CSCI235 – Database Systems

Normalization In Practice

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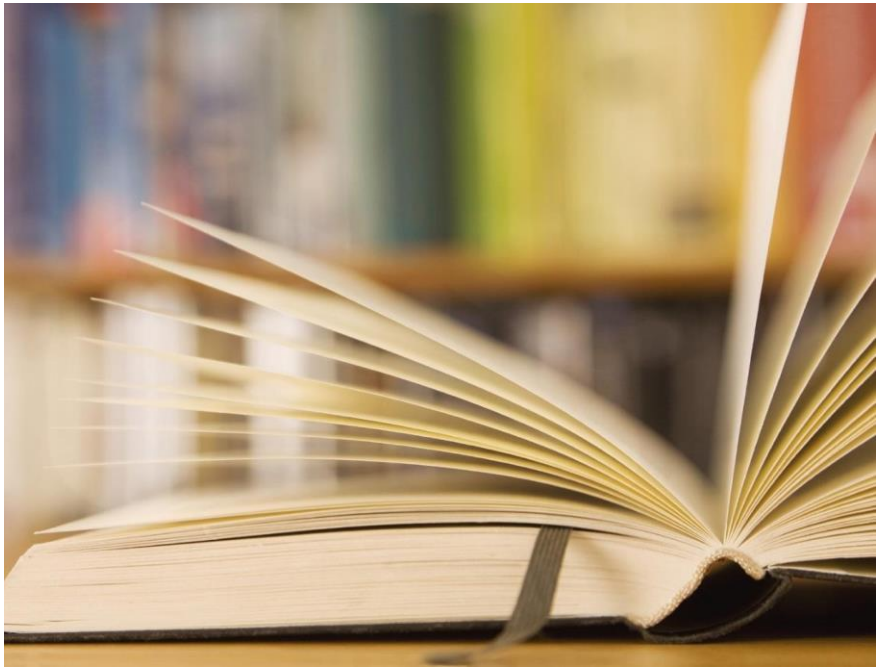

Example 1

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C}$

What is the minimal super key?

Example 1

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C}$

What is the minimal super key?

- If $\boldsymbol{AB \rightarrow C}$ is valid in $\boldsymbol{R}$ and it covers the entire relational schema, then its left hand side, (A, B), is a minimal super key.
- There is no other minimal super key in $\boldsymbol{R}$.
- Hence the minimal super key of R is $\boldsymbol{(A, B)}$.

Example 1

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C}$

What is the normal form?

Example 1

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C}$

What is the normal form?

- There is NO partial dependency in $\boldsymbol{R}$. Hence, the relational schema $\boldsymbol{R}$ is in 2NF.
- There is NO transitive dependency in $\boldsymbol{R}$. Hence, the relational schema $\boldsymbol{R}$ is in 3NF.
- There is NO non-trivial dependency in $\boldsymbol{R}$. Hence, the relational schema $\boldsymbol{R}$ has no BCNF violation.
- $\therefore$ The relational schema $\boldsymbol{R}$ is in $\boldsymbol{BCNF}$.

Example 2

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow B}$

What is the minimal super key?

Example 2

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow B}$

What is the minimal super key?

- If $\boldsymbol{AB \rightarrow C}$ is valid in $\boldsymbol{R}$ and it covers the entire relational schema, then its left hand side, (A, B), is a minimal super key.
- If $\boldsymbol{C \rightarrow B}$, then through **augmentation rule**, $\boldsymbol{AC \rightarrow AB}$.
- If $\boldsymbol{AC \rightarrow AB}$ is valid in R and it covers the entire relational schema, then its left hand side, (A, C), is a minimal super key.
- ∴ the minimal super keys of R are $\boldsymbol{(A, B)}$ and $\boldsymbol{(A, C)}$.

Example 2

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow B}$

What is the normal form?

Example 2

A relational schema $\boldsymbol{R = (A, B, C)}$
Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow B}$

What is the normal form? (Scenario 1)

- Since $\boldsymbol{(A, B)}$ is a minimal super key, there is NO partial dependency and NO transitive dependency, but there exist non-trivial dependency $\boldsymbol{C \rightarrow B}$. Existence of non-trivial dependency is a violation of BCNF requirement. Hence, the relational schema CANNOT be in BCNF.
- $\therefore$ the relational schema $\boldsymbol{R = (A, B, C)}$ is in $\boldsymbol{3NF}$.

Example 2

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow B}$

What is the normal form? (Scenario 2)

- Since $\boldsymbol{(A, C)}$ is a minimal super key, there exist a partial dependency $\boldsymbol{C \rightarrow B}$, a violation of 2NF requirement. There is NO transitive dependency, and there is NO non-trivial dependency.
- $\therefore$ the relational schema $\boldsymbol{R = (A, B, C)}$ is in $\boldsymbol{1NF}$.
- Question: Why the relational schema is not in $\boldsymbol{3NF}$ or $\boldsymbol{BCNF}$?

Example 2

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow B}$

How to transform the relational schema R into BCNF? (Scenario 1)

Example 2

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow B}$

How to transform the relational schema R into BCNF? (Scenario 1)

- Remove the non-trivial dependency $\boldsymbol{C \rightarrow B}$ from the relational schema $\boldsymbol{R}$, and decompose it into two relational schema, $\boldsymbol{R1 = (A, B)}$ and $\boldsymbol{R2 = (C, B)}$.
- In relational schema $\boldsymbol{R1}$, the minimal super key is $\boldsymbol{(A, B)}$.
  - There is NO partial dependency, NO transitive dependency, and NO non-trivial dependency. Hence, the relational schema $\boldsymbol{R1}$ is in $\boldsymbol{BCNF}$.

Example 2

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow B}$

How to transform the relational schema R into BCNF? (Scenario 1)

- Remove the non-trivial dependency $\boldsymbol{C \rightarrow B}$ from the relational schema $\boldsymbol{R}$, and decompose it into two relational schema, $\boldsymbol{R1 = (A, B)}$ and $\boldsymbol{R2 = (C, B)}$.
- In relational schema $\boldsymbol{R2}$, the minimal super key is $\boldsymbol{(C)}$.
  - There is NO partial dependency, NO transitive dependency, and NO non-trivial dependency. Hence, the relational schema $\boldsymbol{R2}$ is in $\boldsymbol{BCNF}$.

