Part 4: Logical Design I

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Objectives

After completing this chapter, you should be able to:

- translate given ER-schemas manually into the relational model.
- explain which cardinalities cannot be enforced with standard constraints of the relational model (and what can be done in such a case).
- explain and compare the alternatives for translating subclasses.

Overview

General Remarks (1)

- In order to develop a relational schema, one usually first designs an ER-schema, and then transforms it into the relational model, because the ER-model
  - ◇ allows better documentation of the relationship between the schema and the real world.

    E.g. entity types and relationships are distinguished.
  - ◇ has a useful graphical notation.
  - ◇ has constructs like inheritance which have no direct counterpart in the relational model.

    The difficult conceptual design can be simplified a bit by first using the extended possibilities.

General Remarks (2)

- Given an ER-schema S_E, the goal is to construct a relational schema S_R such that there is a one-to-one mapping τ between the states for S_E and S_R.

  I.e. each possible DB state with respect to S_E has exactly one counterpart state with respect to S_R and vice versa.

- States that are possible in the relational schema but meaningless with respect to the ER-schema must be excluded by integrity constraints.

  E.g., in the ER-model, relationships can be always only between currently existing entities. In the relational model, "dangling pointers" must be explicitly excluded by means of foreign key constraints.

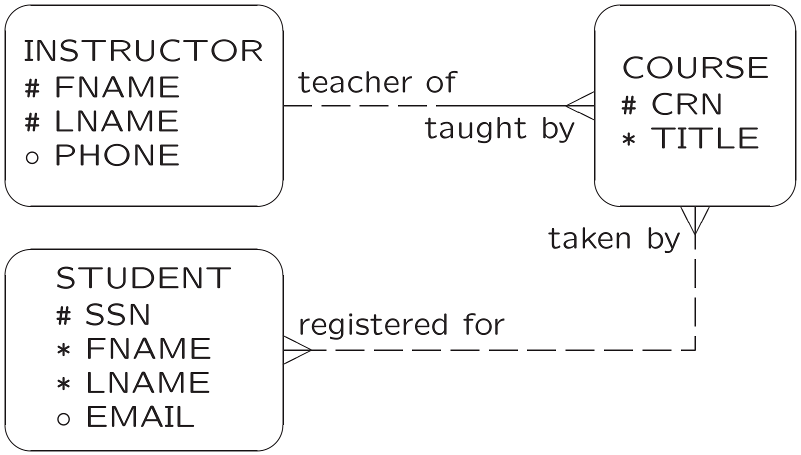
General Remarks (3)

- In addition, it must be possible to translate queries referring to S_E into queries with respect to S_R, evaluate them in the relational system, and then translate the answers back.

- I.e. it must be possible to simulate the designed ER-database with the actually implemented relational database.

  Any schema translation must explain the correspondance of schema elements such that, in our case, a query intended for the ER-schema can also be formulated with respect to the relational schema.

Example



Entities Types (1)

- First a table is created for each entity type.

  The tables created in this step are not necessarily the final result. When one-to-many relationships are translated, columns are added to them. In rare cases, they will later turn out as unnecessary.

- The name of this table is the name of the entity type (maybe in plural form, as in Oracle Designer).

- The columns of this table are the attributes of the entity type.

  Optional attributes translate into columns that permit null values. Depending on how much one considers the goal DBMS in this step, it might be necessary to map attribute data types into something the DBMS supports.

Entities Types (2)

- The primary key of the table is the primary key of the entity type. The same for alternative keys.

  Weak entity types are discussed below.

- If the entity type has no key, an artificial key is added (e.g. Oracle Designer does this).

  The designer really should explicitly define a key for each entity type.

- Result in the example:

  INSTRUCTORS(FNAME, LNAME, PHONE^o)
  STUDENTS(SSN, FNAME, LNAME, EMAIL^o)
  COURSES(CRN, TITLE)

Entity Types (3)

Example State for the Tables Generated So Far:

INSTRUCTORS		
FNAME	LNAME	Phone
Stefan	Brass	624-9404
Michael	Spring	624-9424
Nina	Brass	

Entity Types (4)

COURSES	
CRN	TITLE
12345	DB Management
24816	DB Analysis&Design
56789	Client-Server

STUDENTS			
SSN	FIRST	LAST	EMAIL
111-22-3333	John	Smith	js@acm.org
123-45-6789	Ann	Miller	
235-71-1131	David	Meyer	dm@hotmail.com

One:Many Relationships (1)

- One-to-many Relationships are normally translated by adding the primary key from the "one" side as a foreign key to the "many" side.

  In this way, every entity on the "many" side can refer to the related entity on the "one" side.

- E.g. in the example, first name and last name of the instructor are added to the course table in order to implement the relationship "teacher of/taught by":

  COURSES(CRN, TITLE,
  (FNAME,LNAME)→INSTRUCTORS)

One:Many Relationships (2)

- The example shows already a difficult case because the primary key (and therefore also the foreign key) consists of two columns.

  This is why some designers would prefer primary keys consisting only of one column. But that is a matter of taste.

- Example State:

COURSES			
CRN	TITLE	FNAME	LNAME
12345	DB Management	Stefan	Brass
24816	DB Analysis&Design	Stefan	Brass
56789	Client-Server	Michael	Spring

One:Many Relationships (3)

- The rows corresponding to both entities will be combined with a join (which equates the foreign key on the "many" side to the primary key on the "one" side).
- Although a "pointer" (foreign key) was added only on the "COURSES" side, the join permits to "follow pointers in both directions".

  Of course, one can formulate queries that contain conditions on instructors and then find all their courses. The exact evaluation sequence for the query is a question of query optimization and depends also on the existing indexes.

One:Many Relationships (4)

- It is a common error of beginners to add the foreign key to the wrong side.

  Of course, this cannot happen when one uses a tool that does the translation automatically (like Oracle Designer). But one nevertheless needs to understand the correct translation.

- Adding a foreign key to the table is only possible if the maximum cardinality in the (min,max) notation is 1, i.e. there is at most one related entity.
- This holds for the "many" side of a one-to-many relationship.

