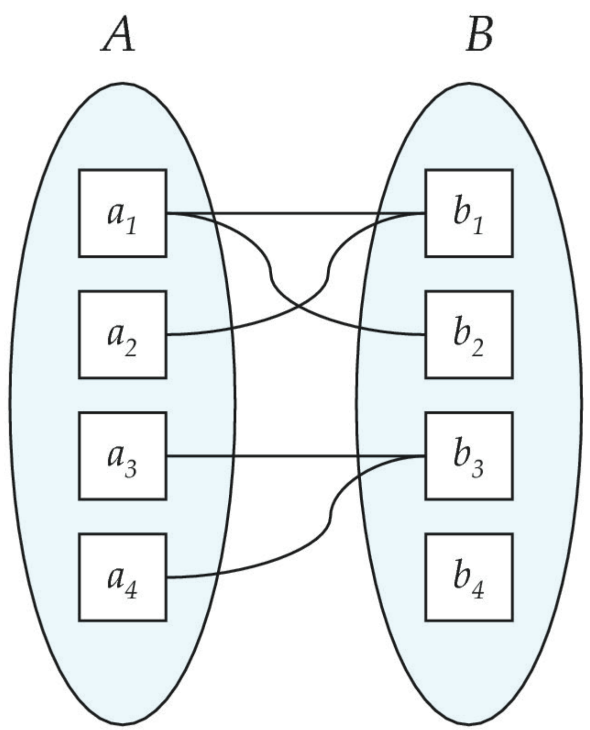
- Mapping Cardinality（映射基数）
  - Express the number of entities to which another entity can be associated via a relationship set.
    - Most useful in describing binary relationship sets
- For a binary relationship set, the mapping cardinality must be one of the following types:
  - One to one
  - One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

Mapping Cardinalities



(a)

Many to one

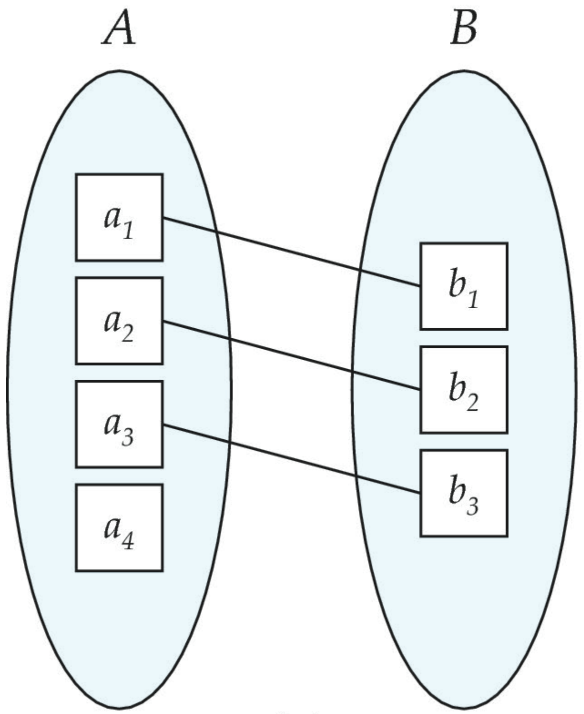


(b)

Many to many

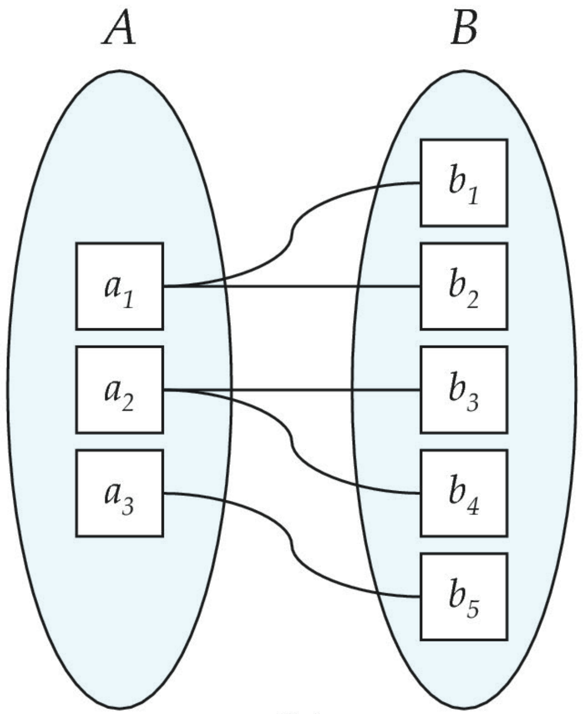
Note: Some elements in *A* and *B* may not be mapped to any
elements in the other set

Mapping Cardinalities



(a)

One to one



(b)

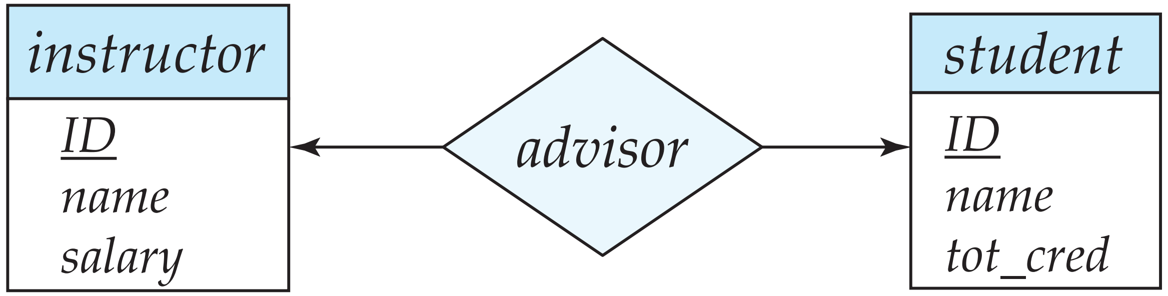
One to many

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

Representing Cardinality Constraints in ER Diagram

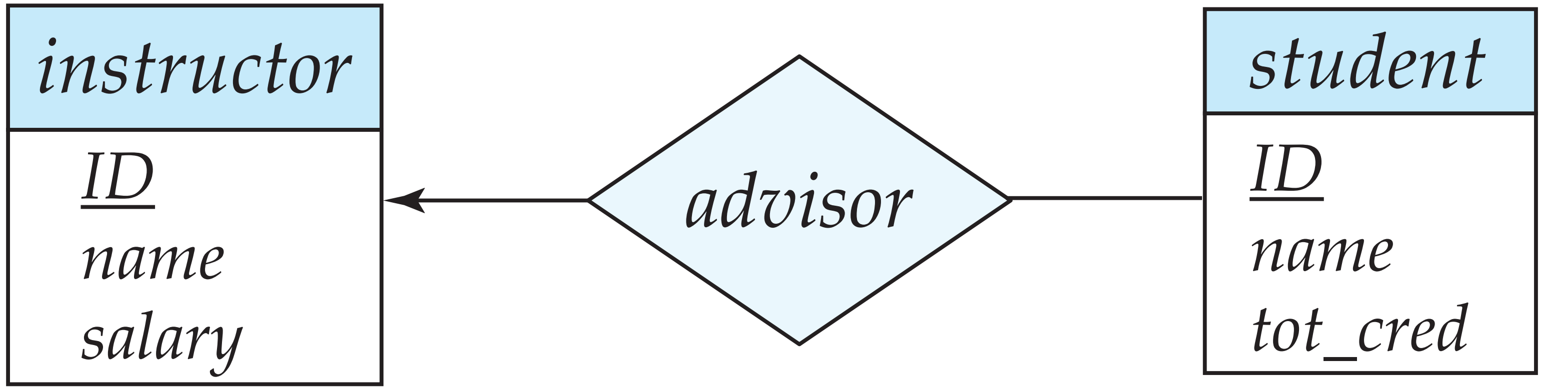
- We express cardinality constraints by:
  - drawing either a directed line (→), signifying "one,"
  - or an undirected line (—), signifying "many,"
- … between the relationship set and the entity set.