Example 2

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow B}$

How to transform the relational schema R into BCNF? (Scenario 2)

Example 2

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow B}$

How to transform the relational schema R into BCNF? (Scenario 2)

- In scenario 2, $\boldsymbol{AC \rightarrow AB}$. Remove the partial dependency $\boldsymbol{C \rightarrow B}$ from the relational schema $\boldsymbol{R}$, and decompose it into two relational schema, $\boldsymbol{R1 = (A, C)}$ and $\boldsymbol{R2 = (C, B)}$.
- In relational schema $\boldsymbol{R1}$, the minimal super key is $\boldsymbol{(AC)}$.
  - There is NO partial dependency, NO transitive dependency, and NO non-trivial dependency. Hence, the relational schema $\boldsymbol{R1}$ is in $\boldsymbol{BCNF}$.

Example 2

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow B}$

How to transform the relational schema R into BCNF? (Scenario 2)

- In scenario 2, $\boldsymbol{AC \rightarrow AB}$. Remove the partial dependency $\boldsymbol{C \rightarrow B}$ from the relational schema $\boldsymbol{R}$, and decompose it into two relational schema, $\boldsymbol{R1 = (A, C)}$ and $\boldsymbol{R2 = (C, B)}$.
- In relational schema $\boldsymbol{R2}$, the minimal super key is $\boldsymbol{(C)}$.
  - There is NO partial dependency, NO transitive dependency, and NO non-trivial dependency. Hence, the relational schema $\boldsymbol{R2}$ is in $\boldsymbol{BCNF}$.

Example 3

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C,\ C \rightarrow B,\ C \rightarrow A}$

What is the minimal super key?

Example 3

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C,\ C \rightarrow B,\ C \rightarrow A}$

What is the minimal super key?

- If $\boldsymbol{AB \rightarrow C}$ is valid in $\boldsymbol{R}$, and it covers the entire relational schema, then the left hand side of the functional dependency, $\boldsymbol{(A, B)}$ is a minimal super key.
- If $\boldsymbol{C \rightarrow B}$ and $\boldsymbol{C \rightarrow A}$, then through **union rule** $\boldsymbol{C \rightarrow AB}$.
- If $\boldsymbol{C \rightarrow AB}$ is valid in R and it covers the entire relational schema, then the left hand side of the functional dependency, $\boldsymbol{C}$ is a minimal super key.
- Hence, the minimal super keys of the relational schema R are $\boldsymbol{(A, B)}$ and $\boldsymbol{(C)}$.

Example 3

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C,\ C \rightarrow B,\ C \rightarrow A}$

What is the normal form?

Example 3

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C,\ C \rightarrow B,\ C \rightarrow A}$

What is the normal form?

- There is NO partial dependency in the relational schema $\boldsymbol{R}$. Hence, the relational schema $\boldsymbol{R}$ is in 2NF.
- There is NO transitive dependency in the relational schema $\boldsymbol{R}$. Hence, the relational schema $\boldsymbol{R}$ is in 3NF.
- There is NO non-trivial dependency in the relational schema $\boldsymbol{R}$. Hence the relational schema $\boldsymbol{R}$ does not have BCNF violation.
- $\therefore$ The relational schema $\boldsymbol{R}$ is in $\boldsymbol{BCNF}$.

Example 4

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B}$

What is the minimal super key?

Example 4

A relational schema $R = (A, B, C)$

Functional dependencies: $A \rightarrow B$

What is the minimal super key?

- If $A \rightarrow B$ is valid in R, then through **augmentation rule**, $AC \rightarrow BC$.
- If $AC \rightarrow BC$ is valid in R and it covers the entire relational schema then the left hand side of the functional dependency (A, C) is a minimal key.
- Hence, the minimal super keys of the relational schema R is (A, C).

Example 4

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B}$

What is the normal form?

Example 4

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B}$

What is the normal form?

- Since $\boldsymbol{(A, C)}$ is a minimal super key, and $\boldsymbol{A \rightarrow B}$, there exist a partial dependency. Hence, the relational schema $\boldsymbol{R}$ CANNOT be in 2NF.
- There is NO transitive dependency and NO non-trivial dependency in the relational schema $\boldsymbol{R}$.
- Hence, the highest normal form of the relational schema $\boldsymbol{R}$ is in $\boldsymbol{1NF}$.

Example 4

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B}$

How to transform the relational schema R into BCNF?

Example 4

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B}$

How to transform the relational schema R into BCNF?

- Since there exists a partial dependency in the relational schema $\boldsymbol{R}$, to transform the relational schema to BCNF, we need to remove the partial dependency, and split it into two relational schemas $\boldsymbol{R1 = (A, C)}$ and $\boldsymbol{R2 = (A, B)}$.

Example 4

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B}$

How to transform the relational schema R into BCNF?

- In the relational schema $\boldsymbol{R1 = (A, C)}$, the minimal super key is $\boldsymbol{(A, C)}$.
  - There is NO partial dependency nor transitive dependency in the relational schema $\boldsymbol{R1}$. In addition, there is also NO non-trivial dependency exist. Hence, the relational schema $\boldsymbol{R1}$ is in $\boldsymbol{BCNF}$.
- In the relational schema $\boldsymbol{R2 = (A, B)}$, the minimal super key is $\boldsymbol{(A)}$.

Example 4

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B}$

How to transform the relational schema R into BCNF?

- In the relational schema $\boldsymbol{R2 = (A, B)}$, the minimal super key is $\boldsymbol{(A)}$.
  - There is NO partial dependency nor transitive dependency. In addition there is also NO non-trivial dependency. Hence, the relational schema $\boldsymbol{R2}$ is in $\boldsymbol{BCNF}$.

Example 5

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow A}$

What is the minimal super key?

Example 5

A relational schema $R = (A, B, C)$

Functional dependencies: $A \rightarrow B,\ B \rightarrow A$

What is the minimal super key?

- If $A \rightarrow B$ then through **augmentation rule**, $AC \rightarrow BC$.
- If $AC \rightarrow BC$ is valid in R and it covers the entire relational schema, then the left-hand-side of the functional dependency (AC) is a minimal super key.
- If $B \rightarrow A$ then through **augmentation rule**, $BC \rightarrow AC$.
- If $BC \rightarrow AC$ is valid in R and it covers the entire relational schema, then the left-hand-side of the functional dependency (BC) is a minimal super key.

Example 5

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow A}$

What is the normal form?

Example 5

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow A}$

What is the normal form?

- Since $\boldsymbol{(A, C)}$ is a minimal super key, and $\boldsymbol{A \rightarrow B}$, there exist a partial dependency (violate 2NF requirement). In addition, the functional dependency $\boldsymbol{B \rightarrow A}$, the determinant $\boldsymbol{B}$ is not a minimal super key and $\boldsymbol{A}$ is part of a minimal super key $\boldsymbol{(A, C)}$, this forms a non-trivial dependency (violate BCNF requirement). Hence, the relational schema is in 1NF.

