Database Programming and Management

Tutorial 8: Normalization

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$$R = \{A, B, C, D, E, F, G, H\}$$

$$\Sigma = \{ \{A\} \rightarrow \{C, E\},\ \ \{A, B\} \rightarrow \{D\},\ \ \{F\} \rightarrow \{H\},\ \ \{C, E\} \rightarrow \{A\},\ \ \{B, C, E\} \rightarrow \{D\},$$
$$\{A, B, F\} \rightarrow \{D, G\},\ \ \{B, C, E, F\} \rightarrow \{G\} \}$$

1.(a) Is R with Σ in 3NF?

A relation R is in **3NF** if, for every functional dependency $X \rightarrow Y$ in Σ:

1. The dependency is **trivial** (i.e, $Y \subseteq X$),

   OR

2. X is a **superkey** for R,

   OR

3. Every attribute in Y is **prime** (i.e., part of some candidate key).

📌 *NOTE:* Satisfying any one of the conditions will suffice and hence **OR**.

1.(a) Is R with Σ in 3NF?

Consider $\{A, B\} \rightarrow \{D\}$.

1. The dependency is **trivial** (i.e, $Y \subseteq X$),

   OR

2. X is a **superkey** for R,

   OR

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📌 *NOTE:* To prove something is NOT in 3NF, all 3 conditions must be False.

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Consider $\{A, B\} \rightarrow \{D\}$.

- It is non-trivial (i.e., $\{D\} \not\subseteq \{A, B\}$).
- $\{A, B\}$ is not a key (i.e., $\{A, B\}^+ = \{A, B, C, D, E\} \subset R$).

  $\{A, B\}$ is *also* not a superset of a key (keys are $\{A, B, F\}$ and $\{B, C, E, F\}$).

  $\Rightarrow$ This is a simpler way to check superkey if we have computed keys.

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  $\Rightarrow$ This is a simpler way to check superkey if we have computed keys.
- D is not a prime attribute.

  Prime attributes are $\{A, B, C, E, F\}$.

NO! NOT in 3NF!

1.(b) Is R with Σ in BCNF?

A relation R is in **BCNF** if, for every functional dependency $X \rightarrow Y$ in Σ:

1. The dependency is **trivial** (i.e, $Y \subseteq X$),

   OR

2. X is a **superkey** for R,

📌 *NOTE:*

- Every BCNF relation is in 3NF, but not every 3NF relation is in BCNF
- BCNF is stricter!

1.(b) Is R with Σ in BCNF?

From Question 1a, we know that R with Σ is not in 3NF. Therefore, it cannot be in BCNF. However, let us verify this from the definition of BCNF. Obviously, we can consider $\{A, B\} \rightarrow \{D\}$, but let us consider a different functional dependency. Consider $\{A\} \rightarrow \{C\}$.

NO! NOT in BCNF!

1.(b) Is R with Σ in BCNF?

From Question 1a, we know that R with Σ is not in 3NF. Therefore, it cannot be in BCNF. However, let us verify this from the definition of BCNF. Obviously, we can consider $\{A, B\} \rightarrow \{D\}$, but let us consider a different functional dependency. Consider $\{A\} \rightarrow \{C\}$.

- It is non-trivial (i.e., $\{C\} \not\subseteq \{A\}$).
- $\{A\}$ is not a superkey (i.e., $\{A\}^+ = \{A, C, E\} \subset R$).

  $\{A\}$ is *also* not a superset of a key (keys are $\{A, B, F\}$ and $\{B, C, E, F\}$).

  $\Rightarrow$ This is a simpler way to check superkey if we have computed keys.

NO! NOT in BCNF!

2.(a) Decompose R with Σ into a lossless-join 3NF.

Algorithm : 3NF Synthesis (Bernstein Algorithm)

When a relation is not in 3NF, we can *synthesize* a schema in 3NF from a *canonical cover* of the set of functional dependencies.

- For each functional dependency $X \rightarrow Y$ in the minimal cover, create a relation

  $$R_i = X \cup Y$$

  Unless it already exists or is *subsumed* by another relation
- If none of the created relations contain one of the keys, pick any candidate key and create a relation with that candidate key.

