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Preamble

How to Use This Guide

These lecture notes are written in an elusive style: they are a support for the explanations that will be made at the board. They are not designed to be self-contained: they are rather a list of topics and reminders, along with handy examples, code and drawings. Reading them before coming to the lecture will help you getting a sense of the next topic we will be discussing, but you may sometimes have trouble deciphering their ... unique style.

When it comes to code, you can normally copy-and-paste it from the document and use it as it is. Or, you can browse the source code of the code snippets at https://rocketgit.com/user/caubert/CSCI_3410/source/tree/branch/master/tree/notes/code to download it directly. Some portion of code starts with a path in comment, like so:

```
/* code/sql/HW_HelloWorld.sql */
```

This means that this code can be found at https://rocketgit.com/user/caubert/CSCI_3410/source/tree/branch/master/blob/notes/code/sql/HW_HelloWorld.sql.

The SQL code frequently starts with

```
DROP SCHEMA IF EXISTS HW_NAME_OF_SCHEMA;
CREATE SCHEMA HW_NAME_OF_SCHEMA;
USE HW_NAME_OF_SCHEMA;
```

This parts starts by deleting the schema HW_NAME_OF_SCHEMA if it exists, then create and use it: it allows the code to run independently of your installation. It needs to be used with care, though, since it would delete everything you have in the HW_NAME_OF_SCHEMA schema before re-creating it, but empty.

Finally, the comments `-- start snippet something` and `-- end snippet something` can be ignored, as their are an artifice from pandoc-include-code to select which portion of the code to display.

To clone this source of those notes and have a local copy of it, please refer to the instructions at http://spots.augusta.edu/caubert/db/ln/README.html. Instructions on how to compile those notes and how to contribute are linked from this document.

On top of the notes, you will find in this document:

- References, at the very end of this document
- and for each chapter,
  - A list of additional resources,
List of Problems

- A list of short exercises,
- Solution to those exercises,
- A list of problem,
- Sometimes, solution to some of those problems.

Any feedback is greatly appreciated. Please refer to http://spots.augusta.edu/caubert/db/ln/RE ADME.html#contributing for how to contribute to those notes.

The syllabus is at http://spots.augusta.edu/caubert/db/, and the webpage for this notes is at http://spots.augusta.edu/caubert/db/ln/. Please, refer to those notes using this entry (Aubert 2019):

@report{AubertCSCI3410-DatabaseSystems,
    author={Aubert, Clément},
    title={CSCI 3410 - Database Systems},
    url={http://spots.augusta.edu/caubert/db/ln/},
    urldate={2019-11-03},
    year={2019},
    institution={School of Computer and Cyber Sciences, Augusta University},
    location={Augusta, Georgia, USA},
    langid={en},
    type={Lecture notes}
}

Planned Schedule

A typical (meeting twice a week, ±17 weeks, ±30 classes) semester is divided as follows:

- Lecture 1: Presentation and Syllabus\(^3\)
- Lecture 2: Introduction
- Lecture 3–5: The Relational Model
- Lecture 6–9: The SQL Programming Language
- Lecture 10–11: Review session and Exam #1
- Lecture 12: Introduction to High-Level Design
- Lecture 13–15: Entity-Relationship Model
- Lecture 16: ER-to-Relational Models Mapping
- Lecture 17–20: Guidelines and Normal Form
- Lecture 23–24: Review session and Exam #2
- Lecture 25–18: Database Applications
- Lecture 29–30: Presentation of NoSQL

For information purposes, an indication like this:

marks the (usual) separation between two lectures.

\(^3\)http://spots.augusta.edu/caubert/db/
Exams Yearbooks

To give you a sense of what you will be asked during the exams, or simply to practise, please find below the exams given previous semesters, in reverse chronological order. The quizzes are not indicated, but were generally a mix of up to five exercises and one problem from the relevant chapter(s).

Spring 2020

Due to the Covid-19 pandemic, only one exam took place, and the final exam was taken remotely on D2L. A second project, more ambitious, was also asked from the students, and accounted for a large portion of their grade.

- Project #1: Problem 3.16 (A simple database for authors of textbooks)
- Exam #1:
  - Problem 3.17 (A database for residencies)
  - Problem 2.5 (Relational model for an auction website)
- Final:
  - Problem 3.10 (Write select queries for the SocialMedia schema), where the last query was treated as a bonus, due to its difficulty.
  - Problem 7.1 (Explaining NoSQL)
  - Problem 4.22 (Normal form of the DELIVERY relation)
  - Problem 4.5 (Incorrect ER diagram)

Fall 2019

- Exam #1:
  - Problem 3.15 (A simple database for published pieces of work)
  - Three exercises (Exercise 3.14, Exercise 3.32 but for the OR operator, and Exercise 3.30)
  - Problem 2.4 (Relational model for universities)
- Exam #2:
  - Problem 4.30 (From Business Statement to ER Diagram to Relational Model – A Network of Libraries)
  - Problem 4.18 (From business statement to dependencies, ROUTE)
  - Problem 5.2 (A GUEST Java Program)
  - Problem 4.25 (PRINT relation in third normal form)
- Final:
  - Problem 7.3 (ER Diagram from XML File – Award)
  - Problem 4.14 (Normal form of a simple relation)
  - Problem 4.19 (From business statement to dependencies, ISP)
  - Problem 3.14 (A database for website certificates)
  - Three small exercises about security (Exercise 6.1, Exercise 6.2, Exercise 6.3)
List of Problems

Spring 2019

• Exam #1:
  – Problem 3.13 (A simple database for books)
  – Five exercises (Exercise 1.5, Exercise 2.12, Exercise 3.32, Exercise 2.14, Exercise 3.39)
  – A variation on Problem 2.3 (Design a relational model for bills)

• Exam #2:
  – Problem 4.4 (ER diagram for job and offers)
  – Problem 4.10 (From ER diagram to Relational model – RECORD)
  – Problem 4.15 (Normal form of a SCHEDULE relation)
  – Problem 4.24 (Normal form of the MESSAGE relation)

• Final:
  – A variation on Problem 7.1 (Explaining NoSQL)
  – Problem 4.21 (Normal form of the BOOK relation)
  – Problem 4.28 (A Relation for Network Cards)
  – Problem 3.11 (Write select queries for a variation of the COMPUTER table)
  – A variation on Problem 4.30 (From Business Statement to ER Diagram to Relational Model – A Network of Libraries)
  – Five exercises from the Database Application chapter.

Spring 2018

• Exam #1:
  – Problem 2.2 (Design a relational model for a cinema company), except that I gave some of the relations and attributes, to help getting started with the problem.
  – Problem 4.1 (Design for your professor)
  – Problem 3.6 (TRAIN table and more advanced SQL coding)
  – Problem 3.7 (Read, correct, and write SQL statements for the COFFEE database)

• Exam #2:
  – A variation on Problem 4.23 (Normal form of the CONTACT relation)
  – A variation on Problem 4.26 (CONSULTATION relation: justification, primary key and normal form)
  – Problem 3.12 (Improving a role-playing game with a relational model)
  – A variation on Problem 4.32 (From business statements to dependencies – KEYBOARD)
  – Problem 4.11 (ER-to-Relation mapping for Country)

• Final:
  – Take the relational model of the solution of Problem 2.2 (Design a relational model for a cinema company), and "reverse-engineer" it to obtain a ER diagram (this problem was probably too hard).
  – Six small exercises (Exercise 4.32, Exercise 7.1, Exercise 7.2, Exercise 7.3, Exercise 7.4)
  – Problem 4.16 (Normalizing the FLIGHT relation)
  – A variation on Problem 4.12 (From business statements to ER diagram – UNIVERSITY)
  – A variation on Problem 4.33 (From UML to relational model – DRIVER): students were asked to draw the ER diagram for that schema.
List of Problems

Fall 2017

- Exam #1:
  - Six small exercises (Exercise 1.11, Exercise 2.4, Exercise 2.8, Exercise 3.6, Exercise 3.8 and Exercise 3.12)
  - Problem 2.1 (Find a candidate key for the CLASS relation)
  - Problem 2.2 (Design a relational model for a cinema company)
  - A variation on (Elmasri and Navathe 2010, Exercise 3.11), (Elmasri and Navathe 2015, Exercise 5.11)
  - Problem 3.6 (TRAIN table and more advanced SQL coding)

- Exam #2:
  - Problem 4.12 (From business statements to ER diagram – UNIVERSITY)
  - Problem 4.17 (From business statement to dependencies, BIKE)
  - Problem 4.23 (Normal form of the CONTACT relation)
  - A variation on Problem 4.11 (ER-to-Relation mapping for Country)

- Final:
  - A variation on (Exercise 5.16)
  - A variation on Problem 3.7 (Read, correct, and write SQL statements for the COFFEE database)
  - A variation on Problem 4.33 (From UML to relational model – DRIVER): students were asked to draw the ER diagram for that schema.
  - Problem 4.21 (Normal form of the BOOK relation)
  - Problem 4.26 (CONSULTATION relation: justification, primary key and normal form)

Typesetting and Acknowledgments

The source code for those notes is hosted at rocketgit5, typeset in markdown6, and then compiled using pandoc7 and multiple filters (pandoc-numbering8, pandoc-citeproc9, pandoc-include-code10). The drawings use various LaTeX11 packages, including PGF, TikZ12, tikz-er213, pgf-umlcd14 and tikz-dependency15. The help from the TeX - LaTeX Stack Exchange16 community greatly improved this document. The underline17 text is obtained using YayText18.

---

4This exam was probably a bit too long, but students managed it pretty well.
5https://rocketgit.com/user/caubert/CSCI_3410
6https://commonmark.org/
7https://pandoc.org/
8https://github.com/chdenv/mathpandoc
9https://github.com/jgm/pandoc-citeproc
10https://github.com/owickstrom/pandoc-include-code
11https://www.latex-project.org/
12https://sourceforge.net/projects/pgf/
13https://bitbucket.org/pavel_calado/tikz-er2/raw/da9f97f169647cad6d91df7975400b1605ae67a/tikz-er2.sty
14https://github.com/pgf-tikz/pgf-umlcd/
15https://ctan.org/pkg/tikz-dependency
16https://tex.stackexchange.com/
17For technical reasons, underlined words cannot be searched in the document.
18https://yaytext.com/underline/
unicode symbols are searched in the “Unicode characters and corresponding LaTeX math mode commands”\(^\text{19}\). Finally, the pdf version of the document uses Linux Libertine fonts\(^\text{20}\), the html version uses Futura\(^\text{21}\).

Those lecture notes were created under an Affordable Learning Georgia\(^\text{22}\) Mini-Grant for Ancillary Materials Creation and Revision\(^\text{23}\) (Proposal M71\(^\text{24}\)).

Resources

You can find at the end of this document the list of references, and some particular resources listed at the beginning of each chapter. Let me introduce some of them:

- (Elmasri and Navathe 2010) and (Elmasri and Navathe 2015) are two editions of an excellent and detailed book on Databases. It is commonly used, cover almost every aspect in a fairly accessible way.
- (Watt and Eng 2014) is an open-source, cost-free textbook on Database design that can be of good support.
- (Sadallage and Fowler 2012) and (Sullivan 2015) are two textbooks on the NoSQL approach that are short and good introductions.
- To get started on Java and how it interfaces with databases, I believe (Gaddis 2014) is a good introduction.
- awesome-mysql\(^\text{25}\) is a “curated list of awesome MySQL free and opensource software, libraries and resources” that is definitely worth checking out. Among other resources, note this bank of SQL programming exercises\(^\text{26}\).

Those resources are listed as complements, but it is not require to read them to understand the content of those notes. (Watt and Eng 2014) –being available free of charge– is more descriptive than the current notes, and as such can constitute a great complement. Unfortunately, it lacks some technical aspects, and the database program aspect is not discussed in detail.

\(^{19}\)http://milde.users.sourceforge.net/LUCR/Math/unimathsymbols.html
\(^{20}\)http://libertine-fonts.org/
\(^{21}\)https://en.wikipedia.org/wiki/Futura_(typeface)
\(^{22}\)https://www.affordablelearninggeorgia.org/
\(^{23}\)https://www.affordablelearninggeorgia.org/about/r13_grantees
\(^{24}\)https://www.affordablelearninggeorgia.org/documents/M71_Augusta_Aubert.pdf
\(^{25}\)https://github.com/shlomi-noach/awesome-mysql#readme
\(^{26}\)https://github.com/XD-DENG/SQL-exercise
Copyright

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Some figures and resources are borrowed from other sources, in which case it is indicated clearly.

\textsuperscript{27}https://creativecommons.org/licenses/by/4.0/
1 Introduction

Resources

- (Elmasri and Navathe 2010, ch. 1.1–1.6)
- (Elmasri and Navathe 2015, ch. 1.1–1.6)
- (Watt and Eng 2014, ch. 2–3)

1.1 The Need for a Specialized Tool

There is a good chance that any programming language you can think of is Turing complete\(^1\). Actually, even some of the extremely basic tools you may be using may be Turing complete\(^2\). However, being complete does not mean being good at any task: it just means that any computable problem can be solved, but does not imply anything in terms of efficiency, comfort, or usability.

In theory, pretty much any programming language can be used to

- Store, retrieve and update data,
- Have accessible catalog describing the metadata,
- Support transactions and concurrency,
- Support authorization of access and update of data,
- Enforce constraints.

But to obtain a system that is fast in reading and writing on the disk, convenient to search in the data, and that provides as many “built-in” tools as possible, one should use a specialized tool.

In those lecture notes, we will introduce one of this tool—the SQL programming language—and the theory underneath it—the relational model—. We will also observe that a careful design is a mandatory step before implementing a catalog, and that how good a catalog is can be assessed, and introduce the tools to do so. Finally, we will discuss how an application interacting with a database can be implemented and secured, and the alternatives to SQL offered by the NoSQL approach, as well as the limitations and highlights of both models.

1.2 Database

A database (DB) is a collection of related data. Data (= information, can be anything, really) + management (= logical organization of the data), through Database Management System.

1. Represent a mini-world, a “Universe of Disclosure” (UoD).
2. Logically coherent, with a meaning.

\(^1\)https://en.wikipedia.org/wiki/Turing-completeness
\(^2\)https://www.gwern.net/Turing-complete
3. Populated for a purpose.

A DBMS has multiple components, as follows:

![Diagram of DBMS components]

Note that

- The program can be written in any language, be a web interface, etc. It is sometimes part of the software shipped with the DBMS, but not necessarily (you can, and we will, develop your own program to interact with the DBMS).
- Most DBMS software includes a Command-Line Interface (CLI).
- The catalog (or schema, meta-data) contains the description of how the data is stored, i.e., the datatypes, nature of the attributes, etc.
- Sometimes, catalog and data are closer than pictured (you can have “self-describing meta-data”, that is, they cannot be distinguished).

1.3 Database Management System (DBMS)

A DBMS contains a general purpose software that is used to

1. Define (= datatype, constraints, structures, etc.)
2. Construct / Create the data (= store the data)
3. Manipulate / Maintain (= change the structure, query the data, update it, etc.)
4. Share / Control access (= among users, applications)

---

3The term “meta-data” has numerous definition (“data about the data”): we use it here to refer to the description of the organization of the data, and not e.g. to statistical data about the data.
1.5 Life of a Project

You can think of a tool to

1. Specify a storage unit,
2. Fill it,
3. Allow to change its content, as well as its organization,
4. Allow multiple persons to access all or parts of it at the same time.

1.4 Subtasks

Exactly like a program can have

- clients, that specify the requirements,
- designers, that define the overall architecture of a program,
- programmers, that implement the details of the program,
- testers, that make sure the program is free of bugs, and
- users, that actually use the program,

a DBMS offers multiple (sub)tasks and can be interacted with different persons with different roles.

<table>
<thead>
<tr>
<th>Role</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client</td>
<td>Specify the business statement, the specifications</td>
</tr>
<tr>
<td>DB Administrator</td>
<td>Install, configure, secure and maintain up-to-date the DBMS</td>
</tr>
<tr>
<td>Designer</td>
<td>Lay out the global organization of the data</td>
</tr>
<tr>
<td>Programmer</td>
<td>Implement the database, work on the programs that will interface with it</td>
</tr>
<tr>
<td>User</td>
<td>Provide, search, and edit the data (usually)</td>
</tr>
</tbody>
</table>

In those lecture notes, the main focus will be on design and implementation, but we will have to do a little bit of everything, without forgetting which role we are currently playing.

1.5 Life of a Project

From the business statement to the usage, a project generally follows one of this path:
Note that reverse-engineering can sometimes happen, i.e., if you are given a poor implementation and want to extract a relational model from it, to normalize it.

1.6 An Example

Let us consider the following:

<table>
<thead>
<tr>
<th>Name</th>
<th>Student_number</th>
<th>Class</th>
<th>Major</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morgan</td>
<td>18</td>
<td>2</td>
<td>IT</td>
</tr>
<tr>
<td>Bob</td>
<td>17</td>
<td>1</td>
<td>CS</td>
</tr>
</tbody>
</table>
You can describe the structure as a collection of relations, and a collection of columns:

**RELATIONS**

<table>
<thead>
<tr>
<th>Relation Name</th>
<th>Number of Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>STUDENT</td>
<td>4</td>
</tr>
<tr>
<td>COURSE</td>
<td>4</td>
</tr>
<tr>
<td>SECCCTION</td>
<td>5</td>
</tr>
<tr>
<td>GRADE_REPORT</td>
<td>3</td>
</tr>
<tr>
<td>PREREQUISITE</td>
<td>2</td>
</tr>
</tbody>
</table>

**COLUMNS**

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Datatype</th>
<th>Belongs to relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>String</td>
<td>STUDENT</td>
</tr>
<tr>
<td>Student_number</td>
<td>Integer</td>
<td>STUDENT</td>
</tr>
<tr>
<td>Class</td>
<td>String</td>
<td>STUDENT</td>
</tr>
<tr>
<td>Major</td>
<td>String</td>
<td>STUDENT</td>
</tr>
<tr>
<td>Course_name</td>
<td>String</td>
<td>COURSE</td>
</tr>
</tbody>
</table>
### 1.6 An Example

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Datatype</th>
<th>Belongs to relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course_number</td>
<td>Integer</td>
<td>COURSE</td>
</tr>
<tr>
<td>Credit_hours</td>
<td>Integer</td>
<td>COURSE</td>
</tr>
<tr>
<td>Department</td>
<td>String</td>
<td>COURSE</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Prerequisite_number</td>
<td>Integer</td>
<td>PREREQUISITE</td>
</tr>
</tbody>
</table>

#### 1.6.1 Structure

- Database structure and records, 5 files (=collection of records), each containing data records of the same type, stored in a persistent way.
- Each record has a structure, different data elements, each has a data type.
- Records have relationships between them (for instance, you expect the Course_number of PREREQUISITE to occur as a Course_number in COURSE).

#### 1.6.2 Interactions

- This organization will allow some interactions. For instance, we can obtain the answer to questions like
  
  "What is the name of the course whose number is 1301?",
  "What courses is Kate teaching this semester?",
  "Does Bob meets the pre-requisite for 2910?"

  Note that this last query is a bit different, as it forces us to look up information in multiple relations.

- We should also be able to perform updates, removal, addition of records in an efficient way (using auxiliary files (indexes), optimization).

- Finally, selection (for any operation) requires care: do we want all the records, some of them, exactly one?

#### 1.6.3 Organization

Why are the files separated like that? Why do not we store the section with the course with the students? For multiple reasons:

- To avoid redundancy ("data normalization"), or having it controlled,
- To control multiple levels of access (multiple user interface),
- Without sacrificing the usability!

In separating the data, we also need to remember to be careful about consistency and referential integrity, which is a topic we will discuss in detail.
1.7 Characteristics of the Database Approach

1.6.4 How Is a Database Conceived?

1. Specification and analysis. "Each student number will be unique, but they can have the same name. We want to access the letter grade, but not the numerical grade", etc. This gives the business statement.
2. Conceptual design
3. Logical design
4. Physical design

There is a gradation, from really abstract specification that is easy to modify, to more solidified description of what needs to be coded. When we will be discussing high-level models, we will come back to those notions. The global idea is that it is easier to move things around early in the conception, and harder once everything is implemented.

1.7 Characteristics of the Database Approach

1. A database is more than just data: it also contains a complete description of the structure and constraints. We generally have a catalog (a.k.a. the meta-data, the schema) and the data (we can also have self-describing data, where meta-data and data are interleaved, but note that both are still present).
2. Data-abstraction: A DBMS provides a conceptual representation, and hides implementation details. This implies that changing the internals of the database should not require to change the application (the DBMS) or the way any of the client (program, or CLI) was interacting with the data.
3. Support of multiple views of the data: view is a subset of the database, or virtual data.
4. Sharing and multiuser transaction processing: concurrency control using transactions (= series of instructions that is supposed to execute a logically correct database access if executed in its entirety). Isolation, atomicity (all or nothing): cf. the ACID principles.

Exercises

**Exercise 1.1** What is the difference between a database and the meta-data of the database?

**Exercise 1.2** Is a pile of trash a database? Why, or why not?

**Exercise 1.3** Define the word “miniworld”.

**Exercise 1.4** Expand the acronym “DBMS”.

**Exercise 1.5** Name two DBMS.

**Exercise 1.6** Name the four different kinds of action that can be performed on data.

**Exercise 1.7** Assign each of the following task to one of the “character” (administrator, client, etc.) we introduced:

<table>
<thead>
<tr>
<th>Task</th>
<th>Assigned to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Install a DBMS on a server.</td>
<td></td>
</tr>
<tr>
<td>Sketch the schema so that the data will not be redundant.</td>
<td></td>
</tr>
<tr>
<td>Write client-side application that uses the DBMS API.</td>
<td></td>
</tr>
</tbody>
</table>
1.7 Characteristics of the Database Approach

<table>
<thead>
<tr>
<th>Task</th>
<th>Assigned to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establish the purpose of the database.</td>
<td></td>
</tr>
</tbody>
</table>

**Exercise 1.8** List some of the tasks assigned to the Database Administrator.

**Exercise 1.9** Why do DBMS include concurrency control?

**Exercise 1.10** Do I have to change my DBMS if I want to change the structure of my data?

**Exercise 1.11** What is independence between program and data? Why does it matter?

**Exercise 1.12** Assume that I have a file where one record corresponds to one student. Should the information about the classes a student is taking (e.g. room, instructor, code, etc.) being stored in the same file? Why, or why not?

**Exercise 1.13** Which one comes first, the physical design, the conceptual design, or the logical design?

**Exercise 1.14** What is a virtual data? How can I access it?

**Solution to Exercises**

**Solution 1.1** The data is the information we want to store, the meta-data is its organization, how we are going to store it. Meta-data is information about the data, but of no use on its own.

**Solution 1.2** No, because it lacks a logical structure.

**Solution 1.3** The mini-world is the part of the universe we want to represent in the database. It is supposed to be meaningful and will serve a purpose.

**Solution 1.4** Database Management System

**Solution 1.5** Oracle RDBMS, IBM DB2, Microsoft SQL Server, MySQL, PostgreSQL, Microsoft Access, etc., are valid answers. Are not valid “SQL”, “NoSQL”, “Relational Model”, or such: we are asking for the names of actual softwares!

**Solution 1.6** The four actions are:

- Add / Insert
- Update / Modify
- Search / Query
- Delete / Remove

**Solution 1.7** We can have something like:

<table>
<thead>
<tr>
<th>Task</th>
<th>Assigned to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Install a DBMS on a server.</td>
<td>Administrator, IT service</td>
</tr>
<tr>
<td>Sketch the schema so that the data will not be redundant.</td>
<td>Designer</td>
</tr>
<tr>
<td>Write client-side application that uses the DBMS API.</td>
<td>Programmer, Developer</td>
</tr>
<tr>
<td>Establish the purpose of the database.</td>
<td>Client, business owner</td>
</tr>
</tbody>
</table>
Solution 1.8 The database administrator is in charge of installing, configuring, securing and keeping up-to-date the database management system. They also control the accesses and the performance of the system, troubleshoot it, and create backup of the data.

Solution 1.9 DBMS have concurrency control to ensure that several users trying to update the same data will do so in a controlled manner. It is to avoid inconsistency to appear in the data.

Solution 1.10 Normally no, data and programs are independent. But actually, this is true only if the model does not change: shifting to a "less structured model", e.g., one of the NoSQL models, can require to change the DBMS.

Solution 1.11 The application should not be sensible to the "internals" of the definition and organization of the data. It matters because having this independence means that changing the data will not require to change the programs.

Solution 1.12 If we were to store all the information about the classes in the student records, then we would have to store it as many time as its number of students! It is better to store it in a different file, and then to "link" the two files, to avoid redundancy.

Solution 1.13 The conceptual design.

Solution 1.14 It is a set of information that is derived from the database but not directly stored in it. It is accessed through queries. For instance, we can infer the age of a person if their date of birth is in the database, but strictly speaking the age is not an information stored in the database.

Problems

Problem 1.1 (Define a database for CAMPUS) Define a CAMPUS database organized into three files as follows:

- A BUILDING file storing the name and GPS coordinates of each building.
- A ROOM file storing the building, number and floor of each room.
- A PROF file storing the name, phone number, email and room number where the office is located for each professor.

Pb 1.1 – Question 1 A database catalog is made of two part: a table containing the relations’ name and their number of columns, and a table containing the columns’ name, their data type, and the relation to which they belong. Refer to the example we made previously or consult, e.g., (Elmasri and Navathe 2010, Figure 1.3) or (Elmasri and Navathe 2015, Figure 1.3). Write the database catalog corresponding to the CAMPUS database.

Pb 1.1 – Question 2 Invent data for such a database, with two buildings, three rooms and two professors.

Pb 1.1 – Question 3 Answer the following, assuming all the knowledge you have of the situation comes from the CAMPUS database, which is an up-to-date and accurate representation of its miniworld:

1. Is it possible to list all the professors?
2. Is it possible to tell in which department is a professor?
3. Is it possible to get the office hours of a professor?
4. Is it possible to list all the professors whose offices are in the same building?
5. Is it possible to list all the rooms?
6. If a new professor arrives, and has to share his office with another professor, do you have to revise your database catalog?
7. Can you list which professors are at the same floor?
8. Can you tell which professor has the highest evaluations?

Solutions to Selected Problems

Solution to Problem 1.1 (Define a database for CAMPUS) Pb 1.1 – Solution to Q. 1

The database catalog should be similar to the following:

RELATIONS

<table>
<thead>
<tr>
<th>Relation name</th>
<th>Number of columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUILDING</td>
<td>3</td>
</tr>
<tr>
<td>ROOM</td>
<td>3</td>
</tr>
<tr>
<td>PROF</td>
<td>4</td>
</tr>
</tbody>
</table>

COLUMNS

<table>
<thead>
<tr>
<th>Column name</th>
<th>Datatype</th>
<th>Belongs to relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building_Name</td>
<td>Character(30)</td>
<td>Building</td>
</tr>
<tr>
<td>GPSLat</td>
<td>Decimal(9,6)</td>
<td>Building</td>
</tr>
<tr>
<td>GPSLon</td>
<td>Decimal(9,6)</td>
<td>Building</td>
</tr>
<tr>
<td>Building_Name</td>
<td>Character(30)</td>
<td>ROOM</td>
</tr>
<tr>
<td>Room_Number</td>
<td>Integer(1)</td>
<td>ROOM</td>
</tr>
<tr>
<td>Floor</td>
<td>Integer (1)</td>
<td>ROOM</td>
</tr>
<tr>
<td>Prof_Name</td>
<td>Character (30)</td>
<td>PROF</td>
</tr>
<tr>
<td>Phone</td>
<td>Integer (10)</td>
<td>PROF</td>
</tr>
<tr>
<td>Email</td>
<td>Character (30)</td>
<td>PROF</td>
</tr>
<tr>
<td>Room_Number</td>
<td>Integer (1)</td>
<td>PROF</td>
</tr>
</tbody>
</table>

Pb 1.1 – Solution to Q. 2

For the data, you could have:

- For the BUILDING file, we could have:

(Allgood Hall, 33.47520, -82.02503)
(Institut Galilé, 48.959001, 2.339999)

- For the ROOM file, we could have:

(Allgood Hall, 128, 1)
(Institut Galilé, 205, 3)
(Allgood Hall, 228, 2)
• For the PROF file, we could have:

(Aubert, 839401, dae@ipn.net, 128)
(Mazza, 938130, Dm@fai.net, 205)

Pb 1.1 – Solution to Q. 3

If everything we knew about the campus came from that database, then

1. Yes, we could list all the professors.
2. No, we could not tell in which department is a professor.
3. No, we could not get the office hours of a professor.
4. Yes, we could list all the professors whose offices are in the same building.
5. Yes, we could list all the rooms.
6. If a new professor arrives, and has to share his office with another professor, we would not have to revise our database catalog (it is fine for two professors to have the same room number, in our model).
7. Yes, we could list which professors are at the same floor.
8. No, we could not tell which professor has the highest evaluations.
2 The Relational Model

Resources

- (Elmasri and Navathe 2010, ch. 3), (Elmasri and Navathe 2015, ch. 5), including the exercises (look at the exercises 15 and 16, for instance).
- The wikipedia page for Relational model¹ and the category “Relational database management systems”².

2.1 Concepts

The relational data model (or relational database schema) is:

- a mathematical model (use mathematical relations, set-theory, first-order predicate logic)
- with multiple implementations (“engineering approximation”)

2.2 Domains, Attributes, Tuples and Relations

2.2.1 Definitions

- **Domain** (or type) = set of atomic (as far as the relation is concerned) values. You can compare it to datatype and literals, and indeed it can be given in the form of a data type, but it can be named and carry a logical definition (i.e., *List_of_major* as an enumerated

---

¹https://en.wikipedia.org/wiki/Relational_model
data type, instead of just `String`, enforce some constraints (i.e., `UNIQUE`, to force all the values to be different), or even have a default value.

- **Attribute** = Attribute name + attribute domain (but we’ll just write the name).
- **Relation Schema** (or scheme) = description of a relation, often written “RELATION_NAME(Attribute₁, ..., Attributeₙ)”, where n is the degree (arity) of the relation, and the domain of Attributeᵢ is written dom(Attributeᵢ).
- **Tuple** t of the schema R(A₁, ..., Aₙ) is an ordered list of values <v₁, ..., vₙ> where vᵢ is in dom(Aᵢ) or a special `NULL` value.
- **Relation** (or relation state) r of the schema R(A₁, ..., Aₙ), also written r(R), is the set of n-tuples t₁, ..., tₘ where each tᵢ is a tuple of the schema R(A₁, ..., Aₙ).

### 2.2.2 Characteristics of Relations

- In a relation, the order of tuples does not matter (a relation is a set). Order in tuple do matter (alternate representation where this is not true exist, cf. self-describing data).
- Value is atomic = “flat relational model”, we will always be in the first normal form (not composite, not multi-valued).
- `NULL` is N/A, unknown, unavailable (or withheld).
- While a relation schema is to be read like an assertion (e.g., “Every student has a name, a SSN, ...”) a tuple is a fact (e.g., “The student Bob Taylor has SSN 12898, ...”).
- Relations represents uniformly entities (STUDENT(...)) and relations (PREREQUISITE(Course_number, Prerequisite_number)).

### 2.2.3 Notation

- **STUDENT** = relation schema + current relation state
- **STUDENT(Name, ..., Major) =** relation schema only
- **STUDENT.Name =** Attribute Name in the relation STUDENT
- `t[Name]`, `t[Name, Major]`, `t.Name` (overloading the previous notation) for the value of Name (and Major) in the tuple t.

### 2.3 Constraints

We now study constraints on the tuples. There are constraints on the scheme, for instance, “a relation cannot have two attributes with the same name”, but we studied those already. The goal of those constraints is to maintain the validity of the relations, and to enforce particular connexions between relations.

#### 2.3.1 Inherent Model-Based Constraints (implicit)

Those are part of the definition of the relational model and are independent of the particular relation we are looking at.

- You can not have two identical tuples in the same relation,
- The arity of the tuple must match the arity of the relation.
2.3.2 Schema-Based Constraints (explicit)

Those constraints are parts of the schema.

- The value must match its domain ("Domain constraint"), knowing that a domain can have additional constraints (**NOT NULL**, **UNIQUE**).
- The entity integrity constraint: no primary key value can be **NULL**.
- The referential integrity constraint: referred values must exist.

Those last two constraints will be studied in the next section.

2.3.3 Application-Based Constraints (semantics)

Constraints that cannot be expressed in the schema, and hence must be enforced by

- the application program,
- or the database itself, using triggers or assertions.

Examples: "the age of an employee must be greater than 16", “this year’s salary increase must be more than last year’s”.

2.4 Keys

Since we can not have two identical tuples in the same relation, there must be a subset of values that distinguish them. We study the corresponding subset of attributes.

- A **superkey** is the subset of attributes for which no two tuples have the same values. Formally, the set of attributes SK is a superkey for the relation R, if for all relation state r of R, all tuples t₁, t₂ in r are such that t₁[SK] ≠ t₂[SK].
- A **key** is a minimal superkey (i.e., removing any attribute from SK would break the uniqueness property).
- A **candidate key** is a key, a **primary key** is the selected candidate key (it is underlined).

Let us consider the following example:

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>Square</td>
<td>10</td>
<td>(5, 3)</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>Rectangle</td>
<td>10</td>
<td>(3, 9)</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>Circle</td>
<td>9</td>
<td>(4, 6)</td>
<td></td>
</tr>
</tbody>
</table>

and the following sets of attributes:

<table>
<thead>
<tr>
<th></th>
<th>{A, B, C, D}</th>
<th>{A}</th>
<th>{B, C}</th>
<th>{D}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superkey</td>
<td>✔</td>
<td>❌</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Key</td>
<td>❌</td>
<td>❌</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

Note that here we “retro-fit” those definitions, in database design, they come first (i.e., you de-
2.5 Foreign Keys

A foreign key (FK) is a set of attributes whose values must match the value in a tuple in another, pre-defined relation. Formally, the set of attributes FK in the relation schema $R_1$ is a foreign key of $R_1$ ("referencing relation") that references $R_2$ ("referenced relation") if:

- FK refers to $R_2$ (i.e., the attributes in FK have the same domain(s) as the primary key PK of $R_2$)
- a value of FK in a tuple $t_1$ of $r_1(R_1)$ either
  - occurs as a value of PK for some tuple $t_2$ of $r_2(R_2)$, i.e., $t_1[FK] = t_2[PK]$
  - is NULL

In the first case, we say that "$t_1$ refers to $t_2$".

If there is a foreign key from $R_1$ to $R_2$, then we say that there is a referential integrity constraint from $R_1$ to $R_2$. We draw it with an arrow from the FK to the PK. Note that it is possible that $R_1 = R_2$. 
2.6 Example

- In CAR, VIN is the primary key, so it must satisfy the entity integrity constraint, and its value can not be NULL. Note also that all the values must be different, as the same value cannot occur twice as the primary key of tuples: we don’t want to enter the same VIN twice, that would mean we are registering a car that was already registered in our database!

- In DRIVER, State and Licence-num are the primary key, so they must together satisfy the integrity constraint: neither of them can be NULL. Furthermore, their pair must be different from all the other values. Stated differently, you can have <GA, 1234>, <GA, 0000> and <NC, 1234> as values for the <State, Licence-num> pair, even if they have one element in common, what is forbidden is to have both element in common (i.e., you cannot have <GA, 1234> twice). If both elements were common, that would mean that we are registering a driver that was already in the database.

- Insurance has a primary key, and three foreign keys. The foreign keys must satisfy the referential integrity constraint: if the value stored in Insured-Car is not NULL (which it could be), then it has to be a value that occurs as the VIN value of some tuple in the CAR relation. For the Insured-Driver-State and Insured-Driver-Licence-Num, the situation is similar: they must either both be NULL, or be values that occurs paired together as the values for State and Licence-Num in a tuple in the CAR relationship. If e.g. Insured-Car was containing the VIN of a car not in the CAR relation, that would mean we are trying to insure a car that is “not known” from the database’s perspective, something we certainly want to avoid.

- In Price, we have a primary key and a foreign key that obey similar requirements as before.

---

3Yes, we do need the state and the licence number to uniquely identify a driver’s licence, since many states use the same licence format4.
2.7 Transactions and Operations

The operations you can perform on your data are of two kinds: retrievals and updates.

- Retrievals leave the relation state as it is and output a result relation. That is, retrieval: relation state $\rightarrow$ result relation
- Updates change the relation state. That is, update: relation state $\rightarrow$ relation state

They are two constraints for updates:

1. The new relation state must be “valid” (i.e., comply with the state constraints).
2. There might be transition constraints (your balance cannot become negative, for instance).

A transaction is a series of retrievals and updates performed by an application program, that leaves the database in a consistent state.

In the following, we give examples of insertion, deletion and update that could be performed, as well as how they could lead a database to become inconsistent. The annotations (1.), (2.) and (3.) refer to the “remedies”, discussed afterward.

2.7.1 Insert

**Insert** <109920, Honda, Accord, 2012> into CAR

How things can go wrong:

- Inserting the values in the wrong order (meta)
- **NULL** for any value of the attributes of the primary key (1.)
- Duplicate value for all the values in the primary key (1.)
- Wrong number of arguments (1.)
- Fail to reference an existing value for a foreign key (1.)

2.7.2 Delete

**Delete** the DRIVER tuple with State = GA and Licence_number = 123

How things can go wrong:

- Deleting tuples inadvertently (meta)
- Deleting tuples that are referenced (1., 2., 3.)

2.7.3 Update (a.k.a. Modify)

**Update** Name of tuple in DRIVER where State = GA and Licence_number = 123 to Georges

How things can go wrong:

- **NULL** for the any value of the attributes of the primary key (1.)
- Duplicate value for the primary key (1.)
- Change value that are referenced (1., 2., 3.)
- Change foreign key to a non-existing value (1.)
2.7 Transactions and Operations

2.7.4 Dealing with Violations

When the operation leads the database to become inconsistent, you can either:

1. Reject (restrict) the operation,
2. Cascade (propagate) the modification,
3. Set default, or set **NULL**, the corresponding value(s).

Exercises

**Exercise 2.1** Connect the dots:

<table>
<thead>
<tr>
<th>Row •</th>
<th>• Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column header •</td>
<td>• Tuple</td>
</tr>
<tr>
<td>Table •</td>
<td>• Relation</td>
</tr>
</tbody>
</table>

**Exercise 2.2** What do we call the number of attributes in a relation?

**Exercise 2.3** At the logical level, does the order of the tuples in a relation matter?

**Exercise 2.4** What is the difference between a database schema and a database state?

**Exercise 2.5** What should we put as a value in an attribute if its value is unknown?

**Exercise 2.6** What, if any, is the difference between a superkey, a key, and a primary key?

**Exercise 2.7** Name the two kinds of integrity that must be respected by the tuples in a relation.

**Exercise 2.8** What is entity integrity? Why is it useful?

**Exercise 2.9** Are we violating an integrity constraint if we try to set the value of an attribute that is part of a primary key to **NULL**? If yes, which one?

**Exercise 2.10** If in a relation \( R_1 \), an attribute \( A_1 \) is a foreign key referencing an attribute \( A_2 \) in a relation \( R_2 \), what does this implies about \( A_2 \)?

**Exercise 2.11** Give three examples of operations.

**Exercise 2.12** What is the difference between an operation and a transaction?

**Exercise 2.13** Consider the following two relations:

- COMPUTER(Owner, RAM, Year, Brand)
- OS(Name, Version, Architecture)

For each, give

1. The arity of the relation,
2. A (preferably plausible) example of tuple to insert.

**Exercise 2.14** Give three different ways to deal with operations whose execution in isolation would result in the violation of one of the constraint.

**Exercise 2.15** Define what is the domain constraint.
Exercise 2.16 Consider the following three relations:

**AUTHOR**

<table>
<thead>
<tr>
<th>Ref</th>
<th>Name</th>
<th>Address</th>
</tr>
</thead>
</table>

**BOOK**

<table>
<thead>
<tr>
<th>ISSN</th>
<th>AuthorRef</th>
<th>Title</th>
</tr>
</thead>
</table>

**GAINED-AWARD**

<table>
<thead>
<tr>
<th>Ref</th>
<th>Name</th>
<th>BookISSN</th>
<th>Year</th>
</tr>
</thead>
</table>

For each relation, answer the following:

1. What is, presumably, the primary key?
2. Are they, presumably, any foreign key?
3. Using the model you defined, could we determine which author won the greatest number of awards a particular year?

Exercise 2.17 Consider the following three relations

**TRAIN**

<table>
<thead>
<tr>
<th>Ref</th>
<th>Model</th>
<th>Year</th>
</tr>
</thead>
</table>

**CONDUCTOR**

<table>
<thead>
<tr>
<th>CompanyID</th>
<th>Name</th>
<th>ExperienceLevel</th>
</tr>
</thead>
</table>

**ASSIGNED-TO**

<table>
<thead>
<tr>
<th>TrainRef</th>
<th>ConductorID</th>
<th>Date</th>
</tr>
</thead>
</table>

1. What are the foreign keys in the ASSIGNED-TO relation? What are they referring?
2. In the ASSIGNED-TO relation, explain why the Date attribute is part of the primary key. What would happen if it was not?
3. Assuming the database is empty, are the following instructions valid? If not, what integrity constraint are they violating?

a) **Insert** <'AM-356', 'Surfliner', 2012> **into** TRAIN
b) **Insert** <NULL, 'Graham Palmer', 'Senior'> **into** CONDUCTOR
c) **Insert** <'XB-124', 'GPalmer', '02/04/2018'> **into** ASSIGNED-TO
d) **Insert** <'BTed', 'Bobby Ted', 'Senior'> and <'BTed', 'Bobby Ted Jr.'>,

**Exercise 2.18** Consider the following relation schema and state:

```
A   B   C   D
2   Blue Austin true
1   Yellow Paris true
1   Purple Pisa false
2   Yellow Augusta true
```

Assuming that this is all the data we will ever have, discuss whenever \{A, B, C, D\}, \{A, B\} and \{B\} are superkeys and/or keys.

**Exercise 2.19** Consider the following relation and possible state. Assuming that this is all the data we will ever have, give two superkeys, and one key, for this relation.

```
A   B   C   D
1   Austin true Shelly
1   Paris true Cheryl
3   Pisa false Sheila
1   Augusta true Ash
1   Pisa true Linda
```

**Exercise 2.20** Consider the following relation and possible state. Assuming that this is all the data we will ever have, give three superkeys for this relation, and, for each of them, indicate if they are a key as well.

```
A   B   C   D
1   A   Austin true
2   B   Paris true
1   C   Pisa false
2   C   Augusta true
1   B   Augusta true
```

**Exercise 2.21** Consider the following two relations:
1. Give two possible tuples for the BUILDING relation, and two possible tuples for the ROOM relation such that the state is consistent.
2. Based on the data you gave previously, write (in pseudo-code) one **INSERT** and one **UPDATE** instruction. Both should violate the integrity of your database.

**Exercise 2.22** Consider the following two relations:

- A **Movie** relation, with attributes “Title” and “Year”. The “Title” attribute should be the primary key.
- A **Character** relation, with attributes “Name”, “First_Appearance”. The “Name” attribute should be the primary key, and the “First_Appearance” attribute should be a foreign key referencing the **Movie** relation.

1. Draw its relational model.
2. Give an example of data that would violate the integrity of your database, and name the kind of integrity you are violating.

**Solution to Exercises**

**Solution 2.1** Row is Tuple, Column header is Attribute, Table is Relation.

**Solution 2.2** The degree, or arity, of the relation.

**Solution 2.3** No, it is a set.

**Solution 2.4** The schema is the organization of the database (the meta-data), while the state is the content of the database (the data).

**Solution 2.5** **NULL**

**Solution 2.6** A superkey is a subset of attributes such that no two tuples have the same combination of values for all those attributes. A key is a minimal superkey, i.e., a superkey from which we cannot remove any attribute without losing the uniqueness constraint. The primary key is one of the candidate key, i.e., the key that was chosen.

**Solution 2.7** Referential integrity and entity integrity.

**Solution 2.8** Entity integrity ensures that each row of a table has a unique and non-null primary key value. It allows to make sure that every tuple is different from the others, and helps to “pick” elements in the database.

**Solution 2.9** Yes, the entity integrity constraint.

**Solution 2.10** Then we know that \( A_2 \) is the primary key of \( R_2 \), and that \( A_1 \) and \( A_2 \) have the same domain.

**Solution 2.11** Reading from the database, performing **UPDATE** or **DELETE** operations.
**Solution 2.12** An operation is an “atomic action” that can be performed on the database (adding an element, updating a value, removing an element, etc.). A transaction is a series of such operations, and the assumption is that, even if it can be made of operations that, taken individually, could violate a constraint, the overall transaction will leave the database in a consistent state.

**Solution 2.13**
1. The arities of the relations are: COMPUTER has for arity 4, and OS has for arity 3.
2. Examples of tuple to insert are ("Linda McFather", 32, 2017, "Purism"), and ("Debian", "Stable", "amd64").

**Solution 2.14** An operation whose execution in isolation would result in the violation of a constraint can either a) be “restricted” (i.e., not executed), b) result in a propagation (i.e., the tuples that would violate a constraint are updated or deleted accordingly), or c) result in some values in tuples that would violate a constraint to be set to a default value, or the NULL value (this last option works only if the constraint violated is the referential entity constraint).

**Solution 2.15** The requirement that each tuple must have for an attribute $A$ an atomic value from the domain $\text{dom}(A)$, or NULL.

**Solution 2.16** To answer 1 and 2, the diagram would become:

```
  AUTHOR
  Ref Name Address

  BOOK
  ISSN AuthorRef Title

  GAINED-AWARD
  Ref Name BookISSN Year
```

For the last question, the answer is yes: based on the ISSN of the book, we can retrieve the author of the book. Hence, knowing which book was awarded which year, by looking in the GAINED-AWARD table, gives us the answer to that question.

**Solution 2.17**
1. In ASSIGNED-TO, TrainRef is a FK to TRAIN.Ref, and ConductorID is a FK to CONDUCTOR.CompanyID.
2. In this model, a conductor can be assigned to different trains on different days. If Date was not part of the PK of ASSIGNED-TO, then a conductor could be assigned to only one train.
3. a) Yes, this instruction is valid.
b) No, it violates the entity integrity constraint: **NULL** can be given as a value to an attribute that is part of the PK.

c) No, it violates the referential integrity constraint: 'XB-124 and 'GPalmer' are not values in TRAIN..Ref and CONDUCTOR..CompanyID.

d) No, it violates the key constraint: two tuples cannot have the same value for the values of the primary key.

**Solution 2.18**
- \{A, B, C, D\} is a superkey (the set of all the attributes is always a superkey), but not a superkey, as removing e.g. D would still make it a superkey.
- \{A, B\} is a superkey and a key, as neither \{A\} nor \{B\} are keys.
- \{A\} is not a key, and not a superkey: multiple tuples have the value 1.

**Solution 2.19** Possible superkeys are \{A, B, C, D\}, \{A, B, C\}, \{A, C, D\}, \{B, C, D\}, \{A, B\}, \{B, C\}, . The possible keys are \{A, B\} \{A, C\}, and \{B, C\}.

**Solution 2.20** For this relation, \{A, B, C, D\}, \{A, B, C\}, and \{D\} are superkey. Only the latter, \{D\}, is a key (for \{A, B, C\}, removing either A or C still gives a superkey).

**Solution 2.21**
2. **INSERT** <"A.H.", **NULL**> would violate the requirement not to have two tuples with the same value for the attributes that constitute the primary key in the BUILDING relation. **UPDATE** ROOM with **CODE** = 12 to Building = "G.C.C." would create an entry referencing a name in the BUILDING relation that does not exist.

**Solution 2.22**
1. The relations would be drawn as follows:

![Diagram](attachment:image.png)

1. Inserting <"Ash", "Evil Dead"> into the CHARACTER relation would cause an error if the database was empty, since no movie with the primary key "Evil Dead" has been introduced yet: this would be a referential integrity constraint violation. To violate the entity integrity constraint, it would suffice to insert the value <**NULL**, 2019> into the MOVIE relation.

**Problems**

**Problem 2.1** *(Find a candidate key for the CLASS relation)* Consider the relation:

CLASS(Course_Number, Univ_Section_Number, Instructor_Name, Semester, Building_Code, Room_Number, Time, Weekdays, Credit_Hours)

- This relation represents classes taught in a university.
- The goal is to be able to have multiple offerings (classes) of courses over several semesters.
List three possible candidate keys and describe under what conditions each candidate key would be valid.

Each candidate key should have between one and three attributes.

Here are some examples of values for the attributes:

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Possible Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course_Number</td>
<td>CSCI3410, CSCI1302</td>
</tr>
<tr>
<td>Building_Code</td>
<td>AH, UH, ECC</td>
</tr>
<tr>
<td>Univ_Section_Number</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>Room_Number</td>
<td>E127, N118</td>
</tr>
<tr>
<td>Instructor_Name</td>
<td>John Smith, Sophie Adams</td>
</tr>
<tr>
<td>Time</td>
<td>1400, 1230, 0900</td>
</tr>
<tr>
<td>Semester</td>
<td>Spring 2015, Fall 2010, Summer 2012</td>
</tr>
<tr>
<td>Weekdays</td>
<td>M, MW, MWF, T, TH</td>
</tr>
<tr>
<td>Credit_Hours</td>
<td>1, 2, 3, 4</td>
</tr>
</tbody>
</table>

Problem 2.2 (Design a relational model for a cinema company) A cinema company wants you to design a relational model for the following set-up:

- The company has movie stars. Each star has a name, birth date, and unique ID.
- The company has the following information about movies: title, year, length, and genre. Each movie has a unique ID and features multiple stars.
- The company owns movie theaters as well. Each theater has a name, address, and a unique ID.
- Furthermore, each theater has a set of auditoriums. Each auditorium has a unique number, and seating capacity.
- Each theater can schedule movies at show-times. Each show-time has a unique ID, a start time, is for a specific movie, and is in a specific theater auditorium.
- The company sells tickets for scheduled show-times. Each ticket has a unique ticket ID and a price.

Problem 2.3 (Design a relational model for bills) Propose a relational model for the following situation:

- The database will be used to store all of the bills that are debated and voted on by the U.S. House of Representatives (HR). Each bill has a name, a unique sponsor who must be a member of the HR, and an optional date of when it was discussed.
- It must record the name, political group, and beginning and expected end-of-term dates for each HR member.
- It will also record the names of the main HR positions: Speaker, Majority Leader, Minority Leader, Majority Whip, and Minority Whip.
- Finally, it will record the vote of every member of the HR for each bill.
Problem 2.4 *(Relational model for universities)* Propose a relational model for the following situation:

- You want to store information about multiple universities. A university has multiple departments, a name and a website.
- Each department offers multiple courses. A course has a name, one (or multiple, when it is cross-listed) code, a number of credit hours.
- A campus has a name, an address, and belong to one university.
- A department has a contact address, a date of creation and a unique code.

Problem 2.5 *(Relational model for an auction website)* We want to design a relational model for an auction website. Members (that can be buyers, sellers, both or neither) can participate in the sale of items.

- Members are identified by a unique identifier and have an email address and a nickname.
- Buyers have a unique identifier, a preferred method of payment and a shipping address.
- Sellers have a unique identifier, a rating and a bank account number.
- Items are offered by a seller for sale and are identified by a unique item number. Items also have a name and a starting bid price.
- Members make bids for items that are for sale. Each bid has a unique identifier, a bidding price and a timestamp.

When creating your schema, do not add any new information, and try as much as possible to avoid relations that will create redundant data and *NULL* entries. Note that we should be able to uniquely determine the member account linked to the seller account, and similarly for buyers accounts. Furthermore, members can have at most one buyer and one seller account.

