Relational Design Theory II

Normalization

Detecting Anomalies

SID	Activity	Fee	Tax
1001	Piano	$20	$2.00
1090	Swimming	$15	$1.50
1001	Swimming	$15	$1.50

- Why is this bad design?
- Can we capture this using FDs?

Normal Forms

- Requirements on relational schemas
- Initiated by Codd (1NF, 2NF, 3NF)

1NF (First NF)	no multivalued attributes
2NF (Second NF)	no partial dependencies
3NF (Third NF)	no bad transitive dependencies
BCNF (Boyce-Codd NF)	strengthening of 3NF
4NF (Fourth NF)	extends BCNF to multivalued dependencies

- there's more …

BCNF

If $X \rightarrow Y$ is not trivial, then X has to be a superkey.

Has to be true for all valid FDs $X \rightarrow Y$

Example:

Activity(SID, Activity, Fee, Tax)

SID, Activity $\rightarrow$ Fee, Tax

Activity $\rightarrow$ Fee

Fee $\rightarrow$ Tax

How to decompose?

BCNF Decomposition

What do we want?

- Relations are in BCNF
- We can reconstruct data in original relation
- Keep functional dependencies?

Note: Relations on two attributes are always BCNF.

BCNF-Normalization

Algorithm (BCNF Normalization)

Input: Relation R, FDs F

Output: BCNF-decomposition D of R

D := {R}

While $X \rightarrow Y$ holds in some $Q(A_1, \ldots, A_n)$ in D, and

$X \rightarrow Y$ not trivial, X not a superkey of Q

add $Q_1(X^+ \cap (\{A_1, \ldots, A_n\})$ and

$Q_2(X \cup (\{A_1, \ldots, A_n\} - X^+))$

remove Q.

BCNF-Example

D := {R}
While $X \rightarrow Y$ holds in some $Q(A_1, \ldots, A_n)$ in D, and
$X \rightarrow Y$ not trivial, X not a superkey of Q
add $Q_1(X^+ \cap (\{A_1, \ldots, A_n\})$ and
$Q_2(X \text{ u } (\{A_1, \ldots, A_n\} - X^+))$
remove Q.

Examples:

R(A, B, C, D), FDs: $A \rightarrow B$, $C \rightarrow D$
R(A, B, C, D), FDs: $AC \rightarrow B$, $C \rightarrow D$
R(A,B,C,D,E), FDs: $A \rightarrow BE$, $E \rightarrow D$

BCNF-Normalization Caveat

Checking whether $X \rightarrow Y$ holds in some Q in D refers to F, not just D.

Example:

R(A,B,C,D,E)
FDs: $A \rightarrow B$
$BC \rightarrow D$ (implies $AC \rightarrow D$)

- naïve implementation of algorithm requires exponential time
- can be improved to polynomial time

(Tsou, Fischer, *Decomposition of a relation scheme into Boyce-Codd Normal Form*, ACM, SIGACT News,1982)

Testing for BCNF

- single R with FDs F
  testing for BCNF can be done in polynomial time,
  it is sufficient to test F
- this is not true for decompositions, e.g.

R(A,B,C,D,E)
FDs: $A \rightarrow B$
$BC \rightarrow D$

decompose into
$R_1(A,B)$
$R_2(A,C,D,E)$

More BCNF-Examples

phone(<u>Name, City</u>, <u>AreaCode, PhoneNumber, Extension</u>)

R(A,B,C,D), keys: AB, CD, FDs: $A \rightarrow C$, $D \rightarrow B$

R(A,B,C,D,E), FDs: $A \rightarrow B$, $C \rightarrow D$, $AC \rightarrow E$

Lossless Join Property

$D = \{R_1, R_2, \ldots, R_n\}$ decomposition of R.

If $R_1 * R_2 * \ldots * R_n = R$, then
D has the **lossless join property**.

BCNF decomposition has lossless join property.

Lossless Join Property

Test lossless join property for binary decomposition

Given: R, $D = \{R_1, R_2\}$, FDs F

D is a lossless join decomposition of R, if

$R = R_1 \cup R_2$, and either

$R_1 \cap R_2 \rightarrow R_1 - R_2$ in F^+ or

$R_1 \cap R_2 \rightarrow R_2 - R_1$ in F^+.

Example: Activity(SID, Activity, Fee)

- necessary?
- sufficient?
- implies correctness of BCNF algorithm

Lossless Join Property

Algorithm (Chase Test)

Input: relation $R(A_1, \ldots, A_n)$, FDs F
decomposition $D = \{R_1, R_2, \ldots, R_m\}$
Output: Is D a lossless join decomposition of R?

