Lecture 4: Normalization

September 24, 2004

Lecturer: Rasmus Pagh
Today’s lecture

- What you should remember from previously.
- Anomalies in relations.
- Decomposing relations.
- Functional dependencies.
- Boyce-Codd normal form (BCNF).
- 3rd normal form.
- Attribute value redundancy.
In this lecture I will assume that you remember:

- Key concepts of the relational data model:
  - Relation
  - Attributes
  - Relation schema
  - Relation instance

- Key concepts in SQL
  - Projection
  - Join

- Key concepts in E/R modeling:
  - Entity set
  - Relationship
Next: Anomalies in relations
Redundancy in a relation

Redundant (i.e., “unnecessary”) information occurs in a relation if the same fact is repeated in several different tuples.

One obvious problem with redundant information is that we use more memory than is necessary. Redundancy is an example of an anomaly of the relation schema.
Other kinds of anomalies

The other principal kinds of unwanted anomalies are:

- **Update anomalies.** Occur when it is possible to change a fact in one tuple but leave the same fact unchanged in another. (E.g., the length of Star Wars in the Movies relation.)

- **Deletion anomalies.** Occur when deleting a tuple (recording some fact) may delete another fact from the database. (E.g., information on a movie in the Movies relation.)

[Figure 3.21 shown on slide]

Ideally, we would like relation schemas that do not allow anomalies. **Normalization** is a process that can often be used to arrive at such schemas.
Next: Decomposing relations
The anomalies in the example we saw can be eliminated by splitting (or **decomposing**) the relation schema

\[
\text{Movies(}\text{title, year, length, filmType, studioName, starName)}
\]

into two relation schemas

\[
\text{Movies1(}\text{title, year, length, filmType, studioName)}
\]

\[
\text{Movies2(}\text{title, year, starName)}
\]

[Figure 3.22 and 3.23 shown on slide]
The relation instances for Movies1 and Movies2 were found by projection of Movies onto their attributes. In SQL, Movies2 could be computed as follows:

```
SELECT title, year, starName
FROM Movies
```

This is a general rule when decomposing: The decomposed relation instances are found by projection of the original relation instance.
Recombining relations

We would like the decomposed relations to contain the same information as the original relation. In particular, we should be able to recombine them to recover the original relation.

Recombining can be done by **joining** the relations on attributes of the same name (this is called a **natural join**). [Figure 3.28 shown on slide]

**Example:** In SQL we can compute Movies as follows:

```
SELECT *
FROM Stars1, Stars2
WHERE Stars1.title = Stars2.title AND
Stars1.year = Stars2.year
```
Problem session (5 minutes)

Consider these two attempts at decomposing Movies into relations

MoviesA(length, filmType, studioName)
MoviesB(title, year, starName)

MoviesX(title, year, length, filmType)
MoviesY(title, year, starName, studioName)

What are the problems with these attempts?
Keys of a relation

A key for a relation is a set of its attributes that satisfy:

- **Uniqueness.** The values of the attributes uniquely identify a tuple.
- **Minimality.** No proper subset of the attributes has the uniqueness property.

If uniqueness is satisfied (but not necessarily minimality) the attributes are said to form a superkey.

**Examples:** [Figure 3.21 shown on slide]

- \{Title, year, starName\} is a key for the Movies relation.
- \{Title, year, starName, length\} is a superkey, but not a key, for the Movies relation.
- \{Title, year\} is not a superkey (or key) for the Movies relation.
Key terminology

Confusingly, what we call a superkey in the context of relations corresponds to what we called a key in the context of E/R models.

According to the book, the key/superkey terminology is not well-established.

Keys consisting of more than one attribute are sometimes called composite.
Recombining requires a superkey

Suppose we decompose a relation $R$ into two relations $R_1$ and $R_2$ with common attributes $B_1, B_2, \ldots, B_m$. What is required to be able to recover $R$?

[Figure 3.28 shown on slide]

**Criterion for being able to recombine:**

$\{B_1, B_2, \ldots, B_m\}$ must be a superkey for $R_1$ or $R_2$. 
Next: Functional dependencies
When values of attribute $B$ can be derived from the attributes $A_1, \ldots, A_n$ we say that $B$ is **functionally dependent** on $A_1, \ldots, A_n$. This is written as follows:

$$A_1 A_2 \ldots A_n \rightarrow B$$

[Figure 3.16 shown on slide]

**Example:** Movies has the functional dependency (FD)

$$title \; year \; \rightarrow \; length$$

but *not* the FD

$$title \; year \; \rightarrow \; starName$$

This is in fact *the very reason* for the anomalies we saw!
Functional dependency on a superkey

Whenever we see the attribute values of some (super)key \( \{A_1, \ldots, A_n\} \), we can uniquely identify the tuple from which the values come.