**Solutions to Selected Problems**

**Solution to Problem 2.2 (Design a relational model for a cinema company)** A possible solution is:
Solution to Problem 2.3 (Design a relational model for bills)  Be careful: saying that a bill has a unique sponsor does not imply that a the sponsor is a good primary key for the bills: a house member could very well be the sponsor of multiple bills! It just implies that a single attribute is enough to hold the name of the sponsor.

For simplicity, we added an ID to our MEMBER and BILL relations. Note that having a "role" in the MEMBER relation to store the information about speaker, etc., would be extremely inefficient, since we would add an attribute to the ~435 members that would be NULL in ~430 of them.
Solution to Problem 2.4 (Relational model for universities) A possible solution follows. The part that is the hardest to accommodate is the fact that a course can have multiple codes. We are reading here “cross-listed” as “a course that is offered under more than one departmental heading and can receive different codes (e.g., CSCI XXXX and AIST YYY)”.

![Database diagram](image-url)
3 The SQL Programming Language

Resources

- (Elmasri and Navathe 2010, ch. 4–5), (Elmasri and Navathe 2015, ch. 6–7) describes SQL, but none of its implementation.

This chapter will be “code-driven”: the code will illustrate and help you understand some concepts. You may want to have a look at the “Setting Up Your Work Environment” Section, as early as possible in this lecture. On top of being a step-by-step guide to install and configure a relational database management system, it contains a list of useful links.

3.1 Actors

3.1.1 Technologies

- There are other models than relational: document-based, graph, column-based, and key-value models. Those corresponds to the “NoSQL” data-model, that are often more flexible, but only defined by opposition. They will be studied separately, in the Presentation of NoSQL Chapter.
- The most commons DBMS are relational database management system (RDBMS):
  - Oracle Database¹
  - MySQL² and its fork, MariaDB³
  - Microsoft SQL Server⁴
  - PostgreSQL⁵
  - IBM DB2⁶
  - Microsoft Access⁷
  - SQLite⁸

²https://www.mysql.com/
³https://mariadb.org/
⁵https://www.postgresql.org/
⁶https://www.ibm.com/analytics/db2
⁷https://products.office.com/en-us/access
⁸https://www.sqlite.org/index.html
Most of them supports semi-structured data, i.e., models that are not strictly speaking relational, some are “multi-model DBMS”.

- The Structured Query Language (SQL) is the language for RDBMS, it is made of 4 sublanguages:
  - Data Query Language,
  - Data Definition Language (schema creation and modification),
  - Data Control Language (authorizations, users),
  - Data Manipulation Language (insert, update and delete).

The three last sublanguages being dubbed “Data Manipulation Language”.

3.1.2 SQL

3.1.2.1 Yet Another Vocabulary

<table>
<thead>
<tr>
<th>“Common” / Relational</th>
<th>SQL</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Set of databases”</td>
<td>Catalog (named collection of schema)⁹</td>
</tr>
<tr>
<td>“Database”</td>
<td>Schema</td>
</tr>
<tr>
<td>Relation</td>
<td>Table</td>
</tr>
<tr>
<td>Tuple</td>
<td>Row</td>
</tr>
<tr>
<td>Attribute</td>
<td>Column, or Field</td>
</tr>
</tbody>
</table>

3.1.2.2 Schema Elements

A schema is made of

- Tables (≈ relation)
- Type (≈ datatype)
- Domain (≈ more complex datatype)
- View (result set of a stored query on the data, ≈ saved search)
- Assertion (constraints, transition constraints)
- Triggers (tool to automate certain actions after pre-defined operations are performed)
- Stored procedures (≈ functions)

Type and domains are two different things in some implementations, cf. for instance PostgreSQL, where a domain is defined to be essentially a datatype with constraint.¹⁰

3.1.2.3 Syntax

SQL is a programming language: it has a strict syntax, sometimes cryptic error messages, it evolves, etc. Some of its salient aspects are:

⁹For a clarification on the distinction between catalog and schemas, you can refer to e.g. https://stackoverflow.com/q/7022755.

• SQL is “kind of” case-insensitive\textsuperscript{11}, does not care about spaces and new lines
• In-line comments are what is after --, multi-line comments uses /* ... */.
• Every statement ends with a ;.
• The exact syntax is left as an exercise in Pb 3.1.
• The list of reserved words can be found at https://dev.mysql.com/doc/refman/8.0/en/keywords.html or https://mariadb.com/kb/en/reserved-words/
• We will focus in this chapter to MariaDB and MySQL (no domain, limited data type definition).

3.1.2.4 Datatypes

The following is an adaptation of w3resource.com\textsuperscript{12}, the canonical source being MySQL’s documentation\textsuperscript{13}:

• For integer types, you can use INTEGER (or its short-hand notation INT) or SMALLINT.
• For floating-point types, you can use FLOAT and DOUBLE (or its synonym, REAL). MySQL also allows the syntax FLOAT \((M, D)\) or REAL \((M, D)\), where the values can be stored up to \(M\) digits in total where \(D\) represents the decimal point.
• For monetary amounts, it is recommended\textsuperscript{14} to use DECIMAL \((10, 2)\) (or its synonym in MySQL NUMERIC).
• Characters can be stored using CHAR and VARCHAR: the length (resp. maximal length) of the CHAR (resp. VARCHAR) has to be declared, and CHAR are right-padded with spaces to the specified length. Historically, 255\textsuperscript{15} was the size used, because it is the largest number of characters that can be counted with an 8-bit number, but, whenever possible, the “right size”\textsuperscript{16} should be used.
• You can store a single bit using BIT \((1)\), and a boolean using BOOLEAN.
• For date and time types, you can use DATE, TIME, DATETIME and TIMESTAMP.

There are many other datatypes, but they really depends on the particular implementation, so we will not consider them too much.

3.2 First Commands

\begin{verbatim}
/* code/sql/HW_Faculty.sql */
-- We first drop the schema if it already exists:
DROP SCHEMA IF EXISTS HW_Faculty;

-- Then we create the schema:
CREATE SCHEMA HW_Faculty;
\end{verbatim}

\textsuperscript{11}The SQL keywords are case-insensitive, but the table and schema names are sometimes case-sensitive, it depends of the actual implementation. For instance, MySQL is completely case-insensitive (reserved words, tables, attributes), MariaDB is not (the case for table names matter).
\textsuperscript{12}https://www.w3resource.com/mysql/mysql-data-types.php
\textsuperscript{13}https://dev.mysql.com/doc/refman/8.0/en/data-types.html
\textsuperscript{14}https://stackoverflow.com/a/4397416
\textsuperscript{15}https://stackoverflow.com/q/1217466
\textsuperscript{16}https://dba.stackexchange.com/a/183277
/*
Or we could have used the syntax:
*/

CREATE DATABASE HW_FACULTY;

-- Now, let us create a table in it:
CREATE TABLE HW_Faculty.PROF ( 
  Fname VARCHAR(15),
  /*
  No String!
  The value "15" was picked randomly, any value below 255 would
  more or less do the same. Note that declaring extremely large
  values without using them can impact the performance of
  your database, cf. for instance
  https://dba.stackexchange.com/a/162117/
  */
  Room INT,
  /*
  shorthand for INTEGER, are also available: SMALLINT, FLOAT,
  REAL, DEC
  The "REAL" datatype is like the "DOUBLE" datatype of C# (they
  are actually synonyms in SQL):
  more precise than the "FLOAT" datatype, but not as exact as
  the "NUMERIC" datatype.
  cf.
  */
  Title CHAR(3),
  -- fixed-length string, padded with blanks if needed
  Tenured BIT(1),
  Nice BOOLEAN,
  -- True / False (= 0) / Unknown
  Hiring DATE,
  /*
  The DATE is always supposed to be entered in a YEAR/MONTH/DAY
  variation.
  To tune the way it will be displayed, you can use the
  "DATE_FORMAT" function
  functions.html#function_date-format),
  but you can enter those values only using the "standard"
  literals
  literals.html
  )
  */
  Last_seen TIME, FavoriteFruit ENUM ('apple', 'orange',
  'pear'), PRIMARY KEY (Fname, Hiring)
);
3.3 Useful Commands

The following commands are particularly useful. They allow you to get a sense of the current state of your databases.

3.3.1 For Schemas

In the following, <SchemaName> should be substituted with an actual schema name.

SHOW SCHEMAS; -- List the schemas.
SHOW TABLES; -- List the tables in a schema.
DROP SCHEMA <SchemaName>; -- "Drop" (erase) SchemaName.

You can also use the variation

DROP SCHEMA IF EXISTS <SchemaName>;

that will not issue an error if <SchemaName> does not exist.

3.3.2 For Tables

In the following, <TableName> should be substituted with an actual table name.

SHOW CREATE TABLE <TableName> -- Gives the command to "re-construct" TableName.
DESCRIBE <TableName>; -- Show the structure of TableName.
DROP TABLE <TableName>; -- "Drop" (erase) TableName.
3.4 Overview of Constraints

You can also use the variation

\textbf{DROP TABLE IF EXISTS} < TableName > ;

that will not issue an error if < TableName > does not exist.

3.3.3 See Also

\textbf{SELECT} * \textbf{FROM} < TableName > \textit{-- List all the rows in TableName.}
\textbf{SHOW WARNINGS; \textit{-- Show the content of the latest warning issued.}}

3.4 Overview of Constraints

There are six different kind of constraints that one can add to an attribute:

1. Primary Key
2. Foreign Key
3. \textbf{NOT NULL}
4. \textbf{UNIQUE}
5. \textbf{DEFAULT}
6. \textbf{CHECK}

We already know the first two from the relational model. The other four are new, and could not be described in this model.

We will review them below, and show how they can be specified at the time the table is declared, or added and removed later. For more in-depth examples, you can refer to https://www.w3resource.com/mysql/creating-table-advance/constraint.php.

3.4.1 Declaring Constraints

We will now see how to declare those constraints when we create the table (except for the foreign key, which we save for later).

```sql
/* code/sql/HW_ConstraintsPart1.sql */
DROP SCHEMA IF EXISTS HW_ConstraintsPart1;

CREATE SCHEMA HW_ConstraintsPart1;

USE HW_ConstraintsPart1;

CREATE TABLE HURRICANE ( 
  NAME VARCHAR(25) \textbf{PRIMARY KEY}, 
  WindSpeed INT \textbf{DEFAULT} 76 
  CHECK (WindSpeed > 74 \textbf{AND} WindSpeed < 500),
  -- 75mph is the minimum to be considered as a hurricane
  -- \textit{cf.} https://www.hwn.org/resources/bws.html 
  Above VARCHAR(25)
)
3.4 Overview of Constraints

```sql
CREATE TABLE STATE (  
    NAME VARCHAR(25) UNIQUE, Postal_abbr CHAR(2) NOT NULL
);  
```

If we wanted to combine multiple constraints, we would have to follow the order described at https://dev.mysql.com/doc/refman/8.0/en/create-table.html.

MySQL can output a description of those tables for us:

MariaDB [HW_ConstraintsPart1] > DESCRIBE HURRICANE;
+----------------+----------+-------+--------+----------------+-------+
| Field          | Type     | Null  | Key    | Default        | Extra |
+----------------+----------+-------+--------+----------------+-------+
| Name           | varchar  | NO    | PRI    | NULL           |       |
| WindSpeed      | int(11)  | YES   |  | 76            |       |
| Above          | varchar  | YES   |  | NULL          |       |
+----------------+----------+-------+--------+----------------+-------+
3 rows in set (0.01 sec)

MariaDB [HW_ConstraintsPart1] > DESCRIBE STATE;
+----------------+----------+-------+--------+----------------+-------+
| Field          | Type     | Null  | Key    | Default        | Extra |
+----------------+----------+-------+--------+----------------+-------+
| Name           | varchar  | NO    | PRI    | NULL           |       |
| Postal_abbr    | char(2)  | NO    | UNI    | NULL           |       |
+----------------+----------+-------+--------+----------------+-------+
2 rows in set (0.00 sec)

Note that more than one attribute can be the primary key, in which case the syntax needs to be something like the following:

```sql
/* code/sql/HW_PKtest.sql */
DROP SCHEMA IF EXISTS HW_PKtest;
CREATE SCHEMA HW_PKtest;
USE HW_PKtest;
CREATE TABLE TEST (  
    A INT, B INT, PRIMARY KEY (A, B)
);
```

For the `UNIQUE` constraint, note that `NULL` can be inserted: the rationale is that all the values need to be different from one another or `NULL`.

A couple of comments about the `CHECK` constraint:
3.4 Overview of Constraints

- Before MariaDB 10.2.1, `WindSpeed INT CHECK (WindSpeed > 74 AND WindSpeed < 500)` would have been parsed but would not have any effect, cf. https://mariadb.com/kb/en/constRAINT/#check-constraints. Since MariaDB 10.2.1, the CHECK constraint are enforced.
- If we try to violate the CHECK constraint, with a command like

```sql
INSERT INTO HURRICANE VALUES ("Test1", 12, NULL);
```

then the insertion would not take place, and the system would issue an error message:

```
ERROR 4025 (23000): CONSTRAINT `HURRICANE.WindSpeed` failed for
`HW_ConstraintsPart1>`.
```

- Note that you could still insert a value of NULL for the wind, and it would not trigger the error.

To use the DEFAULT value, use

```sql
INSERT INTO HURRICANE VALUES ("Test2", DEFAULT, NULL);
```

Note that, by default, the DEFAULT value is NULL, regardless of the datatype:

```sql
/* code/sql/HW_DefaultTest.sql */
DROP SCHEMA IF EXISTS HW_DEFAULT_test;
CREATE SCHEMA HW_DEFAULT_test;
USE HW_DEFAULT_test;
CREATE TABLE TEST (TestA VARCHAR(15), TestB INT, TestC FLOAT, TestD BOOLEAN,
TestE BIT(1), TestF DATE);
INSERT INTO TEST VALUES (DEFAULT, DEFAULT, DEFAULT, DEFAULT, DEFAULT, DEFAULT);
SELECT *
FROM TEST;
```

3.4.2 Editing Constraints

Let us know pretend that we want to edit some attributes, by either adding or removing constraints. SQL’s syntax is a bit inconsistent on this topic, because it treats the constraints as being of different natures.
3.4.2.1 Primary Keys

Adding a primary key:

```
ALTER TABLE STATE ADD PRIMARY KEY (Name);
```

Removing the primary key:

```
ALTER TABLE STATE DROP PRIMARY KEY;
```

3.4.2.2 UNIQUE Constraint

Adding a UNIQUE constraint:

```
ALTER TABLE STATE ADD UNIQUE (Postal_abbr);
```

Removing a UNIQUE constraint:

```
ALTER TABLE STATE DROP INDEX Postal_abbr;
```

Note the difference between adding and removing the UNIQUE constraint: the parenthesis around (Postal_abbr) are mandatory when adding the constraint, but would cause an error when removing it!

3.4.2.3 NOT NULL Constraint

Adding the NOT NULL constraint:

```
ALTER TABLE STATE MODIFY Postal_abbr CHAR(2) NOT NULL;
```

Removing the NOT NULL constraint:

```
ALTER TABLE STATE MODIFY Postal_abbr CHAR(2);
```

The syntax of NOT NULL comes from the fact that this constraint is taken to be part of the datatype.

3.4.2.4 Default value

Changing the default value:

```
ALTER TABLE HURRICANE ALTER COLUMN WindSpeed SET DEFAULT 74;
```

Removing the default value:

```
ALTER TABLE HURRICANE ALTER COLUMN WindSpeed DROP DEFAULT;
```
3.4.2.5 Foreign key

Adding a foreign key constraint:

```sql
ALTER TABLE HURRICANE ADD FOREIGN KEY (Above) REFERENCES STATE(Name);
```

Removing a foreign key constraint is out of the scope of this lecture. If you are curious, you can have a look at https://www.w3schools.com/sql/sql_foreignkey.asp: dropping a foreign key constraint requires your constraint to have a name, something we did not introduce.

Two important remarks:

- The datatype of the foreign key has to be the exactly the same as the datatype of the attribute that we are referring.
- The target of the foreign key must be the primary key.

Refer to Problem 3.4 (Constraints on foreign keys) for a slightly more accurate picture of the constraints related to the creation of foreign keys. Note that a foreign key could be declared at the time of creation of the table as well, using the syntax we will introduce below.

3.4.3 Testing the Constraints

Let us test our constraints:

```sql
INSERT INTO STATE VALUES('Georgia', 'GA');
INSERT INTO STATE VALUES('Texas', 'TX');
INSERT INTO STATE VALUES('FLORIDA', 'FL');
UPDATE STATE SET Name = 'Florida'
    WHERE Postal_abbr = 'FL';

-- There's an error with the following request. Why?
INSERT INTO HURRICANE VALUES('Irma', 150, 'FL');

/*
ERROR 1452 (23000): Cannot add or update a child row: a foreign
key constraint fails (`HW_ConstraintsPart1`.`HURRICANE`,
CONSTRAINT `HURRICANE_ibfk_1` FOREIGN KEY (`Above`)
REFERENCES `STATE` (`Name`))
*/

INSERT INTO HURRICANE VALUES('Harvey', DEFAULT, 'Texas');
INSERT INTO HURRICANE VALUES('Irma', 150, 'Florida');
DELETE FROM HURRICANE
    WHERE Name = 'Irma';
INSERT INTO HURRICANE VALUES('Irma', 150, 'Georgia');

UPDATE HURRICANE SET Above = 'Georgia'
    WHERE Name = 'Irma';

/*
MariaDB [HW_ConstraintsPart1]> SELECT * FROM HURRICANE;
+--------+-----------+---------+
<table>
<thead>
<tr>
<th>Name</th>
<th>WindSpeed</th>
<th>Above</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvey</td>
<td>74</td>
<td>Texas</td>
</tr>
<tr>
<td>Irma</td>
<td>150</td>
<td>Georgia</td>
</tr>
</tbody>
</table>
+--------+-----------+---------+
*/

-- There’s an error with the following request. Why?
UPDATE HURRICANE SET Above = 'North Carolina'
   WHERE Name = 'Irma';

-- Let’s patch it, by adding North Carolina to our STATE table.
INSERT INTO STATE VALUES('North Carolina', 'NC');
UPDATE HURRICANE SET Above = 'North Carolina'
   WHERE Name = 'Irma';

3.5 Foreign Keys

Let us come back more specifically to foreign key.

3.5.1 A First Example

In the example below, we introduce the foreign key update and delete rules. We also introduce, passing by, the enumerated data type, and how to edit it.

CREATE TABLE STORM
   (NAME VARCHAR(25) PRIMARY KEY, Kind ENUM ('Tropical Storm', 'Hurricane'), WindSpeed INT,
    Creation DATE);

-- We can change the enumerated datatype:
ALTER TABLE STORM MODIFY Kind ENUM ('Tropical Storm', 'Hurricane', 'Typhoon');

CREATE TABLE STATE
   (NAME VARCHAR(25) UNIQUE, Postal_abbr CHAR(2) PRIMARY KEY,
    Affected_by VARCHAR(25), FOREIGN KEY (Affected_by)
    REFERENCES STORM (NAME) ON DELETE SET NULL ON UPDATE CASCADE);

Note that we can “inline” the foreign key constraint like we “inlined” the primary key constraint (cf. https://stackoverflow.com/q/24313143/), but that it will not be enforced!

Let us now illustrate this table by introducing some data in it:
3.5 Foreign Keys

```sql
INSERT INTO STORM
VALUES ('Harvey', 'Hurricane', 130, '2017-08-17');

-- In the following, the entry gets created, but date is
-- "corrected" to '2017-08-08'!
-- INSERT INTO STORM
-- VALUES ('Dummy', 'Hurricane', 120, '2017-07-08');
-- The error message returned is
-- 1292 (22007) at line 34: Incorrect date value:
-- '2017-07-08' for column `HW_STORM`.`STORM`.`Creation` at
-- row 1
-- In the following, we explicitely use 'DATE', and since
-- the date is incorrect, nothing gets inserted.
-- INSERT INTO STORM
-- VALUES ('Dummy2', 'Hurricane', 120, DATE
-- '2017-08-08');
-- ERROR 1525 (HY000) at line 40: Incorrect DATE value:
-- '2017-08-08'
-- The next one sets NULL for DATE.
INSERT INTO STORM
VALUES ('Irma', 'Tropical Storm', 102, DEFAULT);

MySQL will always notify you if there is an error in a date attribute when you use the DATE
prefix.

INSERT INTO STATE
VALUES ('Georgia', 'GA', NULL);

INSERT INTO STATE
VALUES ('Texas', 'TX', NULL);

INSERT INTO STATE
VALUES ('Florida', 'FL', NULL);

-- This instruction is not using the primary key, is that a
-- problem?
UPDATE
STATE
SET Affected_by = 'Harvey'
WHERE Name = 'Georgia';

UPDATE
STORM
SET Name = 'Harley'
WHERE Name = 'Harvey';

DELETE FROM STORM
WHERE Name = 'Harley';
```
We will see in the “Reverse-Engineering” section why this schema is poorly designed, but for now, let’s focus on the foreign keys and their restrictions.

### 3.5.2 Foreign Keys Restrictions

The following is a code-driven explanation of the foreign key update and delete rules (or “restrictions”). It is intended to make you understand the default behavior of foreign keys, and to understand how the system reacts to the possible restrictions.

```
CREATE TABLE F_Key(
    Attribute VARCHAR(25) PRIMARY KEY
);

CREATE TABLE Table_default(
    Attribute1 VARCHAR(25) PRIMARY KEY,
    Attribute2 VARCHAR(25),
    FOREIGN KEY (Attribute2) REFERENCES F_Key(Attribute)
);

-- By default, this foreign key will restrict.

CREATE TABLE Table_restrict(
    Attribute1 VARCHAR(25) PRIMARY KEY,
    Attribute2 VARCHAR(25),
    FOREIGN KEY (Attribute2) REFERENCES F_Key(Attribute)
        ON DELETE RESTRICT
        ON UPDATE RESTRICT
);

CREATE TABLE Table_cascade(
    Attribute1 VARCHAR(25) PRIMARY KEY,
    Attribute2 VARCHAR(25),
    FOREIGN KEY (Attribute2) REFERENCES F_Key(Attribute)
        ON DELETE CASCADE
        ON UPDATE CASCADE
);

CREATE TABLE Table_set_null(
    Attribute1 VARCHAR(25) PRIMARY KEY,
    Attribute2 VARCHAR(25),
    FOREIGN KEY (Attribute2) REFERENCES F_Key(Attribute)
        ON DELETE SET NULL
        ON UPDATE SET NULL
);
```

/*
 * You might encounter a
 * ON UPDATE SET DEFAULT
 * but this reference option (cf.
* worked only with a particular engine (https://mariadb.com/kb/en/library/about-pbxt/) and will not be treated here. */

```
INSERT INTO F_Key VALUES('First Test');
INSERT INTO Table_default VALUES('Default', 'First Test');
INSERT INTO Table_restrict VALUES('Restrict', 'First Test');
INSERT INTO Table_cascade VALUES('Cascade', 'First Test');
INSERT INTO Table_set_null VALUES('Set null', 'First Test');
SELECT * FROM Table_default;
SELECT * FROM Table_restrict;
SELECT * FROM Table_cascade;
SELECT * FROM Table_set_null;
```

-- The following will fail because of the Table_default table:
UPDATE F_Key SET Attribute = 'After Update'
  WHERE Attribute = 'First Test';
DELETE FROM F_Key
  WHERE Attribute = 'First Test';

-- Let us drop this table, and try again.
DROP TABLE Table_default;

-- The following fails too, this time because of the Table_restrict table:
UPDATE F_Key SET Attribute = 'After Update'
  WHERE Attribute = 'First Test';
DELETE FROM F_Key
  WHERE Attribute = 'First Test';

-- Let us drop this table, and try again.
DROP TABLE Table_restrict;

-- Let's try again:
UPDATE F_Key SET Attribute = 'After Update' WHERE Attribute = 'First Test';

-- And let's print the situation after this update:
SELECT * FROM Table_cascade;
SELECT * FROM Table_set_null;
```

/*
MariaDB [HW_CONSTRAINTS_PART3]> SELECT * FROM Table_cascade;
+------------+--------------+
<table>
<thead>
<tr>
<th>Attribute1</th>
<th>Attribute2</th>
</tr>
</thead>
</table>
+------------+--------------+"
3.5 Foreign Keys

<table>
<thead>
<tr>
<th>Cascade</th>
<th>After Update</th>
</tr>
</thead>
<tbody>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
</tbody>
</table>

1 row in set (0.00 sec)

MariaDB [HW_CONSTRAINTS_PART3]> SELECT * FROM Table_set_null;
+-------------------+-------------+
| Attribute1 | Attribute2 |
+------------+------------+
| Set null   | NULL       |
+------------+------------+
1 row in set (0.00 sec)
*/

-- Let's make a second test.
INSERT INTO F_Key VALUES('Second Test');
INSERT INTO Table_cascade VALUES('Default', 'Second Test');
INSERT INTO Table_set_null VALUES('Restrict', 'Second Test');

DELETE FROM F_Key
  WHERE Attribute = 'Second Test';

/*
MariaDB [HW_CONSTRAINTS_PART3]> SELECT * FROM Table_cascade;
+-------------------+--------------+
| Attribute1 | Attribute2 |
+------------+------------+
| Cascade   | After Update |
+------------+------------+
1 row in set (0.00 sec)

MariaDB [HW_CONSTRAINTS_PART3]> SELECT * FROM Table_set_null;
+-------------------+-------------+
| Attribute1 | Attribute2 |
+------------+------------+
| Restrict   | NULL       |
| Set null   | NULL       |
+------------+------------+
2 rows in set (0.00 sec)
*/

3.5.3 Constructing and Populating a New Example

3.5.3.1 Construction

- Remember, we start by creating a schema and tables inside of it.
- What if foreign keys are mutually dependent? What if we have something like:
/* code/sql/HW_ProfExample.sql */
CREATE TABLE PROF (  
  Login VARCHAR(25) PRIMARY KEY, NAME VARCHAR(25),  
  Department CHAR(5)  
);  

CREATE TABLE DEPARTMENT (  
  Code CHAR(5) PRIMARY KEY, NAME VARCHAR(25), Head VARCHAR(25),  
  FOREIGN KEY (Head) REFERENCES PROF (LOGIN)  
  ON UPDATE CASCADE  
);  

ALTER TABLE PROF  
ADD FOREIGN KEY (Department) REFERENCES DEPARTMENT (Code);  

Note the structure of the ALTER TABLE command:

- ... KEY Department REFERENCES Code; \(\Rightarrow\) error
- ... KEY (Department) REFERENCES (Code); \(\Rightarrow\) error
- ... KEY PROF(Department) REFERENCES DEPARTMENT(Code); \(\Rightarrow\) ok

CREATE TABLE STUDENT (  
  Login VARCHAR(25) PRIMARY KEY, NAME VARCHAR(25),  
  Registered DATE, Major CHAR(5),  
  FOREIGN KEY (Major) REFERENCES DEPARTMENT (Code)  
);  

CREATE TABLE GRADE (  
  Login VARCHAR(25), Grade INT, PRIMARY KEY (LOGIN, Grade),  
  FOREIGN KEY (LOGIN) REFERENCES STUDENT (LOGIN)  
);  

3.5.3.2 Populating

We can insert multiple values at once:

```
INSERT INTO DEPARTMENT  
VALUES ('MATH', 'Mathematics', NULL), ('CS', 'Computer Science', NULL);  
```
3.6 A First Look at Conditions

We can specify which attributes we are giving:

```sql
INSERT INTO DEPARTMENT (Code, Name)
VALUES ('CYBR', 'Cyber Security');
```

And we can even specify the order (even the trivial one):

```sql
INSERT INTO PROF (LOGIN, Department, Name)
VALUES ('caubert', 'CS', 'Clément Aubert');
```

```sql
INSERT INTO PROF (LOGIN, Name, Department)
VALUES ('aturing', 'Alan Turing', 'CS'), ('perdos', 'Paul Erdős', 'MATH'), ('bgates', 'Bill Gates', 'CYBR');
```

```sql
INSERT INTO STUDENT (LOGIN, Name, Registered, Major)
VALUES ('jrakesh', 'Jalal Rakesh', '2017-12-01', 'CS'), ('svlatka', 'Sacnite Vlatka', '2015-03-12', 'MATH'), ('cjoella', 'Candice Joella', '20120212', 'CYBR'), ('aalyx', 'Ava Alyx', '20121011', 'CYBR'), ('caubert', 'Clément Aubert', NULL, 'CYBR');
```

```sql
INSERT INTO GRADE
VALUES ('jrakesh', 3.8), ('svlatka', 2.5);
```

Note the date literals.

### 3.6 A First Look at Conditions

Order of clauses does not matter, not even for optimization purpose.

```
UPDATE <table>
SET <attribute1> = <value1>, <attribute2> = <value2>, ...
WHERE <condition>;
```

```
SELECT <attribute list, called projection attributes>
FROM <table list>
WHERE <condition>;
```

```
DELETE FROM <table list>
WHERE <condition>;
```

Conditions can

- use the comparison operators:
  - `=`, equal to
  - `>`, greater than,
  - `<`, less than,
  - `>=`, greater than or equal to,
  - `<=`, less than or equal to,
• be compounded:
  - condition1 AND condition2
  - condition1 OR condition2
  - NOT condition
  - Usage of parenthesis is possible
• be trivial or even absent,
• use regular expressions:
  - uses the expression LIKE,
  - escape character is \\
  - _ will match one character (any character), % will match any number of character,
  - advanced regular expression possible using the REGEXP keyword.

```
SELECT LOGIN FROM STUDENT;

UPDATE DEPARTMENT
  SET Head = 'aturing'
WHERE Code = 'MATH';

UPDATE DEPARTMENT
  SET Head = 'bgates'
WHERE Code = 'CS'
  OR Code = 'CYBR';

SELECT LOGIN FROM STUDENT
WHERE NOT Major = 'CYBR';

SELECT LOGIN, Name FROM PROF
WHERE Department = 'CS';

SELECT LOGIN FROM STUDENT
WHERE Major = 'CYBR'
  AND Registered > DATE '20121001';

SELECT LOGIN FROM STUDENT
WHERE Name LIKE 'Ava%';

SELECT Name FROM PROF
WHERE LOGIN LIKE '_aubert';
```
Note that `LIKE` is by default case-insensitive, both in MariaDB\(^\text{17}\) and in MySQL\(^\text{18}\). The `COLLATE` operator can be used to force the search to be case-sensitive, as well as `LIKE BINARY`.

### 3.7 Three-Valued Logic

Cf. (Elmasri and Navathe 2010, 5.1.1), (Elmasri and Navathe 2015, 7.1.1)

#### 3.7.1 Meaning of NULL

**NULL** is

1. Unknown value (“Nobody knows”)
   
   What is the date of birth of Jack the Ripper\(^\text{19}\)?
   
   Does P equal NP\(^\text{20}\)?

2. Unavailable / Withheld (“I do not have that information with me at the moment”)
   
   What is the number of english spies in France?
   
   What is the VIN of your car?
   
   What is the identity of the Tiananmen Square person?

3. Not Applicable (“Your question does not make sense”)
   
   What is the US SSN of a french person?
   
   What is the email address of an author of the XIXth century?

#### 3.7.2 Comparison with Unknown Values

If **NULL** is involved in a comparison, the result evaluates to “Unknown.” If **NULL** is involved in a comparison, the result evaluates to “Unknown.”

<table>
<thead>
<tr>
<th>AND</th>
<th>T</th>
<th>F</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>T</td>
<td>F</td>
<td>U</td>
</tr>
<tr>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>U</td>
<td>U</td>
<td>F</td>
<td>U</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OR</th>
<th>T</th>
<th>F</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
</tr>
</tbody>
</table>

\(^{17}\)https://mariadb.com/kb/en/like/


\(^{19}\)https://en.wikipedia.org/wiki/Jack_the_Ripper

3.8 Various Tools

You can test if a value is NULL with IS NULL.

```
INSERT INTO DEPARTMENT
VALUES ('Hist', 'History', NULL);
```

```
SELECT * FROM DEPARTMENT
WHERE Head IS NULL;
```

```
SELECT * FROM DEPARTMENT
WHERE Head IS NOT NULL;
```

```
SELECT COUNT(*) FROM GRADE
WHERE Grade IS NULL;
```

Note that you can not use IS to compare values: this key word is reserved to test if a value is (not) NULL, and nothing else.

There are no if...then...else statements in SQL, but you can do something similar with CASE (cf. https://dev.mysql.com/doc/refman/8.0/en/case.html). However, note that SQL is probably not the right place to try to control the flow of execution.

This probably depends on the system a lot, but one could wonder if MySQL uses some form of short-cut evaluation when comparing with NULL. Unfortunately, even with three times (!) the verbose option, MySQL does not give more insight as to whenever it drops comparing values once a NULL was encountered (cf. https://dev.mysql.com/doc/refman/8.0/en/mysql-command-options.html#option_mysql_verbose, you can log-in using mysql -u testuser -p --password=password -v -v -v to activate the most verbose mode). Normally, EXPLAIN (https://dev.mysql.com/doc/refman/8.0/en/explain.html) should be useful in answering this question, but failed to answer it as well.

3.8 Various Tools

For DISTINCT, ALL and UNION, cf. (Elmasri and Navathe 2010, 4.3.4) or (Elmasri and Navathe 2015, 6.3.4). For ORDER BY, cf. (Elmasri and Navathe 2010, 4.3.6) or (Elmasri and Navathe 2015, 6.3.6). For aggregate functions, cf. (Elmasri and Navathe 2010, 5.1.7) or (Elmasri and Navathe 2015, 7.1.7).
3.8.1 AUTO_INCREMENT

Something that is not exactly a constraint, but that can be used to “qualify” domains, is the AUTO_INCREMENT feature of MySQL. Cf. https://dev.mysql.com/doc/refman/8.0/en/example-auto-increment.html, you can have MySQL increment a particular attribute (most probably intended to be your primary key) for you.

3.8.2 Transactions

We can save the current state, and start a series of transactions, with the command

```sql
START TRANSACTION;
```

All the commands that follows are “virtually” executed: you can undo them all using

```sql
ROLLBACK;
```

This puts you back in the state you were in before starting the transaction. If you want all the commands you typed in-between to be actually enforced, you can use the command

```sql
COMMIT;
```

Nested transactions are technically possible, but they are counter-intuitive and should be avoided, cf. https://www.sqlskills.com/blogs/paul/a-sql-server-dba-myth-a-day-2630-nested-transactions-are-real/.

3.8.3 DISTINCT / ALL

The result of a SELECT query, for instance, is a table, and SQL treats tables as multi-set, hence there can be repetitions in the result of a query, but we can remove them:

```sql
SELECT DISTINCT Major FROM STUDENT;
```

The default behaviour is equivalent to specifying ALL, and it display the duplicates. In this case, it would be

```sql
> SELECT Major FROM STUDENT;
+--------+
| Major  |
+--------+
| CS     |
| CYBR   |
| CYBR   |
| CYBR   |
| MATH   |
+--------+
```
3.8.4 UNION

Set-theoretic operations are available as well. For instance, one can use:

```
(SELECT Login FROM STUDENT) UNION (SELECT Login FROM PROF);
```

to collect all the logins from both tables.

There is also INTERSECT and EXCEPT in the specification, but MySQL does not implement them (cf. https://en.wikipedia.org/wiki/Comparison_of_relational_database_management_systems#Database_capabilities).

3.8.5 ORDER BY

You can have ORDER BY specifications:

```
SELECT LOGIN
FROM GRADE
WHERE Grade > 2.0
ORDER BY Grade;
```

```
SELECT LOGIN
FROM GRADE
WHERE Grade > 2.0
ORDER BY Grade DESC;
```

```
SELECT LOGIN, Major
FROM STUDENT
ORDER BY Major, Name;
```

ORDER BY order by ascending order by default.

3.8.6 Aggregate Functions

You can use MAX, SUM, MIN, AVG, COUNT:

```
SELECT MAX(Registered) FROM STUDENT;
```

returns the “greatest” date of registration of a student, i.e., the date of the latest registration.

```
SELECT COUNT(Name) FROM STUDENT;
```

returns the number of names, i.e., the number of students.

```
SELECT COUNT(DISTINCT Name) FROM STUDENT;
```

returns the number of different names (which in this case is the same as the number of names, since we have no homonyms).

Note that AVG returns the average of all non-NULL values, as we can see on the following example:
3.9 More Select Queries

For select-project-join, cf. (Elmasri and Navathe 2010, 4.3.1) or (Elmasri and Navathe 2015, 6.3.1). For aliases, cf. (Elmasri and Navathe 2010, 4.3.2) or (Elmasri and Navathe 2015, 6.3.2). For nested queries, cf. (Elmasri and Navathe 2010, 5.1.2) or (Elmasri and Navathe 2015, 7.1.2).
3.9 More Select Queries

3.9.1 Select-Project-Join

```sql
SELECT LOGIN
FROM PROF, DEPARTMENT
WHERE DEPARTMENT.Name = "Mathematics"
   AND Department = Code;
```

- Department.Name = 'Mathematics' is the selection condition
- Department = Code is the join condition, because it combines two tuples.
- Why do we use the fully qualified name attribute for Name?
- We have to list all the tables we want to consult, even if we use fully qualified names.

```sql
SELECT Name
FROM STUDENT, GRADE
WHERE Grade > 3.0
   AND STUDENT.Login = GRADE.Login;
```

- Grade > 3.0 is the selection condition
- STUDENT/Login = GRADE/Login is the join condition

We can have two join conditions!

```sql
SELECT PROF.Name
FROM PROF, DEPARTMENT, STUDENT
WHERE STUDENT.Name = "Ava Alyx"
   AND STUDENT.Major = DEPARTMENT.Code
   AND DEPARTMENT.Head = PROF.Login;
```

Note that for the kind of join we are studying (called “inner joins”), the order does not matter\(^{21}\).

In Problem 3.3 (Duplicate rows in SQL), we saw that SQL was treating tables as multi-sets, i.e., repetitions are allowed. This can lead to strange behaviour when performing Select-Project-Join queries. Consider the following example:

3.9.2 Aliasing Tuples

We can use aliases on tables to shorten the previous query:

```sql
SELECT PROF.Name
FROM PROF, DEPARTMENT, STUDENT AS B
WHERE B.Name = "Ava Alyx"
   AND B.Major = DEPARTMENT.Code
   AND DEPARTMENT.Head = PROF.Login;
```

We can use multiple aliases to make it even shorter (but less readable):

\(^{21}\)https://stackoverflow.com/q/9614922
3.9 More Select Queries

```sql
SELECT A.Name 
FROM PROF AS A, DEPARTMENT AS B, STUDENT AS C 
WHERE C.Name = "Ava Alyx"
  AND C.Major = B.Code 
  AND B.Head = A.Login;
```

For those two, aliases are convenient, but not required to write the query. In some cases, we cannot do without aliases. For instance if we want to compare two rows in the same table:

```sql
SELECT Other.Login 
FROM GRADE AS Mine, GRADE AS Other 
WHERE Mine.Login = "aalyx"
  AND Mine.Grade < Other.Grade;
```

Generally, when you want to perform a join within the same table, then you have to “make two copies of the tables” and name them differently using aliases. Let us try to write a query that answers the question

What are the login of the professors that have the same department as the professor whose login is caubert?

We need a way of distinguishing between the professors we are projecting on (the one whole login is caubert) and the one we are joining with (the ones that have the same department). This can be done using something like:

```sql
SELECT JOINT.Login 
FROM PROF AS PROJECT, PROF AS JOINT 
WHERE PROJECT.Login = "caubert"
  AND PROJECT.Department = JOINT.Department;
```

Note that we are “opening up two copies of the PROF tables”, and naming them differently (PROJECT and JOINT).

Another (improved) example of a similar query is

```sql
SELECT Fellow.Name AS "Fellow of Ava" 
FROM STUDENT AS Ava, STUDENT AS Fellow 
WHERE Ava.Name = "Ava Alyx"
  AND Fellow.Major = Ava.Major 
  AND NOT Fellow.Login = Ava.Login;
```

A couple of remarks about this query:

- At the beginning of the query, AS "Fellow of Ava" is another kind of aliassing, mentioned in a previous section.
• In the condition, \texttt{NOT Fellow.Login = Ava/Login} guarantees that we will not select \texttt{Ava} again, and exclude her from the results (Ava is not supposed to be a fellow of herself).

• In the (unlikely, but possible) case of an homonym, writing \texttt{NOT Fellow.Name = Me.Name}; instead of \texttt{NOT Fellow.Login = Ava/Login} would prevent the homonym from occuring in the results.

• In the condition, substituting \texttt{AND NOT Me = Fellow} by \texttt{NOT Fellow.Login = Ava/Login} would not work: you have to compare attributes of the tuples, not the tuples.

### 3.9.3 Nested Queries

Let us look at a first example

```
SELECT LOGIN
FROM GRADE
WHERE Grade > (
    SELECT AVG(Grade)
    FROM GRADE);
```

A nested query is made of an outer query (\texttt{SELECT Login...}) and an inner query (\texttt{SELECT AVG(Grade)...}). Note that the inner query does not terminate with a ;.

Logical operators such as \texttt{ALL} or \texttt{IN} can be used in nested queries. To learn more about those operators, refer to \url{https://www.w3schools.com/sql/sql_operators.asp}.

An example could be

```
SELECT LOGIN
FROM GRADE
WHERE Grade >= ALL (
    SELECT Grade
    FROM GRADE
    WHERE Grade \texttt{IS NOT NULL});
```

Note that

• We have to use >=, and not >, since no grade is strictly greater than itself.

• The part \texttt{IS NOT NULL} is needed: otherwise, if one of the grade is \texttt{NULL}, then the comparison would yield “unknown”, and no grade would be greater than all of the others.

• This query could be simplified, using \texttt{MAX}:

```
SELECT LOGIN
FROM GRADE
WHERE Grade >= (  
    SELECT MAX(Grade)
    FROM GRADE); 
```

Answering the question
What are the logins of the professors belonging to a department that is the major of at least one student whose name ends with an "a"?

–that sounds like the what would ask a police officer in a whodunit– could be answer using

```sql
SELECT LOGIN
FROM PROF
WHERE DEPARTMENT IN (SELECT Major
                        FROM STUDENT
                        WHERE LOGIN LIKE '%a');
```

For this query, we could not use =, since more than one major could be returned. Furthermore, nested query that uses = can often be rewritten without being nested. For instance,

```sql
SELECT LOGIN
FROM PROF
WHERE DEPARTMENT = (SELECT Major
                     FROM STUDENT
                     WHERE LOGIN = "cjoella");
```

becomes

```sql
SELECT PROF.Login
FROM PROF, STUDENT
WHERE DEPARTMENT = Major
    AND STUDENT.Login = "cjoella";
```

Conversly, you can sometimes write select-project-join as nested queries For instance,

```sql
SELECT Name
FROM STUDENT, GRADE
WHERE Grade > 3.0
    AND STUDENT.Login = GRADE.Login;
```

becomes

```sql
SELECT Name
FROM STUDENT
WHERE LOGIN IN (SELECT LOGIN
                FROM GRADE
                WHERE Grade > 3.0);
```
3.10 Procedures

A “stored” procedure is a SQL function statements that can take arguments and may be called from another part of your program. Stated differently, a procedure is a serie of statements stored in a schema, that can easily be executed repeatedly, cf. https://dev.mysql.com/doc/refman/8.0/en/create-procedure.html or https://mariadb.com/kb/en/library/create-procedure/.

Imagine we have the following:

```sql
/* code/sql/HW_ProcedureExamples.sql */
CREATE TABLE STUDENT (
  Login INT PRIMARY KEY, NAME VARCHAR(30), Major
  VARCHAR(30), Email VARCHAR(30)
);

INSERT INTO STUDENT
  VALUES (123, "Test A", "CS", "a@a.edu"), (124, "Test B", "IT", "b@a.edu"), (125, "Test C", "CYBR", "c@a.edu");
```

SQL is extremely literal: when it reads the delimiter ;, it must execute the command that was shared. But a procedure, being composed of commands, will contain the ; symbol. To “solve” this (weird) issue, and be able to define a procedure, we have to “temporarily alter the language”, using DELIMITER // that makes the delimiter being // instead of ;.

In any case, we can then define and execute a simpe procedure called STUDENTLIST as fol-lows:

```sql
DELIMITER $$
CREATE PROCEDURE STUDENTLIST ()
BEGIN
  SELECT * 
  FROM STUDENT;

-- This ";" is not the end of the procedure definition!
END;
$$
-- This is the delimiter that marks the end of the procedure
-- definition.
DELIMITER ;

-- Now, we want ";" to be the "natural" delimiter again.
CALL STUDENTLIST ();

-- Now, we want ";" to be the "natural" delimiter again.
```

The symbols $$ are often used too, and the documentation, at https://dev.mysql.com/doc/refman/8.0/en/stored-programs-defining.html, reads:

You can redefine the delimiter to a string other than // and the delimiter can consist of a single character or multiple characters. You should avoid the use of the backslash (\) character because that is the escape character for MySQL.

The minus sign twice is also a poor choice, since it is used for commenting.
CALL STUDENTLIST ();

A procedure can also take arguments, and an example could be:

```sql
DELIMITER $$
CREATE PROCEDURE STUDENTLOGIN (  
  NameP VARCHAR(30)
 )
BEGIN
  SELECT LOGIN
  FROM STUDENT
  WHERE NameP = Name;
END;
$$
DELIMITER ;

SHOW CREATE PROCEDURE STUDENTLOGIN;

-- This display information about the procedure just created.
-- We can pass quite naturally an argument to our
-- procedure.
CALL STUDENTLOGIN ("Test A");
```

### 3.11 Triggers

A trigger is a series of statements stored in a schema that can be automatically executed whenever a particular event in the schema occurs. Triggers are extremely powerful, and are a way of automating part of the work in your database. In MariaDB, you could have the following program.

Imagine we have the following:

```sql
CREATE TABLE STUDENT (  
  Login VARCHAR(30) PRIMARY KEY, Average FLOAT
 );

CREATE TABLE GRADE (  
  Student VARCHAR(30), Exam VARCHAR(30), Grade INT, PRIMARY  
  KEY (Student, Exam), FOREIGN KEY (Student) REFERENCES  
  STUDENT (LOGIN)
 );
```

We want to create a trigger that counts the number of times something was inserted in our STUDENT table. SQL supports some primitive form of variables (cf. https://dev.mysql.com/doc/refman/8.0/en/user-variables.html and https://mariadb.com/kb/en/library/user-defined-variables/).
There is no “clear” form of type, https://dev.mysql.com/doc/refman/8.0/en/user-variables.html reads:

In addition, the default result type of a variable is based on its type at the beginning of the statement. This may have unintended effects if a variable holds a value of one type at the beginning of a statement in which it is also assigned a new value of a different type. To avoid problems with this behavior, either do not assign a value to and read the value of the same variable within a single statement, or else set the variable to 0, 0.0, or ’’ to define its type before you use it.

In other words, SQL just “guess” the type of your value and go with it. Creating a simple trigger that increment a variable every time an insertion is performed in the STUDENT table can be done as follows:

```sql
SET @number_of_student = 0;

CREATE TRIGGER NUMBER_OF_STUDENT_INC
    AFTER INSERT ON STUDENT
    FOR EACH ROW
    SET @number_of_student = @number_of_student + 1;
```

Now, assume we want to create a trigger that calculates the average for us. Note that the trigger will need to manipulate two tables (STUDENT and GRADE) at the same time.