Example 5

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow A}$

What is the normal form?

- Similarly, if $\boldsymbol{(B, C)}$ is a minimal super key, then $\boldsymbol{B \rightarrow A}$ forms a partial dependency (this violates 2NF requirement). Hence, the relational schema CANNOT be in 2NF. In addition, the functional dependency $\boldsymbol{A \rightarrow B}$, the determinant $\boldsymbol{A}$ is not a minimal super key and $\boldsymbol{B}$ is part of a minimal super key $\boldsymbol{(B, C)}$, this forms a non-trivial dependency (violate BCNF requirement). Hence, the relational schema is in 1NF.
- Hence, the relational schema $\boldsymbol{R = (A, B, C)}$ is in $\boldsymbol{1NF}$.

Example 5

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow A}$

How to transform the relational schema R into BCNF?

Example 5

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow A}$

How to transform the relational schema R into BCNF?

- Since there exists a partial dependency in the relational schema $\boldsymbol{R}$, to transform the relational schema to BCNF, we need to remove the partial dependency, and split it into two relational schemas $\boldsymbol{R1 = (A, C)}$ and $\boldsymbol{R2 = (A, B)}$.

Example 5

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow A}$

How to transform the relational schema R into BCNF?

- In the relational schema $\boldsymbol{R1 = (A, C)}$, the minimal super key is $\boldsymbol{(A, C)}$.
  - There is NO partial dependency (No violation of 2NF).
  - There is NO transitive dependency (No violation of 3NF).
  - There is NO non-trivial dependency (No violation of BCNF).
  - ∴ the relational schema $\boldsymbol{R1}$ is in $\boldsymbol{BCNF}$.

Example 5

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow A}$

How to transform the relational schema R into BCNF?

- In the relational schema $\boldsymbol{R2 = (A, B)}$, the minimal super key can be $\boldsymbol{(A)}$ or $\boldsymbol{(B)}$.
  - There is NO partial dependency (No violation of 2NF).
  - There is NO transitive dependency (No violation of 3NF).
  - There is NO non-trivial dependency (No violation of BCNF).
  - ∴ the relational schema $\boldsymbol{R2}$ is in $\boldsymbol{BCNF}$.

Example 6

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow C}$.

What is the minimal super key?

Example 6

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow C}$.

What is the minimal super key?

- If $\boldsymbol{A \rightarrow B}$ and $\boldsymbol{B \rightarrow C}$ then through transitivity rule, $\boldsymbol{A \rightarrow C}$.
- If $\boldsymbol{A \rightarrow B}$ and $\boldsymbol{A \rightarrow C}$ then through union rule, $\boldsymbol{A \rightarrow BC}$
- If $\boldsymbol{A \rightarrow BC}$ is valid in $\boldsymbol{R}$ and it covers the entire relational schema then, the left-hand-side of the functional dependency $\boldsymbol{(A)}$ is a minimal super key.

Example 6

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow C}$.

What is the normal form?

Example 6

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow C}$.

What is the normal form?

- With the functional dependency $\boldsymbol{A \rightarrow BC}$, there is NO partial dependency.
- However, there exist a transitive dependency $\boldsymbol{B \rightarrow C}$ (a violation of 3NF requirement), hence, the relational schema $\boldsymbol{R = (A, B, C)}$ is in $\boldsymbol{2NF}$.

Example 6

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow C}$.

How to transform the relational schema R into BCNF?

Example 6

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow C}$.

How to transform the relational schema R into BCNF?

- With the functional dependency $\boldsymbol{A \rightarrow BC}$, there exist a transitive dependency $\boldsymbol{B \rightarrow C}$ (a violation of 3NF requirement).
- To transform the relational schema $\boldsymbol{R}$ to BCNF, we need to remove the transitive dependency violation and decompose the relational schema $\boldsymbol{R}$ into two relational schemas $\boldsymbol{R1 = (A, B)}$ and $\boldsymbol{R2 = (B, C)}$.

Example 6

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow C}$.

How to transform the relational schema R into BCNF?

- In the relational schema $\boldsymbol{R1 = (A, B)}$, the minimal super key is $\boldsymbol{(A)}$ and there is NO partial dependency, transitive dependency, and non-transitive dependency, the relational schema $\boldsymbol{R1}$ is in $\boldsymbol{BCNF}$.

Example 6

A relational schema $\boldsymbol{R = (A, B, C)}$

Functional dependencies: $\boldsymbol{A \rightarrow B,\ B \rightarrow C}$.

How to transform the relational schema R into BCNF?

- In the relational schema $\boldsymbol{R2 = (B, C)}$, the minimal super key is $(\boldsymbol{B})$ and there is NO partial dependency, transitive dependency, and non-transitive dependency, the relational schema $\boldsymbol{R2}$ is also in $\boldsymbol{BCNF}$.

Example 7

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, A \rightarrow C, B \rightarrow D}$

What is the minimal super key?

Example 7

A relational schema $R = (A, B, C, D)$

Functional dependencies: $A \rightarrow B, A \rightarrow C, B \rightarrow D$

What is the minimal super key?

- If $A \rightarrow B$ and $A \rightarrow C$ then through **union rule** $A \rightarrow BC$.
- If $A \rightarrow B$ and $B \rightarrow D$ then through **transitivity rule** $A \rightarrow D$.
- If $A \rightarrow BC$ and $A \rightarrow D$ then through **union rule** $A \rightarrow BCD$.
- If $A \rightarrow BCD$ is valid in R and it covers the entire relational schema, then the left-hand-side of the functional dependency (A) is a minimal super key.

Example 7

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, A \rightarrow C, B \rightarrow D}$

What is the normal form?

Example 7

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, A \rightarrow C, B \rightarrow D}$

What is the normal form?

- In the functional dependency $\boldsymbol{A \rightarrow BCD}$, there is NO partial dependency. However, there is a transitive dependency $\boldsymbol{B \rightarrow D}$ (a violation of 3NF.)
- $\therefore$ the relational schema $\boldsymbol{R = (A, B, C, D)}$ is in $\boldsymbol{2NF}$.

Example 7

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, A \rightarrow C, B \rightarrow D}$

How to transform the relational schema R into BCNF?

Example 7

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, A \rightarrow C, B \rightarrow D}$

How to transform the relational schema R into BCNF?