In particular, we can determine the value of any other attribute \( B \) in the relation, so we unavoidably have the FD

\[
A_1 A_2 \ldots A_n \rightarrow B
\]

Trivial functional dependency

Also, we can always determine the value of attribute \( A_i \) from the value of attribute \( A_i \). So we unavoidably have the FD

\[
A_1 A_2 \ldots A_n \rightarrow A_i
\]
Consider a relation containing an inventory record:
Inventory(part, warehouse, quantity, warehouse-address)

- What are the keys of the relation?
- What are the avoidable functional dependencies?
- Can you suggest a way of decomposing the relation to eliminate the avoidable functional dependencies?
Next: Boyce-Codd normal form (BCNF)
A normal form is a criterion on a relation schema.

A relation is in **Boyce-Codd normal form (BCNF)** if there are only unavoidable functional dependencies among its attributes.

**Example:** Movies has the functional dependency

\[ \text{title} \ \text{year} \ \rightarrow \ \text{length} \]

which is *not* unavoidable because it is nontrivial and \{\text{title}, \text{year}\} is not a (super)key. Thus, Movies is not in BCNF.
The relations of our decomposition:

Movies1(title, year, length, filmType, studioName)
Movies2(title, year, starName)

are in BCNF. The only nontrivial nonreducible FDs are

Movies1: title year → length
Movies1: title year → filmType
Movies1: title year → studioName
Movies2: title year → starName

and they are unavoidable since \{title, year\} is a key for both relations.
— Writing functional dependencies —

**Reducing FDs:** Whenever we can reduce the number of attributes when writing an FD we do so. For example, Movies1 has the FDs

\[
\text{title year filmType} \rightarrow \text{length}
\]

\[
\text{title year studioName} \rightarrow \text{length}
\]

which can both be reduced to

\[
\text{title year} \rightarrow \text{length}
\]

**Combining FDs:** Whenever several FDs have the same left hand side we combine them. For example, the three FDs we saw for Movies can be written succinctly as:

\[
\text{title year} \rightarrow \text{length \ filmType \ studioName}
\]
Suppose we have a relation R which is not in BCNF. Then there is an FD

\[ A_1 A_2 \ldots A_n \rightarrow B_1 B_2 \ldots B_m \]

which is not unavoidable.

To eliminate the FD we split R into two relations: [Figure 3.24]

- One with all attributes of R except \( B_1, B_2, \ldots, B_m \).
- One with attributes \( A_1, A_2, \ldots, A_n, B_1, B_2, \ldots, B_m \).

If any of the resulting relations is not in BCNF, the process is repeated.

**Note:** \( A_1, A_2, \ldots, A_n \) is a superkey for the second relation – therefore we can recover R as the natural join of the two relations.
Recall the relation Movies with schema

Movies(title, year, length, filmType, studioName, starName)

It has the following FD, which is not unavoidable:

\[ \text{title} \quad \text{year} \quad \rightarrow \quad \text{length} \quad \text{filmType} \quad \text{studioName} \]

Thus the decomposition yields the following relations (both in BCNF):

Movies1(title, year, length, filmType, studioName)
Movies2(title, year, starName)
Consider the following relation with information on movie studios:

MovieStudio(title, year, length, filmType, studioName, studioAddr)

Argue that the relation is not in BCNF, and find a decomposition into BCNF.
Finding all FDs

The following systematic method (not described in GUW) can be used to find all FDs in a relation.

Suppose we have a relation with attributes $A_1, A_2, \ldots, A_n$ and $B$. To find all FDs with $B$ on the right hand side, first determine whether

$$A_1 A_2 \ldots A_n \rightarrow B$$

is an FD:

- If not, there are no FDs with (a subset of) $A_1, A_2, \ldots, A_n$ on the left hand side and $B$ on the right hand side, and we may stop.

- Otherwise repeat the same procedure with the $n$ candidate FDs we get by taking one attribute away from the left hand side of the above FD.
To find all nonreducible FDs, we may use the following method, which often looks at much fewer candidate FDs:

First determine whether

\[ A_1A_2 \ldots A_n \rightarrow B \]

is an FD:

- If not, we may stop.