```sql
CREATE TRIGGER STUDENT_AVERAGE
    AFTER INSERT ON GRADE
    FOR EACH ROW -- Woh, a whole query inside our trigger!
    UPDATE STUDENT
    SET STUDENT.Average = (SELECT AVG(Grade)
                            FROM GRADE
                            WHERE GRADE.Student = STUDENT.Login)
    WHERE STUDENT>Login = NEW.Student;

-- The "NEW" keyword here refers to the "new" entry
-- that is being inserted by the INSERT statement
-- triggering
-- the trigger.
```

The source code contains examples of insertion and explanations on how to witness the trigger in action.

### 3.12 Setting Up Your Work Environment

This part is a short tutorial to install and configure a working relational DBMS. We will proceed in 5 steps:

1. Install the required software,
2. Create a user,
3. Log-in as this user,
4. Create and populate our first database,
5. Discuss the security holes in our set-up.

3.12.1 Installation

You will install the MySQL DataBase Management System, or its community-developed fork, MariaDB. Below are the instruction to install MySQL Community Edition on Windows 10 and macOS, and MariaDB on Linux-based distribution, but both are developed for every major operating system (macOS, Windows, Debian, Ubuntu, etc.): feel free to pick one or the other, it will not make a difference in this course (up to some minor aspects). MySQL is more common, MariaDB is growing, both are released under GNU General Public License, well-documented and free of charge for their "community" versions.

It is perfectly acceptable, and actually encouraged, to install MySQL or MariaDB on a virtual machine for this class. You can use the Windows Subsystem for Linux, VMware or Virtual Box to run a “sandboxed” environment that should keep your data isolated from our experiments.

Below are precise and up-to-date instructions, follow them carefully, read the messages displayed on your screen, make sure a step was correctly executed before moving to the next one, and everything should be all right. Also, remember:

1. Do not wait, set your system early.
2. To look for help, be detailed and clear about what you think went wrong.

The following links could be useful:

- https://dev.mysql.com/doc/refman/8.0/en/mysql-installer-workflow.html, and particularly the page on windows installation and the page on Linux installation using package-managers,

3.12.1.1 Installing MySQL on Windows 10

where XXX is a number version (e.g., 8.0.13.0.), and YYY is the size of the file (e.g., 16.3M). On the next page, click on the (somewhat hidden) “No thanks, just start my download.” button.

2. Save the “mysql-installer-web-community-XXX.msi” file, and open it. If there is an updated version of the installer available, agree to download it. Accept the license term.

3. We will now install the various components needed for this class, leaving all the choices by defaults. This means that you need to do the following:

   a) Leave the first option on “Developer Default” and click on “Next”, or click on “Custom”, and select the following:
   b) Click on “Next” even if you do not meet all the requirements
   c) Click on “Execute”. The system will download and install several softwares (this may take some time).
   d) Click on “Next” twice, leave “Type and Networking” on “Standalone MySQL Server / Classic MySQL Replication” and click “Next”, and leave the next options as they are (unless you know what you do and want to change the port, for instance) and click on “Next”.
   e) You now need to choose a password for the MySQL root account. It can be anything, just make sure to memorize it. Click on “Next”.
   f) On the ”Windows Service” page, leave everything as it is and click on “Next”.
   g) On the ”Plugins and Extensions” page, leave everything as it is and click on “Next”.
   h) Finally, click “Execute” on the “Apply Configuration” page, and then on “Finish”.
   i) Click on “Cancel” on the “Product Configuration” page and confirm that you do not want to add products: we only need to have MySQL Server XXX configured.

4. We now want to make sure that MySQL is running: launch Windows’ “Control Panel”, then click on “Administrative Tools”, and on “Services”. Look for “MySQLXX”, its status should be “Running”. If it is not, right-click on it and click on “Start”.
5. Open a command prompt (search for cmd, or use PowerShell\(^{32}\)) and type

```
   cd "C:\Program Files\MySQL\MySQL Server 8.0\bin"
```

If this command fails, it is probably because the version number changed: open the file explorer, go to `C:\Program Files\MySQL\`, look for the right version number, and update the command accordingly.

Then, enter

```
   mysql -u root -p
```

and enter the password you picked previously for the root account. You are now logged as root in your database management system, you should see a brief message, followed by a prompt

```
   mysql >
```

6. Now, move on to “Creating a User”.

### 3.12.1.2 Installing MySQL on macOS

The instructions are almost the same as for Windows. Read [https://dev.mysql.com/doc/refman/8.0/en/osx-installation-pkg.html](https://dev.mysql.com/doc/refman/8.0/en/osx-installation-pkg.html) and download the file from [https://dev.mysql.com/download](https://dev.mysql.com/download) once you selected “macOS” as your operating system. Install it, leaving everything by default but adding a password (refer to the instructions for windows). Then, open a command-line interface (the terminal), enter

```
   mysql -u root -p
```

and enter the password you picked previously for the root account. You are now logged as root in your database management system, you should see a brief message, followed by a prompt

```
   mysql >
```

Now, move on to “Creating a User”.

### 3.12.1.3 Installing MariaDB on Linux

1. Install, through your standard package management system (apt or aptitude for debian-based systems, pacman for Arch Linux, etc.), the packages `mysql-client` and `mysql-server` (or `default-mysql-client` and `default-mysql-server`) as well as their dependencies\(^{33}\).

2. Open a terminal and type

   `/etc/init.d/mysql status`

   or, as root,


\(^{33}\)Yes, the package is called `mysql-server`, but it actually install the package `mariadb-server-10.3` or higher... So do not be confused: we are, indeed, installing MariaDB!
3.12 Setting Up Your Work Environment

service mysql status
to see if MySQL is running: if you read something containing
Active: active (running)
then you can move on to the next step, otherwise run (as root)

service mysqld start
and try again.

3. As root, type in your terminal

mysql_secure_installation
You will be asked to provide the current password for the root MySQL user: this password
has not be defined yet, so just hit “Enter”. You will be asked if you want to set a new password (that you can freely chose, just make sure to memorize it). Then, answer “n” to
the question “Remove anonymous users?”, “Y” to “Disallow root login remotely?”, “n” to
“Remove test database and access to it?” and finally “Y” to “Reload privilege tables now?”.

4. Still as root, type in your terminal

mysql -u root -p
and enter the password you picked previously for the root account. You are now logged as
root in your database management system: you should see a brief message, followed by a
prompt

MariaDB [(none)]>

5. Now, move on to “Creating a User”.

3.12.2 Creating a User

This step will create a non-root user\(^\text{34}\) and grant it some rights. Copy-and-paste or type the
following three commands, one by one (that is, enter the first one, hit “enter”, enter the second,
hit “enter”, etc.). This step will create a non-root user\(^\text{35}\) and grant it some rights. Copy-and-paste
or type the following three commands, one by one (that is, enter the first one, hit “enter”, enter
the second, hit “enter”, etc.).

We first create a new user called testuser on our local installation, and give it the password
password:

\[
\text{CREATE USER 'testuser'@'localhost' IDENTIFIED BY 'password';}
\]

Then, we grant the user all the privileges on the databases whose name starts with HW_:

\[
\text{GRANT ALL PRIVILEGES ON `HW\_`.* TO 'testuser'@'localhost';}
\]

\(^\text{34}\)By default, MySQL and MariaDB only create a root user with all privileges and no password, but we added a password
at the previous step.

\(^\text{35}\)By default, MySQL and MariaDB only create a root user with all privileges and no password, but we added a password
at the previous step.
Be careful: backticks (`) are surrounding HW\_% whereas single quotes (') are surrounding testuser and localhost.

And then we quit the DBMS, using

```sql
EXIT;
```

The message displayed after the two first commands should be

```
Query OK, 0 rows affected (0.00 sec)
```

and the message displayed after the last command should be

```
Bye
```

### 3.12.3 Logging-In as testuser

We now log in as the normal user called “testuser”.

Linux users should type as a normal user, i.e., not as root, in their terminal the following, and Windows users should type in their command prompt the following\(^3\):

```bash
mysql -u testuser -p
```

Enter password as your password. If you are prompted with a message

```
ERROR 1045 (28000): Access denied for user 'testuser'@'localhost' (using password: YES)
```

then you probably typed the wrong password. Otherwise, you should see a welcoming message from MySQL or MariaDB and a prompt.

To save yourself the hassle of typing the password, you can use

```bash
mysql -u testuser --password=password
```

or

```bash
mysql -u testuser -p --password=password
```

to log-in as testuser immediately.

If at some point you want to know if you are logged as root or testuser, simply enter

```
\s;
```

\(^3\)Provided the working directory is still C:\Program Files\MySQL\MySQL Server 8.0\bin or similar. Cf. https://dev.mysql.com/doc/mysql-windows-excerpt/8.0/en/mysql-installation-windows-path.html to add the MySQL bin directory to your Windows system PATH environment variable.
3.12.4 Creating Our First Database

Now, let us create our first schema, our first table, populate it with data, and display various information.

We first create the schema (or database) HW_FirstTest:

```sql
CREATE DATABASE HW_FirstTest; -- Or CREATE SCHEMA HW_FirstTest;
```

Let us make sure that we created it:

```sql
SHOW DATABASES;
```

Let us use it:

```sql
USE HW_FirstTest;
```

And see what it contains now:

```sql
SHOW TABLES;
```

We now create a table called TableTest, with two integer attributes called Attribute1 and Attribute2:

```sql
CREATE TABLE TableTest (Attribute1 INT, Attribute2 INT);
```

And can make sure that the table was indeed created:

```sql
SHOW TABLES;
```

We can further ask our DBMS to display the structure of the table we just created:

```sql
DESCRIBE TableTest; -- Can be abbreviated as DESC TableTest;
```

And even ask to get back the code that would create the exact same structure (but without the data!):

```sql
SHOW CREATE TABLE TableTest;
```

Now, let us populate it with some data:

```sql
INSERT INTO TableTest VALUES (1,2),
    (3,4),
    (5,6);
```

Note that the SQL syntax and your DBMS are completely fine with your statement spreading over multiple lines. Let us now display the data stored in the table:

```sql
SELECT * FROM TableTest;
```

After that last command, you should see
Finally, we can erase the content of the table, then erase ("drop") the table, and finally the schema:

```
DELETE FROM TableTest; -- Delete the rows
DROP TABLE TableTest; -- Delete the table
DROP DATABASE HW_FirstTest; -- Delete the schema
```

You’re all set! All you have to do is to quit, using the command

```
EXIT;
```

### 3.12.5 Security Concerns

Note that we were quite careless when we set-up our installation:

- We installed a software without checking its signature. MySQL has a short tutorial\(^\text{37}\) on how to check the signature of their packages.
- We did not impose any requirement on the root password of our installation. Using a good, secure, and unique password, should have been required / advised.
- We left all the options on default, whereas a good, secure, installation, always fine-tune what is enabled and what is not.
- We chosed a very weak password for `testuser` that is common to all of our installation.

All of those are obvious security risks, and make this installation unsafe to be a production environment. We will only use it as a testing / learning environment, but it is strongly recommended to:

- Install it on a virtual machine, so that your personal files would not be impacted by any mis-use of your DBMS,
- Perform a fresh, secured installation if you want to use a DBMS for anything but testing / learning purposes.

### Exercises

**Exercise 3.1** For each of the following, fill in the blanks:

- In SQL, a relation is called a _________________.
- In SQL, every statement ends with ____ , and in-line comments start with a ____ __.
- In SQL, there is no string datatype, so we have to use _____________.
- The Data Control Language of SQL’s role is to _____________________.

Exercise 3.2  What does it mean to say that SQL is at the same time a “data definition language” and a “data manipulation language”?

Exercise 3.3  Name three kind of objects (for lack of a better word) a CREATE statement can create.

Exercise 3.4  Write a SQL statement that adds a primary key constraint to an attribute named ID in an already existing table named STAFF.

Exercise 3.5  Complete each row of the following table with either a datatype or two different examples:

<table>
<thead>
<tr>
<th>Data type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Char(4)</td>
<td>4, -32</td>
</tr>
<tr>
<td>VarChar(10)</td>
<td>'Train', 'Michelle'</td>
</tr>
<tr>
<td>Bit(4)</td>
<td>TRUE, UNKNOWN</td>
</tr>
</tbody>
</table>

Exercise 3.6  In the datatype CHAR(3), what does the 3 indicate?

Exercise 3.7  Explain this query: CREATE SCHEMA FACULTY;

Exercise 3.8  Write code to

- declare a first table with two attributes, one of which is the primary key,
- declare a second table with two attributes, one of which is the primary key, and the other references the primary key of the first table,
- insert one tuple in the first table,
- insert one tuple in the second table, referencing the only tuple of the first table,

You are free to come up with an example (even very simple or cryptic) or to re-use an example from class.

Exercise 3.9  Explain this query:

```
ALTER TABLE TABLEA
DROP INDEX Attribute1;
```

Exercise 3.10  If I want to enter January 21, 2016, as a value for an attribute with the DATE datatype, what value should I enter?

Exercise 3.11  Write a statement that inserts the values "Thomas" and 4 into the table TRAINS.

Exercise 3.12  If PkgName is the primary key in the table MYTABLE, what can you tell about the number of rows returned by the following statement?

```
SELECT * FROM MYTABLE WHERE PkgName = 'MySQL';
```

Exercise 3.13  If you want that every time a referenced row is deleted, all the referring rows are deleted as well, what mechanism should you use?

Exercise 3.14  By default, does the foreign key restrict, cascade, or set null on update? Can you justify this choice?
Exercise 3.15 If a database designer is using the `ON UPDATE SET NULL` for a foreign key, what mechanism is (s)he implementing (i.e., describe how the database will react a certain operation)?

Exercise 3.16 If the following is part of the design of a table:

```sql
FOREIGN KEY (DptNumber) REFERENCES DEPARTMENT(Number)
ON DELETE SET DEFAULT
ON UPDATE CASCADE;
```

What happen to the rows whose foreign key DptNumber are set to 3 if the row in the DEPARTEMENT table with primary key Number set to 3 is...

1. ... deleted?
2. ...updated to 5?

Exercise 3.17 If the following is part of the design of a WORKER table:

```sql
FOREIGN KEY WORKER(DptNumber) REFERENCES DEPARTMENT(DptNumber)
ON UPDATE CASCADE;
```

What happen to the rows whose foreign key DptNumber are set to 3 if the row in the DEPARTMENT table with primary key Number set to 3 is...

1. ... deleted?
2. ... updated to 5?

Exercise 3.18 Given a relation TOURIST(Name, EntryDate, Address), write a SQL statement printing the name and address of all the tourists who entered the territory after the 15 September, 2012.

Exercise 3.19 Describe what the star do in the statement

```sql
SELECT ALL * FROM MYTABLE;
```

Exercise 3.20 What is the fully qualified name of an attribute? Give an example.

Exercise 3.21 If DEPARTMENT is a database, what is DEPARTMENT. * ?

Exercise 3.22 What is a multi-set? What does it mean to say that MySQL treats tables as multisets?

Exercise 3.23 What is the difference between

```sql
SELECT ALL * FROM MYTABLE;
```

and

```sql
SELECT DISTINCT * FROM MYTABLE;
```

How are the results the same? How are they different?

Exercise 3.24 What is wrong with the statement

```sql
SELECT * WHERE Name = 'CS' FROM DEPARTMENT;
```
Exercise 3.25 Write a query that returns the number of row (i.e., of entries, of tuples) in a table named BOOK.

Exercise 3.26 When is it useful to use a select-project-join query?

Exercise 3.27 When is a tuple variable useful?

Exercise 3.28 Write a query that changes the name of the professor whose Login is 'caubert' to 'Hugo Pernot' in the table PROF.

Exercise 3.29 Can an UPDATE statement have a WHERE condition using an attribute that is not the primary key? If no, justify, if yes, tell what could happen.

Exercise 3.30 Give the three possible meaning of the NULL value, and an example for each of them.

Exercise 3.31 What are the values of the following expressions (i.e., do they evaluate to TRUE, FALSE, or UNKNOWN)?

- TRUE AND FALSE
- TRUE AND UNKNOWN
- NOT UNKNOWN
- FALSE OR UNKNOWN

Exercise 3.32 Write the truth table for AND for the three-valued logic of SQL.

Exercise 3.33 What comparison expression should you use to test if a value is different from NULL?

Exercise 3.34 Explain this query:

```sql
SELECT Login
FROM PROF
WHERE Department IN (SELECT Major
FROM STUDENT
WHERE Login = 'jrakesh');
```

Can you rewrite it without nesting queries?

Exercise 3.35 What is wrong with this query?

```sql
SELECT Name FROM STUDENT
WHERE Login IN (SELECT Code FROM Department WHERE head = 'aturing');
```

Exercise 3.36 Write a query that returns the sum of all the values stored in the Pages attribute of a BOOK table.

Exercise 3.37 Write a query that adds a Pages attribute of type INT into a (already existing) BOOK table.

Exercise 3.38 Write a query that removes the default value for a Pages attribute in a BOOK table.

Exercise 3.39 Under which conditions does SQL allow you to enter the same row in a table twice?
Solution to Exercises

Solution 3.1 The blanks can be filled as follow:

- In SQL, a relation is called a \texttt{table}.
- In SQL, every statement ends with a \texttt{semi-colon (;)} and in-line comments start with a \texttt{two minus signs (--)}.  
- In SQL, there is no \texttt{string} datatype, so we have to use \texttt{VARCHAR(x)} or \texttt{CHAR(x)} where \texttt{x} is an integer reflecting the maximum (or fixed) size of the string.  
- The Data Control Language of SQL's role is to control access to the data stored, by creating users and granting them rights.

Solution 3.2 It can specify the conceptual and internal schema, and it can manipulate the data.

Solution 3.3 Database (schema), table, view, assertion, trigger, etc.

Solution 3.4 \texttt{ALTER TABLE STAFF ADD PRIMARY KEY(ID)};

\begin{tabular}{|c|c|}
\hline
\textbf{Data type} & \textbf{Examples} \\
\hline
\texttt{INT} & 4, -32 \\
\texttt{CHAR(4)} & 'abCD','dEfG' \\
\texttt{VARCHAR(10)} & 'Train','Michelle' \\
\texttt{BIT(4)} & B'1010', B'0101' \\
\hline
\end{tabular}

Solution 3.5 \texttt{BOOL} | \texttt{TRUE, FALSE, NULL'}

\texttt{NULL} is actually a valid answer for every single type of

Solution 3.6 That we can store exactly three characters.

Solution 3.7 It creates a schema, i.e., a database, named \texttt{Faculty}.

Solution 3.8 A simple and compact code could be:

```sql
/* code/sql/HW_Short.sql */
CREATE TABLE A ( 
    Att1 INT PRIMARY KEY, Att2 INT 
);
CREATE TABLE B ( 
    Att3 INT PRIMARY KEY, Att4 INT, FOREIGN KEY (Att4) REFERENCES A (Att1) 
);
INSERT INTO A 
VALUES (1, 2);
INSERT INTO B 
VALUES (3, 1);
```

Solution 3.9 It removes the \texttt{UNIQUE} constraint on the \texttt{Attribute1} in the \texttt{TABLEA} table.
3.12 Setting Up Your Work Environment

Solution 3.10 DATE '2016-01-21', '2016-01-21', '2016/01/21', '20160121'.

Solution 3.11 INSERT INTO TRAINS VALUES ('Thomas', 4);

Solution 3.12 We know that at most one (but possibly 0) row will be returned.

Solution 3.13 We should use a referential triggered action clause, ON DELETE CASCADE.

Solution 3.14 By default, the foreign key restricts updates. This prevents unwanted update of information: if an update needs to be propagated, then it needs to be “acknowledged” and done explicitly.

Solution 3.15 If the referenced row is updated, then the attribute of the referencing rows are set to NULL.

Solution 3.16 In the referencing rows,

1. the department number is set to the default value.
2. the department number is updated accordingly.

Solution 3.17 1. This operation is rejected: the row in the DEPARTMENT table with primary key Number set to 3 cannot be deleted if a row in the WORKER table references it.
2. In the referencing rows, the department number is updated accordingly.

Solution 3.18 We could use the following:

```
SELECT Name, Address
FROM TOURIST
WHERE EntryDate > DATE '2012-09-15';
```

Solution 3.19 It selects all the attributes, it is a wildcard.

Solution 3.20 The name of the relation with the name of its schema and a period beforehand. An example would be EMPLOYEE.Name.

Solution 3.21 All the tables in that database.

Solution 3.22 A multiset is a set where the same value can occur twice. In MySQL, the same row can occur twice in a table.

Solution 3.23 They both select all the rows in the MYTABLE table, but ALL will print the duplicate values, whereas DISTINCT will print them only once.

Solution 3.24 You cannot have the WHERE before FROM.

Solution 3.25 SELECT COUNT(*) FROM BOOK;

Solution 3.26 We use those query that projects on attributes using a selection and join conditions when we need to construct for information based on pieces of data spread in multiple tables.

Solution 3.27 It makes the distinction between two different rows of the same table, it is useful when we want to select a tuple in a relation that is in a particular relation with a tuple in the same relation. Quoting https://stackoverflow.com/a/7698796/:

They are useful for saving typing, but there are other reasons to use them:

- If you join a table to itself you must give it two different names otherwise referencing the table would be ambiguous.
• It can be useful to give names to derived tables, and in some database systems it is required... even if you never refer to the name.

**Solution 3.28** We could use the following:

```sql
UPDATE PROF SET Name = 'Hugo Pernot'
WHERE Login = 'caubert';
```

**Solution 3.29** Yes, we can have select condition that does not use primary key. In that case, it could be the case that we update more than one tuple with such a command (which is not necessarily a bad thing).

**Solution 3.30** Unknown value (“Will it rain tomorrow?”), unavailable / withheld (“What is the phone number of Harry Belafonte?”), N/A (“What is the email address of Abraham Lincoln?”).

**Solution 3.31**
- TRUE AND FALSE → FALSE
- TRUE AND UNKNOWN → UNKNOWN
- NOT UNKNOWN → UNKNOWN
- FALSE OR UNKNOWN → FALSE

**Solution 3.32**
- TRUE AND TRUE → TRUE
- TRUE AND FALSE → FALSE
- TRUE AND UNKNOWN → UNKNOWN
- FALSE AND FALSE → FALSE
- UNKNOWN AND UNKNOWN → UNKNOWN
- FALSE AND UNKNOWN → FALSE
- The other cases can be deduced by symmetry.

For a more compact presentation, refer to the three-valued truth table.

**Solution 3.33** IS NOT

**Solution 3.34** It list the login of the professors teaching in the department where the student whose login is “jrakesh” is majoring. It can be rewritten as

```sql
SELECT PROF.Login
FROM PROF, STUDENT
WHERE Department = Major
AND STUDENT.Login = 'jrakesh';
```

**Solution 3.35** It tries to find a Login in a Code.

**Solution 3.36**

```sql
SELECT SUM(Pages) FROM BOOK;
```

**Solution 3.37**

```sql
ALTER TABLE BOOK ADD COLUMN Pages INT;
```

**Solution 3.38**

```sql
ALTER TABLE BOOK ALTER COLUMN Pages DROP DEFAULT;
```

**Solution 3.39** Essentially, if there are no primary key in the relation, and if no attribute has the UNIQUE constraint. Cf. also this previous problem.
Problems

Problem 3.1 *(Discovering the documentation)* The goal of this problem is to learn where to find the documentation for your DBMS, and to understand how to read the syntax of SQL commands.

You can consult (Elmasri and Navathe 2010, Table 5.2, p. 140) or (Elmasri and Navathe 2015, Table 7.2, p. 235), for a very quick summary of the most common commands. Make sure you are familiar with the Backus–Naur form (BNF) notation commonly used:

- non-terminal symbols (i.e., variables, parameters) are enclosed in angled brackets,

<...>  

- optional parts are shown in square brackets,

[...]  

- repetitions are shown in braces

{...}  

- alternatives are shown in parenthesis and separated by vertical bars,

(... | ... | ...)

The most complete lists of commands are probably at

- https://mariadb.com/kb/en/sql-statements/ and

Those are the commands implemented in the DBMS you are actually using. Since there are small variations from one implementation to the other, it is better to take one of this link as a reference in the future.


Problem 3.2 *(Create and use a simple table in SQL)* This problem will guide you in manipulating a very simple table in SQL.

**Pb 3.2 – Question 1** Log in as testuser, create a database named **HW_Address**, use it, and create two tables:

```sql
CREATE TABLE NAME (
    FName VARCHAR(15),
    LName VARCHAR(15),
    ID INT,
    PRIMARY KEY (ID)
);  
```
CREATE TABLE ADDRESS(
    StreetName VARCHAR(15),
    Number INT,
    Habitants INT,
    PRIMARY KEY (StreetName, Number)
);

Pb 3.2 – Question 2 Observe the output produced by the command DESC ADDRESS;

Pb 3.2 – Question 3 Add a foreign key to the ADDRESS table, using

ALTER TABLE ADDRESS
    ADD FOREIGN KEY (Habitants)
    REFERENCES NAME(ID);

And observe the new output produced by the command DESC ADDRESS;

Is it what you would have expected? How informative is it? Can you think of a command that would output more detailed information, including a reference to the existence of the foreign key?

Pb 3.2 – Question 4 Draw the relational model corresponding to that database and identify the primary and foreign keys.

Pb 3.2 – Question 5 Add this data to the NAME table:

    INSERT INTO NAME VALUES ('Barbara', 'Liskov', 003);
    INSERT INTO NAME VALUES ('Tuong Lu', 'Kim', 004);
    INSERT INTO NAME VALUES ('Samantha', NULL, 080);

What command can you use to display this information back? Do you notice anything regarding the values we entered for the ID attribute?

Pb 3.2 – Question 6 Add some data into the ADDRESS table:

    INSERT INTO ADDRESS VALUES
    ('Armstrong Drive', 10019, 003),
    ('North Broad St.', 23, 004),
    ('Robert Lane', 120, NULL);

What difference do you notice with the insertions we made in the NAME table? Which syntax seems more easy to you?

Pb 3.2 – Question 7 Write a SELECT statement that returns the ID number of the person whose first name is “Samantha”.

Pb 3.2 – Question 8 Write a statement that violates the entity integrity constraint. What is the error message returned?

Pb 3.2 – Question 9 Execute an UPDATE statement that violates the referential integrity constraint. What is the error message returned?

Pb 3.2 – Question 10 Write a statement that violates another kind of constraint. Explain what constraint you are violating and explain the error message.
Problem 3.3 (Duplicate rows in SQL) Log in as testuser and create a database titled HW_REPETITION. Create in that database a table (the following questions refer to this table as EXAMPLE, but you are free to name it whatever you want) with at least two attributes that have different data types. Do not declare a primary key yet. Answer the following:

Pb 3.3 – Question 1 Add a tuple to your table using

```sql
INSERT INTO EXAMPLE VALUES (X, Y);
```

where the X and Y are values have the right datatype. Try to add this tuple again. What do you observe? (You can use `SELECT * FROM EXAMPLE;` to observe what is stored in this table.)

Pb 3.3 – Question 2 Alter your table to add a primary key, using

```sql
ALTER TABLE EXAMPLE ADD PRIMARY KEY (Attribute);
```

where Attribute is the name of the attribute you want to be a primary key. What do you observe?

Pb 3.3 – Question 3 Empty your table using

```sql
DELETE FROM EXAMPLE;
```

and alter your table to add a primary key, using the command we gave at the previous step. What do you observe?

Pb 3.3 – Question 4 Try to add the same tuple twice. What do you observe?

Problem 3.4 (Constraints on foreign keys) From the notes, recall the following about foreign keys:

Two important remarks:

- The datatype of the foreign key has to be the exactly the same as the datatype of the attribute to which we are referring.
- The target of the foreign key must be the primary key.

But, the situation is slightly more complex. Test for yourself by editing the following code as indicated:

```sql
/* code/sql/HW_FKtest.sql */
DROP SCHEMA IF EXISTS HW_FKtest;
CREATE SCHEMA HW_FKtest;
USE HW_FKtest;
CREATE TABLE TARGET (  
    Test VARCHAR(15) PRIMARY KEY
);  
```
CREATE TABLE SOURCE (  
  Test VARCHAR(25), FOREIGN KEY (Test) REFERENCES TARGET  
  ↪ (Test)  
);

1. Remove the PRIMARY KEY constraint.
2. Replace PRIMARY KEY with UNIQUE.
3. Replace one of the VARCHAR(25) with CHAR(25).
4. Replace one of the VARCHAR(25) with INT.
5. Replace one of the VARCHAR(25) with VARCHAR(15)
6. Once you have edited and run the program in all of its modified versions, adjust the remarks above to better reflect the reality of the implementation we are using.

Problem 3.5 (Revisiting the PROF table) Create the PROF, DEPARTMENT, STUDENT and GRADE tables as in the “Constructing and populating a new example” section. Populate them with some data (copy it from the notes or come up with your own data).

To obtain exactly the same schema as the one we developed and edited, you can use mysql-dump to “dump” this table, with a command like

mysql-dump -u testuser -ppassword\  
  -h localhost --add-drop-database\  
  --skip-comments --compact\  
  HW_ProfExample > dump.sql

The code we studied during the lecture is more or less the following.

/* code/sql/HW_ProfExampleRevisitedRevisited.sql */  
DROP SCHEMA IF EXISTS HW_ProfExampleRevisited;

CREATE SCHEMA HW_ProfExampleRevisited;

USE HW_ProfExampleRevisited;

CREATE TABLE PROF (  
  Login VARCHAR(25) PRIMARY KEY, NAME VARCHAR(25),  
  Department CHAR(5)  
);

CREATE TABLE DEPARTMENT (  
  Code CHAR(5) PRIMARY KEY, NAME VARCHAR(25), Head  
  VARCHAR(25), FOREIGN KEY (Head) REFERENCES PROF (LOGIN)  
  ON UPDATE CASCADE  
);

ALTER TABLE PROF  
  ADD FOREIGN KEY (Department) REFERENCES DEPARTMENT (Code);

CREATE TABLE STUDENT (  
  
}
Login VARCHAR(25) PRIMARY KEY, NAME VARCHAR(25),
Registered DATE, Major CHAR(5),
FOREIGN KEY (Major) REFERENCES DEPARTMENT (Code)
);

CREATE TABLE GRADE (  
Login VARCHAR(25), Grade INT, PRIMARY KEY (LOGIN, Grade),
FOREIGN KEY (LOGIN) REFERENCES STUDENT (LOGIN)
);

INSERT INTO DEPARTMENT
VALUES ('MATH', 'Mathematics', NULL), ('CS', 'Computer Science', NULL);

INSERT INTO DEPARTMENT (Code, Name)
VALUES ('CYBR', 'Cyber Security');

INSERT INTO PROF (LOGIN, Department, Name)
VALUES ('caubert', 'CS', 'Clément Aubert');

INSERT INTO PROF (LOGIN, Name, Department)
VALUES ('aturing', 'Alan Turing', 'CS'), ('perdos', 'Paul Erdős', 'MATH'), ('bgates', 'Bill Gates', 'CYBR');

INSERT INTO STUDENT (LOGIN, Name, Registered, Major)
VALUES ('jrakesh', 'Jalal Rakesh', DATE '2017-12-01', 'CS'), ('svlatka', 'Sacnite Vlatka', DATE '2015-03-12', 'MATH'), ('cjoeela', 'Candice Joella', '20120212', 'CYBR'), ('aalyx', 'Ava Alyx', '20121011', 'CYBR'),
('caubert', 'Clément Aubert', NULL, 'CYBR');

INSERT INTO GRADE
VALUES ('jrakesh', 3.8), ('svlatka', 2.5);

We will resume working on this model, and enhance it.

**Pb 3.5 – Question 1** Draw the complete relational model for this database (i.e., for the PROF, DEPARTMENT, STUDENT and GRADE relations).

**Pb 3.5 – Question 2** Create and populate a LECTURE table as follows:

- It should have four attributes: Name, Instructor, Code, and Year, of types VARCHAR(25) for the first two, CHAR(5) for Code, and YEAR(4) for Year.
- The Year and Code attributes should be the primary key (yes, have two attributes be the primary key).
- The Instructor attribute should be a foreign key referencing the Login attribute in PROF.
- Populate the LECTURE table with some made-up data.

Try to think about some of the weaknesses of this representation. For instance, can it accommodate two instructors for the same class? Write down two possible scenarios
in which this schema would not be appropriate.

**Pb 3.5 – Question 3** The `GRADE` table had some limitations too. For example, every student could have only one grade. Add two columns to the `GRADE` table using:

```sql
ALTER TABLE GRADE
    ADD COLUMN LectureCode CHAR(5),
    ADD COLUMN LectureYear YEAR(4);
```

Add a foreign key:

```sql
ALTER TABLE GRADE
    ADD FOREIGN KEY (LectureYear, LectureCode)
    REFERENCES LECTURE(Year, Code);
```

Use `DESCRIBE` and `SELECT` to observe the schema of the `GRADE` table and its rows. Is it what you would have expected?

**Pb 3.5 – Question 4** Update the tuples in `GRADE` with some made-up data. Now every row should contain, in addition to a login and a grade, a lecture year and a lecture code.

**Pb 3.5 – Question 5** Update the relational model you previously drew to reflect the new situation of your tables.

**Pb 3.5 – Question 6**

Write `SELECT` statements answering the following questions (where `PROF.Name`, `LECTURE.Name`, `YYYY`, `LECTURE.Code` and `STUDENT.Login` should be relevant values considering your data):

1. “Could you give me the logins and grades of the students who took `LECTURE.Name` in `YYYY`?”
2. “Could you list the instructors who taught in year `YYYY` without any duplicates?”
3. “Could you list the name and grade of all the student who ever took the class `LECTURE.Code`?”
4. “Could you tell me which years was the class `LECTURE.Code` taught?”
5. “Could you list the other classes taught the same year as the class `LECTURE.Code`?”
6. “Could you print the names of the students who registered after `STUDENT/Login`?”
7. “Could you tell me how many departments’ heads are teaching this year?”

---

**Problem 3.6 (TRAIN table and more advanced SQL coding)** Look at the SQL code below and then answer the following questions.

```sql
/* code/sql/HW_Train.sql */

CREATE TABLE TRAIN ( 
    ID VARCHAR(30), Model VARCHAR(30), ConstructionYear YEAR 
    PRIMARY KEY (4) 
);

CREATE TABLE CONDUCTOR ( 
    ID VARCHAR(20), NAME VARCHAR(20), ExperienceLevel VARCHAR(20)
); 
```
CREATE TABLE ASSIGNED_TO (  
  TrainId VARCHAR(20), ConductorId VARCHAR(20), Day DATE,  
  PRIMARY KEY (TrainId, ConductorId)  
);  

Pb 3.6 – Question 1 Modify the CREATE statement that creates the TRAIN table (lines 1–5), so that ID would be declared as the primary key. It is sufficient to only write the line(s) that need to change.  

Pb 3.6 – Question 2 Write an ALTER statement that makes ID become the primary key of the CONDUCTOR table.  

Pb 3.6 – Question 3 Modify the CREATE statement that creates the ASSIGNED_TO table (lines 13–18), so that it has two foreign keys: ConductorId references the ID attribute in CONDUCTOR and TrainId references the ID attribute in TRAIN. It is sufficient to only write the line(s) that need to change.  

Pb 3.6 – Question 4 Write INSERT statements that insert one tuple of your choosing in each relation (no NULL values). These statements should respect all the constraints (including the ones we added in the previous questions) and result in actual insertions. (Remember that four digits is a valid value for an attribute with the YEAR(4) datatype.)  

Pb 3.6 – Question 5 Write a statement that sets the value of the ExperienceLevel attribute to “Senior” in all the tuples where the ID attribute is “GP1029” in the CONDUCTOR relation.  

Pb 3.6 – Question 6 Write a SELECT statement that answers each of the following questions:  

1. “What are the identification numbers of the trains?”  
2. “What are the names of the conductors with a "Senior" experience level?”  
3. “What are the construction years of the "Surfliner" and "Regina" models that we have?”  
4. “What is the ID of the conductor that was responsible of the train referenced "K-13" on 2015/12/14?”  
5. “What are the models that were ever conducted by the conductor whose ID is "GP1029"?”  

Problem 3.7 (Read, correct, and write SQL statements for the COFFEE database)  
Suppose we have the relational model depicted below, with the indicated data in it:  

<table>
<thead>
<tr>
<th>Ref</th>
<th>Origin</th>
<th>TypeOfRoast</th>
<th>PricePerPound</th>
</tr>
</thead>
<tbody>
<tr>
<td>001</td>
<td>Brazil</td>
<td>Light</td>
<td>8.90</td>
</tr>
<tr>
<td>121</td>
<td>Bolivia</td>
<td>Dark</td>
<td>7.50</td>
</tr>
<tr>
<td>311</td>
<td>Brazil</td>
<td>Medium</td>
<td>9.00</td>
</tr>
<tr>
<td>221</td>
<td>Sumatra</td>
<td>Dark</td>
<td>10.25</td>
</tr>
</tbody>
</table>
3.12 Setting Up Your Work Environment

CUSTOMER

<table>
<thead>
<tr>
<th>CardNo</th>
<th>Name</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>001</td>
<td>Bob Hill</td>
<td><a href="mailto:b.hill@isp.net">b.hill@isp.net</a></td>
</tr>
<tr>
<td>002</td>
<td>Ana Swamp</td>
<td><a href="mailto:swampa@nca.edu">swampa@nca.edu</a></td>
</tr>
<tr>
<td>003</td>
<td>Mary Sea</td>
<td><a href="mailto:brig@gsu.gov">brig@gsu.gov</a></td>
</tr>
<tr>
<td>004</td>
<td>Pat Mount</td>
<td><a href="mailto:pmount@fai.fr">pmount@fai.fr</a></td>
</tr>
</tbody>
</table>

SUPPLY

<table>
<thead>
<tr>
<th>Provider</th>
<th>Coffee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coffee Unl.</td>
<td>001</td>
</tr>
<tr>
<td>Coffee Unl.</td>
<td>121</td>
</tr>
<tr>
<td>Coffee Exp.</td>
<td>311</td>
</tr>
<tr>
<td>Johns &amp; Co.</td>
<td>221</td>
</tr>
</tbody>
</table>

PROVIDER

<table>
<thead>
<tr>
<th>Name</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coffee Unl.</td>
<td><a href="mailto:bob@cofunl.com">bob@cofunl.com</a></td>
</tr>
<tr>
<td>Coffee Exp.</td>
<td><a href="mailto:pat@coffeex.dk">pat@coffeex.dk</a></td>
</tr>
<tr>
<td>Johns &amp; Co.</td>
<td>NULL</td>
</tr>
</tbody>
</table>

In the following, we will assume that this model was implemented in a DBMS (MySQL or MariaDB), the primary keys being COFFEE.Ref, CURTOMER.CardNo, SUPPLY.Provider and SUPPLY.Coffee, and PROVIDER.Name, and the foreign keys being as follows:

- FavorCoffee in the CUSTOMER relation refers to Ref in the COFFEE relation
- Provider in the SUPPLY refers to Name in the PROVIDER relation
- Coffee in the SUPPLY refers to Ref in the COFFEE relation

Read and write SQL commands for the following “what-if” scenarios. Assume that:

1. Datatype do not matter: we use only strings and appropriate numerical datatypes.
2. Every statement respects SQL’s syntax (there’s no “a semi-colon is missing” trap).
3. None of these commands are actually executed; the data is always in the state depicted above.

You can use COFFEE.1 to denote the first tuple (or row) in COFFEE, and similarly for other relations and tuples (so that, for instance, SUPPLY.4 corresponds to "Johns & Co"., 221).

**Pb 3.7 – Question 1** Draw the relational model of this table.

**Pb 3.7 – Question 2** Determine if the following insertion statements would violate the entity integrity constraint, ("primary key cannot be NULL and should be unique"),
the referential integrity constraint ("the foreign key must refer to something that exists"), if there would be some other kind of error (ignoring the plausability/relevance of inserting that tuple), or if it would result in successful insertion.

```
INSERT INTO CUSTOMER VALUES(005, 'Bob Hill', NULL, 001);
INSERT INTO COFFEE VALUES(002, "Peru", "Decaf", 3.00);
INSERT INTO PROVIDER VALUES(NULL, "contact@localcof.com");
INSERT INTO SUPPLY VALUES("Johns Co.", 121);
INSERT INTO SUPPLY VALUES("Coffee Unl.", 311, 221);
```

**Pb 3.7 – Question 3**

Assuming that the referential triggered action clause **ON UPDATE CASCADE** is used for each of the foreign keys in this database, list the tuples modified by the following statements:

```
UPDATE CUSTOMER SET FavCoffee = 001
    WHERE CardNo = 001;

UPDATE COFFEE SET TypeOfRoast = 'Decaf'
    WHERE Origin = 'Brazil';

UPDATE PROVIDER SET Name = 'Coffee Unlimited'
    WHERE Name = 'Coffee Unl.';

UPDATE COFFEE SET PricePerPound = 10.00
    WHERE PricePerPound > 10.00;
```

**Pb 3.7 – Question 4**

Assuming that the referential triggered action clause **ON DELETE CASCADE** is used for each of the foreign keys in this database, list the tuples modified by the following statements:

```
DELETE FROM CUSTOMER
    WHERE Name LIKE '%%$%%';

DELETE FROM COFFEE
    WHERE Ref = 001;

DELETE FROM SUPPLY
    WHERE Provider = 'Coffee Unl.'
        AND Coffee = 001;

DELETE FROM PROVIDER
    WHERE Name = 'Johns & Co.';
```

**Pb 3.7 – Question 5**

Assume that there is more data in our table than what was given at the beginning of the problem. Write SQL queries that answer the following questions:

1. “What are the origins of your dark coffees?”
2. “What is the reference of Bob’s favorite coffee?” (note: it does not matter if you return the favorite coffee of all the Bobs in the database.)
3. “What are the names of the providers who did not give their email?”
4. “How many coffees does Johns & co. provide us with?”
5. “What are the names of the providers of my dark coffees?”

Problem 3.8 (Write select queries for the DEPARTMENT table) Consider the following SQL code:

```sql
/* code/sql/HW_Department.sql */
CREATE TABLE DEPARTMENT (ID INT PRIMARY KEY, NAME VARCHAR(30));
CREATE TABLE EMPLOYEE (ID INT PRIMARY KEY, NAME VARCHAR(30), Hired DATE, Department INT,
FOREIGN KEY (Department) REFERENCES DEPARTMENT (ID));
INSERT INTO DEPARTMENT VALUES (1, "Storage"), (2, "Hardware");
INSERT INTO EMPLOYEE VALUES (1, "Bob", 20100101, 1), (2, "Samantha", 20150101, 1), (3, "Mark", 20050101, 2), (4, "Karen", NULL, 1), (5, "Jocelyn", 20100101, 1);
```

Write queries that return the following information. The values returned in this set-up will be in parenthesis, but keep the queries general.

1. The name of the employees working in the Storage department ("Bob", "Samantha", "Karen" and "Jocelyn").
2. The name of the employee that has been hired for the longest period of time ("Mark").
3. The names of the employee(s) from the Storage department who has(have) been hired for the longest period of time. Phrased differently, the oldest employees of the Storage department ("Bob" and "Jocelyn").

Problem 3.9 (Write select queries for the COMPUTER table) Consider the following SQL code:

```sql
/* code/sql/HW_Computer.sql */
DROP SCHEMA IF EXISTS HW_Computer;
CREATE SCHEMA HW_Computer;
USE HW_Computer;
```
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CREATE TABLE COMPUTER (  
    ID VARCHAR(20) PRIMARY KEY, Model VARCHAR(40)  
);  

CREATE TABLE PRINTER (  
    ID VARCHAR(20) PRIMARY KEY, Model VARCHAR(40)  
);  

CREATE TABLE CONNEXION (  
    Computer VARCHAR(20), Printer VARCHAR(20), PRIMARY KEY  
    (Computer, Printer),  
    FOREIGN KEY (Computer) REFERENCES COMPUTER (ID), FOREIGN KEY (Printer) REFERENCES PRINTER (ID)  
);  

INSERT INTO COMPUTER  
VALUES ('A', 'DELL A'), ('B', 'HP X'), ('C', 'ZEPTO D'), ('D', 'MAC Y');  

INSERT INTO PRINTER  
VALUES ('12', 'HP-140'), ('13', 'HP-139'), ('14', 'HP-140'), ('15', 'HP-139');  

INSERT INTO CONNEXION  
VALUES ('A', '12'), ('A', '13'), ('B', '13'), ('C', '14');  

Write queries that return the following information. The values returned in this set-up will be in parenthesis, but keep the queries general.

1. The number of computers connected to the printer whose ID is '13' (2).
2. The number of different models of printers (2).
3. The model(s) of the printer(s) connected to the computer whose ID is 'A' ('HP-140' and 'HP-139').
4. The ID(s) of the computer(s) not connected to any printer ('D').

Problem 3.10 (Write select queries for the SocialMedia schema) Consider the following SQL code:

/* code/sql/HW_SocialMedia.sql */

CREATE TABLE ACCOUNT (  
    ID INT PRIMARY KEY, NAME VARCHAR(25), Email VARCHAR(25) UNIQUE  
);  

CREATE TABLE SUBSCRIBE (  
    Subscriber INT, Subscribed INT, DATE DATE, FOREIGN KEY  
    (Subscriber) REFERENCES ACCOUNT (ID),  
    FOREIGN KEY (Subscribed) REFERENCES ACCOUNT (ID), PRIMARY KEY (Subscriber, Subscribed)  
);
CREATE TABLE VIDEO (  
    ID INT PRIMARY KEY,  
    Title VARCHAR(25),  
    Released DATE,  
    Publisher INT,  
    FOREIGN KEY (Publisher) REFERENCES ACCOUNT (ID)  
);

CREATE TABLE THUMBS_UP (  
    Account INT,  
    Video INT,  
    DATE DATE,  
    PRIMARY KEY (Account, Video),  
    FOREIGN KEY (Account) REFERENCES ACCOUNT (ID),  
    FOREIGN KEY (Video) REFERENCES VIDEO (ID)  
);

INSERT INTO ACCOUNT  
VALUES (1, "Bob Ross", "bob@ross.com"), (2, NULL, "anon@fai.com"), (3, "Martha", NULL);

INSERT INTO SUBSCRIBE  
VALUES (2, 1, DATE "2020-01-01"), (3, 1, DATE "2019-03-03"), (2, 2, DATE "2019-03-03"), (1, 2, DATE "2019-03-03");

-- The first entry means that 2 subscribed to 1, not the  
-- other way around.  
-- And similarly for the other entries.

INSERT INTO VIDEO  
VALUES (10, "My first video!", DATE "2020-02-02", 1),  
(20, "My second video!", DATE "2020-02-03", 1), (30, "My vacations", DATE "2020-02-04", 2);   

INSERT INTO THUMBS_UP  
VALUES (2, 10, DATE "2020-02-02"), (3, 10, DATE "2020-02-02"), (2, 20, DATE "2020-02-02"), (1, 30, DATE "2020-02-05");

Write queries that return the following information. The values returned in this set-up will be in parenthesis, but keep the queries general.

1. The title of all the videos ("My first video!", "My second video!", "My vacations").
2. The release date of the video whose title is "My first video!" ("2020-02-02").
3. The ID of the account(s) where the "Name" attribute was not given ("2").
4. The ID of the videos whose title contains the word "video" ("10", "20").
5. The number of thumbs up for the video with title "My vacations" ("1").
6. The title of the oldest video ("My first video!").
7. The names of the accounts who gave a thumbs up to the video with ID 30 ("Bob Ross").
8. The ID of the account with the greatest number of subscribers ("2").
Problem 3.11 (Write select queries for a variation of the COMPUTER table)
Consider the following SQL code:

```sql
CREATE TABLE COMPUTER (
  ID VARCHAR(20) PRIMARY KEY, Model VARCHAR(40)
);

CREATE TABLE PERIPHERAL (
  ID VARCHAR(20) PRIMARY KEY, Model VARCHAR(40), TYPE ENUM ('mouse', 'keyboard', 'screen', 'printer')
);

CREATE TABLE CONNEXION (
  Computer VARCHAR(20), Peripheral VARCHAR(20), PRIMARY KEY (Computer, Peripheral),
  FOREIGN KEY (Computer) REFERENCES COMPUTER (ID), FOREIGN KEY (Peripheral) REFERENCES PERIPHERAL (ID)
);

INSERT INTO COMPUTER
VALUES ('A', 'Apple IIc Plus'), ('B', 'Commodore SX-64');

INSERT INTO PERIPHERAL
VALUES ('12', 'Trendcom Model', 'printer'), ('14', 'TP-10 Thermal Matrix', 'printer'), ('15', 'IBM Selectric', 'keyboard');

INSERT INTO CONNEXION
VALUES ('A', '12'), ('B', '14'), ('A', '15');
```

Write queries that return the following information. The values returned in this set-up will be in parenthesis, but keep the queries general.

1. The model of the computer whose ID is 'A' ('Apple IIc Plus').
2. The type of the peripheral whose ID is '14' (printer).
3. The model of the printers (Trendcom Model, TP-10 Thermal Matrix).
4. The model of the peripherals whose NAME starts with 'IBM' ('IBM Selectric').
5. The model of the peripherals connected to the computer whose ID is 'A' (Trendcom Model, IBM Selectric).
6. The number of peripheral connected to the computer whose model is Apple IIc Plus (2).

Problem 3.12 (Improving a role-playing game with a relational model) A friend of yours wants you to review and improve the code for a role-playing game.

The original idea was that each character has a name, a class (e.g., Bard, Assassin, Druid), a certain amount of experience, a level, one or more weapons (providing bonuses) and the
ability to complete quests. A quest has a name and rewards the characters who completed it with a certain amount of experience and, on rare occasions, with a special item.

Your friend came up with the following code:

```sql
CREATE TABLE CHARACTER (  
    Name VARCHAR(30) PRIMARY KEY,  
    Class VARCHAR(30),  
    XP INT,  
    LVL INT,  
    Weapon_Name VARCHAR(30),  
    Weapon_Bonus INT,  
    Quest_Completed VARCHAR(30)  
) ;

CREATE TABLE QUEST (  
    ID VARCHAR(20) PRIMARY KEY,  
    Completed_By VARCHAR(30),  
    XP_Gained INT,  
    Special_Item VARCHAR(20),  
    FOREIGN KEY (Completed_By) REFERENCES CHARACTER (Name)  
) ;

ALTER TABLE CHARACTER  
    ADD FOREIGN KEY (Quest_Completed) REFERENCES QUEST (ID) ;
```

However, there are several problems with the code:

- A character can have only one weapon. (All the attempts to “hack” the CHARACTER table to add an arbitrary number of weapons ended up creating horrible messes.)
- Every time a character completes a quest, a copy of the quest must also be created. (Your friend is not so sure why, but nothing else works. Also it seems that a character can complete only one quest, but your friend is not sure about that either.)
- It would be nice to be able to store features that are tied to the class, not the character, like the bonuses they provide and their associated elements (e.g., all bards use fire, all assassins use wind, etc.), but your friend simply cannot figure out how to make that happen.

Can you provide a relational model (there is no need to write the SQL code, but do remember to indicate the primary and foreign keys) that would solve all of your friend’s troubles?

**Problem 3.13 (A simple database for books)** Consider the following code:

```sql
/* code/sql/HW_SimpleBook.sql */
DROP SCHEMA IF EXISTS HW_SimpleBook;

CREATE SCHEMA HW_SimpleBook;

USE HW_SimpleBook;

CREATE TABLE AUTHOR (  
    FName VARCHAR(30), LName VARCHAR(30), Id INT PRIMARY KEY
```
CREATE TABLE PUBLISHER (  
  NAME VARCHAR(30), City VARCHAR(30), PRIMARY KEY (NAME, City)  
);  

CREATE TABLE BOOK (  
  Title VARCHAR(30), Pages INT, Published DATE,  
  PublisherName VARCHAR(30),  
  PublisherCity VARCHAR(30), FOREIGN KEY (PublisherName, PublisherCity) REFERENCES PUBLISHER (NAME, City),  
  Author INT, FOREIGN KEY (Author) REFERENCES AUTHOR (Id),  
  PRIMARY KEY (Title, Published)  
);  

INSERT INTO AUTHOR  
VALUES ("Virginia", "Wolve", 01), ("Paul", "Bryant", 02), ("Samantha", "Carey", 03);  

INSERT INTO PUBLISHER  

INSERT INTO BOOK  

The values inserted in the database is just to provide some examples; you should assume there is more data in it than what we have inserted. In this long problem, you will be asked to write commands to select, update, delete, insert data, and to improve upon the relational model.

Pb 3.13 – Question 1 Write a command that selects:

1. The Title of all the books.
2. The distinct Name of the publishers.
3. The Titles and Published dates of the books published since January 31, 2012.
4. The first and last names of the authors published by "Gallimard" (from any city).
5. The first and last names of the authors who were not published by an editor in "New-York".
6. The ID of the authors who published a book whose name starts with "Where".
7. The total number of pages in the database.
8. The number of pages in the longest book written by the author whose last name is "Wolve".
3.12 Setting Up Your Work Environment

Pb 3.13 – Question 2 Write a command that updates the title of all the books written by the author whose ID is 3 to "BANNED". Is there any reason for this command to be rejected by the system? If yes, explain the reason.

Pb 3.13 – Question 3 Write one or multiple commands that would delete the author whose ID is 3 and all the books written by that author. Make sure you do not violate any foreign key constraints.

Pb 3.13 – Question 4 Write a command that would create a table used to record the awards granted to authors for particular books. Assume that each award has its own name, is awarded every year, and that it is awarded to an author for a particular book. Pick appropriate attributes, datatypes, primary and foreign keys, and, as always, avoid redundancy.

Pb 3.13 – Question 5 Draw the relational model of the database you created (including all the relations given in the code and the ones you added).

Pb 3.13 – Question 6 Discuss two limitations of the model and how to improve it.

Problem 3.14 (A database for website certificates) A certificate for a website has a serial number (SN) and a common name (CN). It must belong to an organization and be signed by a certificate authority (CA). The organization and CA must both have an SN and a CN. A CA can be trusted, not trusted, or not evaluated. The code below is an attempt to represent this situation and is populated with examples.

```sql
CREATE TABLE ORGANIZATION(
    SN VARCHAR(30) PRIMARY KEY,
    CN VARCHAR(30)
);

CREATE TABLE CA(
    SN VARCHAR(30) PRIMARY KEY,
    CN VARCHAR(30),
    Trusted BOOL
);

CREATE TABLE CERTIFICATE(
    SN VARCHAR(30) PRIMARY KEY,
    CN VARCHAR(30),
    Org VARCHAR(30) NOT NULL,
    Issuer VARCHAR(30) NOT NULL,
    Valid_Since DATE,
    Valid_Until DATE,
    FOREIGN KEY (Org) REFERENCES ORGANIZATION(SN)
    ON DELETE CASCADE,
    FOREIGN KEY (Issuer) REFERENCES CA(SN)
);```

38 You can use the DATE datatype to store a year.
3.12 Setting Up Your Work Environment

INSERT INTO ORGANIZATION VALUES
('01', 'Wikimedia Foundation'),
('02', 'Free Software Foundation');

INSERT INTO CA VALUES
('A', "Let's Encrypt", true),
('B', 'Shady Corp.', false),
('C', 'NewComer Ltd.', NULL);

INSERT INTO CERTIFICATE VALUES
('a', '*.wikimedia.org', '01', 'A',
  20180101, 20200101),
('b', '*.fsf.org', '02', 'A',
  20180101, 20191010),
('c', '*.shadytest.org', '02', 'B',
  20190101, 20200101),
('d', '*.wikipedia.org', '01', 'C',
  20200101, 20220101);

1. Write queries that return the following information. The values returned in this set-up will be in parenthesis, but keep the queries general.

a) The CN's of all certificates ("*.wikimedia.org, *.fsf.org, *.shadytest.org, *.wikipedia.org").

b) The SN's of the organizations whose CN contains "Foundation" ("01, 02").

c) The CN's and expiration dates of all the certificates that expired, assuming today is the 6th of December 2019 ("*.fsf.org", 2019 – 10 – 10).

d) The CN's of the CA's that are not trusted ("Shady Corp., NewComer Ltd.").
3.12 Setting Up Your Work Environment

e) The CN’s of the certificates that are signed by a CA that is not trusted ("*.shadytest.org, *.wikipedia.org").

f) The number of certificates signed by the CA whose CN is "Let's encrypt" (2).

g) A table listing the CN’s of the organizations along with the CN’s of their certificates("Wikimedia Foundation, *.wikimedia.org, Free Software Foundation, *.fsf.org, Free Software Foundation, *.shadytest.org, Wikimedia Foundation, *.wikipedia.org").

