CMSC 461, Database Management Systems
Spring 2018

Lecture 12 - Chapter 8 Relational Database Design Part 2

These slides are based on “Database System Concepts” 6th edition book and are a modified version of the slides which accompany the book (http://codex.cs.yale.edu/avi/db-book/db6/slide-dir/index.html), in addition to the 2009/2012 CMSC 461 slides by Dr. Kalpakis

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https://www.csee.umbc.edu/~jsleem1/courses/461/spr18

Logistics

- Phase 2 due Wednesday 3/7/2018
- HW3 due 3/12/2018
- Midterm 3/14/2018

Lecture Outline

- Midterm Review
- Normalization
- Boyce-Codd (BCNF)
- Third Normal Form
- Functional Dependency Theory

Lecture Outline

- ***Midterm Review***
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Midterm

- See study guide

Lecture Outline

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Why Normalize?

Why Normalize?

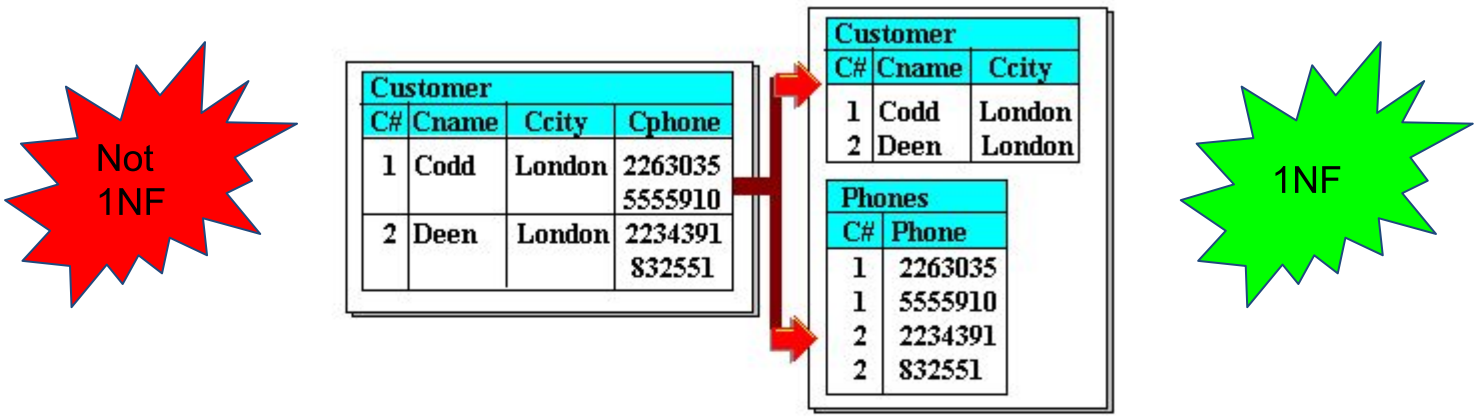
- Reduce the amount of duplicate data
- Reduce data modification issues
- Simplify queries

Normal Forms

- First (we will cover a lot)
- Second (we will briefly cover)
- Third and BCNF (we will cover a lot)
- Fourth (we will briefly cover)
- Fifth (we will not cover)

First Normal Form

- Attributes contains atomic values
- Eliminate composite and multi-valued attributes



Based on and image from https://coronet.iicm.tugraz.at/Dbase1/scripts/rdbh04.htm and slides/book “Database System Concepts” 6th edition

Second Normal Form

- If each attribute in *R* meets one of the following:
  - It appears in a candidate key
  - It is not partially dependent on a candidate key

Therefore, if *R* is in 1st normal form and its non-key attributes are functionally dependent on the candidate key it is in second normal form.

Second Normal Form

Transaction

C#	Cname	Ccity	Cphone	P#	Date	Qnt
1	Codd	London	2263035	1	21.01	20
1	Codd	London	2263035	2	23.01	30
2	Martin	Paris	5555910	1	26.01	25
3	Deen	London	2234391	2	29.01	20

Not 2NF

Transaction

C#	Cname	Ccity	Cphone	P#	Date	Qnt
1	Codd	London	2263035	1	21.01	20
1	Codd	London	2263035	2	23.01	30
2	Martin	Paris	5555910	1	26.01	25
3	Deen	London	2234391	2	29.01	20
4	Smith	Vienna	?	?	?	?