One:Many Relationships (5)

- Since one instructor can teach many courses, adding the key of COURSES to the INSTRUCTORS table would give a set-valued attribute which is not permitted in the standard relational model:

INSTRUCTORS **WRONG!**			
FNAME	LNAME	Phone	CRN
Stefan	Brass	624-9404	{12345, 24816}
Michael	Spring	624-9424	{56789}
Nina	Brass		$\emptyset$

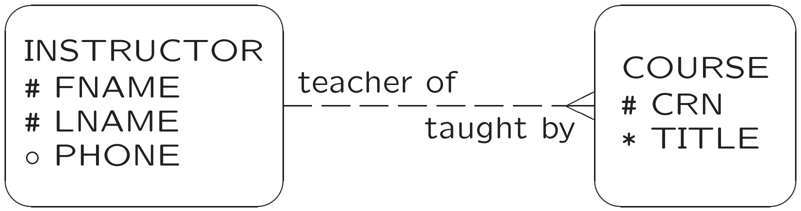
One:Many Relationships (6)

- Unfolding the set-valued attribute would destroy the key, store information redundantly (instructors of multiple courses), and lead to the loss of other information (instructors of no course).

INSTRUCTORS **WRONG!**			
FNAME	LNAME	Phone	CRN
Stefan	Brass	624-9404	12345
Stefan	Brass	624-9404	24816
Michael	Spring	624-9424	56789

One:Many Relationships (7)

- Above, every course had to be taught by an instructor (mandatory participation).
- The translation for the case of optional participation is similar (courses without instructors).



One:Many Relationships (8)

- The only difference is that the foreign key can now be null:

  COURSES(CRN, TITLE,
  (FNAME^o,LNAME^o)
  → INSTRUCTORS)

- Example State:

COURSES			
CRN	TITLE	FNAME	LNAME
12345	DB Management	Stefan	Brass
24816	DB Analysis&Design		
56789	Client-Server	Michael	Spring

One:Many Relationships (9)

- If the foreign key consists of more than one attribute (as in the example), all its attributes must be together null or together not null.

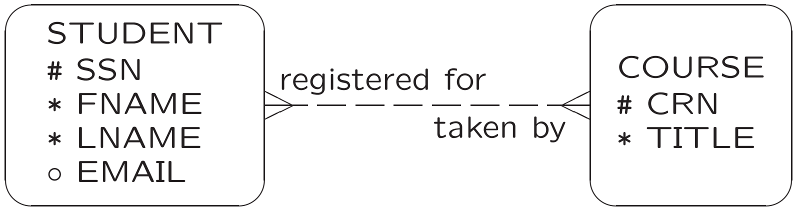
  A partially defined foreign key would make no sense in terms of the relationship that has to be implemented.

- Fortunately, this condition can be enforced declaratively with a `CHECK`-constraint:

```
CHECK((FNAME IS NOT NULL AND LNAME IS NOT NULL)
   OR (FNAME IS NULL AND LNAME IS NULL))
```

Many:Many Relationships (1)

- In the example, a many-to-many relationship still remains:



- Such relationships cannot be implemented by adding a foreign key to one of the two tables, because there can be more than one related entity.

Many:Many Relationships (2)

- Thus, a new table is created for the relationship (it is sometimes called an "intersection table").
- The new table contains the primary keys of both entity types that participate in the relationship.
- The two keys together form the composed key of the intersection table, and each is a foreign key referencing the table for its entity type:

  REGISTERED_FOR(<u>SSN</u>→STUDENTS,
  <u>CRN</u>→COURSES)

Many:Many Relationships (3)

- The intersection table for the relationship simply contains key value pairs of entities that are related:

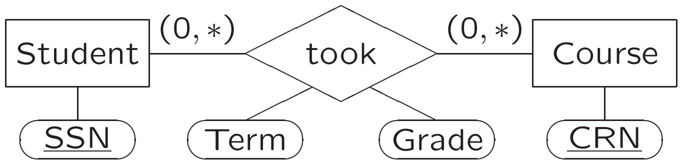
REGISTERED_FOR

<u>SSN</u>	<u>CRN</u>
111-22-3333	12345
111-22-3333	56789
123-45-6789	12345

- E.g. John Smith (SSN 111-22-3333) is registered for Database Management (CRN 12345) and for Client-Server (CRN 56789).

Many:Many Relationships (4)

- Suppose the relationship has attributes:

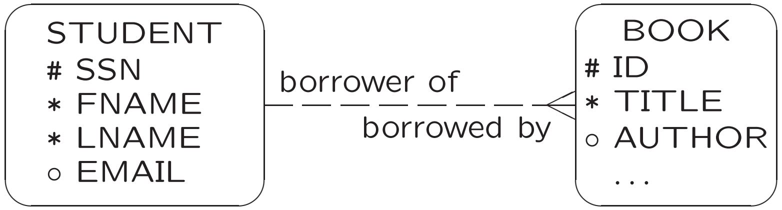


- Then one can simply add the relationship attributes to the relationship table:

  TOOK(<u>SSN</u>→STUDENTS, <u>CRN</u>→COURSES,
  TERM, GRADE)
- These attributes do not become part of the key.

One:Many: Alternative (1)

- One can also translate one-to-many relationships (with optional partcipation on both sides) into tables of their own.
- E.g. consider the following example: The university library wants to store who has borrowed with book:



One:Many: Alternative (2)

- This can also be translated in a similar way to a many-to-many relationship:

  BORROWED_BY(<u>ID</u>→BOOKS,
  SSN→STUDENTS)

- In contrast to a many-to-many relationship, ID alone suffices as key, since every book can be related to at most one student, so there can never be two entries for the same book.

One:Many: Alternative (3)

- Note that this alternative solution needs one more join in most queries than the standard solution.

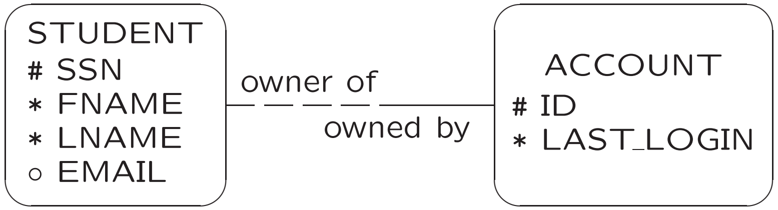
  The standard solution explicitly stores the outer join of the entity table and this relationship table, so that one does not have to compute the join at runtime.

- However, if there are very many books and very few of them are borrowed, the alternative solution permits fast access to the borrowed books.

  It might also be a bit more space-efficient.

One:One Relationships (1)

- Suppose we want to store which student is responsible for which computer account:



- The translation is basically done like a one-to-many relationship. If one side has mandatory participation, one treats that side as the "many" side.

