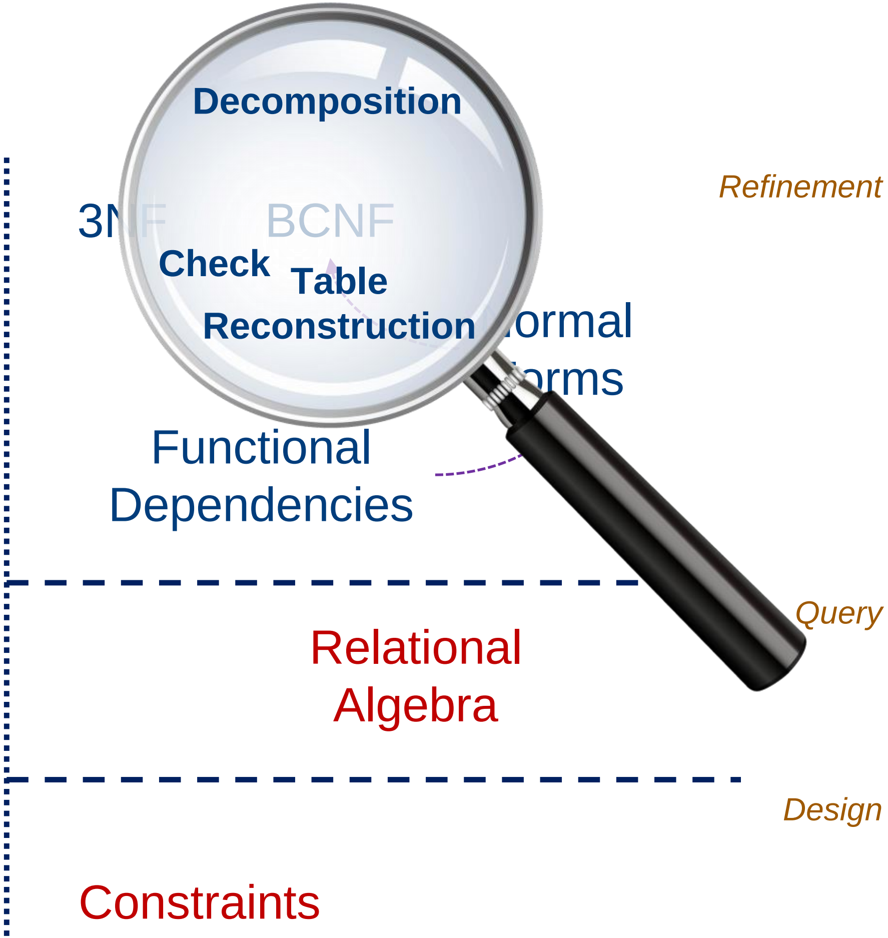
CS2102 Database Systems

Lecture 12 – Third Normal Form

Roadmap

- **Previously**
  - **BCNF Definition:**
    - Every *non-trivial & decomposed* FD has *superkey* as LHS
  - **BCNF Check:**
    - Find violation: *"more but not all"*
  - **BCNF Decomposition:**
    - For violation $A \rightarrow A^+$
      - `R1(`A^+`)`
      - `R2(`$A \cup \{R - A^+\}$`)`
    - *Repeat* until all tables are in BCNF
  - BCNF Properties:
    - ✓ No update or deletion anomalies
    - ✓ Small redundancies
    - ✓ Original table can be reconstructed
    - ✗ *Dependencies may not be preserved in the decomposed table*