Entity Integrity Violation: P# is a part of primary key !

Transaction

C#	Cname	Ccity	Cphone	P#	Date	Qnt
1	Codd	London	2263035	1	21.01	20
1	Codd	London	2263035	2	23.01	30
2	Martin	Paris	5555910	1	26.01	25
3	Deen	London	2234391	2	29.01	20

Delete

Transaction

C#	Cname	Ccity	Cphone	P#	Date	Qnt
1	Codd	London	2263035	1	21.01	20
1	Codd	London	2263035	2	23.01	30
2	Martin	Paris	5555910	1	26.01	25
3	Deen	London	2234391	2	29.01	20

Customer

C#	Cname	Ccity	Cphone
1	Codd	London	2263035
2	Martin	Paris	5555910
3	Deen	London	2234391

C# → Cname
C# → Ccity
C# → Cphone

Transaction

C#	P#	Date	Qnt
1	1	21.01	20
1	2	23.01	30
2	1	26.01	25
3	2	29.01	20

(C#,P#,Date) → Qnt

2NF

Based on and image from https://coronet.iicm.tugraz.at/Dbase1/scripts/rdbh04.htm and slides/book "Database System Concepts" 6th edition

Third Normal Form

- If in 2nd normal form and
- Contains only attributes dependent on the primary key and not other attributes

Customer				
C#	Cname	Ccity	Cphone	Salesperson
1	Codd	London	2263035	Smith
2	Martin	Paris	5555910	Ducruer
3	Deen	London	2234391	Smith
?	?	Sarawak	?	Fatimah

C# -> Cname,Ccity, Cphone,Salesperson

Salesperson has indirect dependency

Based on and image from https://coronet.iicm.tugraz.at/Dbase1/scripts/rdbh04.htm and slides/book “Database System Concepts” 6th edition

Boyce-Codd Normal Form

- Remember BCNF is stricter than 3NF
- So if it is BCNF, then it is 3NF
- However if it is 3NF, it may not be BCNF

Student	Course	Teacher
Sok	DB	John
Sao	DB	William
Chan	E-Commerce	Todd
Sok	E-Commerce	Todd
Chan	DB	William

- Key: {Student, Course}
- Functional Dependency:
  - {Student, Course}→ Teacher
  - Teacher → Course
- Problem: ***Teacher*** is not a superkey but determines ***Course***.

Image from https://www.slideshare.net/kosalgeek/database-normalization-1nf-2nf-3nf-bcnf-4nf-5nf, Based on "Database System Concepts" book and slides, 6th edition

Fourth Normal Form

- Has to be in BCNF
- Requires understanding multivalued dependencies
- Given an entity, should not contain 2 or more independent multi-valued facts

Employee ID	Language	Operating System
1212	C++	Windows
1212	Java	Windows
1212	Python	Windows
1212	Python	Linux
1212	Java	Linux

Based on and image from "Database System Concepts" book and slides, 6th edition

Fourth Normal Form

- Has to be in BCNF
- Requires understanding multivalued dependencies
- Given an entity, should not contain 2 or more independent multi-valued facts

Employee ID	Language
1212	C++
1212	Java
1212	Python

Employee ID	Operating System
1212	Windows
1212	Linux
1212	Linux

Based on and image from "Database System Concepts" book and slides, 6th edition

Fourth Normal Form

Another example (more on 4NF later)

Car_Model (PK)	Engine_Type (PK)	Color (PK)
Mustang	3.7L V6	Red
Mustang	3.7L V6	Blue
Mustang	5.0L V8	Red
Taurus	3.5L V6	Green
Taurus	2.0L Eco	Green

Based on and image from "Database System Concepts" book and slides, 6th edition

Simplified: The Normal Forms

A nice simple discussion of normal forms (not 100% precise, but close enough)

https://www.essentialsql.com/get-ready-to-learn-sql-11-database-third-normal-form-explained-in-simple-english/

Lecture Outline

- Midterm Review
- Normalization
- ***Boyce-Codd (BCNF)***
- Third Normal Form
- Functional Dependency Theory