One:One Relationships (2)

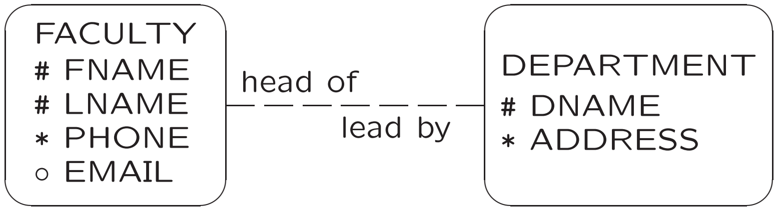
- The result of the translation is

  STUDENTS(SSN, FNAME, LNAME, EMAIL^o)
  ACCOUNTS(ID, LAST_LOGIN,
  SSN→STUDENTS)

- The important difference to a “one-to-many” relationship is that the foreign key that implements the relationship now becomes an alternative key for the ACCOUNTS table.
- I.e. for every student SSN, there can be at most one account.

One:One Relationships (3)

- Now consider the case that the participation is optional on both sides:



- Now the situation is symmetric, and one can choose either side as “many” side.

  It would be a mistake to add a foreign key on both sides (redundant information).

One:One Relationships (4)

- In the example, it is probably an exceptional situation that departments do not have a head.
- One needs less null values if one chooses the side on which participation is “less optional” and adds the foreign key on this side:

  FACULTY(FNAME, LNAME, PHONE, EMAIL^o)
  DEPARTMENTS(DNAME, ADDRESS,
  (LNAME^o, FNAME^o)
  →FACULTY)

One:One Relationships (5)

- The relationship becomes one-to-one by specifying that LNAME, FNAME are an alternative key for DEPARTMENTS.

  Note that as always for optional composed foreign keys, one needs a `CHECK`-constraint specifying that LNAME and FNAME can only be together null.

- Not every DBMS supports alternative keys that can be null.

  And if they are supported, one has to check what the semantics is. E.g. in SQL server, at most one record with a null value in the key is permitted, which would not help here.

One:One Relationships (6)

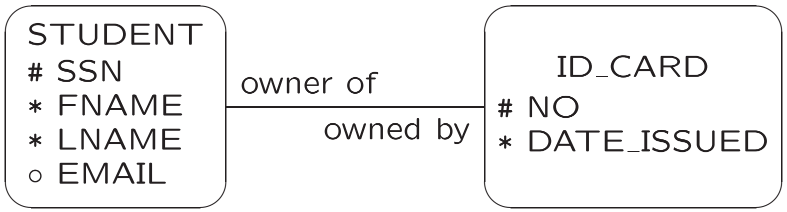
- However, if that does not work, one can also use the alternative translation for one-to-many relationships (with their own table):

  FACULTY(<u>FNAME</u>, <u>LNAME</u>, PHONE, EMAIL^o)
  DEPARTMENTS(<u>DNAME</u>, ADDRESS)
  DEPT_HEAD(<u>DNAME</u>→DEPARTMENTS
  (LNAME, FNAME)→FACULTY)

- LNAME and FNAME together are an alternative key for the relation DEPT_HEAD.

One:One Relationships (7)

- Finally, consider the case with mandatory participation on both sides:

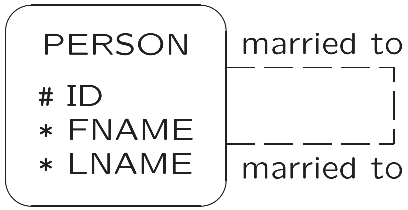


- In this case, one would translate the two entity types into only one table.

  One must select one of the two keys as primary key, the other becomes an alternative key.

One:One Relationships (8)

- I do not know any good solution for recursive one-to-one relationships:

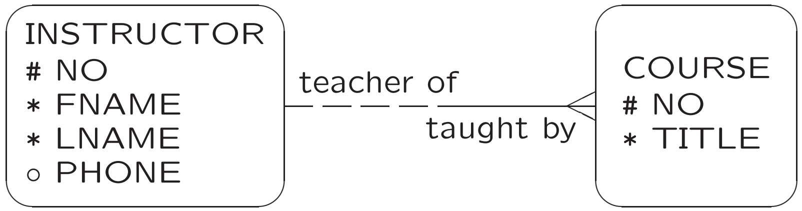


- One needs the constraint that if X references Y, also Y references X.

  The problem is that here one automatically gets the foreign key on both sides.

Renaming of Columns (1)

- Sometimes the direct application of the translation rules would lead to a name clash:



- In this example, one would get:

  COURSES(<u>NO</u>, TITLE, NO→INSTRUCTORS)

- But column names must be unique within a table.

Renaming of Columns (2)

- One can rename attributes during the translation in any understandable way.
- E.g. one could also use the role name in the relationship:
  COURSES(<u>NO</u>, TITLE,
  TAUGHT_BY→INSTRUCTORS)
- One could also add the name of the referenced table, or maybe a shorthand for it:
  COURSES(<u>NO</u>, TITLE,
  INST_NO→INSTRUCTORS)

Renaming of Columns (3)

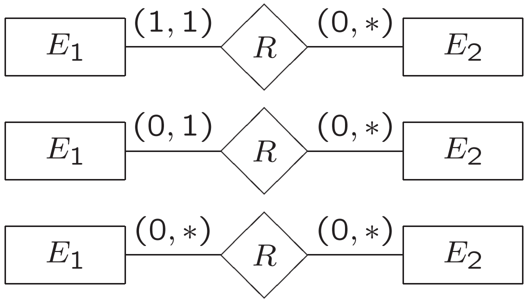
- The renaming must be carefully documented such that the ER-diagram is still useful as documentation for the implemented relational schema.
- Sometimes, it might be good to change the attribute name already on the ER-level.

  However, this is not always possible (e.g. in the case of recursive relationships).
- Also the table names generated for many-to-many relationships are often not very good and should be renamed.

Overview

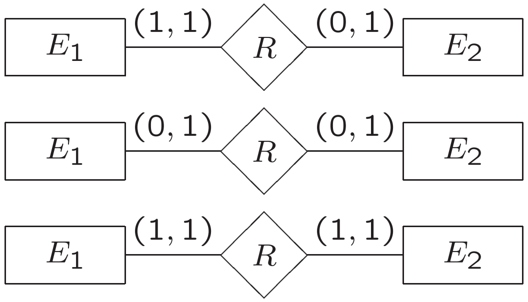
Summary: Limitations (1)

- The following cardinalities can be translated with the methods explained above (using only the standard constraints of the relational model):



Summary: Limitations (2)

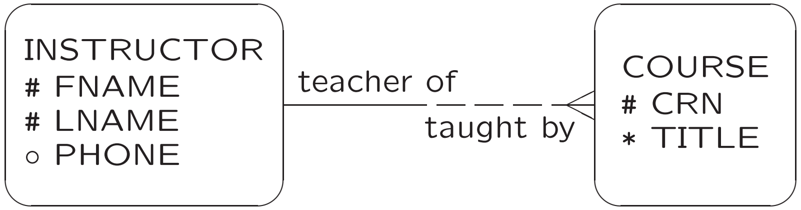
- In addition, all kinds of one-to-one relationships can be handled (except recursive ones):



Recursive 1:1 relationships can be handled, when the entities are partitioned into two subclasses, and connections exist only between them.