- With the functional dependency $\boldsymbol{A \rightarrow BCD}$, there is no partial dependency, but there exists a transitive dependency $\boldsymbol{B \rightarrow D}$ (a violation of 3NF.) To transform the relational schema to BCNF, we need to remove the transitive dependency and split the relational schema $\boldsymbol{R}$ into two schemas $\boldsymbol{R1 = (A, B, C)}$ and $\boldsymbol{R2 = (B, D)}$.

Example 7

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, A \rightarrow C, B \rightarrow D}$

How to transform the relational schema R into BCNF?

- In $\boldsymbol{R1 = (A, B, C)}$, the minimal super key is $\boldsymbol{(A)}$ and there are NO partial dependency, transitive dependency, and non-trivial dependency violations. Hence, the relational schema $\boldsymbol{R1 = (A, B, C)}$ is in $\boldsymbol{BCNF}$.
- In $\boldsymbol{R2 = (B, D)}$, the minimal super key is $\boldsymbol{(B)}$ and there are NO partial dependency, transitive dependency, and non-trivial dependency violations. Hence, the relational schema $\boldsymbol{R2 = (B, D)}$ is in $\boldsymbol{BCNF}$.

Example 8

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow D, C \rightarrow B}$

What is the minimal super key?

Example 8

A relational schema $R = (A, B, C, D)$

Functional dependencies: $A \rightarrow B, B \rightarrow D, C \rightarrow B$

What is the minimal super key?

- If $A \rightarrow B$ and $B \rightarrow D$ then through **transitivity rule** $A \rightarrow D$.
- If $A \rightarrow D$ and $A \rightarrow B$ then through **union rule** $A \rightarrow BD$.
- If $A \rightarrow BD$ then through **augmentation rule** $AC \rightarrow BCD$.
- If $AC \rightarrow BCD$ is valid in R and it covers the entire relational schema, then the left-hand-side of the functional dependency (AC) is a minimal super key.

Example 8

A relational schema $R = (A, B, C, D)$

Functional dependencies: $A \rightarrow B, B \rightarrow D, C \rightarrow B$

What is the minimal super key?

- If $C \rightarrow B$ and $B \rightarrow D$ then through **transitivity rule** $C \rightarrow D$.
- If $C \rightarrow D$ and $C \rightarrow B$ then through **union rule** $C \rightarrow BD$.
- If $C \rightarrow BD$ then through **augmentation rule** $AC \rightarrow ABD$.
- If $AC \rightarrow ABD$ is valid in R and it covers the entire relational schema, then the left-hand-side of the functional dependency (AC) is a minimal super key.

Example 8

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow D, C \rightarrow B}$

What is the normal form?

Example 8

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow D, C \rightarrow B}$

What is the normal form?

- In $\boldsymbol{AC \rightarrow BCD}$, there exists a partial dependency $\boldsymbol{A \rightarrow B}$ and $\boldsymbol{C \rightarrow B}$, hence, a violation of 2NF requirement.
- There exists also a transitive dependency $\boldsymbol{B \rightarrow D}$, hence, a violation of 3NF requirement.
- $\therefore$ the relational schema is in $\boldsymbol{1NF}$.

Example 8

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow D, C \rightarrow B}$

What is the normal form?

- In $\boldsymbol{AC \rightarrow ABD}$, there exists a partial dependency $\boldsymbol{A \rightarrow B}$ and $\boldsymbol{C \rightarrow B}$, hence, a violation of 2NF requirement.
- There exists also a transitive dependency $\boldsymbol{B \rightarrow D}$, hence, a violation of 3NF requirement.
- $\therefore$ the relational schema is in $\boldsymbol{1NF}$.

Example 8

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow D, C \rightarrow B}$

How to transform the relational schema R into BCNF?

Example 8

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow D, C \rightarrow B}$

How to transform the relational schema R into BCNF?

- In $\boldsymbol{AC \rightarrow BCD}$, there exists a partial dependency $\boldsymbol{A \rightarrow B}$ and $\boldsymbol{C \rightarrow B}$, hence, a violation of 2NF requirement.
- There exists also a transitive dependency $\boldsymbol{B \rightarrow D}$, hence, a violation of 3NF requirement.
- To transform the relational schema to BCNF, we need to first remove all partial dependencies from the relational schema $\boldsymbol{AC \rightarrow BCD}$, and we have $\boldsymbol{R1 = (A, B, D),\ R2 = (C, B),\ R3 = (A, C)}$.

Example 8

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow D, C \rightarrow B}$

How to transform the relational schema R into BCNF?

- In the relational schema $\boldsymbol{R1 = (A, B, D)}$, $\boldsymbol{(A)}$ is the minimal super key. There is NO partial dependency, but there exist a transitive dependency $\boldsymbol{B \rightarrow D}$, (a violation of 3NF.)
- To transform the relational schema $\boldsymbol{R1 = (A, B, D)}$ to BCNF, we need to remove the transitive dependency $\boldsymbol{B \rightarrow D}$ by splitting $\boldsymbol{R1}$ into $\boldsymbol{R1 = (A, B)}$ and $\boldsymbol{R4 = (B, D)}$.

Example 8

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow D, C \rightarrow B}$

How to transform the relational schema R into BCNF?

- In relational schema $\boldsymbol{R1 = (A, B)}$, the minimal super key is $\boldsymbol{(A)}$. There are NO partial dependency, no transitive dependency, and no non-trivial dependency. Hence, $\boldsymbol{R1 = (A, B)}$ is in $\boldsymbol{BCNF}$.
- In relational schema $\boldsymbol{R4 = (B, D)}$, the minimal super key is $\boldsymbol{(B)}$. There are NO partial dependency, no transitive dependency, and no non-trivial dependency. Hence, $\boldsymbol{R4 = (B, D)}$ is in $\boldsymbol{BCNF}$.

Example 8

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow D, C \rightarrow B}$

How to transform the relational schema R into BCNF?

- In relational schema, $\boldsymbol{R2 = (C, B)}$, the minimal super key is $\boldsymbol{(C)}$. There are NO partial dependency, no transitive dependency, and no non-trivial dependency. Hence, $\boldsymbol{R2 = (C, B)}$ is in $\boldsymbol{BCNF}$.
- In relational schema, $\boldsymbol{R3 = (A, C)}$, the minimal super key is $\boldsymbol{(AC)}$. There are NO partial dependency, no transitive dependency, and no non-trivial dependency. Hence, $\boldsymbol{R3 = (A, C)}$ is in $\boldsymbol{BCNF}$.

Example 9

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, A \rightarrow C, B \rightarrow A, B \rightarrow C}$

What is the minimal super key?

