# Database Management Systems

## Module 26: Relational Database Design/6: Normal Forms

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# Week Recap



- Identified the features of good relational design
- Familiarized with the First Normal Form
- Introduced the notion and the theory of functional dependencies
- Discussed issues in "good" design in the context of functional dependencies
- Studied Algorithms for Properties of Functional Dependencies
- Understood the Characterization for and Determination of Lossless Join and Determination of Dependency Preservation

# Module Objectives





- To Understand the Normal Forms and their Importance in Relational Design

# Module Outline





- Normal Forms

# Normal Forms

# Normalization or Schema Refinement



- Normalization or Schema Refinement is a technique of organizing the data in the database
- A systematic approach of decomposing tables to eliminate data redundancy and undesirable characteristics
  - Insertion Anomaly
  - Update Anomaly
  - Deletion Anomaly
- Most common technique for the Schema Refinement is decomposition.
  - Goal of Normalization: Eliminate Redundancy
- Redundancy refers to repetition of same data or duplicate copies of same data stored in different locations
- Normalization is used for mainly two purpose:
  - Eliminating redundant (useless) data
  - Ensuring data dependencies make sense, that is, data is logically stored

# Anomalies



a) **Update Anomaly:** Employee 519 is shown as having different addresses on different records

**Employees' Skills**

| Employee ID | Employee Address | Skill |
|---|---|---|
| 426 | 87 Sycamore Grove | Typing |
| 426 | 87 Sycamore Grove | Shorthand |
| 519 | 94 Chestnut Street | Public Speaking |
| 519 | 96 Walnut Avenue | Carpentry |

**Resolution: Decompose the Schema**

a) *Update*: (ID, Address), (ID, Skill)

b) *Insert*: (ID, Name, Hire Date), (ID, Code)

c) *Delete*: (ID, Name, Hire Date), (ID, Code)

b) **Insertion Anomaly**: Until the new faculty member, Dr. Newsome, is assigned to teach at least one course, his details cannot be recorded

**Faculty and Their Courses**

| Faculty ID | Faculty Name | Faculty Hire Date | Course Code |
|---|---|---|---|
| 389 | Dr. Giddens | 10-Feb-1985 | ENG-206 |
| 407 | Dr. Saperstein | 19-Apr-1999 | CMP-101 |
| 407 | Dr. Saperstein | 19-Apr-1999 | CMP-201 |
| 424 | Dr. Newsome | 29-Mar-2007 | ? |

c) **Deletion Anomaly**: All information about Dr. Giddens is lost if he temporarily ceases to be assigned to any courses.

**Faculty and Their Courses**

| Faculty ID | Faculty Name | Faculty Hire Date | Course Code |
|---|---|---|---|
| 389 | Dr. Giddens | 10-Feb-1985 | ENG-206 |
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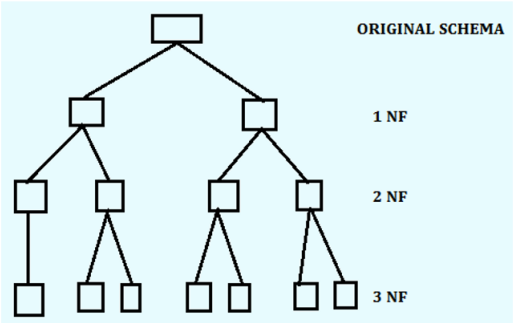
DELETE

# Desirable Properties of Decomposition





- Lossless Join Decomposition Property
  - It should be possible to reconstruct the original table
- Dependency Preserving Property
  - No functional dependency (or other constraints should get violated)



# Normalization and Normal Forms



- A normal form specifies a set of conditions that the relational schema must satisfy in terms of its constraints – they offer varied levels of guarantee for the design
- Normalization rules are divided into various normal forms. Most common normal forms are:
  - First Normal Form (1NF)
  - Second Normal Form (2NF)
  - Third Normal Form (3NF)
- Informally, a relational database relation is often described as "normalized" if it meets third normal form. Most 3NF relations are free of insertion, update, and deletion anomalies

- Additional Normal Forms
  - Elementary Key Normal Form (EKNF)
  - **Boyce-codd Normal Form (BCNF)**
  - **Multivalued Dependencies And Fourth Normal Form (4NF)**
  - Essential Tuple Normal Form (ETNF)
  - Join Dependencies and Fifth Normal Form (5NF)
  - Sixth Normal Form (6NF)
  - Domain/Key Normal Form (DKNF)