Boyce-Codd Normal Form

A relation schema R is in BCNF with respect to a set F of functional dependencies if for all functional dependencies in F^+ of the form

$$\alpha \rightarrow \beta$$

where $\alpha \subseteq R$ and $\beta \subseteq R$, at least one of the following holds:

- $\alpha \rightarrow \beta$ is trivial (i.e., $\beta \subseteq \alpha$)
- α is a superkey for R

Example schema *not* in BCNF:

instr_dept (*ID, name, salary, dept_name, building, budget*)

because *dept_name*→ *building, budget*
holds on *instr_dept*, but *dept_name* is not a superkey

Based on and image from "Database System Concepts" book and slides, 6th edition

Boyce-Codd Normal Form

Are these schemas in BCNF:

instructor (*ID*, *name*, *dept_name*, *salary*)
ID→ *name*,*dept_name*,*salary*

YES – ID is superkey

department(dept_name,building,budget)
dept_name→ *building*, *budget*

YES – dept_name is superkey

Based on and image from "Database System Concepts" book and slides, 6th edition

Decomposing a Schema into BCNF

- Suppose we have a schema R and a non-trivial dependency $\alpha \rightarrow \beta$ causes a violation of BCNF.

  We decompose R into:

  $(\alpha \cup \beta)$

  $(R - (\beta - \alpha))$

- In our example:

  instr_dept (*ID, name, salary, dept_name, building, budget*)

  α = *dept_name*

  β = *building, budget*

  and *inst_dept* is replaced by

  $(\alpha \cup \beta)$ = (*dept_name, building, budget*)

  $(R - (\beta - \alpha))$ = (*ID, name, salary, dept_name*)

Convert it to BCNF

Schema:

Student(ID,Name,AdvisorID,AdvisorName)

What are the functional dependencies?

Convert it to BCNF

Schema:

Student(ID,Name,AdvisorID,AdvisorName)

What are the functional dependencies?

ID -> Name
AdvisorID -> AdvisorName

What uniquely identifies the tuples?

Convert it to BCNF

Schema:

Student(ID,Name,AdvisorID,AdvisorName)

What are the functional dependencies?

ID -> Name
AdvisorID -> AdvisorName

What uniquely identifies the tuples?
(ID,AdvisorID)

Is there a BCNF violation?

Convert it to BCNF

Schema:

Student(ID,Name,AdvisorID,AdvisorName)

What are the functional dependencies?

ID -> Name
AdvisorID -> AdvisorName

What is the primary key?
(ID,AdvisorID)

Is there a BCNF violation? YES!

Based on and image from "Database System Concepts" book and slides, 6th edition

Convert it to BCNF

Schema:
Student(ID,Name,AdvisorID,AdvisorName)

What are the functional dependencies?
ID -> Name
AdvisorID -> AdvisorName

What is the primary key?
(ID,AdvisorID)

Is there a BCNF violation? YES!

Use ID-> Name to decompose R
(ID,AdvisorID,AdvisorName) and (ID,Name)

BCNF and Dependency Preservation

- Constraints, including functional dependencies, are costly to check in practice unless they pertain to only one relation
- If it is sufficient to test only those dependencies on each individual relation of a decomposition in order to ensure that all functional dependencies hold, then that decomposition is dependency preserving
- Because it is not always possible to achieve both BCNF and dependency preservation, we consider a weaker normal form, known as third normal form

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- ***Third Normal Form***
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Third Normal Form

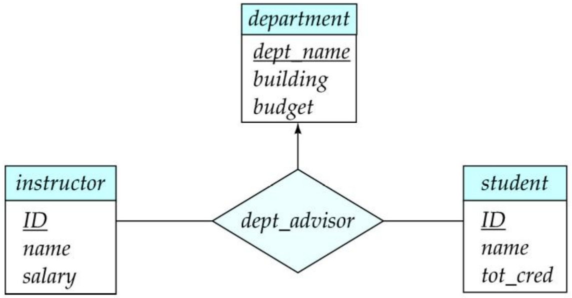
- A relation schema R is in **third normal form (3NF)** if for all:

  $\alpha \rightarrow \beta$ in F^+

  at least one of the following holds:
  - $\alpha \rightarrow \beta$ is trivial
  - α is a superkey for R
  - Each attribute A in $\beta - \alpha$ is contained in a candidate key for R.

