Relational Design Theory

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Based on Jennifer Widom and Christopher Ré slides

Agenda

~~Relational Design Overview~~

~~Functional Dependencies~~

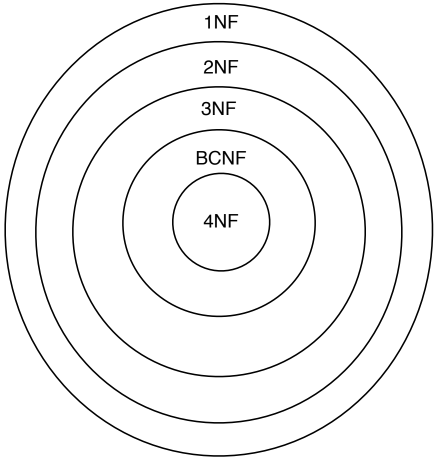
~~Closures, Superkeys and Keys~~

~~Inferring Functional Dependencies~~

Normal Forms

Decompositions

Normal Forms



1st Normal Form (1NF)

All tables are flat

2nd Normal Form

disused

Boyce-Codd Normal Form (BCNF)

3rd Normal Form (3NF)

DB designs based on functional dependencies, intended to prevent data anomalies

4th and 5th Normal Forms

see text books

1st Normal Form (1NF)

The domain of each attribute contains only atomic values and the value of each attribute contains only a single value from that domain

Student	Courses
Mary	{CS145,CS229}
Joe	{CS145,CS106}
…	…

→

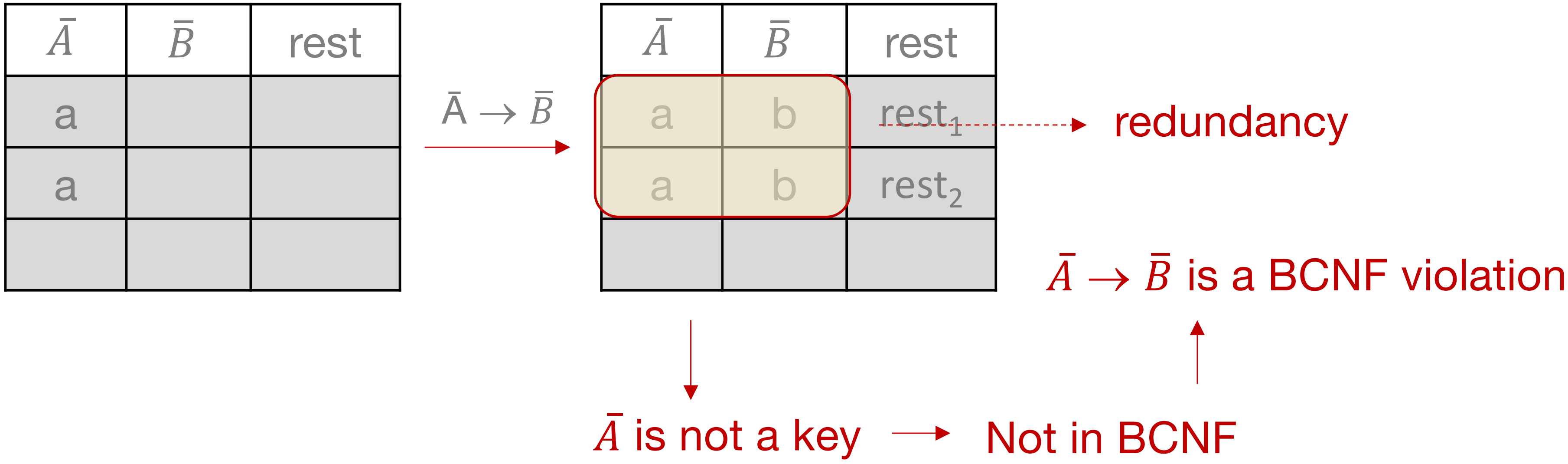
Student	Course
Mary	CS145
Mary	CS229
Joe	CS145
Joe	CS106

Boyce-Codd Normal Form

Relation R with FDs is in BCNF if

For each nontrivial $\bar{A} \to \bar{B}$, $\bar{A}$ is a (super)key

Why do we have a bad design when this doesn't happen?



$\bar{A}$	$\bar{B}$	rest
a		
a		

$\bar{A} \to \bar{B}$

$\bar{A}$	$\bar{B}$	rest
a	b	rest_1
a	b	rest_2

redundancy

$\bar{A} \to \bar{B}$ is a BCNF violation

$\bar{A}$ is not a key → Not in BCNF

2nd Normal Form (2NF)

1NF and no attribute not prime is functionally dependent on a proper subset of a candidate key

An attribute that is member of some key is *prime*

Student-Professor

SID	PID	PName
1	3	Smith
2	2	Bayer

PID->PName

Student-Professor

SID	PID
1	3
2	2

Professor

PID	PName
3	Smith
2	Bayer

BCNF? Example #1

Student (SSN, sName, address, HScode, HSname, HScity, GPA, priority)

SSN → sName, address, GPA

GPA → priority

HScode → HSname, HScity

Keys of the relation?

