Logical database design

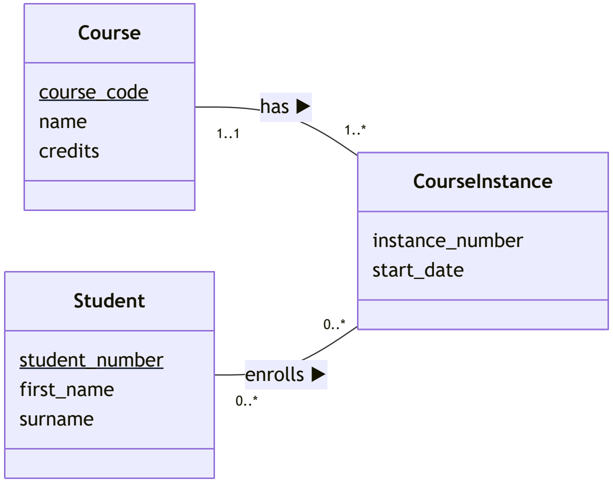
- The learning objectives for this week are:
  - Knowing what is the objective **logical database design**
  - Knowing how to **derive relations** from entity-relationship diagrams
  - Knowing how to determine **natural primary keys** and **foreign keys**

Logical database design

- The typical main phases in a database design process are:
  1. Conceptual database design
  2. Logical database design
  3. Physical database design
- Each phase from top to bottom adds more detail to the design
- We have familiarized ourselves with the **concetual database design** by defining entities and their attributes and relationships based on the requirements
- The **logical database design** is the process of refining and translating the conceptual schema into a **logical database schema** based on a specific data model, for example the relational model

Conceptual vs. logical database schema

- Here's a comparison of conceptual (left) and logical (right) database schema of a course enrollment database:




```
Course(course_code, name, credits)
Student(student_number, first_name, surname)

CourseInstance(course_code, instance_number, start_date)
  FOREIGN KEY (course_code) REFERENCES Course(course_code)

Enrollment(course_code, instance_number, student_number)
  FOREIGN KEY (course) REFERENCES Course(course_code)
  FOREIGN KEY (course_code, instance_number)
  REFERENCES CourseInstance(course_code, instance_number)
  FOREIGN KEY (student_number)
  REFERENCES Student(student_number)
```

Logical database design

- Entity types, attributes, and relationship types can be directly transformed into relations with some simple rules
- Typically, the logical database design process includes the following types of activities:
  1. Deriving relations for the logical data model
  2. Validating relations using normalisation
  3. Validating relations against user transaction
  4. Double-checking integrity constraints
  5. Reviewing logical data model with user

Deriving relations for the logical data model

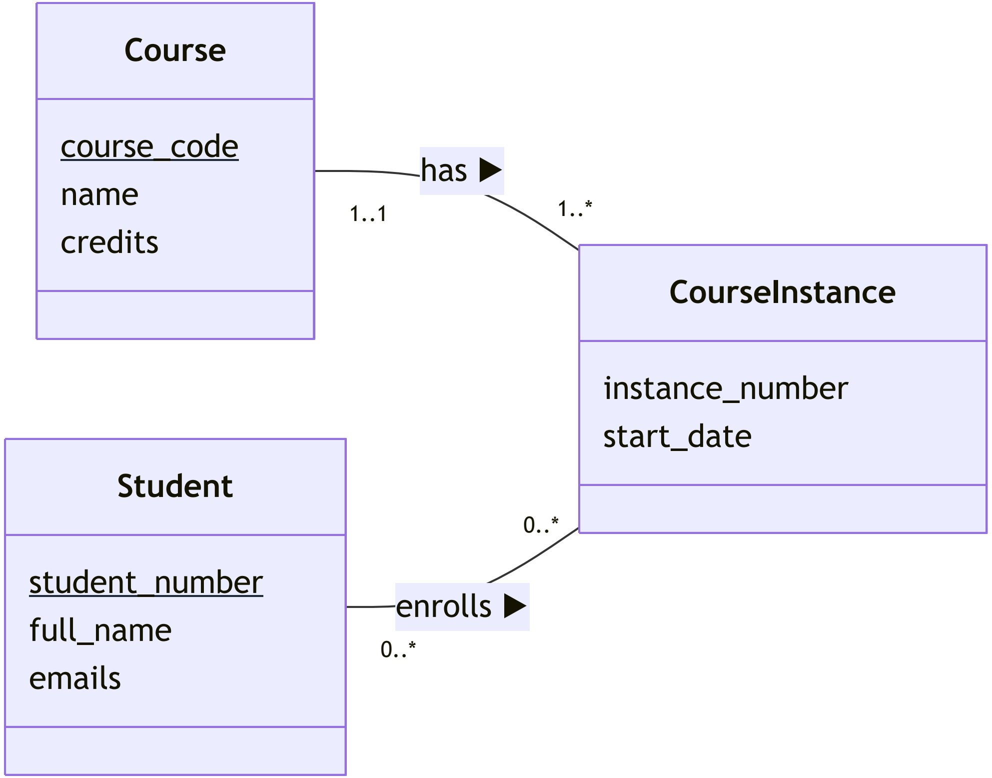
- The process starts by **deriving relations for the logical data model**, which includes:
  1. Creating the relations
  2. Refining the attributes
  3. Determing primary and foreign keys
  4. Determing other types of integrity constraints

