Week 6 Lecture 1

Class	BSCCS2001
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Materials	
Module #	26
Type	Lecture
Week #	6

Relational Database Design (part 6)

Normal Forms

Normalization or Schema Refinement

- Normalization or Schema Refinement is a technique of organizing the data in the DB
- 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 the repetition of same data or duplicate copies of the same data stored in different locations
- Normalization is used for mainly 2 purposes:
    - Eliminating redundant (useless) data
    - Ensuring the data dependencies make sense, that is, data is logically stored

Anomalies

- **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)

- **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	?

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

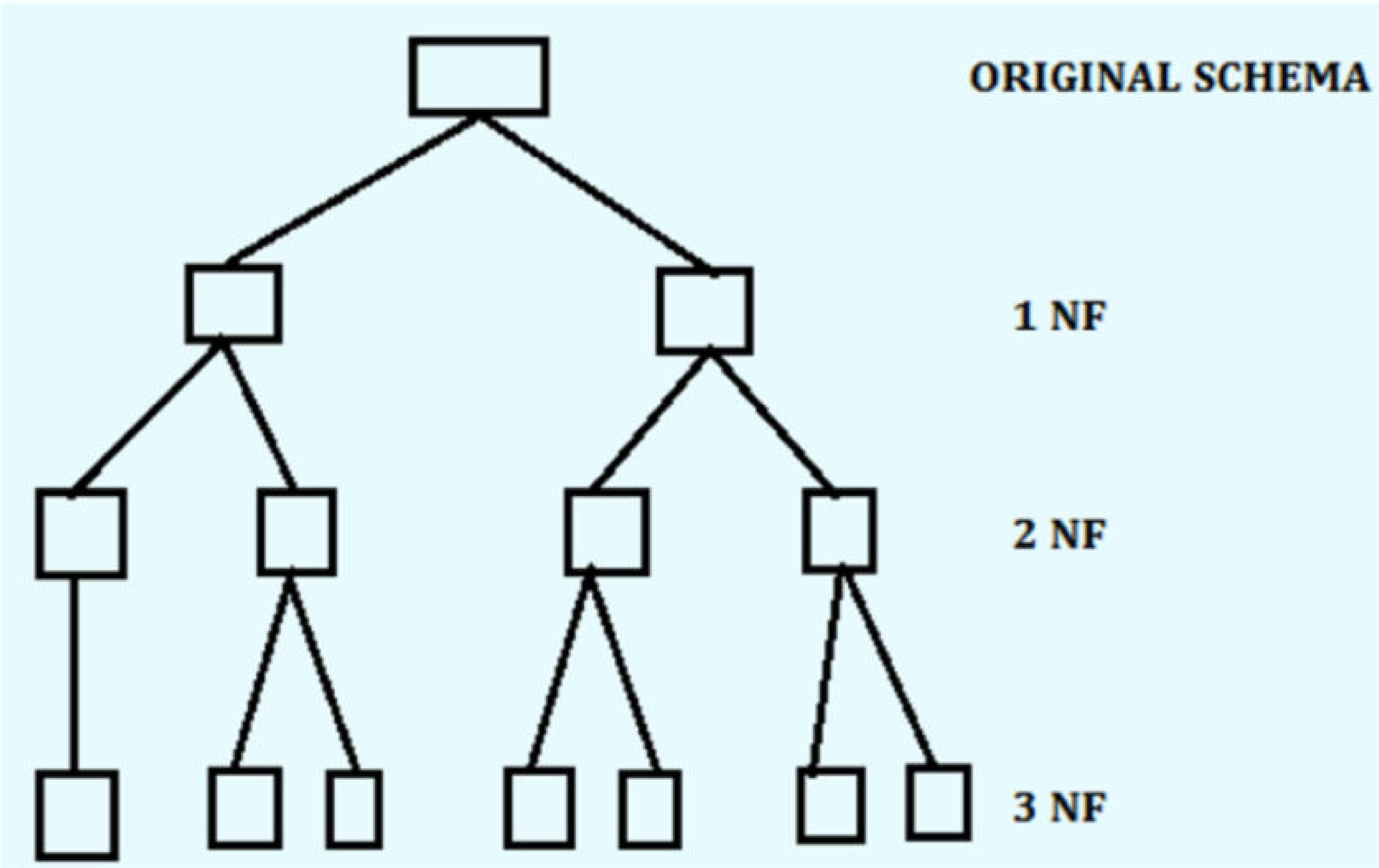
Faculty and Their Courses

Faculty ID	Faculty Name	Faculty Hire Date	Course Code
389	Dr. Giddens	10-Feb-1985	ENG-206
407	Dr. Saperstein	19-Apr-1999	CMP-101
407	Dr. Saperstein	19-Apr-1999	CMP-201

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 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 DB relation is often described as "normalized" if it meets the 3NF (Third Normal Form)
- Most 3NF are free from insertion, update and deletion anomalies

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- Additional Normal Forms:
  - Elementary Key Normal Form (EKNF)
  - Boyce-codd Normal Form (BCNF)
  - Multi-valued 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 multi-valued 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		

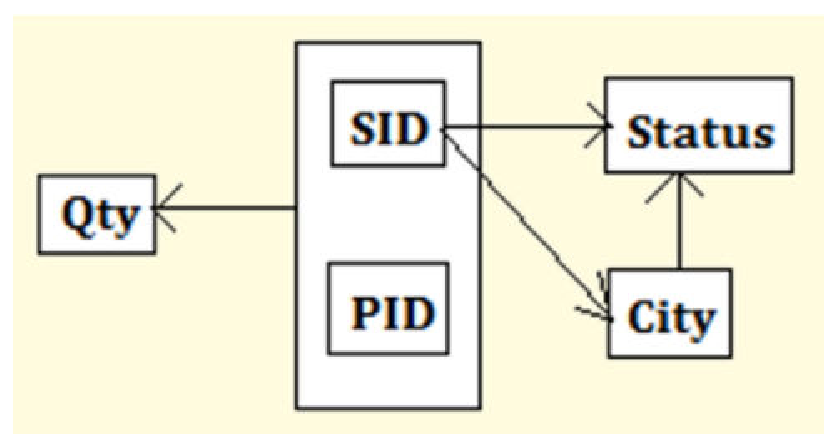
No MVA ⇒ In 1NF

1NF: Possible Redundancy

- **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



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: 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
    - X can duplicate
- **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
    - X cannot duplicate
    - Corresponding Y value may or may not duplicate

- Corresponding Y value would duplicate also

X	Y
1	3
1	3
2	3
2	3
4	6

X	Y
1	4
2	6
3	4

2NF: Second Normal Form

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

Partial Dependency:

Let R be a relational schema and X, Y, A be the attribute sets over R where X: Any Candidate Key, Y: Proper subset of Candidate Key and A: Non-prime attribute