2.(a) Decompose R with Σ into a lossless-join 3NF.

We can start from a canonical cover directly.

$$\{ \{A\} \rightarrow \{C, E\}, \quad \{F\} \rightarrow \{H\}, \quad \{C, E\} \rightarrow \{A\}, \quad \{B, C, E\} \rightarrow \{D\}, \quad \{B, C, E, F\} \rightarrow \{G\} \}$$

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For each functional dependency, we synthesize a fragment.

$$\{\ \{A,C,E\},\ \{F,H\},\ \{A,C,E\},\ \{B,C,D,E\},\ \{B,C,E,F,G\}\ \}$$

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If there is any fragments that can be *subsumed*, we remove them from the result.

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$$\{\ \{A, C, E\},\ \{F, H\},\ \cancel{\{A, C, E\}},\ \{B, C, D, E\},\ \{B, C, E, F, G\}\ \}$$

If no candidate keys is present as a subset of any fragment, we add. Luckily, the key $\{B, C, E, F\}$ is a subset of $\{B, C, E, F, G\}$. So, we do not have to add another relation.

$$\{\ \{A, C, E\},\ \{F, H\},\ \{B, C, D, E\},\ \{B, C, E, F, G\}\ \}$$

If no key is present

We know the keys of R are *{A,B,F}* and *{B,C,E,F}*

Suppose after subsumption we ended up with this:

$$\{\ \{A,C,E\},\ \{F,H\},\ \{B,C,D,E\},\ \boxed{\{B,C,E,F\}}\ \}$$

Add any of the keys! That’s it

NOTE:

- If the questions asks you to just make fragments - Make fragments using the **3NF synthesis algorithm** and you can stop there.
- Skip **FD projections** and **BCNF checks** unless the question **explicitly asks** or you need to verify extras.

Projection steps

5 steps to compute projection of R with Σ onto X.

1. Find all subset X' of attributes of X.
2. For each subset X', compute the closure (i.e., $\varphi_1 := \texttt{AttrClose}(X', \Sigma)$).
3. Keep only the relevant attributes (i.e., $\varphi_2 := \varphi_1 \cap X$).
4. Remove attributes that does not contribute new information (i.e., $\varphi_3 := \varphi_2 - X'$).
5. If φ_3 is not empty, form a functional dependency $X' \rightarrow \varphi_3$.

📌**Question:**
Calculate the projection R with Σ onto X = {A, C, E}

Calculating Projections

Do this for all possible subsets

1 = choose subset $X' \subseteq X$

2 = $\varphi_1 := \mathrm{AttrClose}(X', \Sigma)$

3 = $\varphi_2 := \varphi_1 \cap X$

4 = $\varphi_3 := \varphi_2 - X'$

5 = if $\varphi_3 \neq \varnothing$, emit $X' \rightarrow \varphi_3$

Onto $X = \{A, C, E\}$ (call this Σ_1)

Step 1 X'	**Step 2 φ_1 (closure)**	**Step 3 φ_2**	**Step 4 φ_3**	**Step 5 (FD)**
{A}	{A,C,E} (by A→CE)	{A,C,E}	{C,E}	**A→CE**
{C,E}	{A,C,E} (by CE→A)	{A,C,E}	{A}	**CE→A**
{A,C}	{A,C,E}	{A,C,E}	{E}	AC→E (*implied by A→CE*)
{A,E}	{A,C,E}	{A,C,E}	{C}	AE→C (*implied by A→CE*)

All other X' give $\varphi_3 = \varnothing$. Keep the bold FDs for a minimal projection: **Σ_1 = {A→CE, CE→A}**.