2. In this set-up, what happens if the following commands are issued? List all the entries that are modified or deleted, or specify if the command would not change anything and explain why.

a) DELETE FROM CA WHERE SN = 'A';
b) UPDATE ORGANIZATION SET CN = "FSF" WHERE SN = '02';
c) UPDATE ORGANIZATION SET SN = "01" WHERE SN = '02';
d) DELETE FROM ORGANIZATION;

Problem 3.15 (A simple database for published pieces of work) Consider the following code:

```sql
/* code/sql/HW_Work.sql */
CREATE TABLE AUTHOR (
    NAME VARCHAR(30) PRIMARY KEY, Email VARCHAR(30)
);

CREATE TABLE WORK (
    Title VARCHAR(30) PRIMARY KEY, Author VARCHAR(30),
    FOREIGN KEY (Author) REFERENCES AUTHOR (NAME) ON DELETE CASCADE ON UPDATE CASCADE
);

CREATE TABLE BOOK (
    ISBN INT PRIMARY KEY, Work VARCHAR(30), Published DATE,
    Price DECIMAL(10, 2),
    FOREIGN KEY (WORK) REFERENCES WORK (Title) ON DELETE RESTRICT ON UPDATE CASCADE
);

CREATE TABLE EBOOK (
    ISBN INT PRIMARY KEY, Work VARCHAR(30), Published DATE,
    Price DECIMAL(10, 2),
    FOREIGN KEY (WORK) REFERENCES WORK (Title) ON DELETE RESTRICT ON UPDATE CASCADE
);

INSERT INTO AUTHOR
VALUES ("Virginia W.", "vw@isp.net"), -- A.1
("Paul B.", "pb@isp.net"), -- A.2
("Samantha T.", "st@fai.fr") -- A.3
;
```
3.12 Setting Up Your Work Environment

Assume the following:

1. Every statement respects SQL’s syntax (there’s no “a semi-colon is missing” trap).
2. None of the commands in the rest of this problem are actually executed; they are for hypothetical “what if” questions.

Also, note that each row inserted between line 39 and 50 is given a name in comment ("A.1, A.2, A.3, W.1", etc.).

Pb 3.15 – Question 1 Draw the relational model corresponding to this series of commands.

Pb 3.15 – Question 2 Determine if the following insertion statements would violate the entity integrity constraint, the referential integrity constraint, if there would be some other kind of error, or if it would result in unsuccessful insertion.

```
INSERT INTO EBOOK VALUES (0, NULL, 20180101, 0);
INSERT INTO AUTHOR VALUES("Mary B.", "mb@fai.fr", NULL);
INSERT INTO WORK VALUES("My Life", "Claude A.");
INSERT INTO BOOK VALUES(00000000, NULL, DATE'20001225', 90.9);
INSERT INTO AUTHOR VALUES("Virginia W.", "alt@isp.net");
```

Pb 3.15 – Question 3 List the rows (A.2, W.1, etc.) modified by the following statements. Be careful about the conditions on foreign keys!

```
UPDATE AUTHOR SET Email = 'Deprecated' WHERE Email LIKE '%isp.net';
UPDATE WORK SET Title = "How to eat" WHERE Title = "What to eat";
DELETE FROM WORK;
DELETE FROM AUTHOR WHERE Name = "Virginia W.";
```

Pb 3.15 – Question 4 Assume that there is more data than what we inserted. Write a command that selects:

- The prices of all the ebooks.
- The distinct names of the authors who have authored a piece of work.
- The names of the authors using fai.fr for their email domain.
• The prices of the ebooks published after 2018.
• The price of the most expensive book.
• The number of the pieces of work written by the author whose name is "Virginia W."
• The email of the author who wrote the piece called “My Life.”
• The ISBN’s of the books containing a work written by the author whose email is “vw@isp.net.”

Pb 3.15 – Question 5 Write a command that updates the title of all the pieces of work written by the author whose name is “Virginia W.” to “BANNED.” Is there any reason for this command to be rejected by the system? If yes, explain the reason.

Pb 3.15 – Question 6 Write one or multiple commands that would delete the work whose title is “My Life”, as well as all of the book and ebook versions of it.

Pb 3.15 – Question 7 Discuss two limitations of the model and how to improve it.

Problem 3.16 (A simple database for authors of textbooks) Consider the following code:

```sql
/* code/sql/HW_TextbookAuthored.sql */
DROP SCHEMA IF EXISTS HW_TEXTBOOKAUTHORED;
CREATE SCHEMA HW_TEXTBOOKAUTHORED;
USE HW_TEXTBOOKAUTHORED;

CREATE TABLE TEXTBOOK (  
    Title VARCHAR(50), ISBN CHAR(13) PRIMARY KEY, Price DECIMAL(10, 2)
);

CREATE TABLE AUTHOR (  
    LName VARCHAR(30), FName VARCHAR(30), Email VARCHAR(30),  
    PRIMARY KEY (Lname, Fname)
);

CREATE TABLE AUTHORED (  
    Book CHAR(13), FOREIGN KEY (Book) REFERENCES TEXTBOOK (ISBN), AuthorLName VARCHAR(30), AuthorFName VARCHAR(30),  
    FOREIGN KEY (AuthorLName, AuthorFName) REFERENCES AUTHOR (LName, Fname)
);

INSERT INTO TEXTBOOK VALUES ('Starting Out with Java: Early Objects', 9780133776744, 30.00), ('NoSQL for Mere Mortals', 9780134023212, 47.99);
```
The meaning of the \texttt{AUTHORED} table is that a tuple \( < I, L, F > \) represents that the author whose last name is L and whose first name is F wrote the textbook whose ISBN is I.

Answer the following:

1. Write a command that updates the email address of ‘Gaddis’, ‘Tony.’
2. Write a command that inserts a textbook of your choice into the \texttt{TEXTBOOK} table. No value should be \texttt{NULL}.
3. Write a command that makes ‘Gaddis’, ‘Tony’ the author of the textbook you just added to our database.
4. Write a command that makes “0.01” the default value for the \texttt{Price} attribute of the \texttt{TEXTBOOK} relation.
5. Write a command that inserts a textbook of your choice in the \texttt{TEXTBOOK} table and have the price set to the default value.
6. Write a command that creates a table called \texttt{EDITOR} with three attributes: \texttt{Name}, \texttt{Address}, and \texttt{Website}. The \texttt{Name} attribute should be the primary key. Insert two tuples in the \texttt{EDITOR} table, making sure that one should have the \texttt{Name} attribute set to “Pearson.”
7. Write a command that creates a table called \texttt{PUBLISHED} with two attributes: \texttt{Editor} and \texttt{Textbook}. The \texttt{Editor} attribute should reference the \texttt{EDITOR} table and the \texttt{Textbook} attribute should reference the \texttt{TEXTBOOK} table.
8. Write a command that makes “Pearson” the editor of the textbook whose ISBN is 9780133776744.

Answer the following short questions based on what is in our model so far:

1. Can an author have authored more than one textbook?
2. Can a textbook have more than one author?
3. Can a textbook without an \texttt{ISBN} be inserted in the \texttt{TEXTBOOK} relation?
4. Can the price of a textbook be negative?
5. Can two authors have the same first and last names?
6. Can two textbooks have the same title?
7. Can two editors have the same address?

---

**Problem 3.17 (A database for residencies)** Consider the following code:

```sql
/* code/sql/HW_Residency.sql */
DROP SCHEMA IF EXISTS HW_RESIDENCY;
CREATE SCHEMA HW_RESIDENCY;
USE HW_RESIDENCY;
```
CREATE TABLE PERSON (  
  FName VARCHAR(40), LName VARCHAR(40), SSN VARCHAR(11)  
  PRIMARY KEY, Birthdate DATE  
);

CREATE TABLE HOUSE (  
  Address VARCHAR(40) PRIMARY KEY, Color ENUM ("blue", "white", "green")  
);

CREATE TABLE RESIDENCY (  
  Person VARCHAR(11), House VARCHAR(40), PrincipalResidence BOOLEAN, Status ENUM ("own", "rent", "squat", "other"),  
  FOREIGN KEY (Person) REFERENCES PERSON (SSN),  
  FOREIGN KEY (House) REFERENCES HOUSE (Address) ON DELETE CASCADE  
);

INSERT INTO PERSON  
VALUES (NULL, "Doe", "000-00-0000", NULL), -- P.1  
("Michael", "Keal", "000-00-0001", DATE "1983-02-11"), -- P.2  
("James", "Baldwin", "000-00-0002", DATE "1967-01-01"), -- P.3  
("Mridula", "Warrier", "000-00-0003", DATE "1990-02-11");  
-- P.4

INSERT INTO HOUSE  
VALUES ("123 Main St.", "blue"), -- H.1  
("456 Second St.", "white"), -- H.2  
("11 Third St.", "blue");  
-- H.3

INSERT INTO RESIDENCY  
VALUES ("000-00-0001", "123 Main St.", TRUE, "own"), -- R.1  
("000-00-0001", "456 Second St.", FALSE, "own"), -- R.2  
("000-00-0002", "123 Main St.", TRUE, "rent"), -- R.3  
("000-00-0003", "456 Second St.", TRUE, "own");  
-- R.4

Note that each row inserted in the PERSON, HOUSE and RESIDENCY tables is given the name and noted as afterwards as a comment ("P.1, P.2, P.3, P.4, H.1", etc.).

Answer the following questions and problems, assuming that none of the commands in the rest of the problem are actually executed.

Pb 3.17 – Question 1 Draw the relational model corresponding to this series of commands (it is not necessary to include the state).

Pb 3.17 – Question 2 Write a command that violates the entity integrity constraint.
Pb 3.17 – Question 3 Write a command that violates the referential integrity constraint.

Pb 3.17 – Question 4 List the rows ("P.2, H.1, or none" [sqlmysql]) modified by the following statements:

1. `UPDATE HOUSE SET COLOR = "green";`
2. `DELETE FROM RESIDENCY WHERE House LIKE "1%";`
3. `DELETE FROM HOUSE WHERE Address = "456 Second St.";`
4. `DELETE FROM PERSON WHERE Birthdate=DATE"1990-02-11";`

Pb 3.17 – Question 5 Write queries that return the following information. The values returned in this set-up will be in parenthesis, but keep the queries general.

1. The Addresses' of the houses in the system ("11 Third St., 123 Main St., 456 Second St.").
2. The SSN's of the people whose first name was not entered in the system ("000-00-0000").
3. All the different colors of houses ("white, blue").
4. The Address of the residency of "James Baldwin" ("123 Main St.").
5. The first name of the oldest person in the database ("James").
6. "Michael Keal"'s principal residency address ("123 Main St.").
7. The distinct first and last names of the homeowners ("Michael Keal, Mridula Warrier").
8. The SSN's of the people that have the same principal residency as "James Baldwin" ("000-00-0001").

Pb 3.17 – Question 6 Write a command that updates the SSN of "James Baldwin" to "000-00-0010". Is there any reason for this command to be rejected by the system? If yes, explain the reason.

Pb 3.17 – Question 7 Answer the following short questions from the data in our model, as it is currently:

1. Is it possible for two people to have the same last name?
2. Is it possible for a person to have multiple principal residencies?
3. Is it possible for a house to not be yellow?
4. Is it possible for the SSN to be any series of 11 characters?
5. Is it possible for a person to own any number of houses?
6. Is it possible for a person to rent at most one house?

Pb 3.17 – Question 8 Consider the data currently in the RESIDENCY table and give a possible primary key.

Pb 3.17 – Question 9 Discuss why the primary key identified from the previous question for the RESIDENCY table is a good choice.

Solutions to Selected Problems

Solution to Problem 3.2 (Create and use a simple table in SQL) This problem is supposed to be a straightforward application of what we studied in class. Look back at Setting Up Your Work Environment if you feel like you are stuck before referencing this solution.

Pb 3.2 – Solution to Q. 1 We simply log-in as indicated in the "Logging-in as testuser" section. Then we enter:
CREATE DATABASE HW_Address;
USE HW_Address;

This creates the tables asked for in the problem.

**Pb 3.2 – Solution to Q. 2** Ommiting the Extra column, we have:

```
| Field     | Type       | Null | Key | Default |
+-----------+------------+------|-----+---------|
| StreetName| varchar(15)| NO   | PRI | NULL    |
| Number    | int(11)    | NO   | PRI | NULL    |
| Habitants | int(11)    | YES  |     | NULL    |
```

**Pb 3.2 – Solution to Q. 3** We add the foreign key, still ommiting the Extra column:

```
| Field     | Type       | Null | Key   | Default |
+-----------+------------+------|-------+---------|
| StreetName| varchar(15)| NO   | PRI   | NULL    |
| Number    | int(11)    | NO   | PRI   | NULL    |
| Habitants | int(11)    | YES  | MUL   | NULL    |
```

The only difference is the MUL value, which is a bit surprising: quoting https://dev.mysql.com/doc/refman/8.0/en/show-columns.html,

> If **Key** is MUL, then the column is the first column of a nonunique index in which multiple occurrences of a given value are permitted within the column.

In other words, this does not carry any information about the fact that ADDRESS.Habitants is now a foreign key referencing NAME.ID. A way of displaying information about that foreign key is using **SHOW CREATE TABLE**:

```
| Table | Create Table |
+-------+--------------|
| ADDRESS | CREATE TABLE `ADDRESS` (  
  `StreetName` varchar(15) NOT NULL,
  `Number` int(11) NOT NULL,
  `Habitants` int(11) DEFAULT NULL,
  PRIMARY KEY (`StreetName`,`Number`),
  KEY `Habitants` (`Habitants`),
  CONSTRAINT `ADDRESS_ibfk_1` FOREIGN KEY (`Habitants`)  
) REFERENCES `NAME` (`ID`)  
) ENGINE=InnoDB DEFAULT CHARSET=utf8mb4 |
```

1 row in set (0.01 sec)
Pb 3.2 – Solution to Q. 4

Pb 3.2 – Solution to Q. 5 To display the information back, we can use

```
SELECT * FROM NAME;
```

We should notice that the ID attribute values lost their leading zeros\(^{39}\).

Pb 3.2 – Solution to Q. 6 This syntax is better for “bulk insertion” since it allows for us to write fewer commands and to focus on the data being inserted. However, if an error occurs, then nothing gets inserted.

Pb 3.2 – Solution to Q. 7 `SELECT ID FROM NAME WHERE FName = 'Samantha';`

Pb 3.2 – Solution to Q. 8 This is a command that violates the entity integrity constraint:

```
INSERT INTO NAME VALUES ('Maria', 'Kashi', NULL);
```

The error message that it returns is:

```
ERROR 1048 (23000): Column 'ID' cannot be null
```

Another way of violating the entity integrity constraint is:

```
INSERT INTO NAME VALUES ('Maria', 'Kashi', 80);
```

The error message that it returns is:

```
ERROR 1062 (23000): Duplicate entry '80' for key 'PRIMARY'
```

Pb 3.2 – Solution to Q. 9 This is an **UPDATE** statement that violates the entity integrity constraint:

```
UPDATE ADDRESS SET Habitants = 340 WHERE Number = 120;
```

The error message that it returns is:

```
ERROR 1452 (23000): Cannot add or update a child row: a foreign key constraint fails
```

\(^{39}\)https://en.wikipedia.org/wiki/Leading_zero

Pb 3.2 – Solution to Q. 10 Here is the query that violates another type of constraint:

```
INSERT INTO NAME VALUE ('Hi');
```

The error message that it returns is:
ERROR 1136 (21S01): Column count does not match value count at row 1

The query statement violates the implicit constraint by trying to insert a row with fewer values than there are attributes in the table.

Another example of a statement that violates another type of constraint is:

```
INSERT INTO ADDRESS VALUES ('Maria', 'Random', 98);
```

This is a violation of an explicit constraint, which is that the value must match the domain (datatype) of the attribute where it is inserted. However, MySQL and MariaDB do not return an error, they simply replace 'Random' with 0.

---

**Solution to Problem 3.3 (Duplicate rows in SQL)** Here is how we created our table:

```sql
CREATE SCHEMA HW_REPETITION;
USE HW_REPETITION;
CREATE TABLE EXAMPLE(
    X VARCHAR(15),
    Y INT
);
```

**Pb 3.3 – Solution to Q. 1** The command to add a tuple to our table is:

```
INSERT INTO EXAMPLE VALUES('Train', 4);
```

If we execute this command twice, then SQL is OK with it, and inserts the same tuple twice:

```
SELECT * FROM EXAMPLE;
```

Displays:

```
+-------+------+
| X     | Y    |
+-------+------+
| Train |  4   |
| Train |  4   |
+-------+------+
```

This is an illustration of the fact that the data in a table in SQL is not a set, as opposed to a state in a relation in the relational model.

**Pb 3.3 – Solution to Q. 2** The command:

```
ALTER TABLE EXAMPLE ADD PRIMARY KEY (X);
```

Should return:

```
ERROR 1062 (23000): Duplicate entry 'Train' for key 'PRIMARY'
```
We tried to declare that $X$ was a primary key, but SQL disagreed, since two rows have the same value for that attribute.

**Pb 3.3 – Solution to Q. 3** Once the table is empty, $X$ now qualifies as a candidate key, and can now be made a primary key. SQL stops complaining and lets us assign it as a primary key.

**Pb 3.3 – Solution to Q. 4** After trying this insertion statement twice:

```sql
INSERT INTO EXAMPLE VALUES ('Train', 4);
```

SQL refuses to insert the tuple after the second attempt:

```
ERROR 1062 (23000): Duplicate entry 'Train' for key ↪ 'PRIMARY'
```

Notice that this is exactly the same error message as before, when we tried to add the primary key while we had a duplicate row of tuples!

---

**Solution to Problem 3.4 (Constraints on foreign keys)**

1. Removing the PRIMARY KEY constraint, SQL throws the following error message:

```
ERROR 1005 (HY000): Can't create table
  `HW_FK_test`.`SOURCE` (errno: 150 "Foreign key constraint is incorrectly formed")
```

2. Replacing PRIMARY KEY with UNIQUE does not generate any error messages.

3. Replacing one of the VARCHAR(25) with CHAR(25) does not generate any error messages.

4. Replacing VARCHAR(25) with INT results in this error message:

```
ERROR 1005 (HY000): Can't create table
  `HW_FK_test`.`SOURCE` (errno: 150 "Foreign key constraint is incorrectly formed")
```

5. Replacing one of the VARCHAR(25) with VARCHAR(15) does not generate any error messages.

6. The remarks become:

   - The datatype of the foreign key has to be **compatible** with the datatype of the attribute to which we are referring.
   - The target of the foreign key **must be** the primary key or have the UNIQUE constraint.
Solution to Problem 3.5 (Revisiting the PROF table) Pb 3.5– Solution to Q. 1

Ignoring the LECTURE relation, we have:

Pb 3.5– Solution to Q. 2 The code is straightforward:

```sql
CREATE TABLE HW_Lecture (  
    NAME VARCHAR(25), Instructor VARCHAR(25), Year YEAR  
    (4),  
    Code CHAR(5),  
    PRIMARY KEY (Year, Code), FOREIGN KEY (Instructor)  
    REFERENCES PROF (LOGIN)  
);  

INSERT INTO HW_Lecture  
VALUES ('Intro to CS', 'caubert', 2017, '1304'),  
    ('Intro to Algebra', 'perdos', 2017, '1405'), ('Intro to Cyber', 'aturing', 2017, '1234');
```

However, this representation can not handle the following situations:

- If multiple instructors teach the same class,
- If the lecture is taught more than once a year (either because it is taught in the Fall, Spring and Summer, or if multiple sections are offered at the same time),
- If a Lecture is cross-listed, then some duplication of information will be needed.

We come back to those short-coming in the “Reverse-Engineering” section, using more abstract tools (such as Entity Diagrams) that have not been introduced yet.
Pb 3.5– Solution to Q. 3 The statements are immediate:

```
82  DESCRIBE  GRADE;
83
84  SELECT  *
85  FROM  GRADE;
86
```

What may be surprising is that the values for LectureCode and LectureYear are set to NULL in all the tuples.

Pb 3.5– Solution to Q. 4 We use UPDATE statements:

```
89  UPDATE  GRADE
90      SET  LectureCode = '1304', LectureYear = 2017
91      WHERE  LOGIN = 'jrakesh'
92              AND  Grade = '2.85';
93
94  UPDATE  GRADE
95      SET  LectureCode = '1405', LectureYear = 2017
96      WHERE  LOGIN = 'svlatka'
97    OR (LOGIN = 'jrakesh'
98        AND  Grade = '3.85');
99
100 UPDATE  GRADE
101      SET  LectureCode = '1234', LectureYear = 2017
102      WHERE  LOGIN = 'aalyx'
103     OR  LOGIN = 'cjoella';
104
```

Pb 3.5– Solution to Q. 5 We refer back to the solution to Q. 1.

Pb 3.5– Solution to Q. 6 We use SELECT statements:

```
110  SELECT  LOGIN, Grade
111  FROM  GRADE
112  WHERE  Lecturecode = '1304'
113      AND  LectureYear = '2017';
114
115  SELECT  DISTINCT  Instructor
116  FROM  HW_Lecture
117  WHERE  Year = 2017;
118
119  SELECT  Name, Grade
120  FROM  STUDENT, GRADE
121  WHERE  GRADE.LectureCode = 1405
122      AND  STUDENT.Login = GRADE.Login;
123
124  SELECT  Year
125  FROM  HW_Lecture
```
WHERE Code = '1234';

SELECT Name
FROM HW_Lecture
WHERE Year IN (SELECT Year
                    FROM HW_Lecture
                    WHERE Code = '1234');

SELECT B.name
FROM STUDENT AS A, STUDENT AS B
WHERE A.Name = 'Ava Alyx'
    AND A.Registered > B.Registered;

SELECT COUNT(DISTINCT PROF.Name) AS 'Head Teaching This Year'
FROM HW_Lecture, DEPARTMENT, PROF
WHERE Year = 2017
    AND Instructor = Head
    AND Head = PROF.Login;

---

Solution to Problem 3.6 (TRAIN table and more advanced SQL coding) The code below includes the answers to all of the questions for this problem:

-- Question 1:
CREATE TABLE TRAIN (Id VARCHAR(30) PRIMARY KEY, -- This line was changed.
                      Model VARCHAR(30), ConstructionYear YEAR (4));

-- Question 2:
CREATE TABLE CONDUCTOR (Id VARCHAR(20), NAME VARCHAR(20), ExperienceLevel
                          VARCHAR(20));

ALTER TABLE CONDUCTOR
    ADD PRIMARY KEY (Id);

-- Question 3
CREATE TABLE ASSIGNED_TO (TrainId VARCHAR(20), ConductorId VARCHAR(20), Day DATE,
                           PRIMARY KEY (TrainId, ConductorId), FOREIGN KEY (TrainId) REFERENCES TRAIN (Id), -- This line was changed
                           FOREIGN KEY (ConductorId) REFERENCES CONDUCTOR (Id) -- This line was changed);
-- Question 4:

/*
We insert more than one tuple, to make the SELECT
statements that follow easier
to test and debug.
*/

INSERT INTO TRAIN VALUES ('K-13', 'SurfLiner', 2019),
                     ('K-12', 'Regina', 2015);

INSERT INTO CONDUCTOR
VALUES ('GP1029', 'Bill', 'Junior'), ('GP1030', 'Sandrine', 'Junior');

INSERT INTO ASSIGNED_TO
VALUES ('K-13', 'GP1029', '2015/12/14'), ('K-12', 'GP1030', '20120909');

-- Question 5:

UPDATE CONDUCTOR
SET ExperienceLevel = 'Senior'
WHERE Id = 'GP1029';

-- Question 6:

-- 1.
SELECT Id FROM TRAIN;

-- 2.
SELECT Name FROM CONDUCTOR
WHERE ExperienceLevel = 'Senior';

-- 3.
SELECT ConstructionYear FROM TRAIN
WHERE Model = 'SurfLiner'
    OR Model = 'Regina';

-- 4.
SELECT ConductorId FROM ASSIGNED_TO
WHERE TrainId = 'K-13'
    AND Day = '2015/12/14';

-- 5.
SELECT Model FROM TRAIN, ASSIGNED_TO
WHERE ConductorID = 'GP1029'
    AND TrainId = TRAIN.ID;
Solution to Problem 3.7 (Read, correct, and write SQL statements for the COFFEE database)

Solution to Question 1:

The answers to the rest of the questions are in the following code:

```sql
/* code/sql/HW_DBCoffee.sql */
-- Question 2:
START TRANSACTION;

INSERT INTO CUSTOMER
VALUES (005, 'Bob Hill', NULL, 001);

INSERT INTO COFFEE
VALUES (002, "Peru", "Decaf", 3.00);

-- The following statement raises an error.
-- INSERT INTO PROVIDER
-- VALUES (NULL, "contact@localcof.com");
-- ERROR 1048 (23000) at line 68: Column 'Name' cannot be
-- null

INSERT INTO SUPPLY
VALUES ("Johns & Co.", 121);

-- The following statement raises an error.
-- INSERT INTO SUPPLY
-- VALUES ("Coffee Unl.", 311, 221);
-- ERROR 1136 (21S01): Column count doesn't match value
-- count at row 1

-- Rest the changes:
ROLLBACK;

-- Question 3:
START TRANSACTION;
```
UPDATE
  CUSTOMER
SET  FavCoffee = 001
WHERE CardNo = 001;

-- Rows matched: 1  Changed: 1  Warnings: 0
SELECT *
FROM CUSTOMER;
ROLLBACK;

START TRANSACTION;

UPDATE
  COFFEE
SET  TypeOfRoast = 'Decaf'
WHERE Origin = 'Brazil';

-- Rows matched: 2  Changed: 2  Warnings: 0
SELECT *
FROM COFFEE;
ROLLBACK;

START TRANSACTION;

UPDATE
  PROVIDER
SET  Name = 'Coffee Unlimited'
WHERE Name = 'Coffee Unl.';

-- Rows matched: 1  Changed: 1  Warnings: 0
SELECT *
FROM PROVIDER;

SELECT *
FROM SUPPLY;
ROLLBACK;

START TRANSACTION;

UPDATE
  COFFEE
SET  PricePerPound = 10.00
WHERE PricePerPound > 10.00;

-- Rows matched: 1  Changed: 1  Warnings: 0
SELECT *
FROM COFFEE;
ROLLBACK;

-- Question 4:
START TRANSACTION;

DELETE FROM CUSTOMER
WHERE Name LIKE '%S%';

-- Query OK, 2 rows affected (0.01 sec)
SELECT *
FROM CUSTOMER;

ROLLBACK;

START TRANSACTION;

DELETE FROM COFFEE
WHERE Ref = '001';

-- Query OK, 1 row affected (0.00 sec)
SELECT *
FROM COFFEE;

SELECT *
FROM SUPPLY;

ROLLBACK;

START TRANSACTION;

DELETE FROM SUPPLY
WHERE Provider = 'Coffee Unl.'
    AND Coffee = '001';

-- Query OK, 1 row affected (0.00 sec)
SELECT *
FROM SUPPLY;

ROLLBACK;

START TRANSACTION;

DELETE FROM PROVIDER
WHERE Name = 'Johns & Co.';

-- Query OK, 1 row affected (0.00 sec)
SELECT *
FROM PROVIDER;
3.12 Setting Up Your Work Environment

```sql
SELECT *
FROM SUPPLY;
ROLLBACK;

-- Question 5:

-- 1.
SELECT Origin
FROM COFFEE
WHERE TypeOfRoast = 'Dark';

-- 2.
SELECT FavCoffee
FROM CUSTOMER
WHERE Name LIKE 'Bob%';

-- 3.
SELECT Name
FROM PROVIDER
WHERE Email IS NULL;

-- 4.
SELECT COUNT(*)
FROM SUPPLY
WHERE Provider = 'Johns & Co.';

-- 5.
SELECT Provider
FROM COFFEE, SUPPLY
WHERE TypeOfRoast = 'Dark'
   AND Coffee = Ref;

Solution to Problem 3.8 (Write select queries for the DEPARTMENT table)

1. SELECT Name
   FROM EMPLOYEE, DEPARTMENT
   WHERE DEPARTMENT.Name = "Storage"
      AND EMPLOYEE.Department = DEPARTMENT.ID;

2. SELECT Name
   FROM EMPLOYEE
   WHERE Hired <= ALL (SELECT Hired
                        FROM EMPLOYEE
                        WHERE Hired IS NOT NULL);

3. SELECT EMPLOYEE.Name
   FROM EMPLOYEE, DEPARTMENT
```
WHERE Hired <= ALL (  
    SELECT Hired  
    FROM EMPLOYEE  
    WHERE Hired IS NOT NULL  
    AND DEPARTMENT.Name = "Storage"  
    AND EMPLOYEE.Department = DEPARTMENT.ID)  
AND DEPARTMENT.Name = "Storage"  
AND EMPLOYEE.Department = DEPARTMENT.ID;

Solution to Problem 3.11 (Write select queries for a variation of the COMPUTER table)

SELECT Model  
FROM COMPUTER  
WHERE ID = 'A';

SELECT TYPE  
FROM PERIPHERAL  
WHERE ID = '14';

SELECT Model  
FROM PERIPHERAL  
WHERE TYPE = 'printer';

SELECT Model  
FROM PERIPHERAL  
WHERE Model LIKE 'IBM%';

SELECT Model  
FROM PERIPHERAL, CONNEXION  
WHERE Computer = 'A'  
    AND Peripheral = PERIPHERAL.ID;

SELECT COUNT(Computer)  
FROM CONNEXION, COMPUTER  
WHERE Model = 'Apple IIc Plus'  
    AND Computer = COMPUTER.ID;

Solution to Problem 3.10 (Write select queries for the SocialMedia schema)

/* code/sql/HW_SocialMedia.sql */
-- ... the title of all the videos ("My first video!", "My second video!", "My vacations").
SELECT TITLE  
FROM VIDEO;
-- ... the release date of the video whose title is "My first video!" ("2020-02-02").
SELECT Released
FROM VIDEO
WHERE Title = "My first video!";

-- ... the ID of the account(s) where the "Name" attribute was not given ("2").
SELECT ID
FROM ACCOUNT
WHERE Name IS NULL;

-- ... the ID of the videos whose title contains the word "video" ("10", "20").
SELECT ID
FROM VIDEO
WHERE TITLE LIKE "%video%";

-- or
SELECT ID
FROM VIDEO
WHERE Title REGEXP 'video';

-- ... the number of thumbs up for the video with title "My vacations" ("1").
SELECT COUNT(*)
FROM THUMBS_UP, VIDEO
WHERE VIDEO.Title = "My vacations" AND VIDEO.ID = THUMBS_UP.Video;

-- ... the title of the oldest video ("My first video!").
SELECT Title
FROM VIDEO
WHERE Released <= ALL (SELECT Released
FROM VIDEO);

-- or
SELECT Title
FROM VIDEO
WHERE Released = (SELECT Min(Released)
FROM VIDEO);

-- or even
SELECT Title
FROM VIDEO
ORDER BY Released ASC
LIMIT 1;
Solution to Problem 3.12 (Improving a role-playing game with a relational model)

The following solves all the issues with your friend’s code design. As quests only rarely provide a special item, we added a relation to avoid having a `Special-item` in the `QUEST` table since that would be `NULL` too often.

```
-- ... the names of the accounts who gave a thumbs up to the
-- video with id 30 ("Bob Ross").
SELECT Name
FROM ACCOUNT, THUMBS_UP
WHERE THUMBS_UP.Video = 30
  AND THUMBS_UP.Account = ACCOUNT.ID;

-- ... the ID of the account with the greatest number of
-- subscribers ("2").
SELECT Subscribed
FROM SUBSCRIBE
GROUP BY Subscribed
ORDER BY COUNT(Subscriber) DESC
LIMIT 1;
```

Solution to Problem 3.13 (A simple database for books) Pb 3.13 – Solution to Q. 1

Here are possible ways of getting the required information:

1. The `Title` of all the books:

   ```
   SELECT Title FROM BOOK;
   ```
2. The *distinct* Name of the publishers.

   ```sql
   SELECT DISTINCT Name FROM PUBLISHER;
   ```

3. The Titles and Published dates of the books published since January 31, 2012.

   ```sql
   SELECT Title, Published FROM BOOK
   WHERE Published > DATE'20120131';
   ```

4. The first and last names of the authors published by "Gallimard" (from any city).

   ```sql
   SELECT FName, LName FROM AUTHOR, BOOK
   WHERE PublisherName = "Gallimard"
   AND Author = ID;
   ```

5. The first and last names of the authors who were not published by an editor in "New-York".

   ```sql
   SELECT FName, LName FROM AUTHOR, BOOK
   WHERE NOT PublisherCity = "New-York"
   AND Author = ID;
   ```

6. The ID of the authors who published a book whose name starts with "Where".

   ```sql
   SELECT Author FROM BOOK
   WHERE Title LIKE 'Where%';
   ```

7. The total number of pages in the database.

   ```sql
   SELECT SUM(Pages) FROM BOOK;
   ```

8. The number of pages in the longest book written by the author whose last name is "Wolve".

   ```sql
   SELECT MAX(PAGES) FROM BOOK, AUTHOR
   WHERE LName = "Wolve"
   AND Author = ID;
   ```


   ```sql
   SELECT Title FROM BOOK
   WHERE Published >= DATE'18010101'
   AND Published <= DATE'19001231';
   ```

Pb 3.13 – Solution to Q. 2 We can use the following command:

```sql
UPDATE BOOK SET Title = "BANNED"
WHERE Author = 3;
```

The pair (title, publication date) is the primary key in the BOOK table, so if the author whose ID is 3 has published more than one book at a particular date, then our update will be rejected, as applying it would result in violating the entity integrity constraint.

Pb 3.13 – Solution to Q. 3 To delete the required rows, we can use:
DELETE FROM BOOK WHERE Author = 3;
DELETE FROM AUTHOR WHERE ID = 3;

Note that trying to delete the rows in the AUTHOR table before deleting the rows in the
BOOK table could cause a referential integrity violation, since the BOOK table has a foreign
key assigned to the AUTHOR table’s Id field.

**Pb 3.13 – Solution to Q. 4** We could design that table as follows:

```sql
CREATE TABLE AWARD(
    Name VARCHAR(30),
    Year DATE,
    BookTitle VARCHAR(30),
    BookPubDate DATE,
    FOREIGN KEY (BookTitle, BookPubDate)
        REFERENCES BOOK(Title, Published),
    PRIMARY KEY (Name, Year)
);
```

Note that there is no need to store the name of the author in this relation: this information
can be recovered by looking in the BOOK table for the name of the author of the awarded
book.

**Pb 3.13 – Solution to Q. 5** We obtain something as follows:

![Diagram of database tables](image.png)

Note that having two attributes as the primary key makes the referencing of foreign keys
more cumbersome.

**Pb 3.13 – Solution to Q. 6** Two of the flaws that come to mind are:

1. The choice of the primary key for the BOOK relation: two books with the same
title cannot be published on the same day, which is a serious limitation. Using a
primary key like ISBN would be much more appropriate.
2. This design makes it impossible to deal with books written by multiple authors or
published by multiple publishers. We could address this by having two separate
tables, IS_THE_AUTHOR_OF and PUBLISHED_BY, that “maps” the book’s
ISBN with author’s or editor’s primary key.

---

**Solution to Problem 3.14 (A database for website certificates)** The solution can be read
from the following code:
/* code/sql/HW_Certificate.sql */

DROP SCHEMA IF EXISTS HW_Certificate;

CREATE SCHEMA HW_Certificate;

USE HW_Certificate;

/*
SN = Serial Number
CN = Common Name
CA = Certificate Authority
*/

CREATE TABLE ORGANIZATION (
   SN VARCHAR(30) PRIMARY KEY, CN VARCHAR(30)
);

CREATE TABLE CA (
   SN VARCHAR(30) PRIMARY KEY, CN VARCHAR(30), Trusted BOOL
);

CREATE TABLE CERTIFICATE (
   SN VARCHAR(30) PRIMARY KEY, CN VARCHAR(30) NOT NULL, Org VARCHAR(30) NOT NULL, Issuer VARCHAR(30),
   Valid_Since DATE, Valid_Until DATE, FOREIGN KEY (Org)
      REFERENCES ORGANIZATION (SN) ON DELETE CASCADE, FOREIGN KEY (Issuer) REFERENCES CA (SN)
);

INSERT INTO ORGANIZATION
   VALUES ('01', 'Wikimedia Foundation'), ('02', 'Free Software Foundation');

INSERT INTO CA
   VALUES ('A', "Let's Encrypt", TRUE), ('B', 'Shady Corp.', FALSE), ('C', 'NewComer Ltd.', NULL);

INSERT INTO CERTIFICATE
   VALUES ('a', '*.wikimedia.org', '01', 'A', 20180101, 20200101),
          ('b', '*.fsf.org', '02', 'A', 20180101, 20191010),
          ('c', '*.shadytest.org', '02', 'B', 20190101, 20200101),
          ('d', '*.wikipedia.org', '01', 'C', 20200101, 20220101);

-- CN of all certificates.
SELECT CN
   FROM CERTIFICATE;

-- (*.wikimedia.org | *.fsf.org | *.shadytest.org |
--  * .wikipedia.org)
3.12 Setting Up Your Work Environment

```
-- The SN of the organizations whose CN contains
-- "Foundation"
SELECT SN
FROM ORGANIZATION
WHERE CN LIKE "%Foundation%";

-- (01 | 02)
-- The CN and expiration date of all the certificates that
-- expired (assuming we are the 6th of December 2019).
SELECT CN, Valid_Until
FROM CERTIFICATE
WHERE Valid_Until < DATE '20191206';

-- (*.fsf.org, 2019-10-10)
-- The CN of the CA that are not trusted.
SELECT CN
FROM CA
WHERE Trusted IS NOT TRUE;

-- (Shady Corp. | NewComer Ltd.)
-- The CN of the certificates that are signed by a CA that
-- is not trusted.
SELECT CERTIFICATE.CN
FROM CERTIFICATE, CA
WHERE Trusted IS NOT TRUE
AND CA.SN = CERTIFICATE.Issuer;

-- (Shady Corp. | NewComer Ltd.)
-- The number of certificates signed by the CA whose CN is
-- "Let's encrypt".
SELECT COUNT(CERTIFICATE.SN) AS "Number of certificates
signed
by Let's encrypt"
FROM CERTIFICATE, CA
WHERE CERTIFICATE.Issuer = CA.SN
AND CA.CN = "Let's encrypt";

-- (2)
-- A table listing the CN of the organizations along with
-- the CN of their certificates.
SELECT ORGANIZATION.CN AS Organization, CERTIFICATE.CN AS Certificate
FROM ORGANIZATION, CERTIFICATE
WHERE CERTIFICATE.Org = ORGANIZATION.SN;
```

-- ( Wikimedia Foundation, *.wikimedia.org | Free Software
-- Foundation, *.fsf.org | Free Software Foundation ,
-- *.shadytest.org | Wikimedia Foundation ,
-- *.wikipedia.org
-- )
Solution to Problem 3.15 (A simple database for published pieces of work) Pb 3.15 – Solution to Q. 1

The relational model for this code is:
Pb 3.15 – Solution to Q. 2

The solution to the next questions can be read from the following code:

```sql
START TRANSACTION;

-- We don't want to perform the actual insertions.
INSERT INTO EBOOK
VALUES (0, NULL, 20180101, 0);

/*
  Query OK, 1 row affected (0.003 sec)
  So, "Successful insertion".
*/

-- The following statement raises an error.
-- INSERT INTO AUTHOR
-- VALUES ("Mary B.", "mb@fai.fr", NULL);
/*
ERROR 1136 (21S01): Column count doesn't match value count
at row 1
  So, "Other kind of error".
*/

-- The following statement raises an error.
-- INSERT INTO WORK
-- VALUES ("My Life", "Claude A.");
/*
ERROR 1452 (23000): Cannot add or update a child row: a
foreign key constraint fails
*/
```
3.12 Setting Up Your Work Environment

(`HW_EXAM_1`.`WORK`, CONSTRAINT `WORK_ibfk_1` FOREIGN KEY (`Author`) REFERENCES `AUTHOR` (`Name`) ON DELETE CASCADE ON UPDATE CASCADE)
So, "Referential integrity constraint"
*/

INSERT INTO BOOK
VALUES (00000000, NULL, DATE '20001225', 90.9);

/*
Query OK, 1 row affected (0.000 sec)
So, "Successful insertion".
*/

-- The following statement raises an error.
-- INSERT INTO AUTHOR
-- VALUES ("Virginia W.", "alt@isp.net");
/*
ERROR 1062 (23000): Duplicate entry 'Virginia W.' for key
'PRIMARY'
So, "Entity integrity constraint".
*/
ROLLBACK;

-- We go back to the previous state.
/*
List the rows (i.e., A.2, W.1, etc.) modified by the following statements
(be careful about the conditions on foreign keys!):
*/
START TRANSACTION;

-- We don't want to perform the following operations.
UPDATE
AUTHOR
SET Email = 'Deprecated'
WHERE Email LIKE '%isp.net';

/*
Query OK, 2 rows affected (0.010 sec)
Rows matched: 2 Changed: 2 Warnings: 0
This changed A.1 and A.2
*/
UPDATE
WORK
SET Title = "How to eat"
WHERE Title = "What to eat";
Rows matched: 1 Changed: 1 Warnings: 0
SQL returns only the number of row changed in the WORK table,
but other rows have been changed as well.
This changed W.1, B.1, E.1.
*/
-- The following statement raises an error.
-- DELETE FROM WORK;
/*
ERROR 1451 (23000): Cannot delete or update a parent row: a 
foreign key constraint fails
(‘HW_EXAM_1’.‘BOOK’, CONSTRAINT `BOOK_ibfk_1` FOREIGN KEY 
(‘Work’) REFERENCES `WORK` (‘Title’) ON UPDATE CASCADE)
Does not change any row.
*/
-- The following statement raises an error.
-- DELETE FROM AUTHOR
-- WHERE Name = "Virginia W.";
/*
ERROR 1451 (23000): Cannot delete or update a parent row: a 
foreign key constraint fails
(‘HW_EXAM_1’.‘BOOK’, CONSTRAINT `BOOK_ibfk_1` FOREIGN KEY 
(‘Work’) REFERENCES `WORK` (‘Title’) ON UPDATE CASCADE)
Does not change any row.
*/
ROLLBACK;

-- We go back to the previous state.
-- You can now assume that there is more data than what we
-- inserted, if that helps you. Write a command that
-- selects
-- ...
-- We insert some dummy values for this next part.

INSERT INTO WORK
VALUES ("My Life", "Paul B.");

INSERT INTO BOOK
VALUES (15355627, "My Life", DATE '20180219', 15.00),
        (12912912, "What to eat, 2", DATE '20200101', 13);

INSERT INTO EBOOK
VALUES (15150628, "My Life", DATE '20190215', 10.89),
        (42912912, "What to eat, 2", DATE '20200115', 12);

-- ... the price of all the ebooks.
SELECT Price
FROM EBOOK;

-- ... the (distinct) names of the authors who have authored
3.12 Setting Up Your Work Environment

-- a piece of work.
SELECT DISTINCT Author
FROM WORK;

-- ... the name of the authors using fai.fr for their email.
SELECT Name
FROM AUTHOR
WHERE Email LIKE '%fai.fr';

-- ... the price of the ebooks published after 2018.
SELECT Price
FROM BOOK
WHERE Published >= 20180101;

/
Note that
SELECT Price FROM BOOK WHERE Published > 2018;
would return all the prices, along with a warning:
Incorrect datetime value: '2018'
*/

-- ... the price of the most expensive book.
SELECT MAX(Price)
FROM BOOK;

-- ... the number of pieces of work written by the author
-- whose name is "Virginia W."
SELECT COUNT(*)
FROM WORK
WHERE WORK.Author = "Virginia W.";

-- ... the email of the author who wrote the piece of work
-- called "My Life".
SELECT Email
FROM AUTHOR, WORK
WHERE WORK.Title = "My Life"
  AND WORK.Author = AUTHOR.Name;

-- the isbn(s) of the book containing a work written by the
-- author whose email is "vw@isp.net".
SELECT ISBN
FROM BOOK, WORK, AUTHOR
WHERE AUTHOR.Email = "vw@isp.net"
  AND WORK.Author = AUTHOR.Name
  AND BOOK.Work = WORK.Title;

/
Write a command that updates the title of all the pieces of work written by the author whose name is "Virginia W. to "BANNED".

Is there any reason for this command to be rejected by the system? If yes, explain which one.

/*
-- The following statement raises an error.
*/

UPDATE WORK SET Title = "BANNED" WHERE Author = "Virginia W.";

/*
Gives an error, since "Title" is the primary key in the WORK table, and Virginia W. has authored two pieces of work or more, they are both given the title "BANNED", which violates the unicity of value in primary keys.
*/

-- Write one or multiple commands that would delete the work whose title is "My Life", as well as all of the books and ebooks versions of it.
-- The following statement raises an error.

DELETE FROM WORK WHERE Title = "My Life";

/*
Fails
ERROR 1451 (23000): Cannot delete or update a parent row: a foreign key constraint fails
(`HW_EXAM_1`.`BOOK`, CONSTRAINT `BOOK_ibfk_1` FOREIGN KEY (`Work`) REFERENCES `WORK` (`Title`) ON UPDATE CASCADE)
*/

-- We have to first delete the corresponding publications:
DELETE FROM BOOK WHERE WORK = "My Life";

DELETE FROM EBOOK WHERE WORK = "My Life";

-- And then we can delete the work:
DELETE FROM WORK WHERE Title = "My Life";

/*
And, no, we cannot delete "simply" from multiple tables in one command.


Pb 3.15 – Solution to Q. 3

Finally, to answer the last question, here is a list of the possible limitations:

1. Having the name or the title as a primary key (in the AUTHOR and WORK tables) is not a good idea: we cannot have two authors with the same name or two pieces of work with the same title!
2. If all the attributes in the BOOK and the EBOOK tables are going to be the same, then we should probably have only one table called PUBLICATION with a boolean to indicate whenever the publication is digital or on paper.
3. Having a mix of ON DELETE CASCADE and ON DELETE RESTRICT is not really justified and makes the tables harder to use. We should have used the same update policy on both tables.

Solution to Problem 3.16 (A simple database for authors of textbooks) The answers can be found in the following snippet:

```sql
UPDATE AUTHOR
SET Email = "tgaddis@pearson.com"
WHERE LName = 'Gaddis'
  AND FName = 'Tony';

You can use
SELECT * FROM AUTHOR;
to check that the modification took place.

EXERCISE 2

Write a command that inserts the textbook of your choice in the TEXTBOOK table. No value should be NULL, but you can invent
the values.
*/

```
INSERT INTO TEXTBOOK
VALUES ('Fundamentals of Database Systems',
        9780133970777, 165.89);
```

/*
You can use
SELECT * FROM TEXTBOOK;
to check that the insertion was correctly made.
*/

```
EXERCISE 3

Write a command that makes 'Gaddis', 'Tony' the author of
the
textbook you just added to our database.
*/

```
```
INSERT INTO AUTHORED
VALUES (9780133970777, 'Gaddis', 'Tony');
```
```
/*
You can use
SELECT * FROM AUTHORED;
to check that the insertion was correctly made.
*/

```
EXERCISE 4

Write a command that makes "0.01" becomes the
default value for the Price attribute of the
TEXTBOOK relation.
*/
```

```
ALTER TABLE TEXTBOOK
  ALTER COLUMN Price SET DEFAULT 0.01;
```
```
/*
You can use
DESCRIBE TEXTBOOK;
to check that the Price attribute now has a default
value.
*/

```
EXERCISE 5

Write a command that insert a textbook of
your choice in the TEXTBOOK table, with the
3.12 Setting Up Your Work Environment

price set to the default value.
*/

INSERT INTO TEXTBOOK
VALUES ('Proof Theory', 9780486490731, DEFAULT);

/**
You can use
SELECT * FROM TEXTBOOK;
to check that the insertion was correctly made.

EXERCISE 6

Write a command that creates a table called EDITOR
with 3 attributes, "Name", "Address" and "Website".
The "Name" attribute should be the primary key.
Then, insert two tuples in the EDITOR table, one
should have the "Name" attribute set to "Pearson".
*/

CREATE TABLE EDITOR ( 
    NAME VARCHAR(30) PRIMARY KEY, Address VARCHAR(255),
    Website VARCHAR(100) 
);

INSERT INTO EDITOR
VALUES ('Pearson', NULL, 'http://pearsoned.com/'),
    ('Dover', NULL, 'https://store.doverpublications.com/');

/**
You can use
DESCRIBE EDITOR;
to check that the table was actually created, and
SELECT * FROM EDITOR;
to check that the values were inserted.

EXERCISE 7

Write a command that creates a table called PUBLISHED
with 2 attributes, "Editor", and "Textbook".
The "Editor" attribute should references the EDITOR
table, and the "Textbook" attribute should reference
the TEXTBOOK table.
*/

CREATE TABLE PUBLISHED ( 
    Editor VARCHAR(30), FOREIGN KEY (Editor) REFERENCES
    EDITOR (NAME), Textbook CHAR(13), FOREIGN KEY
(Textbook) REFERENCES TEXTBOOK (ISBN)

/*================================================================*/
You can use
DESCRIBE PUBLISHED;
to check that the table was actually created.

EXERCISE 8

Write a command that makes "Pearson" the editor of
the textbook whose ISBN is 9780133776744.
/*================================================================*/

INSERT INTO PUBLISHED
VALUES ("Pearson", 9780133776744);

/*================================================================*/
You can use
SELECT * FROM PUBLISHED;
to check that the table was actually created.

EXERCISE 9

Answer the following short questions. In our model, as it
is, ...

Can an author have authored more than one textbook?
Yes.

Can a textbook have more than one author?
Yes.

Can a textbook without ISBN be inserted in the TEXTBOOK
relation?
No, unless you create a "dummy" (fake) value for it,
like 0000000000000, but this value can be used only
once, since ISBN is the primary key.

Can the price of a textbook be negative?
Yes. We can actually test it:
INSERT INTO TEXTBOOK VALUES ("Test", 0000000000000, -1);

Can two author have the same first and last name?
No. The query:
INSERT INTO AUTHOR VALUES ("Smith", 'Bob', NULL), ("Smith",
'Smith', 'Bob', NULL);
returns
Can two textbooks have the same title? Yes, as long as they have different ISBN. The command
\[
\text{INSERT INTO TEXTBOOK VALUES } ("Test", 0000000000001, \text{NULL}), ("Test", 0000000000002, \text{NULL});
\]
is processed just fine.

Can two editors have the same address? Yes. The command:
\[
\text{INSERT INTO EDITOR VALUES } ("Test 1", "123 Main St.", \text{NULL}), ("Test 2", "123 Main St.", \text{NULL});
\]
is processed just fine.

---

**Solution to Problem 3.17 (A database for residencies)** The file code/sql/HW_ResidencySol.sql contains the solution to the code part of this problem.