Roadmap

Refinement

3NF BCNF

Normal Forms

Triggers

Functional Dependencies

Stored Procedures

Query

Relational Algebra

SQL Query

Design

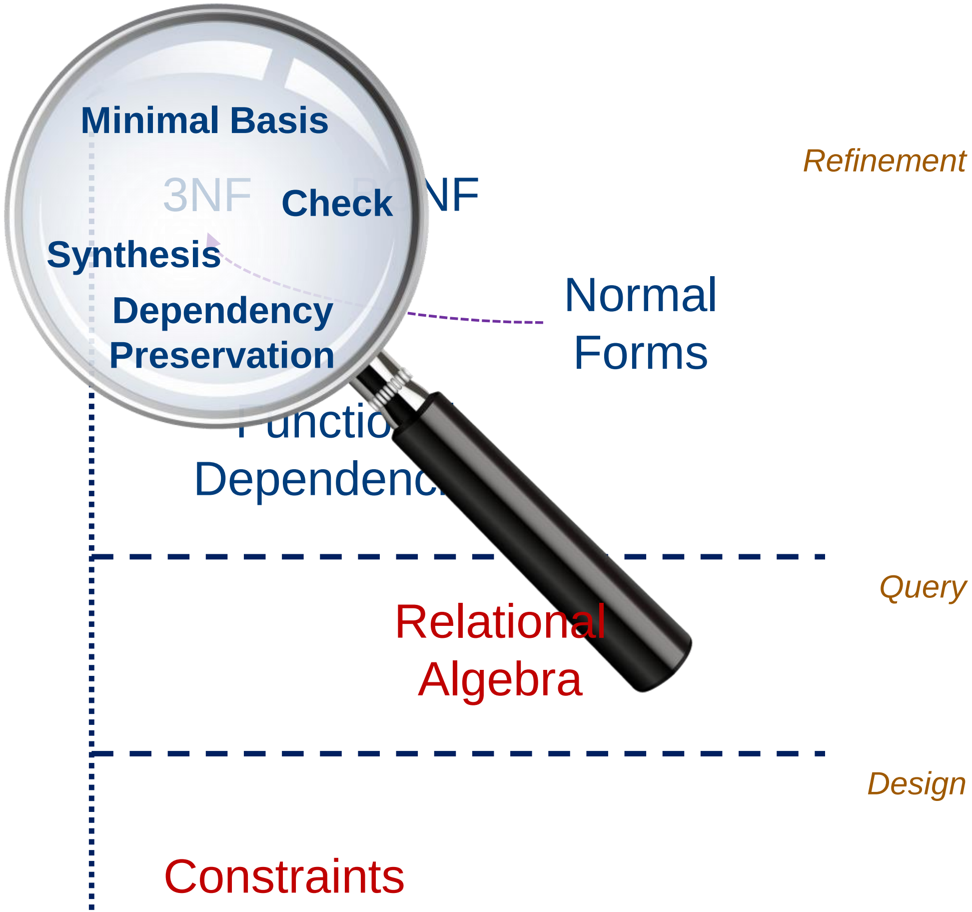
SQL DDL

ER Diagram

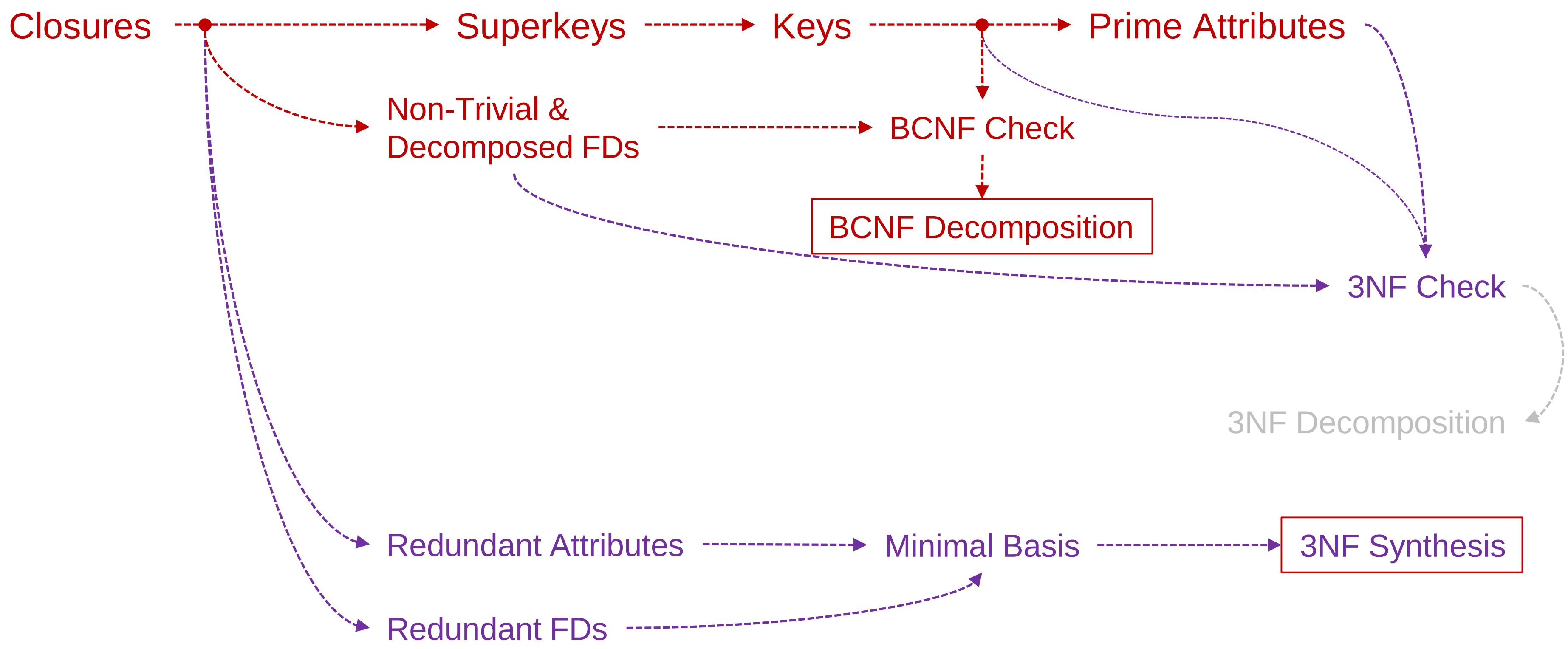
Constraints

Roadmap

- We will do this step by step
  - Dependency Preservation
    (why we need 3NF)
  - Define 3NF
  - Check 3NF
  - Minimal Basis
  - 3NF Synthesis



Algorithm Roadmap



Dependency Preservation

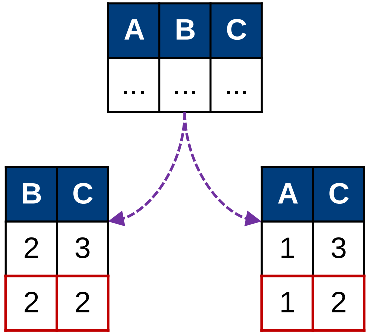
or why we need 3NF

Dependency Preservation → Define 3NF and Check → Minimal Basis → 3NF Synthesis

Dependency Preservation

- **Motivating Example**
  - Table $R(A, B, C)$ with $AB \rightarrow C$ and $C \rightarrow B$
  - $\{C\} \rightarrow \{B, C\}$ violates BCNF of $R(A, B, C)$
    - $R1(B, C)$ *(non-trivial & decomposed FD on R1: $C \rightarrow B$)*
    - $R2(A, C)$ *(non-trivial & decomposed FD on R2: nothing)*

    - *Where is $AB \rightarrow C$??*
      - *Cannot even be derived from FDs on R1 and R2*
      - *Totally "lost"*



❖ This is why we say that a BCNF decomposition may not always preserve all FDs *(non dependency preserving decomposition)*

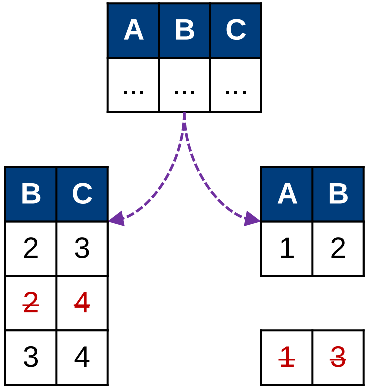
  ❖ *Dilemma!*

    ❖ *either the table has anomalies OR does not preserve constraints!*

Dependency Preservation

- “***What We Want***” **Example**
  - Table `R(A, B, C)` with `A → B`, `B → C` and `A → C`
  - `{B} → {B, C}` violates BCNF of `R(A, B, C)`
    - `R1(B, C)` *(non-trivial & decomposed FD on R1: B → C)*
    - `R2(A, B)` *(non-trivial & decomposed FD on R2: A → B)*

    - *Where is* `A → C`*??*
      - *Can be derived from FDs on* `R1` *and* `R2`
      - Compute $\{A\}^+$ w.r.t. `{B → C, A → B} = {A, B, C}`
        - So this FD is *preserved* even when it spans across multiple tables



❖ No valid insertion into `R1` or `R2` can violates this functional dependencies
  ❖ Gives rise to the notion of *FD equivalence*

Functional Dependency Equivalence

- **Definition**
  - Let F1 and F2 be sets of FDs
  - We say that F1 is *equivalent* to F2 *(i.e., F1 ≡ F2)* if and only if
    - Every FD in F1 can be derived from F2 *(i.e., F2 ⊢ F1)*
    - Every FD in F2 can be derived from F1 *(i.e., F1 ⊢ F2)*
    - ❖ *They can look different, but they carry the same information*

❖ In the context of decomposition, we can let F2 be the FD from the decomposed table

- ❖ How do we get this FD from decomposed table?
- ❖ *Union of projection*

Functional Dependency Equivalence

- **Example**
  - **Example:** R(A, B, C, D, E)
    - F1 = {A → B, AB → C, D → AC, D → E}
    - F2 = {A → BC, D → AE}
    - ❖ Show F1 ≡ F2

1. Prove that F1 can be derived from F2
    - A → B and D → E can be derived easily using *decomposition rule*
    - $\{AB\}^+ = \{ABC\}$ so AB → C is implied by F2
    - $\{D\}^+ = \{ABCDE\}$ so D → AC is implied by F2

∴ F1 can be derived from F2

Functional Dependency Equivalence

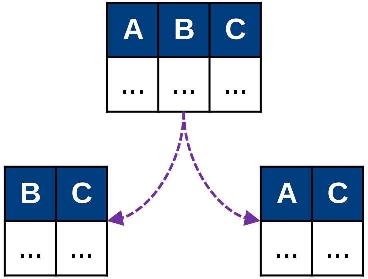
- **Example**
  - **Example:** `R(A, B, C, D, E)`
    - F1 = {A → B, AB → C, D → AC, D → E}
    - F2 = {A → BC, D → AE}
    - ❖ Show F1 ≡ F2

2. Prove that F2 can be derived from F1
    - $\{A\}^+ = \{ABC\}$ so A → BC is implied by F1
    - $\{D\}^+ = \{ABCDE\}$ so D → AE is implied by F1

∴ F2 can be derived from F1

Dependency Preservation

- **Motivating Example**
  - Table R(A, B, C) with AB → C and C → B
  - {C} → {B, C} violates BCNF of R(A, B, C)
    - R1(B, C) *(non-trivial & decomposed FD on R1: C → B)*
    - R2(A, C) *(non-trivial & decomposed FD on R2: nothing)*



    - F1 = {AB → C, C → B}
    - FR1 = {C → B}, FR2 = {}
      - F2 = {C → B}

❖ We can show that F1 $\not\equiv$ F2
  - Can we still enforce AB → C on the decomposed table?
  - YES! But not easy, need to use trigger!

3NF

Third Normal Form

Dependency Preservation → Define 3NF and Check → Minimal Basis → 3NF Synthesis

3NF

- **Definition**
  - A table `R` is in 3NF if *every non-trivial and decomposed FD either:*
    - *its left hand side is a superkey*
    - *the right hand side is a prime attributes* *(appears in a key)*
  - **Example:** `R(A, B, C)` with $C \to B$, $AC \to B$ and $AB \to C$
    - Key: {AB} and {AC}
    - Prime Attributes: {ABC}
    - Non-trivial and decomposed FDs on `R`:
      - $C \to B$
        - B is PA
      - $AB \to C$
        - AB is SK
      - $AC \to B$
        - AC is SK

    ∴ `R` satisfies 3NF

3NF

- **Definition**
  - A table `R` is in 3NF if *every non-trivial and decomposed FD either:*
    - *its left hand side is a superkey*
    - *the right hand side is a prime attributes* *(appears in a key)*

  - **Example:** `R(A, B, C)` with $A \to B$, $B \to C$, $AC \to B$ and $AB \to C$
    - Key: `{A}`
    - Prime Attributes: `{A}`
    - Non-trivial and decomposed FDs on `R`:
      - $A \to B$
        - `A` is SK
      - $B \to C$
        - `B` is **NOT** SK
        - `C` is **NOT** PA

    ∴ `R` violates 3NF

3NF vs BCNF

- **BCNF:** for any non-trivial and decomposed FD
  - The left hand side is a superkey

"Every attribute must depend ONLY on superkeys!"

