Database-enabled web technology
A review of DB design and SQL

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Information science/Informatiekunde

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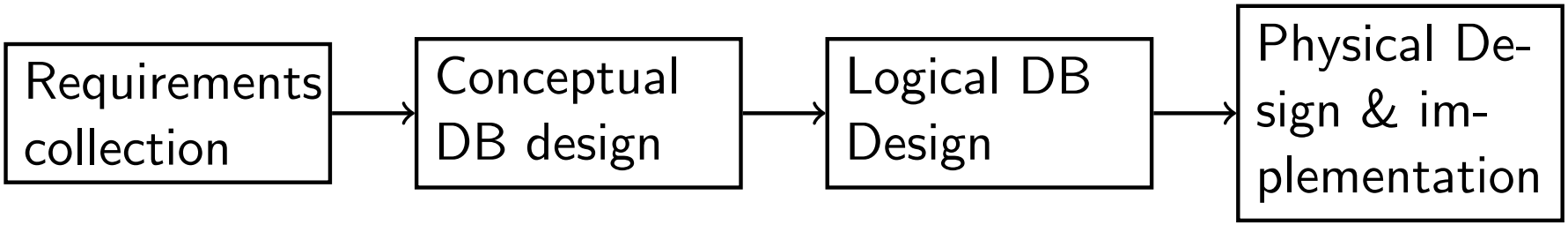
Summary: last week

Last week:
Two quick introductions:

- PHP: the language.
- Git: basics.

Database Design Process



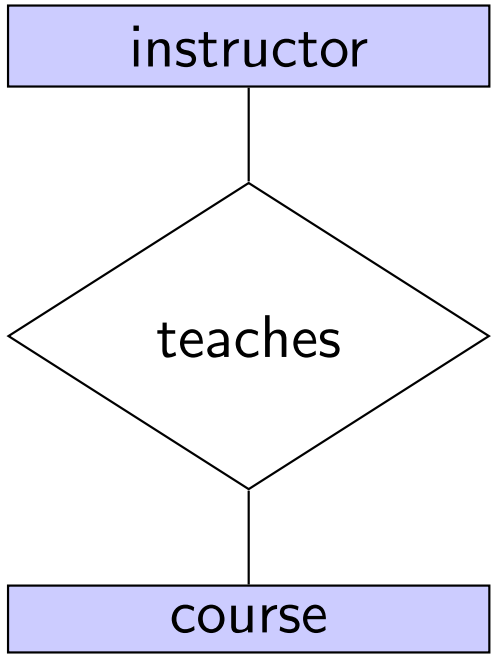
ideas | high-level design | DB schema | database

- DB design is generally part of a bigger software design process.
- These steps reflect the idealized case. Typically, you may need to re-iterate over some of the steps multiple times.

The entity-relationship data model

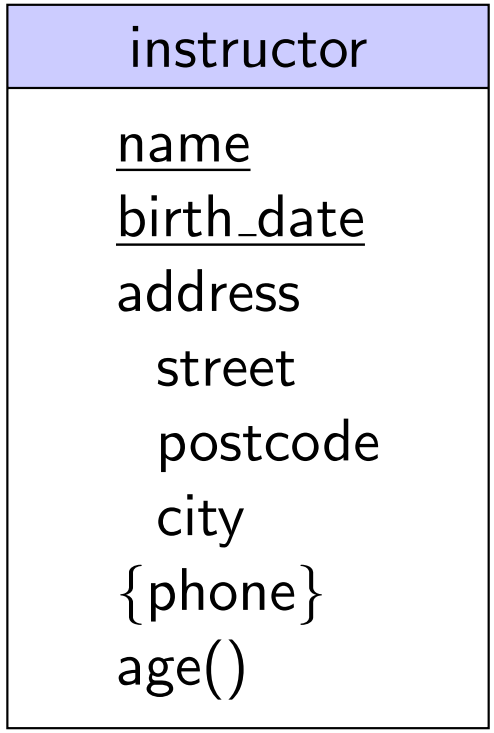
The entity-relationship (E-R) model is commonly used for specifying high-level database design.

- An E-R model specifies real-world entities (objects, things) and their relations.
- It has a diagrammatic representation. That particularly comes handy in communicating your design with non-specialists.

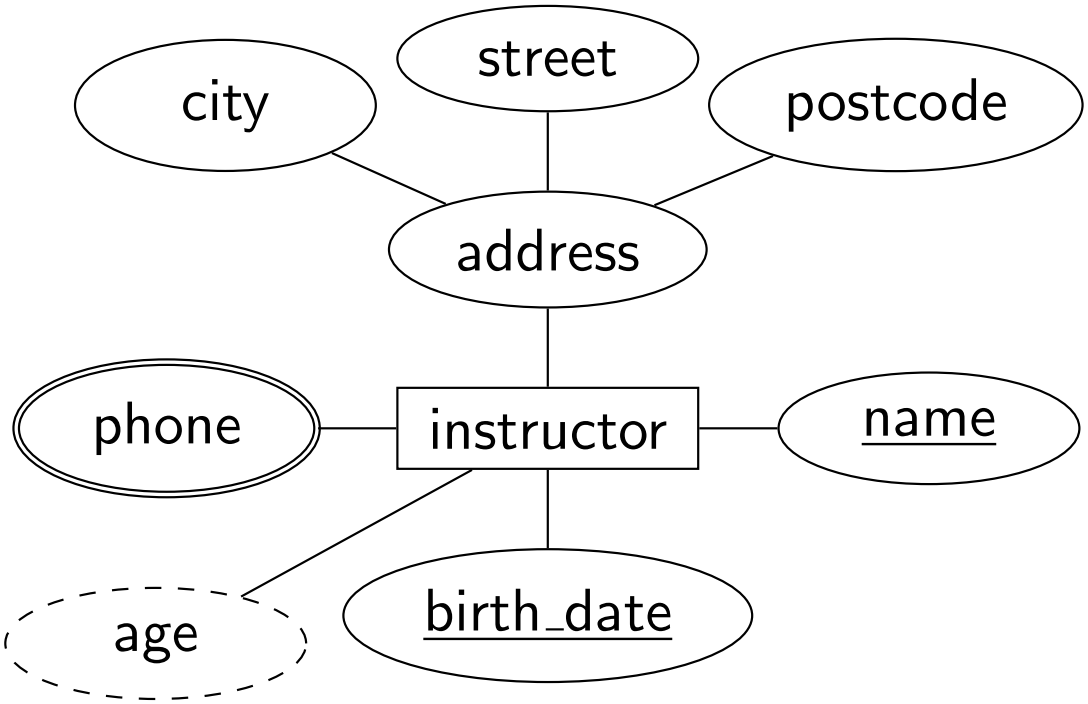


The entity sets (the textbook notation)

- Entity sets are represented with split rectangles.
- The top part is name of the entity set, bottom part lists the attributes.
- Attributes that form the primary key are underlined.
- Composite attributes are listed as part of them indented.
- Multi-valued attributes are listed in curly braces.
- Derived attributes are suffixed with '()'.



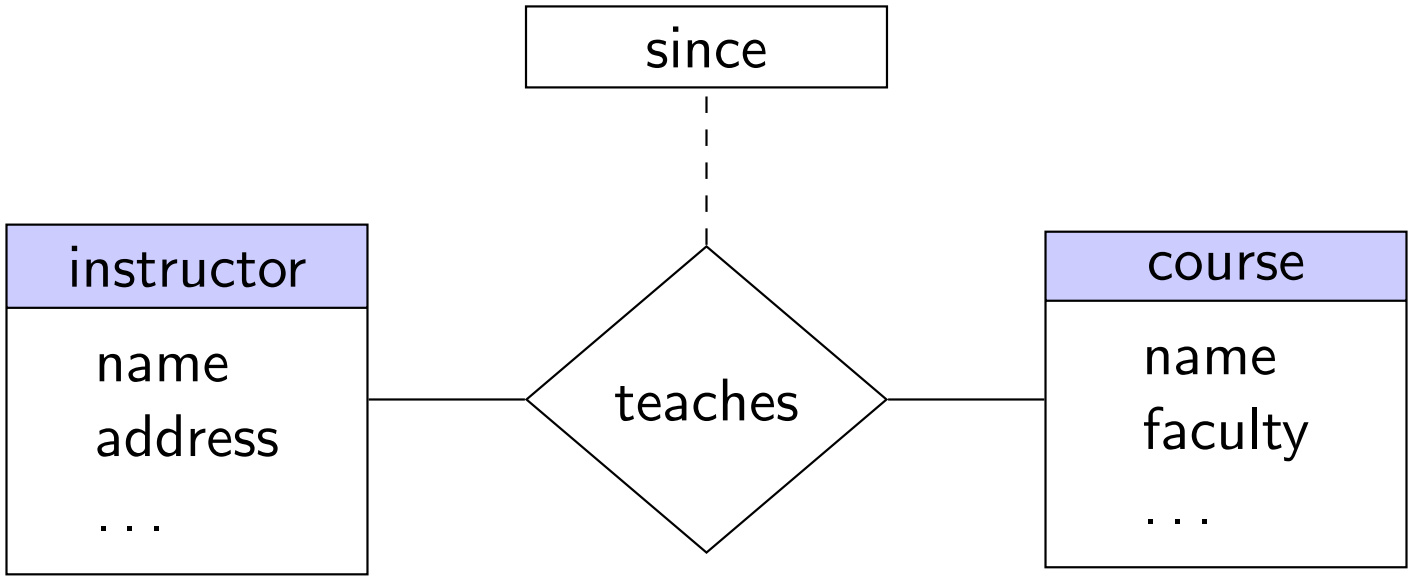
The entity sets (more common notation)