Example 9

A relational schema $R = (A, B, C, D)$

Functional dependencies: $A \rightarrow B, A \rightarrow C, B \rightarrow A, B \rightarrow C$

What is the minimal super key?

- If $A \rightarrow B$ and $A \rightarrow C$, then through **union rule**, $A \rightarrow BC$
- If $A \rightarrow BC$ then through **augmentation rule** $AD \rightarrow BCD$.
- If $AD \rightarrow BCD$ is valid in R and it covers the entire relational schema, then the left-hand-side of the functional dependency (A, D) is a minimal super key.

Example 9

A relational schema $R = (A, B, C, D)$

Functional dependencies: $A \rightarrow B, A \rightarrow C, B \rightarrow A, B \rightarrow C$

What is the minimal super key?

- If $B \rightarrow A$ and $B \rightarrow C$, then through **union rule**, $B \rightarrow AC$
- If $B \rightarrow AC$ then through **augmentation rule** $BD \rightarrow ACD$.
- If $BD \rightarrow ACD$ is valid in R and it covers the entire relational schema, then the left-hand-side of the functional dependency (B, D) is a minimal super key.

Example 9

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, A \rightarrow C, B \rightarrow A, B \rightarrow C}$

What is the normal form?

Example 9

A relational schema $R = (A, B, C, D)$

Functional dependencies: $A \rightarrow B, A \rightarrow C, B \rightarrow A, B \rightarrow C$

What is the normal form?

- In the functional dependency $AD \rightarrow BCD$, there exist:
  - Partial dependencies $A \rightarrow B$ and $A \rightarrow C$. These partial dependencies are a violation of 2NF requirement.
  - Transitive dependency $B \rightarrow C$. This transitive dependency is a violation of 3NF requirement.
  - Non-trivial dependency $B \rightarrow A$. This non-trivial dependency is a violation of BCNF.
- Hence, the relational schema R is in $1NF$.

Example 9

A relational schema $R = (A, B, C, D)$

Functional dependencies: $A \rightarrow B, A \rightarrow C, B \rightarrow A, B \rightarrow C$

What is the normal form?

- In the functional dependency $BD \rightarrow ACD$, there exist:
  - Partial dependencies $B \rightarrow A$ and $B \rightarrow C$. These partial dependencies are a violation of 2NF requirement.
  - Transitive dependency $A \rightarrow C$. This transitive dependency is a violation of 3NF requirement.
  - Non-trivial dependency $B \rightarrow A$. This non-trivial dependency is a violation of BCNF.
- Hence, the relational schema R is in $1NF$.

Example 9

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, A \rightarrow C, B \rightarrow A, B \rightarrow C}$

How to transform the relational schema R into BCNF?

Example 9

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, A \rightarrow C, B \rightarrow A, B \rightarrow C}$

How to transform the relational schema R into BCNF?

- With $\boldsymbol{AD \rightarrow BCD}$, we need to remove the partial dependencies $\boldsymbol{A \rightarrow BC}$ and split the relational schema $\boldsymbol{R}$ into two relational schemas $\boldsymbol{R1 = (A, D)}$ and $\boldsymbol{R2 = (A, B, C)}$
  - In relational schema $\boldsymbol{R1 = (A, D)}$, the minimal super key is $\boldsymbol{(A)}$, and the relational schema has NO partial dependency, NO transitive dependency, and NO non-trivial dependency. Hence, the relational schema $\boldsymbol{R1}$ is in $\boldsymbol{BCNF}$.

Example 9

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, A \rightarrow C, B \rightarrow A, B \rightarrow C}$

How to transform the relational schema R into BCNF?

- In relational schema $\boldsymbol{R2 = (A, B, C)}$, the minimal super key is $\boldsymbol{(A)}$, and the relational schema has NO partial dependency, but there exists a transitive dependency $\boldsymbol{B \rightarrow C}$, and a non-trivial dependency $\boldsymbol{B \rightarrow A}$. To transform the relational schema to BCNF, we need to remove both the transitive dependency $\boldsymbol{B \rightarrow C}$, and the non-trivial dependency $\boldsymbol{B \rightarrow A}$. Split the relational schema **R2** into $\boldsymbol{R3 = (A, B)}$, and $\boldsymbol{R4 = (B, C)}$.

Example 9

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, A \rightarrow C, B \rightarrow A, B \rightarrow C}$

How to transform the relational schema R into BCNF?

- In relational schema $\boldsymbol{R3 = (A, B)}$, the minimal super key is $\boldsymbol{(A)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. Hence the relational schema $\boldsymbol{R3}$ is in $\boldsymbol{BCNF}$.
- In relational schema $\boldsymbol{R4 = (B, C)}$, the minimal super key is $\boldsymbol{(B)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. Hence the relational schema $\boldsymbol{R4}$ is in $\boldsymbol{BCNF}$.

Example 10

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B}$

What is the minimal super key? (Scenario 1)

Example 10

A relational schema $R = (A, B, C, D)$

Functional dependencies: $AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B$

What is the minimal super key? (Scenario 1)

- If $AB \rightarrow C$ and $C \rightarrow D$ then through **transitivity rule**, $AB \rightarrow D$.
- If $AB \rightarrow D$ and $AB \rightarrow C$ then through **union rule**, $AB \rightarrow CD$.
- If $AB \rightarrow CD$ is valid in R and it covers the entire relational schema then the left-hand-side of the functional dependency (A, B) is a minimal key.

Example 10

A relational schema $R = (A, B, C, D)$

Functional dependencies: $AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B$

What is the minimal super key? (Scenario 2)

- If $D \rightarrow A$ and $D \rightarrow B$ then through **union rule**, $D \rightarrow AB$.
- If $D \rightarrow AB$ and $AB \rightarrow C$ then through **transitivity rule**, $D \rightarrow C$.
- If $D \rightarrow C$ and $D \rightarrow AB$ then $D \rightarrow ABC$.
- If $D \rightarrow ABC$ is valid in R and it covers the entire relational schema then the left-hand-side of the functional dependency (D) is a minimal key.

Example 10

A relational schema $R = (A, B, C, D)$

Functional dependencies: $AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B$

What is the minimal super key? (Scenario 3)

- If $C \rightarrow D$ and $D \rightarrow AB$ then through **transitivity rule**, $C \rightarrow AB$.
- If $C \rightarrow D$ and $C \rightarrow AB$ then through **union rule**, $C \rightarrow ABD$.
- If $C \rightarrow ABD$ is valid in R and it covers the entire relational schema then the left-hand-side of the functional dependency (C) is a minimal key.