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

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

- Y: Proper subset of Candidate Key
- A: Non-Prime Attribute

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

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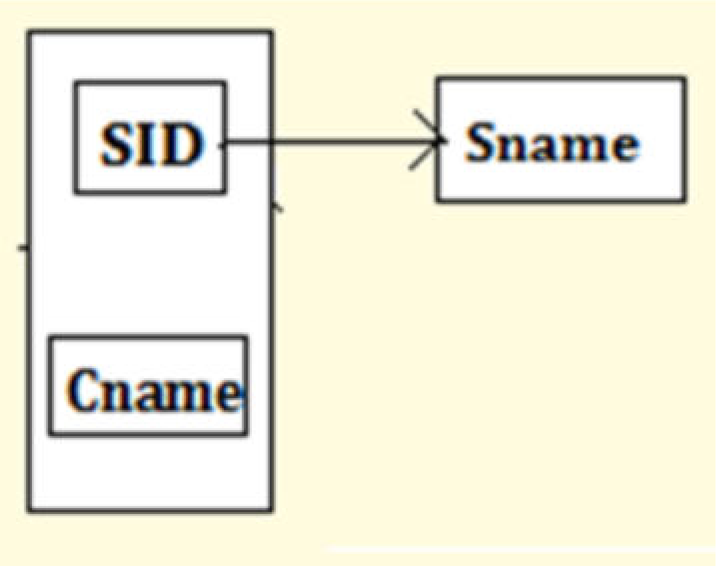
- STUDENT (Sid, Sname, Cname) (already in 1NF)

  Students

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



- Redundancy?
  - Sname
- Anomaly?
  - Yes
- ~~Hotel?~~
  - ~~*Trivago*~~

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}*)

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

2NF: Possible Redundancy

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

  Supplier

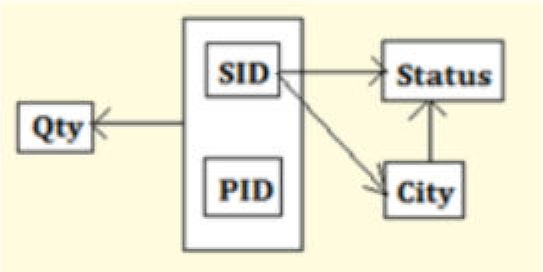
SID	Status	City	PID	Qty
S1	30	Delhi	P1	100
S1	30	Delhi	P2	125
S1	30	Delhi	P3	200
S1	30	Delhi	P4	130
S2	10	Karnal	P1	115
S2	10	Karnal	P2	250
S3	40	Rohtak	P1	245
S4	30	Delhi	P4	300
S4	30	Delhi	P5	315

  Key: (SID, PID)

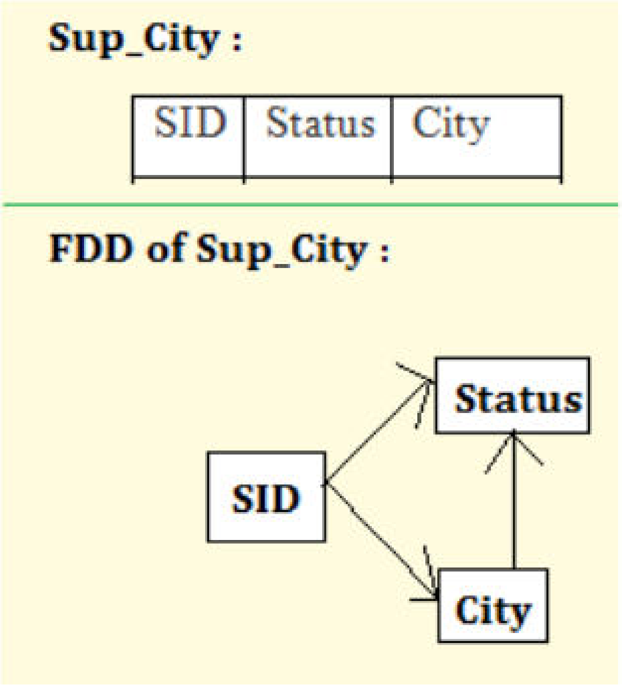
  Partial Dependencies:

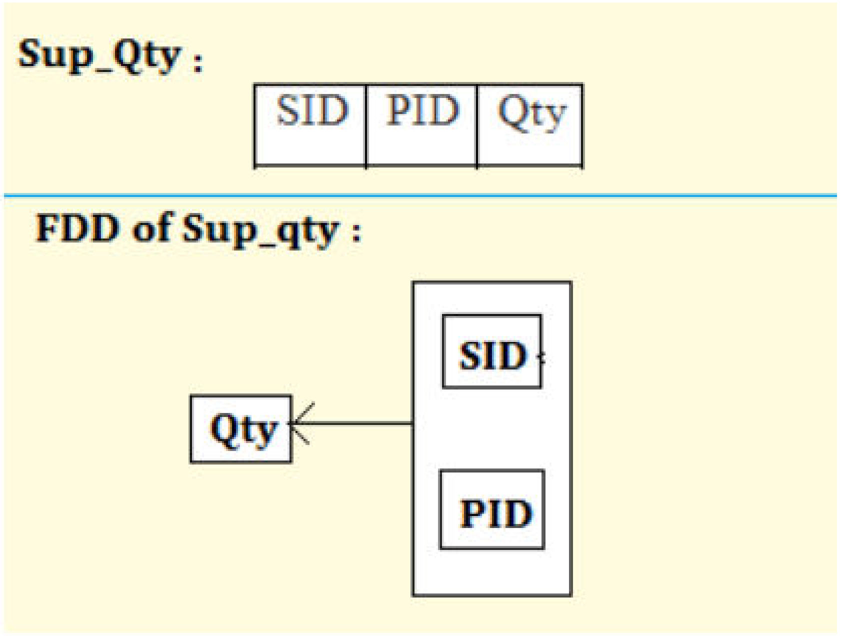
  SID $\rightarrow$ *Status*

  SID $\rightarrow$ *City*



Post Normalization





Drawbacks:

- **Deletion Anomaly:** If we delete a tuple in *Sup_City*, then we not only lose the information about a supplier, but also lose 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 unchanged, then we will face the problem of searching every tuple for that city

3NF: Third Normal Form

Let R be the relational schema

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

3NF: 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 3 or more attributes
- Let A, B and C designate 3 distinct attributes (or distinct collections of attributes) in the relation
- Suppose all 3 of the following conditions hold:
  - A → B
  - It is not the case that B → A
  - B → C
- Then the functional dependency A → C (which follows from1 and 3 by the axiom of transitivity) is a transitive dependency

- Example of transitive dependency
- The functional dependency {Book} → {Author Nationality} applies; that is, if we know the book, we know the author's nationality
- Furthermore:
  - {Book} → {Author}
  - {Author} does not → {Book}
  - {Author} → {Author Nationality}
- Therefore, {Book} → {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

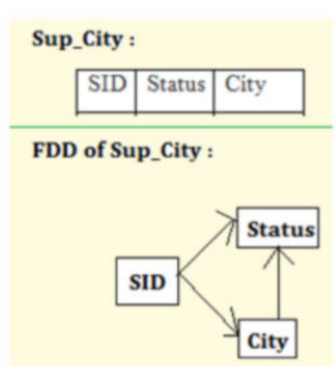
3NF: Example

- 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: Example #2

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

A relational schema R is in 3NF if for every FD X → A associated with R either

- $A \subseteq X$ (ie. the FD is trivial) or

- X is a superkey of R or
- A is part of some key (not just superkey)

3NF: 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 → L, L → 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

Week 6 Lecture 2

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Materials	
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Relational Database Design (part 7)

3NF Decomposition: Motivation

- There are some situations where
    - BCNF is not dependency preserving, and
    - Efficient checking for FD violation on updates is important
- **Solution:** Define a weaker normal form, call Third Normal Form (3NF)
    - Allows some redundancy (with resultant problems, as seen above)
    - But functional dependencies can be checked on individual relations without computing a join
    - There is always lossless-join, dependency-preserving decomposition into 3NF

3NF Decomposition: 3NF Definition

- A relational schema ***R*** is in 3NF if for every FD ***X*** → ***A*** associated with R either
    - $A \subseteq X$ (that is, the FD is trivial) or
    - X is a superkey of R or
    - A is part of some candidate key (not just superkey)
- A relation is 3NF is naturally in 2NF