- <u>One-to-one relationship</u> between an instructor and a student :
  - A student is associated with at most one instructor via the relationship advisor



Representing Cardinality Constraints in ER Diagram

- 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

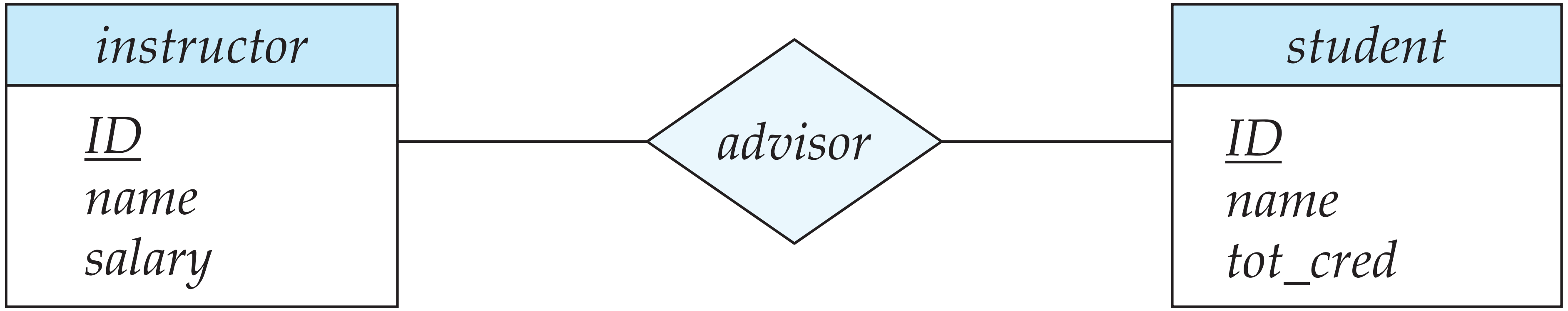


Representing Cardinality Constraints in ER Diagram

- In a <u>many-to-one relationship</u> between an instructor and a student,
  - an instructor is associated with at most one student via advisor
  - and a student is associated with several (including 0) instructors via advisor

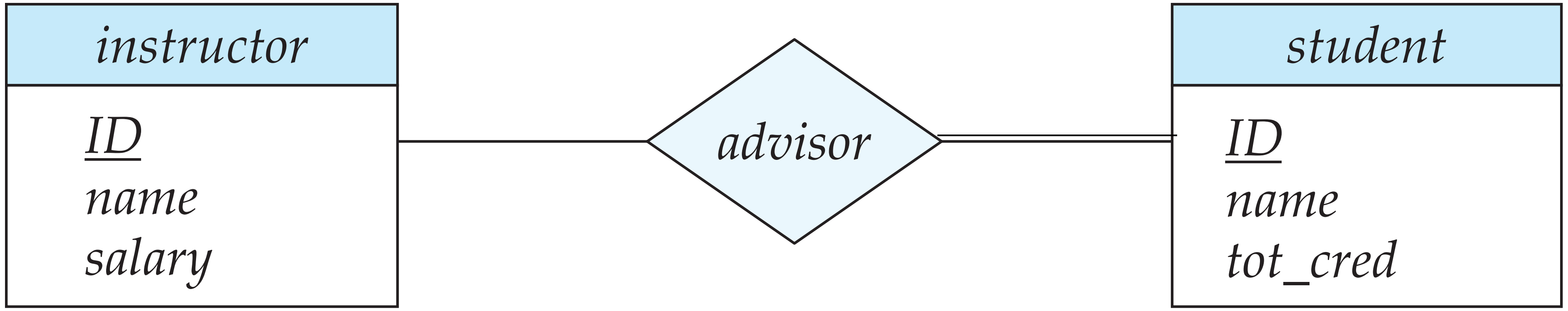
Representing Cardinality Constraints in ER Diagram

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



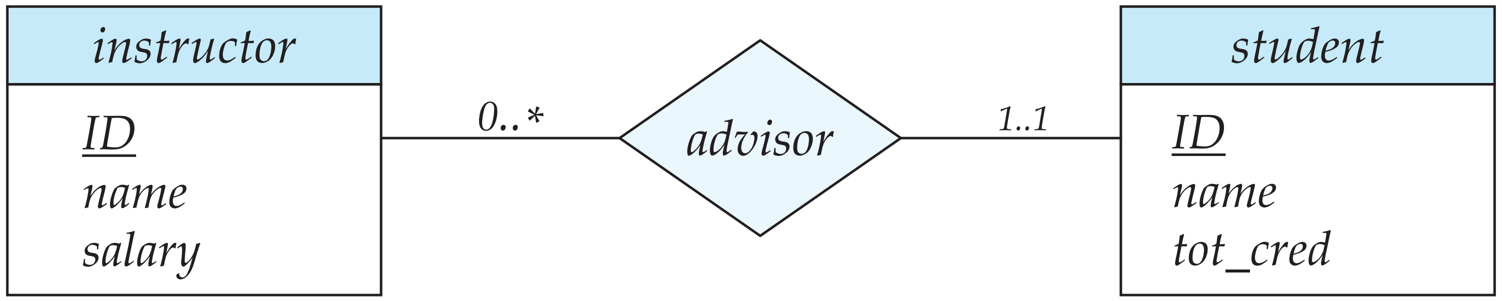
Total and Partial Participation

- Total participation (indicated by *double line*)
  - Every entity in the entity set participates in at least one relationship in the relationship set
  - Example: Participation of student in advisor relation is total
    - i.e., every student must have an associated instructor
- Partial participation
  - Some entities may not participate in any relationship in the relationship set
  - Example: participation of instructor in advisor is partial



Notation for Expressing More Complex Constraints

- A line may have an associated minimum and maximum cardinality, shown in the form *l..h*, where l is the minimum and h the maximum cardinality
  - A minimum value of 1 indicates total participation.
  - A maximum value of 1 indicates that the entity participates in at most one relationship
  - A maximum value of * indicates no limit.



- Example
  - Instructor can advise 0 or more students
  - A student must have 1 advisor; cannot have multiple advisors

Primary Key

- Primary keys provide a way to specify how entities and relations are distinguished

Primary Key for Entity Sets

- By definition, individual entities are distinct
  - From database perspective, the differences among them must be expressed in terms of their attributes.
- The values of the attribute values of an entity must be such that they can uniquely identify the entity.
  - No two entities in an entity set are allowed to have exactly the same value for all attributes

- A key for an entity is a set of attributes that <u>suffice to distinguish entities from each other</u>

Primary Key for Relationship Sets

- To distinguish among the various relationships of a relationship set, we use the **individual primary keys** of the entities in the relationship set.
  - Let R be a relationship set involving entity sets E1, E2, .. En
  - The primary key for R consists of the union of the primary keys of entity sets E1, E2, ..En
  - If the relationship set R has attributes $a_1, a_2, .., a_m$ associated with it, the primary key of R also includes the attributes $a_1, a_2, .., a_m$
- Example: relationship set “advisor”.
  - The primary key consists of instructor.ID and student.ID
- The choice of the primary key for a relationship set depends on the mapping cardinality of the relationship set.

Choice of Primary key for Binary Relationship

- Many-to-Many relationships
  - The preceding union of the primary keys is a minimal superkey and is chosen as the primary key.
- One-to-one relationships
  - The primary key of either one of the participating entity sets forms a minimal superkey, and either one can be chosen as the primary key.

* *K* is a **superkey** of *R* if values for *K* are sufficient to identify a unique tuple of each possible relation *r(R)*

Example: {*ID*} and {ID,name} are both superkeys of *instructor*.

Choice of Primary key for Binary Relationship

- One-to-Many relationships
  - The primary key of the "Many" side is a minimal superkey and is used as the primary key.
- Many-to-one relationships
  - The primary key of the "Many" side is a minimal superkey and is used as the primary key.

Weak Entity Sets

- Consider a section entity, which is uniquely identified by a course_id, semester, year, and sec_id.
  - Clearly, section entities are related to course entities. Suppose we create a relationship set sec_course between entity sets section and course.
  - Note that the information in sec_course is redundant, since section already has an attribute course_id, which identifies the course with which the section is related.
  - One option to deal with this redundancy is to get rid of the relationship sec_course; however, by doing so the relationship between section and course becomes implicit in an attribute, which is not desirable.

Weak Entity Sets

- An alternative way to deal with this redundancy is to not store the attribute course_id in the section entity and to only store the remaining attributes section_id, year, and semester.
  - However, the entity set section then does not have enough attributes to identify a particular section entity uniquely
- To deal with this problem, we treat the relationship sec_course as a special relationship that provides extra information, in this case, the course_id, required to identify section entities uniquely.

- A weak entity set is one whose existence is dependent on another entity, called its <u>identifying entity</u>
- Instead of associating a primary key with a weak entity, we use the identifying entity, along with extra attributes called discriminator to uniquely identify a weak entity.

Weak Entity Sets

- An entity set that is not a weak entity set is termed a strong entity set.

- Every weak entity must be associated with an identifying entity; that is, the weak entity set is said to be existence dependent on the identifying entity set.
  - The identifying entity set is said to own the weak entity set that it identifies.
  - The relationship associating the weak entity set with the identifying entity set is called the identifying relationship

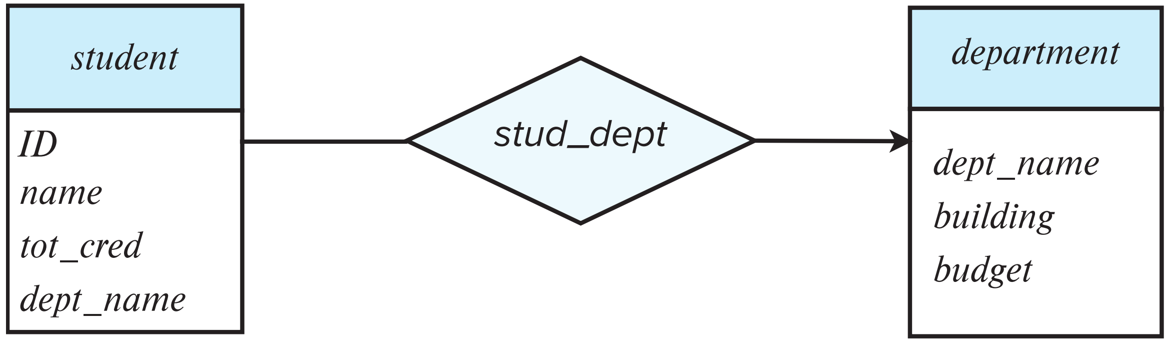
- Note that the relational schema we eventually create from the entity set section does have the attribute course_id, for reasons that will become clear later, even though we have dropped the attribute course_id from the entity set section.