Example 10

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B}$

What is the normal form? (Scenario 1)

Example 10

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B}$

What is the normal form? (Scenario 1)

- In the functional dependency $\boldsymbol{AB \rightarrow CD}$, there is NO partial dependency, but there exist a transitive dependency $\boldsymbol{C \rightarrow D}$. A transitive dependency is a violation of 3NF requirement.
- $\therefore$ the relational schema $\boldsymbol{R = (A, B, C, D)}$ is in $\boldsymbol{2NF}$.

Example 10

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B}$

What is the normal form? (Scenario 2)

- In the functional dependency $\boldsymbol{D \rightarrow ABC}$, there is NO partial dependency, but there exist a transitive dependency $\boldsymbol{AB \rightarrow C}$. A transitive dependency is a violation of 3NF requirement.
- $\therefore$ the relational schema $\boldsymbol{R = (A, B, C, D)}$ is in $\boldsymbol{2NF}$.

Example 10

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B}$

What is the normal form? (Scenario 3)

- In the functional dependency $\boldsymbol{C \rightarrow DAB}$, there is NO partial dependency, but there exist a transitive dependency $\boldsymbol{D \rightarrow AB}$. A transitive dependency is a violation of 3NF requirement.
- ∴ the relational schema $\boldsymbol{R = (A, B, C, D)}$ is in $\boldsymbol{2NF}$.

Example 10

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B}$

How to transform the relational schema R into BCNF? (Scenario 1)

Example 10

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B}$

How to transform the relational schema R into BCNF? (Scenario 1)

- In the functional dependency $\boldsymbol{AB \rightarrow CD}$, we need to remove the transitive dependency $\boldsymbol{C \rightarrow D}$ and split the relational schema $\boldsymbol{R}$ into two relational schemas $\boldsymbol{R1 = (A, B, C)}$ and $\boldsymbol{R2 = (C, D)}$.
  - In relational schema $\boldsymbol{R1 = (A, B, C)}$, the minimal super key is $\boldsymbol{(A, B)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. Hence the relational schema $\boldsymbol{R1}$ is in $\boldsymbol{BCNF}$.

Example 10

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B}$

How to transform the relational schema R into BCNF? (Scenario 1)

- In relational schema $\boldsymbol{R2 = (C, D)}$, the minimal super key is $\boldsymbol{(C)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. Hence the relational schema $\boldsymbol{R2}$ is in $\boldsymbol{BCNF}$.

Example 10

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B}$

How to transform the relational schema R into BCNF? (Scenario 2)

- In the functional dependency $\boldsymbol{D \rightarrow ABC}$, we need to remove the transitive dependency $\boldsymbol{AB \rightarrow C}$ and split the relational schema $\boldsymbol{R}$ into two relational schemas $\boldsymbol{R3 = (D, A, B)}$ and $\boldsymbol{R4 = (A, B, C)}$.
  - In relational schema $\boldsymbol{R3 = (D, A, B)}$, the minimal super key is $\boldsymbol{(D)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. Hence the relational schema $\boldsymbol{R3}$ is in $\boldsymbol{BCNF}$.

Example 10

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B}$

How to transform the relational schema R into BCNF? (Scenario 2)

- In the functional dependency $\boldsymbol{D \rightarrow ABC}$, we need to remove the transitive dependency $\boldsymbol{AB \rightarrow C}$ and split the relational schema $\boldsymbol{R}$ into two relational schemas $\boldsymbol{R3 = (D, A, B)}$ and $\boldsymbol{R4 = (A, B, C)}$.
  - In relational schema $\boldsymbol{R4 = (A, B, C)}$, the minimal super key is $\boldsymbol{(A, B)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. Hence the relational schema $\boldsymbol{R4}$ is in $\boldsymbol{BCNF}$.

Example 10

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B}$

How to transform the relational schema R into BCNF? (Scenario 3)

- In the functional dependency $\boldsymbol{C \rightarrow DAB}$, we need to remove the transitive dependency $\boldsymbol{D \rightarrow AB}$ and split the relational schema $\boldsymbol{R}$ into two relational schemas $\boldsymbol{R5 = (C, D)}$ and $\boldsymbol{R6 = (D, A, B)}$.
  - In relational schema $\boldsymbol{R5 = (C, D)}$, the minimal super key is $\boldsymbol{(C)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. Hence the relational schema $\boldsymbol{R5}$ is in $\boldsymbol{BCNF}$.

Example 10

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{AB \rightarrow C, C \rightarrow D, D \rightarrow A, D \rightarrow B}$

How to transform the relational schema R into BCNF? (Scenario 3)

- In the functional dependency $\boldsymbol{C \rightarrow DAB}$, we need to remove the transitive dependency $\boldsymbol{D \rightarrow AB}$ and split the relational schema $\boldsymbol{R}$ into two relational schemas $\boldsymbol{R5 = (C, D)}$ and $\boldsymbol{R6 = (D, A, B)}$.
  - In relational schema $\boldsymbol{R6 = (D, A, B)}$, the minimal super key is $\boldsymbol{(D)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. Hence the relational schema $\boldsymbol{R6}$ is in $\boldsymbol{BCNF}$.

Example 10

- Note: In the Example 10, the transformation of the relational schema to BCNF is needed (done) only using one of the three possible scenario.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

What is the minimal super key? (Scenario 1)

Example 11

A relational schema $R = (A, B, C, D)$

Functional dependencies: $A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A$

What is the minimal super key? (Scenario 1)

- If $A \rightarrow B$ and $B \rightarrow C$ then through **transitivity rule**, $A \rightarrow C$.
- If $A \rightarrow C$ and $C \rightarrow D$ then through **transitivity rule**, $A \rightarrow D$.
- If $A \rightarrow B$ and $A \rightarrow D$ then through **union rule** $A \rightarrow BCD$.
- If $A \rightarrow BCD$ is valid in R and it covers the entire relational schema then the left-hand-side of the functional dependency (A) is a minimal super key.

Example 11

A relational schema $R = (A, B, C, D)$

Functional dependencies: $A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A$

What is the minimal super key? (Scenario 2)

- If $B \rightarrow C$ and $C \rightarrow D$ then through **transitivity rule**, $B \rightarrow D$.
- If $B \rightarrow D$ and $D \rightarrow A$ then through **transitivity rule**, $B \rightarrow A$.
- If $B \rightarrow C$ and $B \rightarrow D$ and $B \rightarrow A$ then through **union rule** $B \rightarrow ACD$.
- If $B \rightarrow ACD$ is valid in R and it covers the entire relational schema then the left-hand-side of the functional dependency (B) is a minimal super key.