3NF Decomposition: Testing for 3NF

- **Optimization:** Need to check only FDs in F, need not check all FDs in F^+
- Use attribute closure to check for each dependency $\alpha \rightarrow \beta$, if α is the superkey

- If α is not a superkey, we have to verify if each attribute in β is contained in a candidate key of R
  - This test is rather more expensive, since it involve finding candidate keys
  - Testing for 3NF has been shown to be NP-hard
  - Decomposition into 3NF can be done in polynomial time

3NF Decomposition: Algorithm

- **Given:** relation R, set F of functional dependencies
- **Find:** decomposition of R into a set of 3NF relation R_i
- **Algorithm:**
  - Eliminate redundant FDs, resulting in a canonical cover F_c of F
  - Create a relation $R_i = XY$ for each FD X → Y in F_c
  - If the key K of R does not occur in any relation R_i, create one more relation $R_i = K$

Let F_c be a canonical cover for F;

i := 0

for each functional dependency $\alpha \rightarrow \beta$ in F_c do

  if none of the schemas R_j, $1 \leq j \leq i$ contains $\alpha\beta$

    then begin

      i := i + 1

      R_i := $\alpha\beta$

    end

if none of the schemas R_j, $1 \leq j \leq i$ contains a candidate key for R

  then begin

    i := i + 1

    R_i := any candidate key for R;

  end

/* Optionally, remove redundant relations */

repeat

if any schema R_j is contained in another schema R_k

  then /* delete R_j */

    $R_j = R$;

    i = i - 1

return $(R_1, R_2, ..., R_i)$

3NF Decomposition: Algorithm

- Upon decomposition:
  - Each relation schema R_i is in 3NF
  - Decomposition is ...
    - Dependency Preserving
    - Lossless Join
- Prove these properties

3NF Decomposition: Example

- Relation schema:

  cust_banker_branch = *(<u>customer_id</u>, <u>employee_id</u>, branch_name, type)*
- The functional dependencies for this relation schema are:
  - *customer_id, employee_id → branch_name, type*

    - *employee_id → branch_name*
    - *customer_id, branch_name → employee_id*
- We first compute a canonical cover
    - *branch_name* is irrelevant in the RHS of the 1^{st} dependency
    - No other attribute is irrelevant, so we get $F_c =$

      customer_id, employee_id → type

      employee_id → branch_name

      customer_id, branch_name → employee_id

- The **for** loop generates the following 3NF schema:

  (customer_id, employee_id, type)

  (employee_id, branch_name)

  (customer_id, branch_name, employee_id)

    - Observing that *(customer_id, employee_id, type)* contains a candidate key of the original schema, so no further relation schema needs be added
- At the end of for loop, detect and delete schemas, such as *(employee_name, branch_name)*, which are subsets of other schemas
    - Result will not depend on the order in which FDs are considered
- The resultant simplified 3NF schema is:

  (customer_id, employee_id, type)

  (customer_id, branch_name, employee_id)

BCNF Decomposition: BCNF Definition

- A relation schema R is in BCNF with respect to a set of F of FDs if for all FDs in F^+ of the form

  $\alpha \rightarrow \beta$, where $\alpha \subseteq R$ and $\beta \subseteq R$ at least one of the following holds:

    - $\alpha \rightarrow \beta$ is trivial (that is, $\beta \subseteq \alpha$)
    - α is a superkey for R

BCNF Decomposition: Testing for BCNF

- To check if a non-trivial dependency $\alpha \rightarrow \beta$ causes a violation of BCNF
    - Compute α^+ (the attribute closure of α), and
    - Verify that it includes all attributes of R, that is, it is a superkey of R
- **Simplified test:** To check if a relation schema R is in BCNF, it suffices to check only the dependencies in the given set F for violation of BCNF, rather than checking all dependencies in F^+
    - If none of the dependencies in F cause a violation in BCNF, then none of the dependencies in F^+ will cause a violation of BCNF either
- However, simplified test using only F is incorrect when testing a relation in a decomposition of R
    - Consider R = (A, B, C, D, E) with F = {A → B, BC → D}
        - Decompose R into R_1 = (A, B) and R_2 = (A, C, D, E)
        - Neither of the dependencies in F contain only attributes from (A, C, D, E) so we might be mislead into thinking R_2 satisfies BCNF
        - In fact, dependency AC → D in F^+ shows R_2 is not in BCNF

BCNF Decomposition: Testing for BCNF Decomposition

- To check if a relation R_i in a decomposition of R is in BCNF
    - Either test R_i for BCNF w.r.t. the restriction of F to R_i (that is, all FDs in F^+ that contain only attributes from R_i)
    - Or use the original set of dependencies F that hold on R, but with the following test:

- For every set of attributes $\alpha \subseteq R_i$, check that α^+ (the attribute closure of α) either includes no attribute of R_i — α or includes all attributes of R_i
- If the condition is violated by some $\alpha \to \beta$ in F, the dependency $\alpha \to (\alpha - \alpha^+) \cap R_i$ can be shown to hold R_i and R_i violates BCNF
- We use above dependency to decompose R_i

BCNF Decomposition: Testing Dependency Preservation: Using Closure Set of FD (Exp. Algo.):

Consider the example given below, we will apply both the algorithms to check preservation and will discuss the results

- **R** (*A, B, C, D*)

  F = {A → B, B → C, C → D, D → A}
- Decomposition: **R1**(A, B) **R2**(B, C) **R3**(C, D)
  - A → B is preserved on table R1
  - B → C is preserved on table R2
  - C → D is preserved on table R3
  - We have to check whether the one remaining FD: D → A is preserved or not

R1	R2	R3
$F_1 = \{\mathbf{A} \to AB, \mathbf{B} \to BA\}$	$F_2 = \{\mathbf{B} \to BC, \mathbf{C} \to CB\}$	$F_3 = \{\mathbf{C} \to CD, \mathbf{D} \to DC\}$

- $F' = F_1 \cup F_2 \cup F_3$
- Checking for: D → A in F'^+
  - D → C (from R3), C → B (from R2), B → A (from R1) : D → A (by transitivity)

    Hence, all the dependencies are preserved

BCNF Decomposition: Testing Dependency Preservation: Using Closure of Attributes (Poly. Algo.)

- R(ABCD) :. F = {A → B, B → C,C → D, D → A}
- *Decomp* = {*AB, BC, CD*}
- On projections:

R1	R2	R3
F1 A → B	F2 B → C	F3 C → D

  In this algo F1, F2, F3 are not the closure sets, rather the sets of dependencies directly applicable on R1, R2, R3 respectively
- Need to check for: A → B, B → C, C → D, **D** → **A**
- (D) + /F1 = D. (D) + /F2 = D. (D) + /F3 = D. So, **D** → **A** could not be preserved
- In the previous method we saw the dependency was preserved
- In reality also it is preserved
- Therefore, the polynomial time algorithm may not work in case of all examples
- To prove preservation, Algo 2 is sufficient but not necessary whereas Algo 1 is both sufficient as well as necessary

  NOTE: This difference in result can occur in any example where a functional dependency of one decomposed table uses another functional dependency in its closure which is not applicable on any of the decomposed table because of the absence of all attributes in the table