NO EXCEPTION

- **3NF:** for any non-trivial and decomposed FD
  - The left hand side is a superkey
  - OR, the right hand side is a prime attribute

"Exceptions can be made for prime attributes"

3NF vs BCNF

- **BCNF:** for any non-trivial and decomposed FD
  - The left hand side is a superkey

- **3NF:** for any non-trivial and decomposed FD
  - The left hand side is a superkey
  - OR, the right hand side is a prime attribute

- **3NF** is more "*lenient*" than **BCNF**
  - Therefore
    - Satisfying BCNF ⇒ satisfying 3NF but not necessarily vice versa
    - Violating 3NF ⇒ violating BCNF but not necessarily vice versa

3NF

- **Checking 3NF**
  - A table `R` is in **NOT** 3NF if *every non-trivial and decomposed FD both:*
    - *its left hand side is NOT a superkey*
    - *the right hand side is NOT a prime attributes* *(does not appear in any key)*
  - **By Counterexample:**
    1. Consider all non-trivial and decomposed FDs of `R`
    2. For each non-trivial and decomposed FDs of `R`, check that
       a. the left hand side is superkey
       b. the right hand side is in prime attributes
       - If not one of them, then we have a counterexample
    3. If no counterexample found, then `R` satisfies 3NF

More but NOT All
$\{S\} \subset \{S\}^+ \subset R$

3NF

- ## Checking 3NF
  - A table R is in **NOT** 3NF if *every non-trivial and decomposed FD both:*
    - *its left hand side is NOT a superkey*
    - *the right hand side is NOT a prime attributes* *(does not appear in any key)*

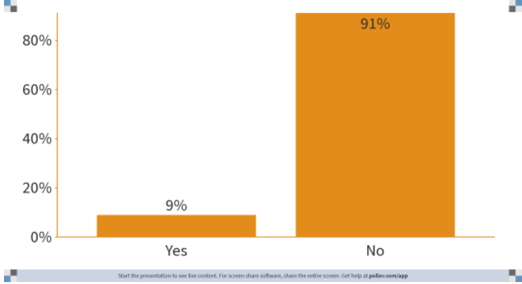
  - **By Counterexample:**
    1. Consider all subset of attributes of R
    2. Compute the closure of each subset
    3. Consider only the subset that are not superkey *(closure ≠ R)*
    4. Remove the “trivial” attributes
    5. We have a counterexample, if
        a. The resulting set is non-empty, **and**
        b. There is an attribute in the right hand side that is not in the left hand side and not a prime attribute

3NF

- ## Checking 3NF
  - **Example:** `R(A, B, C, D)` with `AB` → `C`, `C` → `D` and `D` → `A`
    1. Consider all subset of attributes of `R`
    2. Compute the closure of each subset
    3. Consider only the subset that are not superkey *(closure ≠ `R`)*
    4. Remove the "trivial" attributes
    5. We have a counterexample, if
       a. The resulting set is non-empty, **and**
       b. There is an attribute in the right hand side that is not in the left hand side and not a prime attribute
  - Keys = `{AB}`, `{BC}`, `{BD}` Prime attributes = `{ABCD}`

$\{A\}^+$	=	{A}	$\{B\}^+$	=	{B}	$\{C\}^+$	=	{ACD}	$\{D\}^+$	=	{AD}
$\{AB\}^+$	=	{ABCD}	$\{AC\}^+$	=	{ACD}	$\{AD\}^+$	=	{AD}			
$\{BC\}^+$	=	{ABCD}	$\{BD\}^+$	=	{ABCD}	$\{CD\}^+$	=	{ACD}			
$\{ABC\}^+$	=	{ABCD}	$\{ABD\}^+$	=	{ABCD}	$\{ACD\}^+$	=	{ACD}	$\{BCD\}^+$	=	{ABCD}

3NF

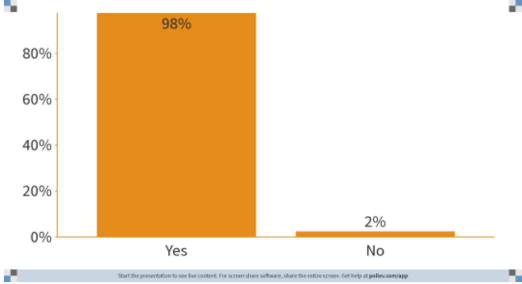


- **Checking 3NF**
  - A table `R` is in **NOT** 3NF if *every non-trivial and decomposed FD both:*
    - *its left hand side is NOT a superkey*
    - *the right hand side is NOT a prime attributes* *(does not appear in any key)*

  - **Exercise:** `R(A, B, C, D)` with `B → C` and `B → D`
    - Keys = {AB} Prime attributes = {AB}

$\{A\}^+$	=	$\{A\}$	$\{B\}^+$	=	$\{BCD\}$	$\{C\}^+$	=	$\{C\}$	$\{D\}^+$	=	$\{D\}$
$\{AB\}^+$	=	$\{ABCD\}$	$\{AC\}^+$	=	$\{AC\}$	$\{AD\}^+$	=	$\{AD\}$			
$\{BC\}^+$	=	$\{BCD\}$	$\{BD\}^+$	=	$\{BCD\}$	$\{CD\}^+$	=	$\{CD\}$			
$\{ABC\}^+$	=	$\{ABCD\}$	$\{ABD\}^+$	=	$\{ABCD\}$	$\{ACD\}^+$	=	$\{ACD\}$	$\{BCD\}^+$	=	$\{BCD\}$

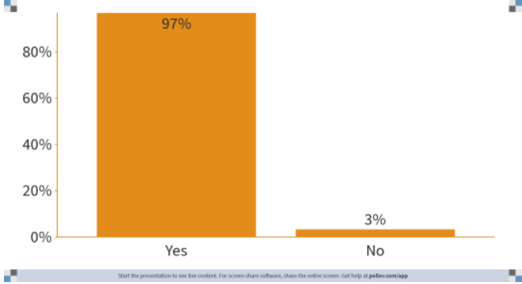
3NF



- ## Checking 3NF
  - A table R is in **NOT** 3NF if *every non-trivial and decomposed FD both:*
    - *its left hand side is NOT a superkey*
    - *the right hand side is NOT a prime attributes* *(does not appear in any key)*
  - **Exercise:** R(A, B, C, D) with A → B, B → C, C → D and D → A
    - Keys = {A}, {B}, {C}, {D} Prime attributes = {ABCD}

$\{A\}^+ = \{ABCD\}$	$\{B\}^+ = \{ABCD\}$	$\{C\}^+ = \{ABCD\}$	$\{D\}^+ = \{ABCD\}$
$\{AB\}^+ = \{ABCD\}$	$\{AC\}^+ = \{ABCD\}$	$\{AD\}^+ = \{ABCD\}$	
$\{BC\}^+ = \{ABCD\}$	$\{BD\}^+ = \{ABCD\}$	$\{CD\}^+ = \{ABCD\}$	
$\{ABC\}^+ = \{ABCD\}$	$\{ABD\}^+ = \{ABCD\}$	$\{ACD\}^+ = \{ABCD\}$	$\{BCD\}^+ = \{ABCD\}$

