ICS 321 Fall 2013
Normal Forms (ii)

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## Redundancies & Decompositions

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### Hourly_Emps

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### RatingWages

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Lossless-join Decomposition

• Decomposition of R into X and Y is *lossless-join* w.r.t. a set of FDs F if, for every instance \( r \) that satisfies F:

\[
\pi_X(r) \text{ join } \pi_Y(r) = r
\]

• In general one direction \( \pi_X(r) \text{ join } \pi_Y(r) \supseteq r \) is always true, but the other may not hold.

• Definition extended to decomposition into 3 or more relations in a straightforward way.

• *It is essential that all decompositions used to deal with redundancy be lossless!* (Avoids Problem (2).)
Conditions for Lossless Join

• The decomposition of $R$ into $X$ and $Y$ is lossless-join wrt $F$ if and only if the closure of $F$ contains:
  – $X \cap Y \rightarrow X$,  or
  – $X \cap Y \rightarrow Y$

• In particular, the decomposition of $R$ into $UV$ and $R - V$ is lossless-join if $U \rightarrow V$ holds over $R$. 
Chase Test for Lossless Join

• R(A,B,C,D) is decomposed into 
  \( S1=\{A,D\}, \ S2=\{A,C\}, \ S3=\{B,C,D\} \)

• Construct a Tableau
  – One row for each decomposed relation
  – For each row \( i \), subscript an attribute with \( i \) if it does not occur in \( Si \).

• FDs: \( A \rightarrow B, \ B \rightarrow C, \ CD \rightarrow A \)

• Rules for “equating two rows” using FDs:
  – If one is unsubscripted, make the other the same
  – If both are subscripted, make the subscripts the same

• Goal: one unsubscripted row

\[
\begin{array}{cccc}
A & B & C & D \\
\hline
a & b_1 & c_1 & d \\
a & b_2 & c & d_2 \\
a_3 & b & c & d \\
\end{array}
\]

\[
\begin{array}{cccc}
A & B & C & D \\
\hline
a & b_1 & \times & c \\
\times & b_2 & c & d_2 \\
a_3 & b & c & d \\
\end{array}
\]
Dependency-preserving Decomposition

- **Dependency preserving decomposition (Intuitive):**
  - If R is decomposed into X, Y and Z, and we enforce the FDs that hold on X, on Y and on Z, then all FDs that were given to hold on R must also hold. *(Avoids Problem (3).)*

- **Projection of set of FDs F:** If R is decomposed into X, ... projection of F onto X (denoted $F_X$) is the set of FDs $U \rightarrow V$ in $F^+$ *(closure of F)* such that $U, V$ are in X.
Dependency-preserving Decomp. (Cont)

Decomposition of R into X and Y is **dependency preserving** if \((F_X \cup F_Y)^+ = F^+\)

- If we consider only dependencies in the closure \(F^+\) that can be checked in X without considering Y, and in Y without considering X, these imply all dependencies in \(F^+\).
- Example: ABC decomposed into AB and BC.
  - \(F=\{A \rightarrow B, \ B \rightarrow C, \ C \rightarrow A\}\).
  - Is this dependency preserving?

- Dependency preserving does not imply lossless join:
  - Eg. ABC, A \rightarrow B, decomposed into AB and BC.
  - And vice-versa! (Example?)
Decomposition into BCNF

• Consider relation R with FDs F. *How do we decompose R into a set of small relations that are in BCNF?*

• Algorithm:
  – If $X \rightarrow Y$ violates BCNF, decompose R into $R - Y$ and $XY$
  – Repeat until all relations are in BCNF.

• Example: $ABCD$, $B \rightarrow C$, $C \rightarrow D$, $C \rightarrow A$.

• Order in which we deal with the violating FD can lead to different relations!
BCNF Decomposition Algorithm (3.20)

- **Input**: $R_0$, set of FDs $S_0$
- **Output**: A decomposition of $R_0$ into a collection of relations, all of which are in BCNF
- Initially $R = R_0$, $S = S_0$

1. If $R$ is in BCNF, return \{R\}
2. Let $X \rightarrow Y$ be a violation.
   a. Compute $X^+$.
   b. Choose $R_1 = X^+$
   c. Let $R_2 = X \cup (R - X^+)$
3. Compute FD projections $S_1$ and $S_2$ for $R_1$ and $R_2$
4. Recursively decompose $R_1$ and $R_2$ and return the union of the results
BCNF & Dependency Preservation

• BCNF decomposition using Algo 3.20 is lossless join

• BUT in general there may not be a dependency preserving decomposition into BCNF
  – Example: Bookings(Title, City, Theater), with FD’s : Th → C, TiC → Th
  – Not in BCNF.
  – Can’t decompose while preserving 2nd FD;

• This is the motivation for 3NF.
Decomposition into 3NF

• Obviously, the algorithm for lossless join decomp into BCNF can be used to obtain a lossless join decomp into 3NF (typically, can stop earlier).

• How can we ensure dependency preservation?
  – If $X \rightarrow Y$ is not preserved, add relation $XY$.
  – Problem is that $XY$ may violate 3NF!
  – Example: $JP \rightarrow C$ is not preserved, so add $JPC$. What if FDs also include $J \rightarrow C$?

• Refinement: Instead of the given set of FDs $F$, use a minimal cover for $F$. 
Minimum Cover for a Set of FDs

• **Minimal cover or basis** $G$ for a set of FDs $F$:
  – Closure of $F = \text{closure of } G$.
  – Right hand side of each FD in $G$ is a single attribute.
  – If we modify $G$ by deleting an FD or by deleting attributes from an FD in $G$, the closure changes.

• Intuitively, every FD in $G$ is needed, and ``as small as possible'' in order to get the same closure as $F$.

• e.g., $A \rightarrow B$, $ABCD \rightarrow E$, $EF \rightarrow GH$, $ACDF \rightarrow EG$ has the following minimal cover:
  – $A\rightarrow B$, $ACD\rightarrow E$, $EF\rightarrow G$ and $EF\rightarrow H$
Computing the Minimal Cover

• Algorithm
  1. **Put the FDs into standard form** $X \rightarrow A$. RHS is a single attribute.
  2. **Minimize the LHS of each FD.** For each FD, check if we can delete an attribute from LHS while preserving $F^+$.
  3. **Delete redundant FDs.**

• Minimal covers are not unique. Different order of computation can give different covers.
• e.g., $A \rightarrow B$, $ABCD \rightarrow E$, $EF \rightarrow GH$, $ACDF \rightarrow EG$ has the following minimal cover:
  – $A \rightarrow B$, $ACD \rightarrow E$, $EF \rightarrow G$ and $EF \rightarrow H$
3NF Decomposition Algorithm (3.26)

• **Input:** R, set of FDs F
• **Output:** A decomposition of R into a collection of relations, all of which are in BCNF

1. Find a minimal basis/cover for F, say G
2. For each FD $X \rightarrow A$ in G, use $XA$ as one of the decomposed relations.
3. If none of the relations from Step 2 is a superkey for R, add another relation whose schema is a key for R.
Summary of Schema Refinement

• If a relation is in BCNF, it is free of redundancies that can be detected using FDs. Thus, trying to ensure that all relations are in BCNF is a good heuristic.

• If a relation is not in BCNF, we can try to decompose it into a collection of BCNF relations.
  – Must consider whether all FDs are preserved.
  – If a lossless-join, dependency preserving decomposition into BCNF is not possible (or unsuitable, given typical queries), should consider decomposition into 3NF.
  – Decompositions should be carried out and/or re-examined while keeping performance requirements in mind.