**Pb 3.17 – Solution to Q. 1** The relational model is:

\[
\begin{align*}
\text{PERSON} & \quad \text{FName} & \text{LName} & \text{SSN} & \text{Birthdate} \\
\text{HOUSE} & \quad \text{Address} & \text{Color} \\
\text{RESIDENCY} & \quad \text{Person} & \text{House} & \text{PrincipalResidence} & \text{Status}
\end{align*}
\]

**Pb 3.17 – Solution to Q. 2**

To violate the entity integrity constraint, it suffices to insert a tuple with \text{NULL} as a value for one of the attributes of a primary key or to insert a value that was already inserted.

Two examples are:
\[
\text{INSERT INTO PERSON VALUES } ("Bob", "Ross", \text{NULL}, \text{DATE}’1942-10-29’);
\]

---

which would return ERROR 1048 (23000): Column 'SSN' cannot be null.

```sql
INSERT INTO HOUSE VALUES ('123 Main St.', 'green');
```

which would return ERROR 1062 (23000): Duplicate entry '123 Main St.' for key 'P haus_name_idx'.

**Pb 3.17 – Solution to Q. 3**

To violate the referential integrity constraint, it suffices to insert a tuple where the value for one of the attributes of a foreign key does not exist in the referenced table.

For instance,

```sql
INSERT INTO RESIDENCY VALUES ('999-99-9999', NULL, NULL, NULL);
```

would return

ERROR 1452 (23000): Cannot add or update a child row: a foreign key constraint fails

```sql
('HW_Residency_SOL`.`RESIDENCY`, CONSTRAINT 
`RESIDENCY_ibfk_1` FOREIGN KEY (`Person`) REFERENCES `PERSON` (`SSN`))
```

Since there is no row in the PERSON table with the value "999-99-9999" for SSN.

**Pb 3.17 – Solution to Q. 4**

The answers can be found in the following snippet:

```sql
/*
   In the following we use transactions to be able to simulate the "what if"
   aspect of the questions: we will not commit the changes we are testing,
   and roll back on them before moving to the next question.
 */
-- Exercise 4
-- List the rows (i.e., P.2, H.1, or even "none")
-- modified by the following statements:
START TRANSACTION;

UPDATE HOUSE
SET COLOR = "green";
-- H.1, H.2 and H.3
ROLLBACK;

START TRANSACTION;

DELETE FROM RESIDENCY
WHERE House LIKE "1%";
```
-- R.1, and R.3
ROLLBACK;

START TRANSACTION;

DELETE FROM HOUSE
WHERE Address = "456 Second St.";

-- H.2, R.2 and R.4 (because of the foreign key).
ROLLBACK;

START TRANSACTION;

-- Commented, because it causes an error.
-- DELETE FROM PERSON
-- WHERE Birthdate = DATE "1990-02-11";
-- None, because of the foreign key and the referential integrity constraint.
-- ERROR 1451 (23000): Cannot delete or update a parent row:
-- a foreign key constraint fails
-- ('HW_RESIDENCY_SOL`.`RESIDENCY`, CONSTRAINT
-- `RESIDENCY_ibfk_1` FOREIGN KEY (`Person`) REFERENCES
-- `PERSON` (`SSN`))
ROLLBACK;

Pb 3.17 – Solution to Q. 5

The answers can be found in the following snippet:

-- Exercise 5
/* Write a query that selects ...
... the addresses of the houses in the system (11 Third St.,
123 Main St., 456 Second St.). */
SELECT Address
FROM HOUSE;

-- ... the SSN of the persons whose first name was not entered in the system (000-00-0000).
SELECT SSN
FROM PERSON
WHERE FName IS NULL;

-- ... all the different colors of houses (white, blue).
SELECT DISTINCT COLOR
FROM HOUSE;

-- ... the address of the residency of James Baldwin (123
3.12 Setting Up Your Work Environment

-- Main St.).

```
SELECT House
FROM RESIDENCY, PERSON
WHERE PERSON.Fname = "James"
    AND PERSON.LName = "Baldwin"
    AND PERSON.SSN = RESIDENCY.Person;
```

-- ... the first name of the oldest person in the database
-- (James).

```
SELECT FName
FROM PERSON
WHERE Birthdate = ( 
    SELECT MIN(Birthdate) 
    FROM PERSON 
    WHERE Birthdate IS NOT NULL);
```

-- ... Michael Keal's principal residency address (123 Main St.).

```
SELECT RESIDENCY.House
FROM RESIDENCY, PERSON
WHERE PERSON.FName = "Michael"
    AND PERSON.LName = "Keal"
    AND PERSON.SSN = RESIDENCY.Person
    AND RESIDENCY.PrincipalResidence = TRUE;
```

-- ... the (distinct) first and last names of the homeowners
-- (Michael Keal, Mridula Warrier).

```
SELECT DISTINCT (PERSON.FName), PERSON.LName
FROM PERSON, RESIDENCY
WHERE RESIDENCY.Status = "own"
    AND RESIDENCY.Person = PERSON.SSN;
```

-- cf comment at snippet homonyms

```
SELECT PERSON.FName, PERSON.LName
FROM PERSON
WHERE SSN IN ( SELECT DISTINCT (RESIDENCY.Person) 
    FROM RESIDENCY 
    WHERE RESIDENCY.Status = "own");
```

-- ... the SSN of the persons that have the same principal residency as James Baldwin (000-00-0001).

```
SELECT RoomMate.Person
FROM RESIDENCY AS James, RESIDENCY AS RoomMate, PERSON
WHERE PERSON.FName = "James"
    AND PERSON.LName = "Baldwin"
    AND PERSON.SSN = James.Person
    AND James.House = RoomMate.House
    AND NOT James.Person = RoomMate.Person
    AND RoomMate.PrincipalResidence = TRUE;
```
Note that the query that returns the name of the homeowners can be improved.

```sql
-- If we have homonyms in our database, e.g.
INSERT INTO PERSON
VALUES ("A", "B", "000-00-0010", NULL), ("A", "B", "000-00-0011", NULL);

INSERT INTO HOUSE
VALUES ("H", NULL);

-- H.3
INSERT INTO RESIDENCY
VALUES ("000-00-0010", "H", TRUE, "own"), ("000-00-0011", "H", TRUE, "own");

-- Then the query below fails, in the sense that it reports
-- the name "A, B" only once.
SELECT DISTINCT (PERSON.FName), PERSON.LName
FROM PERSON, RESIDENCY
WHERE RESIDENCY.Status = "own"
  AND RESIDENCY.Person = PERSON.SSN;

-- A better (and not much more complicated) solution would
-- have been
SELECT PERSON.FName, PERSON.LName
FROM PERSON
WHERE SSN IN (SELECT DISTINCT (RESIDENCY.Person)
                       FROM RESIDENCY
                       WHERE RESIDENCY.Status = "own");
```

Pb 3.17 – Solution to Q. 6

To update the SSN of "James Baldwin" to "000-00-0010", we could use:

```sql
UPDATE PERSON SET SSN = "000-00-0010" WHERE FName = "James"
  AND LName = "Baldwin";
```

However, this command would be rejected because of the foreign key constraint. On `UPDATE`, the foreign key from `RESIDENCY.Person` to `PERSON.SSN` restricts by default. The error would be:

```
ERROR 1451 (23000) at line 75: Cannot delete or update a
parent row: a foreign key constraint fails
```

Pb 3.17 – Solution to Q. 7

In our model, as it is currently,

1. It is possible for two people to have the same last name.
2. It is possible for a person to have multiple principal residencies.
3. It is not possible for a house to not be yellow.
4. It is possible for the SSN to be any series of 11 characters.
5. It is possible for a person to own any number of houses.
6. It is possible for a person to rent any number of houses.

Pb 3.17 – Solution to Q. 8

Considering the given state for the RESIDENCY table, the following two are possible primary keys:

1. Person and PrincipalResidence
2. Person and House

Pb 3.17 – Solution to Q. 9

The first key would not accommodate a person with multiple secondary residencies, which is not a good thing. The second key could make sense, since it would refrain a person from declaring the same address twice as their residency. The only case that could be hard to work around is if a person was trying to own multiple units at the same address; however, this is more an issue with the primary key of HOUSE than an issue with the primary key we suggested for RESIDENCY.
4 Designing a Good Database

Resources

This part of the lecture covers significantly more material than the other, hence we give the details of the references below:

- ER models: (Elmasri and Navathe 2010, ch. 7) or (Elmasri and Navathe 2015, ch. 3)
- The ER to Relational model: (Elmasri and Navathe 2010, ch. 9.1) or (Elmasri and Navathe 2015, ch. 9.1)
- Normalization: (Elmasri and Navathe 2010, ch. 7) or (Elmasri and Navathe 2015, ch. 3)
- UML: not so much in the textbook, but you can look at (Elmasri and Navathe 2010, ch. 7.8, 10.3) or (Elmasri and Navathe 2015, ch. 3.8).

4.1 Interest for High-Level Design

Previous relational models have mistakes and limitations:

- What if a hurricane is over more than one state?
- What if an insurance covers more than one car, more than one driver?
- Changing the code “on the fly”, as we did for the HW_Lecture and Grade tables, is difficult and error-prone.

We could go back and forth between relational models (~ logical level) and SQL implementations (~ physical level), but we will use even more high-level tools (~ conceptual level):

- Entity Relationship Models (ER, static: DB)
- Unified Modelling Diagrams (UML, dynamic: DB + software)
- Enhanced Entity Relationship Models (EER, adds operations to ER)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Conceptual</th>
<th>Logical</th>
<th>Physical</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Main) Audience</td>
<td>Business</td>
<td>Designer</td>
<td>Programmer</td>
</tr>
<tr>
<td>Entity Names</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Entity Relationships</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Attributes</td>
<td>✔ (✓)</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Cardinalities</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Primary Keys</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Foreign Keys</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Column Data types (Domain)</td>
<td>✔ (✓)</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Table Names</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Column Names</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.2 Entity-Relationship Model

The conceptual data model is (in theory at least) independent of the choice of database technology.

Remember that in relational models, relations were representing entities (Student) and relationships (Majors_In). At the conceptual level, and more particularly in ER diagram, the distinction is made between entities and relationship.

4.2 Entity-Relationship Model

Data is organized into entities (with attributes), relationships between entities (with attributes as well).

4.2.1 Entities

- Entity = Thing, object, with independent existence.
- Each entity has attributes (properties)

Entity A:

- Name = Clément Aubert
- Address = HCOB, HA, E. 128 ; Invented St., Auguta, GA
- Diploma = Ph.D in CS; BS in Math
- Highest Diploma = Ph.D in CS
- Favorite Class = CSCI 1301
- Favorite Sport = NULL

Some vocabulary:

- Entity = actual thing (individual)
- Entity type = collection of entities with the same attributes
- Entity set (or collection) = collection of all entities of a particular entity type.

4.2.1.1 Attributes

Attributes can be

- Composite (divided in smaller parts) or simple (atomic)
- Single-valued or multi-valued
- Stored vs derived
- Nested!

{...} = multi-valued
(…) = complex

For instance, one could

- store the name using a composite attribute (First Name, {Middle Name}, Last Name),
• store multiple addresses using the “schema” \{Address(Street, Number, Apt, City, State, ZIP)\}
• derive the value of “Highest Diploma” using the value(s) stored in “Diploma”.

4.2.1.2 Key Attributes

A key attribute is an attribute whose value is distinct for each entity in the entity set.

• Serve to identify an entity,
• Can be more than one such attribute (and we leave the options open),
• Cannot be multiple attributes: if more than one attribute is needed to make a key attribute, combine them into a composite attribute and make it the key,
• A composite attribute that is a key attribute should not still be a key attribute if we were to remove one of the attribute (similar to the minimality requirement).
• An entity with no key is called a weak entity type: it is an entity that will be identified thanks to its relation to other entities, and thanks to its partial key (we will discuss this later).

4.2.1.3 Drawing Entity Types

• Entity = squared box (name in upper case)
• Attribute = rounded box connected to square box (name in lower case)

| Entity Type Name | If the attribute is ..., then...
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Key</td>
<td>can have more than one such attribute</td>
</tr>
<tr>
<td>Atomic</td>
<td>cannot be multiple attributes</td>
</tr>
<tr>
<td>Multi-Valued</td>
<td>the box have double lines</td>
</tr>
<tr>
<td>Composite</td>
<td>the box have dotted lines</td>
</tr>
<tr>
<td>Derived</td>
<td>the name of the attribute is underlined</td>
</tr>
</tbody>
</table>

Diagram:

- Key
- Atomic
- Derived
- Multi-Valued
- Composite
- Attribute 1
- …
- Attribute n
In the following, we’ll focus on the relationship between the entities more than on the attributes of particular entities, so we’ll sometimes simply draw

leaving the attributes un-specified (but that does not mean that they all have to be atomic) or even just

but that does not mean that the entity type have no attribute!
4.2.2 Relationships

4.2.2.1 Vocabulary

- Relationship = actual relation (or action) between entities ("teaches", "loves", "possesses", etc.).
- Relationship instance = $r_1$ associates $n$ entities $e_1, \ldots, e_n$ ("Pr. X teaches CSCI YYY", "There is love between Mary and Paul", etc.)
- Relationship set = collection of instances
- Relationship type = abstraction ("Every course belong to one instructor", "Love is a relation between two persons", etc).

$E_1, \ldots, E_n$ participate in $R$, $e_1, \ldots, e_n$ participate in $r_1$, $n$ is the degree.

Note that we can have Entity Set 1 = Entity Set 2, in which case we say the relation is recursive\(^1\).

Naming convention:

- Use a singular name for entity types.
- Use a verb for relationship.
- Relationship types are drawn in diamonds.
- Drawing usually reads right to left, and up to down.

\(^1\)Some sources call the relationships between an entity and itself "unary." Note that with our convention, it does not make sense to speak of a unary relationship.
4.2.2.2 Role Names and Recursive Relations

Convenient, and sometimes mandatory, to give role names.

If we want to stress that we are considering only one aspect of an entity type (that is, a person is not only an employee, a company is not only an employer, but this aspect is crucial for the "EMPLOYS" relation):

We can also use it to make the “right-side” and the “left-side” of a recursive relationship explicit:
Finally, we will sometimes use “Role Name of Entity 1 : Role Name of Entity 2” as a notation for the relation between them. For instance, we can write “Employer:Employee” to denote the “EMPLOYS” relation, and we will also use this notation when the relationship is between different entities, and write e.g. “PERSON:POSITION” for the “OCCUPIES” relation.

### 4.2.2.3 Constraints

Two constraints, called “structural constraints”, applies to relationship types: cardinality ratio and participation constraint. They both concerns the number of relationship instances an entity can participate in (which is different from the cardinality of a relationship type).

#### 4.2.2.3.1 Cardinality Ratio

**Maximum** number of relationships instances that an entity can participate in.

For binary relations, can be $1 : 1$, $N : 1$, $1 : N$, or $M : N$. The 1 stands for “at most 1”, and the $M$, $N$, and $P$ stand for “possibly more than 1”, or “no maximum”. In ER diagram, we do not count, and do not make the distinction between “at most 5” and “at most 10”, for instance.

Possible examples include:

<table>
<thead>
<tr>
<th>Relation</th>
<th>Possible Ratio</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MENTOR : MENTEE</td>
<td>$1 : N$</td>
<td>“A mentor can have multiple mentees, a mentee has at most one mentor.”</td>
</tr>
<tr>
<td>PERSON : SSN</td>
<td>$1 : 1$</td>
<td>“A person has one SSN, a SSN belongs to one person.”</td>
</tr>
<tr>
<td>COURSE : DEPARTMENT</td>
<td>$N : 1$</td>
<td>“A course is offered by one department, a department can offer any number of courses.”</td>
</tr>
<tr>
<td>STUDENT : TEAM</td>
<td>$M : N$</td>
<td>“A student can participate in multiple team, a team can have multiple students.”</td>
</tr>
</tbody>
</table>

We indicate the ratio on the edges:

\[\text{\texttt{2}}\text{An alternative notation, detailed later on, will address this shortcoming.}\]
4.2 Entity-Relationship Model

Note that reflexive relations can have any ratio as well. An example of $M : N$ recursive relation could be:

\[ \text{SOFTWARE \ Requires \ Requirement} \]

### 4.2.2.3.2 Participation Constraint

**Minimum** number of relationships instances that an entity can participant in, a.k.a. "minimum cardinality constraint."

The participation can be total (a.k.a. existence dependency, the entity **must** be in that relationship at least once) or partial (the entity may or may not be in that relationship).

Total is drawn with a double line, partial is drawn with a single line:

This reads "a course **must** be offered by a department, but a department may or may not offer courses."
4.2.2.4 Attributes

Relationships can have attributes too. The typical example is a date attribute, but other examples include

- TEACHING relation between PROF and CLASS (N : M) could have a “Quarter” attribute.
- MENTORING relation between MENTOR and MENTEE (1 : N) could have a “Since” attribute.
- Emitted_Driving_Licence between DMV and PERSON (N : 1) could have a “Date” attribute.

Note that an attribute on a relationship type can be atomic or composite, single or multi-valued, stored or derived, but that it cannot be a key attribute (after all, there are no entity to identify!).

Note that there are some moving aspects here: attributes on 1 ∶ 1, 1 ∶ N, N ∶ 1 relationships can be migrated (to the N side when there is one, or to either side where there is none).

For instance, imagine that every phone uses exactly (= “at most and at least”) one carrier, that a carrier can provide network to multiple phones, and that the average quality of the network is an attribute in this relationship:

Then each instance of the relation would be of the form (“Phone X”, “Carrier Y”, “9/10”) for some way of ranking the average quality from 0 to 10. Note that, from the fact that the relationship is N ∶ 1, this means that there is only one tuple involving “Phone X”: this means that the average quality could actually be seen as a property of the phone, and hence be migrated as an attribute to the phone side:
Note that we could not migrate the “average phone quality” to the “Carrier” side: imagine if we had the instances (“Phone X”, “Carrier Y”, “9/10”) and (“Phone Z”, “Carrier Y”, “3/10”), then should the attribute of “Carrier Y” be “9/10” or “3/10”: we have no way of deciding based on this model. Whenever it is a good choice to migrate this attribute or not will depend on the requirement of the models, and it may not always be appropriate to migrate the attribute to the entity. In the case of 1 : 1 relationship, migrating the attribute to both sides (i.e., to both entities) would be a mistake, since it would introduce redundancy in your model.

As an exercise, you can look at the relationships TEACHING, MENTORING and EMITED_DRIVING_LICENSE that are listed above, and see if the attributes can be migrated or not, and if yes, on which side.

### 4.2.2.5 Relationships of Degree Higher than Two

Of course, relationships can have a degree higher than two. An example of a ternary relation could be:

![Diagram of a ternary relationship](image)

To determine cardinality ratio, one should fix all but one parameters, and wonder how many values of the remaining parameter can be in that relationship. Another wording for the same idea can be found in this thread[^3].

Four our example, Customer Y and Bank Z could be in relationship with more than one account (hence the “N”). On the opposite, Customer Y and Account K would be in relationship with only one bank (hence the “1” on the bottom), and Bank Z and Account K would belong to only one customer (hence the “1” on the left).

Let us look at two other examples. First, assume we want to collect information about the treatment prescribed by physicians to patients, we could use a relationship like the following one:

[^3]: https://stackoverflow.com/a/38395315
Where

- The “P” stands for the fact that the same physician can prescribe the same treatment to multiple patients,
- The “N” stands for the fact that different treatment can be prescribe by the same physician to the same patient,
- The “M” stands for the fact that the same patient can get the same treatment from different physicians.

Now, if we want to store information about who is the president of a country during a term, we could get something like:

Note that this representation of the data assumes that a citizen cannot be the president of two different countries during the same term (the right 1), which could be debatable.

It is sometimes impossible to do without relations with arity greater than 2. For instance, consider the following two diagrams:\[1\):

\[1\]Where the “BOOK” entity does not refer to one particular physical copy of a book, but to books in general, i.e., “The book on my shelf” (physical copy) as opposed to “The Wizard of Oz” (general).
You should realize that they convey different information. For instance, you can know for a fact that a person visit a bookshop only if they bought something in it, while the second diagram de-correlate the act of buying with the visit to a bookshop. Similarly, the second diagram could give you a hint that a person that owns a copy of a book Z and visits a bookshop X that sells it could also visit it, but you will not know that for sure.

An example of recursive ternary relation could be:

An example of relation of degree 4 could be:
4.2 Entity-Relationship Model

The cardinality ratio are computed using the same method as described before.

4.2.3 Weak Entity Types

There are actually two sorts of entity types:

- Strong (a.k.a. regular, the ones we studied so far), with a key attribute,
- Weak, without key attribute.

Weak (or child) entity types are identified by identifying / owner type that is related to it, in conjunction with one attribute (the partial key). That relation is called identifying (or supporting) relationship, and weak entities have a total participation constraint. The partial key is an attribute, that, when paired with an entity with which they are in relation through their identifying relationship, allows to identify a particular entity.

Weak entities and identifying relationships have a double border, and partial key have a dotted underline, as follows:
The idea here is that we do not need to gather data about all the dependent in the world, or in isolation, but are interested in dependent only if they are related to an employee in our database. Just having the name of a dependent is not enough to identify them, but having their name and the SSN of the employee they are related to is enough. The identifying relation always have ratio $1 : M$ or $1 : 1$: a weak entity cannot be related to more than one entity of the owner type, so that $M : N$ ratio are not possible (cf. e.g. https://dba.stackexchange.com/q/17207). If you need to have, for instance, a dependant connected to multiple employees, then that means that your dependent entity should be strong, because it has an existence “of its own”.

You may wonder why we do not represent weak entities simply as (composite, multi-valued) attributes of their owner type. For instance, why would we use

instead of
The answer depends whenever we need to have the ability to represent our weak entities (here, PET) as being in relationship with other entities (that can themselves be weak!), as follows:

This would be impossible if PET was an attribute of FRIEND! Whenever the pet entity type is involved in other relationships or not should help you in deciding which representation to choose.

- Weak entities types can sometimes be replaced by complex (composite, multi-valued) attributes, unless they are involved in other relationships.
- Owner can itself be weak!
- The degree of the identifying relationship can be more than 2 (cf. e.g., https://stackoverflow.com/q/15393587/).

Another example of weak entity whose owner is weak as well could be:
The idea being that the Health care provider cares about an insure only if they are covered by them, and that they care about the doula only if they are currently helping one of their insure.

4.2.4 Alternative Notations

Multiple notations have been used to represent the ratio and constraint on relationship. In the following, we introduce two of them: the Min/Max and the Crow’s foot notations.

4.2.4.1 Notation with Explicit Maximal (Min/Max Notation)

The two constraints can be written on the same side, and the $N$, $M$, $P$ ratio can be replaced by actual number, providing more information.

For instance,

could be drawn as

...
Figure 4.1: A Quick Overview of the Notations for ER Diagram (courtesy of wikipedia)
meaning that

- A car can be used to carpool between 1 and 5 persons (and that it must be used for at least 1 person),
- A person can be registered for 0, 1, 2 or 3 carpool at the same time.

More generally, we have the following:

\[
\begin{align*}
1 & \quad N & \Rightarrow & & (0, N) & \quad (0, 1) \\
1 & \quad N & \Rightarrow & & (1, N) & \quad (0, 1) \\
M & \quad N & \Rightarrow & & (1, N) & \quad (1, M)
\end{align*}
\]

4.2.4.2 Crow’s Foot Notation

4.2.5 Enhanced Entity–Relationship Model

Extended (or Enhanced) ER Models (EER) have additionally:

- Subtype / Subclass: “every professor is an employee”. There is a class / subclass relationship (you can proceed by specialization or generalization).
- Category (to represent UNION): an OWNER entity that can be either a PERSON, a BANK, or a COMPANY entity type.

Closer to object-oriented programming.
4.2.6 Reverse Engineering

It is possible to go from relational models to ER models, and sometimes needed: if you are given an implementation that seems poorly design, this can be a way of “backing up” and thinking about the (sometimes implicit) choices that were made during the implementation, to eventually correct them.

For instance, consider the code we studied in “A First Example”:

```sql
CREATE TABLE STORM (
    Name VARCHAR(25) PRIMARY KEY, Kind ENUM ('Tropical Storm', 'Hurricane'), WindSpeed INT, 
    Creation DATE
);

-- We can change the enumerated datatype:
ALTER TABLE STORM MODIFY Kind ENUM ('Tropical Storm', 'Hurricane', 'Typhoon');

CREATE TABLE STATE (
    Name VARCHAR(25) UNIQUE, Postal_abbr CHAR(2) PRIMARY KEY, 
    Affected_by VARCHAR(25), FOREIGN KEY (Affected_by) REFERENCES STORM (Name) ON DELETE SET NULL ON UPDATE CASCADE
);
```

It corresponds to the following relational model:

```
+-----------+---------+-----------+---------+---------+-----------------+-----------+---------+
<table>
<thead>
<tr>
<th></th>
<th>Name</th>
<th>Kind</th>
<th>WindSpeed</th>
<th>Creation</th>
<th>STORM</th>
<th>STATE</th>
<th>AffectedBy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Name</td>
<td>PostalAbbr</td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>---------</td>
<td>-----------</td>
<td>----------</td>
<td>----------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>---------</td>
<td>-----------</td>
<td>----------</td>
<td>----------</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

which in turn corresponds to the following ER diagram:
Looking at this diagram made it obvious that our code has a flaw: a storm can affect more than one state! Turning the 1 on the left-hand side of the “AFFECTS” relationship into a M is immediate on the diagram, but, of course, mapping it back to a relational model, and then implementing it correctly, will require more work. In any case, if you had not noted already this flaw, reverse-engineering this code highlighted it quite clearly.

If we look back at Problem 3.5 (Revisiting the PROF table), we had already made a first step, since we converted the code into the following relational model:

Going a bit further, we could extrapolate just a little bit and get the following ER diagram:
As we noted in our solution to the second question, this model has several limitations. To list a few, this representation can not handle the following situations:

- If multiple instructors teach the same class,
- If the lecture is taught more than once a year (either because it is taught in the Fall, Spring and Summer, or if multiple sections are offered at the same time),
- If a Lecture is cross-listed, then some duplication of information will be needed.

Looking at it as an ER diagram should help you in understanding why we have those flaws, and how they could be addressed, and “testing” the model should be made easier in its ER form than as SQL code.

4.3 ER-to-Relational Models Mapping

4.3.1 Intro

We have to map all of the following:

<table>
<thead>
<tr>
<th>Entity</th>
<th>Strong, Weak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attributes</td>
<td>Composite, Key, Atomic, Multi-valued, Partial Key</td>
</tr>
</tbody>
</table>
4.3 ER-to-Relational Models Mapping

| Relationships | Binary (1 ∶ 1, N ∶ 1, 1 ∶ N, N ∶ M), n-ary |

Using four tools: Relations, Attributes, Primary Keys, Foreign Keys.

### 4.3.2 Algorithm

We will use three techniques to represent some of the relationships, the foreign key approach, the merged relations approach and the cross-reference approach. They are detailed and illustrated after the algorithm, which goes as follows:

<table>
<thead>
<tr>
<th>#</th>
<th>is mapped to</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Strong Entity: Relation with all the simple attributes. Decompose complex (composite) attributes. Pick a key to be the PK, if it is composite, take its elements.</td>
</tr>
<tr>
<td>2</td>
<td>Weak Entity: Relation with all the simple attributes. Decompose complex attributes. Add as a foreign key the primary key of the relation corresponding to the owner entity type, and make it a primary key, in addition to the partial key of the weak entity. If the owner entity type is itself weak, start with it.</td>
</tr>
<tr>
<td>3</td>
<td>Binary 1 ∶ 1 Relationship Types: Foreign Key, Merge Relations or Cross-Reference approach</td>
</tr>
<tr>
<td>4</td>
<td>Binary 1 ∶ N Relationship Types: Foreign Key or Cross-Reference approach</td>
</tr>
<tr>
<td>5</td>
<td>Binary M ∶ N Relationship Types: Cross-Reference approach</td>
</tr>
<tr>
<td>6</td>
<td>n-ary Relationship Types: Cross-Reference approach</td>
</tr>
<tr>
<td>7</td>
<td>Multi-valued Attributes: Create a new relation, add as a foreign key the primary key of the relation corresponding to the original strong entity type. Make all the attributes be the primary key.</td>
</tr>
</tbody>
</table>

whose primary key is the foreign key to the relation corresponding to the entity.

1. **Foreign Key Approach**: choose one of the relation (preferably with total participation constraint, or on the N side), add a foreign key and all the attributes of the relationship.
2. **Merged Relation Approach**: If both participation constraints are total, just merge them. Primary key = just pick one (or take both). If we were working on the implementation, we would add a **NOT NULL** constraint on the attribute that is not part of the primary key anymore.
3. **Cross-Reference or Relationship Relation Approach**: Create a lookup table with an appropriate number of foreign keys, pick some of them (the one on the N side, both if the ratio is M ∶ N, for n-ary it is a bit more complex, cf. example below) as the primary key.

Every time a relationships have attributes, they are mapped to the resulting relation.
Let us look in more details at some of those steps. For strong entities, using steps 1 and 7, the following:

would give:

And note that if Serial was a complex attribute, we would just “unfold” it, or decompose it, and make all the resulting attributes the primary key of the relation. If one of the attribute was at the same time multi-valued and composite, as follows:

Then we would obtain:

For relationships, things are a bit more complicated. Consider the following:
Since it is a 1:1 relationship where one of the side has a partial constraint, we have the choice between two approaches. The foreign key approach would give:

Note that we could also have added the foreign key on the side of ENT.B, referencing the key of ENT.A. But since ENT.A has a total participation constraint, we know that the value of FK will always exist, whereas some entities in ENT.B may not be in relationship with an entity from ENT.A, creating the (nefast) need for NULL values.

For the same diagram, the cross-reference approach would give:

Similarly, note that, in MAPPING, KeyB, or KeyA and KeyB, would also be valid primary keys, but that it makes more sense to have KeyA being the primary key, since we know that ENT.A has a total participation constraint, but ENT.B does not.

If both participation constraints were total, as follows:
Then we could use the merged relations approach, and get:

\[\text{ENT.A.AND.B.}\]

\[\begin{array}{c}
\text{KeyA} \\
\text{KeyB}
\end{array}\]

We picked KeyA to be the primary key for the same reason as before. Note that merging the two entities into one relation also means that you have eventually to do some work on the relations that were referring to them.

Of course, if ENT.A and ENT.B are the same entity (that is, REL is recursive), we would get:

\[\text{ENT.A}\]

\[\begin{array}{c}
\text{KeyA} \\
\text{Rel}
\end{array}\]

or

\[\begin{array}{c}
\text{ENT.A} \\
\text{KeyA} \\
\text{REL} \\
\text{KeyA1} \\
\text{KeyA2}
\end{array}\]

depending on the approach we chose.

Binary $1 : N$ and binary $M : N$ relationships are dealt with in a similar way, using foreign key or cross-reference approaches. The most difficult part of the mapping is with $n$-ary relationships: we have to use cross-reference approaches, but determining the primary key is not an easy task. Consider the following:\footnote{This development was actually asked at https://dba.stackexchange.com/q/232068/}:
The arity constraints here can be rephrased as:

- A member can reserve a particular equipment at multiple time slots (the $N$),
- An equipment can be reserved at a particular time slot by only one member (the 1 on the left),
- A member can reserve only one equipment per time slot (the 1 on the right).

And note that there is no total participation constraint.

To represent the \textit{RESERVES} relationship, we need to create a relation with attributes referencing the primary key of MEMBER, the primary key of TIME\_SLOT, and the primary key of EQUIPMENT. Making them all the primary key does not represent the fact that the same equipment cannot be booked twice during the same slot, nor that a member can book only one equipment per slot, but allows members to reserve a particular equipment at multiple time slots. To improve this situation, we can either

1. take the foreign key to MEMBER and the foreign key to TIME\_SLOT to be the primary key of this relation,
2. or take the foreign key to EQUIPMENT and the foreign key to TIME\_SLOT to be the primary key of this relation.

Both solutions enforce only \textit{some} of the requirement expressed by the ER diagram.

### 4.3.3 Outro

<table>
<thead>
<tr>
<th>ER Model</th>
<th>Relational Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entity type</td>
<td>Entity relation</td>
</tr>
<tr>
<td>$1 : 1$ or $1 : N$</td>
<td>Foreign key (or relationship relation)</td>
</tr>
<tr>
<td>relationship type</td>
<td>Relationship relation and two foreign keys</td>
</tr>
<tr>
<td>$M : N$ relationship type</td>
<td>Relationship relation and $n$ foreign keys</td>
</tr>
<tr>
<td>$n$-ary relationship type</td>
<td></td>
</tr>
<tr>
<td>Simple attribute</td>
<td>Attribute</td>
</tr>
<tr>
<td>Composite attribute</td>
<td>Set of simple component attributes</td>
</tr>
<tr>
<td>Multivalued attribute</td>
<td>Relation and foreign key</td>
</tr>
<tr>
<td>Value set</td>
<td>Domain</td>
</tr>
<tr>
<td>Key attribute</td>
<td>Primary key</td>
</tr>
</tbody>
</table>
4.4 Guidelines and Normal Form

What makes a good database? At the logical (conceptual) and physical (implementation) levels.

Goals:

1. Information preservation (and avoid loss of information)
2. Minimum redundancy
3. Make queries easy (avoid redundant work, make \texttt{SELECT} and select-project-join easy)

For ER diagrams, some of the usual techniques\footnote{Cf. for instance \url{http://infolab.stanford.edu/~ullman/fcdb/aut07/slides/er.pdf}.} are:

- Limit the use of weak entity sets.
- Do not use an entity when an attribute will do.

4.4.1 General Rules

4.4.1.1 Semantics

1 relation corresponds to 1 entity or 1 relationship type

4.4.1.2 No Anomalies

1. \textbf{Insertion Anomalies} Having to invent values or to put \texttt{NULL} to insert tuples, especially on a key attribute!
2. \textbf{Deletion Anomalies} Loosing information inadvertently
3. \textbf{Modification Anomalies} Updates have to be consistent.

(Bad!) Example:

\begin{verbatim}
---------- (Login, Name, AdvisoryName, AdvisorOffice, Major, MajorHead)
\end{verbatim}

\begin{verbatim}
----------(Office, PhoneNumber, Building)
\end{verbatim}

1. Advisor without student
2. Delete last student of advisor
3. Advisor change name.
4.4 Guidelines and Normal Form

4.4.1.3 NULL Should Be Rare

**NULL** has 3 meanings, wastes space, and makes join / nested projections harder. 

Example:

STUDENT(Login, ..., siblingEnrolled)

Transform into "Emergency Contact in University" relation (bonus: allow multiple contacts).

4.4.1.4 Identical Attributes in Different Tables Should Be (Primary, Foreign) Key Pairs

Example with advisorOffice and Office: if we try to write a join to obtain the phone number of a student’s advisor, we will obtain all the phone.

4.4.2 Example

MARKER(Owner, Color, OwnerOffice, Brand, BrandEmail)

TEACHER(Office, Name, Phone)

Corrected to:

MARKER(Owner, Color, Brand)

TEACHER(Office, Name, Phone)

BRAND(Name, Email)

4.4.3 Functional Dependencies

Functional dependencies (FD) is a formal tool used to assess how “good” a database is, a property of the relation schema. Functional dependencies list the constraints between two sets of attributes from the database. For instance, if \( X \) and \( Y \) are (sets of) attributes, \( X \rightarrow Y \) reads “\( X \) fixes \( Y \)”, and implies that the value(s) of \( Y \) is fixed by the value(s) of \( X \).

4.4.3.1 Using Semantics of Attributes

“What should be.”

Let us list all the attributes of our previous example:

MARKER.Owner, MARKER.Color, MAKER.Brand, TEACHER.Office, 

\(
\Leftarrow \quad \text{TEACHER.Name, TEACHER.Phone, BRAND.Name, BRAND.Email}
\)
Think about their dependencies, and list them:

- \text{TEACHER.Name} \rightarrow \text{TEACHER.Office}
- \text{BRAND.Name} \rightarrow \text{BRAND.Email}
- \text{TEACHER.Office} \rightarrow \text{TEACHER.Name}
- \text{TEACHER.Office} \rightarrow \text{TEACHER.Phone}
- \text{MAKER.Owner} \text{ and } \text{MARKER.Color} \rightarrow \text{MARKER.Brand}?

### 4.4.3.2 Using Relation States

“What is...”, can disprove some of the assumptions made previously, but should not add new dependencies based on it (they may be by chance!).

- Maybe \text{TEACHER.Office} \rightarrow \text{TEACHER.Name} does not hold, because teachers share offices?
- Maybe \text{TEACHER.Name} \rightarrow \text{MARKER.Brand} \text{ and } \text{MARKER.Color} seemed to be enforced by the state, but we should not add a functional dependency based on that: there are no “requirement” that a Teacher must always buy the same brand and color, this could simply true be by chance so far and should not be imposed to the teachers.

A particular state cannot enforce a FD, but it can negate one.

Example:

<table>
<thead>
<tr>
<th>Att. 1</th>
<th>Att. 2</th>
<th>Att. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bob</td>
<td>15</td>
<td>Boston</td>
</tr>
<tr>
<td>Bob</td>
<td>13</td>
<td>Boston</td>
</tr>
<tr>
<td>Jane</td>
<td>12</td>
<td>Augusta</td>
</tr>
<tr>
<td>Emily</td>
<td>12</td>
<td>Augusta</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>May hold</th>
<th>Will not hold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Att. 2 → Att. 3</td>
<td>Att. 1 → Att. 2</td>
</tr>
<tr>
<td>Att. 3 → Att. 2</td>
<td>Att. 3 → Att. 2</td>
</tr>
<tr>
<td>Att. 1 → Att. 3</td>
<td>Att. 2 → Att. 1</td>
</tr>
<tr>
<td>{Att. 1, Att. 2} → Att. 3</td>
<td>{Att. 3, Att. 2} → Att. 1</td>
</tr>
</tbody>
</table>

### 4.4.3.3 Notations

Or, more conveniently:
If an attribute is a foreign key to another, we will draw an arrow between relations:

Note that:

- $X$ and $Y$ are sets, we will write $A$ instead of $\{A\}$, but keep writing $\{A, B\}$ for $\{A, B\}$.
- $\{A_1, ..., A_n\} \rightarrow \{B_1, ..., B_m\}$ means that $A_1$ and ... and $A_n$ fix $B_1$, and that $A_1$ and ... and $A_n$ fix $B_n$, etc.
- $FD_1, FD_2, ..., FD_n$ for the list of functional dependencies, F for all of them.
- $A \rightarrow B$ does not imply nor refute $B \rightarrow A$.
- We will not write the FD that are implied by (this variation of) Armstrong’s axioms$^8$:
  - Reflexivity: If $Y$ is a subset of $X$, then $X \rightarrow Y$
  - Augmentation: If $X \rightarrow Y$, then $\{X, Z\} \rightarrow Y$
  - Transitivity: If $X \rightarrow Y$ and $Y \rightarrow Z$, then $X \rightarrow Z$

We will assume that the consequence of those axioms always hold (“closure under those rules”), but will generally not write them explicitly, since they do not carry any new or additional information.

### 4.4.3.4 Definitions

Remember superkey (not minimal key), key, candidate key, secondary key? We now have a formal definition.

In one particular relation $R(A_1, ..., A_n)$,

- If $\{A_1, ..., A_n\} \rightarrow Y$ for all attribute $Y$, then $\{A_1, ..., A_n\}$ is a superkey.
- If $\{A_1, ..., A_n\}/A_i$ is not a superkey anymore for all $A_i$, then $\{A_1, ..., A_n\}$ is a key.
- We will often discard candidate keys and focus on one primary key.
- If $A_i$ is a member of some candidate key of $R$, it is a prime attribute of $R$. It is a non-prime attribute otherwise.

Given a FD $\{A_1, ..., A_n\} \rightarrow Y$,

- It is a full functional dependency if for all $A_i$, $\{A_1, ..., A_n\}/A_i \rightarrow Y$, does not hold.
- It is a partial dependency otherwise.

A FD $X \rightarrow Y$ is a transitive dependency if there exist a set of attribute $B$ s.t.

- $B \neq X, B \neq Y$

$^8$https://en.wikipedia.org/wiki/Armstrong%27s_axioms
• $B$ is not a candidate key,
• $B$ is not a subset of any candidate key,
• $X \rightarrow B$ and $B \rightarrow Y$ hold

4.4.4 Normal Forms and Keys

First, Second, Third, Fourth, Fifth normal form ("X"NF). Stronger than the Third, there is the Boyce-Codd NF (BCNF)

If you satisfy $N$, you satisfy $N-1$, $N-2$, etc. The normal form of a relation is the highest normal form condition that it meets.

4.4.4.1 First Normal Form

4.4.4.1.1 Definition  The domain of all attributes must be atomic (simple, indivisible): exclude multi-valued and composite attributes.

Sometimes, additional requirement that every relation has a primary key. We will take this requirement to be part of the definition of 1NF, but some authors take a relation to be in 1NF if it has at least candidate keys (i.e., multiple possible keys, but no primary key, which makes their definition more general, cf. (Elmasri and Navathe 2015, 14.4.1)). Hence, we will always assume that a primary key is given, and it will be underlined.

4.4.4.1.2 Normalization  To be written

4.4.4.2 Second Normal Form

4.4.4.2.1 Definition  1NF + Every non-prime attribute is fully functionnaly dependent on the primary key.

4.4.4.2.2 Normalization  For each attribute $A$ of the relation whose primary key is $A_1, \ldots, A_n$:

• Is it prime (i.e., is $A \in \{A_1, \ldots, A_n\}$)?
  - Yes → Done.
  - No → Is it partially dependent on the primary key ?
    * No, it is fully dependent on the primary key → Done
    * Yes, it depends only of $\{A'_1, \ldots, A'_k\}$ → Do the following:
      • Create a new relation with $A$ and $\{A'_1, \ldots, A'_k\}$, make $\{A'_1, \ldots, A'_k\}$ the primary key, and “import” all the functional dependencies,
      • Remove $A$ from the original relation, and all the functional dependencies that implied it,
      • Add a foreign key from $\{A'_1, \ldots, A'_k\}$ to their original counterparts in the original relation.
### 4.4 Guidelines and Normal Form

#### 4.4.4.3 Third Normal Form

#### 4.4.4.3.1 Definition

2NF + no non-prime attribute is transitively dependent on the primary key.
4.4.4.3.2 Normalization For each attribute $A$ of the relation whose primary key is $A_1, \ldots, A_n$:

- Is it prime (i.e., is $A \in \{A_1, \ldots, A_n\}$)?
  - Yes $\rightarrow$ Done.
  - No $\rightarrow$ Is it transitively dependent on the primary key?
    * No, there is no $\{A_1', \ldots, A_k'\}$ such that $\{A_1, \ldots, A_n\} \rightarrow \{A_1', \ldots, A_k'\} \rightarrow A$ and $\{A_1', \ldots, A_k'\} \nsubseteq \{A_1, \ldots, A_n\}$ and $A \notin \{A_1', \ldots, A_k'\} \rightarrow$ Done
    * Yes, there is such a $\{A_1', \ldots, A_m'\}$ $\rightarrow$ Do the following:
      · Create a new relation with $A$ and $\{A_1', \ldots, A_k'\}$, make $\{A_1', \ldots, A_k'\}$ the primary key, and import all the functional dependencies,
      · Remove $A$ from the original relation, as well as all the functional dependencies involving it,
      · Add a foreign key from $\{A_1', \ldots, A_k'\}$ to their original counterparts in the original relation.

4.4.4.4 Examples

We can have a look at another example:

\[
\text{DRIVER} (\text{State, Driver Licence Num, Name, Governor})
\]

Note that $\{\text{State, Driver Licence Num}\}$ would be a valid primary key for this relation, and that adding it would make it a relation in 1NF.

As we can see, the name “Driver” is somehow counter-intuitive, since the relation also carries information about Governors. This relation is actually not in 2NF, because the FD $\{\text{State, Driver Licence Num}\} \rightarrow \text{Governor}$ is not fully functional. A possible way to fix it is to get:

\[
\text{DRIVER} (\text{State, Driver Licence Num, Name}) \quad \text{GOVERNOR} (\text{State, Governor})
\]

As you can see, the 2NF helped us in separating properly the entities.

An example of a relation that is in 2NF but not in 3NF could be:

\[
\text{STUDENT} (\text{Login, Name, Major, Major Head})
\]
As we can see, all the non-prime attributes are fully functionally dependent from Login, which is our primary key. But, obviously, one of this dependency is transitive, and breaks the 3NF. A way to fix it is:

As we can see, 3NF also helped us in separating properly the entities, in a slightly different way.

In conclusion, we can observe that every FD \( X \rightarrow Y \) s.t. \( X \) is a proper subset of the primary key, or a non-prime attribute, is problematic. 2NF is a guarantee that every entity has its own relation, 3NF is a way to avoid data inconsistency.

4.5 Unified Modeling Language Diagrams

4.5.1 Overview

One approach for analysis, design, implementation and deployment of databases and their applications. Databases interact with multiple softwares and users, we need a common language.

Unified Modeling Language\(^9\) is a standard:

- Generic
- Language-independent
- Platform-independent

Wide, powerful, but also intimidating.

You know UML from object-oriented programming language:

That is an example of a class diagram (with class name, attributes and operators, as well as a particular way to represent that a class extends another), there are other types of diagrams, they are not unrelated! For instance, using communication diagrams, deployment diagrams, and state chart diagrams, you can collect the requirements needed to draw a class diagram! They each offer a viewpoint on a software that will help you in making sure the various pieces will fit together: it is a tool commonly used in software engineering, and useful in database design.

\(^9\)http://uml.org
4.5.2 Types of Diagrams

There are 14 different types of diagrams, divided between two categories: structural and behavioral.

<table>
<thead>
<tr>
<th>Diagram Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class Diagram</td>
<td>Describes static structures: classes, interfaces, collaborations, dependencies, generalizations, etc. We can represent conceptual data base schema with them!</td>
</tr>
<tr>
<td>Object Diagram</td>
<td>Represents the static view of a system at a particular time. You can think of a “freeze” of a program, to be able to observe the value of the variables and the objects (or instances) created.</td>
</tr>
<tr>
<td>Component Diagram</td>
<td>Describes the organization and the dependencies among software components (e.g., executables, files, libraries, etc.), to describe how an arbitrary large software system is split into pieces.</td>
</tr>
<tr>
<td>Deployment Diagram</td>
<td>Is the description of the physical deployment of artifacts (i.e., software components) on nodes (i.e., hardware). If your program runs on a local computer, fetching data from the Internet, and storing output on a server, you may describe this situation using this sort of diagram.</td>
</tr>
</tbody>
</table>

In this category also exist Composite structure diagram, Package diagram and Profile diagram.
4.5.2.2 Behavioral UML diagrams

They describe the behavioral, or dynamic, relationship, between components.

- **Use case diagram** describes the interaction between the user and the system. Supposedly, it is the privileged tool to communicate with end-users.
- **State machine diagram**, a.k.a., state chart diagram, describes how a system react to external events. You can picture yourself a complex form of finite state automata diagram.
- **Activity diagram** is a flow of control between activities. You may have seen them already, they are supposedly easy to follow:

![Activity Diagram Quiz Example](image)

Figure 4.3: Activity Diagram Quiz Example

Then there is the sub-category of “Interaction diagrams”:

- **Sequence diagram** describes the interactions between objects over time, the flow of information or messages between objects. It is helpful to grasp the time ordering of the interactions.
- **Communication diagram**, a.k.a., collaboration diagram, describes the interactions between objects as a series of sequenced messages. It is helpful to grasp the structure of the objects, who is interacting with who.

This sub-category also comprise **Timing diagram** and **Interaction overview diagram**.

4.5.3 Zoom on Classes Diagrams

Looking at the “COMPANY conceptual schema in UML class diagram notation”, and comparing it with the "ER schema diagram for the COMPANY database" from the textbook, can help you in writing your own “Rosetta Stone” between ER and UML diagram. Let us introduce some UML terminology for the class diagrams.
<table>
<thead>
<tr>
<th>UML</th>
<th>ER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>Entity Type</td>
</tr>
<tr>
<td>Class Name</td>
<td>Entity Name</td>
</tr>
<tr>
<td>Attributes</td>
<td>Attributes</td>
</tr>
<tr>
<td>Operations (or Method)</td>
<td>Sometimes Derived Attributes</td>
</tr>
<tr>
<td>Association</td>
<td>Relationship Type</td>
</tr>
<tr>
<td>Link</td>
<td>Relationship Instance</td>
</tr>
<tr>
<td>Multiplicities</td>
<td>Structural Constraint</td>
</tr>
</tbody>
</table>

As well as for ER diagram, the domain (or data type) of the attributes is optional. A composite attribute in an ER diagram can be interpreted as a structured domain in a UML diagram (think of a `struct`), and a multi-valued attribute requires to create a new class.

Associations are, to some extend, more expressive than relationship types:

- **As for relationship types**, they can be recursive (or reflexive), and uses role names to clarify the roles of both parties.
- **As for relationship types** they can have attributes: actually, a whole class can be connected to an association.
- **As for relationship types**, they can express a cardinality constraint on the relation between classes. They are written as `min .. max`, with `*` for “no maximum”, and the following shorthands: `*` stands for `0..*` and `1` stands for `1..1`. An association with `1` on one side and `*` on the other (resp. `1` and `1`, `*` and `1`, `*` and `*`) is sometimes called “one-to-many” (resp., “one-to-one”, “many-to-one”, “many-to-many”). The notation in partially inverted w.r.t. ER diagrams:
Additionally, associations can be “extended”, and they are not the only kind of relationship that can be expressed between two classes.

- **As opposed to the relationship types**, they can be given a direction, indicating that the user should be able to navigate them only in one direction, or in two (which is the default). This is used for security or privacy purposes.
- **As opposed to the relationship types**, they can be qualified, implying that a class is not connected to the other class as a whole, but to one particular attribute, called the qualifier, or discriminator.
- **As opposed to the relationship types**, they are part of a bigger collection of relationships. Other relationships include:
  - *Aggregation*, a.k.a. “is part of” relationship, between a whole object and its component (that have their own existence).
  - *Composition*, which is the particular case of aggregation where the component does not have an existence of their own.
  - *Generalization*, a.k.a. inheritance, that eliminates redundancy and makes a class a specialization of another one.
  - A full list can be consulted, e.g., at https://www.ibm.com/support/knowledgecenter/SS8PJ7_9.5.0/com.ibm.xtools.modeler.doc/topics/rreltyp.html.

Qualified associations can be used for weak entities, but not only.
Association

- **Plane**
  - `assignedPlane`: 0..1
  - `assignedFlights`: 0..*
- **Flight**

Directed (or uni-directional) Association

- **OverdrawnAccountsReport**
  - `overdrawnAccounts`: 0..*
- **BankAccount**

Aggregation

- **Wheel**
  - `assignedPlane`: 0..1
  - `assignedFlights`: 0..*
- **Car**

Composition

- **Department**
  - `assignedPlane`: 1..*
- **Company**

Generalization / Inheritance

- **CheckingAccount**
- **BankAccount**

Implementation / Realization

- **Professor**
- **Person**

Figure 4.4: Class Diagram Relationships
Some of those subtleties depend on your need, and are subjective, but are important tool to design properly a database, and relieving the programmer from the burden of figuring out many details.

**Exercises**

**Exercise 4.1** Name the three high-level models we will be learning about in this class (expand the acronyms).

**Exercise 4.2** What could be the decomposition of an attribute used to store an email address? When could that be useful?

**Exercise 4.3** Draw the ER diagram for a “COMPUTER” entity that has one multivalued attribute “Operating_System”, a composite attribute “Devices” (decomposed into “Keyboard” and “Mouse”) and an “ID” key attribute.

**Exercise 4.4** Draw the ER diagram for a “CELLPHONE” entity that has a composite attribute “Plan” (decomposed into “Carrier” and “Price”), an “MIN” (Mobile Identification Number) key attribute, and a multi-valued “App_Installed” attribute.

**Exercise 4.5** Name one difference between a primary key in the relational model and a key attribute in the ER model.

**Exercise 4.6** What is a derived attribute? Give two examples and justify them.

**Exercise 4.7** Invent an entity type with at least one composite attribute and one atomic attribute, but no multi-valued attributes. Identify a possible key attribute and draw the entity type you obtained using the conventions we used in class.

**Exercise 4.8** What is the degree of a relationship type?

**Exercise 4.9** What is a self-referencing, or recursive, relationship type? Give two examples.

**Exercise 4.10** What does it mean for a binary relationship type “Owner” between entity types “Person” and “Computer” to have a cardinality ratio of $M : N$?

**Exercise 4.11** What are the two possible structural constraints on a relationship type?

**Exercise 4.12** Draw a diagram to represent a relationship type $R$ between two entities types $A$ and $B$ such that:

- An entity in $A$ may or may not be in relationship $R$ with an entity in $B$.
- An entity in $B$ must be in relationship $R$ with an entity in $A$.
- An entity in $A$ can be in relationship $R$ with at most one entity in $B$.
- An entity in $B$ can be in relationship $R$ with any number of entities in $A$.

**Exercise 4.13** Express the constraints represented in the following diagram in plain English.
**Exercise 4.14** What does it mean for a binary relationship type “is the Chair of” between entity types “Professor” and “Department” to have a cardinality ratio of 1:N? Would it make sense to be have a total participation constraint on one side, and if yes, on which side?

**Exercise 4.15** Express the constraints represented in the following diagram in plain English.

![Diagram](image)

**Exercise 4.16** For the following binary relationships, suggest cardinality ratios based on the common-sense meaning of the entity types.

<table>
<thead>
<tr>
<th>Entity 1</th>
<th>Cardinality Ratio</th>
<th>Entity 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>STUDENT</td>
<td>:</td>
<td>MAJOR</td>
</tr>
<tr>
<td>CAR</td>
<td>:</td>
<td>TAG</td>
</tr>
<tr>
<td>INSTRUCTOR</td>
<td>:</td>
<td>LECTURE</td>
</tr>
<tr>
<td>INSTRUCTOR</td>
<td>:</td>
<td>OFFICE</td>
</tr>
<tr>
<td>COMPUTER</td>
<td>:</td>
<td>OPERATING_SYSTEM</td>
</tr>
</tbody>
</table>

**Exercise 4.17** Give an example of a binary relationship type of cardinality 1 : N.

**Exercise 4.18** Give an example of a binary relationship type of cardinality N : 1 and draw the corresponding diagram (you do not have to include details on the participating entity types).

**Exercise 4.19** Draw an ER diagram with a single entity type, with two stored attributes, and one derived attribute. In your answer, it should be clear that the value for the derived attribute can always be obtained from the value(s) of the other attribute(s).

**Exercise 4.20** Draw an ER diagram expressing the total participation of an entity type “BURGER” in a binary relation “CONTAINS” with an entity type “INGREDIENT”. What would be the cardinality ratio of such a relation?

**Exercise 4.21** Under what condition(s) can an attribute of a binary relationship type be migrated to become an attribute of one of the participating entity types?

**Exercise 4.22** Suppose a “PRODUCES” relationship with an attribute “Amount” exists between a “PRODUCER” entity type and a “MOVIE” entity type, with ratio 1 : M. Migrate the “Amount” attribute to one of the entity types and draw the resulting diagram.

**Exercise 4.23** Suppose a “MEMBERSHIP” relationship with an attribute “Level” (e.g., “silver”, “platinium”, etc.) exists between a “PERSON” entity type and a “CLUB” entity type, with ratio M : 1. Migrate the “Level” attribute to one of the entity types and draw the resulting diagram.
Exercise 4.24  Assume we have three entity types, “Lecture Notes”, “Class” and “Professor.”

1. Draw a diagram of a ternary relationship between the three entities.
2. Draw a diagram that has two binary relationships from one of the three entities to the other two entities.
3. Come up with a question that could be answered using one model but not the other from the previous steps (specify which relationship would be able to answer your question).

You can specify role names in your diagrams for added clarity, and remember to list all the constraints.

Exercise 4.25  Can we always replace a ternary relationship with three binary relationships? Give an example.

Exercise 4.26  What is the difference between an entity type and a weak entity type?

Exercise 4.27  What is a partial key?

Exercise 4.28  Why do weak entity types have a total participation constraint?

Exercise 4.29  Invent a weak entity type, its identifying (owner) entity type and the identifying (or supporting) relationship. Both entities should have (partial) key, and each should have at least one composite attribute.

Exercise 4.30  Convert the following ER diagram into a relational model:

Exercise 4.31  What is insertion anomaly? Give an example.

Exercise 4.32  What is deletion anomaly? Is it a desirable feature?
Exercise 4.33 Why should we avoid attributes whose value will often be NULL? Can the usage of NULL be completely avoided?

Exercise 4.34 Consider the following relation:

PROF(SSN_Name, Department, Bike_brand)

Why is it a poor design to have a "Bike_brand" attribute in such a relation? How should we store this information?

Exercise 4.35 Consider the following relation:

STUDENT(SSN_Name, ..., Sibling_On_Campus)

Why is it a poor design to have a "Sibling_On_Campus" attribute in such a relation? How should we store this information?

Exercise 4.36 Consider the following relational database schema:

STUDENT(Login_Name, ..., Major, Major_head)
DEPARTMENT(Code, Name, Major_head)

Assuming that “Major” is a foreign key referencing “DEPARTMENT.Code”, what is the problem with that schema? How could you address it?

Exercise 4.37 Why can we not infer a functional dependency automatically from a particular relation state?

Exercise 4.38 Consider the relation $R(A, B, C, D, E, F)$ and the following functional dependencies:

1. $F \rightarrow \{D, C\}, D \rightarrow \{B, E\}, \{B, E\} \rightarrow A$
2. $\{A, B\} \rightarrow \{C, D\}, \{B, E\} \rightarrow F$
3. $A \rightarrow \{C, D\}, E \rightarrow F, D \rightarrow B$

For each set of functional dependency, give a key for $R$. We want a key, so it has to be minimal.

Exercise 4.39 Consider the relation $R(A, B, C, D, E, F)$ and the following functional dependencies:

$A \rightarrow \{D, E\}, D \rightarrow \{B, F\}, \{B, E\} \rightarrow A, \{A, C\} \rightarrow \{B, D, F\}, A \rightarrow F$

Answer the following:

1. How many candidate keys is there? List them.
2. How many transitive dependencies can you find? Give them and justify them.

Exercise 4.40 What is a composite attribute in a ER diagram? Can a relational schema with composite attribute be in Second Normal Form?

Exercise 4.41 Consider the relation $R(A, B, C, D)$ and answer the following:

1. If $\{A, B\}$ is the only key, is $\{A, B\} \rightarrow \{C, D\}, \{B, C\} \rightarrow D$ a 2NF? List the nonprime attributes and justify.
2. If $\{A, B, C\}$ is the only key, is $A \rightarrow \{B, D\}, \{A, B, C\} \rightarrow D$ a 2NF? List the nonprime attributes and justify.
Exercise 4.42 Consider the relation $R(A, B, C, D, E, F)$ with candidate keys $\{A, B\}$ and $C$. Remember that, in all generality, to be a prime attribute, you just need to be part of a possible candidate key. Answer the following:

1. What are the prime attributes in $R$?
2. Is $\{C, D\} \rightarrow E$ a fully functional dependency?
3. Write a set of functional dependencies containing at least one transitive dependency, and justify your answer.

Exercise 4.43 Consider the relation $R(A, B, C, D, E)$ and the following functional dependencies:

1. $C \rightarrow D$, $\{C, B\} \rightarrow A$, $A \rightarrow \{B, C, D\}$, $B \rightarrow E$
2. $A \rightarrow \{C, D\}$, $C \rightarrow B$, $D \rightarrow E$, $\{E, C\} \rightarrow A$
3. $\{A, B\} \rightarrow D$, $D \rightarrow \{B, C\}$, $E \rightarrow C$

For each one, give one candidate key for $R$.

Exercise 4.44 Consider the relation $R(A, B, C, D, E)$ and answer the following:

1. If $\{A, B\}$ is the primary key, is $B \rightarrow E$, $C \rightarrow D$ a 2NF? List the nonprime attributes and justify.
2. If $\{A\}$ is the primary key, is $B \rightarrow C$, $B \rightarrow D$ a 2NF? List the nonprime attributes and justify.

Exercise 4.45 Consider the relation $R(A, B, C, D, E, F)$, and let $\{B, D\}$ be the primary key, and have additionally the functional dependencies $\{A, D\} \rightarrow E$, $C \rightarrow F$. This relation is not in 3NF, can you tell why?

Exercise 4.46 Consider the relation $R(A, B, C, D)$ and answer the following:

1. If $A$ is the only key, is $A \rightarrow \{B, C, D\}$, $\{A, B\} \rightarrow C$, $\{B, C\} \rightarrow D$ a 3NF? List the nonprime attributes and justify.
2. If $B$ is the only key, is $B \rightarrow \{A, C, D\}$, $A \rightarrow \{C, D\}$, $\{A, C\} \rightarrow D$ a 3NF? List the nonprime attributes and justify.

Exercise 4.47 Consider the relation $R(A, B, C, D, E)$ and the functional dependencies $\{A, B\} \rightarrow C$, $B \rightarrow D$, $C \rightarrow E$. Answer the following:

1. $A$ by itself is not a primary key, but what is the only key that contains $A$?
2. List the non-prime attributes.
3. This relation is not in 2NF: what transformation can you operate to obtain a 2NF?
4. One of the relation you obtained at the previous step is likely not to be in 3NF. Can you normalize it? If yes, how?

Exercise 4.48 What are the two different categories of UML diagram?

Exercise 4.49 Can a C++ developer working on Linux and a Java developer working on MacOS use the same class diagram as a basis to write their programs? Justify your answer.

Exercise 4.50 What kind of diagram should we use if we want to ...

1. describe the functional behavior of the system as seen by the user?
2. capture the flow of messages in a software?
3. represent the workflow of actions of an user?
Exercise 4.51 Name two reasons why one would want to use a UML class diagram over an ER diagram to represent a conceptual schema.

Exercise 4.52 Consider the following diagram:

<table>
<thead>
<tr>
<th>Flight</th>
<th>Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>flightNumber : Integer</td>
<td>airPlaneType : String</td>
</tr>
<tr>
<td>departureTime : Date</td>
<td>maximumSpeed : MPH</td>
</tr>
<tr>
<td>flightDuration : Minutes</td>
<td>maximumDistance : Miles</td>
</tr>
<tr>
<td>departingAirport : String</td>
<td>tailID : String</td>
</tr>
<tr>
<td>arrivingAirport : String</td>
<td></td>
</tr>
<tr>
<td>delayFlight(numberOfMinutes : Minutes)</td>
<td></td>
</tr>
<tr>
<td>getArrivalTime() : Date</td>
<td></td>
</tr>
</tbody>
</table>

Give the number of attributes for both classes, and suggest two operations for the class that does not have any. Discuss the multiplicities: why did the designer picked those values?

Exercise 4.53 Convert the following ER diagram to a UML class diagram.

Exercise 4.54 Briefly explain the difference between an aggregation and a composition association.

Exercise 4.55 How is generalization (or inheritance) represented in a UML class diagram? Why is such a concept useful?

Exercise 4.56 Convert the following ER diagram into a UML class diagram:
Solution to Exercises

Solution 4.1 The three high-level models we will be learning about are the Unified Modeling Language, Entity Relationship, and Enhanced Entity–Relationship models.

Solution 4.2 A useful decomposition of an email address attribute could be: the username part before the @ sign, and the domain part afterwards. It might be useful to have statistics about the domains of the users or to sort the usernames by length, etc.

Solution 4.3
Solution 4.4

Solution 4.5 There can be more than one key in the ER model, but it has to be made of a single attribute, whereas a primary key can be made of multiple attributes.

Solution 4.6 A derived attribute is an attribute whose value can be determined by the value of other attributes. For instance:
- The value of an “Age” attribute could be determined from the value of an “Date of birth” attribute and the current day.
- The value of a “State” attribute can be determined from the value of a “Zip code” attribute.
- The value of a “Body Mass Index” attribute could be calculated from the values of height and weight attributes.
- The value of an “Initials” attribute could be determined using the values of the “First Name”, “Middle Name”, and “Last Name” attributes.

Solution 4.7

Solution 4.8 The degree of a realationship type is the number of its participating entity types.

Solution 4.9 A self-referencing relationship type is where the same entity type participates more than once. On a SEATS entity type, it would be an attribute like “is to the left of” or on a PERSONS entity type, it would be and attribute like “is married to”.

Solution 4.10 The cardinality ratio on the binary relationship type “Owner” between the entity types “Person” and “Computer” means that a person can own multiple computers, and a computer can have multiple owners.

Solution 4.11 The two possible structural constraints on a relationship type are the cardinality ratio and participation constraints.

Solution 4.12 We would obtain the following diagram:
4.5 Unified Modeling Language Diagrams

Solution 4.13 A key opens only one door, and every key must open at least one door. A door can be opened by multiple keys, and some doors may not be opened by any key (think of doors that do not have a lock).

Solution 4.14 The binary relation type “is the Chair of” with a cardinality ratio of 1:N between entity types "Professor" and "Department" means that a department can have at most one professor as its chair, but that a professor can be the chair of multiple departments. It could make sense to require that every department has a chair, hence writing a double line between the Department entity and the “is the Chair of” relationship, but it would not make sense to have a total participation constraint on the side of the professor (which would mean that every professor has to be the chair of a department).

Solution 4.15 An operating system may be supported by many computers, but it is also possible that no computer supports it (think of an operating system in development, or developed for embedded devices). A computer must support at least one operating system and can support multiple operating systems.

<table>
<thead>
<tr>
<th>Entity 1</th>
<th>Cardinality Ratio</th>
<th>Entity 2</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>STUDENT</td>
<td>$N : 1$</td>
<td>MAJOR</td>
<td>“A student has one major, but multiple students can have the same major”</td>
</tr>
<tr>
<td>CAR</td>
<td>$1 : 1$</td>
<td>TAG</td>
<td>“A car has exactly one tag, a tag belongs to one particular car.”</td>
</tr>
<tr>
<td>INSTRUCTOR</td>
<td>$1 : N$</td>
<td>LECTURE</td>
<td>“An instructor can teach multiple lectures, but a lecture is taught by only one person.”</td>
</tr>
<tr>
<td>INSTRUCTOR</td>
<td>$1 : N$</td>
<td>OFFICE</td>
<td>“An instructor can have multiple office, but an office belongs to only one instructor”</td>
</tr>
<tr>
<td>COMPUTER</td>
<td>$M : N$</td>
<td>OPERATING SYSTEM</td>
<td>“A computer can have multiple operating systems, the same operating system can be installed on more than one computer.”</td>
</tr>
</tbody>
</table>

Solution 4.16 Some of these choices are debatable (typically, almost any combination seems reasonable for the INSTRUCTOR : OFFICE relation).

Solution 4.17 A binary of relationship of SUPERVISOR as a recursive relationship on EMPLOYEE.
4.5 Unified Modeling Language Diagrams

Solution 4.18

Solution 4.19

Solution 4.20

**Solution 4.21** An attribute of a binary relationship type can be migrated to one of the participating entity types when the cardinality ratio is $1 : N$, $1 : 1$, or $N : 1$. It can be migrated “to the $N$ side” or, if there is no $N$ side, to either side. Note that for $n$-ary relationships, at least one ratio needs to be 1 for the attribute to be allowed to migrate (and “to the $N$ side”, or, if there is no $N$ side, to any side).

Solution 4.22 We could have the following:

Solution 4.23 We could have the following:
Solution 4.24  
1. A possible example of ternary relationship is:

2. One example of two binary relationships could be:

3. A question like

"Who wrote the lecture notes X?"

could be answered with the binary relationships but not the ternary. Conversely, a question like

"What are the lecture notes refered to by Prof. X in their class Y?"
could not be answered using the binary relationships (since we do not know what classes are taught by Prof. X).

Solution 4.25 No, a ternary relationship cannot always be replaced by three binary relationships. For instance, if I have a “Travelling to” relationship between a "Person", a “City” and a “Transport mode”, to represent the fact that a person is travelling to a city using a particular mode of transportation, there is no way I can convey the same information using binary relationships.

Solution 4.26 The weak entity type does not have a key attribute, it cannot be distinguished from the other weak entities based on a single attribute, for that we also need to know its relationship to some other entity type.

Solution 4.27 For a weak entity attribute, it is the attribute that can uniquely identify weak entities that are related to the same owner entity.

Solution 4.28 Otherwise, we could not identify entities in it without owner entity.

Solution 4.29 A possible solution is:

![Diagram](image)

Note that the two composite attributes are “generic”, in the sense that you can re-use those examples easily.

Solution 4.30 A possible option is:

![Diagram](image)

Note that “Stays_At” could also be a separate relation, with two attributes, “Address” and “Person”, linked to respectively PLACE.Address and PERSON.SSN, and both being the primary key of the relation.

Solution 4.31 When you have to invent a primary key or add a lot of NULL value to be able to add a tuple. I want to add a room in my DB, but the only place where rooms are listed are as an attribute on a Instructor table, so I have to “fake” an instructor to add a room.
Solution 4.32 A delete anomaly exists when certain attributes are lost because of the deletion of other attributes. It is not desirable, since it can lead to the loss of information.

Solution 4.33 Because they waste space, they are ambiguous (N/A, or unknown, or not communicated?), and they make queries harder. No, it is necessary sometimes.

Solution 4.34 Because it will be **NULL** most of the time. In a separate relation, e.g. a “BIKE” relation, with two attributes, “Owner” and “Brand”, “Owner” being a foreign key referencing the SSN attribute of PROF.

Solution 4.35 Because it will be **NULL** most of the time, and because students could have more than one sibling on campus. In a separate relation, e.g. in a “EMERGENCY_CONTACT” relation, with two attributes, “Student” (referencing the SSN attribute of STUDENT), and “Contact”. If the emergency contacts are not related to the student, or if we want to preserve the fact that one student is a sibling to another, we can create another relation to store that information.

Solution 4.36 Major_Head will give update anomalies. By putting the Head of the department in the DEPARTMENT relation only, i.e., removing it from STUDENT.

Solution 4.37 Just because a coincidence exists (i.e., “in my data set, no android user is color-blind”) does not mean that it will always be true (i.e., “no color-blind person will ever use android”). Functional dependencies should come from a principled reasoning about the attributes, and not from the observation of the data.

Solution 4.38 1. \( F \)
2. \( \{ A, B, E \} \)
3. \( \{ A, E \} \)

Solution 4.39 1. Only one: \( \{ A, C \} \),
2. \( A \rightarrow F \) by \( A \rightarrow D, D \rightarrow F \).

Solution 4.40 A composite attribute is an attribute made of multiple attributes, like an “Address” attribute could be composed of the ”sub”-attributes “Street”, “City”, “Zip” and ”State. A relational schema needs a primary key and to have only atomic domains to be in first normal form, so, no, a relational schema with composite attributes can not be in second normal form.

Solution 4.41 1. Yes. \( C \) and \( D \) are non prime, and they fully depend on \( \{ A, B \} \).
2. No. \( D \) is the only non prime, and it depends only on \( A \).

Solution 4.42 1. \( A, B \) and \( C \).
2. No, because we can remove \( D \),
3. \( A \rightarrow D, D \rightarrow E \) and \( A \rightarrow E \)

Solution 4.43 1. \( \{ B, C \}, A \)
2. \( A, \{ C, E \} \),
3. \( \{ A, D, E \}, \{ A, B, E \} \)

Solution 4.44 1. No. \( C, D, E \), and \( E \) has a partial relation to \( B \)
2. Yes. Since the primary key is a singleton, it is obvious.

Solution 4.45 \( \{ B, D \} \rightarrow C \rightarrow F \) breaks the 3NF.

Solution 4.46 1. No. \( B, C \) and \( D \) are non prime, \( A \rightarrow \{ B, C \} \rightarrow D \) breaks the 3NF.
2. No. \( A, B \) and \( D \) are non prime, \( B \rightarrow \{ A, C \} \rightarrow D \) breaks the 3NF.
Solution 4.47 1. \{A, B\},
2. C, D, E,
3. \(R_1(A, B, C, E)\) and \(R_2(B, D)\)
4. \(R_1(A, B, C), R_2(C, E)\) and \(R_3(B, D)\)

Solution 4.48 The two different categories of UML diagram are behaviour and structure.

Solution 4.49 Yes, UML diagram is language-independent and platform-independent.

Solution 4.50 1. Use-case
2. Sequence diagram
3. Activity diagram

Solution 4.51 To use direction for association, to have a common language with someone less knowledgeable of other diagrammatic notations. For the concept of integration.

Solution 4.52 Flight has 5 attributes, Plane has 4. The Plane class could have the operations `getLastFlightNumber()` : Integer and `setMaximumSpeed(MPH)` : void.

For the multiplicities: A flight could not have a plane assigned, and a plane could not be assigned to a flight. A plane can be assigned to multiple (or no) flights, but a flight must have at most one plane (and could have none).

Solution 4.53 The absence of total participation constraint on the left side of the diagram may seem odd: what would be a hand not belonging to a person? Still, we have to accept it: we do not know what the requirements are, or the precise nature of the entities. As far as we know “hand” could refer to a card game, and “person” could refer to players. A straightforward representation of the same diagram as a UML class diagram could be:

```
<table>
<thead>
<tr>
<th>Hand</th>
<th>Belongs</th>
<th>0..*</th>
<th>Person</th>
</tr>
</thead>
<tbody>
<tr>
<td>attributes would go here</td>
<td>0..1</td>
<td></td>
<td>attributes would go here</td>
</tr>
<tr>
<td>operations would go here</td>
<td></td>
<td></td>
<td>operations would go here</td>
</tr>
<tr>
<td>(\text{Belongs}) 0..1 (\text{Possesses}) 0..*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

Note that we could convey more information, for instance by using aggregation, or even composition, but, without more information about those entities and this relationship, it may be safer not to make any additional supposition.

Solution 4.54 Aggregation: associated class can have an existence of its own.

Composition association: class does not exist without the association.

Solution 4.55 Because it avoids redundancy.

Solution 4.56
Problems

Problem 4.1 *(Design for your professor)* Your professor designed the following relational model, at some point in his career, to help him organize his exams and the students’ exam grades:

<table>
<thead>
<tr>
<th>Table Name and Attributes</th>
<th>Example of Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXAM(Number, Date, Course)</td>
<td>&lt; 1, '2018-02-14', 'CSCI3410'&gt;</td>
</tr>
<tr>
<td>PROBLEM(Statement, Points, Length, Exam)</td>
<td>&lt; 'Your professor designed...', 10, '00:10:00', 1&gt;</td>
</tr>
<tr>
<td>STUDENT_GRADE(Login, Exam, Grade)</td>
<td>&lt; 'aalyx', 1, 83&gt;</td>
</tr>
</tbody>
</table>

EXAM.Number, PROBLEM.Statement, STUDENT_GRADE.Login and STUDENT GRADE.Exam are all the primary key, and STUDENT GRADE.Exam and PROBLEM.Exam are foreign keys that both refer to EXAM.Number.

The idea was to have the following design elements:

- The EXAM table for storing information about exams.
- The PROBLEM table for storing each problem as its’ own entry and to associate every problem to an exam.
- The STUDENT GRADE table for storing the grade of one student for one particular exam.

Unfortunately, this design turned out to be terrible.

1. Describe at least one common and interesting situation where this model would fail to fulfill its purpose.
2. Propose a way to correct the particular problem you identified.

Problem 4.2 *(Reading the MOVIES database ER schema)* Consider the ER schema for the MOVIES database (inspired from (Elmasri and Navathe 2010, Figure 7.24)):

Where the attributes are omitted, and separate entities are created for actors, producers and directors even if they happen to be the same person (to deal with e.g. pseudonyms or different attributes, like agent or address).

Given the constraints shown in the ER schema, respond to the following statements with True or False. Justify each answer.

1. There are no actors in this database that have been in no movies.
2. There might be actors who have acted in more than ten movies.
3. Some actors could have done a lead role in multiple movies.
4. A movie can have only a maximum of two lead actors.
5. Every director has to have been an actor in a movie.
6. No producer has ever been an actor.
7. A producer cannot be an actor in some other movie.
8. There could be movies with more than a dozen actors.
9. Producers can be directors as well.
Figure 4.5: Movies Database Example
10. A movie can have one director and one producer.
11. A movie can have one director and several producers.
12. There could be actors who have performed a lead role, directed a movie, and produced a movie.
13. It is impossible for a director to play in the movie (s)he directed.

**Problem 4.3 (ER diagram for car insurance)**  Draw the ER diagram for the following situation:

1. A car insurance company wants to have a database of accidents.
2. An accident involves cars, drivers, and several aspects: the time and location of where it took place, the amount of damages, and a unique report number.
3. A car has a license, a model, a year, and an owner.
4. A driver has an ID, an age, a name, and an address.

One of the interesting choices is: should “accident” be an entity type or a relationship type?

**Problem 4.4 (ER diagram for job and offers)**  You want to design a database to help you apply for jobs and to compare offers. Every job has a salary range, a title, multiple requirements (like languages known, years of experience, etc.) and was advertised by a company at a particular url. Every company has a physical and numerical address, provides some benefits (assuming they provide the same benefits to all their employees). Sometimes you know one or multiple persons working there, and you want to keep track of their names, role, and (if this is the case) of the job they told you about. Finally, you want to keep track of the offers you received: the job they correspond to, the actual salary offered and the possible starting date.

1. Draw the ER diagram for this situation.
2. Add attributes for the key attributes if needed.
3. Specify the cardinality ratios and participation constraints.

**Problem 4.5 (Incorrect ER diagram)**  A company wants to develop a database to keep track of the programmers, projects and programming languages they know of. They are not willing to store guidelines for the sake of it, but believe that if a project requires a particular guideline (like, which IDE to use, what spacing convention they use, etc.), it should be stored somewhere. They want to accommodate the fact that a project can use multiple programming languages (and sometimes even multiple versions of the same language), and keep track of which programmer is leading which project. To ease “match making”, they also want to track which programmer is knowledgeable of what programming language. They would also like to store links to the specifications of programming languages, as well as urls of the projects and their guidelines.

They came up with the following ER diagram:
This diagram, to your expert eyes, has multiple flaws, missing constraints, and has some inconsistencies with their requirements. List as many as you can, and suggest improvements or solutions when you can think of one.

**Problem 4.6 (Reverse engineering by hand)** Look at the following relational model and “reverse-engineer” it to obtain an ER diagram:

**Problem 4.7 (Discovering MySQL Workbench)** In this problem, we will install and explore the basic functionalities of MySQL Workbench, which is a cross-platform, open-source, and free graphical interface for database design.
1. Install MySQL Workbench if needed. Maybe you already included it in the packages to install when you installed MySQL (cf. the instructions to install MySQL on Windows): try to find if this is the case before trying to install it. Otherwise, use your package manager, or download the binaries from https://dev.mysql.com/downloads/workbench/. The installation should be straightforward for all operating systems.

2. Once installed, execute the software. The instructions below were tested for the 6.3.8 version on Debian and 8.0.19 version on Windows. The trouble with GUI-software is that the menus may differ slightly with what you see, but the core tools we will be using should still be there under a similar name, if not the same name.

3. Under the panel "MySQL Connections", you should see your local installation listed as “Local instance 3306.” Click on the top-right corner of that box and then on “Edit Connections.” Alternatively, click on “Database”, then “Manage Connections”, and then on “Local instance 3306.”

4. Check that all the parameters are correct. Normally, you only have to change the name of the user to “testuser” and leave the rest as it is. Click on “Test the connection” and enter your password (which should be “password”) when prompted. If you receive a warning about "Incompatible/nonstandard server version or connection protocol detected", click on “Continue anyway.”

5. Now, click on the box “Local instance 3306” and enter your password. A new tab appears in which you can see the list of schemas in the bottom part of the left panel.

6. Click on “Database”, then on “Reverse Engineering” (or hit ctrl + r), then click on “next”, enter your password, and click on “next.” You should see the list of the schemas stored in your database. Select one (any one, we are just exploring the functionalities at that point. You can pick, for instance, HW_DB_COFFEE from Problem 3.7 (Read, correct, and write SQL statements for the COFFEE database)), click on “next”, then click on “execute”, “next”, and “close.”

7. You’re back on the previous view, but you should now see “EER diagram” on the top of the middle panel. Click on “EER diagram” twice, scroll down if needed, and you should see the EER diagram.

8. This diagram is not exactly an ER diagram and it is not a UML diagram either: it is an EER diagram, that uses Crow’s foot notation. Make sure you understand it.

9. Try to modify the EER diagram. Make some relations mandatory, change their name, add an attribute, change the name of another relation, insert a couple of elements in an entity, add a row in a table, etc. Make sure you understand the meaning of the lines between the entities.

10. Once you’re done, try to “Forward Engineer” by hitting “Ctrl” + “G.” Click on “next” twice, enter your password, click on “next” once more and you should see the SQL code needed to produce the table you just designed using the graphical tool.

---

**Problem 4.8 (ER-to-Relation mapping for car insurance)**

Apply the ER-to-Relation mapping to your ER diagram from Problem 4.3 (ER diagram for car insurance).

---

**Problem 4.9 (From ER diagram to Relational model – BIKE)** Consider the following ER diagram:
1. Using this diagram, answer the following:

<table>
<thead>
<tr>
<th>Is it true that ...</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>... a customer cannot drop two bikes at the exact same time and date?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... two different customers cannot drop two different bikes at the exact same time and date?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... an employee cannot repair two bikes at the same time?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... a customer can be assigned to more than one employee?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... a customer can have a bike repaired by an employee that is not assigned to him/her?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... a bike can be in the database without having been dropped by a customer?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... an employee can be asked to repair a bike without having that type of bike as one of their specialties?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Convert that ER diagram into a relational model. Try to make as few assumptions as possible.

**Problem 4.10 (From ER diagram to Relational model – RECORD)** Consider the following ER diagram:
1. Using this diagram, answer the following:

<table>
<thead>
<tr>
<th>Is it true that …</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>a label can have multiple logos?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a recording can be released by multiple labels and at different dates?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a record shop can have multiple exclusivities?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>two record shops can have the same address?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>two logos can have the same name?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>two recordings can have the same title?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a record shop must sell at least one recording?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Convert that ER diagram into a relational model. Try to make as few assumptions as possible.

Problem 4.11 (ER-to-Relation mapping for Country) Consider the following ER schema:
where
- “W_IN” stands for “WRITTEN_IN”, and
- “B_W_F” stands for “BORROWS_WORDS_FROM.”
- “W_IN” stands for “WRITTEN_IN”, and
- “B_W_F” stands for “BORROWS_WORDS_FROM”.

For this relationship, on the left-hand side is the language that borrows a word and on the right-hand side is the language that provides the loanword.

Map that ER diagram to a relational database schema.

Problem 4.12 *(From business statements to ER diagram – UNIVERSITY)* Consider the following requirements for a UNIVERSITY database used to keep track of students’ transcripts.

- The university keeps track of each student’s name, student number, class (freshman, sophomore, …, graduate), major department, minor department (if any), and degree program (BA, BS, …, PhD). Student number has unique values for each student.
- Each department is described by a name and has a unique department code.
- Each course has a course name, a course number, credit hours, and is offered by at least one department. The value of course number is unique for each course. A course has at least one section.
- Each section of a course has an instructor, a semester, a year, and a section number. The section number distinguishes different sections of the same course that are taught during the same semester/year; its values are 1, 2, 3, …, up to the number of sections taught during each semester. Students can enroll in sections and receive a letter grade and grade point (0, 1, 2, 3, 4 for F, D, C, B, A, respectively).

1. Draw an ER diagram for this schema.
2. Specify the key attributes of each entity type and the structural constraints on each relationship type.
3. Note any unspecified requirements and make appropriate assumptions to complete the specification.

Problem 4.13 (Normal form of a CAR_SALE relation) Consider the following relation and its functional dependencies:

\[
\text{CAR\_SALE}(\text{Car\_no}, \text{Date\_sold}, \text{Salesman\_no}, \text{Commission}, \text{Discount\_amt})
\]

<table>
<thead>
<tr>
<th>{Car_no, Salesman_no} →</th>
<th>{Date_sold, Commission, Discount_amt}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date_sold</td>
<td>Discount_amt</td>
</tr>
<tr>
<td>Salesman_no</td>
<td>Commission</td>
</tr>
</tbody>
</table>

and let \{Car\_no, Salesman\_no\} be the primary key of this relation.

1. Based on the given primary key, is this relation in 1NF, 2NF, or 3NF? Why or why not?
2. Normalize it to its third normal form.

Problem 4.14 (Normal form of a simple relation) Consider the following relation:

\[
\text{REL}(A, B, C, D, E)
\]

Suppose we have the following dependencies:

\[
\begin{align*}
A & \rightarrow D \\
\{A, B\} & \rightarrow C \\
D & \rightarrow E
\end{align*}
\]

1. What would be a suitable key for this relation?
2. How could this relation not be in first normal form?
3. Assume that it is in first normal form, and normalize it to the third normal form.

Problem 4.15 (Normal form of a SCHEDULE relation) Consider the following relation:

\[
\text{SCHEDULE}(\text{Period\_Start}, \text{Period\_End}, \text{Date}, \text{Room}, \text{Building}, \text{Organizer}, \text{Length})
\]

And the following dependencies:

\[
\begin{align*}
\{\text{Period\_Start, Date}\} & \rightarrow \{\text{Room, Period\_End}\} \\
\{\text{Period\_Start, Length}\} & \rightarrow \text{Period\_End} \\
\{\text{Period\_Start, Period\_End}\} & \rightarrow \text{Length} \\
\{\text{Period\_End, Length}\} & \rightarrow \text{Period\_Start} \\
\{\text{Date, Period\_Start}\} & \rightarrow \text{Organizer}
\end{align*}
\]
Problem 4.16 *(Normalizing the FLIGHT relation)* Consider the following relation:

\[\text{FLIGHT(From, To, Airline, Flight#, Date\_Hour, HeadQuarter, Pilot, TZDifference)}\]

A tuple in the FLIGHT relation contains information about an airplane flight: the airports of departure and arrival, the airline carrier, the number of the flight, its time of departure, the headquarter of the company chartering the flight, the name of the pilot(s), and the time zone difference between the departure and arrival airports.

- The “Pilot” attribute is multi-valued (so that between 1 and 4 pilot’s names can be stored in it).
- Given an airline and a flight number, one can determine the departure and arrival airports, as well as the date, time, and the pilot(s).
- Given the airline carrier, one can determine the headquarter.
- Finally, given the departure and arrival airports, one can determine their time zone difference.

Normalize the “FLIGHT” relation to its third normal form. You can indicate your steps, justify your reasoning, and indicate the foreign keys if you want to, but you do not have to.

Problem 4.17 *(From business statement to dependencies, BIKE)* This problem asks you to convert business statements into dependencies. Consider the following relation:

\[\text{BIKE(Serial\_no, Manufacturer, Model, Batch, Wheel\_size, Retailer)}\]

Each tuple in the relation BIKE contains information about a bike with a serial number, made by a manufacturer, with a particular model number, released in a certain batch, which has a certain wheel size, and is sold by a certain retailer.

1. Write each of the following dependencies as a functional dependency (the first one is given as an example):

   a) A retailer cannot have two bikes of the same model from different batches. *solution:* \{Retailer, Model\} → Batch

   b) The manufacturer and serial number uniquely identifies the bike and where it is sold.

   c) A model number is registered by a manufacturer and therefore cannot be used by another manufacturer.

   d) All bikes in a particular batch are of the same model.

   e) All bikes of a certain model have the same wheel size.

2. Based on those statements, what could be a key for this relation?
3. Assuming all those functional dependencies hold, and taking the primary key you identified at the previous step, what is the degree of normality of this relation? Justify your answer.

---

**Problem 4.18 (From business statement to dependencies, ROUTE)** This problem asks you to convert business statements into dependencies. Consider the following relation:

ROUTE(Name, Direction, Fare_zone, Ticket_price, Type_of_vehicle, Hours_of_operations)

A tuple in the ROUTE relation contains information about a public transportation route: its name (e.g., "Gold", "Green", ...), its direction (e.g., "Medical Campus", "GCC", ...), the fare zone where the route operates (e.g., "Zone 1", "Zone 2", ...), the price of a ticket, the nature of the vehicles assuring the route (e.g., "subway", "bus", ...) and the time of operations (e.g., "24 hours a day", "from 0600 to 2200", etc.).

1. Write each of the following business statement as a functional dependency:
   a) Two different types of vehicle can not operate on routes with the same name.
   b) The ticket price depends on the fare zone and the type of vehicle.
   c) Both the name and the direction are needed to determine the hours of operations.
   d) Two routes with the same name and the same direction must have the same fare zone.

2. Based on those statements, what could be a key for this relation?

---

**Problem 4.19 (From business statement to dependencies, ISP)** Consider the following business statement:

We want to represent the market of Internet Service Providers (ISP). Each ISP offers multiple bundles, that have a maximum bandwidth and a price. Some ISP uses the same name for their bundles (e.g., "premium", or "unlimited"). Each ISP is given multiple Internet Protocol addresses (IP), and those never change. Every client has an ID that is proper to the ISP (i.e., ISP A and ISP B could both have a client with ID "00001"), an email and subscribes to a particular bundle from a particular ISP. The IP of a client changes over the time.

1. Assuming we have a relation with all the attributes written in bold in the business statement, list all the functional dependencies given by the statement.
2. Based on the functional dependencies you identified at the first step, construct a collection of relations, all in 3rd normal form, that would represent this situation.

---

**Problem 4.20 (Normalization)** Consider the relations $R$ and $T$ below and their functional dependencies (as well as the one induced by the primary keys):

- $R(\text{EventId}, \text{Email}, \text{Time}, \text{Date}, \text{Location}, \text{Status})$
- $T(\text{Invno}, \text{Subtotal}, \text{Tax}, \text{Total}, \text{Email}, \text{Lname}, \text{Fname}, \text{Phone})$
Normalize the relations to 2NF and 3NF. Show all relations at each stage (2NF and 3NF) of the normalization process.

### Problem 4.21 (Normal form of the BOOK relation)
Consider the following relation for published books:

BOOK(Book_title, Book_type, Author_name, List_price, Author_affil, Publisher)

Suppose we have the following dependencies:

- Book_title → {Publisher, Book_type}
- Book_type → List_price
- Author_name → Author_affil

1. What would be a suitable key for this relation?
2. Explain how this relation could not be in first normal form.
3. This relation is not in second normal form: explain why and normalize it.
4. Are the relations you obtained in the previous step in third normal form? Explain why and normalize them if needed.

### Problem 4.22 (Normal form of the DELIVERY relation)
Consider the following relation for deliveries:

DELIVERY(Shipment, PackageNumber, RecipientName, Weight, DriverName, DriverPhone, RecipientPhone)

Suppose we have the following functional dependencies:

- Shipment → DriverName
- PackageNumber → Shipment
- PackageNumber → {RecipientName, RecipientPhone}
- PackageNumber → Weight
- DriverName → DriverPhone

Answer the following three questions:

1. Reply Yes / No to the following: In this model...
   a) ... can the shipment being handled by two drivers?
   b) ... can a package have two different recipient?
   c) ... can a package being in different shipments?
Problem 4.23 (Normal form of the CONTACT relation) Consider the relation

CONTACT(Phone, Call_center, Email, Zip, Brand, Website)

and the following functional dependencies:

\[
\begin{align*}
\{\text{Zip, Brand}\} & \rightarrow \{\text{Phone}\} \\
\{\text{Brand}\} & \rightarrow \{\text{Email}\} \\
\{\text{Brand}\} & \rightarrow \{\text{Website}\} \\
\{\text{Phone}\} & \rightarrow \{\text{Call}_\text{center}\}
\end{align*}
\]

Assume that \{Zip, Brand\} is the primary key. Normalize this relation to the second normal form, and then to the third normal form. Give the relations, their primary keys, and functional dependencies for both steps.

Problem 4.24 (Normal form of the MESSAGE relation) This exercise asks you to convert business statements into dependencies. Consider the following relation:

MESSAGE(SenderId, Time, Date, ReceiverId, Content, Length, Attachment, Size)

A tuple in the MESSAGE relation contains information about a text message: its sender, the time and date when it was sent, the receiver, the content, the length (in characters), the attachment, and the size (in bytes).

1. Write each of the following business statements as a functional dependency:
   a) The length of a message, which can be computed from its content.
   b) The content and attachment, which determines the size of a message.
   c) A sender can send the same content and attachment to multiple receivers at the exact same time and date, but cannot send two different contents and attachments at the exact same time and date.

2. Assuming all the functional dependencies you identified at the previous step hold, determine a suitable primary key for this relation.

3. Taking the primary key you identified at the previous step, what is the degree of normality of this relation? Justify your answer.

4. If needed, normalize this relation to the third normal form.

Problem 4.25 (PRINT relation in third normal form) Normalize the following relation to the third normal form.
Do not forget to indicate all the primary keys in your relations.

---

**Problem 4.26 (CONSULTATION relation: justification, primary key and normal form)**

Consider the relation

CONSULTATION(Doctor_no, Patient_no, Date, Diagnosis, Treatment, Charge, Insurance)

with the following functional dependencies:

\[
\begin{align*}
\{\text{Doctor_no, Patient_no, Date}\} & \rightarrow \{\text{Diagnosis}\} \\
\{\text{Doctor_no, Patient_no, Date}\} & \rightarrow \{\text{Treatment}\} \\
\{\text{Treatment, Insurance}\} & \rightarrow \{\text{Charge}\} \\
\{\text{Patient_no}\} & \rightarrow \{\text{Insurance}\}
\end{align*}
\]

1. The designer decided not to add the functional dependency \(\{\text{Diagnosis}\} \rightarrow \{\text{Treatment}\}\). Explain what could be the designer’s justification (at the level of the mini-world).
2. Identify a primary key for this relation.
3. What is the degree of normalization of this relation? Normalize it to the third normal form if necessary.

---

**Problem 4.27 (COFFEE relation: primary key and normal form)**

Consider the relation

COFFEE(Origin, Type_Of_Roast, Price, Roasted_Date, Best_Before, Color, Customer, Rating)

with the following functional dependencies:

\[
\begin{align*}
\{\text{Origin, Type_Of_Roast}\} & \rightarrow \text{Price} \\
\{\text{Origin, Type_Of_Roast, Customer}\} & \rightarrow \text{Rating} \\
\{\text{Origin, Type_Of_Roast, Roasted_Date}\} & \rightarrow \text{Color} \\
\text{Roasted_Date} & \rightarrow \text{Best_Before}
\end{align*}
\]

Assume that all the attributes are atomic and answer the following.

1. Based on those functional dependencies, what would be a suitable primary key?
2. What is the degree of normalization of this relation? Justify your answer.
3. Normalize this relation to the third normal form, and do not forget to indicate all the functional dependencies. You can indicate the second normal form if that helps you.
Problem 4.28 (A Relation for Network Cards) A network card (NIC) has a manufacturer, a model, and a unique serial number (MAC address). It offers one or multiple network technologies (ethernet, wi-fi, bluetooth, etc.), and can be connected to the motherboard using one or multiple connections (PCI connector, FireWire, usb, etc.).

1. Assuming we have a NIC relation with all the attributes emphasized in the business statement, list all the functional dependencies.
2. The relation you obtained is not in 1st normal form, since two of the attributes (network technology and connection) are multi-valued. Propose a way to fix it, and suggest a primary key for the relation(s) you obtained.
3. Based on the functional dependencies you identified in the first step, is (are) the relation(s) you constructed in the second step in second normal form? If yes, explain why, if no, normalize it (them).

Problem 4.29 (From ER to relational schema and UML class diagram – CAR_INFO)

Consider the following ER schema for the CAR_INFO database:

Note that a car can have at most one driver, $N$ passengers, $N$ insurances, and that the car insurance entity exists only if it is “tied up” to a car (i.e., it is a weak entity, and its identifying relationship is called “Insured”).

1. Find the key attribute for Car, and the partial key for Car Insurance. If you cannot think of any, add a dummy attribute and make it be the key.
2. Convert the ER diagram to a relational database schema.
3. Convert the ER diagram to a UML class diagram. Hint: Comparing Figure 7.16 with Figure 7.2 from your textbook should guide you.
Problem 4.30 (From Business Statement to ER Diagram to Relational Model – A Network of Libraries)

You are asked to design a database for a network of libraries.

Each library has a name, an address (made of a number, a street, and a zip), and have copies of documents available to borrow and to reserve. A document is of a particular kind (book, video, or disk), has a title, and an internal catalog number (that can be the ISBN, a barcode, etc.). There can be multiple copies of a document in the network, and each copy has a particular unique code. A copy of a document always "belongs" to a particular library, even when it is checked out.

Furthermore, you want to be able to add the patrons in your database. A patron has a name, a unique library card number, and an email. A patron can reserve (put a hold on) multiple copies of documents for up to two weeks, and can borrow multiple copies of documents for one week if it is a video or a disk, and one month if it is a book. Of course, a copy can be borrowed by only one patron, but it can be put on hold for one patron while being borrowed.

1. Draw the ER diagram for this situation. Remember to add all the constraints on your relations.
2. Convert your ER diagram to the relational model.

Problem 4.31 (Using MySQL Workbench’s reverse engineering) This problem requires you to have successfully completed Pb 4.7 and Pb 4.33.

Using the relational database schema you obtained in Pb 4.33, write the SQL implementation of that database. Then, using MySQL Workbench, use the "Reverse Engineering" function to obtain an EER diagram of your database and compare it with the UML diagram from Pb 4.33. Apart from the difference inherent to the nature of the diagram (i.e., UML vs EER), how else are they different? How are they the same? Is the automated tool as efficient and accurate as you are?

Problem 4.32 (From business statements to dependencies – KEYBOARD) This exercise asks you to convert business statements into dependencies. Consider the following relation:

KEYBOARD(Manufacturer, Model, Layout, Retail_Store, Price)

A tuple in the KEYBOARD relation contains information about a computer keyboard; its manufacturer, its model, its layout (AZERTY, QWERTY, etc.), the place where it is sold, and its price.

1. Write each of the following business statements as a functional dependency:
   - A model has a fixed layout.
   - A retail store cannot have two different models produced by the same manufacturer.
2. Based on those statements, what could be a key for this relation?

3. Assuming all those functional dependencies hold, and taking the primary key you identified at the previous step, what is the degree of normality of this relation? Justify your answer.

Problem 4.33 (From UML to relational model – DRIVER) Consider the UML diagram below, and convert it to the relational model. Do not forget to indicate primary and foreign keys.

Solutions to Selected Problems

Solution to Problem 4.2 (Reading the MOVIES database ER schema) 1. True. The double lines on either side of the “PERFORMS IN” relation denote a total participation constraint. This means in particular that an actor must have performed in at least one movie and that a movie must have had at least one actor who performed in it.

2. True. The arity on the right side of the “PERFORMS IN” relation is “N.” This means there are an unlimited amount of movies in which an actor may perform.

3. True. The arity on the right side of “LEAD ROLE” is “N.” This means that an actor may have performed in multiple lead roles for movies.

4. True. The arity on the left side of “LEAD ROLE” is “2.” This means that a movie can have a maximum of two lead roles.

5. False. The single line from the “DIRECTOR” to “ALSO A DIRECTOR” is unconstrained and means that the relation is optional for that entity.

6. False. There exists an “ACTOR PRODUCER” relation between the “ACTOR” and “PRODUCER” entities to facilitate this situation.

7. False. Although the single line between “PRODUCER” and “ACTOR PRODUCER” means the relationship is optional, it does not mean it cannot happen.

8. True. The arity on the left side of “PERFORMS IN” is “M.” This means that a movie can have an unlimited amount of actors in it.

9. True. It is not explicit in this schema, but an actor can be both a director and a producer, which implies that a producer can also be a director by transitivity.
10. True. In fact, there is a partial participation constraint that means a movie must have one director and one producer at least.
11. True. The arity on the left of "DIRECTS" is "1" and is "M" on the left of "PRODUCES." This means that a movie can only have up to one director, but have an unlimited amount of producers.
12. True. All of these relations exist to enable an actor to act in a lead role, be a director, and be a producer.
13. False. There exists a relation for a director to be an actor and there are no constraints keeping the director to perform in the movie they are directing.

Solution to Problem 4.3 (ER diagram for car insurance) A possible solution is: Re-work on that solution?

![Figure 4.6: ER Diagram Car Insurance](fig/er/accident)

Solution to Problem 4.4 (ER diagram for job and offers) A possible solution is:
4.5 Unified Modeling Language Diagrams

Note that CONTACT could be a weak entity with the identifying relationship being either DISCUSSED_BY or EMPLOYS, but both have disadvantages: they would not allow a contact to discuss more than one offer or to be hired by more than one company.

---

Solution to Problem 4.5 (Incorrect ER diagram) Among the numerous flaws, come to mind:

1. “Technical errors” (making the diagram incorrect):
   a) Multiple keys for an entity (“PROGRAMMER”),
   b) Absence of a key (“PROGRAMMING_LANGUAGE”),
   c) Absence of the total participation constraint between the weak entity and its identifying relationship (“GUIDELINES” and “RECOMMENDED_BY”),
   d) Absence of an arity (between the “USES” relationship and the “PROJECT” entity),
   e) To a certain extent, inconsistent naming (spaces / underscore, absence of capital letter for “leader” or “url”)

2. Violations of the business statement:
   a) “They want to accommodate the fact that a project can use multiple programming languages (and sometimes even multiple versions of the same language)”: this is not possible. There are two ways of adding this feature:
      i. Make the “PROGRAMMING_LANGUAGE” entity become a “VERSION_OF_PROGRAMMING_LANGUAGE” entity, and make the “USE” relationship M:N.
      ii. Leave the “PROGRAMMING_LANGUAGE” entity as it is, make the “USE” relationship M:N, and add a “Version” attribute to it. The first option being a bit more elegant, to some extent (but we lose the capacity of deriving the latest version).
   b) “keep track of which programmer is leading which project”: As a leader is supposed to be a programmer as well, there should be a “IS_THE_LEADER_OF” relationship between “PROGRAMMER” and “PROJECT”, instead of an attribute on the “PROJECT” entity.
c) “they also want to track which programmer is knowledgeable of what programming language”: the “KNOWS” relationship should not be “M:1”, as a programmer can probably being knowledgeable in more than one programming language.
d) “if a project requires a particular guideline[…], it should be stored somewhere”: The “RECOMMENDED_BY” relationship should be 1:1.

3. Basic understanding errors:

a) The lack of “Name” attribute in the “PROGRAMMING_LANGUAGE” entity is puzzling.
b) “CONTRIBUTES_TO” should probably not being total on any side, as you may want to record programmers even if they are not contributing to any project, and project even if nobody is actively working on them. Also, it should not be 1:1, but M:N.
c) “RECOMMENDED_BY” could probably be renamed “GUIDE_THE_DEVELOPMENT_OF”, for added clarity.