3NF

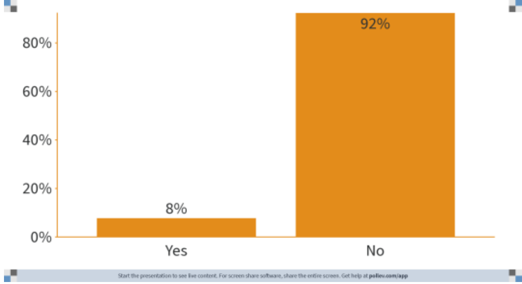


- **Checking 3NF**
  - A table R is in **NOT** 3NF if *every non-trivial and decomposed FD both:*
    - *its left hand side is NOT a superkey*
    - *the right hand side is NOT a prime attributes* *(does not appear in any key)*

  - **Exercise:** R(A, B, C, D) with AB → D, BD → C, CD → A and AC → B
    - Keys = {AB}, {AC}, {BD}, {CD}   Prime attributes = {ABCD}

$\{A\}^+ = \{A\}$	$\{B\}^+ = \{B\}$	$\{C\}^+ = \{C\}$	$\{D\}^+ = \{D\}$
$\{AB\}^+ = \{ABCD\}$	$\{AC\}^+ = \{ABCD\}$	$\{AD\}^+ = \{AD\}$	
$\{BC\}^+ = \{BC\}$	$\{BD\}^+ = \{ABCD\}$	$\{CD\}^+ = \{ABCD\}$	
$\{ABC\}^+ = \{ABCD\}$	$\{ABD\}^+ = \{ABCD\}$	$\{ACD\}^+ = \{ABCD\}$	$\{BCD\}^+ = \{ABCD\}$

3NF



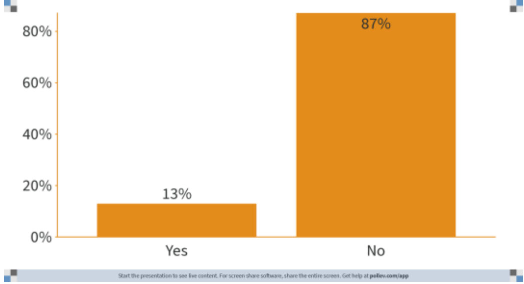
- **Checking 3NF**
  - A table R is in **NOT** 3NF if *every non-trivial and decomposed FD both:*
    - *its left hand side is NOT a superkey*
    - *the right hand side is NOT a prime attributes* *(does not appear in any key)*
  - **Exercise:** R(A, B, C, D, E) with AB → C, C → E, E → A and E → D
    - Keys = {AB} , {BC} , {BE} Prime attributes = {ABCE}

$\{A\}^+ = \{A\}$ | $\{B\}^+ = \{B\}$ | $\{C\}^+ = \{ACDE\}$

Sometimes the violation is obvious like this E → D

Or you can always start from smallest subset of attributes and try to find violation

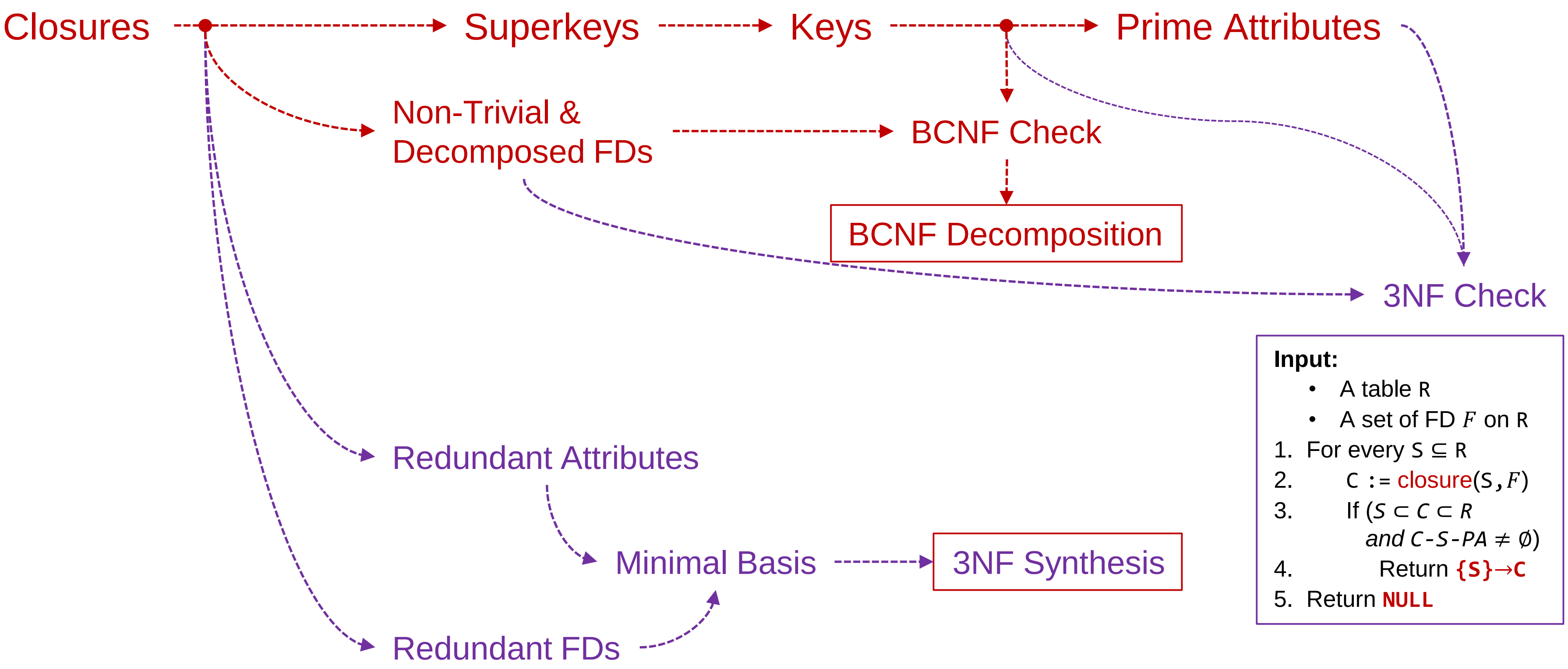
3NF



- **Checking 3NF**
  - A table R is in **NOT** 3NF if *every non-trivial and decomposed FD both:*
    - *its left hand side is NOT a superkey*
    - *the right hand side is NOT a prime attributes* *(does not appear in any key)*
  - **Exercise:** R(A, B, C, D, E) with AB → C, DE → C and B → E
    - Keys = {ABD}   Prime attributes = {ABD}

$\{A\}^+ = \{A\}$ | $\{B\}^+ = \{BE\}$

Algorithm Roadmap



Input:

- A table R
- A set of FD F on R

1. For every S ⊆ R
2. C := closure(S, F)
3. If ($S \subset C \subset R$ *and* C-S-$PA \neq \emptyset$)
4. Return **{S}→C**
5. Return **NULL**

3NF Decomposition

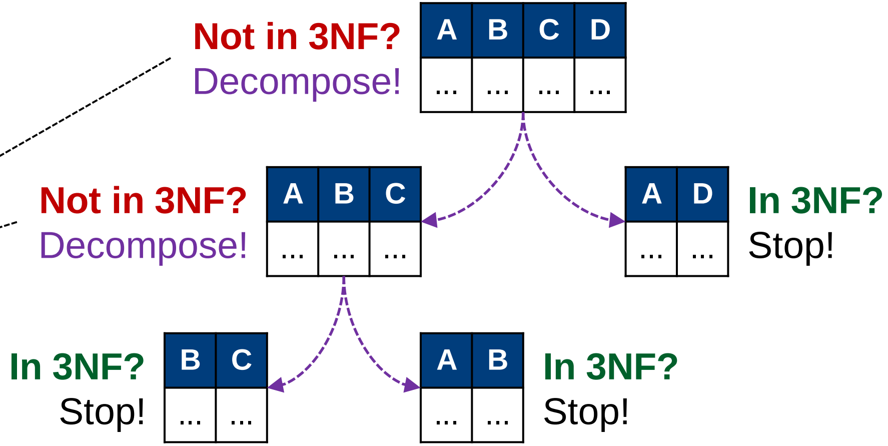
Dependency Preservation → Define 3NF and Check → Minimal Basis → 3NF Synthesis

3NF Decomposition

- **Normalization**
  - **Same Idea as BCNF Decomposition:**
    - Same potential problem of non dependency preserving decomposition
    - Is there a better idea?