Calculating Projections

Exhaustive check (all 8 subsets of X)

Step 1 X'	**Step 2** $\varphi_1 = (X')^+$	**Step 3** $\varphi_2 = \varphi_1 \cap X$	**Step 4** $\varphi_3 = \varphi_2 \setminus X'$	**Step 5 (FD if any)**
∅	∅	∅	∅	—
{E}	{E}	{E}	∅	—
{C}	{C}	{C}	∅	—
{A}	{A,C,E} (by $A \to CE$)	{A,C,E}	{C,E}	**A → CE**
{C,E}	{A,C,E} (by $CE \to A$)	{A,C,E}	{A}	**CE → A**
{A,E}	{A,C,E}	{A,C,E}	{C}	AE → C *(implied by $A \to CE$)*
{A,C}	{A,C,E}	{A,C,E}	{E}	AC → E *(implied by $A \to CE$)*
{A,C,E}	{A,C,E}	{A,C,E}	∅	—

1 = choose subset $X' \subseteq X$

2 = $\varphi_1 := \mathrm{AttrClose}(X', \Sigma)$

3 = $\varphi_2 := \varphi_1 \cap X$

4 = $\varphi_3 := \varphi_2 - X'$

5 = if $\varphi_3 \neq \emptyset$, emit $X' \to \varphi_3$

Calculating Projections

Do this for all possible subsets

1 = choose subset $X' \subseteq X$

2 = $\varphi_1 := \mathrm{AttrClose}(X', \Sigma)$

3 = $\varphi_2 := \varphi_1 \cap X$

4 = $\varphi_3 := \varphi_2 - X'$

5 = if $\varphi_3 \neq \varnothing$, emit $X' \to \varphi_3$

Onto $X = \{F, H\}$ (Σ_2)

Step 1 X'	**Step 2** φ_1	**Step 3** φ_2	**Step 4** φ_3	**Step 5**
{F}	{F,H} (by F→H)	{F,H}	{H}	**F→H**

Other subsets yield $\varphi_3 = \varnothing$. So **Σ_2 = {F→H}**.

📌**Early Exit Rule:**
Let S = AttrClose(X′, Σ). If φ_2 = X′, stop for this X′ (no FD).

Calculating Projections

Do this for all possible subsets

1 = choose subset $X' \subseteq X$

2 = $\varphi_1 := \mathrm{AttrClose}(X', \Sigma)$

3 = $\varphi_2 := \varphi_1 \cap X$

4 = $\varphi_3 := \varphi_2 - X'$

5 = if $\varphi_3 \neq \varnothing$, emit $X' \to \varphi_3$

Onto $X = \{B, C, D, E\}$ (Σ_3)

Step 1 X'	**Step 2 φ_1**	**Step 3 φ_2**	**Step 4 φ_3**	**Step 5**
{B,C,E}	{B,C,E,D} (by **BCE→D**)	{B,C,E,D}	{D}	**BCE→D**

All other subsets inside $\{B, C, D, E\}$ do not gain D (or add nothing beyond themselves), so $\varphi_3 = \varnothing$.

Thus **Σ_3 = {BCE→D}**.

Calculating Projections

Do this for all possible subsets

1 = choose subset $X' \subseteq X$

2 = $\varphi_1 := \mathrm{AttrClose}(X', \Sigma)$

3 = $\varphi_2 := \varphi_1 \cap X$

4 = $\varphi_3 := \varphi_2 - X'$

5 = if $\varphi_3 \neq \varnothing$, emit $X' \to \varphi_3$

Onto $X = \{B, C, E, F, G\}$ **(Σ_4)**

Step 1 X'	**Step 2** φ_1	**Step 3** φ_2	**Step 4** φ_3	**Step 5**
{B,C,E,F}	{B,C,E,**F**,G} (by **BCEF→G**)	{B,C,E,F,G}	{G}	**BCEF→G**

Others give $\varphi_3 = \varnothing$. Hence **Σ_4 = {BCEF→G}**.

Final Projections

Do this for all possible subsets

1 = choose subset $X' \subseteq X$

2 = $\varphi_1 := \mathrm{AttrClose}(X', \Sigma)$

3 = $\varphi_2 := \varphi_1 \cap X$

4 = $\varphi_3 := \varphi_2 - X'$

5 = if $\varphi_3 \neq \varnothing$, emit $X' \rightarrow \varphi_3$

- $\{A, C, E\}$ with $\Sigma_1 = \{ \{A\} \rightarrow \{C\}, \ \{A\} \rightarrow \{E\}, \{C, E\} \rightarrow \{A\} \}$
- $\{F, H\}$ with $\Sigma_2 = \{ \{F\} \rightarrow \{H\} \}$
- $\{B, C, D, E\}$ with $\Sigma_3 = \{ \{B, C, E\} \rightarrow \{D\} \}$
- $\{B, C, E, F, G\}$ with $\Sigma_4 = \{ \{B, C, E, F\} \rightarrow \{G\} \}$

Mistake : "Keep only FDs that use attributes from X"

R(A, B, C), Σ = { A→B, B→C }, project onto X = {A, C}.

