# Schema Refinement and Normalization

Nobody realizes that some people expend tremendous energy merely to be normal.
Albert Camus

## Functional Dependencies (Review)

- **A <u>functional dependency</u> X → Y holds over relation schema R if, for every allowable instance *r* of R:**

  $t1 \in r,\ t2 \in r,\ \pi_X(t1) = \pi_X(t2)$
  implies $\pi_Y(t1) = \pi_Y(t2)$

  *(where t1 and t2 are tuples;X and Y are sets of attributes)*

- **In other words: X → Y means**

  Given any two tuples in *r*, if the X values are the same, then the Y values must also be the same. (but not vice versa)

- **Can read "→" as "determines"**

## Normal Forms

- **Back to schema refinement…**
- **Q1: is any refinement is needed??!**
- **If a relation is in a *normal form* (BCNF, 3NF etc.):**
  - we know that certain problems are avoided/minimized.
  - helps decide whether decomposing a relation is useful.
- **Role of FDs in detecting redundancy:**
  - Consider a relation R with 3 attributes, ABC.
    - No (non-trivial) FDs hold: There is no redundancy here.
    - Given A → B: If A is not a key, then several tuples could have the same A value, and if so, they'll all have the same B value!
- **1st Normal Form – all attributes are atomic**
- **1st ⊃2nd (of historical interest) ⊃ 3rd ⊃ Boyce-Codd ⊃ …**

## Boyce-Codd Normal Form (BCNF)

- **Reln R with FDs *F* is in BCNF if, for all X → A in F⁺**
  - A ∈ X (called a *trivial* FD), or
  - X is a superkey for R.
- **In other words: "R is in BCNF if the only non-trivial FDs over R are *key constraints.*"**
- **If R in BCNF, then every field of every tuple records information that cannot be inferred using FDs alone.**
  - Say we know FD X → A holds this example relation:

| X | Y | A |
|---|---|---|
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |

- Can you guess the value of the missing attribute?

- Yes, so relation is not in BCNF

## Decomposition of a Relation Schema

- If a relation is not in a desired normal form, it can be *decomposed* into multiple relations that each are in that normal form.
- Suppose that relation R contains attributes *A1 ... An.* A *<u>decomposition</u>* of R consists of replacing R by two or more relations such that:
  - Each new relation scheme contains a subset of the attributes of R, and
  - Every attribute of R appears as an attribute of at least one of the new relations.

## Example (same as before)

| S | N | L | R | W | H |
|---|---|---|---|---|---|
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |

Hourly_Emps

- SNLRWH has FDs S → SNLRWH and R → W
- Q: Is this relation in BCNF?

No, The second FD causes a violation;
W values repeatedly associated with R values.

## Decomposing a Relation

- Easiest fix is to create a relation RW to store these associations, and to remove W from the main schema:

| S | N | L | R | H |
|---|---|---|---|---|
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |

Hourly_Emps2

| R | W |
|---|---|
| [redacted] | [redacted] |
| [redacted] | [redacted] |

Wages

- Q: Are both of these relations are now in BCNF?
- **Decompositions should be used only when needed.**
  - Q: potential problems of decomposition?

## Problems with Decompositions

- There are three potential problems to consider:
  1) May be impossible to reconstruct the original relation! (Lossiness)
     - Fortunately, not in the SNLRWH example.
  2) Dependency checking may require joins.
     - Fortunately, not in the SNLRWH example.
  3) Some queries become more expensive.
     - e.g., How much does Guldu earn?

***Tradeoff*: Must consider these issues vs. redundancy.**

## Lossless Decomposition (example)

| S | N | L | R | H |
|---|---|---|---|---|
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |

$\bowtie$

| R | W |
|---|---|
| [redacted] | [redacted] |
| [redacted] | [redacted] |

=

| S | N | L | R | W | H |
|---|---|---|---|---|---|
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |

## Lossy Decomposition (example)

| A | B | C |
|---|---|---|
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |

→

| A | B |
|---|---|
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |

| B | C |
|---|---|
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |

$A \rightarrow B;\ C \rightarrow B$

| A | B |
|---|---|
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |

$\bowtie$

| B | C |
|---|---|
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |

=

| A | B | C |
|---|---|---|
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |
| 1 | 2 | 8 |
| 7 | 2 | 3 |

## Lossless Join Decompositions

- **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:**

  $\pi_X(r) \bowtie \pi_Y(r) = r$

- **It is always true that $r \subseteq \pi_X(r) \bowtie \pi_Y(r)$**
  - In general, the other direction does not hold! If it does, the decomposition is lossless-join.
- **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 #1)***

## More on Lossless Decomposition

- The decomposition of R into X and Y is **lossless with respect to F** *if and only if* the closure of F contains:

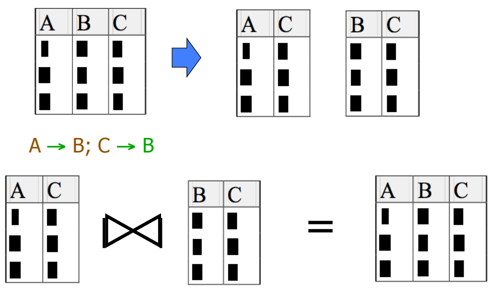
  $X \cap Y \rightarrow X$, **or**

  $X \cap Y \rightarrow Y$

  Common attributes form a superkey for one side or the other

  in example: decomposing ABC into AB and BC is lossy, because intersection (i.e., "B") is not a key of either resulting relation.
- Useful result: If $W \rightarrow Z$ holds over R and $W \cap Z$ is empty, then decomposition of R into R-Z and WZ is loss-less.