Input:
- A table `R`
- A set of FD F on `R`

1. For every `S` ⊆ `R`
2.   `C :=` closure(`S`,F)
3.   If ($S \subset C \subset R$ *and* $C\text{-}S\text{-}PA \neq \emptyset$)
4.   Return **`{S}→C`**
5. Return **`NULL`**



Minimal Basis

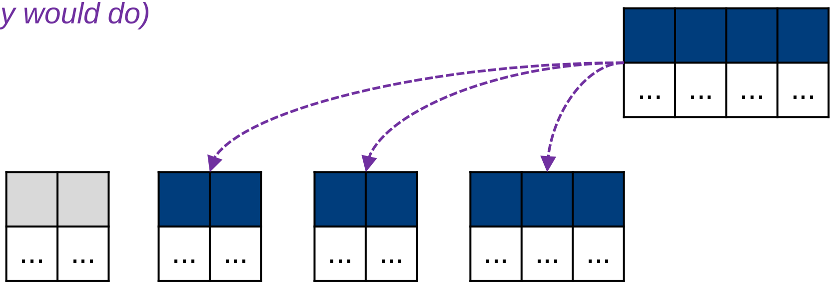
on our path to 3NF synthesis

Dependency Preservation → Define 3NF and Check → Minimal Basis → 3NF Synthesis

Minimal Basis

- **A Sneak Peek**
  - **3NF Synthesis**
    - **Input:** Table R and a set of FDs F

    1. Derive minimal basis of F
    2. From the minimal basis, combine the FDs for which the left hand sides are the same *(union rule, producing what's called as canonical cover)*
    3. Create a table for each FDs remained in the minimal basis after union
    4. If none of the tables contains a key of the original table R, create a table that contains a key of R *(any key would do)*



Minimal Basis

- **Definition**
  - Given a set F of FDs, the minimal basis of F is a *simplified* version of F
    - Also called minimal cover *(let's call this F_b)*
  - How simplified?
    - Four conditions
      1. Every FD in F_b can be derived from F and vice versa
      2. Every FD in F_b are non-trivial and decomposed FD
      3. For each FD in F_b, none of the attributes on the left hand side is redundant *(no redundant attributes)*
      4. No FD in F_b are redundant *(no redundant FD)*

❖ *Redundant means that we can remove them (attributes or FDs) without affecting the original FD (i.e., still equivalent)*

Minimal Basis

- ## Definition
  - Given a set F of FDs, the minimal basis of F is a *simplified* version of F
    - Also called minimal cover *(let's call this F_b)*
  - How simplified?
    - Four conditions

1. Every FD in F_b can be derived from F and vice versa

```
-  F  = {A → BD,  AB → C,  C → D,  BC → D}
✓  F1 = {A → B,   A → C,   C → D}
✗  F2 = {A → D,   A → C,   C → D}
✗  F3 = {A → B,   A → C,   C → D,  D → C}
```

NOTE
F cannot be derived from F2
F3 cannot be derived from F

Minimal Basis

- **Definition**
  - Given a set F of FDs, the minimal basis of F is a *simplified* version of F
    - Also called minimal cover *(let's call this F_b)*
  - How simplified?
    - Four conditions

2. Every FD in F_b are non-trivial and decomposed FD

```
-  F  = {A → BD,  AB → C,  C → D,  BC → D}
✓  F1 = {A → B,   A → C,   C → D}
✗  F2 = {A → BD,  A → C,   C → D}
✓  F3 = {A → B,   A → C,   C → D,  BC → D}
```

NOTE
A → BD is non-decomposed

Minimal Basis

- **Definition**
  - Given a set F of FDs, the minimal basis of F is a *simplified* version of F
    - Also called minimal cover *(let's call this F_b)*
  - How simplified?
    - Four conditions

3. For each FD in F_b, none of the attributes on the left hand side is redundant *(no redundant attributes)*
   - $F = \{A \rightarrow BD,\ AB \rightarrow C,\ C \rightarrow D,\ BC \rightarrow D\}$
     - Consider $AB \rightarrow C$, if we remove B from left hand side, we have $A \rightarrow C$
     - We can derive $A \rightarrow C$ from F since $\{A\}^+ = \{ABCD\}$ *(i.e., $A \rightarrow C$ is "hidden" in F)*
     - So we can add $A \rightarrow C$ without adding extraneous constraints
     - But once we add $A \rightarrow C$ then $AB \rightarrow C$ is redundant!
       - Effectively, we found that B is redundant in $AB \rightarrow C$

       $\therefore$ $AB \rightarrow C$ should not be in minimal basis

Minimal Basis

- **Definition**
  - Given a set `F` of FDs, the minimal basis of `F` is a *simplified* version of F
    - Also called minimal cover *(let's call this F_b)*
  - How simplified?
    - Four conditions

4. No FD in F_b are redundant *(no redundant FD)*
   - $F = \{A \rightarrow BD,\ AB \rightarrow C,\ C \rightarrow D,\ BC \rightarrow D\}$
     - Consider $BC \rightarrow D$
     - We can derive it from $C \rightarrow D$
       - So we can remove it without removing any important information

       ∴ $BC \rightarrow D$ should not be in minimal basis

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - $F = \{A \rightarrow B,\ B \rightarrow C,\ A \rightarrow C\}$ $F_b = \{A \rightarrow B,\ B \rightarrow C\}$
  - Is F_b a minimal basis for F?
    1. $A \rightarrow C$ in F can be derived from F_b
       - F_b is F by removal of $A \rightarrow C$
    2. All FDs in F_b are non-trivial and decomposed
    3. For any FD in F_b, if we remove an attribute from left hand side, then the FD cannot be derived from F *(in fact, they have no left hand side!)*
    4. If any FD in F_b is removed, then some FD in F cannot be derived

$\therefore$ F_b is a minimal basis for F

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - $F = \{A \rightarrow B,\ B \rightarrow C,\ A \rightarrow C\}$ $F_b = \{A \rightarrow B,\ AB \rightarrow C\}$
  - Is F_b a minimal basis for F?
    1. $B \rightarrow C$ in F can **NOT** be derived from F_b

    $\therefore$ F_b is **NOT** a minimal basis for F

ERRATA

There was a typo error:
Originally it was written as
$A \rightarrow C$ in F can NOT be derived from F_b
It should be $B \rightarrow C$ in F can NOT be derived from F_b

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - $F = \{A \rightarrow B,\ B \rightarrow C,\ A \rightarrow C\}$ $F_b = \{A \rightarrow BC,\ A \rightarrow C\}$
  - Is F_b a minimal basis for F?
    1. $B \rightarrow C$ in F can **NOT** be derived from F_b
    2. Also...
       - $A \rightarrow BC$ is **NOT** a decomposed FD

$\therefore$ F_b is **NOT** a minimal basis for F

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - $F = \{A \rightarrow B, \quad A \rightarrow C, \quad C \rightarrow B\}$ $\qquad F_b = \{A \rightarrow B, \quad AB \rightarrow C, \quad C \rightarrow B\}$
  - Is F_b a minimal basis for F?
    1. ✓
    2. ✓
    3. B in $AB \rightarrow C$ in can be removed in Fb *(**redundant attribute**)*
       - $\{A\}^+ = \{ABC\}$

    ∴ F_b is **NOT** a minimal basis for F

Minimal Basis

Conditions

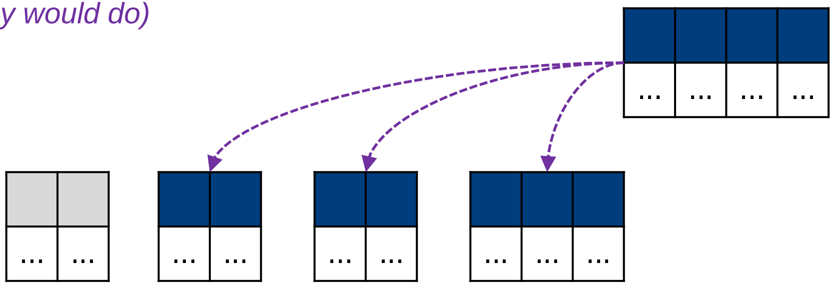
1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - $F = \{A \rightarrow B, \quad B \rightarrow C, \quad A \rightarrow C\}$ $\qquad F_b = \{A \rightarrow B, \quad B \rightarrow C, \quad A \rightarrow C\}$
  - Is F_b a minimal basis for F?
    1. ✓
    2. ✓
    3. ✓
    4. $A \rightarrow C$ can be removed! ***(redundant FD)***