BCNF Decomposition: Algorithm

- For all dependencies A → B in F^+, check if A is a superkey
  - By using attribute closure
- If not, then ...
  - Choose a dependency in F^+ that breaks the BCNF rules, say A → B
  - Create R1 = AB
  - Create R2 = (R — (B — A))
  - **NOTE:** $R1 \cap R2 = A$ and A → AB (=R1), so this is lossless decomposition
- Repeat for R1 and R2
  - By defining $F1^+$ to be all the dependencies in F that contain only attributes in R1
  - Similarly $F2^+$

result := {R};

done := false;

compute F^+;

while (**not** done) **do**

  if (there is schema R_i in result that is not in BCNF)

    then begin

      let $\alpha \rightarrow \beta$ be a nontrivial functional dependency that

        holds on R_i such that $\alpha \rightarrow \beta$ is not in F^+

          and $\alpha \cap \beta = \phi$;

        result := (result — R_i) $\cup$ $(R_i - \beta) \cup (\alpha, \beta)$;

      end

  else done := true;

NOTE: each R_i is in BCNF and decomposition is lossless-join

BCNF Decomposition: Example

- R = (A, B, C)

  F = {A→ B

  B → C}

  Key = {A}
- R is not in BCNF (B → C but B is not superkey)
- Decomposition
  - $R_1 = (B, C)$
  - $R_2 = (A, B)$

BCNF Decomposition: Example #2

- *class* (*course_id, title, dept_name, credits, sec_id, semester, year, building, room_number, capacity, time_slot_id*)
- Functional dependencies:
  - *course_id* → *title, dept_name, credits*
  - *building, room_number* → *capacity*
  - *course_id, sec_id, semester, year* → *building, room_number, time_slot_id*
- A candidate key *course_id, sec_id, semester, year*
- BCNF Decomposition:
  - *course_id* → *title, dept_name, credits* holds
    - but *course_id* is not a superkey

- We replace *class* by:
    - *course* (*course_id, title, dept_name, credits*)
    - *class-1* (*course_id, sec_id, semester, year, building, room_number, capacity, time_slot_id*)
- *course* is in BCNF
  - How do we know this?
- *building, room_number* → *capacity* holds on

  class-1 (*course_id, sec_id, semester, year, building, room_number, capacity, time_slot_id*)
  - But {*building, room_number*} is not a superkey for *class-1*
  - We replace *class-1* by:
    - *classroom* (*building, room_number, capacity*)
    - *section* (*course_id, sec_id, semester, year, building, room_number, time_slot_id*)
- *classroom* and *section* are in BCNF

BCNF Decomposition: Dependency Preservation

- It is not always possible to get a BCNF Decomposition that is dependency preserving
- R = (J, K, L)

  F = {JK → L

  L → K}

  Two candidate keys = JK and JL
- R is not in BCNF
- Any decomposition of R will fail to preserve

  JK → L

  This implies that testing for JK → L requires a join

Comparison of BCNF and 3NF

- It is always possible to decompose a relation into a set of relations that are in 3NF such that:
  - the decomposition is lossless
  - the dependencies are preserved
- It is always possible to decompose a relation into a set of relations that are in BCNF such that:
  - the decomposition is lossless
  - it may not be possible to preserve dependencies

S#	3NF	BCNF
1.	It concentrates on Primary Key	It concentrates on Candidate Key
2.	Redundancy is high as compared to BCNF	0% redundancy
3.	It preserves all the dependencies	It may not preserve the dependencies
4.	A dependency $X \rightarrow Y$ is allowed in 3NF if X is a super key or Y is a part of some key	A dependency $X \rightarrow Y$ is allowed if X is a super key

Week 6 Lecture 3

Class	BSCCS2001
Created	@October 13, 2021 11:36 AM
Materials	
Module #	28
Type	Lecture
Week #	6

Relational Database Design (part 8)

Case Study

Library Information System (LIS)

We are asked to design a relational DB schema for a Library Information System (LIS) of an Institute

- The specification document of the LIS has already been shared with you
- We include key points from the Specs
- We carry out the following tasks in the module:
    - Identify the Entity sets with attributes
    - Identify the relationships
    - Build the initial set of relational schema
    - Refine the set of schema with FDs that hold on them
    - Finalize the design of the schema
- The coding of various queries in SQL, based on these schema are left as exercise

LIS Specs Excerpts

- An institute library has 200,000+ books and 1,000+ members
- Books are regularly issued by members on loan and returned after a period
- The library needs an LIs to manage the books, the members and the issue-term process

- Every book has
  - title
  - author (in case of multiple authors, only the first author is mentioned)
  - publisher
  - year of publication
  - ISBN number (which is unique for the publication)
  - accession number (which is the unique number of the copy of the book in the library)

  There may be multiple copies of the same book in the library

---

There are 4 categories of members of the library:

- Undergraduate students
- Post-graduate students
- Research scholars
- Faculty members

Every student has ...

- Name
- Roll number
- Department
- Gender
- Mobile number
- Date of Birth
- Degree
  - Undergrad
  - Grad
  - Doctoral

Every faculty has ...

- Name
- Employee ID
- Department
- Gender
- Mobile number
- Date of Joining

Library also issues a unique membership number to every member

Every member has a max quota for the number of books he/she can issue for the maximum duration allowed to her/him

Currently, these are set as:

- Each undergraduate student can issue up to 2 books for 1 month duration
- Each postgraduate student can issue up to 4 books for 1 month duration
- Each research scholar can issue up to 6 books for 3 months duration
- Each faculty member can issue up to 10 books for 6 months duration

---

The library has the following rules for issue:

- A book may be issued to a member if it is not already issued to someone else (trivial)
- A book may not be issued to a member if another copy of the same book is already issued to the same member

- No issue will be done to a member if at the time of issue one or more of the books issued by the member has already exceeded its duration of issue
- No issue will be allowed also if the quota is exceeded for the member
- It is assumed that the name of every author or member has two parts
    - First name
    - Last name

LIS Specs Excerpts: Queries

LIS should support the following operations / queries:

- Add / Remove members, categories of members, books
- Add / Remove / Edit quota for a category of member, duration for a category of member
- Check if the library has a book given its title (part of title should match)
    - If yes, title, author, publisher, year and ISBN should be listed
- Check if the library has a book given its author
    - If yes, title, author, publisher, year and ISBN should be listed
- Check if a copy of a book (given its ISBN) is available with the library for issue
    - All accession numbers should be listed with issued or available information
- Check the available (free) quota of a member
- Issue a book to a member
    - This should check for the rules of the library
- Return a book from a member
- and so on ...

LIS Entity Sets: books

- Every book has title, author (in case of multiple authors, only the first author is maintained), published, year of publication, ISBN number (which is unique for the publication) and accession number (which is the unique number of the copy of the book in the library)
    - There may be multiple copies of the same book in the library
- Entity set:
    - **books**
- Attributes:
    - title
    - author_name (composite);
    - publisher
    - year
    - ISBN_no
    - accession_no

LIS Entity Sets: students

- Every student has name, roll number, department, gender, mobile number, date of birth and degree (undergrad, grad, doctoral)
- Entity Set:
    - **students**
- Attributes
    - member_no - is unique
    - name (composite)

- roll_no - is unique
- department
- gender
- mobile_no - may be null
- dob
- degree

LIS Entity Sets: faculty

- Every faculty has name, employee id, department, gender, mobile number and date of joining
- Entity Set:
  - **faculty**
- Attributes:
  - member_no - is unique
  - name (composite)
  - id - is unique
  - department
  - gender
  - mobile_no - may be null
  - doj