## Lossless Decomposition (example)




But, now we can't check A → B without doing a join!

## Dependency Preserving Decomposition

- **Dependency preserving decomposition (Intuitive):**
  - If R is decomposed into X, Y and Z, and we enforce the FDs that hold individually on X, on Y and on Z, then all FDs that were given to hold on R must also hold. *(Avoids Problem #2 on our list.)*
- ***Projection of set of FDs F*: If R is decomposed into X and Y the projection of F on X (denoted $F_X$) is the set of FDs U → V in $F^+$ (*closure of F, not just F*) such that all of the attributes U, V are in X. *(same holds for Y of course)***

## Dependency Preserving Decompositions (Contd.)

- **Decomposition of R into X and Y is *dependency preserving* if $(F_X \cup F_Y)^+ = F^+$**
  - i.e., 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 $F^+$.
- **Important to consider $F^+$ in this definition:**
  - ABC, A → B, B → C, C → A, decomposed into AB and BC.
  - Is this dependency preserving? Is C → A preserved?????
    - note: $F^+$ contains F ∪ {A → C, B → A, C → B}, so…
- $F_{AB}$ contains A → B and B → A; $F_{BC}$ contains B → C and C → B
- So, $(F_{AB} \cup F_{BC})^+$ contains C → A

## Decomposition into BCNF

- **Consider relation R with FDs F. If X → Y violates BCNF, decompose R into R - Y and XY (guaranteed to be loss-less).**
  - Repeated application of this idea will give us a collection of relations that are in BCNF; lossless join decomposition, and guaranteed to terminate.
  - e.g., CSJDPQV, key C, JP → C, SD → P, J → S
  - *{contractid, supplierid, projectid,deptid,partid, qty, value}*
  - To deal with SD → P, decompose into SDP, CSJDQV.
  - To deal with J → S, decompose CSJDQV into JS and CJDQV
  - So we end up with: SDP, JS, and CJDQV
- **Note: several dependencies may cause violation of BCNF. The order in which we ``deal with'' them could lead to very different sets of relations!**

## BCNF and Dependency Preservation

- **In general, there may not be a dependency preserving decomposition into BCNF.**
  - e.g., CSZ, CS → Z, Z → C
  - Can't decompose while preserving 1st FD; not in BCNF.
- **Similarly, decomposition of CSJDPQV into SDP, JS and CJDQV is not dependency preserving (w.r.t. the FDs JP → C, SD → P and J → S).**
- ***{contractid, supplierid, projectid,deptid,partid, qty, value}***
  - However, it is a lossless join decomposition.
  - In this case, adding JPC to the collection of relations gives us a dependency preserving decomposition.
    - but JPC tuples are stored only for checking the f.d. (*Redundancy!*)

## Third Normal Form (3NF)

- **Reln R with FDs *F* is in 3NF if, for all X → A in $F^+$**
  - A ∈ X (called a *trivial* FD), or
  - X is a superkey of R, or
  - A is part of some candidate key (not superkey!) for R. (sometimes stated as "A is *prime*")
- ***Minimality* of a key is crucial in third condition above!**
- **If R is in BCNF, obviously in 3NF.**
- **If R is in 3NF, some redundancy is possible. It is a compromise, used when BCNF not achievable (e.g., no ``good'' decomp, or performance considerations).**
  - *Lossless-join, dependency-preserving decomposition of R into a collection of 3NF relations always possible.*

## What Does 3NF Achieve?

- **If 3NF violated by X → A, one of the following holds:**
  - X is a subset of some key K ("partial dependency")
    - We store (X, A) pairs redundantly.
    - e.g. Reserves SBDC (C is for credit card) with key SBD and S → C
  - X is not a proper subset of any key. ("transitive dep.")
    - There is a chain of FDs K → X → A
    - So we can't associate an X value with a K value unless we also associate an A value with an X value (different K's, same X implies same A!) – problem with initial SNLRWH example.
- **But: even if R is in 3NF, these problems could arise.**
  - e.g., Reserves SBDC (note: "C" is for credit card here), S → C, C → S is in 3NF (why?), but for each reservation of sailor S, same (S, C) pair is stored.
- **Thus, 3NF is indeed a compromise relative to BCNF.**
  - You have to deal with the partial and transitive dependency issues in your application code!

## 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) but does not ensure dependency preservation.**
- **To ensure dependency preservation, one idea:**
  - If X → Y is not preserved, add relation XY.

  Problem is that XY may violate 3NF! e.g., consider the addition of CJP to `preserve' JP → C. What if we also have J → C ?
- **Refinement: Instead of the given set of FDs F, use a *minimal cover for F*.**

## Minimal Cover for a Set of FDs

- ***Minimal cover* G for a set of FDs F:**
  - Closure of F = 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 → B, ABCD → E, EF → GH, ACDF → EG has the following minimal cover:**
  - A → B, ACD → E, EF → G and EF → H
- **M.C. implies Lossless-Join, Dep. Pres. Decomp!!!**
  - (in book)

## Summary of Schema Refinement

- **BCNF: each field contains information that cannot be inferred using only FDs.**
  - ensuring BCNF is a good heuristic.
- **Not in BCNF? Try decomposing into BCNF relations.**
  - Must consider whether all FDs are preserved!
- **Lossless-join, dependency preserving decomposition into BCNF impossible? Consider 3NF.**
  - Same if BCNF decomp is unsuitable for typical queries
  - Decompositions should be carried out and/or re-examined while keeping *performance requirements* in mind.
- **Note: even more restrictive Normal Forms exist (we don't cover them in this course, but some are in the book.)**