<table>
<thead>
<tr>
<th>Is it true that ...</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>... a customer cannot drop two bikes at the exact same time and date?</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>... two different customers cannot drop two different bikes at the exact same time and date?</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>... an employee cannot repair two bikes at the same time?</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>... a customer can be assigned to more than one employee?</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>... a customer can have a bike repaired by an employee that is not assigned to him/her?</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>... a bike can be in the database without having been dropped by a customer?</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>... an employee can be asked to repair a bike without having that type of bike as one of their specialties?</td>
<td>✔</td>
<td></td>
</tr>
</tbody>
</table>

**Solution to Problem 4.9 (From ER diagram to Relational model – BIKE)**

1. For the 1 : M relationships that are not identifying, we can choose between the foreign key and the cross-reference approaches. If we use the former, we obtain:
We could also have used a combination of both!

<table>
<thead>
<tr>
<th>Is it true that ...</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>a label can have multiple logos?</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>a recording can be released by multiple labels and at different dates?</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>a record shop can have multiple exclusivities?</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>two record shops can have the same address?</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>two logos can have the same name?</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>two recordings can have the same title?</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>a record shop must sell at least one recording?</td>
<td>✔</td>
<td></td>
</tr>
</tbody>
</table>

Solution to Problem 4.10 (From ER diagram to Relational model – RECORD) 1.

2. For the 1:M relationship IS_AN_EXCLUSIVITY_OF, we can choose between the foreign key and the cross-reference approaches. For the 1:1 relationship USES, we can use any approach we want (foreign key, merged relation, or cross-reference). We will choose to merge the two relations LABEL and LOGO and to have a look-up table for the IS_AN_EXCLUSIVITY_OF relation. This obtains:

Solution to Problem 4.13 (Normal form of a CAR_SALE relation) 1. The CAR_SALE relation is in 1st normal form, since it has a primary key, and by assuming that all the attributes are atomic. This relation is not in 2nd Normal Form: since Date_sold → Discount_amount and Salesman_no → Commission, then some attributes (namely Discount_amount and Commission) are not fully functional dependent on the primary key. Hence, this relation cannot be in 3rd normal form either.

2. To normalize, 2NF:
4.5 Unified Modeling Language Diagrams

Relations |
---|
**Car_Sale1***(Car_no, Date_sold, Discount_amt)*** |
**Car_Sale2***(Car_no, Salesman_no)*** |
**Car_Sale3***(Salesman_no, Commission)*** |

**Functional Dependencies** |
---|
***Car_no → {Date_Sold, Discount_amt} and Date_Sold → Discount_amt*** |
***Car_no → Salesman_no*** |
***Salesman_no → Commission*** |

3NF:

<table>
<thead>
<tr>
<th>Relations</th>
<th>Functional Dependencies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Car_Sale1-1</strong> <em>(Car_no, Date_sold)</em></td>
<td><strong>Car_no → Date_Sold</strong>*</td>
</tr>
<tr>
<td><strong>Car_Sale1-2</strong> <em>(Date_sold, Discount_amt)</em></td>
<td><strong>Date_Sold → Discount_amt</strong>*</td>
</tr>
<tr>
<td><strong>Car_Sale2</strong> <em>(Car_no, Salesman_no)</em></td>
<td><strong>Car_no → Salesman_no</strong>*</td>
</tr>
<tr>
<td><strong>Car_Sale3</strong> <em>(Salesman_no, Commission)</em></td>
<td><strong>Salesman_no → Commission</strong>*</td>
</tr>
</tbody>
</table>

**Solution to Problem 4.14 (Normal form of a simple relation)**

1. {A, B} would be a suitable primary key (actually, it is the only one).
2. If no key was selected, or if an attribute has a multi-valued domain, then this relation would not be in first normal form.
3. The following three relations are in third normal form:
   a) R1(A, B, C)
   b) R2(D, E)
   c) R3(A, D)

**Solution to Problem 4.15 (Normal form of a SCHEDULE relation)**

1. {Period_Start, Date} would be a suitable primary key.
2. This relation is already in second normal form: there are no non-prime attributes that are not fully dependent of the primary key. Stated differently, there are no non-prime A such that {Period_Start} → A or {Date} → A.
3. This relation is not in 3rd normal form. Consider the following relation: {Period_Start, Date} → {Period_Start, Period_End} → Length. {Period_Start, Period_End} is different from {Period_Start, Date} and from Length, and it is not included in a candidate key. The same goes for {Period_Start, Date} → Room → Building.

Once normalized to the third normal form, we get:

**SCHEDULE** *(Period Start Date Room Organizer Period End)*

**LENGTH** *(Period Start Period End Length)*

**ROOM** *(Room Building)*
Solution to Problem 4.17 (From business statement to dependencies, BIKE)

1. The functional dependencies we obtain are:
   a) \( \{ \text{Manufacturer, Serial_no} \} \rightarrow \{ \text{Model, Batch, Wheel_size, Retailer} \} \)
   b) \( \text{Model} \rightarrow \text{Manufacturer} \)
   c) \( \text{Batch} \rightarrow \text{Model} \)
   d) \( \{ \text{Model, Manufacturer} \} \rightarrow \text{Wheel_size} \)

2. \( \{ \text{Manufacturer, Serial_no} \} \)

3. If every attribute is atomic, it is in second normal form. \( \{ \text{Manufacturer, Serial_no} \} \rightarrow \text{Batch} \rightarrow \text{Model} \) breaks the 3NF.

Solution to Problem 4.18 (From business statement to dependencies, ROUTE)

The relation we consider is:

\[
\text{ROUTE}(
\text{Name, Direction, Fare\_zone, Ticket\_price, Type\_of\_vehicle, Hours\_of\_operations})
\]

1. This problem asks to convert business statements into dependencies.
   a) Two different types of vehicles can not operate on routes with the same name.
      \( \text{Name} \rightarrow \text{Type\_of\_vehicle} \)
   b) The ticket price depends of the fare zone and the type of vehicle. \( \{ \text{Fare\_zone, Type\_of\_vehicle} \} \rightarrow \text{Ticket\_price} \)

2. Both the name and the direction are needed to determine the hours of operations.
   \( \{ \text{Name, Direction} \} \rightarrow \text{Hours\_of\_operations} \)

3. Two routes with the same name and the same direction must have the same fare zone.
   \( \{ \text{Name, Direction} \} \rightarrow \text{Fare\_zone} \)

4. Based on those statements, \( \{ \text{Name, Direction} \} \) is the only key for this relation.

Solution to Problem 4.19 (From business statement to dependencies, ISP)

1. The relation we consider is:

\[
\text{ISP}(\text{ISP, bunle, bandwith, price, IP, ID, email, time})
\]

The functional dependencies suggested by the business statement are:

\[
\begin{align*}
\{ \text{ISP, bundle} \} & \rightarrow \{ \text{bandwidth, price} \} \\
\text{IP} & \rightarrow \text{ISP} \\
\{ \text{ISP, ID} \} & \rightarrow \{ \text{email, bundle} \} \\
\{ \text{ISP, ID, time} \} & \rightarrow \text{IP}
\end{align*}
\]

1. We obtain the following four relations when we normalize it to the third normal form:
   a) \( \text{BUNDLE}(\text{ISP, bundle, bandwidth, price}) \)
   b) \( \text{IP}(\text{ISP, IP}) \)
c) CLIENT(ISP, id, email, bundle)

d) CLIENT_IP(ISP, id, time, IP)

Solution to Problem 4.21 (Normal form of the BOOK relation)
1. {Book Title, Author Name}
2. If an attribute is composite or multi-valued, then the relation would not be in first normal form.
3. It is not in second normal form because of {Book_title} → {Publisher, Book_type}. We can normalize it like so: (Book Title, Publisher, Book Type, List Price), (Author Name, Author Affiliation), (Author Name, Book Title).
4. The relations are in third normal form because of {Book title} → {Book_type} → {List_price} (Book Title, Publisher, Book Type) and (Book Type, List Price), (Author Name, Author Affiliation), (Author Name, Book Title).

Solution to Problem 4.22 (Normal form of the DELIVERY relation)
1. Reply Yes / No to the following: In this model...
   a) ... can the shipment being handled by two drivers? No
   b) ... can a package have two different recipient? No
   c) ... can a package being in different shipments? No
   d) ... can a recipient have two different phone numbers for the same name? Yes
   e) ... can a driver have two different phone numbers for the same name? No
2. PackageNumber would be a suitable primary key for this relation.
3. A possible third normal form is (where the only functional dependencies are the one given by the primary keys): SHIPMENT(Shipment, DriverName) DRIVER(DriverName, DriverPhone) PACKAGE(PackageNumber, Shipment, Weight, RecipientName, RecipientNumber)

Solution to Problem 4.25 (PRINT relation in third normal form)
After normalizing PRINT to the second normal form (by adding the primary key {Author, Title, Size}, and working on dependencies like {Author, Title} → Technique, which does not fully depend of the primary key), we would obtain three relations that are already in third normal form:

1. PRICING(Author, Title, Size, Price)
2. ART(Author, Title, Technique)
3. SHIPPING_COSTS(Size, Price)

Solution to Problem 4.26 (CONSULTATION relation: justification, primary key and normal form)
The treatment for a particular disease can vary with the patient (for instance, his age can be a crucial parameter).
2. \{Doctor\_no, Patient\_no, Date\} is a primary key for this relation.
3. Because there are no partial dependencies, the given relation is in 2NF already. This, however, is not 3NF because Charge is a non-key attribute that is determined by another non-key attribute (Treatment). We must decompose the relation further:

CONSULTATION (Doctor\_no, Patient\_no, Date, Diagnosis, Treatment)
PRICE\_LISTING (Treatment, Charge)

---

**Solution to Problem 4.27 (COFFEE relation: primary key and normal form)** The original relation is:

COFFEE(Origin, Type\_Of\_Roast, Price, Roasted\_Date, Best\_Before, Color, Customer, Rating)

1. A suitable primary key would be \(PK_{COFFEE} = \{Origin, Type\_Of\_Roast, Roasted\_Date, Customer\}\). Note that it is the minimal and only primary key.

2. This relation is in first normal form because it has a primary key (the one we just defined), and because all the attributes are atomic. It is not in second normal form, because, for example, the functional dependency \(PK_{COFFEE} \rightarrow Price\) is not fully functionally dependent, since \(\{Origin, Type\_Of\_Roast\} \rightarrow Price\) holds.

3. Normalizing to the second normal form actually gives us relations in third normal form:

-CLIENT\_RATING(Origin, Type\_Of\_Roast, Customer, Rating)
-PRICING(Origin, Type\_Of\_Roast, Price)
-EXPIRATION\_DATE(Roasted\_Date, Best\_Before)
-COFFEE\_BATCH(Origin, Type\_Of\_Roast, Roasted\_Date, Color)

Where the functional dependencies always are in such a way that all the attributes but the last one fix the value of the last one, and are taken to be the primary key.

Checking that they are all in third normal form is straightforward. Note that the “original” relation was somewhat lost, since we do not have a relation whose primary key is \(PK_{COFFEE}\) anymore. We could have re-introduced a relation with only the attributes of \(PK_{COFFEE}\) to be on the “safe side”, but the benefit would not have been clear.

---

**Solution to Problem 4.29 (From ER to relational schema and UML class diagram – CAR\_INFO)**

For Car, we need to create an attribute, like VIN. For Car Insurance, Policy Number is the perfect key attribute.
Note that, during the conversion, we had to make Insured Car part of the primary key of CAR INSURANCE.

Solution to Problem 4.30 (From Business Statement to ER Diagram to Relational Model – A Network of Libraries)

For the ER diagram, we could get something like:
Note that:

- We want to represent the fact that a single document can have multiple copies, which suggests that DOCUMENT and COPY are two separate entities.
- COPY could be made into a weak entity, OF being the identifying relation.
- Nothing in the statement forces a relationship between the patron and the library to exist, so, by simplicity, we do not add it. However, adding it would not have been a mistake.
- The fact that a COPY has to be of a particular kind does not force the kind attribute to be multi-valued or composite: it just means that if we were representing the domains as well, this attribute would have a particular domain that restricts the values to three possibilities (book, video or disk).
- POSSESS is total on the COPY side because the statement reads “A copy of a document always ‘belongs’ to a particular library.”
- HOLD_BY could be $N : M$, since nothing in the statement says that a document can be put on hold by only one patron.

1. Its mapping to a relational model could be:
Note that:

- The relationships HOLD_BY and BORROWED_BY could be represented using the foreign key approach. However, their value would be `NULL` most of the time, so it would not be very efficient.
- COPY could be the only attribute in the primary key of BORROWING and HOLD because a copy can be borrowed or put on hold only once. Having both attributes being the primary key could allow for more flexibility (typically, a copy could be put on hold by multiple patrons at the same time).

Solution to Problem 4.31 (Using MySQL Workbench’s reverse engineering) We give the code first, then the drawing:

```sql
/* code/sql/HW_Person.sql */
DROP SCHEMA IF EXISTS HW_Person;
CREATE SCHEMA HW_Person;
USE HW_Person;
CREATE TABLE PERSON (
  ID VARCHAR(25) PRIMARY KEY, NAME VARCHAR(25), Street VARCHAR(25), City VARCHAR(25),
  Seat VARCHAR(25), Position VARCHAR(25)
);

CREATE TABLE CAR (
  Vin VARCHAR(25) PRIMARY KEY, Make VARCHAR(25), Model VARCHAR(25), Model Year DATE,
  Driver VARCHAR(25), FOREIGN KEY (Driver) REFERENCES PERSON (ID) ON UPDATE CASCADE
);

ALTER TABLE PERSON
  ADD FOREIGN KEY (Seat) REFERENCES CAR (Vin);
CREATE TABLE CAR_INSURANCE (
  Policy_number VARCHAR(25) PRIMARY KEY, Company_name VARCHAR(25), Insured_car VARCHAR(25),
  FOREIGN KEY (Insured_car) REFERENCES CAR (Vin)
);

CREATE TABLE PHONE (
  ID VARCHAR(25), Number VARCHAR(25), FOREIGN KEY (ID) REFERENCES PERSON (ID), PRIMARY KEY (ID, number)
);
Figure 4.7: mysql Workbench Diagram
5 Database Applications

Resources

- http://spots.augusta.edu/caubert/teaching/general/java/
- If you experience any trouble, https://www.ntu.edu.sg/home/ehchua/programming/howto/ErrorMessages.html#JDBCErrors might be a good read.
- (Elmasri and Navathe 2010, 13.3.2) or (Elmasri and Navathe 2015, Chapter 10) is a condensed, but good, read.
- Many textbooks on Java include a part on Databases, just like this one: (Gaddis 2014, Chapter 16).

5.1 Overview

Two options to interact with a database:

- Interactive interfaces (command line interface and graphical user interface like workbench\(^1\)): what we used so far.
- Application program / Database application, what we will study. They can be of several types:
  1. Embeded SQL\(^2\): the idea is to embed SQL commands directly in the program: a pre-compiler scans the code, extract the SQL commands, execute them on the DBMS. This system is used primarily for C, C++, COBOL or Fortran, and Language Integrated Query\(^3\) to some extend is part of this approach.
  2. Use a library, or Application Programming Interface for accessing the database from application programs.
  3. Create a new language that extends SQL (for instance, PL/SQL\(^4\)).

In this chapter, we will study how to develop a database application that uses a library.

Every database application follows the same routine:

1. Establish / open the connection with the DBMS,
2. Interact with the DBMS (Update, Query, Delete, Insert),
3. Terminate / close the connection with the DBMS.

Which API is used vary with the pair Language / DBMS. Here are some of the most commonly used pairs:

\(^1\)https://en.wikipedia.org/wiki/MySQL_Workbench
\(^2\)https://en.wikipedia.org/wiki/Embedded_SQL
\(^3\)https://docs.microsoft.com/en-us/dotnet/standard/using- LINQ
\(^4\)https://www.oracle.com/database/technologies/appdev/plsql.html
In this chapter, we will more precisely study how to develop a database application coded in Java that uses the Java DataBase Connectivity library.

5.2 Java’s Way

Java actually uses

- A protocol (the API, a class library), Java DataBase Connectivity (JDBC), common to all DBMS and used at compilation time. Essentially, it is a collection of classes to send SQL statements, retrieve and update the results of a query, handle exceptions, etc.
- A subprotocol (the driver, connector), Connector/J for MySQL, that is used at execution time.

The situation is similar e.g. in Python, where you have to use an API and a connector. Among Python’s connector compatible with MySQL’s API, there is PyMySQL or mysql-connector-python.\(^5\)
Note that the A.P.I. is needed when you write and compile your program, and the driver / connector is needed when you execute it. We will come back to this when we explore our first program.

5.3 Flash Intro to Java


5.4 A First Program

We will write and compile a simple java program that manipulates a simple database. Even if the creation and population of the database could have been done from within the program, we will do it as a preliminary step, using the C.L.I., to make our program simpler.

5.4.1 The Database (SQL)

For this program, we will use the following database:

```sql
/* code/sql/HW_EBookshop.sql */
DROP SCHEMA IF EXISTS HW_EBookshop;

CREATE DATABASE HW_EBookshop;

USE HW_EBookshop;

CREATE TABLE BOOKS ( 
    ID INT PRIMARY KEY, title VARCHAR(50), author VARCHAR(50), price DECIMAL(10, 2), 
    qty INT 
);

INSERT INTO BOOKS 
    VALUES (1, 'The Communist Manifesto', 'Karl Marx and Friedrich Engels', 11.11, 11);

INSERT INTO BOOKS 
    VALUES (2, 'Don Quixote', 'Miguel de Cervantes', 22.22, 22);

INSERT INTO BOOKS 
    VALUES (3, 'A Tale of Two Cities', 'Charles Dickens', 33.33, 33);
```

This program owes a lot to the one presented at http://www.ntu.edu.sg/home/ehchua/programming/java/jdbc_basic.html.
5.4 A First Program

```sql
INSERT INTO BOOKS
VALUES (4, 'The Lord of the Rings', 'J. R. R. Tolkien',
        44.44, 44);

INSERT INTO BOOKS
VALUES (5, 'Le Petit Prince', 'Antoine de
        Saint-Exupéry', 55.55, 55);

SELECT *
FROM BOOKS;
```

MariaDB [HW_EBookshop]> SELECT * FROM BOOKS;

```
+----+-------------------------+-------------------------------+
<table>
<thead>
<tr>
<th>ID</th>
<th>title</th>
<th>author</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The Communist Manifesto</td>
<td>Karl Marx and Friedrich Engels</td>
</tr>
<tr>
<td>2</td>
<td>Don Quixote</td>
<td>Miguel de Cervantes</td>
</tr>
<tr>
<td>3</td>
<td>A Tale of Two Cities</td>
<td>Charles Dickens</td>
</tr>
<tr>
<td>4</td>
<td>The Lord of the Rings</td>
<td>J. R. R. Tolkien</td>
</tr>
<tr>
<td>5</td>
<td>Le Petit Prince</td>
<td>Antoine de Saint-Exupéry</td>
</tr>
<tr>
<td>11</td>
<td>11.11</td>
<td>11</td>
</tr>
<tr>
<td>22</td>
<td>22.22</td>
<td>22</td>
</tr>
<tr>
<td>33</td>
<td>33.33</td>
<td>33</td>
</tr>
<tr>
<td>44</td>
<td>44.44</td>
<td>44</td>
</tr>
<tr>
<td>55</td>
<td>55.55</td>
<td>55</td>
</tr>
</tbody>
</table>
+----+-------------------------+-------------------------------+
```

5 rows in set (0.00 sec)

You can copy and paste the code, then execute it, or use MySQL's batch mode: you can find the code previously given at `code/sql/HW_EBookshop.sql`, i.e., at https://rocketgit.com/user/caubert/CSCI_3410/source/tree/branch/master/blob/notes/code/sql/HW_EBookshop.sql. Open a terminal (or command-line interpreter), navigate to the folder where you stored that file (using `cd`), and type

```
mysql -u testuser -p < HW_EBookshop.sql
```

for Linux, or (something like)

```
"C:\Program Files\MySQL\MySQL Server 5.7\bin\mysql.exe" -u
testuser -p < HW_EBookshop.sql
```

for Windows. Refer to the Logging-In as testuser section if you forgot how to log-in to your database.

You just discovered MySQL's batch mode, that perform series of instructions from a file. You can easily make sure that the database and the table were indeed created, and the values inserted, by logging the way you used to, and executing the usual commands.
5.4.2 Executing Database Application

As we are about to see, a database application needs to be written following this order:

1. Load the API,
2. Try to open the connection (i.e., create Connection and Statement objects), using a try/catch statement,
3. Perform the required actions on the database (using Statement object),
4. Close the connection.

and the program needs to load the driver (which is specific to DBMS) at execution time.

Of course, if the second step failed, then the program needs to exit gracefully, or to provide debugging information to the user. The program we will obtain can (normally) be compiled, using something like `javac FirstProg.java` (or an equivalent command for windows). But another refinement is needed when you want to execute it. We need to set up the driver (or connector) to make the java SQL API and MySQL communicate. To do so,

- Go to https://dev.mysql.com/downloads/connector/j/
- Select "Platform Independent",
- Click on “Download” in front of “Platform Independent (Architecture Independent), ZIP Archive”
- Look for the (somewhat hidden) “No thanks, just start my download.”
- Download the file named "mysql-connector-java-***.zip", where *** is the version number.
- Unzip the file, and locate the "mysql-connector-java-***.jar" file (normally, in the root folder).
- Copy that file in the same folder as where you intend to compile your program.

Once this is done and your program was compiled, you can execute it using (where you replace *** with the actual number, of course, e.g. 8.0.19):

```
java -cp ./mysql-connector-java-***.jar FirstProg
```

in Linux, or

```
java -cp .;mysql-connector-java-***.jar FirstProg
```

in Windows. The `-cp` option lists the places where java should look for the class used in the program: we are explicitly asking java to use the `mysql-connector-java-***.jar` executable (the driver) to execute our `FirstProg` executable.

If we try to execute `FirstProg` without that flag, we obtain the following error message:

```
$ java FirstProg
java.sql.SQLException: No suitable driver found for
→ jdbc:mysql://localhost:3306/HW_EBOOKSHOP
at java.sql.DriverManager.getConnection(DriverManager.java:689)
at java.sql.DriverManager.getConnection(DriverManager.java:247)
at FirstProg.main(FirstProg.java:9)
```
5.4 A First Program

5.4.3 The Application Program (java)

```java
// code/java/FirstProg.java

import java.sql.*;

public class FirstProg {
  public static void main(String[] args) {
    try (Connection conn =
        DriverManager.getConnection(
          "jdbc:mysql://localhost:3306/HW_EBOOKSHOP",
          "testuser", "password");
    /*
     * If at execution time you receive an error that starts
     * with
     * "java.sql.SQLException: The server time zone value
     * 'EDT' is unrecognized or
     * represents more than one time zone. You must
     * configure either the server ..."
     * add ?serverTimezone=UTC at the end of the previous
     * string,
     * i.e., replace the previous lines of code with:
     * Connection conn = DriverManager.getConnection("jdbc:mysql://localhost:3306/HW_EBOOKSHOP?serverTimezone=UTC",
     * "testuser", "password");
     * cf. for instance https://stackoverflow.com/q/26515700
     * Or, change your server's configuration, cf.
     * https://stackoverflow.com/a/44720416
     */
    Statement stmt = conn.createStatement(); ) {
      String strSelect = "SELECT title, price, qty FROM BOOKS
                         WHERE qty > 40";
      System.out.println("The SQL query is: " + strSelect + "\n");
      ResultSet rset = stmt.executeQuery(strSelect);
      System.out.println("The records selected are:");
      int rowCount = 0;
      String title;
      double price;
      int qty;

      while (rset.next()) {
        title = rset.getString("title");
        price = rset.getDouble("price");
        qty = rset.getInt("qty");
        System.out.println(title + ", " + price + ", " + qty);
        rowCount++;
      }
    }
```
5.4 A First Program

```java
System.out.println("Total number of records = " + rowcount);
conn.close();

} catch (SQLException ex) {
    ex.printStackTrace();
}
```

A couple of comments:

- `java.sql.*`, whose documentation is at https://docs.oracle.com/javase/8/docs/api/java/sql/package-summary.html, contains the classes
  - `DriverManager`, used for managing a set of JDBC drivers,
  - `Connection`, used to make a connection with a database via `DriverManager` objects,
  - `Statement`, used to send basic SQL statements via `Connection` objects,
  - `ResultSet`, to retrieve and update the results of a query, returned by a `Statement` object,
  - `ResultSetMetadata`, to get information about the columns of a `ResultSet` object,
  - `SQLException`, a class of exceptions relative to SQL.

- Intuitively, a `Connection` is a bridge (the physical connection), and `Statement` is a lane (a symbolic, or logic, path on the bridge).

- In the string "jdbc:mysql://localhost:3306/HW_EBOOKSHOP",
  - `jdbc` is the protocol,
  - `mysql` is the subprotocol,
  - `localhost` is the url of the database,
  - `3306` is the port, and
  - `HW_EBOOKSHOP` is the schema (that needs to already exist in this case).

- Note that `strSelect` does not end with ; (it could, but does not have to).

- `next()` returns true if there is something left in the set of result, and move to the next line if it is the case. It resembles what we would use to read from a file. If you try to use `getString` before moving to the first row, you'll get an error like `java.sql.SQLException: Before start of result set` indeed, the cursor is "above" the first row of results when the `ResultSet` object is created.

- We could use `1,2`, and `3` instead of "title", "price" and "qty" in the `while` loop:
  the `getString`, `getDouble`, and `getInt` are overloaded, and have versions that take one integer as input, corresponding to the position of the attribute in the result set.

### 5.4.4 The Result

If you store the program in `FirstProg.java`, compile it, with

```bash
javac FirstProg.java
```

and then execute it, with
java -cp .:mysql-connector-java-***.jar FirstProg

(refer back to "Executing Database Application" for more details) then you should obtain:

The SQL query is: SELECT title, price, qty FROM BOOKS WHERE qty > 40
The records selected are:
The Lord of the Rings, 44.44, 44
Le Petit Prince, 55.55, 55
Total number of records = 2

Take the time to make sure you have the same result on your installation, and that you understand how the code works before moving on.

5.4.5 A Variation

If you were to replace the body of try in the previous program with

```java
String strSelect = "SELECT * FROM BOOKS";
ResultSet rset = stmt.executeQuery(strSelect);
System.out.println("The records selected are:");
ResultSetMetaData rsmd = rset.getMetaData();
int columnsNumber = rsmd.getColumnCount();
String columnValue;
while (rset.next()) {
    for (int i = 1; i <= columnsNumber; i++) {
        if (i > 1) System.out.print(", ");
        columnValue = rset.getString(i);
        System.out.print(columnValue + " " + rsmd.getColumnName(i));
    }
    System.out.println();
}
```

You would obtain:

The records selected are:
1 ID, The Communist Manifesto title, Karl Marx and Friedrich Engels author, 11.11 price, 11 qty
2 ID, Don Quixote title, Miguel de Cervantes author, 22.22 price, 22 qty
3 ID, A Tale of Two Cities title, Charles Dickens author, 33.33 price, 33 qty
4 ID, The Lord of the Rings title, J. R. R. Tolkien author, 44.44 price, 44 qty
5 ID, Le Petit Prince title, Antoine de Saint-Exupéry author, 55.55 price, 55 qty

In that code, please note:

- the use of ResultSetMetadata,
• that we could “extract” the number of columns in the ResultSet using the getColumnCount method,
• that we used the getString method with integer input to read all the data in the table, no matter its “original” data type.

Overall, this code would work equally well if the table had a different number of columns, as opposed to our first program.

5.5 Mapping Datatypes

Note that in the previous code, we read everything as a string. But, actually, SQL and JAVA datatypes can be mapped as follows:

<table>
<thead>
<tr>
<th>SQL</th>
<th>JAVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTEGER</td>
<td>int</td>
</tr>
<tr>
<td>CHARACTER(n)</td>
<td>String</td>
</tr>
<tr>
<td>VARCHAR(n)</td>
<td>String</td>
</tr>
<tr>
<td>REAL</td>
<td>float</td>
</tr>
<tr>
<td>DOUBLE</td>
<td>double</td>
</tr>
<tr>
<td>DECIMAL(t,d)</td>
<td>java.math.BigDecimal</td>
</tr>
<tr>
<td>DATE</td>
<td>java.sql.date</td>
</tr>
<tr>
<td>BOOLEAN</td>
<td>boolean</td>
</tr>
<tr>
<td>BIT(1)</td>
<td>byte</td>
</tr>
</tbody>
</table>

(DECIMAL(t, d) was not previously introduced: the t stands for the number of digits, the d for the precision.)

We cannot always have that correspondence: what would correspond to a reference variable? To a private attribute? This series of problems is called “object-relational impedance mismatch”, it can be overcome, but at a cost.

5.6 Differences Between executeQuery, executeUpdate and execute

Previously, we used executeQuery to send a SQL command to the DBMS. This method is tailored for SELECT statement, and it is not the only method we can use.

<table>
<thead>
<tr>
<th>Name</th>
<th>executeQuery</th>
<th>executeUpdate</th>
<th>execute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used for</td>
<td>SELECT</td>
<td>INSERT, UPDATE,</td>
<td>Any type</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DELETE</td>
<td></td>
</tr>
<tr>
<td>Input Type</td>
<td>string</td>
<td>string</td>
<td>string</td>
</tr>
<tr>
<td>Name</td>
<td>executeQuery</td>
<td>executeUpdate</td>
<td>execute</td>
</tr>
<tr>
<td>-----------------------</td>
<td>--------------</td>
<td>---------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Return Type</td>
<td>ResultSet</td>
<td>int, the number of rows affected by the query</td>
<td>boolean, true if the query returned a ResultSet, false if the query returned an int or nothing</td>
</tr>
</tbody>
</table>

To retrieve the ResultSet obtained by an execute statement, you need to use getResultSet or getUpdateCount. For more details, consult [https://docs.oracle.com/javase/7/docs/api/java/sql/Statement.html](https://docs.oracle.com/javase/7/docs/api/java/sql/Statement.html).

---

### 5.7 A Second Program

The program in Problem 5.1 (Advanced Java Programming) uses the modifications discussed below. Please refer to it once you are done with this section.

#### 5.7.1 Passing Options

We can pass options (values of fields) when connecting to the database:

```java
Connection conn =
    DriverManager.getConnection(
        "jdbc:mysql://localhost:3306/HW_DBPROG"
        + "?user=testuser"
        + "&password=password"
        + "&allowMultiQueries=true"
        + "&createDatabaseIfNotExist=true"
        + "&useSSL=true");
```

On top of `user` and `password` (which are self-explanatory), setting `allowMultiQueries` to `true` allows to pass multiple queries with one `executeUpdate` statement, and `createDatabaseIfNotExist` creates the `schema` passed in the `url` (so, here, `HW_DBPROG`) if it does not already exists.

The syntax used is the syntax of querying strings\(^9\), i.e., it follows the pattern

```
?field1=value1&field2=value2...&fieldN=valueN
```

That is, it starts with an `?` and then “pile up” the field / value pairs with `&`. In particular, if you needed to add `?serverTimezone=UTC` in the first application program we used, you will need here to replace

---

5.7 A Second Program

+ "&useSSL=true")

with

+ "&useSSL=true
+ "&serverTimezone=UTC")


5.7.2 Creating a Table

We can create a table with the method stmt.execute.

```java
stmt.execute(
    "CREATE TABLE DVD ("
    + "Title CHAR(25) PRIMARY KEY, "
    + "Minutes INTEGER, "
    + "Price DOUBLE)";
)
```

If we were to execute `SHOW TABLES;` after this `execute` instruction directly in the MySQL interpreter, this would display at the screen:

```
+---------------------+
| Tables_in_HW_DBPROG |
+---------------------+
| DVD                  |
+---------------------+
```

But here, to access this information, we will use the connection’s metadata. The `DatabaseMetaData` is a class used to get information about the database: the driver, the user, the versions, etc. We can use the `getMetaData()` method of this class to obtain information about the schema we just created:

```java
DatabaseMetaData md = conn.getMetaData();
ResultSet rs = md.getTables("HW_DBPROG", null, "%", null);
```

The first parameter of `getMetaData()` is the schema’s name, as you probably guessed, and the third parameter is `String tableNamePattern`, i.e., what must match the table name stored in the database to be selected. Here, by using the wildcard `%`, we select all the table names (which is only “DVD” at this point).

The `getMetaData()` method returns a `ResultSet` (here named `rs`), where 3 is the `TABLE_NAME`. We can now iterate over this `rs` object to list all the elements in it, as we would with any `ResultSet` object:

```java
while (rs.next()) {
    System.out.println(rs.getString(3));
}
```
You can read at https://docs.oracle.com/javase/7/docs/api/java/sql/DatabaseMetaData.html#getTables(java.lang.String,%20java.lang.String,%20java.lang.String,%20java.lang.String%5B%5D) the full specification of this method.

### 5.7.3 Inserting Values

To insert values in our table, we can use `stmt.executeUpdate`:

```java
String sqlStatement = "INSERT INTO DVD VALUES ('Gone With The Wind', 221, 3);";
int rowsAffected = stmt.executeUpdate(sqlStatement);
System.out.print(sqlStatement + " changed " + rowsAffected + " row(s).\n"");
```

Note that the `executeUpdate` returns an integer, the number of rows changed. We can even use this method to perform multiple insertions at the same time, if `allowMultiQueries` was set to true, cf. https://stackoverflow.com/a/10804730/:

```java
String insert1 = "INSERT INTO DVD VALUES ('Aa', 129, 0.2)";
String insert2 = "INSERT INTO DVD VALUES ('Bb', 129, 0.2)";
stmt.executeUpdate(insert1 + ";" + insert2);
```

Another way of “batch processing” statements (i.e., of executing multiple insertions at the same time) is to use `addBatch` (that “loads” statements in the `statement` object) and `executeBatch()` (that execute all the statement loaded):

```java
String insert3 = "INSERT INTO DVD VALUES ('Cc', 129, 0.2)";
String insert4 = "INSERT INTO DVD VALUES ('DD', 129, 0.2)";
stmt.addBatch(insert3);
stmt.addBatch(insert4);
stmt.executeBatch();
```

Note that the database is not solicited until the `executeBatch` method is called: we simply loaded the instruction in the program, and connect to the database only once, with all the instructions, when this `executeBatch()` instruction is met.

Note also that `executeBatch` may be used, per https://docs.oracle.com/javase/tutorial/jdbc/basics/retrieving.html#batch_updates:

- for updating, inserting, or deleting a row; and it may also contain DDL statements such as `CREATE TABLE` and `DROP TABLE`. It cannot, however, contain a statement that would produce a `ResultSet` object, such as a `SELECT` statement.

Also, the name suggests that it should be possible to fetch the SQL instructions from a file and load them in your Java program, but there is actually no easy way to do this, c.f. https://stackoverflow.com/q/2071682/.
5.7.4 Prepared Statements

A prepared statement is “a query with a slot”: it is a query that takes one or multiple parameters, is parsed and stored on the database, but not executed. It is only after the value of the slot(s) are fixed by the program that this query can be executed. The program can re-use the same prepared statement with multiple (different) values multiple times.

Compared to executing SQL statements directly, prepared statements have three main advantages:

- They reduce parsing time (we store the prepared statement only once, VS as many times as there are values),
- They minimize bandwidth usage (once the prepared statement is sent, the server needs only the parameters, and not the whole query again),
- They protect against SQL injections (cf. A Bit About Security).

Let us look at a first example:

```java
/*
 * We create a string with an empty slot,
 * represented by "?".
 */
sqlStatement = "SELECT title FROM DVD WHERE Price <= ?";

/*
 * We create a PreparedStatement object, using that string with an
 * empty slot.
 */
PreparedStatement ps = conn.prepareStatement(sqlStatement);

/*
 * Then, we "fill" the first slot with the value of a variable.
 */
double maxprice = 0.5;
ps.setDouble(1, maxprice);

/*
 * Finally, we can execute the query, and display the results.
 */
ResultSet result = ps.executeQuery();

System.out.printf("For %.2f you can get:
\n", maxprice);

while (result.next()) {
    System.out.printf("\t %s \n", result.getString(1));
}
```

Note that once the `ps` PreparedStatement object is created, we cannot change the content of the query, beside instantiating the slot. cf. e.g. the discussion at https://stackoverflow.com/q/25902881/.
As we said earlier, a prepared statement can have multiple “slots”, as we can see in that second example:

```java
sqlStatement = "INSERT INTO DVD VALUES (?, ?, ?)";
// Now, our string has 3 empty slots, and it is an INSERT statement.
PreparedStatement preparedStatement = conn.prepareStatement(sqlStatement);

preparedStatement.setString(1, "The Great Dictator");
preparedStatement.setInt(2, 124);
preparedStatement.setDouble(3, 5.4);

rowsAffected = preparedStatement.executeUpdate();

/* You can check "by hand" that this statement was correctly executed. Note that the toString method is quite verbose. */
System.out.print(preparedStatement.toString() + " changed " + rowsAffected + " row(s).\n);
```

Where we stored the integer value returned by `executeUpdate` and displayed the prepared statement using the `toString` method.

If we try to mess things up, i.e., provide wrong datatypes:

```java
preparedStatement.setString(1, "The Great Dictator");
preparedStatement.setString(2, "Not-an-integer");
preparedStatement.setString(3, "Not-a-double");

/* This command will make your program crash: */
* rowsAffected = preparedStatement.executeUpdate();
*/
```

Java compiler will be ok, but we’ll have an error at execution time when executing the query.

Executing `rowsAffected = preparedStatement.executeUpdate();` would return an error containing

```
com.mysql.cj.jdbc.exceptions.MysqlDataTruncation: Data truncation: Incorrect integer value: 'Not-an-integer' for column `HW_DBPROG`.`DVD`.`Minutes` at row 1
```

since "Not-an-integer" is not ... a valid integer!

Of course, prepared statements are particularly convenient when you want to automate some tasks or repeat them multiple times, as you write the query only once, and then re-use it. For instance, inserting the whole “Saw” franchise can be made into a loop:

```java
for (int i = 1; i < 5; i++) {
    preparedStatement.setString(1, "Saw " + i);
    preparedStatement.setInt(2, 100);
    preparedStatement.setDouble(3, .5);
    preparedStatement.executeUpdate();
}
5.7.5 More Complex Statement Objects

When you create the `Statement` objects, you can give two arguments to the `createStatement` method:

```java
Statement stmtNew =
    conn.createStatement(ResultSet.TYPE_SCROLL_SENSITIVE,
                       ResultSet.CONCUR_UPDATABLE);
```

Those options change two things about the ResultSet we obtain using this statement. The first argument indicates whenever you can scroll (go forward and backward) in the ResultSets objects that will be created using this `Statement` object:

- **TYPE_FORWARD_ONLY** is the default (you can only move forward).
- **TYPE_SCROLL_INSENSITIVE** means that you can scroll, but that updates don't impact result set.
- **TYPE_SCROLL_SENSITIVE** means that you can scroll, and that updates impact result set.

Allowing to go in both directions extends the methods one can use in the `ResultSet` class: now, to scroll through the results, one can use:

- `first()`
- `last()`
- `next()`
- `previous()`
- `relative(x)`: move cursor x times (positive = forward, negative = backward)
- `absolute(x)`: move to the row number x, where 1 is the first.

The second argument is the concurrency level, it indicates whenever you can update the values into the `ResultSet` directly:

- **CONCUR_READ_ONLY** is the default.
- **CONCUR_UPDATABLE** means that we can change the database without issuing SQL statement.

In other terms, manipulating the `ResultSet` object will directly impact the data stored in the database if we set the second parameter to **CONCUR_UPDATABLE**.

This `createStatement` method is documented at https://docs.oracle.com/javase/7/docs/api/java/sql/Connection.html#createStatement(int,%20int).

You can find below a simple example of “scrollable” `ResultSet`:

```java
// code/java/ScrollingProgram.java
import java.sql.*;

public class ScrollingProgram {
    public static void main(String[] args) {
        try (Connection conn =
             DriverManager.getConnection(
             // We connect to the database, not to a
             → particular schema.
```
5.7 A Second Program

"jdbc:mysql://localhost:3306/
  + "?user=testuser"
  + "&password=password"
  + "&allowMultiQueries=true"
/*
* We want to allow multiple statements
* to be shipped in one execute() call.
*/
);
Statement stmt =
  conn.createStatement(ResultSet.TYPE_SCROLL_SENSITIVE,
                   ResultSet.CONCUR_READ_ONLY);
  /*
  * Finally, we want to be able to move back and forth in
  * our
  * ResultSets. This implies that we have to also chose
  * if the
  * ResultSets will be updatable or not: we chose to have
  * them
  * to be "read-only".
  */
  }
  /*
  * Before you ask: no, there are no "simple" way of
  * constructing a string over multiple lines,
  * besides concatenating them,
  * cf. e.g. https://stackoverflow.com/q/878573
  */
stmt.execute(  
  "DROP SCHEMA IF EXISTS HW_SCROLLABLE_DEMO;"
  +  
  "CREATE SCHEMA HW_SCROLLABLE_DEMO;"
  +  "USE HW_SCROLLABLE_DEMO;"
  +  "CREATE TABLE TEST(
    Id INT"  
  +  
  "CREATE TABLE TEST("  
  +  ");"
  /*
  * We can execute all those queries at once
  * because we passed the "allowMultiQueries=true"
* token when we created the Connection object.
*/

// Let us insert some dummy values in this dummy table:
for (int i = 0; i < 10; i++) stmt.addBatch("INSERT INTO
  TEST VALUES (" + i + ")");
/*
  * no ";" in the statements that we add
  * to the batch!
  */
stmt.executeBatch();
// We execute the 10 statements that were loaded at once.

// Now, let us write a simple query, and navigate in the
  result:
ResultSet rs = stmt.executeQuery("SELECT * FROM TEST");
/*
  * We select all the tuples in the table.
  * If we were to execute this instruction on the
  * command-line interface, we would get:

  * MariaDB [HW_SCROLLABLE_DEMO]> SELECT * FROM TEST;
  * +----+
  * | Id |
  * +----+
  * | 0 |
  * | 1 |
  * | 2 |
  * | 3 |
  * | 4 |
  * | 5 |
  * | 6 |
  * | 7 |
  * | 8 |
  * | 9 |
  * +----+
  * 10 rows in set (0.001 sec)
  */

  // We can "jump" to the 8th result in the set:
rs.absolute(8);
System.out.printf("%-22s %s %d.\n", "After absolute(8),", "we are at Id", rs.getInt(1));
/* Note that this would display "7" since the
  * 8th result contains the value 7 (sql starts
  * counting at 1.
  */

  // We can move back 1 item:
rs.relative(-1);
System.out.printf("%-22s %s %d.\n", "After relative(-1)", "we are at Id", rs.getInt(1));

// We can move to the last item:
rs.last();
System.out.printf("%-22s %s %d.\n" , "After last()", "we are at Id", rs.getInt(1));

// We can move to the first item:
rs.first();
System.out.printf("%-22s %s %d.\n", "After first()", "we are at Id", rs.getInt(1));

conn.close();

} catch (SQLException ex) {
    ex.printStackTrace();
}
}

You can also have a look at the end of code/java/AdvancedProg.java, which creates a second Statement object is created and used.

**Exercises**

**Exercise 5.1** What are the technologies that make it possible for a Java application to communicate with a DBMS?

**Exercise 5.2** Why is it important to have the statements creating the connection to the database inside a try...catch statement?

**Exercise 5.3** Name three classes in the SQL API of java.

**Exercise 5.4** What JDBC method do you call to get a connection to a database?

**Exercise 5.5** What is the class of the object used to create a ResultSet object?

**Exercise 5.6** Briefly explain what the next() method from the ResultSet class does and give its return type.

**Exercise 5.7** How do you submit a SELECT statement to the DBMS?

**Exercise 5.8** What method should be used to perform an INSERT command from your program?

**Exercise 5.9** Where is a ResultSet object’s cursor initially pointing? How do you move the cursor forward in the result set?

**Exercise 5.10** Give three navigation methods provided by ResultSet.

**Exercise 5.11**

Explain this JDBC URL format:
jdbc:mysql://localhost:3306/HW_NewDB?createDatabaseIfNotExist=true&useSSL=true

Exercise 5.12 In what class is the getColumnName() method?

Exercise 5.13 Assuming stmt is a Statement object, in the statement:

```java
modif = stmt.executeUpdate(strC);
```

What is...

1. ... the datatype of modif?
2. ... the datatype of strC?
3. ... a possible value for strC?

Exercise 5.14 What is a prepared statement?

Exercise 5.15 Assume ps is the prepared statement:

```sql
INSERT INTO EXAM VALUES (?, ?);
```

Write the three statements needed to allocate “Quiz” and “5” to the two slots and to execute the prepared statement in the database.

Exercise 5.16 In the code below, there are five errors between line 13 and line 32. They are not subtle Java errors (like misspelling a key word) and do not come from the DBMS (so you should assume that the password is correct, that the database exists, etc.). Highlight each error and explain why it is an error.

```java
// code/java/ProgWithErrors.java

import java.sql.*;

public class ProgWithErrors {
    public static void main(String[] args) {
        try (Connection conn = DriverManager.getConnection(  
            "jdbc:mysql://localhost:3306/" +  
            "HW_TestDB?user=testuser&password=password"));

            Statement stmt = conn.createStatement(); ) {

                // Errors after this point.

                String strSelect = "SELECT title FROM DISKS WHERE qty > 40;";
                ResultSet rset = stmt.executeUpdate(strSelect);
                System.out.println("The records selected are: (listed last first):");
                rset.last();

                while (rset.previous()) {
                    String title = rset.getDouble("title");
                    System.out.println(title + "\n");
                }
```
String sss = "SELECT title FROM DISKS WHERE Price <= \\
  " ?";  
PreparedStatement ps = conn.prepareStatement(sss);  
ResultSet result = ps.executeQuery();  

// Errors before this point.

} catch (SQLException ex) {
  ex.printStackTrace();
}

Exercise 5.17 Write a program that determines if the null value from Java code is equal to the NULL value in the DBMS.

Solution to Exercises

Solution 5.1 The technologies that make it possible for a Java application to communicate with a DBMS are API’s and the drivers to implement them.

Solution 5.2 It is important to put the statements that create the connection to the database inside the try...catch statement because the program will interact with the environment if this interaction fails (typically, if the connection does not succeed), for which we want to be able to catch the exception and recover from that failure.

Solution 5.3 There are many classes in the SQL API if Java. There are Connection, DatabaseMetaData, ResultSetMetaData, PreparedStatement, and Statement to name a few. You can find them listed at https://docs.oracle.com/javase/7/docs/api/java/sql/package-summary.html.

Solution 5.4 The JDBC method that must be called to connect to a database is DriverManager.getConnection()

Solution 5.5 The class of the object used to create a ResultSet object is the Statement class. A Statement object is used to create a ResultSet object, e.g. by calling the executeQuery method.

Solution 5.6 The next() method checks if there is data to read and, if there is, it moves the cursor to read it. Its return type is Boolean.

Solution 5.7 You submit a SELECT statement to the DBMS by using .executeQuery(strSelect).

Solution 5.8 The executeUpdate() or execute() methods can be used to perform an INSERT command from our program.

Solution 5.9 The ResultSet object’s cursor is initially pointing at the position before the first line. We move the cursor forward by using the next() method.
Solution 5.10 There are many navigation methods provided by ResultSet. They are the `first()`, `last()`, `next()`, `previous()`, `relative()`, and `absolute()` methods.

Solution 5.11 This JDBC URL format connects to localhost:3306, creates a new database if needed, and uses the secure SSL connection.

Solution 5.12 The `getColumnName()` method is in the ResultSetMetaData class.

Solution 5.13 In the statement `modif = stmt.executeUpdate(strC);...`

1. `modif` is an integer (the number of rows modified by the query).
2. `strC` is a `String` (a SQL command).
3. A possible value for `strC` is `DELETE FROM BOOKS Where Price > 0.5`.

Solution 5.14 A prepared statement is a feature used to execute SQL statements repeatedly with high efficiency that protects against SQL injections.

Solution 5.15

```java
ps.setString(1, "Quiz");
ps.setInt(2, 5);
ps.executeUpdate();
```

Solution 5.16 The errors are:

- The first highlighted portion is found in the ResultSet object creation line and should only be this part:

```java
stmt.executeUpdate(strSelect);
```

The error is that the `executeUpdate()` method cannot be used to perform `SELECT` statements.

- The second highlighted portion is found in the while loop condition statement:

```java
rset.previous()
```

This error is subtle: we need to display the last record before using the `previous()` method, otherwise it would be skipped. We can fix this using a `do...while` loop.

- The third highlighted portion is found in the creation statement for the `String` object named `title`:

```java
String title = rset.getDouble("title");
```

The error is that the `getDouble()` method returns a `double`, which cannot be stored as a `String`.