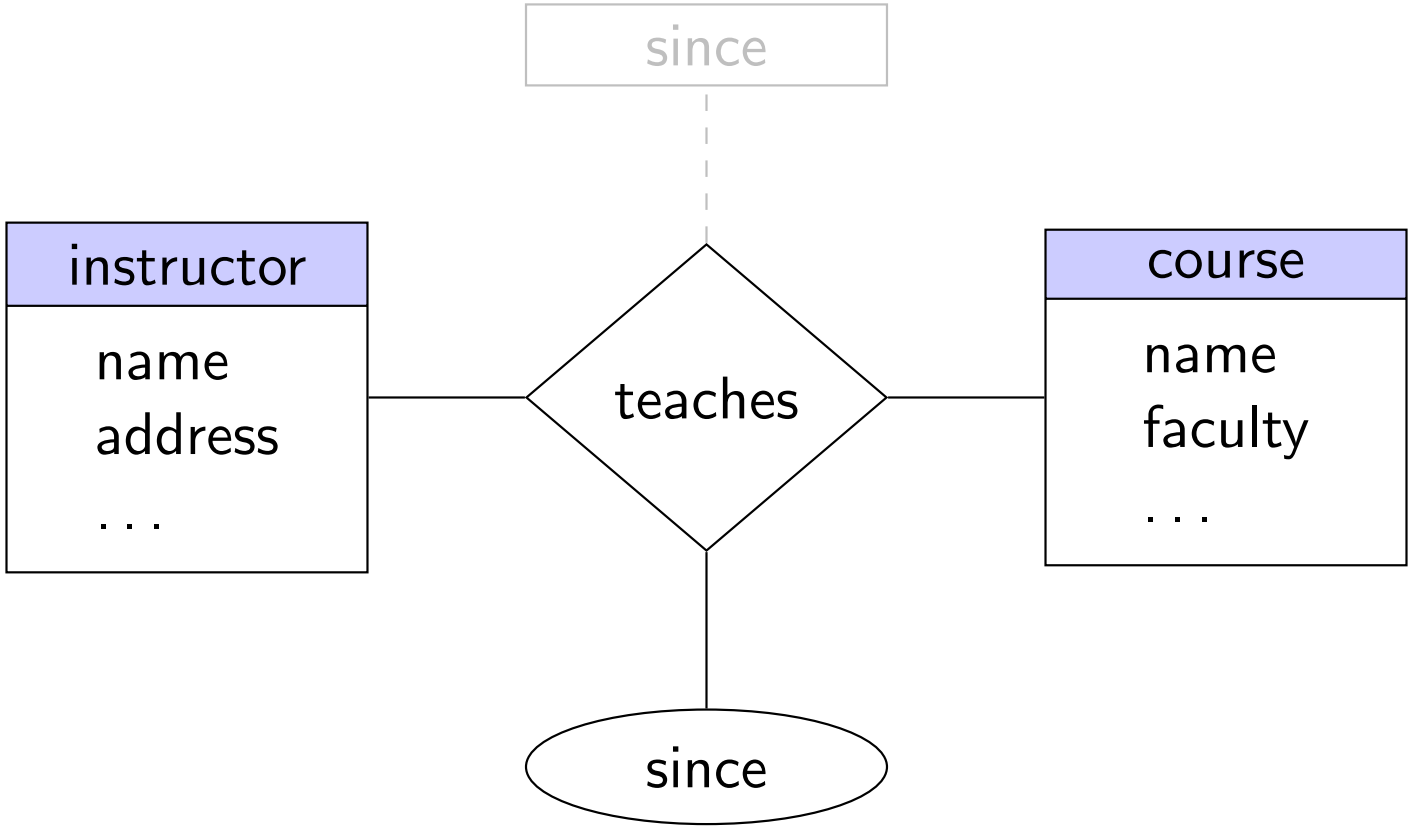
instructor

name
birth_date
Address
  street
  postcode
  city
{Phone}
age()