One:Many Relationships (1)

- Mandatory participation on the "one" side of a one-to-many relationship cannot be translated into the relational model using only the standard constraints (not null, keys, foreign keys, `CHECK`).
- Instructors must teach at least one course:



One:Many Relationships (2)

- In this case, one uses the same translation as if the participation on the " INSTRUCTOR" side would be optional.
- This is more general: The cardinality restriction $(1,*)$ is weakend to $(0,*)$.
- Thus, all DB states required by the ER-schema can be represented in the relational schema.
- But the relational schema permits DB states that would be illegal with respect to the ER-schema.

One:Many Relationships (3)

- In order to make the two schemas equivalent, one needs to add a constraint that excludes instructors without courses.
- E.g. one could run from time to time an SQL query that finds violations of the constraint:

```
SELECT FNAME, LNAME
FROM   INSTRUCTORS I
WHERE  NOT EXISTS (SELECT *
                   FROM   COURSES C
                   WHERE  C.FNAME = I.FNAME
                   AND    C.LNAME = I.LNAME)
```

Integrity Control (1)

- The problem with the above approach (searching for violations e.g. every night) is that it does not really enforce the integrity of the DB state.
- The invalid information can be entered, and is detected only after some time.
- In the meantime, it might have been used already.

  E.g. a salary was paid.
- It is also more difficult to correct the integrity violation if it is not immediately detected.

  Who has entered this? What did he/she meant to do?

Integrity Control (2)

- One can also program the check in the application programs used for entering data.

  The instructor can only be added with his/her first course, and when the last course is deleted, the instructor is deleted, too.
- Then one has to exclude direct changes to the database that do no use the application programs.
- Also, one must be very careful that all application programs check this condition.

  E.g. also the one used for updating instructor assignments for courses.

Integrity Control (3)

- Good application programs anyway should handle all possible constraint violations, even if the DBMS enforces the constraint.

  At least all constraint violations that could possibly occur due to bad user input. Other constraint violations are automatically prevented by the application logic (e.g. if the user first selects a customer and then enters an order), and then the check in the DBMS suffices (in case the program contains a bug or somebody else deletes the customer in the meantime).

  The error message generated by the DBMS is normally not very clear for the untrained user, therefore at least some form of exception handling that produces a better error message for the specific application context should be done. Of course, the application could simply check for these constraint violations itself before executing the critical update. But this duplication could also be considered bad style.

Integrity Control (4)

- Thus constraint checks in the DBMS basically give a second level of protection against:
  - ◇ application programs that contain bugs,
  - ◇ application programs that contain holes,

    It is easy to overlook that a specific update might violate a certain constraint, although there is a formal theory that can compute all possible "critical updates" from the given constraint formula.
  - ◇ users that have direct SQL access to the DBMS,
  - ◇ unexpected interference of concurrent users.
- Declarative constraints are also a formal and concise specification for the checks in the software.

Integrity Control (5)

- If a constraint is not declaratively supported by the DBMS, triggers can be used to enforce it.

  Triggers are procedures stored in the database that the DBMS automatically calls when a certain event has happend, e.g. when an instructor was inserted. Triggers often consist of the three parts "event, condition, action".

- One can also define elementary transactions as stored procedures in the database and change the DB state only via these stored procedures.

  Then checks do not have to be repeated in the application programs, it is more likely that checks are not forgotten, and they are more clearly separated from the user interface.

Integrity Control (6)

- The SQL-92 standard would permit to specify the constraint declaratively ("`CREATE ASSERTION`").

  This is not implemented in any DBMS I know. However, DBMS vendors now feel some pressure from their customers to offer more support for integrity enforcement.

- The constraint needed in the example (no instructor without course) is similar to a foreign key.

  Like a foreign key it requires the inclusion of attribute values: Every combination of FNAME, LNAME values in the INSTRUCTORS table must also appear in the COURSES table.

- But it is no foreign key since the referenced attribute combination is no key.

Integrity Control (7)

- Because of these problems, one can of course ask: "Should I use such cardinality specifications?"

- But if in the real world, there cannot be instructors that do not teach courses, the ER-schema with optional participation would be simply wrong.

  Of course, as for any constraint, one must always ask: Could there possibly be exceptional situations that would permit an instructor without courses? In that case, the mandatory participation would be wrong, because constraints do not permit any exceptions.

- Clearer example: Invoices without line items really do not make sense.

Integrity Control (8)

- When defining the conceptual schema, one should not think about limitations of current technology.

- That is the task of logical (and physical) design.

- The problem can be solved (e.g. with checks in application programs and by searching for integrity violations with a query at least once a month).

- When technology advances, the same conceptual schema can be translated in a nicer way.

  More tasks are given to the system, less is explicitly programmed.

Integrity Control (9)

- Defining the right cardinalities is also important because it influences the application programs:
  - ◇ If there cannot be instructors without courses, the application program to insert an instructor must also insert at least one course.

    Probably, the application should permit to insert more than one course, since there is no real reason to select one specific out of the many courses an instructor might teach.
  - ◇ Otherwise, there will probably be different programs to insert instructors and to insert courses.

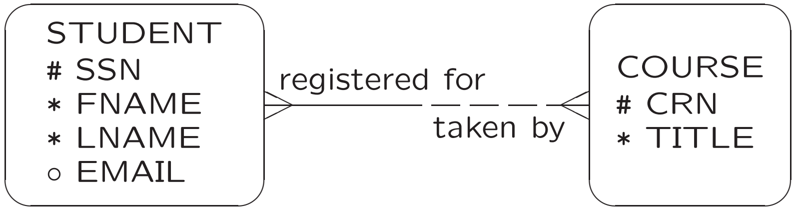
Integrity Control (10)

- One can analyse ER-diagrams for elementary transactions as given by the cardinalities.
- If these should turn out to be too complicated, one should think again about the minimal cardinalities.
- For such an approach, it would make sense to define already on the ER-level
  - ◇ Which attributes are updatable?
  - ◇ Which entities are deletable?
  - ◇ Which entities can be independently inserted?