- The fourth highlighted portion is found in the creation statement for the `ResultSet` object named `result`:

```java
ps.executeQuery();
```

The error here comes from the previous prepared statement that did not receive a value for the `?`.
You can find the corrected program in
`code/java/ProgWithErrorsPatched.java`, which looks like:

```bash
16c16
< ResultSet rset = stmt.executeUpdate(strSelect);
---
> ResultSet rset = stmt.executeQuery(strSelect); // Error 1
21,24c21,24
< while(rset.previous()) {
< String title = rset.getDouble("title");
< System.out.println(title + "\n");
< }
---
> do { // Error 2
> String title = rset.getString("title"); // Error 3
> System.out.println(title); // Not an error, but we
probably do not need two new lines.
> }while(rset.previous()); // Error 2 bis
27a28
> ps.setInt(1, 10); // Error 4
```

Solution 5.17 Here is what the program should look like:

```java
// code/java/TestForNull.java

import java.sql.*;

public class TestForNull {
    public static void main(String[] args) {
        try (Connection conn =
            DriverManager.getConnection(
                "jdbc:mysql://localhost:3306/HW_DBPROG?user=testuser&password=password&createDatabaseIfNotExist=true&serverTimezone=UTC")) {
            Statement stmt = conn.createStatement();
            stmt.executeUpdate("CREATE TABLE Test (" + "A CHAR(25), " + "B INTEGER, " + "C DOUBLE)";
            String strAdd = "INSERT INTO Test VALUES (NULL, NULL, NULL);";
            int numberOf_row_changed = stmt.executeUpdate(strAdd);
            System.out.println("This last query changed " + numberOf_row_changed + " row(s).\n");
            ResultSet result = stmt.executeQuery("SELECT * FROM Test");
            if (result.next()) {
```
This program should display:

```
This last query changed 1 row(s).
null 0.0 0
And null for CHAR in SQL is null for String in Java.
```

5.8 Problems

Problem 5.1 *(Advanced Java Programming)* Read, execute, break, edit, compile, patch, hack and (most importantly) understand the following program:

```java
// code/java/AdvancedProg.java

/*
 * This is a long program, introducing:
 * I. How to pass options when connecting to the database,
 * II. How to create a table and read its meta-data,
 * III. How to insert values,
 * IV. How to use prepared statements,
 * V. How to read backward and write in ResultSets.
 * 
 * To be able to execute this program multiple times, the
 * schema is dropped and re-created.
 */

import java.sql.*;

public class AdvancedProg {
    public static void main(String[] args) {
        try {
            // I. Passing options to the database
            // start snippet passing-options
            Connection conn =
```

```
DriverManager.getConnection(
    "jdbc:mysql://localhost:3306/HW_DBPROG"
    + "?user=testuser"
    + "&password=password"
    + "&allowMultiQueries=true"
    + "&createDatabaseIfNotExist=true"
    + "&useSSL=true");
    // end snippet passing-options

Statement stmt = conn.createStatement();

/* Below, we drop the schema and re-create it to allow multiple execution of the program. You can ignore this part if you want. */

stmt.execute(
    "DROP SCHEMA IF EXISTS HW_DBPROG;" + "CREATE SCHEMA HW_DBPROG;" + "USE HW_DBPROG;";

    // II. Creating a table and reading its meta-data

    // start snippet table-creation
    stmt.execute(
        "CREATE TABLE DVD ("
        + "Title CHAR(25) PRIMARY KEY, "
        + "Minutes INTEGER, "
        + "Price DOUBLE)"
    );
    // end snippet table-creation

    // start snippet table-metadata-1
    DatabaseMetaData md = conn.getMetaData();
    ResultSet rs = md.getTables("HW_DBPROG", null, ",%");
    // end snippet table-metadata-1

    // start snippet table-metadata-2
    while (rs.next()) {
        System.out.println(rs.getString(3));
    }
    // end snippet table-metadata-2

    // III. Inserting values

    // start snippet inserting-1
    String sqlStatement = "INSERT INTO DVD VALUES ('Gone With The Wind', 221, 3);";
    int rowsAffected = stmt.executeUpdate(sqlStatement);
System.out.print(sqlStatement + " changed " + rowsAffected + " row(s).\n");
// end snippet inserting-1

// start snippet inserting-2
String insert1 = "INSERT INTO DVD VALUES ('Aa', 129, 0.2)";
String insert2 = "INSERT INTO DVD VALUES ('Bb', 129, 0.2)";
stmt.executeUpdate(insert1 + ";" + insert2);
// end snippet inserting-2

// start snippet inserting-3
String insert3 = "INSERT INTO DVD VALUES ('Cc', 129, 0.2)";
String insert4 = "INSERT INTO DVD VALUES ('DD', 129, 0.2)";
stmt.addBatch(insert3);
stmt.addBatch(insert4);
stmt.executeBatch();
// end snippet inserting-3

// IV. Prepared Statements

// start snippet prepared-queries-1

/*
 * We create a string with an empty slot, represented by "?".
 */
sqlStatement = "SELECT title FROM DVD WHERE Price <= ?";

/*
 * We create a PreparedStatement object, using that string with an empty slot.
 */
PreparedStatement ps = conn.prepareStatement(sqlStatement);

/*
 * Then, we "fill" the first slot with the value of a variable.
 */
double maxprice = 0.5;
ps.setDouble(1, maxprice);
/*
 * Finally, we can execute the query, and display the results.
 */
5.8 Problems

```java
/*
ResultSet result = ps.executeQuery();

System.out.printf("For %.2f you can get:\n",
                   maxprice);

while (result.next()) {
    System.out.printf("\t %s \n", result.getString(1));
}
// end snippet prepared-queries-1

// start snippet prepared-queries-2
sqlStatement = "INSERT INTO DVD VALUES (?, ?, ?)";
// Now, our string has 3 empty slots, and it is an
// INSERT statement.
PreparedStatement preparedStatement =
    conn.prepareStatement(sqlStatement);

preparedStatement.setString(1, "The Great Dictator");
preparedStatement.setInt(2, 124);
preparedStatement.setDouble(3, 5.4);

rowsAffected = preparedStatement.executeUpdate();
/* You can check "by hand" that this statement was
   correctly
   * executed. Note that the toString method is quite
   verbose.
   */
System.out.print(preparedStatement.toString() + "changed " + rowsAffected + " row(s).\n");
// end snippet prepared-queries-2

// start snippet prepared-queries-3
preparedStatement.setString(1, "The Great Dictator");
preparedStatement.setString(2, "Not-an-integer");
preparedStatement.setString(3, "Not-a-double");

/* This command will make your program crash:
   * rowsAffected = preparedStatement.executeUpdate();
   */
// end snippet prepared-queries-3

// start snippet prepared-queries-4
for (int i = 1; i < 5; i++) {
    preparedStatement.setString(1, "Saw " + i);
    preparedStatement.setInt(2, 100);
    preparedStatement.setDouble(3, 0.5);
    preparedStatement.executeUpdate();
}
// end snippet prepared-queries-4
```
5.8 Problems

// V. Reading backward and writing in ResultSets

// start snippet new-statement-1
Statement stmtNew =
< conn.createStatement(ResultSet.TYPE_SCROLL_SENSITIVE,
< ResultSet.CONCUR_UPDATABLE);
< // end snippet new-statement-1

// Reading backward
sqlStatement = "SELECT title FROM DVD WHERE Price < 1;";
result = stmtNew.executeQuery(sqlStatement);
System.out.println("For $1, you can get:");
if (result.last()) {
    // We can jump to the end of the ResultSet
    System.out.print(result.getString("Title") + "");
}
System.out.print("and also, (in reverse order) ");

while (result.previous()) {
    // Now we can scroll back!
    System.out.print(result.getString("Title") + "");
}

// Changing the values
System.out.print("\n\nLet us apply a 50% discount. 
    Currently, the prices are:\n");
sqlStatement = "SELECT title, price FROM DVD;";
result = stmtNew.executeQuery(sqlStatement);
while (result.next()) {
    System.out.printf("%20s \t $%3.2f\n",
        result.getString("title"),
        result.getDouble("price"));
}

// We need to scroll back!
result.absolute(0);

while (result.next()) {
    double current = result.getDouble("price");
    result.updateDouble("price", (current * 0.5));
    result.updateRow();
}
System.out.print("\n\nAfter update, the prices are: \n"); 

// We need to scroll back!
result.absolute(0);

while (result.next()) {
    System.out.printf("%20s \t $%3.2f\n",
                     result.getString("title"),
                     result.getDouble("price"));
}

conn.close();
} catch (SQLException ex) {
    ex.printStackTrace();
}
}

Problem 5.2 *(A GUEST Java Program)* Consider the code below:

```java
// code/java/GuestProgram.java

import java.sql.*;
import java.util.Scanner;

// This first part is "standard". Just note that we allow multiple statements.
public class GuestProgram {
    public static void main(String[] args) {
        try (Connection conn =
             DriverManager.getConnection(
                 "jdbc:mysql://localhost:3306/?user=testuser&password=
                 + "&allowMultiQueries=true"));
            Statement stmt = conn.createStatement(); ) {
            // We create a schema, use it, create two tables, and insert a value in the second one.
            stmt.execute(
                "CREATE SCHEMA HW_GUEST_PROGRAM;"
                + "USE HW_GUEST_PROGRAM;"
                + "CREATE TABLE GUEST(
                    Id INT PRIMARY KEY,
                    Name VARCHAR(30),
                    Confirmed BOOL"
                + ");"
                + "CREATE TABLE BLACKLIST ("
                + "Name VARCHAR(30)"
                + ");";
```
5.8 Problems

```java
+ "INSERT INTO BLACKLIST VALUES ("Marcus Hells");"

    /*
     * INSERT HERE Solution to exercises 1, 2 and 3.
     * Tip for Exercise 1, this solves the first item.
     */
    System.out.println("How many guests do you have?\n");
    Scanner key = new Scanner(System.in);
    int guest_total = key.nextInt();

    } catch (SQLException ex) {
        ex.printStackTrace();
    }
}

In the following three exercises, you will add some code below the comment
// INSERT HERE Solution to exercises 1, 2 and 3. in order to
obtain a behavior like the following one (you do not have to reproduce it exactly!). The
user input is underlined, and hitting “enter” is represented by ↵:

How many guests do you have?

Enter name of guest 1.
Marcus Hells

Enter name of guest 2.
Cynthia Heavens

Oh no, (at least) one of the guest from the black list confirmed their presence!
The name of the first one is Marcus Hells.

Do you want to remove all the guests that are on the black list and who have confirmed
their presence? Enter "Y" for yes, anything else for no.

You should suppose that BLACKLIST contains more than one name, and that some other
operations are performed where .................% .............. is (typically, some guests will confirm
their presence). Using batch processing or prepared statements will be a plus, but is not
mandatory to solve these exercises.

1. Write a snippet that
   a) Asks the user how many guests they have,
   b) For each guest, asks their name (using key.nextLine(), that returns the
      String entered by the user),
   c) For each guest name entered, inserts in the GUEST table an integer that is incre-
      mented after each insertion, the name entered by the user, and NULL.

2. Write a snippet such that if there is at least one guest who confirmed their presence
   and whose name is on the blacklist, a message will be displayed on the screen contain-
   ing the name of (at least) one of those guests.
3. Write a snippet that asks the user whenever they want to remove from the guest list all the persons on the blacklist that confirmed their presence, and do so if they enter “yes” (or some variation).

Solutions to Selected Problems

Solution to Problem 5.2 (A GUEST Java Program) The file code/java/GuestProgramSolution.java contains the whole code for you to compile and test.

Pb 5.2 – Solution to Q. 1

We explore two solutions, one with batch processing, the second with prepared statement.

They both starts with:

```java
int guest_id;
String guest_name;
int counter = 0;
```

Then the solution using batch processing could be:

```java
while (counter < guest_total) {
    // Ask the name of the guest.
    System.out.print("Enter name of guest " + (counter + 1) + ".\n");
    // Read the name of the guest.
    guest_name = key.nextLine();
    stmt.addBatch("INSERT INTO GUEST VALUES (" + counter + ", " + guest_name + ", NULL)");
    // Add to the batch the statement to insert the required data in the table
    counter++;
}
stmt.executeBatch(); // Execute the batch statement.
```

while the solution using prepared statements could be:

```java
PreparedStatement ps = conn.prepareStatement("INSERT INTO
GUEST VALUES(?, ?, NULL);");
while (counter < guest_total) {
    System.out.print("Enter name of guest " + (counter + 1) + ".\n");
    guest_name = key.nextLine();
    ps.setInt(1, counter);
    ps.setString(2, guest_name);
    ps.executeUpdate();
    counter++;
}
```

Pb 5.2 – Solution to Q. 2

We let SQL do all the hard work:
ResultSet rset = stmt.executeQuery("SELECT * FROM GUEST, BLACKLIST WHERE GUEST.Name = BLACKLIST.Name AND GUEST.Confirmed = true");

if (rset.next()) {
    System.out.print("Oh no, (at least) one of the guest from the black list confirmed their presence!\nThe name of the first one is "+ rset.getString(2) + ".\n");
}

Pb 5.2 – Solution to Q. 3

Similarly, we let SQL do all the hard work:

System.out.print("Do you want to remove all the guests that are on the black list and confirmed their presence? Enter \"Y\" for yes, anything else for no.\n");

if (key.nextLine().equals("Y")) {
    stmt.execute("DELETE FROM GUEST WHERE NAME IN (SELECT NAME FROM BLACKLIST) AND Confirmed = true;\")
}
6 A Bit About Security

DBMS, as any software, needs to be secured. DBMS, as any online service, needs to be well secured. DBMS, as any place where (possibly confidential) data is stored, needs to be extremely well secured.

In this Chapter, we review some “usual” aspects of security, before focusing on one particular type of attack on DBMS, SQL injections.

6.1 Usual Aspects

6.1.1 Threat Model

As usual, a threat model needs to be sketched when designing how your DBMS will be used. It should answer questions like

- Who is threatening you?
- What are the risks?
- What are the type of attacks?

The first question is of importance, as you will not be securing your application the same way depending of if you fear attack from script kiddies\(^1\), competitors, former employee, or government. However, thinking “this system can not possibly be secured against Google’s quantum computer, so let’s do nothing” is probably giving your system too much importance (Google is not going to waste its resources to hack your database), and counter-productive (you should protect your database against low-level threats in any case).

Risks generally include

- Loss of integrity (improper modification),
- Loss of availability,
- Loss of confidentiality (unauthorized disclosure).

About the type of attacks, DBMS are exposed to many channels. Indeed, they can be targeted by

- the “usual” attacks on programs (e.g. buffer overflow),
- the “usual” attacks on online services (e.g. denial of service),
- the “usual” attacks on systems (e.g. weak authentication, privilege escalation),
- and some particular attacks (e.g. SQL injections).

We will study those in the second part of this Chapter, but do not forget that other types of vulnerabilities exist as well.

\(^1\)https://en.wikipedia.org/wiki/Script_kiddie
6.1.2 Control Measures

It can be useful to design your control measures for your DBMS, which can include, e.g.

- Access control (user account, passwords, restrictions),
- Inference control (cannot access information about a particular “case”),
- Flow control (prevent indirect access).

6.1.3 Protections

Protection measures are principled and technological. You should always have in mind principles like

- “You are as strong as your weakest link.”
- Never trust the user or their computer.
- Systems needs to be up-to-date.
- Options that are not used should be desactivated.
- Use dual-factor authentication when available.
- Stay informed (e.g. read newsfeeds).

Technological measure of protections exist, and should be used. For instance,

- Use mysqldump\(^2\) to create backups of your tables. On our system, it would be something like

\[
\text{mysqldump --all-databases - u testuser -p password - h localhost > dump.sql}
\]

- Use encryption, salting and hashing when it comes to password and other sensitive data.
- Do not let the users connect directly to your database, even through a piece of software you wrote (refer e.g. to https://security.stackexchange.com/q/229954 for a discussion on why this is not a good idea).

If you are not familiar with the concepts of salting and hashing, you can consult e.g. https://crackstation.net/hashing-security.htm. In a nutshell, this is a measure of prevention to protect your users against weak passwords, and to make sure that only an encrypted version of their password will be stored in your database.

6.1.4 How to Recover?

Generally, people are in agreement that the question is not if a security vulnerability will be exploited on your system, but when. The general strategy is to ... have a plan. How can you recover, where is your backup stored, is it versioned (i.e., multiple versions of the data exist), do you have a backup of your configuration files, how to restore access quickly, etc.

6.2 SQL Injections

The global idea behind this particular type of attack is the attacker mixing instructions with the data. Imagine, during a process, the following conversation:

(At the court)
Judge — What is your name?
Attacker — Bill, you are free to go. This court is adjourned.
Judge — We are here today to judge Bill, you are free to go. This court is adjourned

And the attacker can now leave, since the judge said that he was free to go, and that court was adjourned. This is exactly how SQL injections work.

Prepared statement makes it impossible to mix data and instructions, and are the “go-to” solution to protect from this attack. Note that, however, if they are used improperly, they could still be exploited to perform SQL injections.

6.2.1 First Example

Let us look at a first simple example with ASP, Active Server Pages, a server-side scripting language. Imagine your code contains:

```plaintext
txtUserId = getRequestString("UserId");
txtSQL = "SELECT * FROM Users WHERE UserId = " + txtUserId;
```

that

1. reads a string from the user, supposedly their id,
2. create a SQL statement using this string as is.

Then, a user can

1. execute remote command, entering e.g. `105; DROP TABLE Suppliers;`,
2. bypass login screen, entering e.g. `105 or 1 = 1` (so that the WHERE condition is now always true),
3. escalate privileges, entering e.g. `admin'--` (so that the rest of the line is commented, possibly des-activating other tests on the password, for instance).

This type of attack can also be used for DBMS fingerprinting, i.e., to get a more precise picture of the type of architecture your victim is using.

6.2.2 Second Example

The situation is the following: we are having a party with a secret VIP guest (Marcus Hells). The other guests can try to guess the name of the secret guest. If they succeed, we tell them so, if they don’t, we simply that they do not know who the secret guest is.

An improper program would allow the name of the secret guest to be displayed even if the user does not know that Marcus Hells is the secret VIP. We will see two examples of insecure programs (code/java/SimpleInjection01.java and code/java/SimpleInjection02.java), where SQL injection are possible, and a possible fix (code/java/SimpleInjection03.java), using prepared statements.
The gist of code/java/SimpleInjection01.java is that writing a statement like

```java
ResultSet rset =
    stmt.executeQuery("SELECT * FROM SECRETVIP WHERE Name ='" +
               entered + "';");
```

leaves the door open for an attacker to enter `n' OR '1' = '1` as a value for `entered`, so that the condition would always be true.

For code/java/SimpleInjection02.java, it shows how

```java
stmt.executeQuery("SELECT * FROM SECRETVIP WHERE Name ='" + entered +
               "';");
```

could be a serious issue if `nope'; DROP SCHEMA HW_SIMPLE_INJECTION_2;` was entered as a value for `entered`, destroying the whole schema `HW_SIMPLE_INJECTION_2`.

Finally, code/java/SimpleInjection03.java shows how to use proper statements to avoid this situation.

### 6.2.3 Protections

Possible protections from SQL injections (-like) includes:

1. Prepared statements (a.k.a. stored procedures),
2. White list input validation,
3. Escaping (AT YOUR OWN RISK).

If parts of your prepared statement is determined by the user, then SQL injection could still be possible. For instance, having

```java
PreparedStatement ps =
    conn.prepareStatement("SELECT * FROM " + table_given_by_user + " WHERE Name = ?;");
```

would still leave you exposed, as `table_given_by_user` could mix instructions with data.

### Exercises

**Exercise 6.1** You forgot your password for an online service, and click on their "Forgot your password?" link. You enter your email and a few seconds later receive an email with your original password in it. What is the issue here? What are the next steps you should take?

**Exercise 6.2** Briefly explain what a prepared statement is and the benefits it provides.

**Exercise 6.3** You are using a software that is directly connected to a database. You do not have access to the source code, but you suspect it is vulnerable to SQL injections. How do you proceed to test if injections are possible?
Solution to Exercises

Solution 6.1 The issue is that they are storing your password in clear text, which is an extremely bad security practice. This suggests that this service does not care about the security of their users, and that all the data in it should be considered compromised. The next steps are:

- If the same password was used on different websites, change it immediately.
- Change the password on this website.
- Delete your account on this website, or, if that is not possible, remove as much information as possible (credit card, address, email, etc.).
- Contact them to express your worries about this security flaw.
- (Optional) See if your account has already been hacked using a service like: https://haveibeenpwned.com/.

Solution 6.2 A prepared statement is stored in a DBMS as a “query with parameters,” or a template waiting for values to be passed to fill those placeholders, or slots, and then is executed all together as one statement. It is used to execute the same or similar statements repeatedly and with high efficiency, since it is pre-compiled, and compiled only once, it takes less computational resources to be executed. Also, in the case where the arguments are transmitted over the network, it means that only the arguments, and not the whole query, has to be sent, which may result in a increase in speed.

Moreover, since only the arguments are passed, it prevents SQL injection, when properly utilized.

Solution 6.3 There are two ways to test if SQL injections are possible:

- Look for places where the program is asking for user input and enter values like `1 OR 1 = 1` or `DROP TABLE Users;--`
- Look for an automated tool (like http://sqlmap.org/) that will test the server to which we are connecting.

Note that both options can be explored in parallel. You can also check out coder resources, e.g. https://sqa.stackexchange.com/q/1527/, for more ideas on how to test for injections.

Problems

Problem 6.1 (Insecure Java Programming) Consider the following code:

```java
Scanner key = new Scanner(System.in);
System.out.print("Do you want to browse the table containing ", " or ");
String table = key.nextLine();
System.out.print("How much money do you have?\n");
String max = key.nextLine();
ResultSet rst =
    stmt.executeQuery("SELECT Title FROM " + table + " WHERE PRICE <= " + max + ";");
```
Assume this software is connecting to a schema in a database hosted at http://example.com/ using:

```java
Connection conn = DriverManager.getConnection(
    "jdbc:mysql://example.com/:3306/?user=admin&password=admin");
```

The schema contains three tables (DISK, BOOK and VINYL), each with Title and Price attributes. The compiled version is then shared with customers all around the world.

You can find a program in a compilable state at code/java/InsecureProgram.java that connects to localhost, if you want to test it.

**Question 1** The authors of this program believe that the top-secret title of the next disk by a secret group will not be accessible to the user of this program because its price is set to NULL in the DISK table. Prove them wrong.

**Question 2** This database application and the whole set-up contains at least three vulnerabilities. List as many as you can think of, and, when relevant, describe how to fix them.

### Solutions to Selected Problems

**Solution to Problem 6.1 (Insecure Java Programming)**

**Pb 6.1 – Solution to Q. 1**

This program is vulnerable to SQL injection. A user entering “DISK” followed by 0 OR PRICE IS NULL OR PRICE IS NOT NULL would have access to all the entries, no matter their price tag or lack of one.

**Pb 6.1 – Solution to Q. 2** Some of the issues are:

- Disclosing the name of the tables to the user (DISK, BOOK and VINYL). It would be preferable to use some other name in the program.
- Not asking explicitly for a secure connection is probably not a good idea. Using the default port can sometimes be problematic as well.
- Reading a figure as a string is a bad idea, since the user can try to manipulate the content of that field. The datatype read in the application should match the datatype we are trying to get.
- Having admin / admin as a login / password is unforgivable. The login and password should be changed. And, at least, the application should not connect to the database with admin rights!
- Giving the credentials in the source code is not a good idea. The application should connect to another application, hosted on the the server-side, that performs the connection to the database. Refer e.g. to https://security.stackexchange.com/q/229954 for explanations on why users should not be allowed to connect directly to your database.
• Not using a prepared statement is a huge mistake. This can lead to SQL injection like the one we saw above.
7 Presentation of NoSQL

Resources

To write this chapter, were used

- (Sadalage and Fowler 2012),
- https://en.wikipedia.org/wiki/NoSQL,
- (Sullivan 2015),
- (Elmasri and Navathe 2015, Chapter 24),
- (Pavlo and Aslett 2016)
- (Lakshman and Malik 2010) and
- (Ellis 2013)

7.1 A Bit of History

This part is partially inspired from (Sadalage and Fowler 2012, Chap. 1), but it has been further updated.

7.1.1 Database Applications and Application Databases

When you write a database application, you have two options:

1. One database for multiple applications,
2. One database for each application.

The first option can cause severe impacts on the efficiency of your database: since maintaining the integrity of the database is a requirement, a lot of synchronization is needed, and your database becomes a bottleneck. With the second option, you develop an “application database” (i.e., a database dedicated to a particular application), and you have more freedom in the design, schema, and even DBMS (you can use one particular software solution for one particular database application, and a different one for a different database application).

7.1.2 Clusters, Clusters...

The increase in everything (traffic, size of data, number of clients, etc.) meant “up or out”, and raised numerous challenges for the “one database for multiple application” option. There was two ways to increase the resources and to scale up:

1. Bigger machines,
The second option was generally less expensive (compare buying 1,000 raspberry pi VS buying 1 supercomputer that is not a cluster of more modest computers), but came with two drawbacks w.r.t. databases:

1. The cost of licences was excessive (indeed, you had to buy one licence per computer),
2. and it forced to perform “unnatural acts”: relational model are really not made to be distributed.

### 7.1.3 A First Shift

Developing DBMS more suited for distributed architectures became growingly important, and some companies took at stab at it. The more important attempts were

- Google Big Table\(^1\), 2004 (made public in ... 2015!) (Chang et al. 2006)
- Amazon DynamoDB\(^2\), 2004 (used in Simple Storage Service (S3) in 2007)
- Facebook’s Cassandra is sometimes mentioned, but it came later on, around 2009 (Lakshman and Malik 2009).

It was solutions suited to the needs of those big companies, that were very specific. But it was interesting to see SQL’s supremacy being questioned.

One of the goal was to get rid of “impedance mismatch”: mapping classes or objects to database tables defined by a relational schema is complex and cumbersome. However, if you want your database application to go naturally from their data representation to the representations in the DBMS, solving this issue becomes critical. Among the issues,

- There is no absolute notion of “private” and “public” in RDBMS (relative to needs),
- There are many differences in the data-type (no pointer, weird way of defining string, etc.),
- The values in a relational structure have to be simple (no complex datatype, no structure).

The term “impedance mismatch” describes that annoying need for a translation, and one of the goal of this first shift was to get rid of it.

Also, the data is now moving, growing fast, extremely diverse, and traditional relational DBMS seemed not necessarily well-suited to handle those changes.

### 7.1.4 Gathering Forces

To renew the world of DBMS, there were multiple attempts, going in multiple directions. A meetup to discuss them coined the term “NoSQL” in an attempt to have a “twittable” hashtag, and it stayed (even it is as specific as describing a dog as “not being a cat”). The original meet-up asked for “open-source, distributed, nonrelational database”. Today, there is no “official” definition of NoSQL, but NoSQL often implies the following:

- No relational model,
- Not using SQL. Some still have a query language, and it resembles SQL (to minimize learning cost), for instance Cassandra’s CQL,
- Run well on clusters,
- Schemaless: you can add records without having to define a change in the structure first,

\(^1\)[https://cloud.google.com/bigtable/]
\(^2\)[https://aws.amazon.com/dynamodb/]
• Open source.

Another important notion that emerged was the notion of “polyglot persistence”, which is the idea of “using different data storage technologies to handle varying data storage needs.” In other terms, if you adopt the “application database” approach (i.e., one database dedicated to one particular application), the you can use the DBMS A for your application 1, and the DBMS B for your application 2, or even use A and B for the same application!

7.1.5 The Future or the Past?

There was a lot of enthusiasm, also because this approach “frees the data” (and, actually, the metadata, cf. application/ld+json, JavaScript Object Notation for Linked Data, schema.org, etc.): sharing e.g. a json file is much easier that sharing a SQL view along with its schema (the example in the Document-Oriented Database will make it clearer).

Some of it will last for sure: polyglot persistency, the possibility of being schema-less, being “distributed first”, the possibility of sacrificing consistency for greater good, etc. This does not mean that SQL (“OldSQL”) and relational database are over: there are still useful in many scenario, and the powerful query language is great (writing your own every time is a nightmare...).

Starting ~ 2010, one reaction was to develop “NewSQL”, which would combine aspects of both approaches. For instance, having to drop the ACID requirements (detailed in this Section) was often seen as a major drawback, but, for instance, MongoDB announced\(^3\) that it would have more and more of the ACID properties!

Also, a really great use of NoSQL is to adopt it at an early stage of the development, when it is not clear what the schemas should be. When the schemas are final, then you can shift to relational DBMS!

The retro-acronym “Not Only SQL” emphasizes that SQL will still be one of the principal actor, but that developer should be aware of other solutions for other needs.

7.2 Comparison

SQL and the NoSQL approach can be compared in many different ways. Note that there is no “best tool”: it would be like trying to decide if a hammer is better than a saw, the answer is “it depends of what you want to do with it!”. But you can use one relational or non-relational DBMS for different purposes, sometimes, again, within the same application (“polyglot persistency”).

7.2.1 Overview

« Comparaison n’est pas raison »\(^4\)

NoSQL
• Semi-structured data (no schema)
• High performance
• Availability
• Data Replication (improves availability and performance)

\(^3\)https://www.mongodb.com/blog/post/multi-document-transactions-in-mongodb

\(^4\)A French proverb, meaning that “things should be judged on the individual qualities they posses, rather than by comparing one with another.” (Manser 2007)
7.3 Categories of NoSQL Systems

- Scalability (horizontal scalability (add nodes) instead of vertical (add memory))
- Eventual Consistency
- Natively versionning

**SQL**
- Immediate data consistency
- Powerful query language (for instance, join is often missing in NoSQL, has to be implemented on the application-side)
- Structured data storage (can be too restrictive)

7.2.2 ACID vs CAP vs BASE

ACID and BASE are three acronyms capturing desirable features of DBMS, while CAP is a theorem stating the impossibility to have some desirable properties at the same time in distributed systems.

ACID is the guarantee of validity even in the event of errors, power failures, etc.

- Atomicity → Transactions are all or nothing
- Consistency → Transactions maintains validity
- Isolation → Executing two transactions in parallel or one after the other would have the same result
- Durability → Once a transaction has been committed, it is stored in non-volatile memory.

CAP (a.k.a. Brewer’s theorem): Roughly, “In a distributed system, one has to choose between consistency (every read receives the most recent write or an error) and availability (every request receives a (non-error) response, without guarantee that it contains the most recent write)” (the P. standing for “Partition tolerance”, a guarantee of availability).

BASE (also formulated by Brewer) corresponds to Basic Availability, Soft state, Eventual consistency. It is a series of properties that can be reached by distributed systems, including NoSQL systems, and is often seen as the “NoSQL’s version of ACID”. This answer\(^5\) for answer, gives some insight on its meaning.

7.3 Categories of NoSQL Systems

There are multiple ways to be “non-relational”. A rough hierarchy of the different approaches can be sketched as follows.

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Document-based</td>
<td>Data is stored as “documents” (JSON, for instance), accessible via their ID (other indexes).</td>
<td>Apache CouchDB(^6) (simple for web applications, and reliable), MongoDB(^7) (easy to operate), Couchbase(^8) (high concurrency, and high availability).</td>
</tr>
<tr>
<td>Key-value stores</td>
<td>Fast access by the key to the value. Value can be a record, an object, a document, or be more complex.</td>
<td>Redis(^9) (in-memory but persistent on disk database, stores everything in the RAM!)</td>
</tr>
</tbody>
</table>

\(^5\)https://stackoverflow.com/a/3382260
<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column-based (a.k.a. wide column)</td>
<td>Partition a table by columns into column families, where each column family is stored in its own files.</td>
<td>Cassandra\textsuperscript{10}, HBase\textsuperscript{11} (both for huge amount of data)</td>
</tr>
<tr>
<td>Graph-based</td>
<td>Data is represented as graphs, and related nodes can be found by traversing the edges using path expressions.</td>
<td>Neo4J\textsuperscript{12} (excellent for pattern recognition, and data mining)</td>
</tr>
<tr>
<td>Multi-model</td>
<td>Support multiple data models</td>
<td>Apache Ignite\textsuperscript{13}, ArangoDB\textsuperscript{14}, etc.</td>
</tr>
</tbody>
</table>

7.4 MongoDB

7.4.1 Resources

- https://www.mongodb.com/
- https://university.mongodb.com
- https://en.wikipedia.org/wiki/MongoDB
- (Sadalage and Fowler 2012, ch. 9)
- (Sullivan 2015, ch. 6)

7.4.2 Introduction

MongoDB is

- Free (i.e., provided at no cost). Their business model leverages training, support, and DB as service. They actually developed MongoDB because they wanted a good solution for a cloud solution!
- Open-source, even if recent changes make their license not really open source\textsuperscript{15}, they share most of their code\textsuperscript{16}.
- Cross-platform: their community server\textsuperscript{17}, for instance, runs on all major operating systems.

\textsuperscript{1}https://couchdb.apache.org/
\textsuperscript{2}https://www.mongodb.com/
\textsuperscript{3}https://www.couchbase.com/
\textsuperscript{4}https://redis.io/
\textsuperscript{5}https://cassandra.apache.org/
\textsuperscript{6}https://hbase.apache.org/
\textsuperscript{7}https://neo4j.com/
\textsuperscript{8}https://ignite.apache.org/
\textsuperscript{9}https://www.arangodb.com/
\textsuperscript{10}https://opensource.org/LicenseReview122018
\textsuperscript{11}https://github.com/mongodb
\textsuperscript{12}https://www.mongodb.com/download-center/community
• Document-oriented: it uses a JSON-like documents with schemas, and it is the most popular\textsuperscript{18} DBMS using documents (the next ones are Amazon DynamoDB, Couchbase, CouchDB).

### 7.4.2.1 Technologies

MongoDB is endowed with

- API\textsuperscript{19} and drivers\textsuperscript{20} for C, C++, C#, Hadoop Connector, Haskell, Java, node.js, PHP, Perl, Python, Ruby, Scala (Casbah),
- a “mongo shell” (a command-line interface), which is an interactive JavaScript interface to MongoDB. You can try it on-line\textsuperscript{21}.

### 7.4.2.2 Design

Note that while the design of your database becomes a “second class citizen”, as you can start manipulating data before a schema has been defined, this does not mean that design became irrelevant. General design principles still needs to be adopted, and everything that was said about design remains true. The key difficulty is that there is no foreign key, in MongoDB, or at least no contraints attached to the relationships two documents can have, except for the one you implement. This is generally considered to be a downside in terms of consistency, and an advantage in terms of flexibility and scalability.

### 7.4.2.3 Security

Mongodb is vulnerable to SQL injection (cf. https://zanon.io/posts/nosql-injection-in-mongodb) and should respect the same general guidelines as discussed in A Bit About Security (cf. https://docs.mongodb.com/manual/administration/security-checklist/).

And additional challenge is that e.g. since JOIN operations need to be performed “by hand”, in the application program (cf. https://www.w3schools.com/nodejs/nodejs_mongodb_join.asp), your attack surface grows.

### 7.4.3 Document

Let us start by detailing what a “document” is. There are multiple different implementations and definition of what a document is, but at the core of all of them are the followings:

- Documents encapsulate and encode data (Self-Describing Data),
- Documents do not need to adhere a standard schema (but they can, if you want),
- One program can have many different types of objects, and those objects often have many optional fields.

---
\textsuperscript{18}https://db-engines.com/en/ranking/document+store
\textsuperscript{19}https://api.mongodb.com/
\textsuperscript{20}https://docs.mongodb.com/drivers/
\textsuperscript{21}https://docs.mongodb.com/manual/tutorial/getting-started/
Among the formats of documents, there is XML, YAML, JSON (JavaScript Object Notation), PDF, etc. You can generally convert from one format to the others, which is an important feature.

An example of XML (Extensible Markup Language) document, storing information about what Martin and Pradmod like, which cities they visited, etc:

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!-- code/xml/person.xml -->
<root>
  <element>
    <firstname>Martin</firstname>
    <lastVisited>Paris</lastVisited>
    <lastcity>Boston</lastcity>
    <likes>
      <element>Biking</element>
      <element>Photography</element>
    </likes>
  </element>
  <element>
    <firstname>Pradmod</firstname>
    <lastcity>Chicago</lastcity>
    <addresses>
      <element><city>DILLINGHAM</city><state>AK</state></element>
      <element><city>PUNE</city><state>MH</state></element>
    </addresses>
    <citiesvisited>
      <element>Chicago</element>
      <element>London</element>
      <element>Pune</element>
      <element>Bangalore</element>
    </citiesvisited>
  </element>
</root>
```

As you can see, from this document:

- The two `element` (person) contains different information: we know the first name of both, but not the address of Martin, nor the `lastVisited` of Pradmod.
- Tags can have an internal structure (like `addresses`), but their order does not matter.
- Invalid document exists! Imagine if one tag is not properly closed, then the parsing would fail.
- Documents are somehow human and computer-readable.
- There are no or little predefined tags: the `shiporder` or `item` tags are made-up!
• Documents are extensible, as one can invent new tags, re-fine the organization inside an item, etc.

A more detailed example, including the design of a schema, can be found at w3schools.com.

The kind of document MongoDB uses is called BSON (portmanteau of the words “binary” and “JSON”), and it actually extends JSON. Think of BSON as a binary representation of JSON documents.

### 7.4.4 Document-Oriented Database

Mongodb is a document-oriented database (document store), which means that the databases contain semi-structured data. It is a subclass of the key-value store:

• Relational databases (RDB) pre-define the data structure (i.e., the schema) in the database (fields + data type).
• Key-value (KV) treats the data as a single opaque collection, which may have any number (including 0) fields for every record.
• Document-oriented (DO) system relies on internal structure in the data to extract metadata.

RDB is excellent for optimization, but sometimes waste space (placeholders for optional values) and is sometimes too rigid. KV does not allow any optimization, but provides flexibility and follows more closely modern programming concepts. DO has the flexibility of KV, and allows for some optimization.

One important difference: in RDB, data is stored in separate tables, and a single object (entity) may be spread across several tables. In DO, one object = one instance, and every stored object can be different from every other. There are pros to this approach:

• Mapping objects to a DB simpler,
• Change “in place”,
• Increase speed of deployment.

### 7.4.5 General Organization of MongoDB Databases

Let us start by mapping the common notions of RDBMS to the mongoDB ecosystem:

<table>
<thead>
<tr>
<th>RDBMS</th>
<th>MongoDB</th>
</tr>
</thead>
<tbody>
<tr>
<td>database instance</td>
<td>MongoDB instance</td>
</tr>
<tr>
<td>schema</td>
<td>database</td>
</tr>
<tr>
<td>table</td>
<td>collection</td>
</tr>
<tr>
<td>row</td>
<td>document</td>
</tr>
</tbody>
</table>

Each MongoDB instance has multiple databases, each database can have multiple collections.

Our previous XML “person” example can be converted into two documents delimited by [...],

---

22[https://www.w3schools.com/xml/schema_example.asp](https://www.w3schools.com/xml/schema_example.asp)
24We actually had to have three documents: as JSON does not really have comments (cf. [https://stackoverflow.com/q/244777/](https://stackoverflow.com/q/244777/)), we added a document containing only the attribute "_comment" to specify the path where that file
used to delimit an array of document.

```python
[
  {
    "_comment": "code/json/person.json"
  },
  {
    "firstname": "Martin",
    "likes": [
      "Biking",
      "Photography"
    ],
    "lastcity": "Boston",
    "lastVisited": "Paris"
  },
  {
    "firstname": "Pramod",
    "citiesvisited": [
      "Chicago",
      "London",
      "Pune",
      "Bangalore"
    ],
    "addresses": [
      {
        "state": "AK",
        "city": "DILLINGHAM"
      },
      {
        "state": "MH",
        "city": "PUNE"
      }
    ],
    "lastcity": "Chicago"
  }
]
```

Note that
- `addresses` is a document!
- Some attributes are common, some are not: that’s fine, every document can have its own schema.

A collection should be on “related” entities (do not store server logs, store customers and list of employee in the same collection!), and not too abstract ones (no “Server stuff”). Also, if you store document that are too different, your performances will take a big hit. Bottom line: think about your usage, and the kind of queries you will perform.

So, in summary, “Schema-less” does not mean “organization-less”!
7.4.6 Set Up

The instructions are only for Linux, but should be easy to adapt.

- Download and install `mongodb` from https://www.mongodb.com/download-center/community, select the “server” and “shell” packages.
- As root, type

  ```bash
  mkdir /tmp/mongotest
  mongod --dbpath /tmp/mongotest
  ```

  to start the server and create a “dummy” database in the folder `/tmp/mongotest`.
- Then, open another terminal, and type in, as a normal user `mongo`.

The documentation is nicely written and well-organized: we’ll follow parts of it, please refer to it if needed. You can start by opening the “Getting started” tutorial and running its examples on your own installation.

7.4.7 First Elements of Syntax

The syntax for the command-line interface can be found at https://docs.mongodb.com/manual/reference/mongo-shell/. In a first approximation, the syntax is of the form:

```
db.<name of the collection>.<command>(<arguments>)
```

Where `db` is not the name of the database, it is just the prefix.

- To get information about your installation, use
  - `show dbs` to see the databases,
  - `use mydb` to use the `mydb` database,
  - `show collections` to see the collections in a particular database,
- To insert, use:

  ```bash
  db.books.insert({"title": "Mother Night", "author": "Kurt Blabal"})
  ```

  MongoDB will add a unique identifier (`_id`) if you do not provide one. You can think of that as a primary key.
- To remove an entry, use:

  ```bash
  db.books.remove({"title":"Mother Night"})
  ```
- To update an entry, use:

  ```bash
  db.books.update({"title":"Mother Night"}, {$set {"quantity" : 10}})
  ```

  Other function, such as `$inc`, to increment, can be used.

---

25https://docs.mongodb.com/manual/tutorial/getting-started/
7.4 MongoDB

- To select, use:
  - `db.books.find()`
    
    is like 'SELECT * FROM Books;
  - `db.books.find({"title":"Mother Night"})`
    
    `db.books.find({"title":"Mother Night"}, {"author":1,  "quantity":1})`
    
    both search for the book with title "Mother Night", and the second query displays only
    the author and quantity attributes.
  - `db.books.find({"title":"Mother Night"}, {"author":0,  "quantity":0})`
    
    display all the attributes, except the author and the quantity.
  - `db.books.find({"quantity":{"$gte": 10,  "$lt": 50}})`
    
    displays the entries were the quantity is greater than equal to 10, and less than 50.

It is possibility to mimic some features of SQL (like the unique attributes), but there are no refer-
ential key integrity, for instance.

Most insert / update / delete will return success as soon as one node received your command, but
you may tweak them so that success is returned only once the operation has been performed on
the majority of the nodes.

MongoDB does not offer as many features as e.g. MySQL, and there is the need to write a lot on the
program side. However, you can find a lot of API (i.e., it is taking the "package manager" approach
to offer a modular software), cf. for instance an API over mongo-java-driver: http://jongo.org/
(support some form of prepared statement).

7.4.8 MongoDB Database Program

This section will follow MongoDB’s “quick tour” of the Java api, as discussed at https://mongodb.
github.io/mongo-java-driver/3.9/driver/getting-started/quick-start/

You will need to:

- Make sure mongodb server is up and running as noted in the “Set-up” section,

Place those two files, mongo-java-driver-3.9.1.jar and QuickTour.java in the
same folder, and run

```
java -cp .:mongo-java-driver-3.9.1.jar QuickTour.java
```
You should see a large number of lines displayed at the screen, and around the top, the message
INFO: Opened connection [connectionId{localValue:2, serverValue:12}] to localhost:27017.

After various import statement, the program create a MongoClient object called
mongoClient, and connects it to the local database server:

```java
MongoClient mongoClient;

if (args.length == 0) {
    // connect to the local database server
    mongoClient = MongoClients.create();
} else {
    mongoClient = MongoClients.create(args[0]);
}
```

To get a database and a collection, the program uses:

```java
// get handle to "mydb" database
MongoDatabase database = mongoClient.getDatabase("mydb");

// get a handle to the "test" collection
MongoCollection<Document> collection =
    database.getCollection("test");
```

Note that a collection is simply an ArrayList of documents. Assume we want to create the following document:

```java
{
    "name": "MongoDB",
    "type": "database",
    "count": 1,
    "info": {
        "x": 203,
        "y": 102
    }
}
```

(Remember: order does not matter!)

Then we can use the Document class to create it, and then insert the document created:

```java
// make a document and insert it
Document doc =
    new Document("name", "MongoDB")
        .append("type", "database")
        .append("count", 1)
        .append("info", new Document("x", 203).append("y", 102));

collection.insertOne(doc);
```

https://docs.oracle.com/javase/8/docs/api/java/util/ArrayList.html
Note that we can “chain” the `append`, using `doc.append("type", "database").append("count", 1)` etc.

Only at this point would the database and collection being created.

To “witness” what the program is doing from the command line, you can, for instance,

1. Edit the Java program, by commenting the statement `database.drop();`.
2. Execute the modified version,
3. Open the command-line-interface (simply type `mongo`), and run:

   ```
   use mydb
   show collections
   db.test.find()
   ```

   This last command should returns something like

   ```
   {
   "_id": ObjectId("5ea72152d8b5777d53c1a148"),
   "name": "MongoDB",
   "type": "database",
   "count": 1,
   "info": {
   "x": 203,
   "y": 102
   }
   }
   ```

   The program goes on and is discussed in details at https://mongodb.github.io/mongo-java-driver/3.9/driver/getting-started/quick-start/. You can see for instance that to construct lists of documents and insert them, one can use:

   ```java
   // now, lets add lots of little documents to the collection so
   // we can explore queries and
   List<Document> documents = new ArrayList<Document>();
   for (int i = 0; i < 100; i++) {
      documents.add(new Document("i", i));
   }
   collection.insertMany(documents);
   ```

   A discipline similar to what we saw on Java applications interacting with MySQL should apply:

   - read the documentation,
   - think about what should be the role of the application, and what should be left to the DBMS (knowing that mongoDB can not do as much as MySQL),
   - secure your application,
   - think if you need one database per application, or if you want to share a single database accross multiple users and applications.

### 7.5 Principles

We can summarize some of the principles we have learned, and introduce some new, as follows:

- “Schemaless means more responsibility”
In NoSQL, it is sometimes ok to have a bit of denormalization: duplicating the information, to have everything in the same document, can save time at the price of memory. For instance, you could imagine having a table for phone number, for employee, for emergency contact. You can duplicate that information, it is not going to consume a lot of memory, but will allow you to perform fewer join operations (which are resources expensive), at the price of course of storage.

As we said, “NoSQL injection” exists, and the same remedies apply: your application should accept only strings from your users (never allow objects by design) and sanitize the inputs before using them (mongo-sanitize\(^{27}\) or content-filter\(^{28}\) are good modules for this).

Exercises

Exercise 7.1 What is polyglot persistence? Is it useful?

Exercise 7.2 What does it mean to be “schemaless”? What does it imply?

Exercise 7.3 What is denormalization? When could it be useful?

Exercise 7.4 What is the object-relational impedance mismatch? Is it an issue that cannot be overcome?

Exercise 7.5 For each of the following notions, indicate if they are usually an attribute of NoSQL or of “traditional” SQL:

<table>
<thead>
<tr>
<th></th>
<th>Schema First</th>
<th>Distributed</th>
<th>Relational</th>
<th>Scalable</th>
</tr>
</thead>
<tbody>
<tr>
<td>NoSQL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SQL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Solution to Exercises

Solution 7.1 It is the act of picking the right DBMS for the task and involving multiple DBMS’s in a single application. Yes, it is useful. Per wikipedia\(^{29}\), “Polyglot persistence is the concept of using different data storage technologies to handle different data storage needs within a given software application.”

Solution 7.2 “Schemaless” means that a table can contain documents, or tuples, with different attributes. It implies more responsibilities.

Solution 7.3 Denormalization is to duplicate data about other entities in some entities. It is useful when joining is expensive.

Solution 7.4 Database and object-oriented principles are different and it requires work to make them work together. This correspondance, or matching, can be implemented in the application, or lead to the design of a new DBMS.

\(^{27}\)https://www.npmjs.com/package/mongo-sanitize
\(^{28}\)https://www.npmjs.com/package/content-filter
\(^{29}\)https://en.wikipedia.org/wiki/Polyglot_persistence
Solution 7.5

Problems

Problem 7.1 (Explaining NoSQL) “NoSQL” used to mean “Non SQL”, but was retro-actively given the meaning “Not Only SQL.” Below, write a short essay that explains:

1. What motivated the “Non SQL” approach.
2. What is the meaning of “Not Only SQL.”
3. The benefits and drawbacks of the relational approach.

Problem 7.2 (ER Diagram from XML File – Customer) Consider the following xml file:

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!-- code/xml/customers.xml -->
<Customers>

<Customer Name="Pamela Zave" ID="C001">
  <Orders>
    <Order Date="2012-07-04T00:00:00" ID="10248">
      <Product Quantity="5" ID="10">
        <Description>A Box of Cereal</Description>
        <Brand>Cereal Company</Brand>
        <Price>$3</Price>
      </Product>

      <Product Quantity="10" ID="43">
        <Description>A Box of Matches</Description>
        <Brand>Match Ltd</Brand>
        <Price>$1.20</Price>
        <Caution>Not suitable for children</Caution>
      </Product>
    </Order>
  </Orders>

  <Address>123 Main St., Augusta, GA, 30904</Address>
</Customer>

<Customer Name="Nancy Lynch" ID="C002">
  ...
</Customer>
```
Try to draw the ER model that would correspond to the relational implementation of this database. Justify your choices.

Problem 7.3 (ER Diagram from XML File – Award) Find below a mashup of actual data from the National Science Foundation (courtesy of https://www.nsf.gov/awardsearch/download.jsp):

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!-- code/xml/NSFAward.xml -->
<rootTag>
  <Award>
    <AwardTitle>CAREER: Advances in Graph Learning and Inference</AwardTitle>
    <AwardEffectiveDate>11/01/2019</AwardEffectiveDate>
    <AwardExpirationDate>01/31/2023</AwardExpirationDate>
    <AwardAmount>105091</AwardAmount>
    <Organization>
      <Code>05010000</Code>
      <Directorate>
        <Abbreviation>CSE</Abbreviation>
        <LongName>Direct For Computer &amp; Info Scie &amp; Enginr</LongName>
      </Directorate>
    </Organization>
  </Award>
</rootTag>
```
<Division>
  <Abbreviation>CCF</Abbreviation>
  <LongName>Division of Computing and Communication Foundations</LongName>
</Division>
</Organization>
 ProgramOfficer>
  <SignBlockName>Phillip Regalia</SignBlockName>
</ProgramOfficer>
<AwardID>2005804</AwardID>
<Investigator>
  <FirstName>Patrick</FirstName>
  <LastName>Hopkins</LastName>
  <EmailAddress>phopkins@virginia.edu</EmailAddress>
  <StartDate>11/22/2019</StartDate>
</Investigator>
<Investigator>
  <FirstName>Jon</FirstName>
  <LastName>Ihlefeld</LastName>
  <EmailAddress>jfi4n@virginia.edu</EmailAddress>
  <StartDate>11/22/2019</StartDate>
</Investigator>
</Investigator>
</Institution>
</Award>
</rootTag>

It contains information about one particular award that was awarded to an institution on behalf of two researchers. Quoting the National Science Foundation (NSF):

NSF is divided into the following seven directorates that support science and engineering research and education:... Each is headed by an assistant director and each is further subdivided into divisions like ...

From this XML file and the information given above, draw an ER diagram for NSF’s awards. Do not hesitate to comment on the choices you are making and on what justifies them.

30https://www.nsf.gov/about/research_areas.jsp
Solutions to Selected Problems

Solution to Problem 7.2 (ER Diagram from XML File – Customer) It should be clear that three entities are present in this file: Customer, Order, and Product. An order can contain a certain quantity of a product, and a customer can pass 0 or more orders. Some attributes are natural primary keys (they are named “ID” in the diagram below), and some attributes seems to be optional (“Caution”, or “Material”), but should still be made an attribute.

Put together, this gives the following diagram:

We made further assumptions: an order cannot be empty (transcribed by the total constraint on CONTAINS), and an order does not exist if it was not passed by a customer (transcribed by the fact that ORDER is a weak entity), which also implies that an order cannot be passed by more than one customer. Note that the same product cannot be present “twice” (with the equal or different quantities) in an order: an order can contain a particular product only once in any quantity, implying that if an order had two of the product A, and three of the same product A, then those two quantities of A should be merged so that an order contains five of this product A. This is enforced by the cardinality ratio of 1 in the CONTAINS relationship.

Of course, other choices are possible.

Solution to Problem 7.3 (ER Diagram from XML File – Award) Two entities are easy to distinguish: RESEARCHER (for “Investigator”) and INSTITUTION. The status of the the content between the <Organization> tags is less clear; apparently, an organization has a code, and is made of two parts: a Directorate and a Division. Using the quote, we know that a Division should be a part of exactly one Directorate, and that a Directorate has an assistant director. But what is the status of that “Organization”? Is it subsumed by
the Directorate or is it orthogonal? We decide to create an entity for it, but its precise role should be clarified. The relationship between Division and Directorate is clear, but, once again, the relationship between Division and Organization could have any constraint, we can not really infer that information from the document.

The next difficulty is the status of the award itself: should it be a relationship with many attributes, between the RESEARCHER and INSTITUTION entities? The issue with this approach is that an award can have multiple investigators, as shown in the example, and that this number can vary. Hence, fixing the arity and constraints on this relationship will be difficult. We could have a relation of arity $2$, and “duplicate it” if multiple researchers are involved in the same grant, but that seems like a poor choice (since all the information about the grant will need to be duplicated). Therefore, it seems more reasonable to make the award an entity.

How should we connect the AWARD entity with the RESEARCHER and INSTITUTION entities? A ternary relation has some drawbacks, since it would require some duplication when multiple investigators are working on the same award. Instead, having one binary relationship between the award and the institution, and one binary relationship between the award and the researcher (that specifies further the role of the researcher for that particular award), seems like a safer choice. An award must be awarded to at least one researcher and one institution, but we do not know if there is a maximum number of institutions that can obtain the same award, so it is better not to restrict this arity. Whether there should be a relationship between the researcher and the institution is up in the air; we do not know if a researcher has to work for an institution to get a grant, nor if getting a grant for an institution means that you work for it, so it is probably better to refrain from adding such a relationship.

Most of the attributes are straightforward once we see that “Role” is an attribute of a relationship, not of an entity.

All together, this gives the following diagram:
References


Sullivan, Dan. 2015. NoSQL for Mere Mortals. Addison-Wesley Professional.