# CZ2007 Introduction to Database Systems (Week 3)

## Topic 3: Boyce-Codd Normal Form (1)

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# This Lecture

- Boyce-Codd Normal Form
- BCNF Decomposition

# Normal Forms

- Various normal forms (in increasing order of strictness)
  - First normal form
  - Second normal form
  - Third normal form (3NF)
  - Boyce-Codd normal form (BCNF)
  - Fourth normal form
  - Fifth normal form
  - Sixth normal form
- 3NF and BCNF are most commonly used

# Boyce-Codd Normal Form (BCNF)

- A table R is in BCNF, if and only if
  - The left hand side of every non-trivial FD contains a key of R
- Non-trivial FD:
  - An FD that is not implied by the axiom of reflexivity
  - Example:
    - A→B -- Non-trivial
    - AC→BC -- Non-trivial
    - AC→A -- Trivial
    - AC→C -- Trivial

# Boyce-Codd Normal Form (BCNF)

- A table R is in BCNF, if and only if
  - The left hand side of every non-trivial FD contains a key of R
- R(A, B)
- Given FD: A→B
- Key: A
- All FDs on R: A→B, AB→A, AB→B, AB→AB
  - AB→A, AB→B, AB→AB: trivial
  - A→B: The left hand side contains a key
- Therefore, R is in BCNF

# Boyce-Codd Normal Form (BCNF)

- A table R is in BCNF, if and only if
  - The left hand side of every non-trivial FD contains a key of R
- R(A, B, C)
- Given FD: $A \rightarrow B$
- Key: AC
- All FDs on R: $A \rightarrow B$, $AB \rightarrow B$, $AC \rightarrow C$, …
  - The left hand side of $A \rightarrow B$ does not contain a key
- Therefore, R is NOT in BCNF

# BCNF: Example

| Name | NRIC | Phone | Address |
|---|---|---|---|
| Alice | 1234 | 67899876 | Jurong East |
| Alice | 1234 | 83848384 | Jurong East |
| Bob | 5678 | 98765432 | Pasir Ris |

- NRIC → Name, Address
- Key: {NRIC, Phone}; key has two attributes
- Not in BCNF

# BCNF: Straightforward Checking

- Given: A table R, a set of FDs on R
- Step 1: Derive the keys of R
- Step 2: Derive all non-trivial FDs on R

- Step 3: For each non-trivial FD, check if its left hand side contains a key
- Step 4: If all FDs pass the check, then R is in BCNF; otherwise, R is not in BCNF

# BCNF: Straightforward Checking

- Given: A table R, a set of FDs on R
- Step 1: Derive the keys of R
- Step 2: Derive all non-trivial FDs on R
  - This is too time-consuming
  - Trick: Only check the FDs given on R instead of all FDs
- Step 3: For each non-trivial FD, check if its left hand side contains a key
- Step 4: If all FDs pass the check, then R is in BCNF; otherwise, R is not in BCNF

# BCNF Checking: Example

- R(A, B, C, D)
- Given: A→B, A→C, A→D
- Key: A (no other keys)
- Check: For each given non-trivial FD, check if its left hand side contains a key
- A→B: Non-trivial, LHS contains a key
- A→C: Non-trivial, LHS contains a key
- A→D: Non-trivial, LHS contains a key
- Therefore, R is in BCNF

# BCNF Checking: Example

- R(A, B, C, D)
- Given: A→B, B→C, C→D
- Key: A (no other keys)
- Check: For each given non-trivial FD, check if its left hand side contains a key
- A→B: Non-trivial, LHS contains a key
- B→C: Non-trivial, LHS does NOT contain a key
- Therefore, R is NOT in BCNF

# BCNF Checking: Rationale

- A table R is in BCNF, if and only if for every FD on R,
  - Either the FD is trivial
  - Or the left hand side of the FD contains a key
- The definition says "every", but we only check the ones "given" on R
- This leaves the "hidden" ones unchecked
- Why does it work?
- Rationale: If the "given" FDs pass the check, then all "hidden" ones will pass the check

# BCNF Checking: Rationale

- R(A, B, C, D)
- Given: A→B, B→C, C→D
- If the 3 FDs pass the check, then any other FDs derived from them will either have the same LHS as them, or LHS with more attributes
- Reflexitivity axiom: we ignore since this yields trivial FDs
- Augmentation axiom: LHS of new FD will have more attributes (A→B becomes AC→BC); if original LHS contains key, so will the new LHS
- Transitivity axiom: LHS of new FD is same as original LHS (A→B and B→C yields A→C)