    Can an existing order be extended by new positions?

Many:Many Relationships (1)

- Optional participation (minimum cardinality 0) is the only form of many-to-many relationship that can be implemented with an "intersection table" and the standard constraints supported in SQL.
- Suppose students must take at least one course:



Many:Many Relationships (2)

- As before, if one has mandatory participation, one uses the more general translation, and adds a constraint (to be checked e.g. in application programs).
- If a student can register for at most three courses, one could discuss also the following solution:

  STUDENTS(<u>SSN</u>, FNAME, LNAME, EMAIL^o,
  CRN1 →COURSES, CRN2^o→COURSES,
  CRN3^o→COURSES)
- However, this significantly complicates queries (one will need a lot of "OR" and "UNION").

Many:Many Relationships (3)

- Even in the general case, there are tricky solutions that would formally solve the problem (mandatory participation in a many-to-many relationship).

  If a student has to register for at least one course, it would be possible to store the CRN for the first course redundantly in the STUDENTS table and then one could declare SSN and CRN in STUDENTS as a foreign key referencing REGISTERED_FOR, but this is at least very ugly (one would also get severe problems inserting any data). One could also leave the foreign key out and take in all queries the union of the registration in the STUDENTS table and the registrations in the REGISTERED_FOR table.

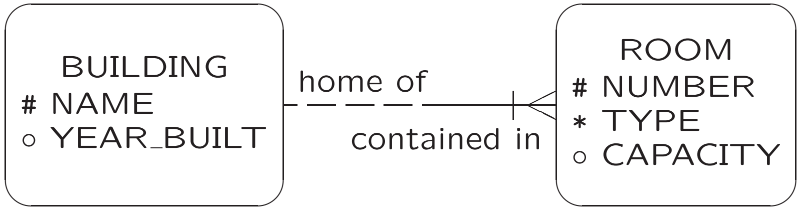
- However, such strange solutions lead to complicated programs and possibly errors.

Overview

1. Basic Schema Translation
2. Limitations, Integrity Control
3. Weak Entity Types
4. Subclasses
5. Special Cases, Final Steps

Weak Entity Types (1)

- When weak entities are translated, the "borrowed" key attributes of the parent entity must be added.



- The key of the "ROOMS" table will consist of the building name and the room number.

Weak Entity Types (2)

- The result of the translation is:

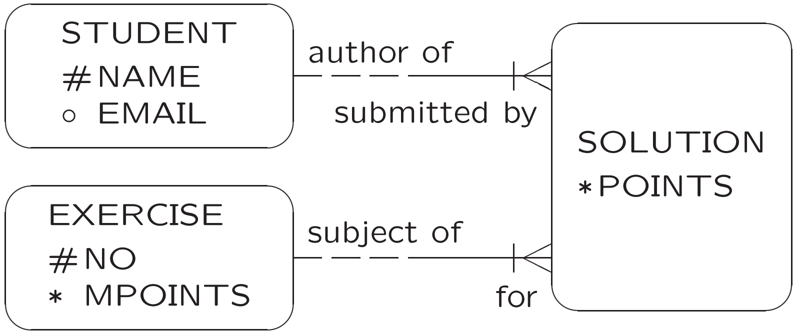
  BUILDINGS(<u>NAME</u>, YEAR_BUILT^o)

  ROOMS(<u>NAME</u>→BUILDINGS, <u>NUMBER</u>, TYPE, CAPACITY^o)

- I.e. the foreign key that is added to the weak entity table in order to implement the relationship with the parent entity type becomes part of the key.

Weak Entity Types (3)

- Next, consider a weak entity type with more than one parent (“Association Entity Type”):



Weak Entity Types (4)

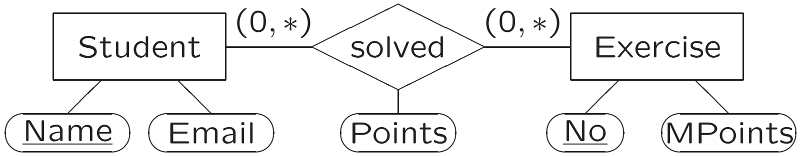
- The translation is done in the same way: The key of the weak entity type now consists of the keys of the two parent entity types (i.e. the two foreign keys added to implement the relationships):

  STUDENTS(<u>NAME</u>, EMAIL^o)
  EXERCISES(<u>NO</u>, MPOINTS)
  SOLUTIONS(<u>NAME</u>→STUDENTS,
  <u>NO</u>→EXERCISES,
  POINTS)

- Of course, any key attributes declared in the weak entity type itself would be added.

Weak Entity Types (5)

- Note that the translation result is exactly the same as if we had used a relationship with an attribute:

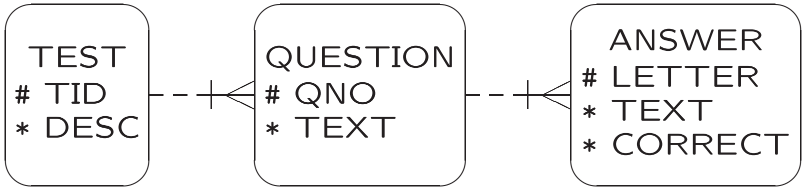


- This demonstrates again that the two ER-schemas are equivalent.

  When one has to check two ER-constructs for equivalence, one can try to translated them into the relational model. If the results are the same, the ER-schemas are equivalent. The converse does not hold.

Weak Entity Types (6)

- A weak entity can also be constructed over several steps. Consider a database schema for storing multiple choice online tests:



Each test consists of several questions. For each question, the student has to check the correct answer among several alternatives. Within a test, questions are identified by a number. For a given question, each possible answer is identified by a letter (a, b, c).

Weak Entity Types (7)

- Before a weak entity type can be translated, all its parent entity types must be translated.

  In the example, first TEST must be translated, then QUESTION, then ANSWER.

- The reason is that in order to construct the primary key for a weak entity type, one must know the primary key of its parent entity type(s).
- This also means that any cycles in the "parent of" relation would give an ill-formed schema that has no meaning and cannot be translated.