    (**NOTE**: each attribute may be in a different candidate key)
- If a relation is in BCNF it is in 3NF (since in BCNF one of the first two conditions above must hold).
- Third condition is a minimal relaxation of BCNF to ensure dependency preservation (will see why later).

Third Normal Form



- Given dept_advisor with dependencies:
  - i_ID $\rightarrow$dept_name
  - s_ID,dept_name $\rightarrow$i_ID

dept_advisor(s_ID, i_ID, dept_name)

- i_ID $\rightarrow$dept_name make dept_advisor not BCNF
  - α = i_ID
  - β = dept_name
  - $\beta - \alpha$ = dept_name
- But since s_ID,dept_name $\rightarrow$i_ID holds on dept_advisor then dept_name is a candidate key which means
- dept_advisor is in 3NF

Based on and image from "Database System Concepts" book and slides, 6th edition

Goals of Normalization

- Let R be a relation scheme with a set F of functional dependencies
- Decide whether a relation scheme R is in “good” form
- In the case that a relation scheme R is not in “good” form, decompose it into a set of relation scheme $\{R_1, R_2, ..., R_n\}$ such that:
    - each relation scheme is in good form
    - the decomposition is a lossless-join decomposition
    - Preferably, the decomposition should be dependency preserving

How Good is BCNF?

- There are database schemas in BCNF that do not seem to be sufficiently normalized
- Consider a relation
  inst_info (ID, child_name, phone)
  - where an instructor may have more than one phone and can have multiple children

ID	*child_name*	*phone*
99999	David	512-555-1234
99999	David	512-555-4321
99999	William	512-555-1234
99999	Willian	512-555-4321

inst_info

Based on and image from "Database System Concepts" book and slides, 6th edition

How Good is BCNF?

- There are no non-trivial functional dependencies and therefore the relation is in BCNF
- Insertion anomalies – i.e., if we add a phone 981- 992-3443 to 99999, we need to add two tuples (99999, David, 981-992-3443) (99999, William, 981-992-3443)

How Good is BCNF?

- Therefore, it is better to decompose inst_info into:

inst_child

ID	*child_name*
99999	David
99999	David
99999	William
99999	Willian

inst_phone

ID	*phone*
99999	512-555-1234
99999	512-555-4321
99999	512-555-1234
99999	512-555-4321

This suggests the need for higher normal forms, such as Fourth Normal Form (4NF), which we shall see later

Based on and image from "Database System Concepts" book and slides, 6th edition

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Functional Dependencies

- *Let R be a relation schema*

  $\alpha \subseteq R$ and $\beta \subseteq R$
- *The functional dependency*

  $\alpha \rightarrow \beta$
- *holds on R if and only if for any legal relations r(R), whenever any two tuples t_1 and t_2 of r agree on the attributes* **α**, *they also agree on the attributes* **β**. *That is*

  $$t_1[\alpha] = t_2[\alpha] \Rightarrow t_1[\beta] = t_2[\beta]$$
- *Example: Consider r(A,B) with the following instance of r*

1	4
1	5
3	7

- *On this instance, A⟶B does NOT hold, but B⟶A does hold*

Based on and image from "Database System Concepts" book and slides, 6th edition

Functional Dependencies

- Functional dependencies allow us to express constraints that cannot be expressed using superkeys. Consider the schema:
  inst_dept (ID, name, salary, dept_name, building, budget)

We expect these functional dependencies to hold:

dept_name→building

but would not expect the following to hold:

dept_name→salary

Based on and image from "Database System Concepts" book and slides, 6th edition

Functional Dependencies

- We use functional dependencies to:
  - test relations to see if they are legal under a given set of functional dependencies
    - If a relation r is legal under a set F of functional dependencies, we say that r ***satisfies*** F
  - specify constraints on the set of legal relations
- We say that F ***holds on*** R if all legal relations on R satisfy the set of functional dependencies F
- Note: A specific instance of a relation schema may satisfy a functional dependency even if the functional dependency does not hold on all legal instances
  - For example, a specific instance of *instructor* may sometimes satisfy