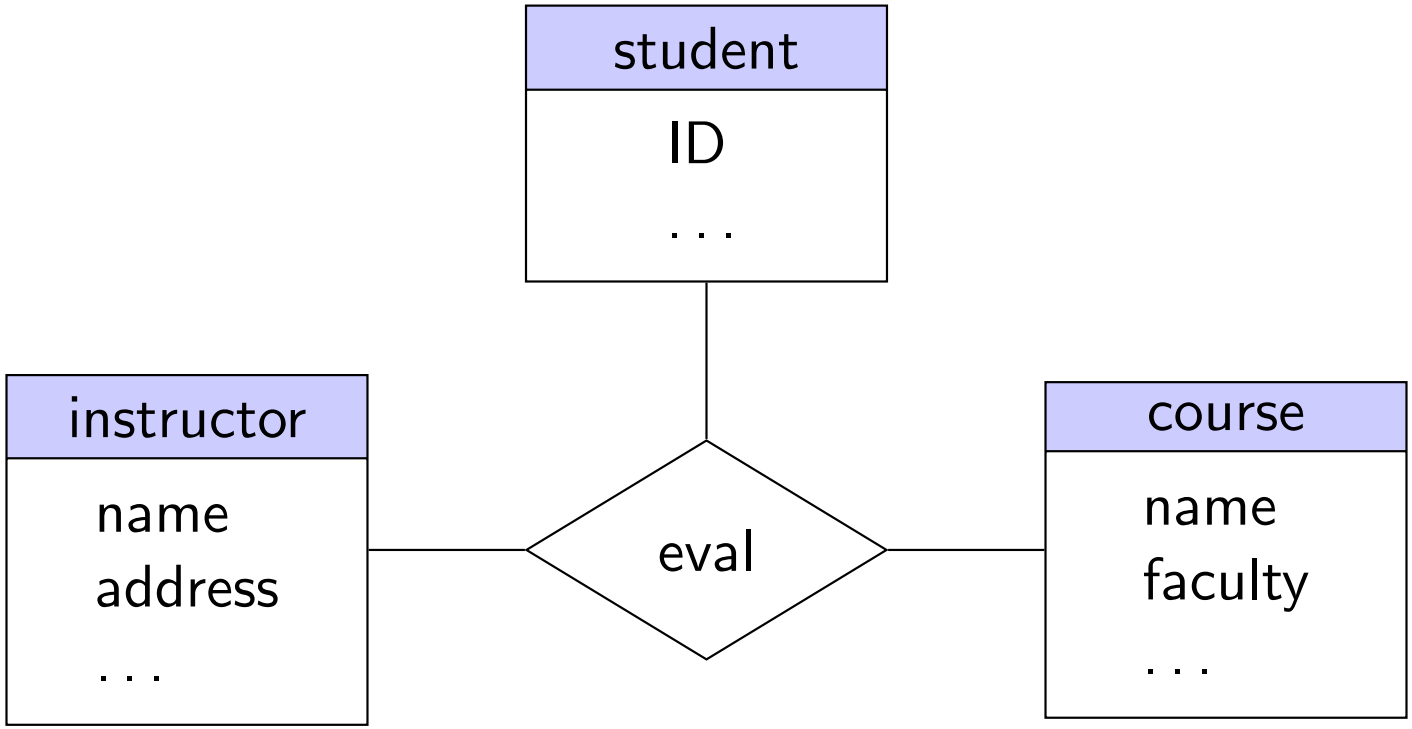
Relationship sets



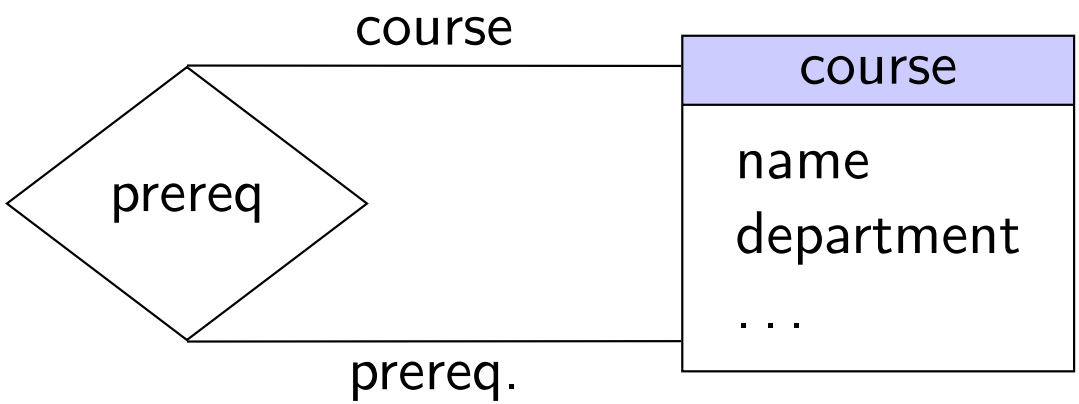
Relationship sets



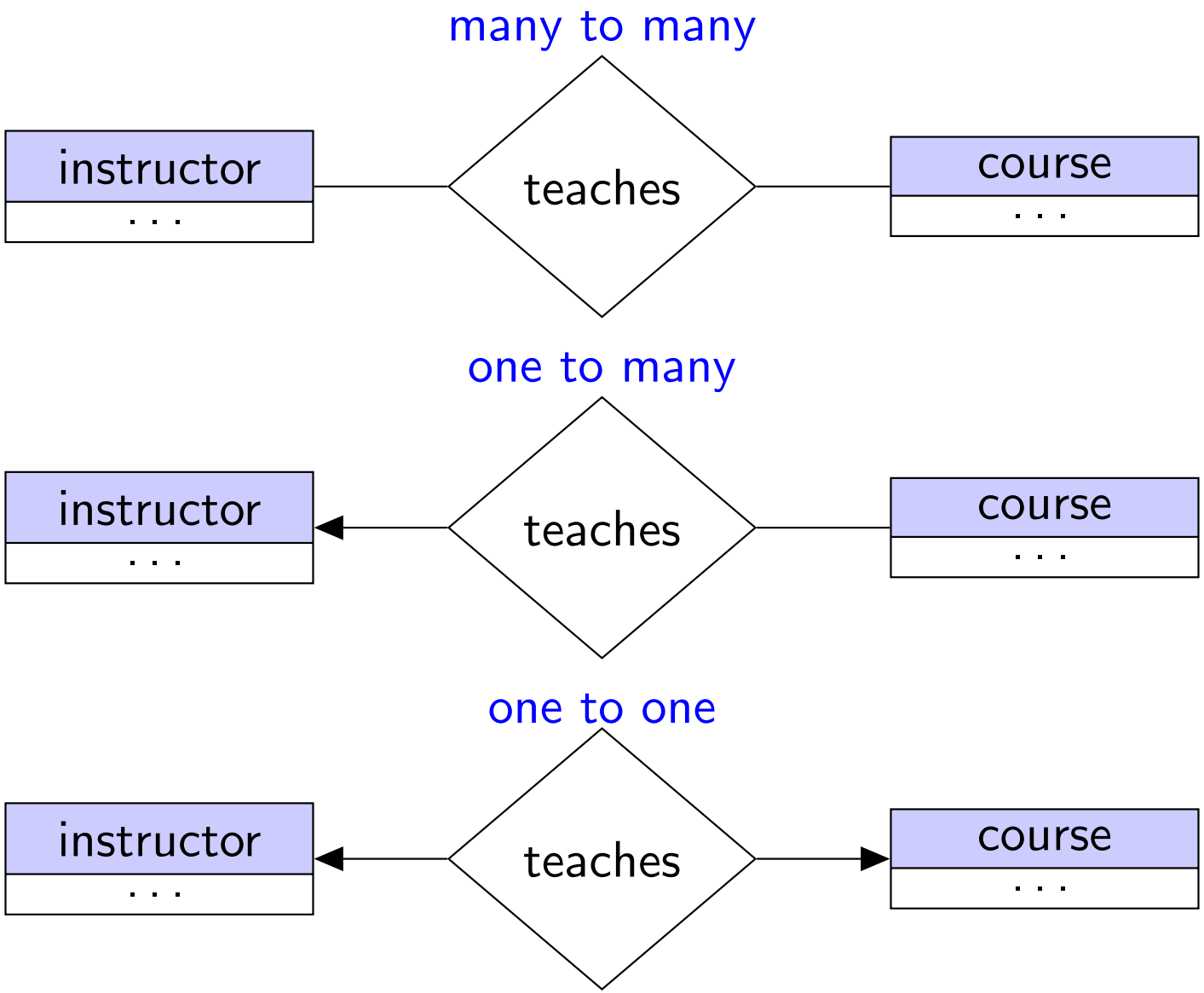
N-ary relations



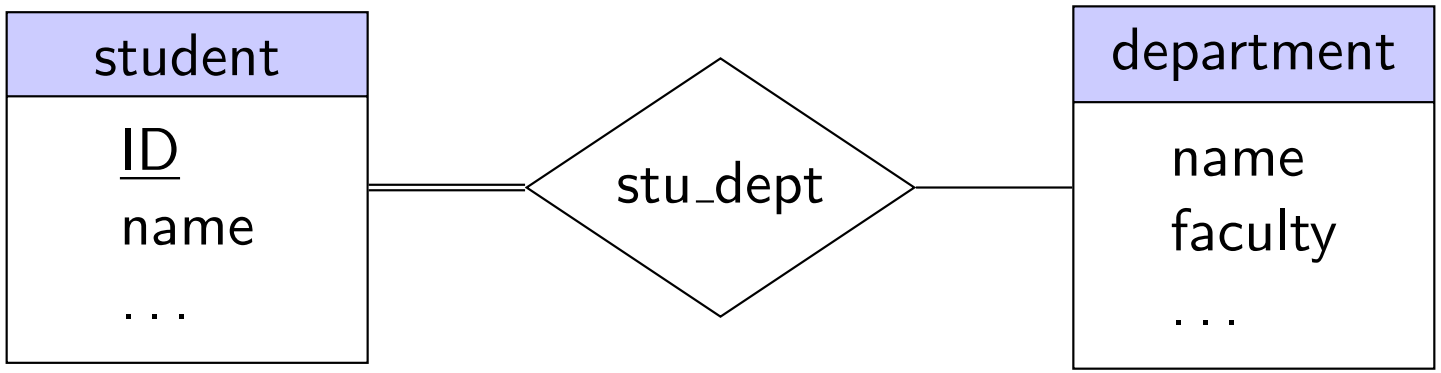
Recursive relationship sets/roles



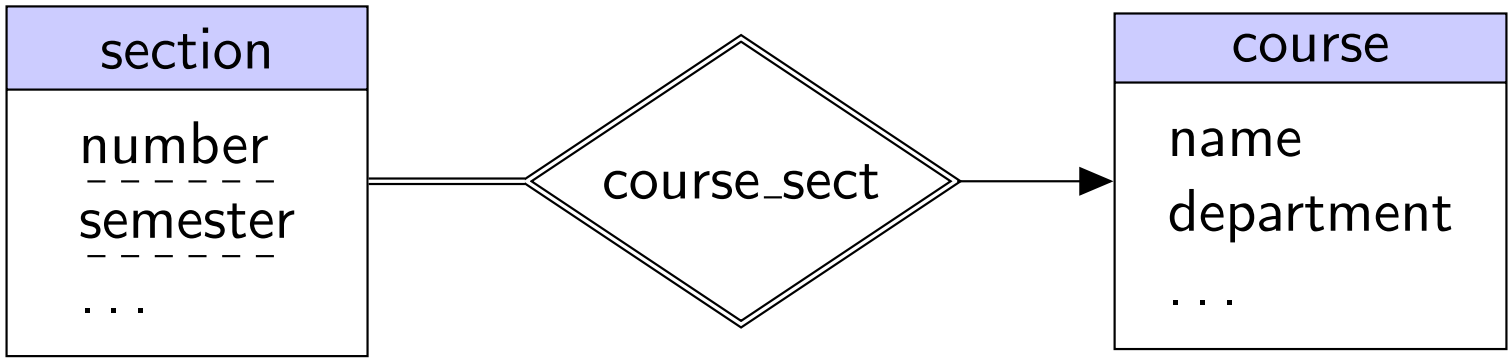
Mapping cardinalities



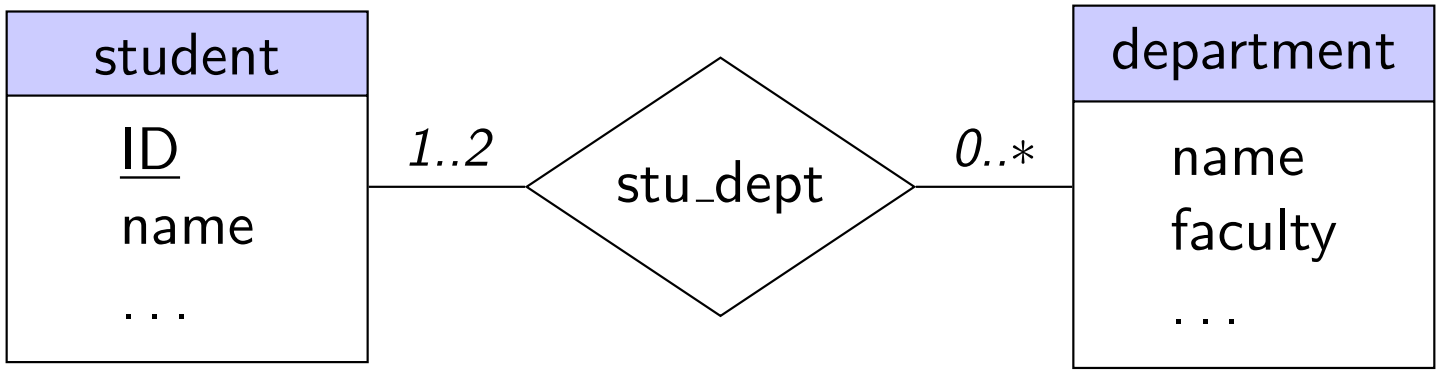
Participation constraints



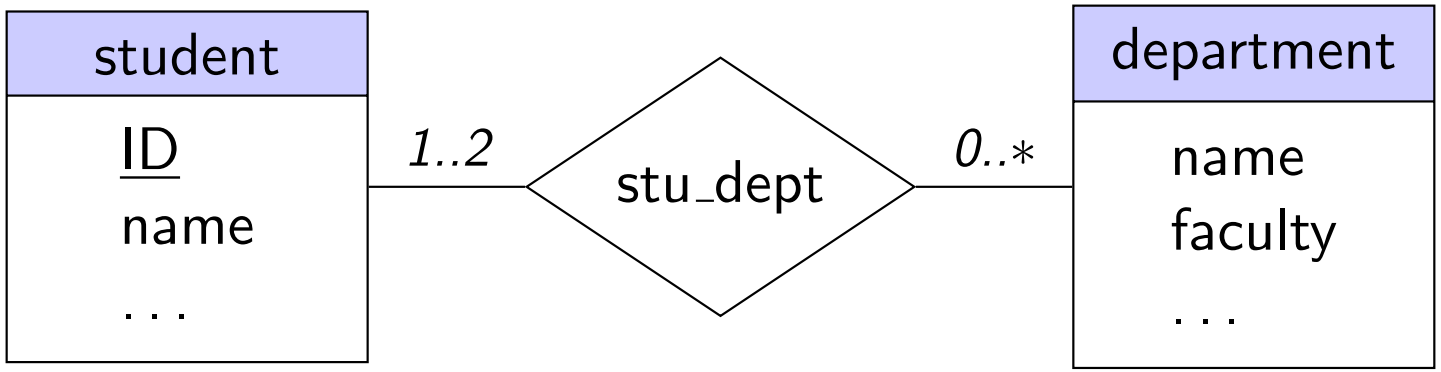
Weak entities