Creating relations

- To transform a conceptual schema into a relational database schema, we might need **additional relations** to establish specific relationships
- We create the relations in the following manner:
  - For **each entity type**, we create a relation that includes all simple (single-value) attributes of the entity
  - For **many-to-many relationship types** ("…*" on both sides of the relationship), we create a **"bridge relation"** to represent the relationship
  - For **multi-valued attributes**, we create a new relation to represent the multi-valued attribute. For example, a person may have several phone numbers, but multi-valued attributes are not allow in relations

Example of creating relations

- Let’s consider creating relations for the following conceptual model:



Example of creating relations

- In the example we have one **many-to-many relationship** between the *Student* and *CourseInstance* entities ("…*" on both sides of the "enrolls" relationship):
  - *"Student enrolls to zero or many course instances and course instance has zero or many students"*
  - In this case we create an additional **bridge relation**, for example *Enrollment*
- There is a **multi-valued attribute** *emails* in the *Student* entity
  - In this case we create an additional entity, for example *StudentEmail*
- This leaves with the following relations: *Student*, *CourseInstance*, *Enrollment* and *StudentEmail*

Refining the attributes

- Once we have created the relations we need to refine the attributes in the following manner:
  - We divide a non-atomic attribute into smaller (atomic) attributes. For example student’s home address can be divided into, city, postal code and street_address attributes
  - We define general (not DBMS-specific) attribute data-types, for example "string" or "integer"
  - We define which attributes can have `NULL` values. We should allow `NULL` in an attribute only based on **strong arguments**

Determining primary keys

```
Student(student_number, first_name, surname)
```

- There should be **exactly one primary key in each relation**
- The primary key can be either a **simple key** (single column) or a **composite key** (several columns)
- By definition, the primary key should always satisfy the properties of **requiredness** (not `NULL`), **uniqueness** and **minimality**
- The primary key **should remain stable**. That is, primary key values should not need to be updated later
- The primary key should be **reasonably short**
- The primary key should have **no privacy issues**. For example social security number has privacy issues

Determing primary key for a weak entity type

- A **weak entity type** is an entity type that is dependent on the existence of another entity type
- For example *CourseGrade* is existence-dependent on *Student* and *CourseInstance*
- When a relation derived from a weak entity type, the natural primary key is partially or fully derived from the weak entity type's owner entity type
- For example, the natural primary key of the *CourseGrade* relation is a composite key that **includes columns from two foreign keys**, one referencing *Student* and other referencing *CourseInstance*
- The primary key of the weak entity's relation cannot be made until after the foreign keys have been determined for the relation

Surrogate keys

- If there is initially no suitable candidate key for a relation, then we cannot determine a natural primary key
- We have to take care of the situation by including an extra attribute in the relation to act as the primary key
- This kind of primary key is a **surrogate key**
- Surrogate keys are commonly generated values, such as incrementing or random numbers

Alternate keys

- Candidate keys that are not selected to be primary the key are called **alternate keys**
- We should consider the use of the **unique constraint** on alternate keys to make sure that their values remain unique:

```
Student (studentnumber, ssn, familyname, givenname)
  UNIQUE (ssn)
```

- Especially, when we are using a surrogate primary key, a unique constraint on at least one natural alternate key improves data quality

Determing foreign keys

- In a relational database, **relationships** are represented by the **primary key/foreign key mechanism**
- To know in which relation be need to place the foreign key, we need to identify the **relationship type** between the two entities
- During the course, we will use the following syntax to define the relation's foreign keys in the **relation schema**:

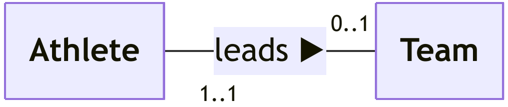
```
Course(course_code, name, credits)

CourseInstance(course_code, instance_number, start_date)
  FOREIGN KEY (course_code) REFERENCES Course(course_code)
```