LIS Entity Sets: members

- Library also issues a unique membership number to every member
- There are 4 categories of members of the library:
  - undergraduate students
  - post graduate students
  - research scholars
  - faculty members
- Entity Set:
  - **members**
- Attributes:
  - member_no
  - member_type (takes a value in ug, pg, rs or fc)

LIS Entity Sets: quota

- Every member has a max quota for the number of books she / he can issue for the max duration allowed to her / him
- Currently, these are set as:
  - Each undergraduate student can issue up to 2 books for 1 month duration
  - Each postgraduate student can issue up to 4 books for 1 month duration
  - Each research scholar can issue up to 6 books for 3 months duration
  - Each faculty member can issue up to 10 books for 6 months duration
- Entity Set:
  - **quota**
- Attributes:
  - member_type
  - max_books

- max_duration

LIS Entity Sets: staff

- Thought not explicitly stated, library would have staffs to manage the LIS
- Entity Set:
  - **staff**
- Attributes: (speculated — to ratify from customer)
  - name (composite)
  - id - is unique
  - gender
  - mobile_no
  - doj

LIS Relationships

- Books are regularly issued by members on loan and returned after a period
- The library needs an LIS to manage the books, the members and the issue-return process
- Relationship
  - **book_issue**
- Involved Entity Sets
  - **students / faculty / members**
    - member_no
  - **books**
    - accession_no
- Relationship Attribute
  - doi — date of issue
- Type of relationship
  - Many-to-one from **books**

LIS Relational Schema

- **books** (title, author_fname, author_lname, publisher, year, ISBN_no, accession_no)
- **book_issue** (members, accession_no, doi)
- **members** (member_no, member_type)
- **quota** (member_type, max_books, max_duration)
- **students** (member_no, student_fname, student_lname, roll_no, department, gender, mobile_no, dob, degree)
- **faculty** (member_no, faculty_fname, faculty_lname, id, department, gender, mobile_no, doj)
- **staff** (staff_fname, staff_lname, id, gender, mobile_no, doj)

LIS Schema Refinement: books

- **books** (title, author_fname, author_lname, publisher, year, ISBN_no, accession_no)
  - ISBN_no → title, author_fname, author_lname, publisher, year
  - accession_no → ISBN_no
  - Key: accession_no
- Redundancy of book information across copies
- Good to normalize:
  - **book_catalogue** (title, author_fname, author_lname, publisher, year, ISBN_no)

        - ISBN_no → title, author_fname, author_lname, publisher, year
        - Key: ISBN_no
    - **book_copies** (ISBN_no, accession_no)
        - accession_no → ISBN_no
        - Key: accession_no
- Both in BCNF
- Decomposition is lossless join and dependency preserving

LIS Schema Refinement: book_issue

- book_issue (member_no, accession_no, doi)
    - member_no, accession_no → doi
    - Key: members, accession_no
- In BCNF

LIS Schema Refinement: quota

- **quota** (member_type, max_books, max_duration)
    - member_type → max_books, max_duration
    - Key: member_type
- In BCNF

LIS Schema Refinement: members

- **members** (member_no, member_type)
    - member_no → member_type
    - Key: menber_no
    - Value constraint on member_type
        - ug, pg or rs: if the member is a student
        - fc: if the member is a faculty
    - In BCNF
    - How to determine the member_type?

LIS Schema Refinement: students

- **students** (member_no, student_fname, student_lname, roll_no, department, gender, mobile_no, dob, degree)
    - roll_no → student_fname, student_lname, department, gender, mobile_no, dob, degree
    - member_no → roll_no
    - roll_no → member_no
    - 2 Keys: roll_no | member_no
- In BCNF
- Issues:
    - member_no is needed for issue / return queries
        - It is unnecessary to have student's details with that
    - member_no may also come from faculty relation
    - member_type is needed for issue / return queries
        - This is implicit in degree — not explicitly given

LIS Schema Refinement: faculty

- **faculty** (member_no, faculty_fname, faculty_lname, id, department, gender, mobile_no, doj)

- id → faculty_fname, faculty_lname, department, gender, mobile_no, doj
    - id → member_no
    - member_no → id
    - 2 Keys: id | member_no
- In BCNF
- Issues:
    - member_no is needed for the issue / return queries
        - It is unnecessary to have faculty details with that
    - member_no may also come from **student** relation
    - member_type is needed for issue / return queries
        - This is implicit by the fact that we are in faculty relation

LIS Schema Refinement: Query

- Consider a query:
    - Get the name of the member who has issued the book having accession number = 162715
        - If the member is a student

        ```
        SELECT student_fname as First_Name, student_lname as Last_Name
        FROM students, book_issue
        WHERE accession_no = 162715 AND book_issue.member_no = students.member_no;
        ```

        - If the member is a faculty

        ```
        SELECT faculty_fname as First_Name, faculty_lname as Last_Name
        FROM faculty, book_issue
        WHERE accession_no = 162715 AND book_issue.member_no = faculty.member_no;
        ```

    - Which query to fire!?

LIS Schema Refinement: members

There are 4 categories of members: ug students, grad students, research scholars and faculty members

This leads to the following specialization relationships

- Consider the entity set **members** of a library and refine:
    - Attributes:
        - member_no
        - member_class — 'student' or 'faculty', used to choose table
        - member_type — ug, pg, rs, fc, ...
        - roll_no (if member_class — 'student', else null)
        - if (if member_class — 'faculty', else null)
- We can the exploit some hidden relationship:
    - student IS A members
    - faculty IS A members
- Types of relationship
    - One-to-one

LIS Schema Refinement: Query

- Consider the access query again:
    - Get the name of the member who has issued the book having accession number = 162715

```
SELECT
((SELECT faculty_fname as First_Name, faculty_lname as Last_Name
FROM faculty
WHERE member_class = 'faculty' AND members.id = faculty.id)
UNION
(SELECT student_fname as First_Name, student_lname as Last_Name
FROM students
WHERE member_class = 'student' AND members.roll_no = students.roll_no))
FROM members, book_issue
WHERE accession_no = 162715 AND book_issue.member_no = members.member_no;
```

LIS Schema Refinement: members

- **members** (member_no, member_class, member_type, roll_no, id)
  - member_no → member_type, member_class, roll_no, id
  - member_type → member_class
  - Key: member_no

LIS Schema Refinement: students

- **students** (student_fname, student_lname, roll_no, department, gender, mobile_no, dob, degree)
  - roll_no → student_fname, student_lname, department, gender, mobile_no, dob, degree
  - Keys: roll_no
  - Note:
    - member_no is no longer used
    - member_type and member_class are set in **members** from degree at the time of creation of a new record

LIS Schema Refinement: faculty

- **faculty** (faculty_fname, faculty_lname, id, department, gender, mobile_no, doj)
  - id → faculty_fname, faculty_lname, department, gender, mobile_no, doj
  - Keys: id
  - Note:
    - member_no is no longer used
    - member_type and member_class are set in **members** at the time of creation of a new record

LIS Scheme Refinement: Final

- **book_catalogue** (title, author_fname, author_lname, publisher, year, ISBN_no)
- **book_copies** (ISBN_no, accession_no)
- book_issue (member_no, accession_no, doi)
- **quota** (member_type, max_books, max_duration)
- **members** (member_no, member_class, member_type, roll_no, id)
- **students** (student_fname, student_lname, roll_no, department, gender, mobile_no, dob, degree)
- **faculty** (faculty_fname, faculty_lname, id, department, gender, mobile_no, doj)
- **staff** (staff_fname, staff_lname, id, gender, mobile_no, doj)

