Database Normalization

(Normalization of relational schemas and examples)

CSIT882: Data Management Systems

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Second normal form (2NF)

Relational schema R is in 2NF if every nonprime attribute A in R is fully functionally dependent on a primary key of schema R

Third normal form (3NF)

Relational schema R is in 3NF if it is in 2NF and no nonprime attribute of R is transitively dependent on the primary key

Third normal form (3NF)

Alternative definition

A relational schema R is in 3NF if whenever a functional dependency $X \rightarrow A$ is valid in R then either:

(1) X is a superkey in R, or

(2) A is a prime attribute in R

Boyce-Codd normal form (BCNF)

A relational schema R is in BCNF if whenever functional dependency $X \rightarrow A$ holds in R then:

(1) X is a superkey in R

~~(2) or A is a prime attribute in R~~ (3NF only !!!)

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Normalization of relational schemas

Given a relational schema $R = \{ A_1, ..., A_n\}$

Identify all functional dependencies

Use functional dependencies to derive all minimal keys

Use functional dependencies and minimal keys to identify the highest normal form satisfied by R

Decompose R into the schemas in BCNF

Normalization of relational schemas

Shipment

s#	city	status	p#	quantity

s# $\rightarrow$ city

s# $\rightarrow$ status

city $\rightarrow$ status

s#, p# $\rightarrow$ quantity

s#, p# $\rightarrow$ city

s#, p# $\rightarrow$ status

Schema Shipment is in 1NF

Minimal key = (s#, p#)

Normalization of relational schemas

Shipment				
s#	city	status	p#	quantity

$s\# \rightarrow city$

$s\# \rightarrow status$

$city \rightarrow status$

$s\#, p\# \rightarrow quantity$

$s\#, p\# \rightarrow city$

$s\#, p\# \rightarrow status$

Minimal key = (s#, p#)

Schema Shipment is not in 2NF

Nonprime attribute city depends on a part of a key (s#, p#)

Normalization of relational schemas

Shipment				
s#	city	status	p#	quantity

Schema Shipment should be decomposed into the following schemas

SP		
s#	p#	quantity

Supplier		
s#	city	status

Schema SP is in BCNF

s#,p# → quantity

Schema Supplier is not in 3NF(& BCNF)

s# → city

city → status

s# → status

Normalization of relational schemas

Supplier		
s#	city	status

Schema Supplier should be decomposed into the following schemas

Supplier_new	
s#	city

Schema Supplier_new is in BCNF

s# → city

Location	
city	status

Schema Location is in BCNF

city → status

Normalization of relational schemas

Supplier		
s#	city	status

Schema Supplier may be alternatively decomposed into the following schemas

Supplier1	
s#	city

Schema Supplier1 is in BCNF

s# → city

Supplie2	
s#	status

Schema Supplie2 is in BCNF

s# → status

Example 1

R =(A, B, C)   F ={ AB → C}

Keys ?

$AB \rightarrow C \;\Rightarrow\; K_1 = (A, B)$

BCNF

ROOM=(bldg#, room#, capacity)

room#, bldg# → capacity

A	B	C
a_1	b_1	c_1
a_3	b_2	c_2
a_1	b_2	c_3
a_2	b_1	c_3
a_2	b_2	c_3

Redundancies: none

Example 2

$R = (A, B, C)$ $F = \{ AB \to C, C \to B \}$

Keys ?

$AB \to C \Rightarrow K_1 = (A, B)$

If $C \to B$ then (augmentation) $AC \to AB \Rightarrow K_2 = (A, C)$

3NF and not BCNF ($C \to B$)

Redundancies:

A	B	C
a_1	b_1	c_1
a_2	b_1	c_1
a_3	b_1	c_2
a_1	b_2	c_3
a_1	b_2	c_3
a_2	b_3	c_4

ROOM=
(room#, bldg#, bldg-name)

room#,bldg# $\to$ bldg-name
bldg-name $\to$ bldg#

Decomposition: $R_1 = (C, B)$, $R_2 = (A, B)$

Example 3

R =(A, B, C)   F ={ $AB \to C$, $C \to B$, $C \to A$ }

Keys ?

$AB \to C \Rightarrow K_1 = (A, B)$

If $C \to B$ and $C \to A$ then (union) $C \to AB \Rightarrow K_2 = (C)$

BCNF

Redundancies: none

Example 4

$R = (A, B, C)$ $\qquad$ $F = \{ A \rightarrow B \}$

Keys ?

If $A \rightarrow B$ then (augmentation) $AC \rightarrow BC \Rightarrow K_1 = (A, C)$

not 2NF ($A \rightarrow B$)

Redundancies:

A	B	C
a_1	b_1	c_1
a_1	b_1	c_2
a_1	b_1	c_3
a_3	b_2	c_1
a_3	b_2	c_2

STUDENT=(student#, sname, subject#)

student# $\rightarrow$ sname

Decomposition: $R_1 = (A, B)$, $R_2 = (A, C)$

or $R_1 = (A, B)$, $R_2 = (B, C)$

Example 5

$R = (A, B, C)$ $\quad F = \{ A \rightarrow B, B \rightarrow A \}$

Keys ?

