Nomalization Overview

Database Design

- Requirements Analysis
- Conceptual Modeling (ER Model)
- Logical Modeling (Relational Model)
- Schema Refinement (Normalization)

Schema Refinement

- Redundancy
- Schema Refinement
  - Minimizing Redundancy
  - Functional Dependencies (FDs)
  - Normalization using FDs
    - First Normal Form (1NF)
    - Second Normal Form (2NF)
    - Third Normal Form (3NF)
    - Boyce-Codd Normal Form (BCNF)
  - Multivalued Dependencies (MVDs), Join Dependencies JDs)
  - Normalization using MVDs and JDs
    - Higher Normal Forms (4NF, 5NF)

Redundancy

- Storing the same information in more than one place within a database
- Redundant Storage: Some information is stored repeatedly
- Update Anomalies : Inconsistencies are created unless each and every copy of the data is updated
- Insertion Anomalies: It may not be possible to store certain information unless storing some other, unrelated, information as well
- Deletion Anomalies: It may not be possible to delete certain information without loosing some other, unrelated, information as well

Normalization is done for “minimizing” redundancy

Anomalies

Instructor (Instr_ID, Instr_name**, Course**, Credit**)**

Redundancy: Same course can be taught by several instructors, each time the credit for such course is repeated

- **Update Anomaly:** Update information that DBMS from Semester I, 2008-2009 is 4.5 units course
- **Insert Anomaly:** Cannot insert a new course credit unless an instructor is assigned to it
  - ***Inversely*** **-** Cannot insert an instructor information unless she is assigned to a course to teach
- **Delete Anomaly:** Last instructor available for teaching a course say Semantic Approaches leaves institute. The information that this course is a 3 credit course is also lost

Outline

- Features of Good Relational Design
- Functional Dependencies
- Decomposition Using Functional Dependencies
- Normal Forms
- Functional Dependency Theory
- Algorithms for Decomposition using Functional Dependencies
- Decomposition Using Multivalued Dependencies
- More Normal Form
- Atomic Domains and First Normal Form
- Database-Design Process
- Modeling Temporal Data

Overview of Normalization

Features of Good Relational Designs

- Suppose we combine *instructor* and *department* into ***in_dep,*** which represents the natural join on the relations *instructor* and *department*

ID	*name*	*salary*	*dept_name*	*building*	*budget*
22222	Einstein	95000	Physics	Watson	70000
12121	Wu	90000	Finance	Painter	120000
32343	El Said	60000	History	Painter	50000
45565	Katz	75000	Comp. Sci.	Taylor	100000
98345	Kim	80000	Elec. Eng.	Taylor	85000
76766	Crick	72000	Biology	Watson	90000
10101	Srinivasan	65000	Comp. Sci.	Taylor	100000
58583	Califieri	62000	History	Painter	50000
83821	Brandt	92000	Comp. Sci.	Taylor	100000
15151	Mozart	40000	Music	Packard	80000
33456	Gold	87000	Physics	Watson	70000
76543	Singh	80000	Finance	Painter	120000

- There is repetition of information
- Need to use null values (if we add a new department with no instructors)

A Combined Schema Without Repetition

Not all combined schemas result in repetition of information

- Consider combining relations
  - *sec_class(sec_id, building, room_number)* and
  - *section(course_id, sec_id, semester, year)*

  into one relation
  - *section(course_id, sec_id, semester, year, building, room_number)*
- No repetition in this case

Decomposition

- The only way to avoid the repetition-of-information problem in the i*n_dep* schema is to decompose it into two schemas – instructor and *department* schemas.
- Not all decompositions are good. Suppose we decompose

  employee(ID, name, street, city, salary)

  into

  employee1 (*ID*, *name*)

  employee2 (*name*, *street, city, salary*)

  The problem arises when we have two employees with the same name
- The next slide shows how we lose information -- we cannot reconstruct the original *employee* relation -- and so, this is a **lossy decomposition**.