Week 6 Lecture 4

Class	BSCCS2001
Created	@October 13, 2021 6:02 PM
Materials	
Module #	29
Type	Lecture
Week #	6

Relational Database Design (part 9)

MVD: Multi-valued Dependency

- Persons (Man, Phones, Dog_Like)

Person :			**Meaning of the tuples**
Man(M)	**Phones(P)**	**Dogs_Like(D)**	Man M have phones P, and likes the dogs D.
M1	P1/P2	D1/D2	M1 have phones P1 and P2, and likes the dogs D1 and D2.
M2	P3	D2	M2 have phones P3, and likes the dog D2.
Key : MPD			

There are no non-trivial FDs because all attributes are combined forming Candidate Key, that is, MDP

In the above relation, 2 multi-valued dependencies exist:

- Man $\twoheadrightarrow$ Phones
- Man $\twoheadrightarrow$ Dog_Like

A man's phone is independent of the phone they like

But, after converting the above relation in Single Valued Attribute, each of a man's phone appears with each of the dogs they like in all combinations

Post 1NF Normalization

Man(M)	Phones(P)	Dogs_Likes(D)
M1	P1	D1
M1	P2	D2
M2	P3	D2
M1	P1	D2
M1	P2	D1

MVD

- If two or more independent relations are kept in a single relation, then Multi-valued Dependency is possible
- For example, let there be 2 relations:
  - **Student (SID, Sname)** *where* **(SID → Sname)**
  - **Course (CID, Cname)** *where* **(CID → Cname)**
- There is no relation defined between Student and Course
- If we kept them in a single relation named **Student_Course**, then MVD will exist because of m:n Cardinality
- If two or more MVDs exist in a relation, then while converting into SVAs, MVD exists

Student:

SID	Sname
S1	A
S2	B

Course:

CID	Cname
C1	C
C2	B

SID	Sname	CID	Cname
S1	A	C1	C
S1	A	C2	B
S2	B	C1	C
S2	B	C2	B

2 MVDs exist:
1. SID →→ CID
2. SID →→ Cname

- Suppose we record names of the children, and phone numbers for the instructors
  - *inst_child (ID, child_name)*
  - *inst_phone (ID, phone_number)*
- If we were to combine these schema to get
  - inst_info (ID, child_name, phone_number)
  - Example data:

    (99999, David, 512-555-1234)

    (99999, David, 512-555-4321)

    (99999, William, 512-555-1234)

    (99999, William, 512-555-4321)
- This relation is in BCNF

MVD: Definition

- Let R be a relation schema and let $\alpha \subseteq R$ and $\beta \subseteq R$

- The multi-valued dependency $\alpha \twoheadrightarrow \beta$ holds on R if in any legal relation $r(R)$, for all pairs of tuples t_1 and t_2 in r such that $t_1[\alpha] = t_2[\alpha]$, there exist tuples t_3 and t_4 in r such that:

$$t_1[\alpha] = t_2[\alpha] = t_3[\alpha] = t_4[\alpha]$$

$$t_3[\beta] = t_1[\beta]$$

$$t_3[R - \beta] = t_2[R - \beta]$$

$$t_4[\beta] = t_2[\beta]$$

$$t_4[R - \beta] = t_1[R - \beta]$$

Example: A relation of university courses, the books recommended for the course, and the lecturers who will be teaching the course:

- **course** $\twoheadrightarrow$ **book**
- **course** $\twoheadrightarrow$ **lecturer**

Test: **course $\twoheadrightarrow$ book**

Course	Book	Lecturer	Tuples
AHA	Silberschatz	John D	t1
AHA	Nederpelt	William M	t2
AHA	Silberschatz	William M	t3
AHA	Nederpelt	John D	t4
AHA	Silberschatz	Christian G	
AHA	Nederpelt	Christian G	
OSO	Silberschatz	John D	
OSO	Silberschatz	William M	

- Let R be a relation schema with a set of attributes that are partitioned into 3 non-empty subsets

  Y, Z, W

- We say that Y $\twoheadrightarrow$ Z (Y multidetermines Z) if and only if for all possible relations $r(R) < y_1, z_1, w_1 > \in r$ and $< y_1, z_2, w_2 > \in r$

  $< y_1, z_1, w_2 > \in r$ and $< y_1, z_2, w_1 > \in r$

- Note that since the behaviour of Z and W are identical it follows that

  Y $\twoheadrightarrow$ Z if Y $\twoheadrightarrow$ W

In our example:

- ID $\twoheadrightarrow$ child_name
- ID $\twoheadrightarrow$ phone_number

The above formal definition is supposed to formalize the notion that given a particular value of Y(ID) it has associated with it a set of values of Z (child_name) and a set of values of W (phone_number) and these two sets are in some sense independent of each other

NOTE:

- IF Y $\rightarrow$ Z, then Y $\twoheadrightarrow$ Z
- Indeed we have (in above notation) $Z_1 = Z_2$

  The claim follows

MVD: Use

- We use multi-valued dependencies in 2 ways:
  - To test relations to determine whether they are legal under a given set of functional and multivalued dependencies
  - To specify the constraints on the set of legal relations
  - We shall thus concern ourselves only with the relations that satisfy a given set of functional and multivalued dependencies
- If a relation r fails satisfy a given multivalued dependency, we can construct a relation r' that does satisfy the multivalued dependency by adding tuples to r

MVD: Theory

	Name	Rule
C-	Complementation	If $X \twoheadrightarrow Y$, then $X \twoheadrightarrow (R - (X \cup Y))$.
A-	Augmentation	If $X \twoheadrightarrow Y$ and $W \supseteq Z$, then $WX \twoheadrightarrow YZ$.
T-	Transitivity	If $X \twoheadrightarrow Y$ and $Y \twoheadrightarrow Z$, then $X \twoheadrightarrow (Z - Y)$.
	Replication	If $X \rightarrow Y$, then $X \twoheadrightarrow Y$ but the reverse is not true.
	Coalescence	If $X \twoheadrightarrow Y$ and there is a W such that $W \cap Y$ is empty, $W \rightarrow Z$ and $Y \supseteq Z$, then $X \rightarrow Z$.

- A MVD **X** ↠ **Y** in **R** is called a trivial MVD is
  - **Y** is a subset of X (X ⊇ Y) or
  - X ∪ Y = R
    - Otherwise, it is a non-trivial MVD and we have to repeat values redundantly in the tuples

---

- From the definition of multi-valued dependency we can derive the following rule:
  - If $\alpha \rightarrow \beta$, then $\alpha \twoheadrightarrow \beta$

  That is, every functional dependency is also a multi-valued dependency
- The closure D^+ of D is the set of all functional and multi-valued dependencies logically implied by D
  - We can compute D^+ from D, using the formal definitions of functional dependencies and multi-valued dependencies
  - We can manage with such reasoning for very simple multi-valued dependencies, which seem to be most common in practice
  - For complex dependencies, it is better to reason about sets of dependencies using a system of inference rules

Decomposition of 4NF

Fourth Normal Form (4NF)

- A relation schema R is in 4NF w.r.t. a set D of functional and multi-valued dependencies if for all multi-valued dependencies in D^+ of the form $\alpha \twoheadrightarrow \beta$, where $\alpha \subseteq R$ and $\beta \subseteq R$, at least one of the following hold:
  - $\alpha \twoheadrightarrow \beta$ is trivial (that is, $\beta \subseteq \alpha$ or $\alpha \cup \beta = R$)
  - α is a superkey for schema R
- If a relation is in 4NF it is in BCNF