    $name \longrightarrow ID$

Functional Dependencies

- A functional dependency is trivial if it is satisfied by all instances of a relation
  - Example:
    - *ID, name* $\rightarrow$ *ID*
    - *name* $\rightarrow$ *name*
  - In general, $\alpha \rightarrow \beta$ is trivial if $\beta \subseteq \alpha$

Based on and image from "Database System Concepts" book and slides, 6th edition

Functional Dependencies Examples

Assume schema:

student(student_id, first_name, last_name, major, SSN)

Which are true in regards to functional dependencies:

student_id → last_name TRUE
last_name → student_id FALSE
student_id → last_name, major, SSN, student_id TRUE
SSN → student_id, last_name, major, SSN TRUE
first_name→ last_name FALSE
last_name → last_name TRUE

Based on and image from "Database System Concepts" book and slides, 6th edition

Functional Dependency Theory

We now consider the formal theory that tells us which functional dependencies are implied logically by a given set of functional dependencies.

Closure of a Set of Functional Dependencies

- Given a set F of functional dependencies, there are certain other functional dependencies that are logically implied by *F*
  - For example:
    Given a schema r(A,B,C)
    If $A \rightarrow B$ and $B \rightarrow C$
    then we can infer that $A \rightarrow C$
- The set of all functional dependencies logically implied by *F* is the closure of *F*
- We denote the closure of *F* by F^+
- F^+ is a superset of *F*

Closure of a Set of Functional Dependencies

- We can find F^+, the closure of F, by repeatedly applying **Armstrong's Axioms:**
  - if $\beta \subseteq \alpha$, then $\alpha \rightarrow \beta$ (**reflexivity**)
  - if $\alpha \rightarrow \beta$, then $\gamma \alpha \rightarrow \gamma \beta$ (**augmentation**)
  - if $\alpha \rightarrow \beta$, and $\beta \rightarrow \gamma$, then $\alpha \rightarrow \gamma$ (**transitivity**)
- These rules are
  - **sound** (generate only functional dependencies that actually hold), and
  - **complete** (generate all functional dependencies that hold).

Based on and image from "Database System Concepts" book and slides, 6th edition

Closure of a set of Functional Dependencies

- Additional rules:
  - If $\alpha \rightarrow \beta$ holds and $\alpha \rightarrow \gamma$ holds, then $\alpha \rightarrow \beta\gamma$ holds (**union**)
  - If $\alpha \rightarrow \beta\gamma$ holds, then $\alpha \rightarrow \beta$ holds and $\alpha \rightarrow \gamma$ holds (**decomposition**)
  - If $\alpha \rightarrow \beta$ holds and $\gamma\beta \rightarrow \delta$ holds, then $\alpha\gamma \rightarrow \delta$ holds (**pseudotransitivity**)

The above rules can be inferred from Armstrong's axioms.

Based on and image from "Database System Concepts" book and slides, 6th edition

Closure of a set of Functional Dependencies Example

- $R = (A, B, C, G, H, I)$

  $F = \{ A \rightarrow B$

  $A \rightarrow C$

  $CG \rightarrow H$

  $CG \rightarrow I$

  $B \rightarrow H\}$
- some members of F^+
  - $A \rightarrow H$
    - by transitivity from $A \rightarrow B$ *and* $B \rightarrow H$
  - $AG \rightarrow I$
    - by augmenting $A \rightarrow C$ with G, to get $AG \rightarrow CG$ and then transitivity with $CG \rightarrow I$
  - $CG \rightarrow HI$
    - *by union rule, since* $CG \rightarrow H$ *and* $CG \rightarrow I$*, implies* $CG \rightarrow HI$

Based on and image from "Database System Concepts" book and slides, 6th edition

Computing F+

- To compute the closure of a set of functional dependencies F:

$F^+ = F$
repeat
for each functional dependency f in F^+
    apply reflexivity and augmentation rules on f
    add the resulting functional dependencies to F^+
for each pair of functional dependencies f_1 and f_2 in F^+
    if f_1 and f_2 can be combined using transitivity
 then add the resulting functional dependency to F^+
until F^+ does not change any further

NOTE: We shall see an alternative procedure for this task later