A Lossy Decomposition

ID	*name*	*street*	*city*	*salary*
⋮				
57766	Kim	Main	Perryridge	75000
98776	Kim	North	Hampton	67000
⋮				

employee

ID	*name*
⋮	
57766	Kim
98776	Kim
⋮	

name	*street*	*city*	*salary*
⋮			
Kim	Main	Perryridge	75000
Kim	North	Hampton	67000
⋮			

natural join

ID	*name*	*street*	*city*	*salary*
⋮				
57766	Kim	Main	Perryridge	75000
57766	Kim	North	Hampton	67000
98776	Kim	Main	Perryridge	75000
98776	Kim	North	Hampton	67000
⋮				

Lossless Decomposition

- Let R be a relation schema and let R_1 and R_2 form a decomposition of R . That is R = R_1 U R_2
- We say that the decomposition is a **lossless decomposition** if there is no loss of information by replacing R with the two relation schemas R_1 U R_2
- Formally,

$$\Pi_{R_1}(r) \bowtie \Pi_{R_2}(r) = r$$

- And, conversely a decomposition is lossy if

$$r \subset \Pi_{R_1}(r) \bowtie \Pi_{R_2}(r)$$

Example of Lossless Decomposition

- Decomposition of $R = (A, B, C)$

  $R_1 = (A, B) \qquad R_2 = (B, C)$

A	*B*	*C*
α	1	A
β	2	B

r

A	*B*
α	*1*
β	*2*

$\Pi_{A,B}(r)$

B	*C*
1	A
2	B

$\Pi_{B,C}(r)$

$\Pi_A (r) \bowtie \Pi_B (r)$

A	*B*	*C*
α	1	A
β	2	B

Normalization Theory

- Decide whether a particular relation *R* is in "good" form.
- In the case that a relation *R* is not in "good" form, decompose it into set of relations $\{R_1, R_2, ..., R_n\}$ such that
  - Each relation is in good form
  - The decomposition is a lossless decomposition
- Our theory is based on:
  - Functional dependencies
  - Multivalued dependencies
  - Join Dependencies

Schema Refinement

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Functional Dependencies

- There are usually a variety of constraints (rules) on the data in the real world.
- For example, some of the constraints that are expected to hold in a university database are:
  - Students and instructors are uniquely identified by their ID.
  - Each student and instructor has only one name.
  - Each instructor and student is (primarily) associated with only one department.
  - Each department has only one value for its budget, and only one associated building.

Functional Dependencies (Cont.)

- An instance of a relation that satisfies all such real-world constraints is called a **legal instance** of the relation;
- A legal instance of a database is one where all the relation instances are legal instances
- Constraints on the set of legal relations.
- Require that the value for a certain set of attributes determines uniquely the value for another set of attributes.
- A functional dependency is a generalization of the notion of a *key.*

Functional Dependencies Definition

- Let R be a relation schema

$$\alpha \subseteq R \text{ and } \beta \subseteq R$$

- The **functional dependency**

$$\alpha \rightarrow \beta$$

holds on *R* if and only if for any legal relations ***r*(R)**, whenever any two tuples t_1 and t_2 of ***r*** agree on the attributes α, they also agree on the attributes β. That is,

$$t_1[\alpha] = t_2[\alpha] \Rightarrow t_1[\beta] = t_2[\beta]$$

- Example: Consider *r*(A,*B*) with the following instance of *r.*

1	**4**
1	**5**
3	**7**

- On this instance, $B \rightarrow A$ hold; $A \rightarrow B$ does **NOT** hold,

Functional Dependencies (FDs)

- A <u>functional dependency</u> $X \rightarrow Y$ holds over relation R if, for every allowable instance *r* of R:
  - $t1 \in r$, $t2 \in r$, $\pi_X(t1) = \pi_X(t2)$ implies $\pi_Y(t1) = \pi_Y(t2)$
  - i.e., given two tuples in *r*, if the X values agree, then the Y values must also agree. (X and Y are *sets* of attributes.)
- An FD is a statement about *all* allowable relations.
  - Must be identified based on semantics of application.
  - Given some allowable instance *r1* of R, we can check if it violates some FD *f*, but we cannot tell if *f* holds over R!
- K is a candidate key for R means that $K \rightarrow R$
  - However, $K \rightarrow R$ does not require K to be *minimal*!