$\therefore$ F_b is **NOT** a minimal basis for F

Minimal Basis

- ## A Reminder on Why We Need Minimal Basis
  - **3NF Synthesis**
    - **Input:** Table R and a set of FDs F
    1. Derive ***minimal basis*** of F
    2. From the ***minimal basis***, combine the FDs for which the left hand sides are the same *(union rule, producing what's called as canonical cover)*
    3. Create a table for each FDs remained in the ***minimal basis*** after union
    4. If none of the tables contains a key of the original table R, create a table that contains a key of R *(any key would do)*



Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Algorithm**

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
4. Remove redundant FDs *(maintain $F_b \equiv F$)*

❖ *Clearly, at the end, we have satisfied all conditions* *(as long as we maintain $F_b \equiv F$)*

➢ But how do we perform step 3?

IDEA

Start with F = F1 ∪ {AB → C}.

- If A is redundant, then F1 ∪ {A → C} is equivalent to F.
- F can definitely be derived from F1 because {AB → C} can be derived from {A → C} using Augmentation + Decomposition.
- So we only have to check that F1 can be derived from F.
- This is done by deriving {AB → C} from F1 ∪ {A → C}
  - How? Compute $\{A\}^+$ and check if C is inside

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Algorithm: Remove Redundant Attribute**

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
4. Remove redundant FDs *(maintain $F_b \equiv F$)*

   - Consider an FD `{A}` → `B` in `F` for any `A` and `B` *(in here, `{A}` is a set of attributes)*
     1. Consider an attribute `C` in `{A}`
        - Compute $\{A\text{-}C\}^+$ using `F` *(in here, `{A-C}` means we remove `C` from `{A}`)*
        - If $B \in \{A\text{-}C\}^+$, then we can remove `C` *(because `{A-C}`→`B`)*
          - Repeat step 1 but with `{A}` → `B` changed with `{A-C}` → `B`
     2. Do this for all FDs

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Algorithm: Remove Redundant Attribute**

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
4. Remove redundant FDs *(maintain $F_b \equiv F$)*

- **Example:**
  - `F = {A → B, A → D, AB → C, C → D, BC → D}`
    - Consider `AB → C`
      - `{A}+ = {A,B,C,D}`
        - `B` can be removed from `AB → C`
    - Repeat with
      - `F = {A → B, A → D, A → C, C → D, BC → D}`

Algorithm

- For `{A} → B` in `F`

1. Consider an attribute `C` in `{A}`
   - Compute `{A-C}+` using `F`
   - If `B` in `{A-C}+`, replace `{A} → B` with `{A-C} → B` then repeat
2. Do this for all FDs

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- ## Algorithm: Remove Redundant Attribute

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
4. Remove redundant FDs *(maintain $F_b \equiv F$)*

- **Example:**
  - F = {A → B, A → D, A → C, C → D, BC → D}
    - Consider BC → D
      - $\{B\}^+ = \{B\}$
        - C can **NOT** be removed from BC → D
      - $\{C\}^+ = \{CD\}$
        - B can be removed from BC → D
    - Repeat with
      - F = {A → B, A → D, A → C, C → D, C → D}

Algorithm

- For {A} → B in F

1. Consider an attribute C in {A}
   - Compute $\{A-C\}^+$ using F
   - If B in $\{A-C\}^+$, replace {A} → B with {A-C} → B then repeat
2. Do this for all FDs

Minimal Basis

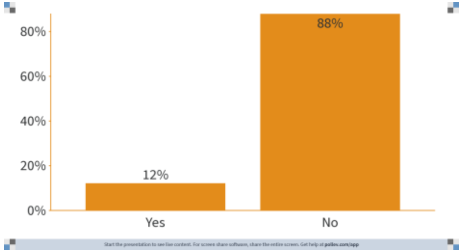
Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

• Algorithm: Remove Redundant Attribute

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
4. Remove redundant FDs *(maintain $F_b \equiv F$)*

- **Example:**
  - `F = {A → B, A → D, A → C, C → D, C → D}`
    - Nothing else to remove
- **Question:**
  - Is this always gives us a unique solution?



Algorithm

- For `{A}` → `B` in `F`
1. Consider an attribute `C` in `{A}`
   - Compute $\{A\text{-}C\}^+$ using `F`
   - If `B` in $\{A\text{-}C\}^+$, replace `{A}` → `B` with `{A-C}` → `B` then repeat
2. Do this for all FDs

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Algorithm: Remove Redundant Attribute**

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
4. Remove redundant FDs *(maintain $F_b \equiv F$)*

- **Example:**
  - `F = {A → B, B → A, AB → C}`
    - Consider `AB → C`
      - $\{A\}^+ = \{A,B,C\}$
        - `B` can be removed from `AB → C`
    - We could have started with
      - $\{B\}^+ = \{A,B,C\}$
        - `A` can be removed from `AB → C`
    - BUT, we cannot remove both!
      - So two possible solutions

Algorithm

- For `{A} → B` in `F`

1. Consider an attribute `C` in `{A}`
   - Compute $\{A-C\}^+$ using `F`
   - If `B` in $\{A-C\}^+$, replace `{A} → B` with `{A-C} → B` then repeat
2. Do this for all FDs

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Algorithm**
  2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
  3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
  4. Remove redundant FDs *(maintain $F_b \equiv F$)*

❖ *Clearly, at the end, we have satisfied all conditions* *(as long as we maintain $F_b \equiv F$)*

➢ But how do we perform **step 4**?

IDEA

Start with F = F1 ∪ {A → B}.

- If {A → B} is redundant, then F1 is equivalent to F.
- F1 can definitely be derived from F because F1 contains everything that F has but F has an additional {A → B}.
- So we only have to check that F can be derived from F1.
- But the difference is only {A → B}.
- This is done by deriving {A → B} from F1
  - How? Compute $\{A\}^+$ and check if B is inside

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Algorithm: Remove Redundant FD**

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
4. Remove redundant FDs *(maintain $F_b \equiv F$)*

- Consider an FD $\{A\} \rightarrow B$ in F for any A and B *(in here, $\{A\}$ is a set of attributes)*
  - **Observation:**
    - If we can remove $\{A\} \rightarrow B$, that means $F - \{\{A\} \rightarrow B\} \equiv F$
    - The only difference is the removal of $\{A\} \rightarrow B$
      - Clearly, all FD in $F - \{\{A\} \rightarrow B\}$ can be derived from F
      - So what we need to show is only that $\{A\} \rightarrow B$ can be derived from $F - \{\{A\} \rightarrow B\}$
    - Compute $\{A\}^+$ using $F - \{\{A\} \rightarrow B\}$
      - Then check if B is in $\{A\}^+$

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Algorithm: Remove Redundant FD**

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
4. Remove redundant FDs *(maintain $F_b \equiv F$)*

   - Consider an FD `{A}` → `B` in `F` for any `A` and `B` *(in here, `{A}` is a set of attributes)*
     1. Compute $\{A\}^+$ using `F - {{A} → B}`
        - If $B \in \{A\}^+$, then we can remove `{A}` → `B` *(because `{A}`→`B` even in its absence)*
          - Repeat with next FD but with `{A}` → `B` removed
     2. Do this for all FDs

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

• Algorithm: Remove Redundant FD

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
4. Remove redundant FDs *(maintain $F_b \equiv F$)*

- **Example:**
  - $F = \{A \rightarrow B, A \rightarrow D, A \rightarrow C, C \rightarrow D\}$
    - Consider $A \rightarrow B$
      - $\{A\}^+$ w.r.t $\{A \rightarrow D, A \rightarrow C, C \rightarrow D\}$ $= \{A,C,D\}$
        - $A \rightarrow B$ can **NOT** be remove