Weak Entity Types (8)

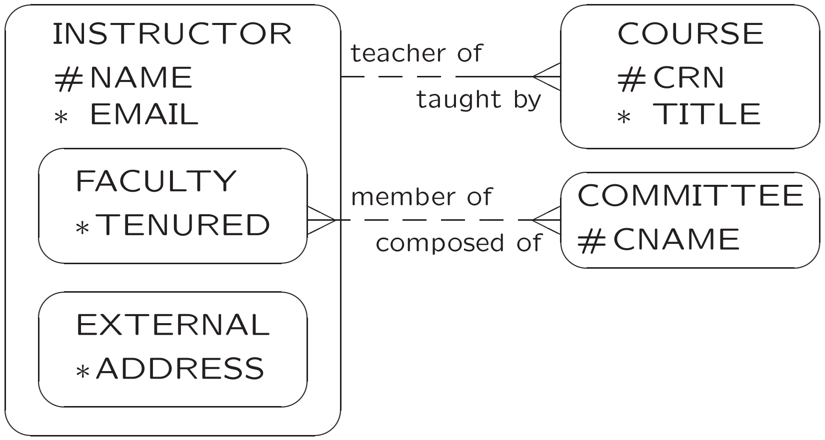
- The result of the translation in the example is:

  TESTS(<u>TID</u>, DESC)
  QUESTIONS(<u>TID</u>→TESTS, <u>QNO</u>, TEXT)
  ANSWERS((<u>TID</u>, <u>QNO</u>)→QUESTIONS,
  <u>LETTER</u>, TEXT, CORRECT)

- ANSWERS contains a foreign key that references its direct parent entity table QUESTIONS.
- This contains a foreign key referencing TESTS.
- It is logically implied that any TID value appearing in ANSWERS also appears in TESTS.

Overview

Subtypes/Specialization (1)



Subtypes/Specialization (2)

Method 1 (Table for the Supertype):

- One big relation is created that contains all attributes of the supertype and of all subtypes.

  Including possibly indirect subtypes.

- In the example, the result is:

  INSTRUCTORS(<u>NAME</u>, EMAIL, TYPE,
  TENURED^o, ADDRESS^o)

- The column "TYPE" identifies to which subtype the entity belongs, e.g. "F" for Faculty and "E" for External: `CHECK(TYPE = 'F' OR TYPE = 'E')`.

Subtypes/Specialization (3)

- Example State:

INSTRUCTORS				
<u>NAME</u>	EMAIL	TYPE	TENURED	ADDRESS
Brass	sb@...	F	N	
Spring	spring@...	F	Y	
Mundie	mundie@...	E		CMU

- Attributes of subtypes are defined only for rows corresponding to elements of the subtype.
- This means that the corresponding columns in the table must permit null values.

Subtypes/Specialization (4)

- With the following constraints one can make sure that subtype attribute columns are really defined only for the subtype:

```
CHECK(TYPE = 'F' OR TENURED IS NULL)
CHECK(TYPE = 'E' OR ADDRESS IS NULL)
```

- Conversely, if an attribute was not optional in the ER-schema, one must add a CHECK-constraint to make sure that the corresponding column is not null for elements of this subtype:

```
CHECK(TYPE <> 'F' OR TENURED IS NOT NULL)
CHECK(TYPE <> 'E' OR ADDRESS IS NOT NULL)
```


Subtypes/Specialization (5)

- It might be useful to declare views for the subtypes:

```
CREATE VIEW FACULTY AS
            SELECT NAME, EMAIL, TENURED
            FROM   INSTRUCTORS
            WHERE  TYPE = 'F'
```

- Sometimes, the "TYPE" column is not really needed.

  E.g. in the example, all instructors where "TENURED" is a null value are external instructors.

- But it might be clearer to retain it. This might also help to adapt the schema to additional subtypes.

Subtypes/Specialization (6)

- With this method, relationships refering to the supertype are no problem:

  COURSES(CRN, TITLE, INST_NAME→INSTRUCTOR)

- Example State:

COURSES		
CRN	TITLE	INST_NAME
11111	Database Management	Brass
22222	DB Analysis&Design	Brass
33333	Client-Server	Spring
44444	Document Processing	Mundie

Subtypes/Specialization (7)

- Relationships with a subtype can only be translated in the same way as a relationship to the supertype:

  COMMITTEE_MEMBERS(CNAME→COMMITTEES,
  FAC_NAME→INSTRUCTOR)

COMMITTEE_MEMBERS	
CNAME	FAC_NAME
PhD Admissions	Spring
PhD Admissions	Brass

- The table declaration does not prevent that an external instructor is entered as a committee member.

Subtypes/Specialization (8)

- The standard constraints of the relational model do not help in this case.

  As mentioned before, one can run a query that finds violations from time to time, one can do checks in application programs or stored procedures, or one can use triggers. Note that a foreign key cannot reference a view. One can hope that in future DBMS vendors will implement more general constraints. In this case one needs something like a foriegn key that specifies in addition a condition on the referenced tuple.

- If there are relationships on subclasses, one should consider using one of the other translation methods (or do the trick on the next page).

Subtypes/Specialization (9)

- In the special case that one uses artificial keys (i.e. numbers that one can assign), one can reserve different ranges for the different subtypes.
- E.g. faculty members have IDs from 100 to 499, external instructs have IDs from 500 to 999:

INSTRUCTORS					
ID	NAME	EMAIL	TYPE	TENURED	ADDRESS
101	Brass	sb@...	F	N	
102	Spring	spring@...	F	Y	
501	Mundie	mundie@...	E		CMU

Subtypes/Specialization (10)

- The column "TYPE" should now be removed, since it is redundant.

  Of course, one can define a view that reconstructs it. If one really wants to retain it, one must add at least a CHECK constraint that ensures that IDs are in the correct range for the instructor type.

- Some designers would leave part of the possible range of IDs for future subtypes.

Subtypes/Specialization (11)

- Now relationships defined on subtypes are no problem. Consider again:

```
COMMITTEE_MEMBERS(CNAME→COMMITTEES,
                  FAC_ID→INSTRUCTOR)
```

COMMITTEE_MEMBERS	
CNAME	FAC_ID
PhD Admissions	101
PhD Admissions	102

- This constraint ensures that only the subtype is referenced: `CHECK(FAC_ID BETWEEN 100 AND 499)`

Subtypes/Specialization (12)

- This method can be easily adapted for partial or overlapping specialization:
  - ◇ If specialization is partial, one simply has one more TYPE value for elements of the supertype that do not belong to any subtype.

    Actually, partial specialization is never a problem: One can always add an "Other" subclass.