# BCNF Checking: Multiple-Key Cases

- R(A, B, C, D)
- Given: A→B, B→A, B→C, B→D, A→D
- Keys: A, B
- Check: For each given non-trivial FD, check if its left hand side contains a key
- A→B, A→D: Non-trivial, LHS contains a key
- B→A, B→C, B→D: Non-trivial, LHS contains a key
- Therefore, R is in BCNF

# BCNF: Intuition

- Basically, BCNF requires that there cannot be any non-trivial $X \rightarrow Y$ such that the X does not contain a key
- Why does this make sense?
- Intuition: $X \rightarrow Y$ indicates that the table has some redundancies

# BCNF Intuition: Example

| Name | NRIC | Phone | Address |
|---|---|---|---|
| Alice | 1234 | 67899876 | Jurong East |
| Alice | 1234 | 83848384 | Jurong East |
| Bob | 5678 | 98765432 | Pasir Ris |

- NRIC → Name, Address
- Key: {NRIC, Phone}
- NRIC determines Name and Address
- Therefore, every time NRIC appears repeatedly in the table, Name and Address also appear repeatedly
- Since NRIC is not a key, the same NRIC can appear multiple times in the table
- This leads to redundancies
- BCNF prevents this

# This Lecture

- Boyce-Codd Normal Form
- BCNF Decomposition

# BCNF Decomposition

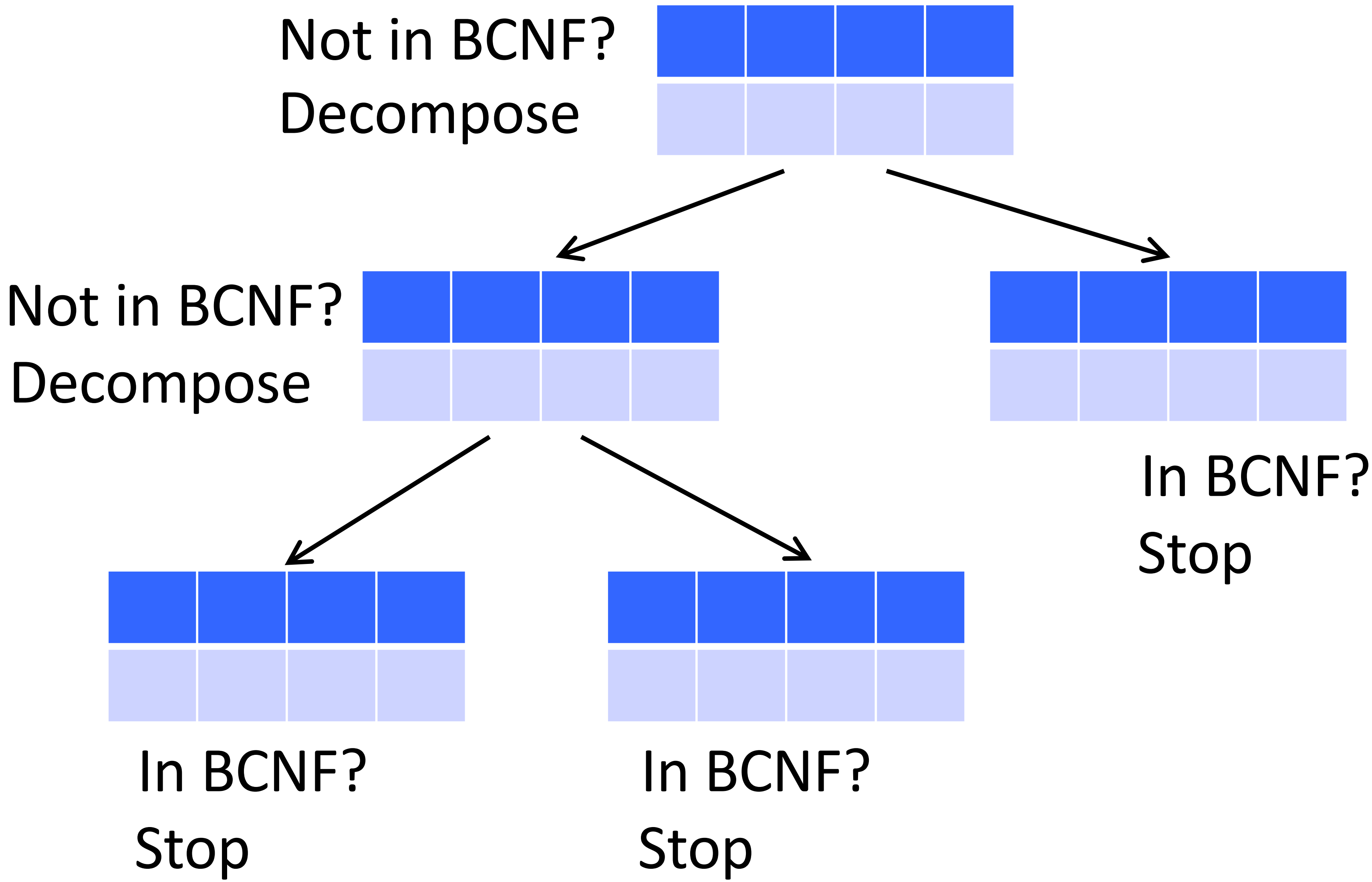
| Name | NRIC | Phone | Address |
|---|---|---|---|
| Alice | 1234 | 67899876 | Jurong East |
| Alice | 1234 | 83848384 | Jurong East |
| Bob | 5678 | 98765432 | Pasir Ris |