Alternative notation for constraints



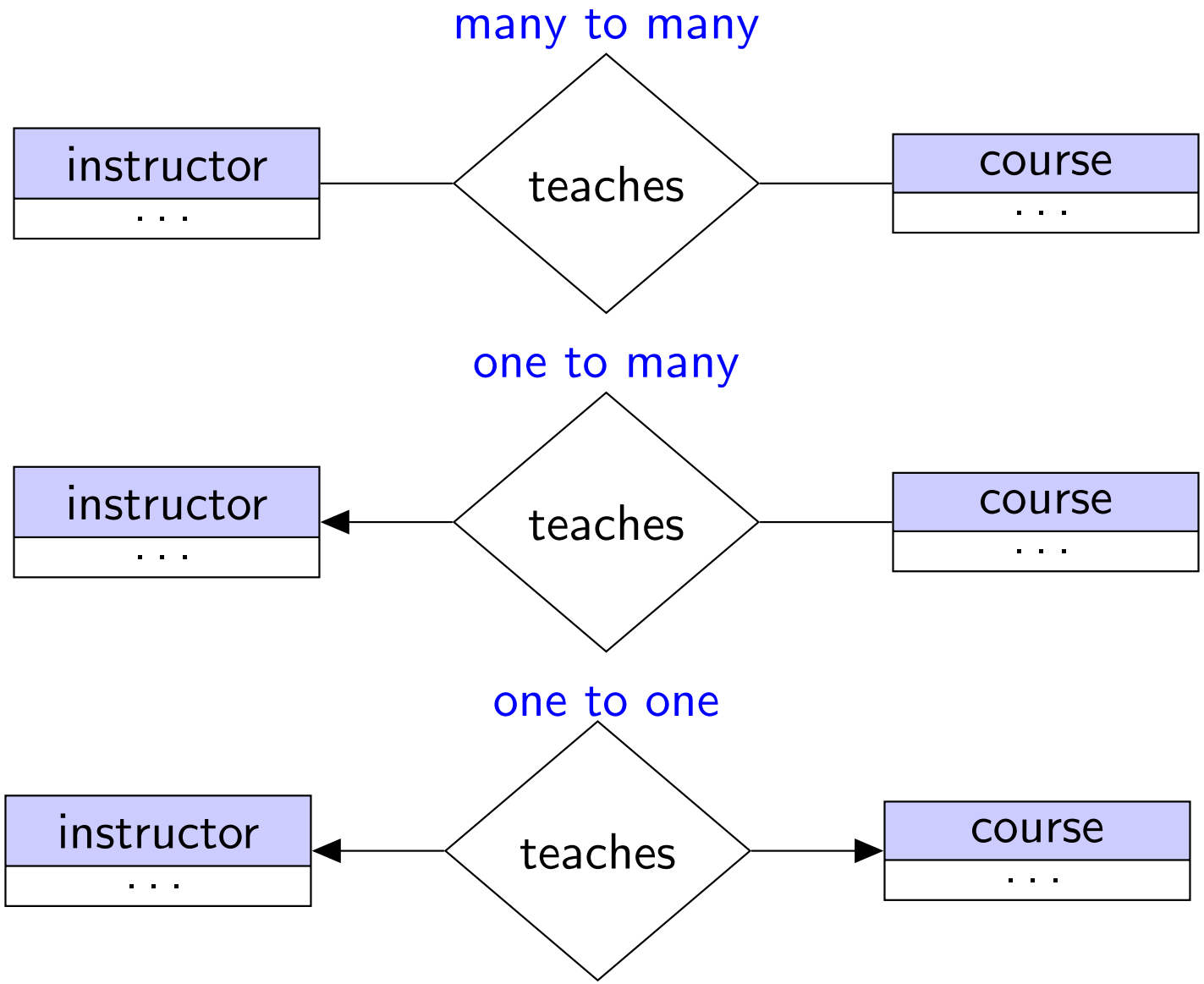
Alternative notation for constraints



- Lower limit of 1 means that the participation is total.
- Upper limit of 1 on both sides means a one-to-one relationship set.
- Upper limit of 1 only on the right side means a one-to-many relationship set.

Mapping cardinalities (example)

Mapping cardinalities (example)



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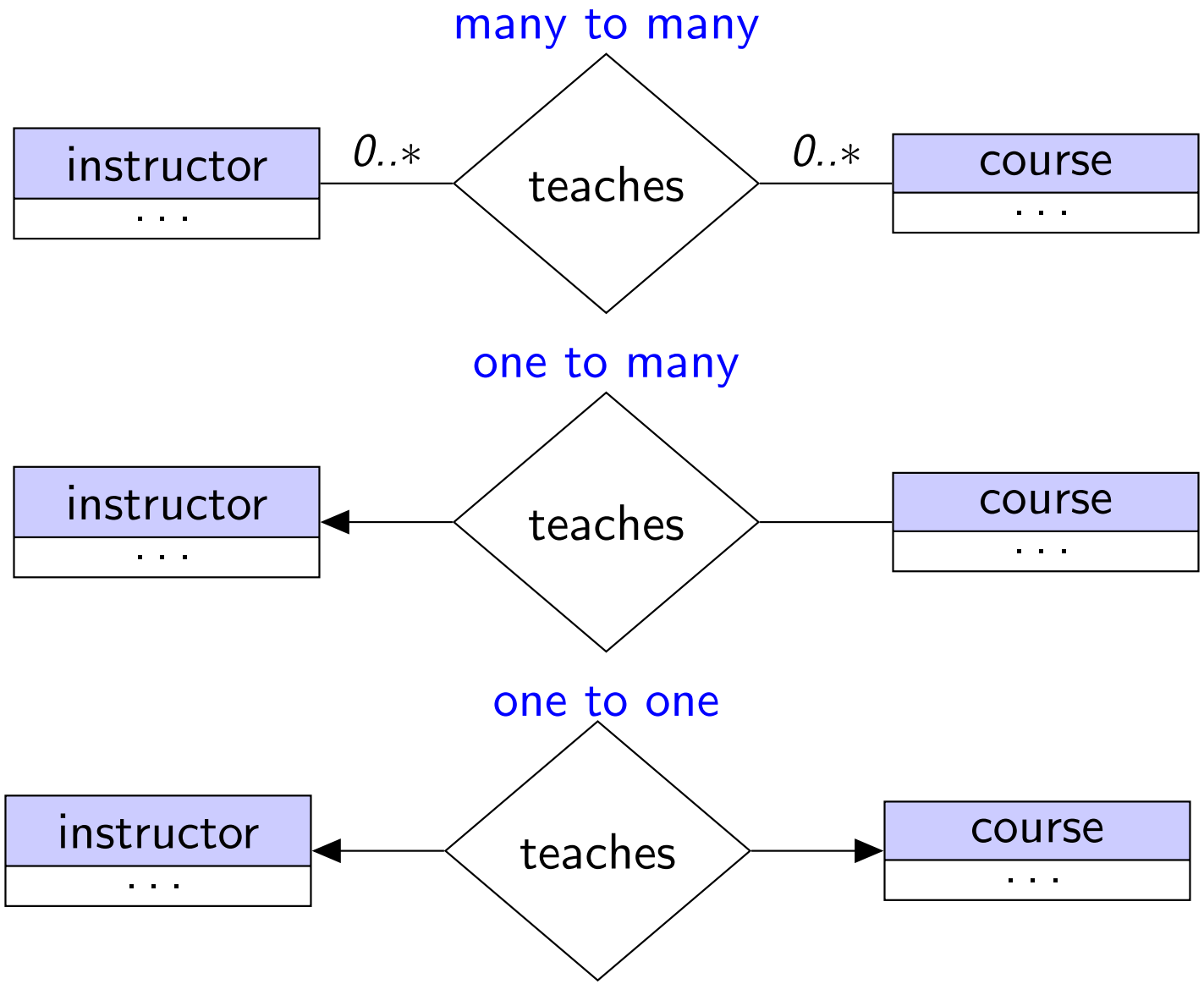