  - ◇ If specialization is overlapping, one uses instead of the TYPE column one boolean column for each subtype (e.g. IS_FACULTY, IS_EXTERNAL).

Subtypes/Specialization (13)

Method 2 (Tables for the Subtypes):

- In this case, one table is created for each subtype. It contains the attributes of the subtype plus all inherited attributes.
- In the example, the result is:

```
FACULTY(NAME, EMAIL, TENURED)
EXTERNAL(NAME, EMAIL, ADDRESS)
```

- Since each entity of the supertype belongs to only one subtype, no data is stored redundantly.

  This method would not work for overlapping specialization.

Subtypes/Specialization (14)

- Example State:

FACULTY		
NAME	EMAIL	TENURED
Brass	sb@...	N
Spring	spring@...	Y

EXTERNAL		
NAME	EMAIL	ADDRESS
Mundie	mundie@...	CMU

- This method does not need null values and the corresponding `CHECK`-constraints like Method 1.

Subtypes/Specialization (15)

- One can define a view for the supertype:

```
CREATE VIEW INSTRUCTOR(NAME, EMAIL) AS
            SELECT NAME, EMAIL FROM FACULTY
            UNION  ALL
            SELECT NAME, EMAIL FROM EXTERNAL
```

  Without the view, queries will often be more complicated than with the first method. In any case, queries refering to the supertype will run a bit slower, although `UNION ALL` is only concatenation.

- Queries refering only to a subtype are slightly simpler and will run slightly faster than with Method 1.

  If there are subtypes that contain only a small fraction of the entities of the supertype, queries to these subtypes will be significantly faster.

Subtypes/Specialization (16)

- This method cannot enforce the uniqueness of keys between subtypes: E.g. a faculty member and an external instructor with the same name can exist.

  The constraint that the values in the `NAME` columns of the tables `FACULTY` and `EXTERNAL` must be disjoint is not one of the standard constraints and cannot be specified (today) in the `CREATE TABLE` statement.

- If one can assign numbers as key values, one can use `CHECK` constraints that enforce that the key value ranges in the two tables are disjoint.

  E.g. `FACULTY` uses only IDs 100 to 499, `EXTERNAL` only 500 to 999.

Subtypes/Specialization (17)

- For Method 2, relationships with a subtype are no problem (since each subtype has its own table):

  COMMITTEE_MEMBERS(CNAME→COMMITTEES, FAC_NAME→FACULTY)

COMMITTEE_MEMBERS	
CNAME	FAC_NAME
PhD Admissions	Spring
PhD Admissions	Brass

- However, the translation of relationships with a supertype is significantly more complicated.

Subtypes/Specialization (18)

- Since there is no table for the supertype, one must split foreign keys that are generated for relationships with the supertype:

  COURSES(<u>CRN</u>, TITLE, FAC_NAME^o→FACULTY,
  EXT_NAME^o→EXTERNAL)

COURSES			
<u>CRN</u>	TITLE	FAC_NAME	EXT_NAME
11111	Database Management	Brass	
22222	DB Analysis&Design	Brass	
33333	Client-Server	Spring	
44444	Document Processing		Mundie

Subtypes/Specialization (19)

- Only one of the two foreign keys can be defined:

  CHECK(FAC_NAME IS NULL OR EXT_NAME IS NULL)

- In addition, one must be defined (because the relationship has mandatory participation):

  CHECK(FAC_NAME IS NOT NULL
  OR EXT_NAME IS NOT NULL)

- Queries become more complicated in this way.

  It would be possible to hide these complications with another view defined for COURSES that merges the two columns (using UNION ALL). But in any case, query evaluation will be slower (with today's query optimizers). Of course, if the tables are small, this is no problem.

Subtypes/Specialization (20)

- When the foreign key would be part of a primary key (for many-to-many relationships or weak entities), there are two options:
  - ◇ Either one uses the splitting of foreign keys as above and accepts null values in keys: This translation works only for some DBMS.

    DBMS differ in whether they support UNIQUE-constraints for columns that can be null, and in the exact semantics for this. One would need here that only exact copies are excluded. If necessary, one could replace the null value by a single "invalid" faculty member or external instructor.

Subtypes/Specialization (21)

- Translation of many-to-many and weak entity relationsships, continued:
  - ◇ Or one splits the entire table: E.g. suppose that instructors can suggest students for awards (i.e. there is a many-to-many relationship between instructors and students).

    AWARD1(<u>NAME</u>→FACULTY, <u>SSN</u>→STUDENTS)
    AWARD2(<u>NAME</u>→EXTERNAL, <u>SSN</u>→STUDENTS)

- Because of these problems, one would probably use one of the other methods for translating specialization in this case.

Subtypes/Specialization (22)

- Method 2 can work also with partial specialization.

  The trick is to add another subclass and works with any method.

- E.g. if there are instructors that are neither faculty members nor external (e.g. PhD students), one would simply add another table for them:

  ```
  FACULTY(NAME, EMAIL, TENURED)
  EXTERNAL(NAME, EMAIL, ADDRESS)
  OTHER_INSTRUCTORS(NAME, EMAIL)
  ```

- The OTHER_INSTRUCTORS table contains only those entities that are direct instances of the supertype, it does not contain the subtype entities.

Subtypes/Specialization (23)

Method 3 (Tables for Supertype and Subtypes):

- Method 3 creates
  - ◇ a table for the supertype that contains all entities, including those of subtypes, but has only columns for the supertype attributes, and
  - ◇ one table for each subtype which contains columns for the attributes that are specific to the subtype, plus the key of the supertype.

Subtypes/Specialization (24)

- In the example, the result is:

  ```
  INSTRUCTORS(NAME, EMAIL)
  FACULTY(NAME→INSTRUCTORS, TENURED)
  EXTERNAL(NAME→INSTRUCTORS, ADDRESS)
  ```

- One must use a join to get all attributes of an entity together (the same entity is now represented in two different tables):

```
CREATE VIEW FACULTY2(NAME, EMAIL, TENURED) AS
            SELECT I.NAME, I.EMAIL, F.TENURED
            FROM   INSTRUCTORS I, FACULTY F
            WHERE  I.NAME = F.NAME
```


Subtypes/Specialization (25)

- Example State:

INSTRUCTORS

NAME	EMAIL
Brass	sb@...
Spring	spring@...
Mundie	mundie@...

FACULTY

NAME	TENURED
Brass	N
Spring	Y

EXTERNAL

NAME	ADDRESS
Mundie	CMU

Subtypes/Specialization (26)

- For Method 3, relationships defined on the supertype and relationships defined on the subtypes are both no problem.
- A problem of this method is that it really supports only partial, overlapping specialization.