Expressing Weak Entity Sets

- In E-R diagrams, a weak entity set is depicted via a double rectangle.
  - We underline the discriminator of a weak entity set with a dashed line.
  - The relationship set connecting the weak entity set to the identifying strong entity set is depicted by a double diamond.
- Primary key for section – (course_id, sec_id, semester, year)

Redundant Attributes

- Suppose we have entity sets:
  - student, with attributes: ID, name, tot_cred, dept_name
  - department, with attributes: dept_name, building, budget
- We model the fact that each student has an associated department using a relationship set stud_dept
- The attribute dept_name in student below replicates information present in the relationship and is therefore redundant
  - and needs to be removed.



(a) Incorrect use of attribute

- BUT: when converting back to tables, in some cases the attribute gets reintroduced.

Reduction to Relation Schemas

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

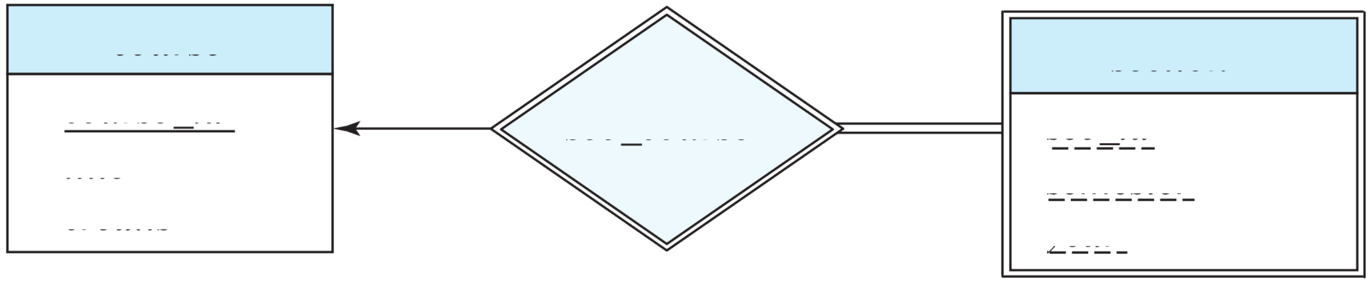
- A strong entity set reduces to a schema with the same attributes

student(ID, name, tot_cred)

- A weak entity set becomes a table that includes a column for the primary key of the identifying strong entity set

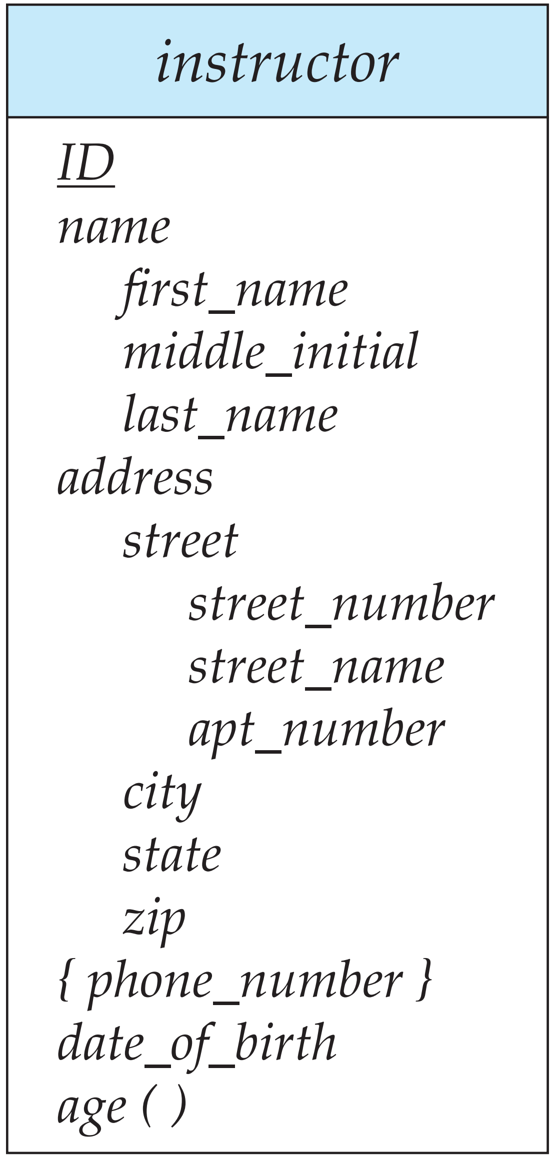
section (course_id, sec_id, sem, year)

- Example



Representation of Entity Sets with Composite Attributes

- 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 (name_first_name could be first_name)
- 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)



Representation of Entity Sets with 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:

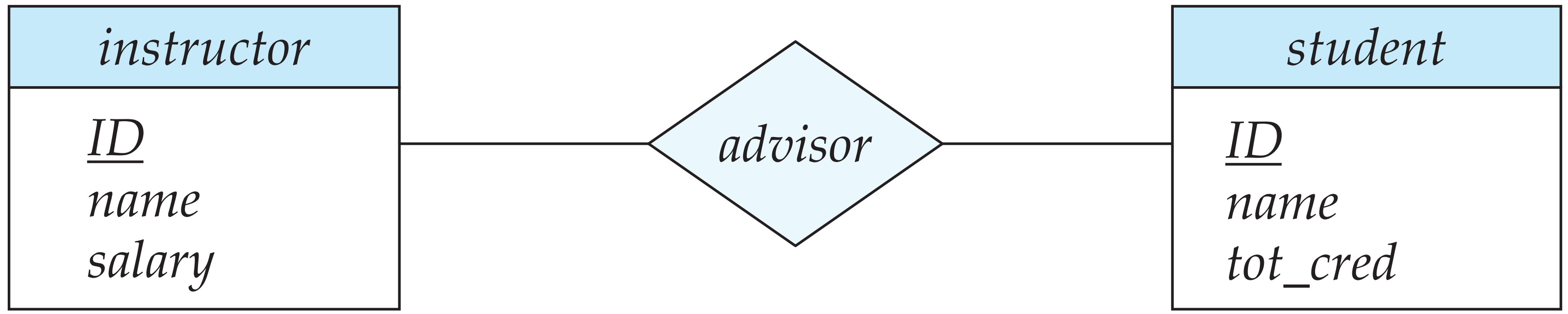
    inst_phone= (*ID*, *phone_number)*
  - Each value of the multivalued attribute maps to a separate tuple of the relation on schema EM
  - For example, an instructor entity with primary key 22222 and phone numbers 456-7890 and 123-4567 maps to two tuples:

    (22222, 456-7890) and *(22222, 123-4567)*

Representing Relationship Sets

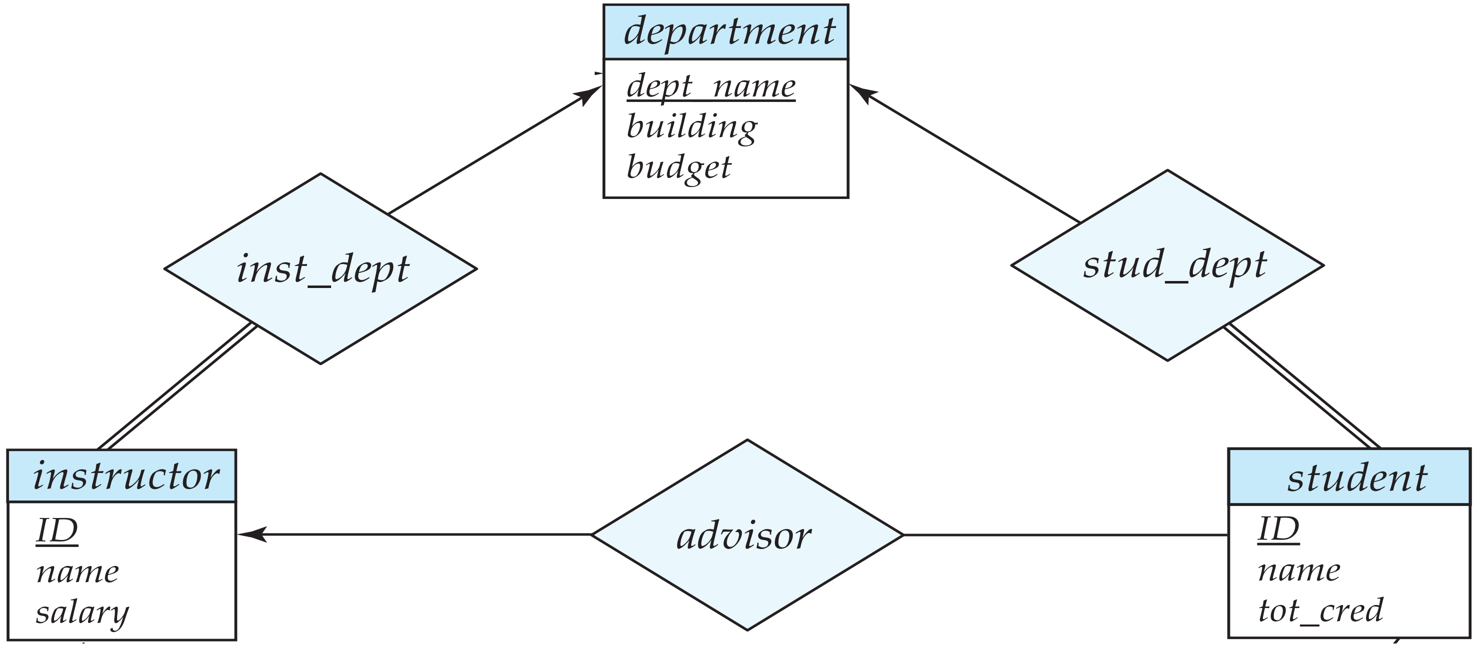
- A many-to-many relationship set is represented as a schema with attributes for the primary keys of the two participating entity sets, and any descriptive attributes of the relationship set.
  - Example: schema for relationship set advisor

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*
  - Example



Redundancy of Schemas

- For one-to-one relationship sets, either side can be chosen to act as the "many" side
  - That is, an 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

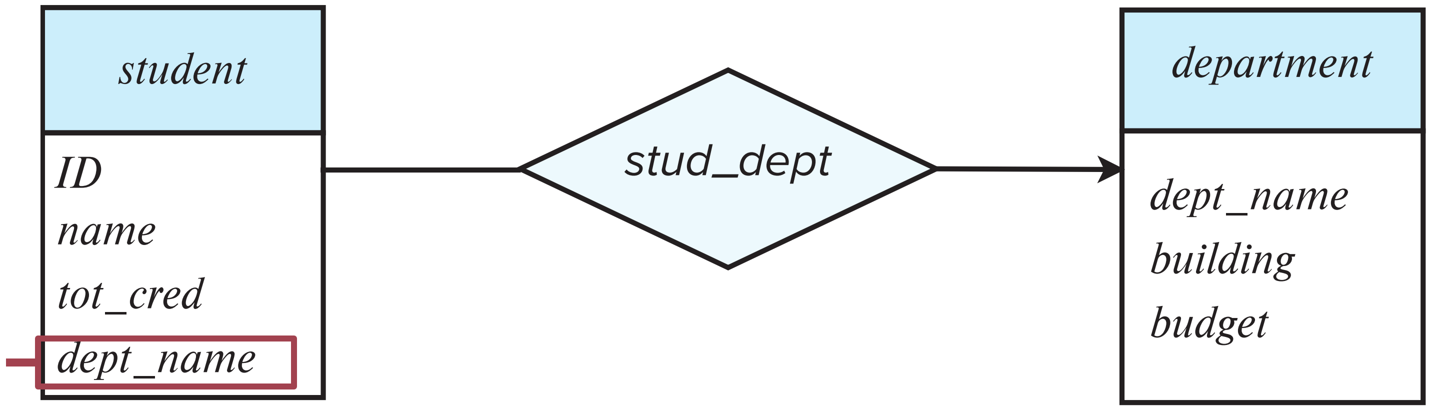
Redundancy of Schemas

- 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

Design Issues

Common Mistakes in E-R Diagrams

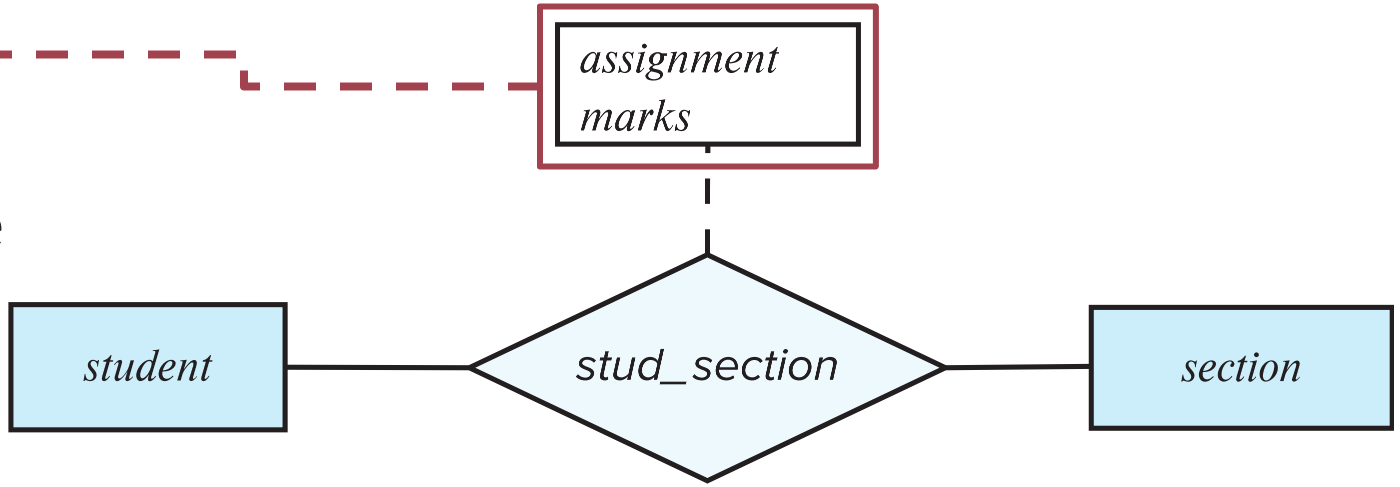
- Examples of erroneous E-R diagrams
  - (a) Unnecessary attribute
    - … which is the primary key of another entity
    - Problem: data redundancy
      - The relationships are already presented in the relationship set (*stud_dept*)



(a) Incorrect use of attribute

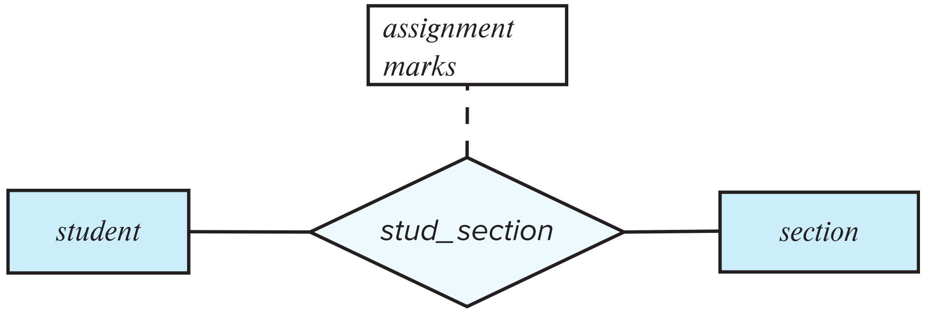
Common Mistakes in E-R Diagrams

- Examples of erroneous E-R diagrams
  - (b) Erroneous relationship attributes
    - Problem: It cannot represent multiple assignments released in the same section



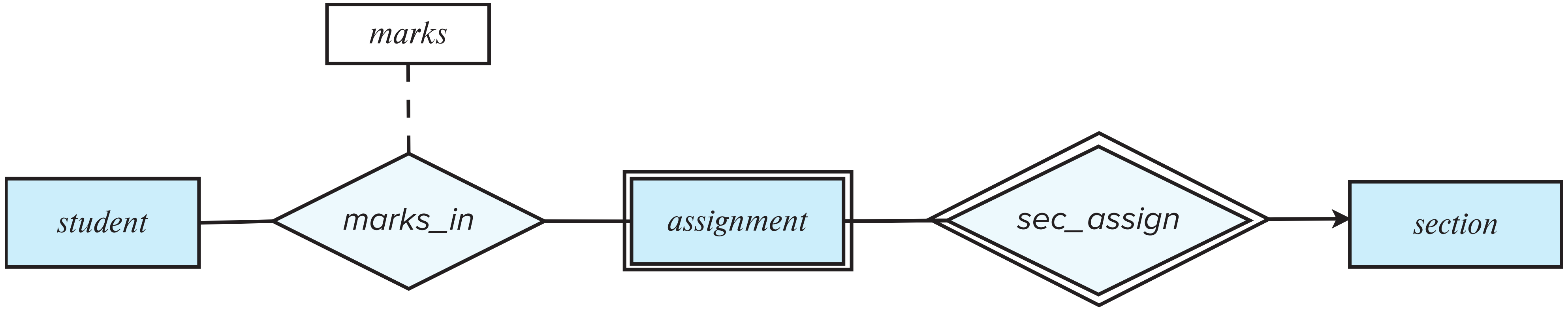
(b) Erroneous use of relationship attributes