Determing foreign keys

- Most often the relationship type between two entities falls in **many-to-one**, **many-to-many** and **one-to-one** categories
- Example of **many-to-one relationship** with "...*" on one side and "...1" on another:

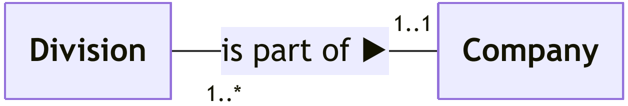
- Example of **many-to-many relationship** with "...*" on both sides:

- Example of **one-to-one relationship** with "...1" on both sides:



Many-to-one relationship (1:N)

> *"Division has one or many companies"*



- Place a copy of the **parent relation's** ("…1" side) primary key into the **child relation** ("…*" side), to act as a foreign key
- If the child relation is derived from a weak entity type, then the primary key of the child relation is typically a composite key

```
Company (company_id, name)

Division (division_id, company_id, name)
  FOREIGN KEY (company_id) REFERENCES Company(company_id)
```

Many-to-many relationship (M:N)

> "Athlete participates in zero or many races and race zero or many athlete participants"

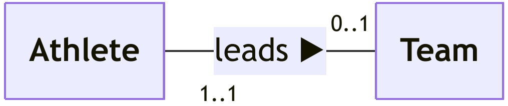
- Create a **bridge relation** to represent the relationship and place a copy of the primary key from each of the parent relations into the bridge relation to act as foreign keys

- Typically, the bridge relation's primary key is a composite key that includes the both foreign keys

```
Athlete (athlete_id, first_name, family_name)
Race (race_id, name, date)
RaceParticipation(athlete_id, race_id)
  FOREIGN KEY (athlete_id) REFERENCES Athlete(athlete_id),
  FOREIGN KEY (race_id) REFERENCES Race(race_id)
```

One-to-one relationship (1:1)

> "Team has exaclty one athlete leader"



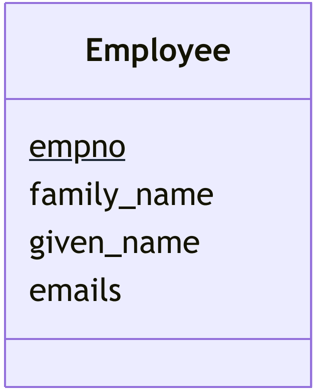
- In case of **mandatory participation** ("1…1" on one side only), place a copy of the primary key from the relation on the "1…1" side into the relation on the "0…1" side to act as the foreign key

- In case of **mandatory participation on both sides** we can usually **combine the two** into one relation

- In case **optional participation** ("0…1" on both sides) the foreign key can be placed in either relation

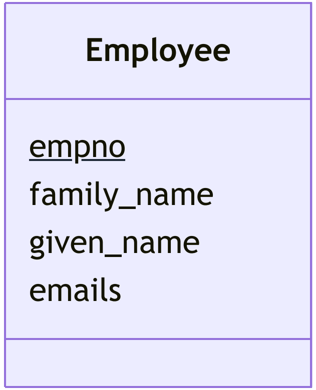
```
Athlete (athlete_id, first_name, family_name)
Team (team_id, athlete_id, name)
  FOREIGN KEY (athlete_id) REFERENCES Athlete(athlete_id)
```

Multi-value attributes



- A relation can't have attributes with **multiple values**, such as the *emails* attribute of the *Employee* entity type in this example (employee has many emails)
- In such case, we must create a **new relation** to represent the multi-valued attribute, for example *EmployeeEmail*
- We move the attribute from the original relation and place it to the new relation and place a copy of the parent relation's primary key into the child relation, to act as the foreign key

Multi-value attributes



- In this example, we would get the following relation schema:

```
Employee (empno, first_name, family_name)
EmployeeEmail (email, empno)
  FOREIGN KEY (empno) REFERENCES Employee(empno)
```

Summary

- The objective of logical database design is to translate the conceptual schema into a **logical database schema** based on a specific data model
- During the course, we represent logical database schema as **relation schema**, containing relations their attributes, primary key and foreign keys
- When we derive relations from entity types, we create a relation for each entity type
- Many-to-many relationship requires an additional **bridge relation**
- A **multi-valued attributes** requires an additional relation
- There should be exactly one primary key in each relation
- The foreign key placement depends on the **relationship type** (many-to-one, many-to-many or one-to-one)