Restriction of Multivalued Dependencies

- The restriction of D is R_i is the set of D_i consisting of
  - All functional dependencies in D^+ that include only attributes of R_i
  - All multivalued dependencies of the form

    $\alpha \twoheadrightarrow (\beta \cap R_i)$

    where $\alpha \subseteq R_i$ and $\alpha \twoheadrightarrow \beta$ is in D^+

4NF Decomposition Algorithm

- For all dependencies $A \twoheadrightarrow B$ in D^+, check if A is a superkey
    - By using attribute closure
- if not, then
    - Choose a dependency in F^+ that breaks the 4NF rules, say $A \twoheadrightarrow B$
    - Create R1 = A B
    - Create R2 = (R - (B - A))
    - Note: $R1 \cap R2 = A$ and $A \twoheadrightarrow AB(= R1)$, so this is lossless decomposition
- Repeat for R1 and R2
    - By defining $D1^+$ to be all dependencies in F that contain only attributes in R1
    - Similarly $D2^+$

result := {R};

done := false;

compute D^+;

Let D_i denote the restriction of D^+ to R_i

while (not done)

    if (there is a schema R_i in result that is not in 4NF) then

        begin

            let $\alpha \twoheadrightarrow \beta$ be a non-trivial multi-valued dependency that holds

                on R_i such that $\alpha \rightarrow R_i$ is not in D_i and $\alpha \cap \beta = \phi$

            result := (result - R_i) $\cup$ $(R_i - \beta) \cup (\alpha, \beta)$

        end

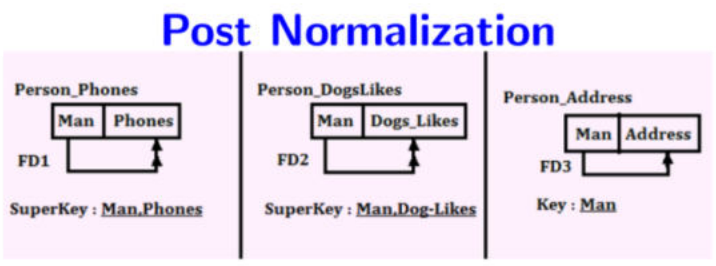
    else done := true;

NOTE: each R_i is in 4NF and decomposition is lossless-join

4NF Decomposition: Example

- Example:
    - **Person_Modify(Man(M), Phones(P), Dog_Likes(D), Address(A))**
    - FDs:
        - FD1 : Man $\twoheadrightarrow$ Phones
        - FD2 : Man $\twoheadrightarrow$ Dogs_Like
        - FD3 : Man $\rightarrow$ Address
    - Key = MPD
    - All dependencies violate 4NF

Man(M)	Phones(P)	Dogs_Likes(D)	Address(A)
M1	P1	D1	49-ABC,Bhiwani(HR.)
M1	P2	D2	49-ABC,Bhiwani(HR.)
M2	P3	D2	36-XYZ,Rohtak(HR.)
M1	P1	D2	49-ABC,Bhiwani(HR.)
M1	P2	D1	49-ABC,Bhiwani(HR.)



In the above relations for both the MVD's – ***'X' is Man***, which is again not the super key, but as ***X ∪Y = R*** i.e. (Man & Phones) together make the relation.
So, the above MVD's are trivial and in FD 3, Address is functionally dependent on Man, where **Man** is the key in **Person_Address**, hence all the three relations are in 4NF.

- R =(A, B, C, G, H, I)
  F = A $\twoheadrightarrow$ B
  B $\twoheadrightarrow$ HI
  CG $\twoheadrightarrow$ H
- R is not in 4NF since $A \twoheadrightarrow B$ and A is not a superkey for R
- Decomposition
  a) R_1 = (A, B) (R_1 is in 4NF)
  b) R_2 = (A, C, G, H, I) (R_2 is not in 4NF, decompose into R_3 and R_4)
  c) R_3 = (C, G, H) (R_3 is in 4NF)
  d) R_4 = (A, C, G, I) (R_4 is not in 4NF, decompose into R_5 and R_6)
    - $A \twoheadrightarrow B$ and $B \twoheadrightarrow$ HI $\rightarrow$ A $\twoheadrightarrow$ HI, (MVD transitivity), and
    - and hence A $\twoheadrightarrow$ I (MVD restriction to R_4)

  e) R_5= (A, I) (R_5 is in 4NF)
  f) R_6 = (A, C, G) (R_6 is in 4NF)

Week 6 Lecture 5

Class	BSCCS2001
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Materials	
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Relational Database Design (part 10)

Database Design Process

Design Goals

- Goal for a relational DB design:
  - BCNF / 4NF
  - Lossless join
  - Dependency preservation
- If we cannot achieve this, we accept one of
  - Lack of dependency preservation
  - Redundancy due to use of 3NF
- Interestingly, SQL does not provide a direct way of specifying functional dependencies other than superkeys
- Can specify FDs using assertions, but they are expensive to test (and currently not supported by any of the widely used DB)
- Even if we had a dependency preserving decomposition, using SQL we could not be able to efficient test a functional dependency whose left hand side is not a key

Further Normal Forms

- Further NFs:
  - Elementary Key Normal Form (EKNF)

- Essential Tuple Normal Form (ETNF)
  - Join Dependencies and Fifth Normal Form (5NF)
  - Sixth Normal Form (6NF)
  - Domain/Key Normal Form (DKNF)
- Join dependencies generalize multi-valued dependencies
  - Lead to project-join normal form (PJNF) (also called Fifth Normal Form)
- A class of even more general constraints, leads to a normal form called Domain-Key Normal Form
- Problem with these generalized constraints: are hard to reason with, and no set of sound and complete set of inference rules exist
- Hence rarely used

Overall DB Design Process

- We have assumed schema R is given
  - R could have been generated when converting E-R diagram to a set of tables
  - R could have been a single relation containing all attributes that are of interest (universal relation)
  - Normalization breaks R into smaller relations
  - R could have been the result of some ad hoc design of relations, which we then test/convert to normal form

ER Model and Normalization

- When an E-R diagram is carefully designed, identifying all entities correctly, the tables generated from the E-R diagram should not need further optimization
- However, in a real (imperfect) design there can be functional dependencies from non-key attributes of an entity to other attributes of the entity
  - Example: an employee entity with attributes

    department_name and building

    and a functional dependency

    department_name → building
  - Good design would have made department an entity
- Functional dependencies from non-key attributes of a relationship set possible, but rare — most relationships are binary

Denormalization for Performance

- May want to use non-normalized schema for performance
- For example, displaying prereqs along with course_id, and title requires join of course with prereq
  - **Course (course_id, title, ...)**
  - **Prerequisite (course_id, prereq)**
- **Alternative #1:** Use denormalized relation containing attributes of course as well as prereq with all above attributes: **Course (course_id, title, prereq, ...)**
  - faster lookup
  - extra space and extra execution time for updates
  - extra coding work for programmers and possibility of error in extra code
- **Alternative #2:** Use a materialized view defined as **Course** ⋈ **Prerequisite**
  - Benefits and drawbacks same as above, except no extra coding work for programmers and avoids possible errors

Other Design Issues

- Some aspects of DB design are not caught by normalization
- Examples of bad DB design, to be avoided:

Instead of earnings (company_id, year, amount), use

- earnings_2004, earnings_2005, earnings_2005, etc. all on the schema (company_id, earnings)
  - Above are in BCNF, but make querying across years difficult and needs new table each year
- company_year (company_id, earnings_2004, earnings_2005, earnings_2006)
  - Also in BCNF, but also makes querying across years difficult and requires new attribute each year
  - is an example of **crosstab**, where values for one attribute become column names
  - Used in spreadsheets, and in data analysis tools