If $A \rightarrow B$ then (augmentation) $AC \rightarrow CB \Rightarrow K_1 = (A, C)$

If $B \rightarrow A$ then (augmentation) $BC \rightarrow AC \Rightarrow K_2 = (B, C)$

3NF and not BCNF ($A \rightarrow B$)

Redundancies:

Decomposition 1:
$R_1 = (A, B)$,
$R_2 = (A, C)$

Decomposition 2:
$R_1 = (A, B)$,
$R_2 = (B, C)$

A	B	C
a_1	b_1	c_1
a_1	b_1	c_2
a_1	b_1	c_3
a_2	b_2	c_2
a_2	b_2	c_3
a_3	b_3	c_3

STUDENT=
(student#, licence#, subject#)

student# $\rightarrow$ licence#
licence# $\rightarrow$ student#

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Example 6

$R = (A, B, C)$ $F = \{ A \rightarrow B, B \rightarrow C\}$

Keys ?

If $A \rightarrow B$ and $B \rightarrow C$ then (transitivity) $A \rightarrow C \Rightarrow K_1 = (A)$

2NF and not 3NF ($A \rightarrow B, B \rightarrow C$)

Redundancies:

A	B	C
a_1	b_1	c_1
a_2	b_1	c_1
a_3	b_1	c_1
a_4	b_2	c_1
a_5	b_2	c_1

EMPLOYEE=
(e#, department, address)

e# $\rightarrow$ department
department $\rightarrow$ address

Decomposition 1:
$R_1 = (A, B)$,
$R_2 = (B, C)$

Decomposition 2:
$R_1 = (A, B)$,
$R_2 = (A, C)$

Example 7

$R = (A, B, C, D)$ $F = \{ A \rightarrow B, A \rightarrow C, B \rightarrow D\}$

Keys ?

If $A \rightarrow B$ and $A \rightarrow C$ then (union) $A \rightarrow BC$

If $A \rightarrow B$ and $B \rightarrow D$ then (transitivity) $A \rightarrow D$

If $A \rightarrow BC$ and $A \rightarrow D$ then (union) $A \rightarrow BCD \Rightarrow K_1 = (A)$

2NF and not 3NF ($A \rightarrow B, B \rightarrow D$)

Decomposition
R1 = (A, B, C), R2 = (B, D)

Example 8

$R = (A, B, C, D) \quad F = \{ A \rightarrow B, B \rightarrow D, C \rightarrow B \}$

Keys ?

If $A \rightarrow B$ and $B \rightarrow D$ then (transitivity) $A \rightarrow D$

If $A \rightarrow D$ and $A \rightarrow B$ then (union) $A \rightarrow BD$

If $A \rightarrow BD$ then (augmentation) $AC \rightarrow BCD \Rightarrow K_1 = (AC)$

If $C \rightarrow B$ and $B \rightarrow D$ then (transitivity) $C \rightarrow D$

If $C \rightarrow D$ and $C \rightarrow B$ then (union) $C \rightarrow BD$

If $C \rightarrow BD$ then (augmentation) $AC \rightarrow ABD \Rightarrow K_1 = (AC)$!

not 2NF ($A \rightarrow B$)

Decomposition

R1 = (A, B), R2 = (B, C), R3 = (B, D)

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Example 9

$R = (A, B, C, D) \qquad F = \{ A \rightarrow B, A \rightarrow C, B \rightarrow A, B \rightarrow C \}$

Keys ?

If $A \rightarrow B$ and $A \rightarrow C$ then (union) $A \rightarrow BC$

If $A \rightarrow BC$ then (augmentation) $AD \rightarrow BCD \Rightarrow K_1 = (AD)$

If $B \rightarrow A$ and $B \rightarrow C$ then (union) $B \rightarrow AC$

If $B \rightarrow AC$ then (augmentation) $BD \rightarrow ACD \Rightarrow K_2 = (BD)$

not 2NF ($B \rightarrow C$)

Decomposition

$R1 = (A, B, C), R2 = (A, D)$

Example 10

$R = (A, B, C, D)$ $F = \{ AB \to C, C \to D, D \to A, D \to B\}$

Keys ?

If $AB \to C$ and $C \to D$ then (transitivity) $AB \to D$

If $AB \to D$ and $AB \to C$ then (union) $AB \to CD \Rightarrow K_1 = (AB)$

If $D \to A$ and $D \to B$ then (union) $D \to AB$

If $D \to AB$ and $AB \to C$ then (transitivity) $D \to C$

If $D \to AB$ and $D \to C$ then (union) $D \to ABC \Rightarrow K_2 = (D)$

If $C \to D$ and $D \to AB$ then (transitivity) $C \to AB$

If $C \to D$ and $C \to AB$ then (union) $C \to ABD \Rightarrow K_3 = (C)$

BCNF

Example 11

$R = (A, B, C, D) \qquad F = \{ A \to B, B \to C, C \to D, D \to A \}$

Keys ?

If $A \to B$ and $B \to C$ then (transitivity) $A \to C$

If $A \to C$ and $C \to D$ then (transitivity) $A \to D$

If $A \to B$ and $A \to C$ and $A \to D$ then (union) $A \to BCD \Rightarrow K_1 = (A)$

If $B \to C$ and $C \to D$ then (transitivity) $B \to D$

If $B \to D$ and $D \to A$ then (transitivity) $B \to A$

If $B \to C$ and $B \to D$ and $B \to A$ then (union) $B \to ACD \Rightarrow K_2 = (B)$

and so on $\Rightarrow K_3 = (C), K_4 = (D)$

BCNF

References

Elmasri R., Navathe S. B., *Fundamentals of Database Systems*, chapters 10.3, 10.4, 10.5

R. Ramakrishnan, J. Gehrke *Database Management Systems*, chapters 19.2, 19.3