# 1NF: First Normal Form



- A relation is in First Normal Form if and only if all underlying domains contain atomic values only (doesn't have multivalued attributes (MVA))
- **STUDENT(Sid, Sname, Cname)**

**Students**

| SID | Sname | Cname |
|---|---|---|
| S1 | A | C,C++ |
| S2 | B | C++, DB |
| S3 | A | DB |

**SID : Primary Key**

MVA exists ⇒ Not in 1NF

**Students**

| SID | Sname | Cname |
|---|---|---|
| S1 | A | C |
| S1 | A | C++ |
| S2 | B | C++ |
| S2 | B | DB |
| S3 | A | DB |

**SID, Cname : Primary Key**

No MVA ⇒ In 1NF

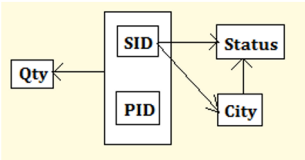
Source: http://www.edugrabs.com/normal-forms/#fnf

- Example: **Supplier(SID, Status, City, PID, Qty)**

**Supplier:**

| SID | Status | City | PID | Qty |
|---|---|---|---|---|
| S1 | 30 | Delhi | P1 | 100 |
| S1 | 30 | Delhi | P2 | 125 |
| S1 | 30 | Delhi | P3 | 200 |
| S1 | 30 | Delhi | P4 | 130 |
| S2 | 10 | Karnal | P1 | 115 |
| S2 | 10 | Karnal | P2 | 250 |
| S3 | 40 | Rohtak | P1 | 245 |
| S4 | 30 | Delhi | P4 | 300 |
| S4 | 30 | Delhi | P5 | 315 |

**Key : (SID, PID)**




**Drawbacks:**

- Deletion Anomaly: If we delete <S3,40,Rohtak,P1,245>, then we lose the information that S3 lives in Rohtak.
- Insertion Anomaly: We cannot insert a Supplier S5 located in Karnal, until S5 supplies at least one part.
- Update Anomaly: If Supplier S1 moves from Delhi to Kanpur, then it is difficult to update all the tuples having SID as S1 and City as Delhi.

Normalization is a method to reduce redundancy. However, sometimes 1NF increases redundancy.

# 1NF (3): Possible Redundancy



- **When LHS is not a Superkey** :
  - Let $X \rightarrow Y$ be a non trivial FD over R with $X$ is not a superkey of $R$, then redundancy exist between $X$ and $Y$ attribute set.
  - Hence in order to identify the redundancy, we need not to look at the actual data, it can be identified by given functional dependency.
  - Example : $X \rightarrow Y$ and X is not a Candidate Key
    $\Rightarrow X$ can duplicate
    $\Rightarrow$ Corresponding $Y$ value would duplicate also.

| X | Y |
|---|---|
| 1 | 3 |
| 1 | 3 |
| 2 | 3 |
| 2 | 3 |
| 4 | 6 |

- **When LHS is a Superkey** :
  - If $X \rightarrow Y$ is a non trivial FD over $R$ with $X$ is a superkey of $R$, then redundancy does not exist between $X$ and $Y$ attribute set.
  - Example : $X \rightarrow Y$ and $X$ is a Candidate Key
    $\Rightarrow X$ cannot duplicate
    $\Rightarrow$ Corresponding $Y$ value may or may not duplicate.

| X | Y |
|---|---|
| 1 | 4 |
| 2 | 6 |
| 3 | 4 |

# 2NF: Second Normal Form



- Relation $\boldsymbol{R}$ is in Second Normal Form (2NF) only iff :
  - $\boldsymbol{R}$ is in 1NF and
  - $\boldsymbol{R}$ contains no Partial Dependency

**Partial Dependency:**

Let $\boldsymbol{R}$ be a relational Schema and $\boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{A}$ be the attribute sets over $\boldsymbol{R}$ where $\boldsymbol{X}$ : Any Candidate Key, $\boldsymbol{Y}$ : Proper Subset of Candidate Key, and $\boldsymbol{A}$ : Non Prime Attribute

If $Y \rightarrow A$ exists in $R$, then $R$ is not in 2NF.