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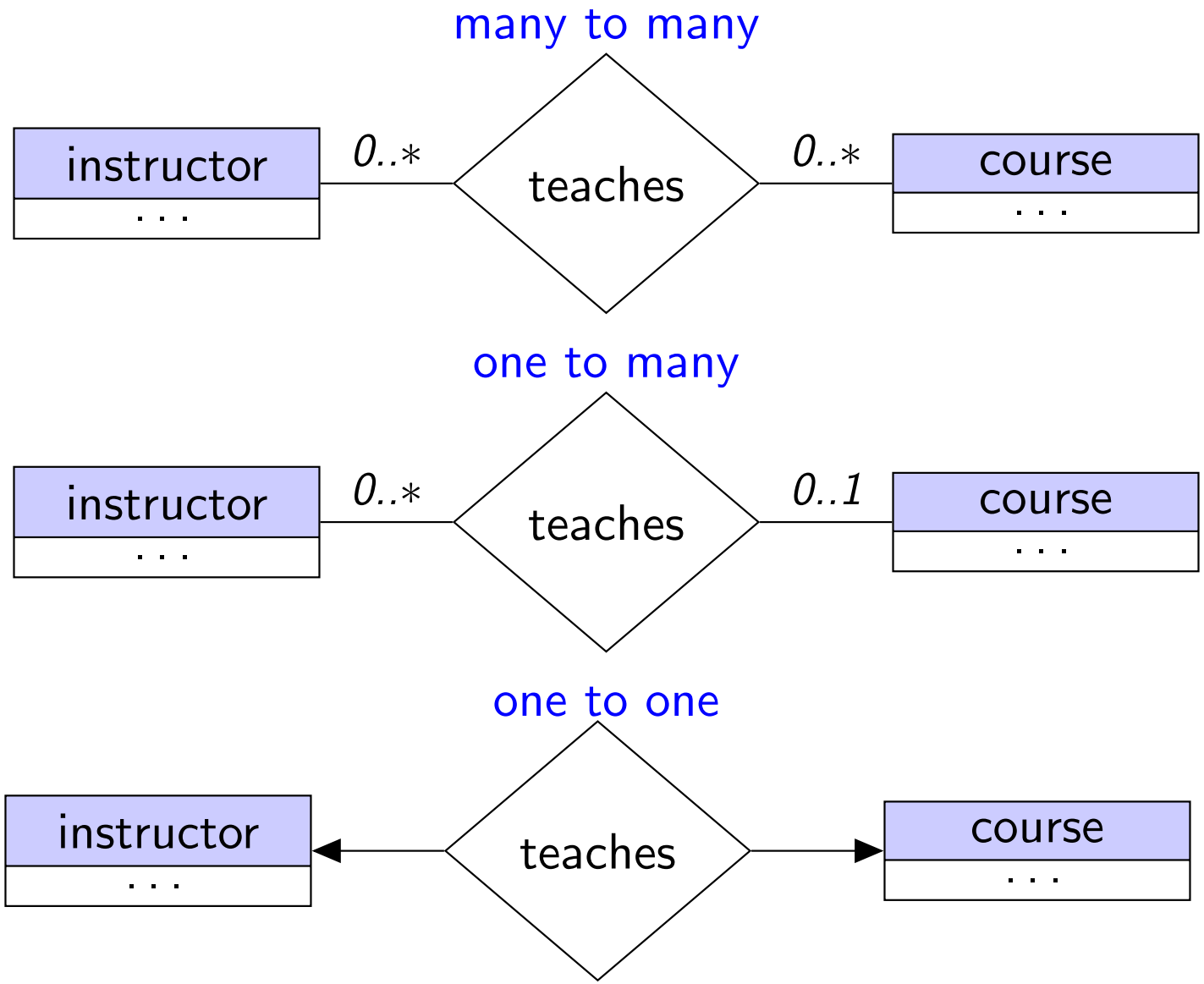

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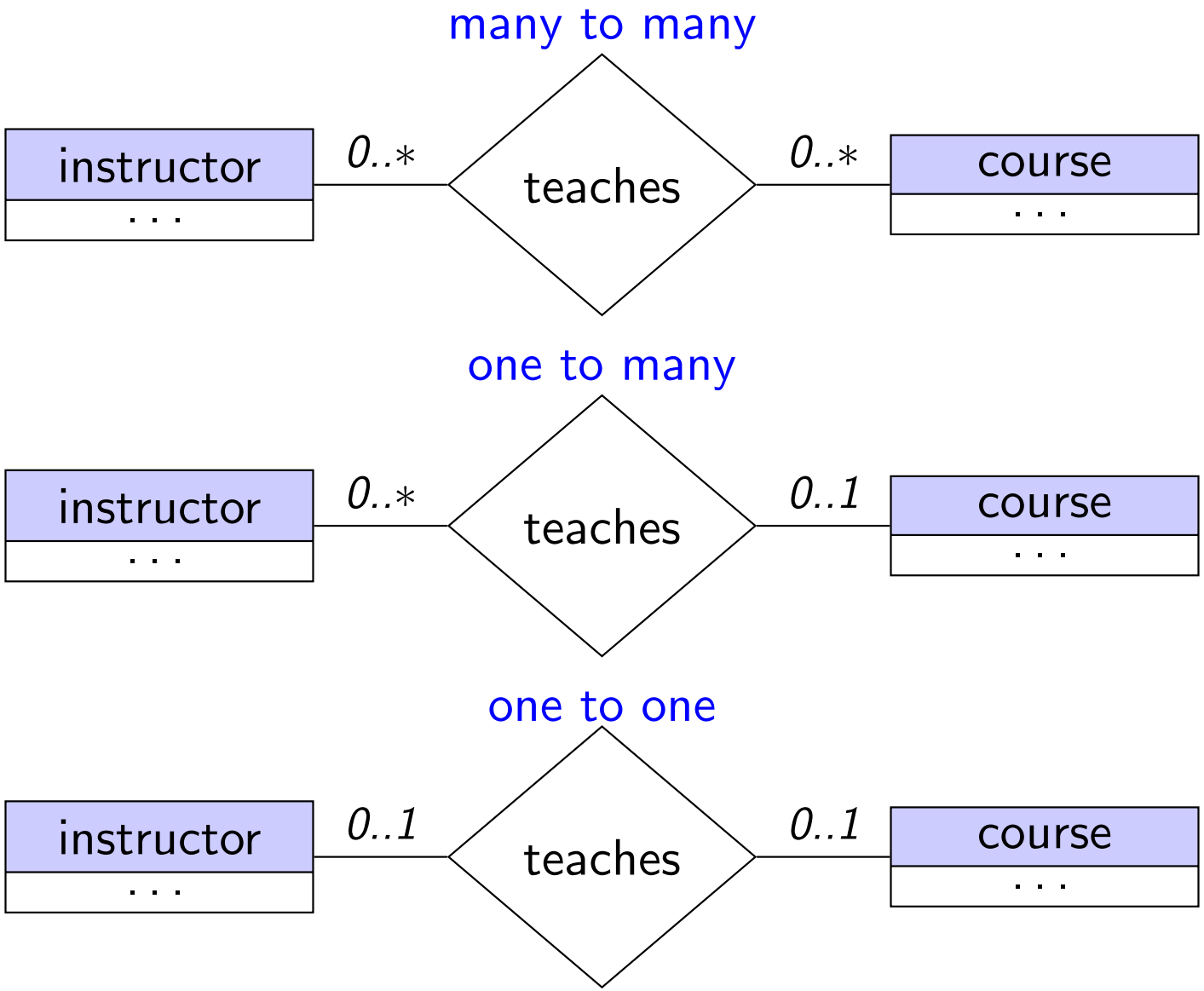
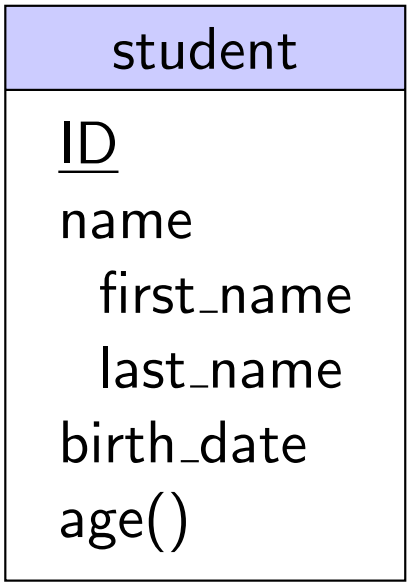


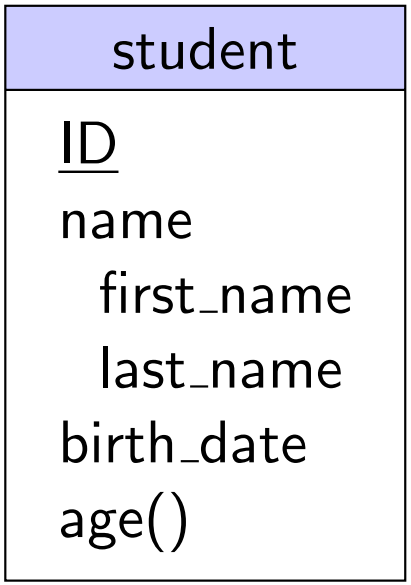
E-R entity to relation schema (example)



$\Rightarrow$

```
student(ID, first_name,
        last_name, birth_date)
```

E-R entity to relation schema (example)

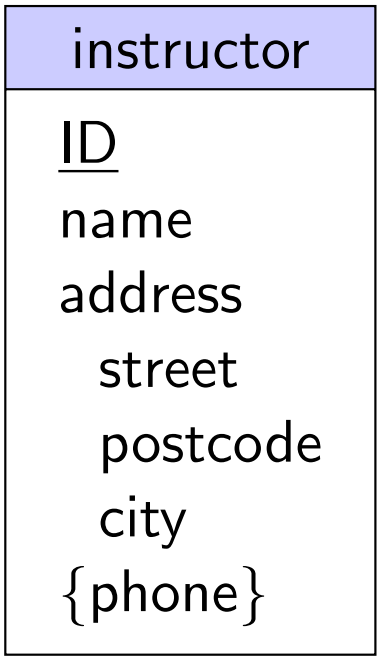



```
student(ID, first_name,
        last_name, birth_date)
```

$\Rightarrow$

```
create table student (ID int,
                      fname varchar(20),
                      lname varchar(20),
                      birth_date date,
                      primary key (ID));
```

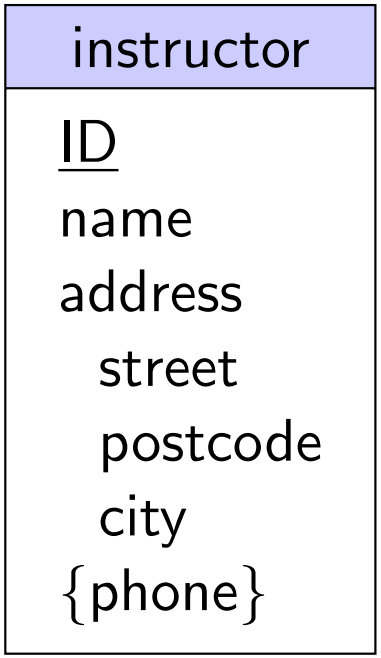
E-R multi-valued attribute to relation schema (example)