Naive keeps none (since both FDs mention B).

Correct (by the algorithm):

- For X′ = {A}: A^+ = {A, B, C} ⇒ (A^+ ∩ X) − {A} = {C} ⇒ **A→C**

  Projection is **{ A→C }**.

  The naive method **misses** A→C (transitive via B).

📌 *NOTE:*
Using shortcuts can lead to error in **MANY different ways!**
This is not the only one!

Projection – Caution Points ⚠️

- Projection is **error-prone** → don't skip steps!
- Shortcuts can omit valid **derived FDs**.
- Always follow all **5 steps** for correctness ✅ .
- Tedious ⏳, but ensures **accurate results**.
- ❌ Shortcuts **don't guarantee** correctness.

(b) Is the result dependency preserving?

Definition

- Let R be a relation schema and Σ a set of functional dependencies (FDs).
- Decompose R into $\Delta = \{R_1, \ldots, R_n\}$.
- For each piece R_i, let $\Sigma|_{R_i}$ be the projection of Σ onto R_i.
- The decomposition is *dependency-preserving* iff

$$\Sigma^+ = \left(\Sigma|_{R_1} \cup \cdots \cup \Sigma|_{R_n}\right)^+.$$

Note (how to check)

- For every FD $X \to Y$ in Σ, compute X^+ using $\Sigma|_{R_1} \cup \cdots \cup \Sigma|_{R_n}$.
- If $Y \subseteq X^+$ for all FDs in Σ, the decomposition is dependency-preserving.

(b) Is the result dependency preserving?

Yes. This is guaranteed by the algorithm. 3NF synthesis algorithm produces lossless-join dependency-preserving decomposition in 3NF.

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- $\{A, C, E\}$ with $\Sigma_1 = \{ \{A\} \rightarrow \{C\},\ \{A\} \rightarrow \{E\}, \{C, E\} \rightarrow \{A\} \}$

📌 *NOTE:*
All non-trivial FDs here (A→C, A→E, CE→A, and A→CE) have LHS ∈ {A, CE} (keys) ⇒ BCNF

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The 3NF synthesis only guarantees that the result is in 3NF, it may not be in BCNF.

- $\{A, C, E\}$ with $\Sigma_1 = \{\ \{A\} \rightarrow \{C\},\ \{A\} \rightarrow \{E\}, \{C, E\} \rightarrow \{A\}\ \}$
- $\{F, H\}$ with $\Sigma_2 = \{\ \{F\} \rightarrow \{H\}\ \}$

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- $\{B, C, D, E\}$ with $\Sigma_3 = \{\ \{B, C, E\} \rightarrow \{D\}\ \}$
- $\{B, C, E, F, G\}$ with $\Sigma_4 = \{\ \{B, C, E, F\} \rightarrow \{G\}\ \}$

YES! It is in BCNF!

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The 3NF synthesis only guarantees that the result is in 3NF, it may not be in BCNF.

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Note that it is not always the case that we are lucky to obtain a BCNF decomposition using 3NF synthesis, but it may happen.

🏁 One Last Lap

💙 **One last class to go!** (BCNF + Extra problems + doubt clearing) — hope to all of you there! 📚✨

💬 If you enjoyed the module, please take a moment to leave your **feedback/rating** after the course — it really helps me grow as a teacher! 🙏💫

👋 I'll see you all around campus — don't hesitate to say hi or wave! 😄🎓

Thank you for joining!