Common Mistakes in E-R Diagrams



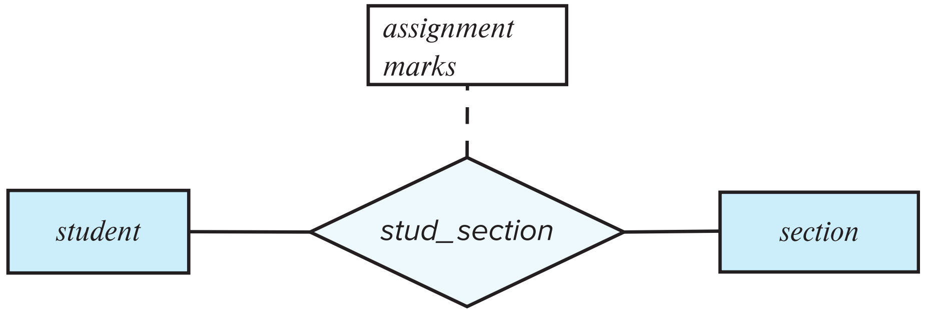
(b) Erroneous use of relationship attributes

- Examples of erroneous E-R diagrams
  - (b) Erroneous relationship attributes
    - Problem: It cannot represent multiple assignments released in the same section
    - Solutions:
      - 1) **Weak entity set**
      - 2) Composite attributes



(c) Correct alternative to erroneous E-R diagram (b)

Common Mistakes in E-R Diagrams



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- Examples of erroneous E-R diagrams
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- Solutions:
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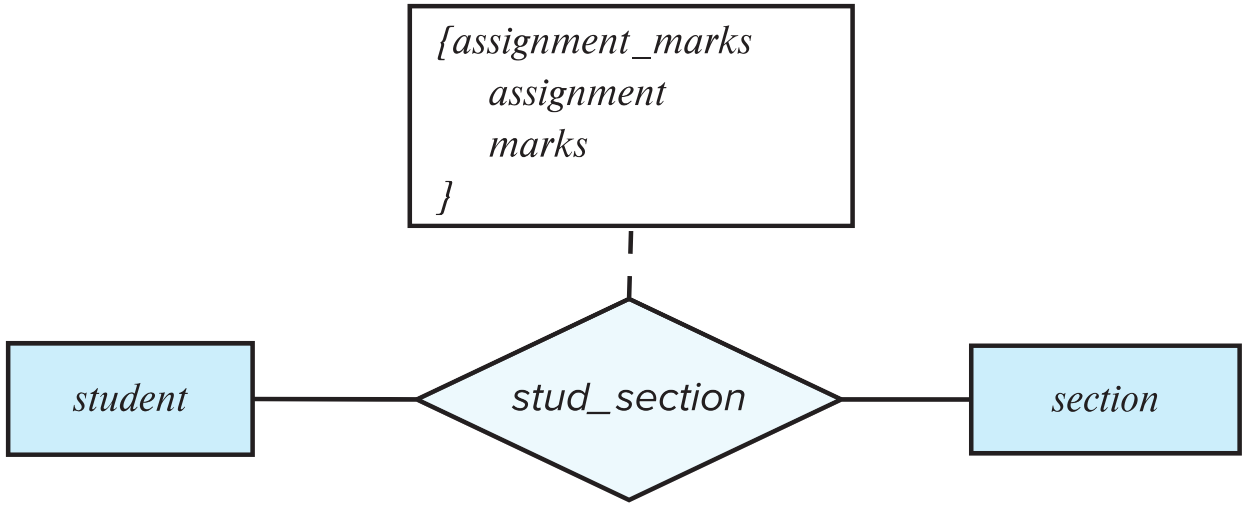
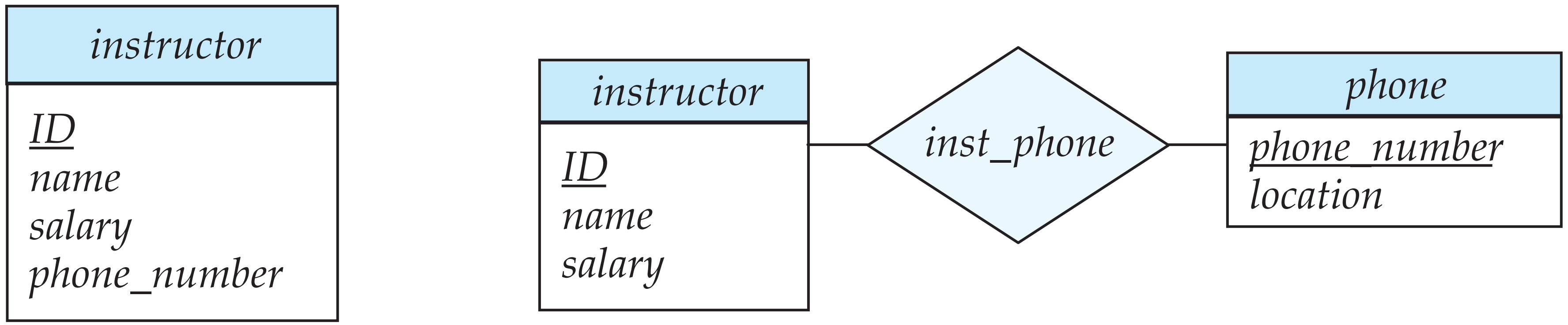
  - **2) Composite attributes**



(d) Correct alternative to erroneous E-R diagram (b)

Entities vs. Attributes

- Use entity sets or attributes?



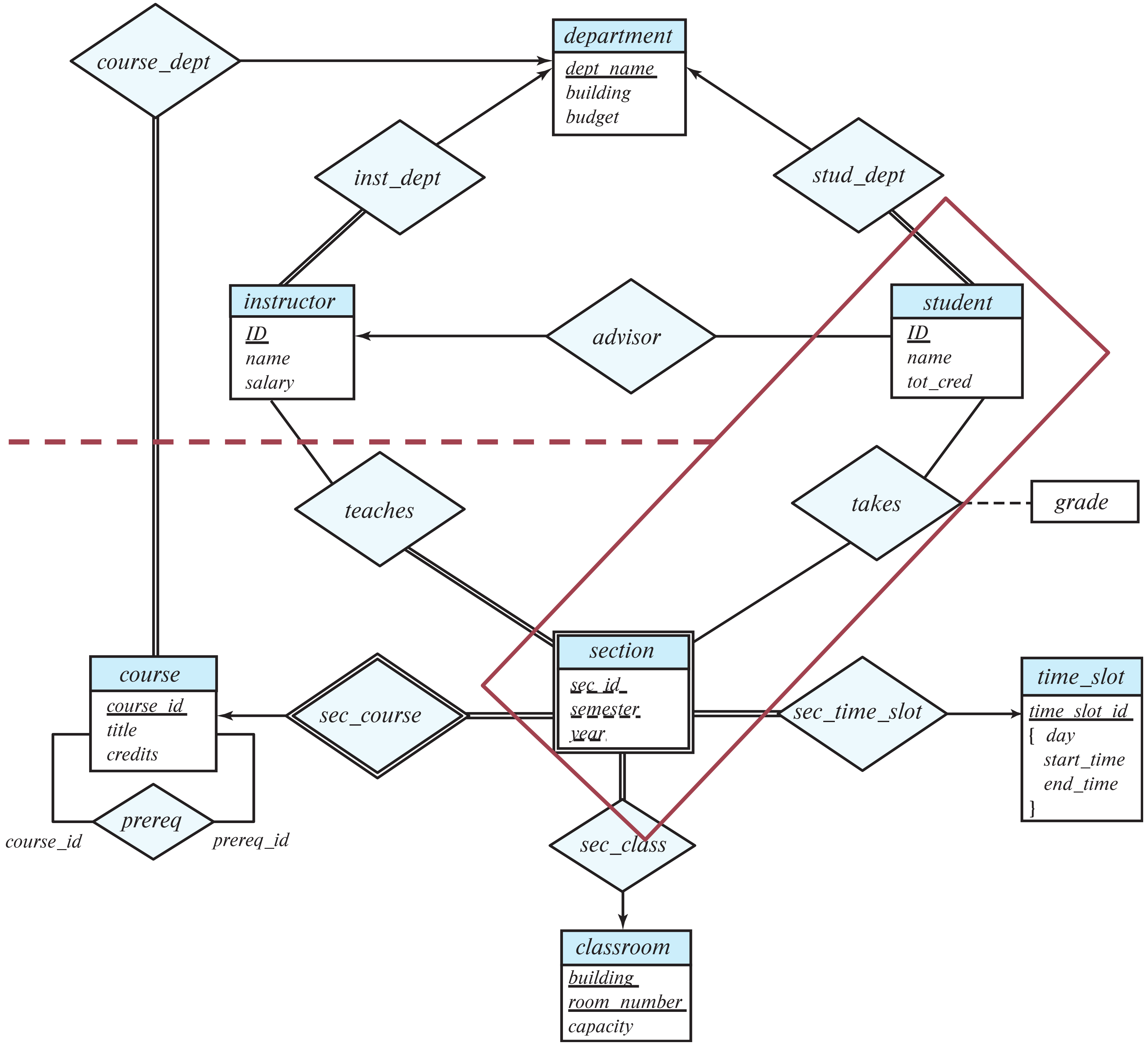
  - Use of *phone* as an entity allows extra information about phone numbers
    - … plus multiple phone numbers