  Nothing prevents that instructors are also entered in one or both of the two subtype tables (needs a general constraint). With key value ranges, at least disjoint specialization can be enforced.
- Also the join can be a performance problem.

  If one uses artificial numbers as keys, the join will be basically always necessary whenever one accesses the subtype.

Subtypes/Specialization (27)

Method 4 (Variant of Method 3 Using an "Arc"):

- Method 4 creates a table for the supertype and one table for each subtype (like Method 3).
- Artificial keys (numbers) are added to the subtype tables.
- Foreign keys are added to the supertype table (one for each subtype).

Subtypes/Specialization (28)

- In the example, the result is:

  INSTRUCTORS($\underline{\texttt{NAME}}$, EMAIL,
  FNO^o→FACULTY, ENO^o→EXTERNAL)
  FACULTY($\underline{\texttt{FNO}}$, TENURED)
  EXTERNAL($\underline{\texttt{ENO}}$, ADDRESS)
- Check constraints are needed to ensure that exactly one of the two columns FNO and ENO are defined (not null) in INSTRUCTORS.

  By adapting this constraint, Method 4 also works with partial or overlapping specialization.
- In this way, the problem of Method 3 is avoided.

Subtypes/Specialization (29)

- Relationships on supertype and subtypes can be represented.

  Although it is a bit strange that relationships defined on the subtypes now have to use the artificial numbers.
- This method does not prevent rows in the subtype tables without entry in the supertype table.

  Such rows are meaningless: One does not even have the name of the instructor. One possibility would be to treat such rows as "not really present". Practically all queries have to join the subtype tables with the supertype table, and then the problematic rows are filtered out. From time to time, one can simply remove such rows. The drawback of this solution is that one does not get an error message if one enters such a row. But if all queries do the join, bad rows are never used.

Subtypes/Specialization (30)

Comparison:

- Method 1 is probably most often chosen, but:
  - ◇ If one cannot assign key value ranges, and there are relationships with subtypes, it does not work.
  - ◇ The many null values might be a problem.

    Real world designers are used to null values. One should not leave out the `CHECK`-constraints that restrict them.
  - ◇ If small subtypes (few rows) of a large supertype (many rows) are accessed often, Method 1 might have a performance problem.

    Powerful DBMS offer partition features that solve this problem.

Subtypes/Specialization (31)

- Method 2 is good when one accesses the subtypes often, but:
  - ◇ Relationships with the supertype are a problem, especially if these are many-to-many relationships or weak entity relationships.
  - ◇ Uniqueness of keys cannot be enforced between subtypes unless one can assign key value ranges.
  - ◇ Some people don't like `UNION` in their queries.

    It is a bit uncommon, but one can hide it in views. `UNION ALL` should really run fast. Modern optimizers should be able to work with it, old might produce not very efficient query execution plans.

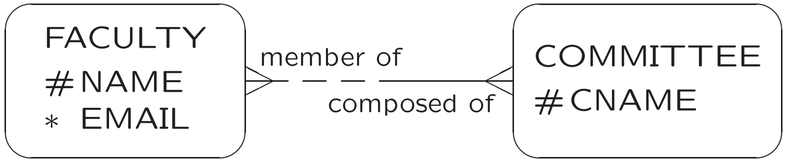
Subtypes/Specialization (32)

- Method 3 can easily represent relationships on supertypes and subtypes, but:
  - ◇ This method works only for partial specialization.
  - ◇ The joins are a performance problem.
- Method 4 is similar, and also has problems:
  - ◇ Integrity violations are possible (partial entity data), but the invalid data is never used.
  - ◇ Joins are needed as in Method 3.
- There is no perfect solution!

Overview

Unnecessary Tables (1)

- Sometimes, tables generated for entity types might seem unnecessary. E.g. consider this example:



- The translation result is:

```
FACULTY(NAME, EMAIL)
COMMITTEES(CNAME)
COMMITTEE_MEMBERS(CNAME→COMMITTEE,
                  FAC_NAME→FACULTY)
```


Unnecessary Tables (2)

- The entire contents of the table COMMITTEES can be derived from the table COMMITTEE_MEMBERS:

```
SELECT DISTINCT CNAME
FROM   COMMITTEE_MEMBERS
```

- This works because of the mandatory participation of COMMITTEE in the relationship.

  Therefore, all committee names must be present in COMMITTEE_MEMBERS.

- It is also important in this example that the entity type COMMITTEE has only the key attributes, and no additional information.

Unnecessary Tables (3)

- Formally, the table COMMITTEES is indeed redundant and one must discuss to delete it.
- However, deleting the table changes the behaviour of updates:
  - ◇ With the table, COMMITTEE entities are explicitly created by inserting a row into COMMITTEES.
  - ◇ Without the table, COMMITTEE entities are only implicitly created by inserting a member of a new committee.

Unnecessary Tables (4)

- Therefore, when inserting a committee member, a typing error in the committee name would be detected with the table, but maybe not without it.
- However, this also depends on the application program: Even without the table, one could distinguish
  - ◇ Create a new committee and add its first member (e.g. the chairman).
  - ◇ Add a member to a committee (with all currently existing committees shown in a selection box).

Unnecessary Tables (5)

- With the `COMMITTEES` table, one has the problem how to enforce the mandatory participation (see above).
- The entire problem would vanish if it turns out that
  - ◇ there can be committees without members (at least temporarily or in exceptional situations), or
  - ◇ some other information has to be stored about committees.

    It would be even interesting if such changes in the requirements can be expected for future extensions.
- Again, there is no unique, perfect solution.

Final Step: Check (1)

- At the end, one should check the generated tables to see whether they really make sense.
- E.g. one should fill them with a few example rows.

  This is also a useful part of the documentation.
- A correct translation of a correct ER-schema results in a correct relational schema.
- However, a by-hand translation can result in mistakes, and the ER-schema can contain hidden flaws.

Final Step: Check (2)

- Think a last time about renaming tables/columns.

  Later changes will be difficult: The table/column names are already used in the application programs, and the DBMS might not permit to rename tables or columns (without deleting and recreating them).
- Check for normal forms (see Chapter 7).

  This is not an automatic step: It requires that the designer thinks about possible functional dependencies.
- If there are tables with the same key, one might consider to merge them.

  But this is not always the right thing to do: E.g. Methods 2–4 for translating specialization generate such tables, merging them would move back to Method 1.