Got questions? Post them on the forum or email me:

biswadeep@u.nus.edu

(I reply **within 2 working days** — *faster if coffee is strong* ☕)

Because your learning matters to me! 😊

NUS

National University of Singapore

You can generate all implied FDs by running the above closure for **every** subset X⊆UX \subseteq UX⊆U (U = all attributes):

```
Σplus := ∅

for each X ⊆ U:

    S := AttrClosure(X, Σ)

    for each attribute A in (S - X):

        add FD  X → A  to Σplus   // (often we ignore trivial A∈X)
```

Subsumption

Keep

In some cases like $R = \{A, B, C\}$ with $\Sigma = \{ \{A,B\} \rightarrow \{C\}, \{C\} \rightarrow \{B\} \}$, we ***cannot remove*** $R_2 = \{B, C\}$ even when it is subsumed by $R_1 = \{A, B, C\}$.

R2(B, C)

```sql
CREATE TABLE R2 (
  B  INT,
  C  INT
    UNIQUE,
  PRIMARY KEY (B, C)

);
```

R1(A, B, C)

```sql
CREATE TABLE R1 (
  A  INT,
  B  INT,
  C  INT,
  PRIMARY KEY (A, B),
  FOREIGN KEY (B, C) REFERENCES R2(B, C)
);
```

Lemma #1: Lossless-Join Binary Decomposition

A **binary decomposition** of R into R_1 and R_2 is ***lossless-join*** if $R = R_1 \cup R_2$ and $(R_1 \cap R_2) \rightarrow R_1$ or $(R_1 \cap R_2) \rightarrow R_2$

Lemma #2: Lossless-Join Decomposition

A **decomposition** of R into R_1, R_2, ..., R_n is ***lossless-join*** if there exists **at least one sequence** of binary lossless-join decomposition that generates that decomposition.

Note

If $(R_1 \cap R_2)$ is the primary key of one of the two tables, then it can be a foreign key in the other table referencing the primary key.

0) Pick an anchor that contains a key

Compute $(BCEF)^+$ under Σ:

- BCEF ⟶ G (BCEF→G) ⇒ add G
- BCE ⟶ D (BCE→D) ⇒ add D
- CE ⟶ A (CE→A) ⇒ add A
- F ⟶ H (F→H) ⇒ add H

So $(BCEF)^+$ = **A B C D E F G H ⇒ BCEF is a key**.
Fragment **R_4(BCEFG)** contains BCEF ⇒ use **R_4** as the anchor.

1) Join R_4(BCEFG) with R_3(BCDE)

- Intersection: **$R_4 \cap R_3$ = {B,C,E}**.
- Check binary test: does {B,C,E} ⟶ R_3 ?
  Yes: {B,C,E} ⟶ D (given) and trivially ⟶ {B,C,E}, so {B,C,E} ⟶ **BCDE**.

✅ Step 1 is **lossless**.

2) Join the result with R_1(ACE)

(Current attributes after step 1: {B,C,E,F,G,D})

- Intersection: **{C,E}**.
- Check: {C,E} ⟶ R_1 ?
  Yes: {C,E} ⟶ A (given) and trivially ⟶ {C,E} ⇒ {C,E} ⟶ **ACE**.

✅ Step 2 is **lossless**.

3) Join the result with R_2(FH)

(Current attributes after step 2: {A,B,C,D,E,F,G})

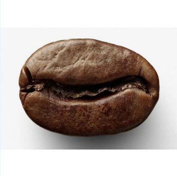
- Intersection: **{F}** (H isn't in the current set yet).
- Check: {F} ⟶ R_2 ?
  Yes: {F} ⟶ H (given) and trivially ⟶ F ⇒ {F} ⟶ **FH**.

✅ Step 3 is **lossless**.

Problem Overview

Design a relational schema for the management of coffee bean, drinks and cafes

The Coffee Bean Entity

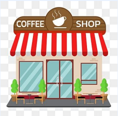


- Identified by *BrandName* **OR** *(Cultivar, Region)*
- One bean → many drinks
- Attributes: *(BrandName, Cultivar, Region)*
- PK: *(BrandName)* or *(Cultivar, Region)*

Drink Entity

- Made from **one coffee bean**
- Name unique **per bean**
- Attributes: *(BeanID, DrinkName, Price)*
- PK: *(BeanID, DrinkName)*

Branch



- Represents a **physical coffee shop branch**
- Each branch has a **unique name**
- **Attributes:** (BranchName, Address)
- **PK:** (BranchName)