$\Rightarrow$

```
instructor(ID, name, street, pcode, city)
phone(inst_id, phone_nr)
```

E-R multi-valued attribute to relation schema (example)



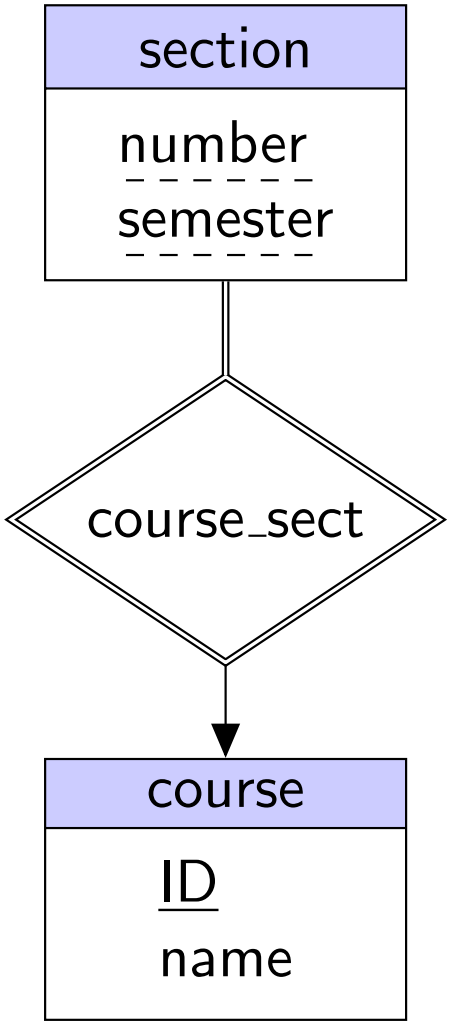
$\Rightarrow$

```
instructor(ID, name, street, pcode, city)
phone(inst_id, phone_nr)

create table
    instructor (ID int,
                name varchar(50),
                street varchar(20),
                postcode char(6),
                primary key (ID));

create table
    phone (inst_id int, phone_nr int,
           primary key(inst_id, phone_nr),
           foreign key (inst_id)
                references instructor(ID));
```

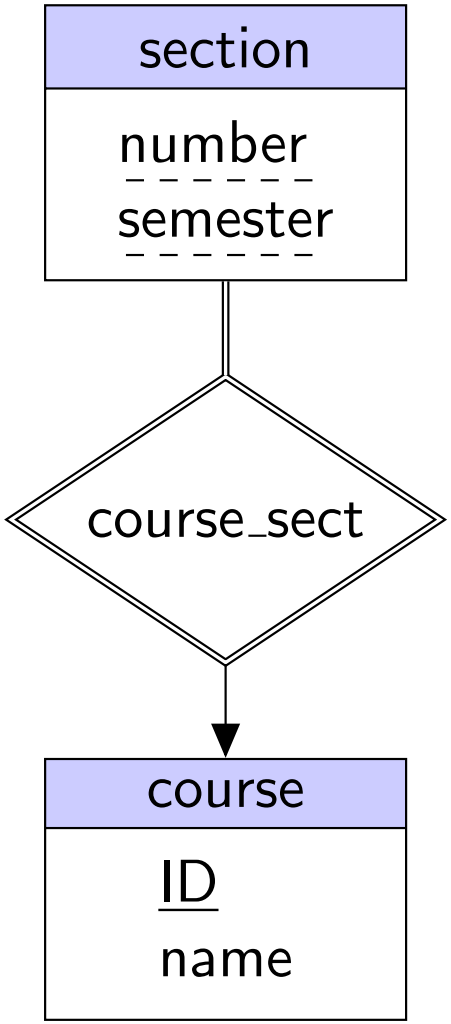
E-R weak entity to relation schema (example)



$\Rightarrow$

course(ID, name)
section(c_ID, num, semester)

E-R weak entity to relation schema (example)

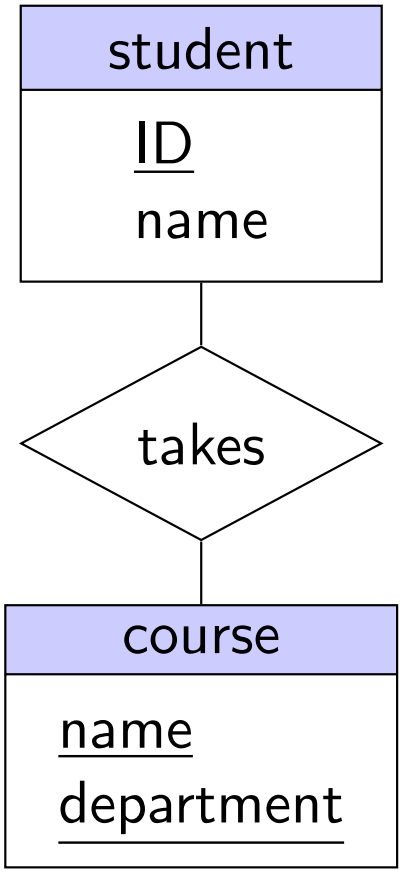



```
course(ID, name)
section(c_ID, num, semester)

create table
    course (ID int,
            name varchar(50),
            primary key (ID));
⇒

create table
    section (c_ID intint,
             num int, semester int,
             primary key(c_id, num, smester),
             foreign key(c_id)
                references course(ID);
```

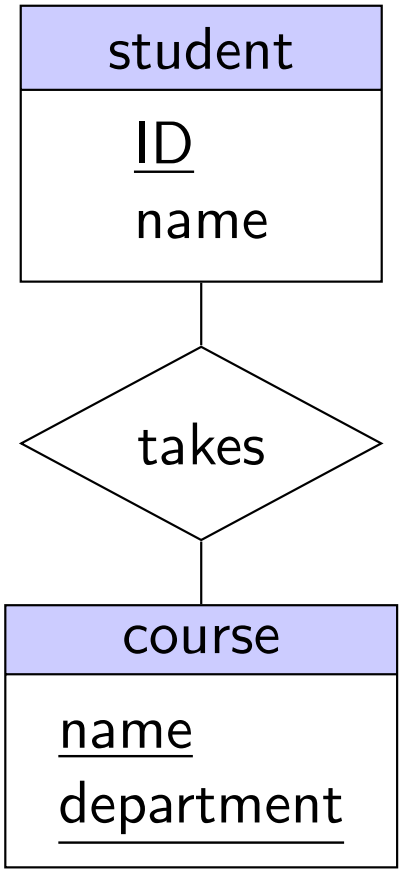
E-R relationship to relation schema (example)



$\Rightarrow$

```
student(ID, name)
course(cname, cdept)
takes(s_ID, cname, cdept);
```

E-R relationship to relation schema (example)

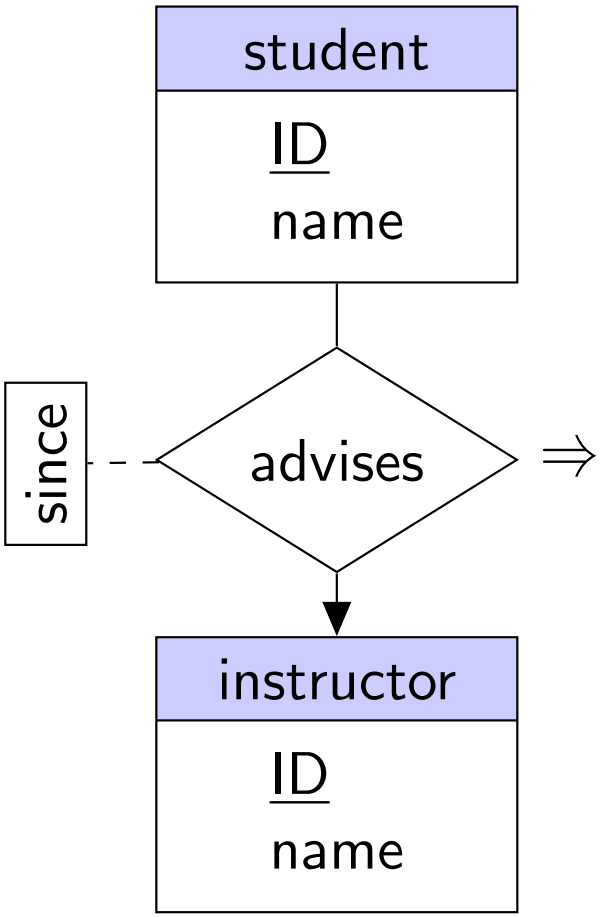


$\Rightarrow$

```
student(ID, name)
course(cname, cdept)
takes(s_ID, cname, cdept);

create table student (ID int,
                      name varchar(50),
                      primary key (ID));
create table course (cname varchar(50),
                     cdept varchar(50),
                     primary key(cname, cdept));
create table
    takes (s_ID int,
           cname varchar(50),
           cdept varchar(50),
           primary key(s_ID, cname, cdept),
           foreign key (s_ID) references student(ID),
           foreign key (cname, cdept) references course);
```