Entities vs. Relationships

- Use entity sets or relationship sets?
  - Well, sometimes it is difficult to answer
  - **A possible guideline**: Use a relationship set to describe an <u>action</u> that <u>occurs between entities</u>

Entities vs. Relationships

- Example: *takes*



Entities vs. Relationships

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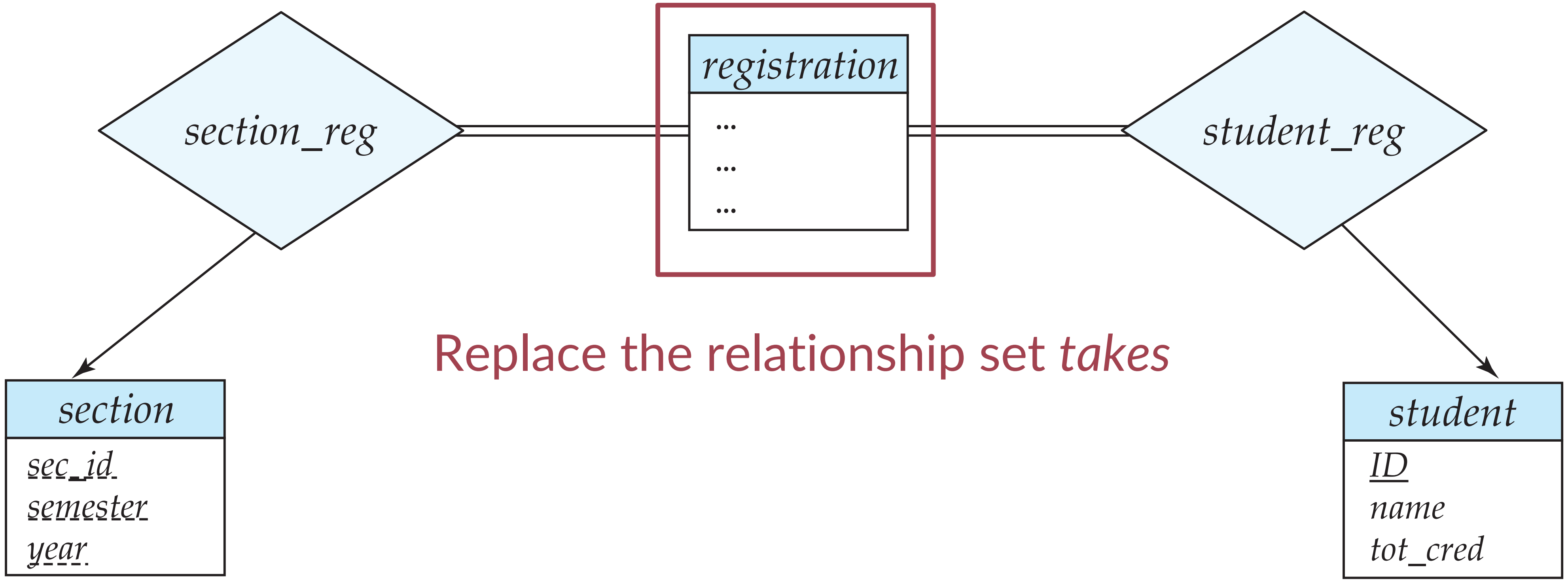
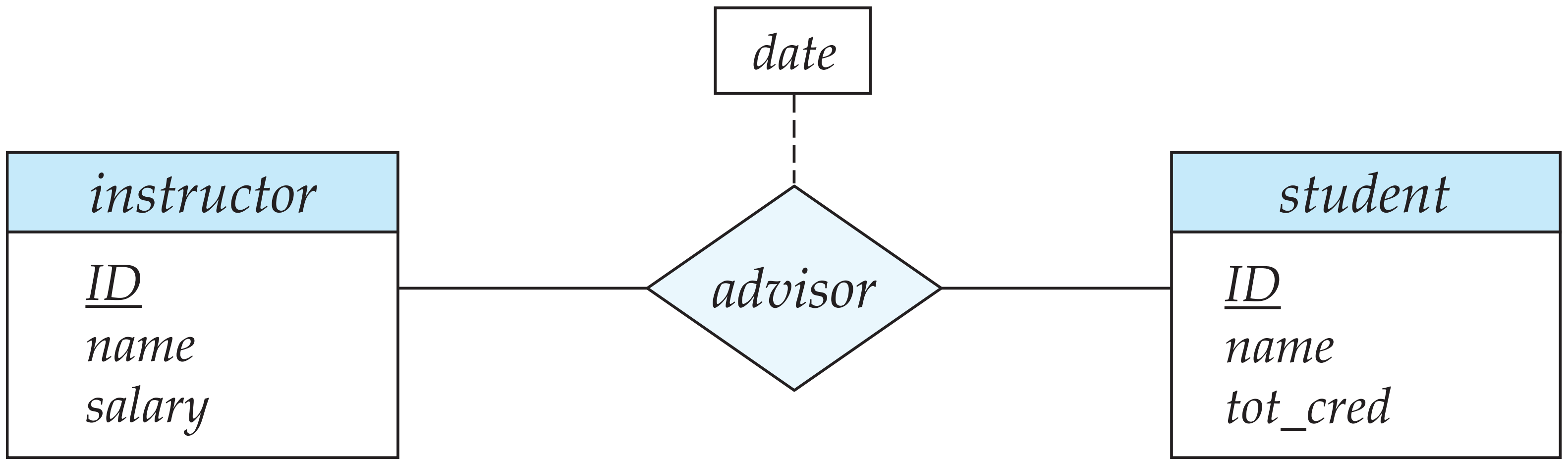


Replace the relationship set *takes*

Entities vs. Relationships

- Use entity sets or relationship sets?
  - Well, sometimes it is difficult to answer
  - **A possible guideline**: Use a relationship set to describe an <u>action</u> that <u>occurs between entities</u>
    - This guideline can be used for <u>designing relationship attributes</u>
      - For example, attribute *date* as attribute of advisor or as attribute of student



Binary Vs. Non-Binary Relationships

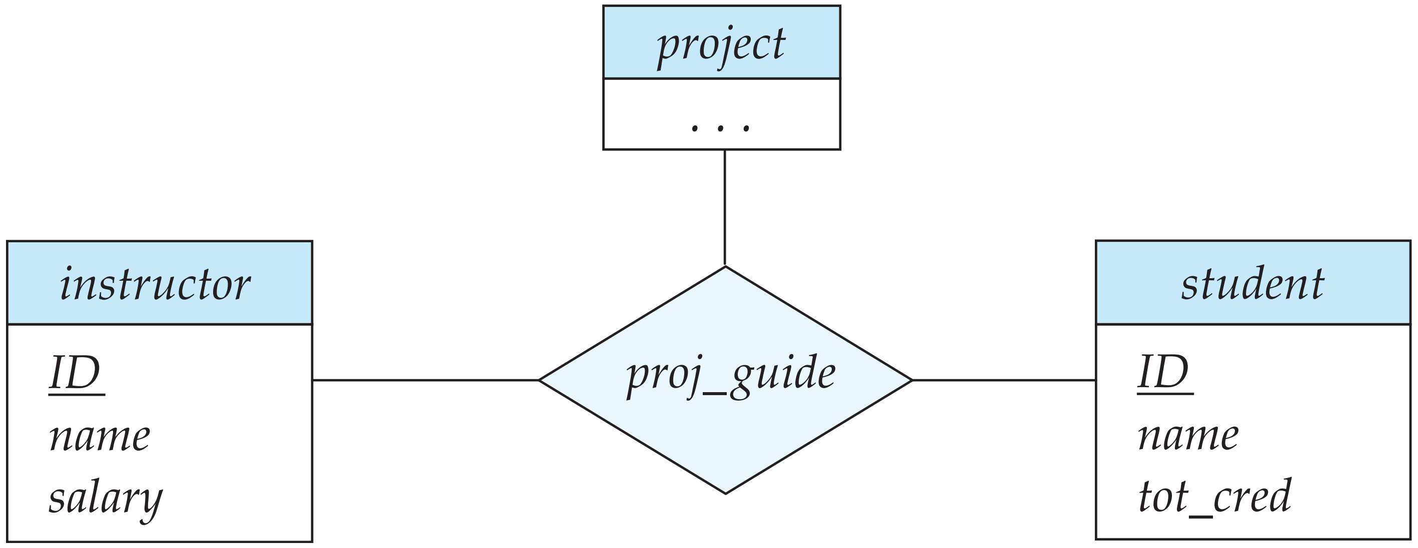
- Although it is possible to replace any non-binary (n-ary, for n > 2) relationship set by a number of distinct binary relationship sets, a n-ary relationship set shows more clearly that several entities participate in a single relationship.