- Otherwise, if we can spot an FD from a subset of \( A_1, A_2, \ldots, A_n \) to \( B \), repeat the procedure with each of the attributes of the subset removed from the left hand side of the above FD.

- Otherwise repeat the procedure with all \( n \) candidate FDs we get by taking one attribute away from the left hand side of the above FD.
Example of finding all nonreducible FDs

To find all nonreducible FDs with studioName on the right hand side, we consider the following candidate FDs:

- \( \text{title year length filmType starName} \rightarrow \text{studioName} \) (FD)
- \( \text{title year starName} \rightarrow \text{studioName} \) (spotted FD)
- \( \text{year length filmType starName} \rightarrow \text{studioName} \) (not FD)
- \( \text{title length filmType starName} \rightarrow \text{studioName} \) (not FD)
- \( \text{title year length filmType} \rightarrow \text{studioName} \) (FD)
- \( \text{title year} \rightarrow \text{studioName} \) (spotted FD)
- \( \text{year length filmType} \rightarrow \text{studioName} \) (not FD)
- \( \text{title length filmType} \rightarrow \text{studioName} \) (not FD)
Next: 3rd normal form
Consider the relation with schema Bookings(title, theater, city)

Under certain assumptions, it has the FD theater → city, but theater is not a superkey. The BCNF decomposition yields relation schemas Bookings1(theater, city) and Bookings2(theater, title).

These schemas and their FDs allow, e.g., the relation instances:

<table>
<thead>
<tr>
<th>theater</th>
<th>city</th>
<th>theater</th>
<th>title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guild</td>
<td>Menlo Park</td>
<td>Guild</td>
<td>The net</td>
</tr>
<tr>
<td>Park</td>
<td>Menlo Park</td>
<td>Park</td>
<td>The net</td>
</tr>
</tbody>
</table>

which violate the presumed FD title city → theater.

Thus, there are implicit dependencies between values in different relations. *We cannot check FDs separately in each relation to see such a dependency.*
As we just saw, decomposition can result in a relational database schema where a functional dependency “disappeared”.

The problem in the previous example arose because we decomposed according to the FD $\text{theater} \rightarrow \text{city}$, where $\text{city}$ is part of a key for the Bookings relation. Thus we ended up splitting the key $\{\text{city, theater}\}$.

This problem of FDs that are not preserved never arises if we do not decompose in this case.
We have motivated the following normal form which never splits a keys of the original relation:

A relation is in **3rd normal form** (3NF) if any functional dependency among its attributes is either unavoidable, or has a member of some key on the right hand side.

In words: A relation is in 3NF if there are no unavoidable functional dependencies among non-key attributes.
Whether it is a good idea to stop decomposition when third normal form is reached depends on the specific scenario.

- Mostly, 3NF and BCNF coincide, so there is nothing to consider.
- If not, the redundancy in tuples in 3NF should be weighed against the fact that some FD is difficult to check/maintain in BCNF.

**Example:**
In the Bookings example, we might want to make the DBMS check that to every title and city, there is at most one theater. For the BCNF decomposed relations, this would involve a query on Bookings1 for every change of Bookings2, and vice versa.
Next: Attribute value redundancy (not in book)
A kind of redundancy, which is different from functional dependence, is redundancy in attribute values.

**Example:** The string *Star Wars* was repeated many times to designate the movie. Longer strings would make the problem even more obvious.

This kind of redundancy could also cause update anomalies.

**Example:** Suppose the working title *Lucky Luke Skywalker* had to be changed in the whole database to *Star Wars*.
A way of reducing this redundancy is to use (or introduce) a short key value for each string, and put strings in a separate relation like

\[ \text{MovieNames(key,name)} \]

Whether this is a good idea depends on the number of occurrences and other factors such as the need for efficiency.
Most important points in this lecture

As a minimum, you should after this week:

- Understand the significance of normalization.
- Be able to determine whether a relation is in Boyce Codd normal form or 3rd normal form.
- Be able to split a relation in several relations to achieve any of the normal forms.
- Know how to recombine normalized relations in SQL.
Next time

Next week we finish the study of normalization:

- 4th normal form
- Some observations on normalization.

Then we will go through a number of cases of database design, including

- E/R design
- Conversion to relation schemas
- Normalization