($\boldsymbol{Y} \rightarrow \boldsymbol{A}$) is a Partial dependency only if

- $\boldsymbol{Y}$: Proper subset of Candidate Key
- $\boldsymbol{A}$: Non Prime Attribute

*A* **prime attribute** *of a relation is an attribute that is a part of a candidate key of the relation*

# 2NF (2)

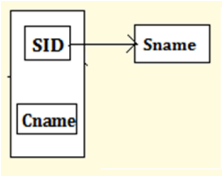


- **STUDENT(Sid, Sname, Cname)** (already in 1NF)

Students:

| SID | Sname | Cname |
|---|---|---|
| S1 | A | C |
| S1 | A | C++ |
| S2 | B | C++ |
| S2 | B | DB |
| S3 | A | DB |

**(SID, Cname)**: Primary Key




**Functional Dependencies:**
$\{SID, Cname\} \rightarrow Sname$
$SID \rightarrow Sname$

**Partial Dependencies:**
$SID \rightarrow Sname$ (as $SID$ is a Proper Subset of Candidate Key $\{SID, Cname\}$)

- Redundancy?
  - Sname
- Anomaly?
  - Yes

**Key Normalization**

R1:

| SID | Sname |
|---|---|
| S1 | A |
| S2 | B |
| S3 | A |

**{SID}**: Primary Key

R2:

| SID | Cname |
|---|---|
| S1 | C |
| S1 | C++ |
| S2 | C++ |
| S2 | DB |
| S3 | DB |

**{SID,Cname}**: Primary Key

The above two relations R1 and R2 are
1.Lossless Join
2.2NF
3.Dependency Preserving

Source: http://www.edugrabs.com/2nf-second-normal-form/

# 2NF (3): Possible Redundancy

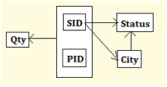
- **Supplier(SID, Status, City, PID, Qty)**

**Supplier:**

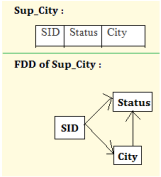
| SID | Status | City | PID | Qty |
|---|---|---|---|---|
| S1 | 30 | Delhi | P1 | 100 |
| S1 | 30 | Delhi | P2 | 125 |
| S1 | 30 | Delhi | P3 | 200 |
| S1 | 30 | Delhi | P4 | 130 |
| S2 | 10 | Karnal | P1 | 115 |
| S2 | 10 | Karnal | P2 | 250 |
| S3 | 40 | Rohtak | P1 | 245 |
| S4 | 30 | Delhi | P4 | 300 |
| S4 | 30 | Delhi | P5 | 315 |

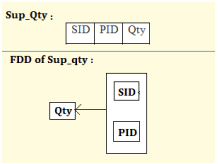
**Key : (SID, PID)**

**Partial Dependencies**:
$SID \rightarrow Status$
$SID \rightarrow City$




**Post Normalization**




**Drawbacks:**

- **Deletion Anomaly**: If we delete a tuple in *Sup_City*, then we not only loose the information about a supplier, but also loose the status value of a particular city.
- **Insertion Anomaly**: We cannot insert a City and its status until a supplier supplies at least one part.
- **Update Anomaly**: If the status value for a city is changed, then we will face the problem of searching every tuple for that city.

Source: http://www.edugrabs.com/2nf-second-normal-form/

# 3NF: Third Normal Form





Let $\boldsymbol{R}$ be the relational schema.

- [E. F. Codd,1971] $\boldsymbol{R}$ is in 3NF only if:
  - $\boldsymbol{R}$ should be in 2NF
  - $\boldsymbol{R}$ should not contain transitive dependencies (OR, Every non-prime attribute of $R$ is non-transitively dependent on every key of $R$)
- [Carlo Zaniolo, 1982] Alternately, $\boldsymbol{R}$ is in 3NF iff for each of its functional dependencies $X \rightarrow A$, at least one of the following conditions holds:
  - $X$ contains $A$ (that is, $A$ is a subset of $X$, meaning $X \rightarrow A$ is trivial functional dependency), or
  - $X$ is a superkey, or
  - Every element of $A - X$, the set difference between $A$ and $X$, is a *prime attribute* (i.e., each attribute in $A - X$ is contained in some candidate key)
- [Simple Statement] A relational schema $\boldsymbol{R}$ is in 3NF if for every FD $\boldsymbol{X \rightarrow A}$ associated with $R$ either
  - $\boldsymbol{A \subseteq X}$ (that is, the FD is trivial) or
  - $\boldsymbol{X}$ is a superkey of $\boldsymbol{R}$ or
  - $\boldsymbol{A}$ is part of some candidate key (not just superkey!)
- **A relation in 3NF is naturally in 2NF**

# 3NF (2): Transitive Dependency



- A **transitive dependency** is a functional dependency which holds by virtue of transitivity. A transitive dependency can occur only in a relation that has three or more attributes.
- Let $A, B$, and $C$ designate three distinct attributes (or distinct collections of attributes) in the relation. Suppose all three of the following conditions hold:
  - $A \rightarrow B$
  - It is not the case that $B \rightarrow A$
  - $B \rightarrow C$
- Then the functional dependency $A \rightarrow C$ (which follows from 1 and 3 by the axiom of transitivity) is a transitive dependency