Binary Vs. Non-Binary Relationships

- Some relationships that appear to be non-binary may be better represented using binary relationships
  - For example, a ternary relationship *parents*, relating a child to his/her father and mother, is best replaced by <u>two binary relationships</u>, *father* and *mother*
    - Using two binary relationships allows partial information (e.g., only mother being known)

Binary Vs. Non-Binary Relationships

- Some relationships that appear to be non-binary may be better represented using binary relationships
  - For example, a ternary relationship *parents*, relating a child to his/her father and mother, is best replaced by <u>two binary relationships</u>, *father* and *mother*
    - Using two binary relationships allows partial information (e.g., only mother being known)
  - But there are some relationships that are naturally non-binary
    - Example: *proj_guide*



E-R Design Decisions

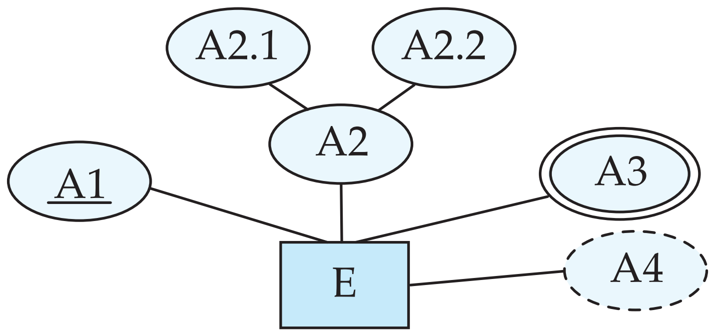
- The use of an attribute or entity set to represent an object
- Whether a real-world concept is best expressed by an entity set or a relationship set
- The use of a ternary relationship versus a pair of binary relationships
- The use of a strong or weak entity set

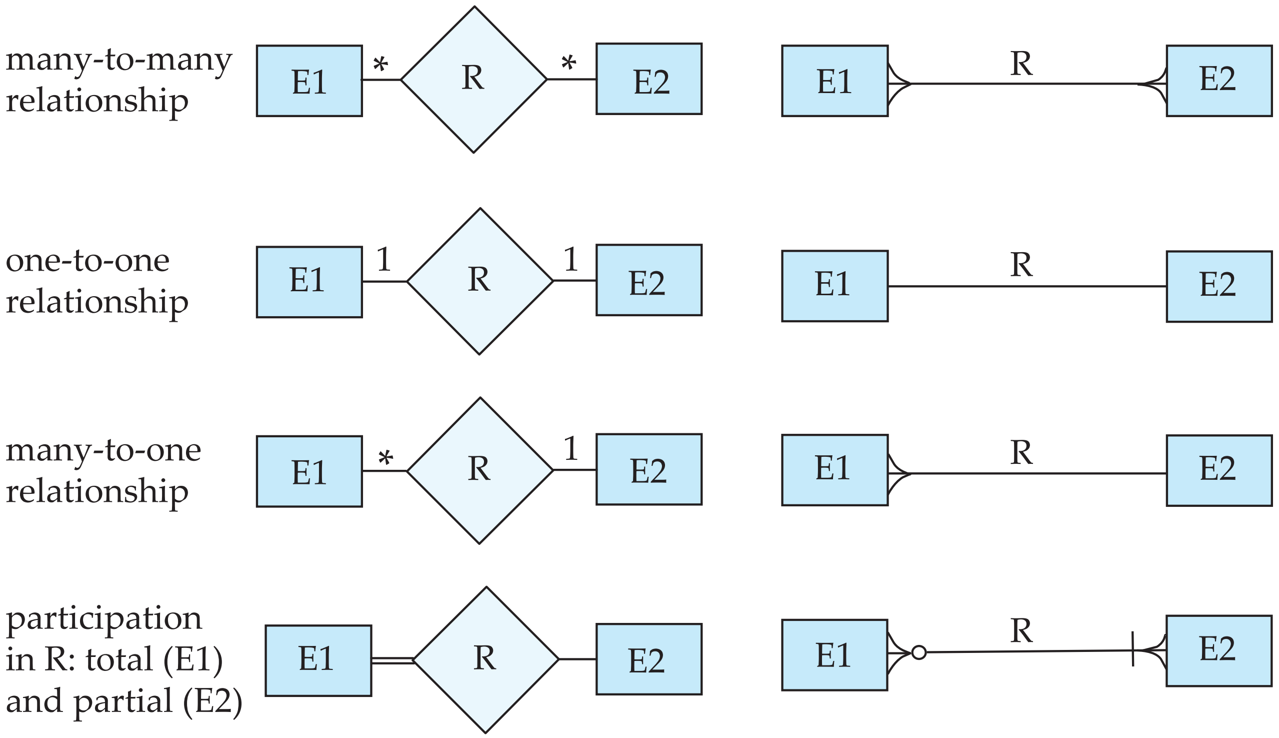
- ** Extra:*
  - ** The use of specialization/generalization – contributes to modularity in the design*
  - ** The use of aggregation – can treat the aggregate entity set as a single unit without concern for the details of its internal structure*

Self Study: Alternative ER Notations

- Chapter 7.10, Database System Concepts (7th Edition)

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





Normalization: A First Look

Recall: Design Alternatives

- In designing a database schema, we must ensure that we avoid two major pitfalls:
  - **Redundancy**: a bad design may result in repeat information
    - Redundant representation of information may lead to data inconsistency among the various copies of information
  - **Incompleteness**: a bad design may make certain aspects of the enterprise difficult or impossible to model
- Avoiding bad designs is not enough
  - There may be a large number of good designs from which we must choose

Recall: Design Alternatives

- In designing a database schema, we must ensure that we avoid two major pitfalls:
  - **Redundancy**: a bad design may result in repeat information
    - Redundant representation of information may lead to data inconsistency among the various copies of information
  - **Incompleteness**: a bad design may make certain aspects of the enterprise difficult or impossible to model
- Avoiding bad designs is not enough
  - There may be a large number of good designs from which we must choose
- Do we have any guidelines on how to get a good design?
  - Normal Forms!

First Normal Form (1NF)

- A relational schema R is in **first normal form** if the domains of all attributes of R are atomic
  - Domain is atomic if its elements are considered to be indivisible units
  - Examples of non-atomic domains:
    - Set of names, composite attributes
    - Identification numbers like CS307 that can be broken up into parts
      - However, in practice, we can also consider it atomic
  - Non-atomic values complicate storage and encourage redundant (repeated) storage of data

First Normal Form (1NF)

- Example: Non-atomic attribute

station_id	name	location
1	Luohu(罗湖)	114.11833 , 22.53111
2	Guomao(国贸)	114.11889 , 22.54
3	Laojie(老街)	114.11639 , 22.54444
4	Grand Theater(大剧院)	114.10333 , 22.54472
5	Science Museum(科学馆)	114.08972 , 22.54333
6	Huaqiang Rd(华强路)	114.07889 , 22.54306
7	Gangxia(岗厦)	114.06306 , 22.53778
8	Convention and Exhibition Center Station(会展中心)	114.05472 , 22.5375
9	Shopping Park(购物公园)	114.05472 , 22.53444
10	Xiangmihu(香蜜湖)	114.034 , 22.5417

First Normal Form (1NF)

- Another example: Starring
  - Problems: 1) Redundant names; 2) difficulties in updating/deleting a specific person; 3) extra cost in splitting names; 4) difficulties in making statistics

Movie ID	Movie Title	Country	Year	Director	Starring
0	Citizen Kane	US	1941	welles, o.	Orson Welles, Joseph Cotten
1	La règle du jeu	FR	1939	Renoir, J.	Roland Toutain, Nora Grégor, Marcel Dalio, Jean Renoir
2	North By Northwest	US	1959	HITCHCOCK, A.	Cary Grant, Eva Marie Saint, James Mason
3	Singin' in the Rain	US	1952	Donen/Kelly	Gene Kelly, Debbie Reynolds, Donald O'Connor
4	Rear Window	US	1954	Alfred Hitchcock	James Stewart, Grace Kelly

First Normal Form (1NF)