T := table with columns $A_1, \ldots, A_n$, rows $R_1, R_2, \ldots, R_m$

$$T[i,j] := \begin{cases} a_{i,j} & \text{if } A_i \text{ not in } R_j \\ a_i & \text{if } A_i \text{ in } R_j \end{cases}$$

Apply FDs in F to identify elements until

- there is a row $(a_1, \ldots, a_n)$: lossless join
- no more changes are possible: not lossless join

Chase Test Examples

$R(A,B,C)$, FDs: $A \rightarrow B$,
D = {P(A,B), Q(A,C)}

$R(A,B,C)$, FDs: $A \rightarrow B$,
D = {P(B,C), Q(A,C)}

$R(A,B,C,D)$, FDs: $A \rightarrow B$, $C \rightarrow D$,
D = {P(A,B), Q(B,C),T(C,D)}

Dependency Preservation

banker(BranchName, CustomerName, BankerName)
BankerName→BranchName
BranchName, CustomerName → BankerName

$R(A,B,C)$, FDs: $A \rightarrow B$, $BC \rightarrow A$

- why not in BCNF? (Keys?)
- what are possible BCNF decompositions?
- what happens to dependencies?

Deciding whether a given relation has a dependency preserving BCNF decomposition is NP-complete

Tsou, Fischer, *Decomposition of a relation scheme into Boyce-Codd Normal Form*, ACM, SIGACT News,1982

Prime Attributes

prime attribute: part of some key

Examples:

R(A,B,C,D,E), AB is key, C is key, B→D, D→E
A,B,C are prime,
D,E are nonprime

R(A,B,C,D,E)
AC→D, BD→E, E→AC

Prime Attributes

prime attribute: part of some key

- How many keys can there be on n attributes?
- How hard is it to find all keys? Algorithm?

Prime Attributes

prime attribute: part of some key

- How many keys can there be on n attributes?
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Determining primality of an attribute is NP-complete.

(Lucchesi, Osborne, *Candidate keys for relations*, J. Comput. System Sci. 17, 1978

3NF

If $X \rightarrow Y$ is not trivial, then X has to be a superkey, *or*, all attributes in Y-X are prime.

Has to be true for all valid FDs $X \rightarrow Y$

Violated in

Book(Author, Title, PriceCategory, Price)
Movie(Title, Year, MPAA, MinimumAge)

3NF-Examples

R(A,B,C,D) with key A and
$B \rightarrow CD$, $C \rightarrow D$, $D \rightarrow C$

Can we find a decomposition of these relations that contains the same information?

3NF-Normalization

Algorithm (3NF Normalization):
Input: Relation R with FDs F
Output: 3NF decomposition D of R

1. Compute canonical cover C of F
2. D = {}
3. For every $X \rightarrow Y$ in C such that no S in D contains all of XY, add new relation Q(XY) to D
4. If no relation in D contains a key of R, then add new relation Q(X) on some key X of R

3NF-Examples

- R(A,B,C,D) with A key, $B \to CD$, $C \to D$, $D \to C$
- R(A,B,C,D) with AB key, $A \to C$, $B \to D$
- R(A,B,C,D,E) with AB and AC keys, $BC \to D$, $C \to E$
- R(A,B,C,D,E) with AB key, $A \to E$, $BC \to D$, $D \to E$
- R(A,B,C,D,E,F) with ABC key, $A \to E$, $AC \to F$, $EF \to G$
- R(A,B,C,D,E,F) with A and BC keys, $B \to D$, $D \to F$
- R(A,B,C,D,E) with AB and CD keys, $A \to E$, $C \to E$

Find 3NF normalization

Results can depend on canonical cover, and order of execution

3NF Algorithm

- 3NF Normalization Algorithm is loss-less join (chase test)
- It is dependency preserving (obviously)
- The resulting relations are in 3NF (not trivial).

3NF vs BCNF: properties

- BCNF is stronger than 3NF
- BCNF and 3NF are loss-less join (no spurious tuples)
- 3NF preserves dependencies
- BCNF does not always preserve dependencies

3NF vs BCNF: algorithmics

- Normalization Algorithms:
  - naïve algorithm for 3NF in polynomial time
  - naïve algorithm for BCNF in exponential time, but can be done in polynomial time
- Recognition Algorithms:
  - BCNF is easy to recognize (polynomial time)
  - Recognizing 3NF is NP-complete

(Jou, Fischer, *The complexity of recognizing 3NF relation schemes*, Information Processing Letters 14, 1982)