Closure of a Set of Functional Dependencies

- Given a set *F* set of functional dependencies, there are certain other functional dependencies that are logically implied by *F*.
  - If $A \rightarrow B$ and $B \rightarrow C$, then we can infer that $A \rightarrow$ C
  - etc.
- The set of **all** functional dependencies logically implied by *F* is the **closure** of *F*.
- We denote the *closure* of *F* by F^+.

Keys and Functional Dependencies

- K is a superkey for relation schema R if and only if $K \rightarrow R$
- K is a candidate key for R if and only if
  - $K \rightarrow R$, and
  - for no $\alpha \subset K$, $\alpha \rightarrow R$
- Functional dependencies allow us to express constraints that cannot be expressed using superkeys. Consider the schema:

  in_dep (*ID, name, salary, dept_name, building, budget*).

  We expect these functional dependencies to hold:

  $$dept\_name \rightarrow building$$

  $$ID \rightarrow building$$

  but would not expect the following to hold:

  $$dept\_name \rightarrow salary$$

Use of Functional Dependencies

- We use functional dependencies to:
  - To test relations to see if they are legal under a given set of functional dependencies.
    - If a relation *r* is legal under a set *F* of functional dependencies, we say that *r* **satisfies** *F.*
  - To specify constraints on the set of legal relations
    - We say that *F* **holds on** *R* if all legal relations on *R* satisfy the set of functional dependencies *F.*
- Note: A specific instance of a relation schema may satisfy a functional dependency even if the functional dependency does not hold on all legal instances.
  - For example, a specific instance of *instructor* may, by chance, satisfy $name \rightarrow ID$.

Trivial Functional Dependencies

- *A* functional dependency is **trivial** if it is satisfied by all instances of a relation
- Example*:*
  - *ID, name* $\rightarrow$ *ID*
  - *name* $\rightarrow$ *name*
- In general, $\alpha \rightarrow \beta$ is trivial if $\beta \subseteq \alpha$

Lossless Decomposition

- We can use functional dependencies to show when certain decomposition are lossless.
- For the case of $R = (R_1, R_2)$, we require that for all possible relations r on schema R

$$r = \Pi_{R1}(r) \bowtie \Pi_{R2}(r)$$

- A decomposition of R into R_1 and R_2 is lossless decomposition if at least one of the following dependencies is in F^+:
  - $R_1 \cap R_2 \rightarrow R_1$
  - $R_1 \cap R_2 \rightarrow R_2$
- The above functional dependencies are a sufficient condition for lossless join decomposition; the dependencies are a necessary condition only if all constraints are functional dependencies

Example

- $R = (A, B, C)$
  $F = \{A \rightarrow B, B \rightarrow C)$
- $R_1 = (A, B)$, $R_2 = (B, C)$
  - Lossless decomposition:

    $$R_1 \cap R_2 = \{B\} \text{ and } B \rightarrow BC$$
- $R_1 = (A, B)$, $R_2 = (A, C)$
  - Lossless decomposition:

    $$R_1 \cap R_2 = \{A\} \text{ and } A \rightarrow AB$$
- *Note:*
  - $B \rightarrow BC$

    is a shorthand notation for
  - $B \rightarrow \{B, C\}$

Dependency Preservation

- Testing functional dependency constraints each time the database is updated can be costly
- It is useful to design the database in a way that constraints can be tested efficiently.
- If testing a functional dependency can be done by considering just one relation, then the cost of testing this constraint is low
- When decomposing a relation it is possible that it is no longer possible to do the testing without having to perform a Cartesian Produced.
- A decomposition that makes it computationally hard to enforce functional dependency is said to be NOT **dependency preserving**.

Dependency Preservation Example

- Consider a schema:

  dept_advisor(s_ID, i_ID, department_name)
- With function dependencies:

  $i\_ID \rightarrow dept\_name$

  $s\_ID, dept\_name \rightarrow i\_ID$
- In the above design we are forced to repeat the department name once for each time an instructor participates in a *dept_advisor* relationship.
- To fix this, we need to decompose *dept_advisor*
- Any decomposition will not include all the attributes in

  $s\_ID, dept\_name \rightarrow i\_ID$
- Thus, the composition NOT be dependency preserving