- Fix it by splitting the names into two columns

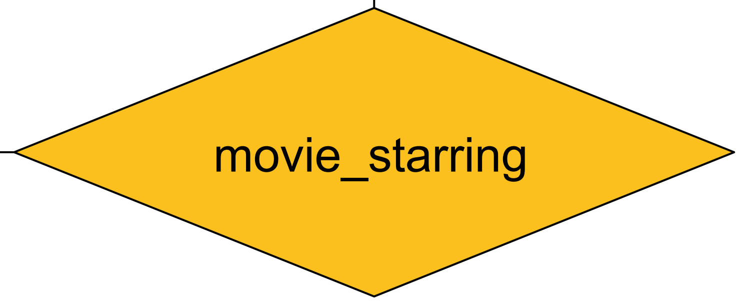
station_id	english_name	chinese_name	longitude	latitude
1	Luohu	罗湖	114.11833	22.53111
2	Guomao	国贸	114.11889	22.54
3	Laojie	老街	114.11639	22.54444
4	Grand Theater	大剧院	114.10333	22.54472
5	Science Museum	科学馆	114.08972	22.54333
6	Huaqiang Rd	华强路	114.07889	22.54306
7	Gangxia	岗厦	114.06306	22.53778
8	Convention and Exhibition Cent…	会展中心	114.05472	22.5375
9	Shopping Park	购物公园	114.05472	22.53444
10	Xiangmihu	香蜜湖	114.034	22.5417

First Normal Form (1NF)

- Fix it by treating the column as a multi-valued attribute

Movie ID	Movie Title	Country	Year	Director
0	Citizen Kane	US	1941	welles, o.
1	La règle du jeu	FR	1939	Renoir, J.
2	North By Northwest	US	1959	HITCHCOCK, A.
3	Singin' in the Rain	US	1952	Donen/Kelly
4	Rear Window	US	1954	Alfred Hitchcock

Star ID	Firstname	Lastname	Born	Died
1				
2				
3				



Second Normal Form (2NF)

- A relation satisfying 2NF must:
  - be in 1NF
  - not have any non-prime attribute that is dependent on any proper subset of any candidate key of the relation
    - A non-prime attribute of a relation is an attribute that is not a part of any candidate key of the relation.

Second Normal Form (2NF)

- Example: Consider this table with the <u>composite primary key</u> (*station_id, line_id*)

station_id	english_name	chinese_name	district	line_id	line_color	operator
1	Luohu	罗湖	Luohu	1	Green	Shenzhen Metro Corporation
2	Guomao	国贸	Luohu	1	Green	Shenzhen Metro Corporation
3	Laojie	老街	Luohu	1	Green	Shenzhen Metro Corporation
4	Grand Theater	大剧院	Luohu	1	Green	Shenzhen Metro Corporation
4	Grand Theater	大剧院	Luohu	11	Purple	Shenzhen Metro Corporation
4	Grand Theater	大剧院	Luohu	2	Orange	Shenzhen Metro Corporation
3	Laojie	老街	Luohu	3	DeepSkyBlue	Shenzhen Metro No.3 Line

  - The columns *line_color* and *operator* are not related to *station_id*
    - They are only related to *line_id*, which is only part of (a subset of) the primary key
  - Similarly, *english_name*, *chinese_name*, and *district* are not related to *line_id*
    - They are only related to *station_id*, which is only part of (a subset of) the primary key

Second Normal Form (2NF)

- Example: Consider this table with the composite primary key *(station_id, line_id)*

station_id	english_name	chinese_name	district	line_id	line_color	operator
1	Luohu	罗湖	Luohu	1	Green	Shenzhen Metro Corporation
2	Guomao	国贸	Luohu	1	Green	Shenzhen Metro Corporation
3	Laojie	老街	Luohu	1	Green	Shenzhen Metro Corporation
4	Grand Theater	大剧院	Luohu	1	Green	Shenzhen Metro Corporation
4	Grand Theater	大剧院	Luohu	11	Purple	Shenzhen Metro Corporation
4	Grand Theater	大剧院	Luohu	2	Orange	Shenzhen Metro Corporation
3	Laojie	老街	Luohu	3	DeepSkyBlue	Shenzhen Metro No.3 Line

  - Problem when not meeting 2NF: Insertion and deletion anomaly
    - We cannot insert a new station with no lines assigned yet (unless using NULLs)
    - If we delete a line, all stations associated with this line will be deleted as well

Second Normal Form (2NF)

- Fix it by
  - Splitting the two unrelated parts into two different tables of entities
  - And create a relationship set (if it is the many-to-many relationship between the two entities)

- By the way…
  - A relation with a single-attribute primary key is <u>automatically in 2NF</u> once it meets 1NF.

stations

station_id	english_name	chinese_name	district
1	Luohu	罗湖	Luohu
2	Guomao	国贸	Luohu
3	Laojie	老街	Luohu
4	Grand Theater	大剧院	Luohu

Foreign key

primary key(line_id, station_id)

line_detail

line_id	station_id	num	dist
1	1	1	0
1	2	2	1
1	3	3	1
1	4	4	1
11	4	21	<null>
2	4	26	2
3	3	10	2

Foreign key

lines

line_id	line_color	operator
1	Green	Shenzhen Metro Corporation
2	Orange	Shenzhen Metro Corporation
3	DeepSkyBlue	Shenzhen Metro No.3 Line
11	Purple	Shenzhen Metro Corporation

Third Normal Form (3NF)

- A relation satisfying 3NF must:
  - be in 2NF
  - all the attributes in a table are determined only by the candidate keys of that relation and not by any non-prime attributes

Third Normal Form (3NF)

- Example: Consider this table which describes the bus lines and their stops
  - Primary key (*bus_line*)

bus_line	station_id	chinese_name	english_name	district
B796	21	鲤鱼门	Liyumen	Nanshan
M343	21	鲤鱼门	Liyumen	Nanshan
M349	21	鲤鱼门	Liyumen	Nanshan
M250	26	坪洲	Pingzhou	Bao'an
374	61	安托山	Antuo Hill	Futian
B733	61	安托山	Antuo Hill	Futian
B828	120	临海	Linhai	Nanshan

- The column *station_id* depends on the primary key (*bus_line*)
- However, the columns *chinese_name*, *english_name*, and *district* depend on *station_id*, which is not the primary key.
  - They only have "indirect/transitive" dependence on the primary key
- Problem: Data redundancy

Third Normal Form (3NF)

- Example: Consider this table which describes the bus lines and their stops
  - Primary key (*bus_line*)

bus_line	station_id	chinese_name	english_name	district
B796	21	鲤鱼门	Liyumen	Nanshan
M343	21	鲤鱼门	Liyumen	Nanshan
M349	21	鲤鱼门	Liyumen	Nanshan
M250	26	坪洲	Pingzhou	Bao'an
374	61	安托山	Antuo Hill	Futian
B733	61	安托山	Antuo Hill	Futian
B828	120	临海	Linhai	Nanshan

- Problem when not meeting 3NF:
  - Data redundancy: as you can see in the table, the attributes for a station have been stored multiple times
  - Insertion and deletion anomaly: inserting a new bus line with no station becomes impossible without NULLs; deleting a station/bus line may also delete corresponding bus lines/stations.

Third Normal Form (3NF)

- Fix it by:
  - <u>Create a new table</u> with *station_id* as the primary key
    - i.e., the column which *chinese_name*, *english_name*, and *district* depend on
  - Move all columns which depend on the new primary key into the new table
    - … and, only leave the primary key of the new table (*station_id*) in the original table
  - (*In practice, if necessary) Add a foreign-key constraint
    - Not related to relational database modeling, only in implementations

stations

station_id	chinese_name	english_name	district
21	鲤鱼门	Liyumen	Nanshan
26	坪洲	Pingzhou	Bao'an
61	安托山	Antuo Hill	Futian
120	临海	Linhai	Nanshan
121	宝华	Baohua	Bao'an

Foreign key

bus_lines

station_id	bus_line
21	B796
21	M343
21	M349
26	M250
61	374
61	B733
120	B828
121	B828
121	M235

Normalization

- In practice, we usually just satisfy 1NF, 2NF and 3NF

	UNF (1970)	1NF (1970)	2NF (1971)	3NF (1971)	EKNF (1982)	BCNF (1974)	4NF (1977)	ETNF (2012)	5NF (1979)	DKNF (1981)	6NF (2003)
Primary key (no duplicate tuples)[4]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Atomic columns (cells cannot have tables as values)[5]	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Every non-trivial functional dependency either does not begin with a proper subset of a candidate key or ends with a prime attribute (no partial functional dependencies of non-prime attributes on candidate keys)[5]	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓
Every non-trivial functional dependency either begins with a superkey or ends with a prime attribute (no transitive functional dependencies of non-prime attributes on candidate keys)[5]	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓
Every non-trivial functional dependency either begins with a superkey or ends with an elementary prime attribute	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	N/A
Every non-trivial functional dependency begins with a superkey	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	N/A
Every non-trivial multivalued dependency begins with a superkey	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	N/A
Every join dependency has a superkey component[8]	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	N/A
Every join dependency has only superkey components	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	N/A
Every constraint is a consequence of domain constraints and key constraints	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗
Every join dependency is trivial	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓

https://en.wikipedia.org/wiki/Database_normalization

Normalization

Every non key attribute must provide a fact about the key, the whole key, and nothing but the key.

William Kent (1936 – 2005)

William Kent. "A Simple Guide to Five Normal Forms in Relational Database Theory", Communications of the ACM 26 (2), Feb. 1983, pp. 120–125.