- What can we do if a table violates BCNF?
- Answer: Decompose it (i.e., normalize it)

| Name | NRIC | Address |
|---|---|---|
| Alice | 1234 | Jurong East |
| Bob | 5678 | Pasir Ris |

| NRIC | Phone |
|---|---|
| 1234 | 67899876 |
| 1234 | 83848384 |
| 5678 | 98765432 |

# Decompose, until all are in BCNF



# BCNF Decomposition: Example

- R(A, B, C, D)
- Given: A→B, B→C, C→D
- Key of R: A
- Step 1: Identify a FD that violates BCNF
- B→C is a violation, since
  - It is non-trivial
  - Its left hand side does not contain a key

# BCNF Decomposition: Example

- R(A, B, C, D)
- Given: $A \rightarrow B$, $B \rightarrow C$, $C \rightarrow D$
- Key of R: A
- Step 1: $B \rightarrow C$ is a violation
- Step 2: Compute the closure of the left hand side of the FD
- $\{B\}^+ = \{BCD\}$

# BCNF Decomposition: Example

- R(A, B, C, D)
- Given: A→B, B→C, C→D
- Key of R: A
- Step 1: B→C is a violation
- Step 2: $\{B\}^+ = \{BCD\}$
- Step 3: Decompose R into two tables $R_1$ and $R_2$
  - $R_1$(B, C, D), i.e., it contains all attributes in the closure
  - $R_2$(A, B), i.e., it contains B and all attributes NOT in the closure
- Step 4: Check $R_1$ and $R_2$, decompose if necessary

# BCNF Decomposition Algorithm

- Input: A table R
- Step 1: Find a FD $X \rightarrow Y$ on R that violates BCNF
  - If cannot find, stop
- Step 2: Compute the closure $\{X\}^+$
- Step 3: Break R into two tables $R_1$ and $R_2$
  - $R_1$ contains all attributes in $\{X\}^+$
  - $R_2$ contains X and attributes NOT in $\{X\}^+$
- Repeat Steps 1-3 on $R_1$ and $R_2$