LIS Example for 4NF

- Consider a different version of relation ***book_catalogue*** having the following attributes:
  - *book_title*
  - *book_catalogue, author_lname*: A *book_title* may be associated with more than one author
- **book_title** {*book_title, author_fname, author_lname, edition*}

  book_catalogue

book_title	author_fname	author_lname	edition
DBMS CONCEPTS	BRINDA	RAY	1
DBMS CONCEPTS	AJAY	SHARMA	1
DBMS CONCEPTS	BRINDA	RAY	2
DBMS CONCEPTS	AJAY	SHARMA	2
JAVA PROGRAMMING	ANITHA	RAJ	5
JAVA PROGRAMMING	RIYA	MISRA	5
JAVA PROGRAMMING	ADITI	PANDEY	5
JAVA PROGRAMMING	ANITHA	RAJ	6
JAVA PROGRAMMING	RIYA	MISRA	6
JAVA PROGRAMMING	ADITI	PANDEY	6

- Since, the relation has no FDs, it is already in BCNF
- However, the relation has 2 non-trivial MVDs

  book_title → *{author_fname, author_lname}* and *book_title* → *edition*

  Thus, it is not in 4NF
- Non-trivial MVDs must be decomposed to convert it into a set of relationsin 4NF

- We decompose **book_catalogue** into **book_author** and **book_edition** because:
  - **book_author** has trivial MVD

    book_title ↠ {author_fname, author_lname}
  - **book_edition** has trivial MVD

    book_title ↠ edition

book_title	author_fname	author_lname
DBMS CONCEPTS	BRINDA	RAY
DBMS CONCEPTS	AJAY	SHARMA
JAVA PROGRAMMING	ANITHA	RAJ
JAVA PROGRAMMING	RIYA	MISRA
JAVA PROGRAMMING	ADITI	PANDEY

Figure: **book_author**

book_title	edition
DBMS CONCEPTS	1
DBMS CONCEPTS	2
JAVA PROGRAMMING	5
JAVA PROGRAMMING	6

Figure: **book_edition**

Temporal Databases

- Some data may be inherently historical because they include time-dependent / time-varying data, such as:
  - Medical Records
  - Judicial Records
  - Share prices
  - Exchange rates
  - Interest rates
  - Company profits
  - etc.
- The desire to model such data means that we need to store not only the respective value but also an associated data or a time period for which the value is valid
- Typical queries expressed informally might include:
  - Give me last month's history of the Dollar-Pound Sterling exchange rate
  - Give me the share prices of the NYSE on October 17, 1996
- Temporal DB provides a uniform and systematic way of dealing with historical data

Temporal Data

- Temporal data have an association time interval during which the data is valid
- A snapshot is the value of the data at a particular point in time
- In practice, DB engineers may add start and end time attributes to relations
- For example, course (course_id, course_title) is replaced by

  course (course_id, course_title, start, end)

- Constraint: no 2 tuples can have overlapping valid times and are hard to enforce efficiently
- Foreign key references may be to current version of data, or to data at a point in time
  - For example: student transcript should refer to the course information at the time the course was taken

Temporal Database Theory

- **Model of Temporal Domain:** Single-dimensional linearly ordered which may be ...
  - Discrete or dense
  - Bounded or unbounded
  - Single dimensional or multi-dimensional
  - Linear or non-linear
- **Timestamp Model**
- **Temporal ER model** by adding valid time to
  - Attributes: address of an instructor at different points in time
  - Entities: time duration when a student entity exists
  - Relationships: time during which a student attended a course
  - But no accepted standard
- **Temporal Functional Dependency Theory**
- **Temporal Logic**
- **Temporal Query Language:**
  - TQuel [1987]
  - TSQL2 [1995]
  - SQL/Temporal [1996]
  - SQL/TP [1997]

Modeling Temporal Data: Uni / Bi Temporal

- There are 2 different aspects of time in temporal DBs
  - **Valid Time:** Time period during which a fact is true in the real world, provided to the system
  - **Transaction Time:** Time period during which a fact is stored in the DB, based on transaction serialization order and is the timestamp generated automatically by the system
- Temporal Relation is one where each tuple has associated time; either valid time or transaction time or both associated with it
  - **Uni-Temporal Relations:** Has one axis of time, either Valid Time or Transaction Time
  - Bi-Temporal Relations: Has both axis of time — Valid time and Transaction time
    - It includes Valid Start Time, Valid End Time, Transaction Start Time, Transaction End Time

Modeling Temporal Data: Example

- **Example**
  - Let's see an example of a person, John:
    - John was born on April 3, 1992 in Chennai
    - His father registered his birth after 3 days on April 6, 1992
    - John did his entire schooling and college in Chennai
    - He got a job in Mumbai and shifted to Mumbai on June 21, 2015
    - He registered his change of address only on Jan 10, 2016

John's Data in Non-Temporal DB

Date	Real world event	Address
April 3, 1992	John is born	
April 6, 1992	John's father registered his birth	Chennai
June 21, 2015	John gets a job	Chennai
Jan 10, 2016	John registers his new address	Mumbai

- In a non-temporal DB, John's address is entered as Chennai from 1992
- When he registers his new address in 2016, the DB gets updated and the address field now shows his Mumbai address
- The previous Chennai address details will not be available
- So, it will be difficult to find out exactly when he was living in Chennai and when he moved to Mumbai

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Uni-Temporal Relation (Adding Valid Time to John's Data)

Name	City	Valid From	Valid Till
John	Chennai	April 3, 1992	June 20, 2015
John	Mumbai	June 21, 2015	∞

- The valid time temporal DB contents look like this:
  `Name, City, Valid From, Valid Till`
- Johns father registers his birth on 6th April 1992, a new DB entry is made:
  `Person (John, Chennai, 3-Apr-1992, ∞ )`
- On January 10, 2016 John reports his new address in Mumbai:
  `Person (John, Mumbai, 21-June-2015, ∞ )`
  - The original entry is updated:
    `Person (John, Chennai, 3-Apr-1992, 20-June-2015)`

Bi-Temporal Relation (John's Data Using Both Valid And Transaction Time)

Name	City	Valid From	Valid Till	Entered	Superseded
John	Chennai	April 3, 1992	June 20, 2015	April 6, 1992	Jan 10, 2016
John	Mumbai	June 21, 2015	∞	Jan 10, 2016	∞

- The database contents look like this:
  `Name, City, Valid From, Valid Till, Entered, Superseded`
- Johns father registers his birth on 6th April 1992:
  `Person(John, Chennai, 3-Apr-1992, ∞ , 6-Apr-1992, ∞ )`

- On January 10, 2016 John reports his new address in Mumbai:

  `Person(John, Mumbai, 21-June-2015, ∞ , 10-Jan-2016, ∞ )`

  - The original entry is updated as:

    `Person(John, Chennai, 3-Apr-1992, 20-June-2015, 6-Apr-1992 , 10-Jan-2016)`

Modeling Temporal Data: Summary

- **Advantages**
  - The main advantages of this bi-temporal relations is that it provides historical and roll back information
    - **Historical information** — Valid time
    - **Rollback information** — Transaction time
  - For example, you can get the result of a query on John's history, like: Where did John live in the year 2001?
    - The result for this query can be got with the valid time entry
    - The transaction time entry is important to get the rollback information
- **Disadvantages**
  - More storage
  - Complex query processing
  - Complex maintenance including backup and recovery