Example 11

A relational schema $R = (A, B, C, D)$

Functional dependencies: $A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A$

What is the minimal super key? (Scenario 3)

- If $C \rightarrow D$ and $D \rightarrow A$ then through **transitivity rule**, $C \rightarrow A$.
- If $C \rightarrow A$ and $A \rightarrow B$ then through **transitivity rule**, $C \rightarrow B$.
- If $C \rightarrow A$ and $C \rightarrow B$ and $C \rightarrow D$ then through **union rule** $C \rightarrow ABD$.
- If $C \rightarrow ABD$ is valid in R and it covers the entire relational schema then the left-hand-side of the functional dependency (C) is a minimal super key.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

What is the normal form? (Scenario 1)

Example 11

A relational schema $R = (A, B, C, D)$

Functional dependencies: $A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A$

What is the normal form? (Scenario 1)

- In the functional dependency $A \rightarrow BCD$, there is NO partial dependency, but there exist transitive dependencies $B \rightarrow C$ and $C \rightarrow D$. Existence of transitive dependency is a violation of 3NF requirement. In addition, there also exist a non-trivial dependency $D \rightarrow A$. Existence of non-trivial dependency is a violation of BCNF requirement.
- $\therefore$ the relational schema $R = (A, B, C, D)$ is in $2NF$.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

What is the normal form? (Scenario 2)

- In the functional dependency $\boldsymbol{B \rightarrow ACD}$, there is NO partial dependency, but there exist transitive dependencies $\boldsymbol{C \rightarrow D}$ and $\boldsymbol{D \rightarrow A}$. Existence of transitive dependency is a violation of 3NF requirement. In addition, there also exist a non-trivial dependency $\boldsymbol{A \rightarrow B}$. Existence of non-trivial dependency is a violation of BCNF requirement.
- $\therefore$ the relational schema $\boldsymbol{R = (A, B, C, D)}$ is in $\boldsymbol{2NF}$.

Example 11

A relational schema $R = (A, B, C, D)$

Functional dependencies: $A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A$

What is the normal form? (Scenario 3)

- In the functional dependency $C \rightarrow ABD$, there is NO partial dependency, but there exist transitive dependencies $D \rightarrow A$ and $A \rightarrow B$. Existence of transitive dependency is a violation of 3NF requirement. In addition, there also exist a non-trivial dependency $B \rightarrow C$. Existence of non-trivial dependency is a violation of BCNF requirement.
- $\therefore$ the relational schema $R = (A, B, C, D)$ is in $2NF$.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

How to transform the relational schema R into BCNF? (Scenario 1)

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

How to transform the relational schema R into BCNF? (Scenario 1)

- In the functional dependency $\boldsymbol{A \rightarrow BCD}$, we need to remove the transitive dependencies $\boldsymbol{B \rightarrow C}$ and $\boldsymbol{C \rightarrow D}$, and the non-trivial dependency $\boldsymbol{D \rightarrow A}$. Split the relational schema $\boldsymbol{R}$ into four relational schemas $\boldsymbol{R1 = (A, B)}$, $\boldsymbol{R2 = (B, C)}$, $\boldsymbol{R3 = (C, D)}$, and $\boldsymbol{R4 = (D, A)}$.
  - In relational schema $\boldsymbol{R1 = (A, B)}$, the minimal super key is $\boldsymbol{(A)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. $\therefore$ the relational schema $\boldsymbol{R1}$ is in $\boldsymbol{BCNF}$.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

How to transform the relational schema R into BCNF? (Scenario 1)

- In the functional dependency $\boldsymbol{A \rightarrow BCD}$, we need to remove the transitive dependencies $\boldsymbol{B \rightarrow C}$ and $\boldsymbol{C \rightarrow D}$, and the non-trivial dependency $\boldsymbol{D \rightarrow A}$. Split the relational schema $\boldsymbol{R}$ into four relational schemas $\boldsymbol{R1 = (A, B)}$, $\boldsymbol{R2 = (B, C)}$, $\boldsymbol{R3 = (C, D)}$, and $\boldsymbol{R4 = (D, A)}$.
  - In relational schema $\boldsymbol{R2 = (B, C)}$, the minimal super key is $\boldsymbol{(B)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. $\therefore$ the relational schema $\boldsymbol{R2}$ is in $\boldsymbol{BCNF}$.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

How to transform the relational schema R into BCNF? (Scenario 1)

- In the functional dependency $\boldsymbol{A \rightarrow BCD}$, we need to remove the transitive dependencies $\boldsymbol{B \rightarrow C}$ and $\boldsymbol{C \rightarrow D}$, and the non-trivial dependency $\boldsymbol{D \rightarrow A}$. Split the relational schema $\boldsymbol{R}$ into four relational schemas $\boldsymbol{R1 = (A, B)}$, $\boldsymbol{R2 = (B, C)}$, $\boldsymbol{R3 = (C, D)}$, and $\boldsymbol{R4 = (D, A)}$.
  - In relational schema $\boldsymbol{R3 = (C, D)}$, the minimal super key is $\boldsymbol{(C)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. ∴ the relational schema $\boldsymbol{R3}$ is in $\boldsymbol{BCNF}$.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

How to transform the relational schema R into BCNF? (Scenario 1)

- In the functional dependency $\boldsymbol{A \rightarrow BCD}$, we need to remove the transitive dependencies $\boldsymbol{B \rightarrow C}$ and $\boldsymbol{C \rightarrow D}$, and the non-trivial dependency $\boldsymbol{D \rightarrow A}$. Split the relational schema $\boldsymbol{R}$ into four relational schemas $\boldsymbol{R1 = (A, B)}$, $\boldsymbol{R2 = (B, C)}$, $\boldsymbol{R3 = (C, D)}$, and $\boldsymbol{R4 = (D, A)}$.
  - In relational schema $\boldsymbol{R4 = (D, A)}$, the minimal super key is $\boldsymbol{(D)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. $\therefore$ the relational schema $\boldsymbol{R4}$ is in $\boldsymbol{BCNF}$.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

How to transform the relational schema R into BCNF? (Scenario 2)

- In the functional dependency $\boldsymbol{B \rightarrow ACD}$, we need to remove the transitive dependencies $\boldsymbol{C \rightarrow D}$ and $\boldsymbol{D \rightarrow A}$, and the non-trivial dependency $\boldsymbol{D \rightarrow B}$. Split the relational schema $\boldsymbol{R}$ into four relational schemas $\boldsymbol{R1 = (B, C)}$, $\boldsymbol{R2 = (C, D)}$, $\boldsymbol{R3 = (D, A)}$, and $\boldsymbol{R4 = (D, B)}$.
  - In relational schema $\boldsymbol{R1 = (B, C)}$, the minimal super key is $\boldsymbol{(B)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. ∴ the relational schema $\boldsymbol{R1}$ is in $\boldsymbol{BCNF}$.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