# 3NF (3): Transitive Dependency



- Example of **transitive dependency**
- The functional dependency $\{Book\} \rightarrow \{Author\ Nationality\}$ applies; that is, if we know the book, we know the author's nationality. Furthermore:
  - $\{Book\} \rightarrow \{Author\}$
  - $\{Author\}$ does not $\rightarrow \{Book\}$
  - $\{Author\} \rightarrow \{Author\ Nationality\}$
- Therefore $\{Book\} \rightarrow \{Author\ Nationality\}$ is a transitive dependency.
- Transitive dependency occurred because a non-key attribute (Author) was determining another non-key attribute (Author Nationality).

| Book | Genre | Author | Author Nationality |
|---|---|---|---|
| Twenty Thousand Leagues Under the Sea | Science Fiction | Jules Verne | French |
| Journey to the Center of the Earth | Science Fiction | Jules Verne | French |
| Leaves of Grass | Poetry | Walt Whitman | American |
| Anna Karenina | Literary Fiction | Leo Tolstoy | Russian |
| A Confession | Religious Autobiography | Leo Tolstoy | Russian |

# 3NF (4): Example

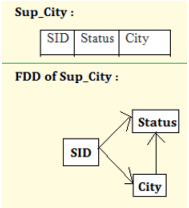


- Example:
  **Sup_City(SID, Status, City) (already in 2NF)**

**Sup_City:**

| SID | Status | City |
|---|---|---|
| S1 | 30 | Delhi |
| S2 | 10 | Karnal |
| S3 | 40 | Rohtak |
| S4 | 30 | Delhi |

**SID**: Primary Key




- Redundancy?
  - Status
- Anomaly?
  - Yes

**Functional Dependencies:**
SID → Status,
SID → City,
City→ Status
**Transitive Dependency :**
SID → Status
{As SID → City and City → Status}

**Post Normalization**

**SC:**

| SID | City |
|---|---|
| S1 | Delhi |
| S2 | Karnal |
| S3 | Rohtak |
| S4 | Delhi |

**SID**: Primary Key

**CS:**

| City | Status |
|---|---|
| Delhi | 30 |
| Karnal | 10 |
| Rohtak | 40 |

**City**: Primary Key

The above two relations SC and CS are

- Lossless Join
- 3NF
- Dependency Preserving

# 3NF (5): Example

- Relation ***dept_advisor***(***s_ID***, ***i_ID***, ***dept_name***)
- $F = \{$***s_ID***, ***dept_name*** $\rightarrow$ ***i_ID***, ***i_ID*** $\rightarrow$ ***dept_name***$\}$
- Two candidate keys: ***s_ID***, ***dept_name***, and ***i_ID***, ***s_ID***
- $R$ is in 3NF
  - ***s_ID***, ***dept_name*** $\rightarrow$ ***i_ID***
    - ***s_ID***, ***dept_name*** is a superkey
  - ***i_ID*** $\rightarrow$ ***dept_name***
    - ***dept_name*** is contained in a candidate key

A relational schema ***R*** is in 3NF if for every FD ***X*** $\rightarrow$ ***A*** associated with ***R*** either

- ***A*** $\subseteq$ ***X*** (i.e., the FD is trivial) or
- ***X*** is a superkey of ***R*** or
- ***A*** is part of some key (not just superkey!)

# 3NF (6): Redundancy



- **There is some redundancy in this schema**
- Example of problems due to redundancy in 3NF ($J : s\_ID, L : i\_ID, K : dept\_name$)
  - $R = (J, L, K)$. $F = \{JK \rightarrow L, L \rightarrow K\}$

| $J$ | $L$ | $K$ |
|---|---|---|
| $j_1$ | $l_1$ | $k_1$ |
| $j_2$ | $l_1$ | $k_1$ |
| $j_3$ | $l_1$ | $k_1$ |
| *null* | $l_2$ | $k_2$ |

- Repetition of information (for example, the relationship $l_1, k_1$)
  - ($i\_ID$, $dept\_name$)
- Need to use null values (for example, to represent the relationship $l_2, k_2$ where there is no corresponding value for $J$).
  - ($i\_ID$, $dept\_name$) if there is no separate relation mapping instructors to departments

# Module Summary



- Studied the Normal Forms and their Importance in Relational Design – how progressive increase of constraints can minimize redundancy in a schema

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