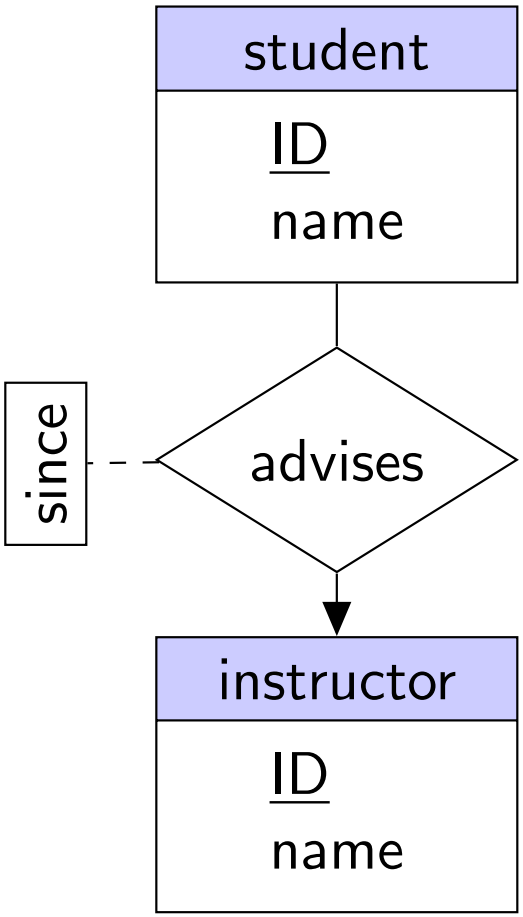
E-R relationship to relation schema (example 2)



$\Rightarrow$

```
student(ID, name)
instructor(ID, name)
advises(i_ID, s_ID, since)
```

E-R relationship to relation schema (example 2)



⇒

```
student(ID, name)
instructor(ID, name)
advises(i_ID, s_ID, since)

create table student (ID int,
                      name varchar(50),
                      primary key (ID));
create table instructor (ID int,
                         name varchar(50),
                         primary key(ID));
create table advises (i_ID int, s_ID int,
      since date,
      primary key(s_ID),
      foreign key (s_ID) references student(ID),
      foreign key (i_ID) references instructor(ID));
```

Rules of thumb

Conceptual database design is an art as much as it is a science.
Generally, there is no single correct solution.

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Conceptual database design is an art as much as it is a science. Generally, there is no single correct solution.

- Do try to represent the real-world as faithful as possible.
- Don't model same thing twice: avoid redundancy.
- Don't model things that are not needed: look for simpler solutions.

An overall summary

- A conceptual design using E-R data model allows us to
  - think about the DB requirements systematically and formalize the ideas from the requirement analysis,
  - communicate the overall design of the database using a graphical representation.
- E-R notation is varied and non-standard, one can alternatively use another representation like UML.
- E-R constructs can be reduced to a database schema.
- Conceptual modeling is helpful, however, it does not guarantee correct relational database design.

What do we want to avoid?

In DB design we want to avoid:

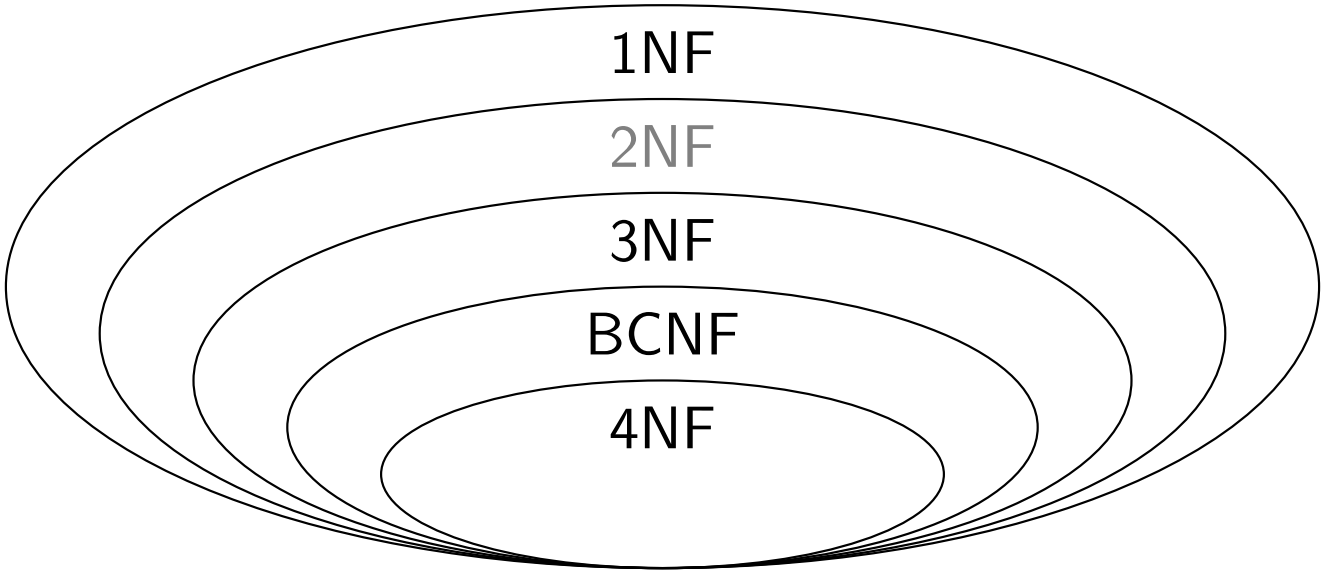
Update anomalies , where we update the same information in one place but not the other.

Deletion anomalies , where we have to delete unwanted data together with the data we want to delete.

Insertion anomalies , where it is not possible to store a certain information without inserting additional unnecessary/unrelated data.

Main cause of these anomalies are redundant/repeated storage of the same information.

Normal forms



- Normal forms are a set of formal rules that ensure certain types of anomalies do not occur.
- Except Boyce-Codd normal form (BCNF), they are named as first normal form, second normal form, ...
- Higher level normal forms are more strict, and require all lower level forms.

Normal forms: a summary

- Normal forms state (formal) rules that a DB table should meet so that it is guarded against certain forms of redundancy/inconsistency.
- Once we detect a violation of a normal form, we decompose the table into smaller tables until all conform to the the normal form.
- While decomposing the tables, we seek lossless-join and dependency-preserving decomposition.
- Requiring 3NF, BCNF or 4NF is common in practice.
- Sometimes normal forms are intentionally violated for reasons of performance, which is called denormalization.
- Higher forms exist, but they cover rather rare problematic cases and they are complicated to understand and apply.

Functional dependencies: formal definition

A set of attributes $B = \beta_1 \cdots \beta_M$ is functionally dependent on another set of attributes $A = \alpha_1 \cdots \alpha_N$ if for all possible tuples in the relation, value of A on a certain tuple determine the value of B in the same tuple.

We note this functional dependency as

$$\alpha_1\ \alpha_2\ \cdots\ \alpha_N \rightarrow\ \beta_1\ \beta_2\ \cdots\ \beta_M$$

and if this is a valid for a particular relation (table), we say that the functional dependency holds for that particular relation.

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and if this is a valid for a particular relation (table), we say that the functional dependency holds for that particular relation.

In other words: the functional dependency $A \rightarrow B$ means that 'if two tuples (rows) have identical value(s) for A then they have to have identical value(s) for B'.

Functional dependencies and keys

Where do the keys come from?

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A set of attributes K is a key, if for all attributes A, functional dependency $K \rightarrow A$ holds, and K is the minimal set of attributes with this property.

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Functional dependencies and keys

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Where do the functional dependencies come from?

We assert them based on our knowledge about entities/relationships that we are modeling.

Boyce-Codd Normal form (BCNF)

The formal definition:

A relation is in Boyce-Codd normal form if for any non-trivial functional dependency $A \rightarrow B$, A is a superkey.

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A more intuitive definition (due to Bill Kent/Chris Date):

Each attribute must represent a fact about the key, the complete key, and nothing but the key.

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- BCNF eliminates most (but not all!) causes of redundancy/inconsistency.
- A table can be decomposed into multiple tables to achieve BCNF.

Third normal form: one step back

A relation is in third normal form (3NF) if for any non-trivial FD $A \rightarrow B$ one of the following holds.

1. A is a superkey.
2. B-A (attributes in B but not in A) is part of a key.

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The intuitive definition of 3NF:

Every non-key attribute must represent a fact about the key, the complete key, and nothing but the key.

- 3NF is less strict than BCNF.
- It may be desirable in cases where BCNF decomposition is not dependency preserving.

Multi valued dependencies

For set of attributes that A, B, the multivalued dependency (MVD)

$$A \twoheadrightarrow B$$

holds if

- given the value of A, B may have multiple values
- but the set of values only depend on A,
- and only A (no other attribute in the table affects the dependency)

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holds if

- given the value of A, B may have multiple values
- but the set of values only depend on A,
- and only A (no other attribute in the table affects the dependency)

Note: every FD is an MVD, but not every MVD is an FD.

Fourth normal form (4NF)

A relation is in fourth normal form (4NF) if for any non-trivial multivalued dependency $A \twoheadrightarrow B$, A is a superkey.

- The definition of 4NF is similar to definition of BCNF, except we require MVDs to hold instead of FDs.
- 4NF eliminates most causes of anomalies, but (still) not all.

Fourth normal form (4NF)

A relation is in fourth normal form (4NF) if for any non-trivial multivalued dependency $A \twoheadrightarrow B$, A is a superkey.

- The definition of 4NF is similar to definition of BCNF, except we require MVDs to hold instead of FDs.
- 4NF eliminates most causes of anomalies, but (still) not all.

Note: every relation that is in 4NF is also in BCNF, but the reverse is (obviously) not true.

Normal forms: a summary

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- While decomposing the tables, we seek lossless-join and dependency-preserving decomposition.
- Requiring 3NF, BCNF or 4NF is common in practice.
- Sometimes normal forms are intentionally violated for reasons of performance, which is called denormalization.
- Higher forms exist, but they cover rather rare problematic cases and they are complicated to understand and apply.

Some guidelines on DB design

- Clear semantics: it should be easy to explain the meaning of your DB schema.
  - use understandable names
  - do not overload your tables
- Avoid redundancy and inconsistency: a good DB design should prevent all anomalies. Follow the most strict normal form you can.
- Avoid null values.
- Joins should reference only keys.