How to transform the relational schema R into BCNF? (Scenario 2)

- In the functional dependency $\boldsymbol{B \rightarrow ACD}$, we need to remove the transitive dependencies $\boldsymbol{C \rightarrow D}$ and $\boldsymbol{D \rightarrow A}$, and the non-trivial dependency $\boldsymbol{A \rightarrow B}$. Split the relational schema $\boldsymbol{R}$ into four relational schemas $\boldsymbol{R1 = (B, C)}$, $\boldsymbol{R2 = (C, D)}$, $\boldsymbol{R3 = (D, A)}$, and $\boldsymbol{R4 = (A, B)}$.
  - In relational schema $\boldsymbol{R2 = (C, D)}$, the minimal super key is $\boldsymbol{(C)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. ∴ the relational schema $\boldsymbol{R2}$ is in $\boldsymbol{BCNF}$.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

How to transform the relational schema R into BCNF? (Scenario 2)

- In the functional dependency $\boldsymbol{B \rightarrow ACD}$, we need to remove the transitive dependencies $\boldsymbol{C \rightarrow D}$ and $\boldsymbol{D \rightarrow A}$, and the non-trivial dependency $\boldsymbol{D \rightarrow B}$. Split the relational schema $\boldsymbol{R}$ into four relational schemas $\boldsymbol{R1 = (B, C)}$, $\boldsymbol{R2 = (C, D)}$, $\boldsymbol{R3 = (D, A)}$, and $\boldsymbol{R4 = (D, B)}$.
  - In relational schema $\boldsymbol{R3 = (D, A)}$, the minimal super key is $\boldsymbol{(D)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. ∴ the relational schema $\boldsymbol{R3}$ is in $\boldsymbol{BCNF}$.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

How to transform the relational schema R into BCNF? (Scenario 2)

- In the functional dependency $\boldsymbol{B \rightarrow ACD}$, we need to remove the transitive dependencies $\boldsymbol{C \rightarrow D}$ and $\boldsymbol{D \rightarrow A}$, and the non-trivial dependency $\boldsymbol{D \rightarrow B}$. Split the relational schema $\boldsymbol{R}$ into four relational schemas $\boldsymbol{R1 = (B, C)}$, $\boldsymbol{R2 = (C, D)}$, $\boldsymbol{R3 = (D, A)}$, and $\boldsymbol{R4 = (D, B)}$.
  - In relational schema $\boldsymbol{R4 = (D, B)}$, the minimal super key is $\boldsymbol{(D)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. ∴ the relational schema $\boldsymbol{R4}$ is in $\boldsymbol{BCNF}$.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

How to transform the relational schema R into BCNF? (Scenario 3)

- In the functional dependency $\boldsymbol{C \rightarrow DAB}$, we need to remove the transitive dependencies $\boldsymbol{D \rightarrow A}$ and $\boldsymbol{A \rightarrow B}$, and the non-trivial dependency $\boldsymbol{B \rightarrow C}$. Split the relational schema $\boldsymbol{R}$ into four relational schemas $\boldsymbol{R1 = (C, D)}$, $\boldsymbol{R2 = (D, A)}$, $\boldsymbol{R3 = (A, B)}$, and $\boldsymbol{R4 = (B, C)}$.
  - In relational schema $\boldsymbol{R1 = (C, D)}$, the minimal super key is $\boldsymbol{(C)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. ∴ the relational schema $\boldsymbol{R1}$ is in $\boldsymbol{BCNF}$.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

How to transform the relational schema R into BCNF? (Scenario 3)

- In the functional dependency $\boldsymbol{C \rightarrow DAB}$, we need to remove the transitive dependencies $\boldsymbol{D \rightarrow A}$ and $\boldsymbol{A \rightarrow B}$, and the non-trivial dependency $\boldsymbol{B \rightarrow C}$. Split the relational schema $\boldsymbol{R}$ into four relational schemas $\boldsymbol{R1 = (C, D)}$, $\boldsymbol{R2 = (D, A)}$, $\boldsymbol{R3 = (A, B)}$, and $\boldsymbol{R4 = (B, C)}$.
  - In relational schema $\boldsymbol{R2 = (D, A)}$, the minimal super key is $\boldsymbol{(D)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. ∴ the relational schema $\boldsymbol{R2}$ is in $\boldsymbol{BCNF}$.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

How to transform the relational schema R into BCNF? (Scenario 3)

- In the functional dependency $\boldsymbol{C \rightarrow DAB}$, we need to remove the transitive dependencies $\boldsymbol{D \rightarrow A}$ and $\boldsymbol{A \rightarrow B}$, and the non-trivial dependency $\boldsymbol{B \rightarrow C}$. Split the relational schema $\boldsymbol{R}$ into four relational schemas $\boldsymbol{R1 = (C, D)}$, $\boldsymbol{R2 = (D, A)}$, $\boldsymbol{R3 = (A, B)}$, and $\boldsymbol{R4 = (B, C)}$.
  - In relational schema $\boldsymbol{R3 = (A, B)}$, the minimal super key is $\boldsymbol{(A)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. ∴ the relational schema $\boldsymbol{R3}$ is in $\boldsymbol{BCNF}$.

Example 11

A relational schema $\boldsymbol{R = (A, B, C, D)}$

Functional dependencies: $\boldsymbol{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A}$

How to transform the relational schema R into BCNF? (Scenario 3)

- In the functional dependency $\boldsymbol{C \rightarrow DAB}$, we need to remove the transitive dependencies $\boldsymbol{D \rightarrow A}$ and $\boldsymbol{A \rightarrow B}$, and the non-trivial dependency $\boldsymbol{B \rightarrow C}$. Split the relational schema $\boldsymbol{R}$ into four relational schemas $\boldsymbol{R1 = (C, D)}$, $\boldsymbol{R2 = (D, A)}$, $\boldsymbol{R3 = (A, B)}$, and $\boldsymbol{R4 = (B, C)}$.
  - In relational schema $\boldsymbol{R4 = (B, C)}$, the minimal super key is $\boldsymbol{(B)}$, and the relational schema has NO partial dependency, NO transitive dependency and NO non-trivial dependency. ∴ the relational schema $\boldsymbol{R4}$ is in $\boldsymbol{BCNF}$.

Example 11

- Note: In the Example 11, the transformation of the relational schema to BCNF is needed (done) only using one of the three possible scenario.

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