Algorithm

- For $\{A\} \rightarrow B$ in F
  1. Compute $\{A\}^+$ using $F-\{\{A\}\rightarrow B\}$
     - If B in $\{A\}^+$, remove $\{A\} \rightarrow B$ then repeat with next FD
  2. Do this for all FDs

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Algorithm: Remove Redundant FD**

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
4. Remove redundant FDs *(maintain $F_b \equiv F$)*

   - **Example:**
     - F = {A → B, A → D, A → C, C → D}
       - Consider A → D
         - $\{A\}^+$ w.r.t {A → B, A → C, C → D}
           = {A,B,C,D}
             - A → D can be removed
       - Repeat with
         - F = {A → B, A → C, C → D}

Algorithm

- For {A} → B in F
  1. Compute $\{A\}^+$ using F-{{A}→B}
     - If B in $\{A\}^+$, remove {A} → B
       then repeat with next FD
  2. Do this for all FDs

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Algorithm: Remove Redundant FD**

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
4. Remove redundant FDs *(maintain $F_b \equiv F$)*

- **Example:**
  - F = {A → B, A → C, C → D}
    - Consider A → C
      - $\{A\}^+$ w.r.t {A → B, C → D}
        = {A,B}
        - A → C can **NOT** be removed

Algorithm

- For {A} → B in F
  1. Compute $\{A\}^+$ using F-{{A}→B}
     - If B in $\{A\}^+$, remove {A} → B then repeat with next FD
  2. Do this for all FDs

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- ## Algorithm: Remove Redundant FD

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
4. Remove redundant FDs *(maintain $F_b \equiv F$)*

- **Example:**
  - F = {A → B, A → C, C → D}
    - Consider C → D
      - $\{C\}^+$ w.r.t {A → B, A → C}
        = {C}
        - C → D can **NOT** be removed

Algorithm

- For {A} → B in F
  1. Compute $\{A\}^+$ using F-{{A}→B}
     - If B in $\{A\}^+$, remove {A} → B
       then repeat with next FD
  2. Do this for all FDs

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

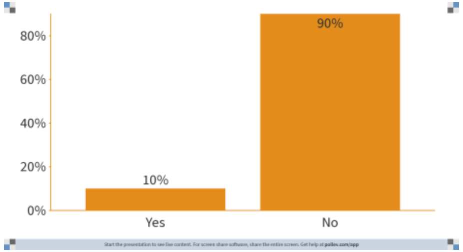
- ## Algorithm: Remove Redundant FD

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
4. Remove redundant FDs *(maintain $F_b \equiv F$)*

Algorithm

- For `{A}` → `B` in `F`
  1. Compute `{A}`$^+$ using `F-{{A}→B}`
     - If `B` in `{A}`$^+$, remove `{A}` → `B` then repeat with next FD
  2. Do this for all FDs

- **Example:**
  - `F = {A → B, A → C, C → D}`
    - No other FDs to consider
- **Question:**
  - Is this always gives us a unique solution?



Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- ## Algorithm: Remove Redundant FD

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
4. Remove redundant FDs *(maintain $F_b \equiv F$)*

- **Example:**
  - `F = {A→B, A→C, B→A, B→C, C→A, C→B}`
    - Can remove either one but not both
      - A → B
        - `{A}`$^+$ w.r.t. `{A→C, B→A, B→C, C→A, C→B}` `= {A, B, C}`
      - A → C
        - `{A}`$^+$ w.r.t. `{A→B, B→A, B→C, C→A, C→B}` `= {A, B, C}`

Algorithm

- For `{A} → B` in `F`
  1. Compute `{A}`$^+$ using `F-{{A}→B}`
     - If `B` in `{A}`$^+$, remove `{A} → B` then repeat with next FD
  2. Do this for all FDs

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Algorithm**

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*

- For `{A}` $\rightarrow$ `B` in `F`

1. Consider an attribute `C` in `{A}`
   - Compute $\{A-C\}^+$ using `F`
   - If `B` in $\{A-C\}^+$, replace `{A}` $\rightarrow$ `B` with `{A-C}` $\rightarrow$ `B` then repeat
2. Do this for all FDs

4. Remove redundant FDs *(maintain $F_b \equiv F$)*

- For `{A}` $\rightarrow$ `B` in `F`
  1. Compute $\{A\}^+$ using `F-{{A}→B}`
     - If `B` in $\{A\}^+$, remove `{A}` $\rightarrow$ `B` then repeat with next FD
  2. Do this for all FDs

❖ *Clearly, at the end, we have satisfied all conditions* *(as long as we maintain $F_b \equiv F$)*

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - $F = \{BC \rightarrow DE,\ A \rightarrow E,\ D \rightarrow A,\ E \rightarrow B\}$

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
   - $F = \{BC \rightarrow D,\ BC \rightarrow E,\ A \rightarrow E,\ D \rightarrow A,\ E \rightarrow B\}$
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
   - Two candidates
     1. $BC \rightarrow D$
     2. $BC \rightarrow E$

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - `F = {BC → D, BC → E, A → E, D → A, E → B}`

3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
   - Consider `BC → D`
     - `{B}+ = {B}`
       - So `C` can **NOT** be removed
     - `{C}+ = {C}`
       - So `B` can **NOT** be removed

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - `F = {BC → D, BC → E, A → E, D → A, E → B}`

3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
   - Consider `BC → E`
     - `{B}+ = {B}`
       - So `C` can **NOT** be removed
     - `{C}+ = {C}`
       - So `B` can **NOT** be removed

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - $F = \{BC \rightarrow D,\ BC \rightarrow E,\ A \rightarrow E,\ D \rightarrow A,\ E \rightarrow B\}$

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
   - $F = \{BC \rightarrow D,\ BC \rightarrow E,\ A \rightarrow E,\ D \rightarrow A,\ E \rightarrow B\}$
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
   - No redundant attributes
4. Remove redundant FDs *(maintain $F_b \equiv F$)*
   - Need to check everything

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - $F = \{BC \rightarrow D,\ BC \rightarrow E,\ A \rightarrow E,\ D \rightarrow A,\ E \rightarrow B\}$

4. Remove redundant FDs *(maintain $F_b \equiv F$)*
   - Consider $BC \rightarrow D$
     - $\{BC\}^+$ w.r.t. $\{BC \rightarrow E,\ A \rightarrow E,\ D \rightarrow A,\ E \rightarrow B\}$
       $= \{B, C\}$
       - So $BC \rightarrow D$ is **NOT** redundant

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - $F = \{BC \rightarrow D,\ BC \rightarrow E,\ A \rightarrow E,\ D \rightarrow A,\ E \rightarrow B\}$

4. Remove redundant FDs *(maintain $F_b \equiv F$)*
   - Consider $BC \rightarrow E$
     - $\{BC\}^+$ w.r.t. $\{BC \rightarrow D,\ A \rightarrow E,\ D \rightarrow A,\ E \rightarrow B\}$ $= \{A, B, C, D, E\}$
       - So $BC \rightarrow E$ is **redundant**
   - ❖ Continue with $F = \{BC \rightarrow D,\ A \rightarrow E,\ D \rightarrow A,\ E \rightarrow B\}$

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - F = {BC → D, A → E, D → A, E → B}

  4. Remove redundant FDs *(maintain $F_b \equiv F$)*
     - Consider A → E
       - $\{A\}^+$ w.r.t. {BC → D, D → A, E → B} = {A}
         - So A → E is **NOT** redundant

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - $F = \{BC \rightarrow D,\ A \rightarrow E,\ D \rightarrow A,\ E \rightarrow B\}$

4. Remove redundant FDs *(maintain $F_b \equiv F$)*
   - Consider $D \rightarrow A$
     - $\{D\}^+$ w.r.t. $\{BC \rightarrow D,\ A \rightarrow E,\ E \rightarrow B\}$
       $= \{D\}$
       - So $D \rightarrow A$ is **NOT** redundant

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - F = {BC → D, A → E, D → A, E → B}