SQL basics: summary (1)

- SQL includes a data definition language (DDL) and data manipulation language (DML) statements as well as being a database query language.
- The DDL statements include `create table`, `alter table` and `drop table`
- The DML statements include `insert into`, `update` and `delete from` statements.
- The SQL query language is closely related to formal query language relational algebra.
- Relational algebra operations include, selection (σ), projection (π), Cartesian product ($\times$), natural join ($\bowtie$), other join operations such as outer joins, and set operations union, intersection, set difference.

SQL basics: summary (2)

- Basic form of SQL queries is:

```
select attribute_1, ···, attribute_N
from table_name_1, ···, table_name_M
where condition;
```

- `from` clause lists the tables used in the query.
- `where` statement picks the rows we are interested in using predicates containing
  - comparisons: `=`, `<>` `>`, `<`, `>=` and `<=`.
  - sub-strings match operator `like`.
  - logical operators `and`, `or` and `not`.
- `select` clause picks the columns we are interested in.
- `select` and `where` may include arithmetic operations, and string operations, `upper`, `lower`, and `concat`

SQL basics: summary (3)

- We can sort the output of an SQL query by adding an `order by` clause at the end of our queries.
- A set of aggregate functions, `count`, `sum`, `avg`, `max` and `min` can be used to gather statistics about certain column(s) of a query.
- The results of aggregate functions can be grouped together by `group by` clause.
- Set operations `union`, `intersection` and difference (`expect`), can be used to combine the results of two queries.
- Sub-queries can be used in the `from` clause, or as an argument to `in`.

SQL and distinct values

- By default, SQL does not eliminate duplicate records.
- Except in set operations `union`, `intersect` and `except`.
- For an SQL query to return only the distinct values, we need to add `distinct` keyword to select clause. For example, `select distinct name from student;`
- `distinct` keyword can also be used in aggregate functions. For example, `select count(distinct name) from student;`

SQL and `null` values

Null values create a number of difficult cases in relational database theory.

- Arithmetic expressions involving `null` are `null` (`1 + null = null`).
- Any comparison (like `1 = null`, `1 < null`) involving nulls results in a third truth value: unknown.
- This includes the comparison `null = null`, except for set operations and for `distinct`.
- Expressions `is null` or `is not null` can be used to test if a value is null or not.
- Logical operations with unknown values:
  - true **and** unknown = unknown, false **and** unknown = false
  - true **or** unknown = true, false **or** unknown = unknown
  - **not** unknown = unknown
- Except `count(*)` aggregate functions ignore null values.

Joins: summary

- A join is a combination of rows from multiple tables according to one or more related columns on each table.
- In SQL a join can either be specified implicitly in `where` clause, or explicitly in `from` clause.
- Inner joins are join operations which select only the tuples that meet the join condition.
- Outer joins allow tuples that do not meet the join condition to be included from one or both tables being joined.
- A natural join uses matching attribute names from each table.
- Joins can be restricted to certain columns with a `using` clause, or full join conditions can be specified using `on`.

Natural Join

student			
sID	**s_dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	3

advisor		
aID	**a_dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

`natural join` joins two or more tables using matching column names.

Natural Join

student			
sID	**s_dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	3

advisor		
aID	**a_dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

`natural join` joins two or more tables using matching column names.

```
select sID, s_dept, aID, phone
from student natural join advisor;
```

Natural Join

student			
sID	**s_dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	3

advisor		
aID	**a_dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

`natural join` joins two or more tables using matching column names.

```
select sID, s_dept, aID, phone
from student natural join advisor;
```

sID	**s_dept**	**aID**	**phone**
1	IK	1	1111
2	CIW	2	2222
3	IK	1	1111
4	CIW	3	3333

Natural Join

student			
sID	**s_dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	3

advisor		
aID	**a_dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

`natural join` joins two or more tables using matching column names.

```
select sID, s_dept, aID, phone
from student natural join advisor;
```

sID	**s_dept**	**aID**	**phone**
1	IK	1	1111
2	CIW	2	2222
3	IK	1	1111
4	CIW	3	3333

You can join more than two tables using the same syntax:

t_1 `natural join` t_2 `natural join` t_3 `...`

Inner join: accidental column match

student			
sID	**dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	3

advisor		
aID	**dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

Inner join: accidental column match

student			
sID	**dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	3

advisor		
aID	**dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

```
select sID, student.dept, aID, phone
from student natural join advisor;
```

sID	student.dept	aID	phone
3	IK	1	1111
4	CIW	3	3333

Inner join: accidental column match

student			
sID	**dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	3

advisor		
aID	**dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

```
select sID, student.dept, aID, phone
from student join advisor using (aID);
```

sID	student.dept	aID	phone
1	IK	1	1111
2	CIW	2	2222
3	IK	1	1111
4	CIW	3	5555

Inner join:
arbitrary column expressions

student			
ID	**s_dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	3

advisor		
ID	**a_dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

Inner join: arbitrary column expressions

student			
ID	**s_dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	3

advisor		
ID	**a_dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

```
select student.ID, s_dept, advisor.ID, phone
from student natural join advisor;
```

studetn.ID	**s_dept**	**advisor.ID**	**phone**
1	IK	1	1111
2	CIW	2	2222
3	IK	3	3333
4	CIW	4	4444

Inner join: arbitrary column expressions

student			
ID	**s_dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	3

advisor		
ID	**a_dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

```
select student.ID, s_dept, advisor.ID, phone
from student join advisor on student.aID = advisor.ID;
```

studetn.ID	s_dept	advisor.ID	phone
1	IK	1	1111
2	CIW	2	2222
3	IK	1	1111
4	CIW	3	3333

Inner join: arbitrary column expressions

student			
ID	**s_dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	3

advisor		
ID	**a_dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

```
select student.ID, s_dept, advisor.ID, phone
from student join advisor on student.aID = advisor.ID;
```

studetn.ID	s_dept	advisor.ID	phone
1	IK	1	1111
2	CIW	2	2222
3	IK	1	1111
4	CIW	3	3333

`on` clause can take any expression allowed in a `where` clause.

Join conditions with an equation are sometimes called equi-join and join conditions with arbitrary comparisons are called θ-join (theta-join).

Left outer join

student			
sID	**s_dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	null

advisor		
aID	**a_dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

```
select * from student natural join advisor;
```

sID	**s_dept**	**year**	**aID**	**a_dept**	**phone**
1	IK	1	1	CIW	1111
2	CIW	2	2	IK	2222
3	IK	3	1	CIW	1111

Left outer join

student			
sID	**s_dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	null

advisor		
aID	**a_dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

```
select * from student natural left outer join advisor;
```

sID	**s_dept**	**year**	**aID**	**a_dept**	**phone**
1	IK	1	1	CIW	1111
2	CIW	2	2	IK	2222
3	IK	3	1	CIW	1111
4	CIW	2	null	null	null

Right outer join

student			
sID	**s_dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	null

advisor		
aID	**a_dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

```
select * from student join advisor using (aID);
```

sID	**s_dept**	**year**	**aID**	**a_dept**	**phone**
1	IK	1	1	CIW	1111
2	CIW	2	2	IK	2222
3	IK	3	1	CIW	1111

Right outer join

student			
sID	**s_dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	null

advisor		
aID	**a_dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

```
select * from student right outer join advisor using (aID);
```

sID	**s_dept**	**year**	**aID**	**a_dept**	**phone**
1	IK	1	1	CIW	1111
2	CIW	2	2	IK	2222
3	IK	3	1	CIW	1111
null	null	null	3	IK	3333
null	null	null	4	CIW	4444

Full outer join

student			
sID	**s_dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	null

advisor		
aID	**a_dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

```
select * from student join advisor on student.aID = advisor.aID;
```

sID	**s_dept**	**year**	**aID**	**a_dept**	**phone**
1	IK	1	1	CIW	1111
2	CIW	2	2	IK	2222
3	IK	3	1	CIW	1111

Full outer join

student			
sID	**s_dept**	**year**	**aID**
1	IK	1	1
2	CIW	2	2
3	IK	3	1
4	CIW	2	null

advisor		
aID	**a_dept**	**phone**
1	CIW	1111
2	IK	2222
3	IK	3333
4	CIW	4444

```
select * from student full outer join advisor on student.aID = advisor.aID;
```

sID	**s_dept**	**year**	**aID**	**a_dept**	**phone**
1	IK	1	1	CIW	1111
2	CIW	2	2	IK	2222
3	IK	3	1	CIW	1111
4	CIW	2	null	null	null
null	null	null	3	IK	3333
null	null	null	4	CIW	4444

SQL and programming

- SQL has limited use unless combined with a general purpose programming language.
- SQL has the advantage that it abstracts away the way data is stored from the application.
- However, it cannot do many things that a typical application program would require. Just to list a few:
  - arbitrary computation
  - flexible I/O, user interaction
  - formatted input output
  - graphical presentation of data
- There are a number of ways to combine SQL and general purpose programming
  - On DB side: stored procedures.
  - On application side: embedded SQL, or call-level interfaces
- We will be using call-level interfaces in this course.

A first PHP/MySQL example

```
1  <?php
2      $host="hostname";
3      $user="username";
4      $pass="password";
5      $db="dbname";
6      mysql_connect($host,$user,$pass);
7      mysql_select_db($db);
8      $q = 'select * from book';
9
10     $res = mysql_query($q);
11     echo "<table border=\"1\">";
12     echo "<tr><th>ISBN</th><th>title</th></tr>";
13     while ($row = mysql_fetch_assoc($res)) {
14         echo "<tr><td>${row['ISBN']}</td>";
15         echo "<td>${row['title']}</td></tr>";
16     }
17     echo "</table>";
18     mysql_close();
19 ?>
```

This week:

- A review of past course: DB design and SQL.
- A simple PHP/MySQL example.

Next week:

- What happens 'under the hood' when you do web-based programming?
- PHP and user interaction.