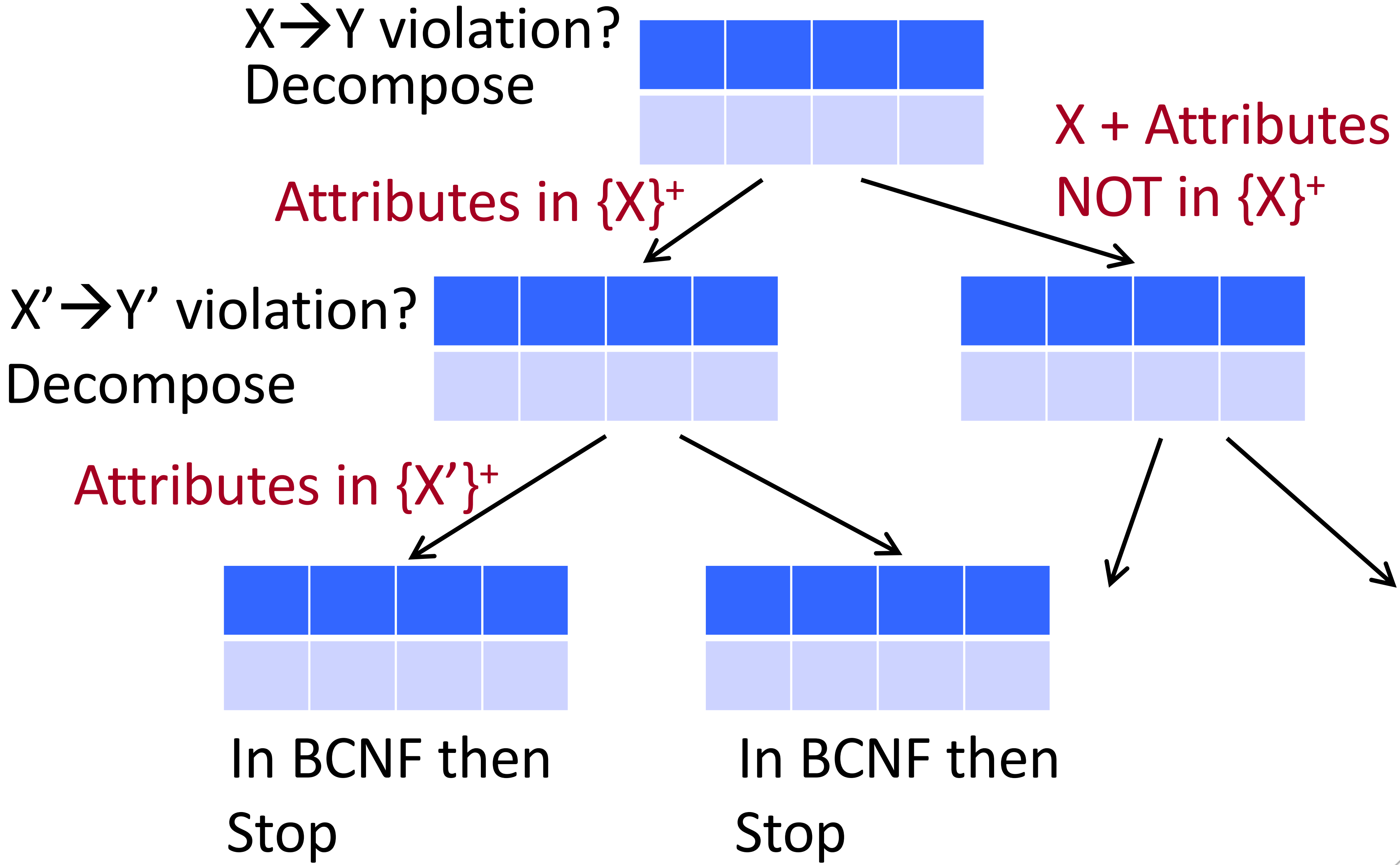
# BCNF Decomposition: Example

- R(A, B, C, D)
- Given: A→B, B→C, C→D
- Key of R: A
- Previous results: $R_1$(B, C, D), $R_2$(A, B)
- Is $R_2$ in BCNF?
  - Yes. So $R_2$ is done
- Is $R_1$ in BCNF?
  - No. Key of $R_1$ is B. In that case, C→D is a violation.
- Decompose $R_1$ into $R_3$ and $R_4$
  - $\{C\}^+ = \{CD\}$
  - $R_3$(C, D), i.e., it contains all attributes in $\{C\}^+$
  - $R_4$(B, C), i.e., it contains C and all attribute NOT in $\{C\}^+$
- Are $R_3$ and $R_4$ in BCNF?
  - Yes. So we stop here.

# BCNF Decomposition: Example

- R(A, B, C, D)
- Given: A→B, B→C, C→D
- Key of R: A
- Final BCNF Decomposition
  - $R_2(A, B)$
  - $R_3(C, D)$
  - $R_4(B, C)$

# Decompose, until all are in BCNF



# Notes

- The BCNF decomposition of a table may not be unique

- If a table has only two attributes, then it must be in BCNF
  - Therefore, you do not need to check tables with only two attributes

# Exercise: BCNF Decomposition

- R(A, B, C, D, E)
- Given: $AB \rightarrow C$, $C \rightarrow D$, $D \rightarrow E$
- Key of R: AB
- $D \rightarrow E$ is a violation
- Decompose R(A, B, C, D, E)
  - $\{D\}^+ = \{D, E\}$
  - $R_1(D, E)$, $R_2(A, B, C, D)$
  - $R_1$ has only two attributes. Must be in BCNF.
  - $R_2$… Key of $R_2$: AB. Therefore, $C \rightarrow D$ is a violation
- Decompose $R_2(A, B, C, D)$
  - $\{C\}^+ = \{C, D, E\}$. E is omitted since it is not in $R_2$
  - $R_3(C, D)$, $R_4(A, B, C)$
  - $R_3$ has only two attributes. Must be in BCNF.
  - $R_4$… Key of $R_4$: AB. No violation of BCNF. Done

To continue in

**Topic 3: Boyce-Codd Normal Form (2)**