4. Remove redundant FDs *(maintain $F_b \equiv F$)*
   - Consider E → B
     - $\{E\}^+$ w.r.t. {BC → D, A → E, D → A}
       = {E}
       - So E → B is **NOT** redundant

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Example**
  - F = {BC → D, A → E, D → A, E → B}

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
   - F = {BC → D, BC → E, A → E, D → A, E → B}
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
   - No redundant attributes
4. Remove redundant FDs *(maintain $F_b \equiv F$)*
   - BC → E is redundant

❖ F_b = {BC → D, A → E, D → A, E → B}

Minimal Basis

Conditions

1. $F_b \equiv F$
2. Non-trivial and decomposed
3. No redundant attributes
4. No redundant FD

- **Exercise**
  - $F = \{A \rightarrow C, \; AC \rightarrow D, \; AD \rightarrow B\}$

2. Transform the FDs so that it is non-trivial and decomposed *(maintain $F_b \equiv F$)*
   - $F = \{A \rightarrow C, \; AC \rightarrow D, \; AD \rightarrow B\}$
3. Remove redundant attributes on the left hand sides of each FDs *(maintain $F_b \equiv F$)*
   - Two candidates
     1. $AC \rightarrow D$ *(C is redundant)*
     2. $AD \rightarrow B$ *(D is redundant)*
   - $F = \{A \rightarrow C, \; A \rightarrow D, \; A \rightarrow B\}$
4. Remove redundant FDs *(maintain $F_b \equiv F$)*
   - No redundant FD
   - $F_b = \{A \rightarrow C, \; A \rightarrow D, \; A \rightarrow B\}$

3NF Synthesis

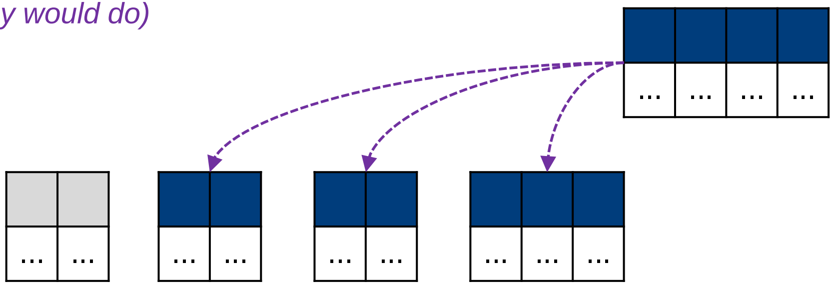
our final product

Dependency Preservation → Define 3NF and Check → Minimal Basis → 3NF Synthesis

3NF Synthesis

- **Algorithm**
  - **3NF Synthesis**
    - **Input:** Table R and a set of FDs F

1. Derive minimal basis of F
2. From the minimal basis, combine the FDs for which the left hand sides are the same *(union rule, producing what's called as canonical cover)*
3. **Create a table for each FDs remained in the minimal basis after union**
4. If none of the tables contains a key of the original table R, create a table that contains a key of R *(any key would do)*



3NF Synthesis

3NF Synthesis
1. Derive *minimal basis* of F
2. Produce *canonical cover*
3. Create a table for each FD
4. Add the *key* if missing

- ## Algorithm
  - **Example:** R(A, B, C, D, E) with BC → DE, A → E, D → A and E → B
    - F = {BC → DE, A → E, D → A, E → B}

1. Derive minimal basis of F
   - F_b = {BC → D, A → E, D → A, E → B}
2. Produce canonical cover
   - F_c = {BC → D, A → E, D → A, E → B}
3. Create a table for each FD
   - R1(B, C, D), R2(A, E), R3(A, D) and R4(B, E)
4. Add the key if missing
   - Keys = {AC}, {BC}, {CD}, {CE}
   - R1 contains a key

Why add Key?
Ensure *lossless join* decomposition

3NF Synthesis

3NF Synthesis
1. Derive *minimal basis* of `F`
2. Produce *canonical cover*
3. Create a table for each FD
4. Add the *key* if missing

- ## Lossless Join Decomposition
  - **Example:** `R(A, B, C, D)` with `A → B` and `C → D`
    - `F = {A → B,  C → D}`
    1. Derive minimal basis of `F`
       - F_b `= {A → B,  C → D}`
    2. Produce canonical cover
       - F_c `= {A → B,  C → D}`
    3. Create a table for each FD
       - `R1(A, B)` and `R2(C, D)`
    4. Add the key if missing
       - `Keys = {AC}`
       - Add `R3(A, C)`

Why add Key?
`R1(A, B)` and `R2(C, D)` cannot be used to reconstruct `R(A, B, C, D)`

3NF Synthesis

3NF Synthesis

1. Derive *minimal basis* of F
2. Produce *canonical cover*
3. Create a table for each FD
4. Add the *key* if missing

- ## Algorithm
  - **Exercise:** R(A, B, C, D, E) with $A \rightarrow B$, $A \rightarrow C$, $B \rightarrow C$, $E \rightarrow C$ and $E \rightarrow D$
    - $F = \{A \rightarrow B,\ A \rightarrow C,\ B \rightarrow C,\ E \rightarrow C,\ E \rightarrow D\}$

    1. Derive minimal basis of F
       - $F_b = \{A \rightarrow B,\ B \rightarrow C,\ E \rightarrow C,\ E \rightarrow D\}$
    2. Produce canonical cover
       - $F_C = \{A \rightarrow B,\ B \rightarrow C,\ E \rightarrow CD\}$
    3. Create a table for each FD
       - R1(A, B), R2(B, C) and R3(C, D, E)
    4. Add the key if missing
       - Keys = {AE}
       - Add R4(A, E)

3NF Synthesis

3NF Synthesis
1. Derive *minimal basis* of F
2. Produce *canonical cover*
3. Create a table for each FD
4. Add the *key* if missing

- ## Algorithm
  - **Exercise:** R(A, B, C, D, E) with $A \rightarrow B$, $AB \rightarrow C$, $C \rightarrow DE$, $E \rightarrow C$ and $E \rightarrow D$
    - $F = \{A \rightarrow B,\ AB \rightarrow C,\ C \rightarrow DE,\ E \rightarrow C,\ E \rightarrow D\}$

    1. Derive minimal basis of F
       - $F_b = \{A \rightarrow B,\ A \rightarrow C,\ C \rightarrow D,\ C \rightarrow E,\ E \rightarrow C\}$
    2. Produce canonical cover
       - $F_C = \{A \rightarrow BC,\ C \rightarrow DE\ ,\ E \rightarrow C\}$
    3. Create a table for each FD
       - R1(A, B, C), R2(C, D, E) and R3(C, E)
    4. Add the key if missing
       - Keys = {A}
       - R1 contains a key

Final Thought

closing statement

Summary

- Poorly designed tables give rise to redundancy, update anomalies and deletion anomalies
- **BCNF** eliminates these problems
    - BCNF: for any non-trivial and decomposed FD on a table `R`, its left hand side is a superkey for `R`
    - But BCNF does not always preserve all FDs *(non dependency preserving)*
    - We may need to perform a join of multiple tables to check whether an FD holds
- **3NF** is slightly weaker than BCNF *(has more redundancies, has update and deletion anomalies in some rare cases)* but preserves all FDs
    - 3NF: for any non-trivial and decomposed FD on a table `R`, either its left hand side is a superkey for `R`, *or its right hand side is a prime attribute*

BCNF or 3NF or *Lower*?

- BCNF is only *inferior* to 3NF in the sense that sometimes it does not preserve all FDs
- **Idea:**
  - Go for BCNF if we can find a BCNF decomposition that preserves all FDs
  - If such decomposition cannot be found, then
    - Still go for BCNF if preserving all FDs is not important
    - Or go for 3NF otherwise
      - If we are lucky, 3NF synthesis may actually find a BCNF decomposition!
- Should we go **lower** than 3NF?
  - Notice how there can be many tables produced by 3NF
  - What will happen to queries?
    - We may have to perform lots of joins
    - This can slow down queries by a lot since joins are expensive
  - Even 3NF may not be suitable in that case

QUESTION?