{SSN, HScode}

Does every FD have a key on its left-hand side?

No, none.

BCNF? Example #2

Apply (SSN, cName, state, date, major)

SSN, cName, state → date, major

Keys of the relation?

{SSN, cName, state}

Does every FD have a key on its left-hand side?

Yes.

3rd Normal Form (3NF)

2NF and all non-prime attributes are functionally dependent of every candidate key in a non-transitive way

OR

Relation R is in 3NF if, for each nontrivial $\bar{A} \rightarrow \bar{B}$,

- $\bar{A}$ is a (super)key or
- $\bar{B}$ consists of prime attributes only

3NF Example

Bookings (title, theater, city)

theater → city
title, city → theater

No booking of a movie in two theaters of the same city

Keys of the relation?

{title, city}, {theater, title}

BCNF?

FD theater → city is a BCNF violation

3NF?

FD theater → city has only prime attributes on its right-side

FD title, city → theater has a key on its left-hand side and only prime attributes on its right-side

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~~Normal Forms~~

Decompositions

Decomposition of a relational schema

R1 and R2 are a decomposition of R (A_1, …, A_n) if

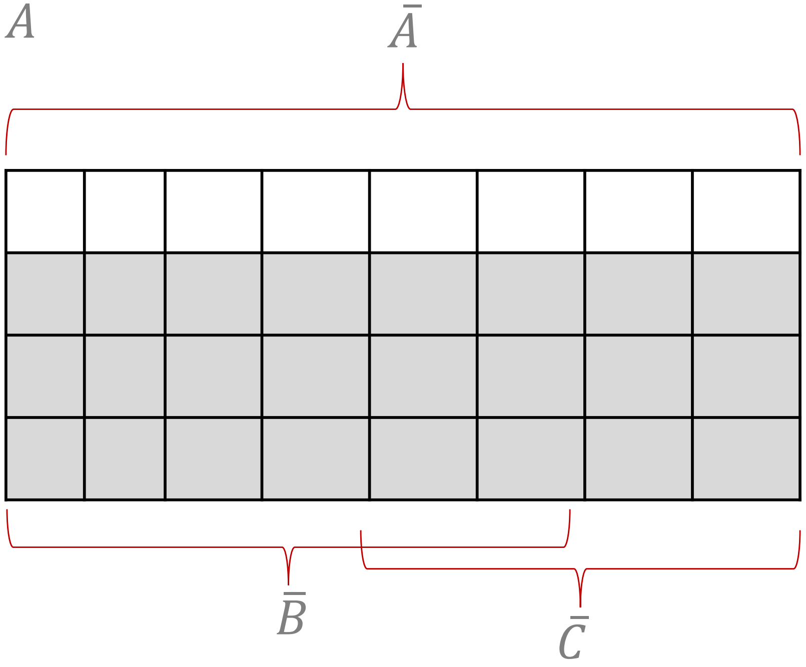
$$R_1 = \pi_{B_1,\ldots,B_n}(R)$$

$$R_2 = \pi_{C_1,\ldots,C_n}(R)$$

$$\underbrace{\{B_1, \ldots, B_n\}}_{\bar{B}} \cup \underbrace{\{C_1, \ldots, C_n\}}_{\bar{C}} = \underbrace{\{A_1, \ldots, A_n\}}_{\bar{A}}$$

If: $R_1 \bowtie R_2 = R$

Lossless join property



Natural Join (⋈)

Student

sID	sName	GPA	HS
12	Mary	3.5	90
23	John	3.8	50

Apply

sID	cName	major	dec
12	Stanford	CS	Y
23	MIT	CS	N

$Student \bowtie Apply$

sID	sName	GPA	HS	cName	major	dec
12	Mary	3.5	90	Stanford	CS	Y
23	John	3.8	50	MIT	CS	N

Decomposition Example #1

Student (SSN, sName, address, HScode, HSname,
HScity, GPA, priority)

S_1 (SSN, sName, address, HScode, GPA, priority)

S_2 (HScode, HSname, HScity)

Is it a correct decomposition?

$$\bar{B} \cup \bar{C} = \bar{A}$$

$$S_1 \bowtie S_2 = Student$$

Decomposition Example #2

Student (SSN, sName, address, HScode, HSname, HScity, GPA, priority)

S_1 (SSN, SName, address, HScode, HSname, HScity)

S_2 (SName, HSname, GPA, priority)

Is it a correct decomposition?

$\bar{B} \cup \bar{C} = \bar{A}$

$S_1 \bowtie S_2 = Student$?

SName and HSname may not be unique

BCNF decomposition algorithm

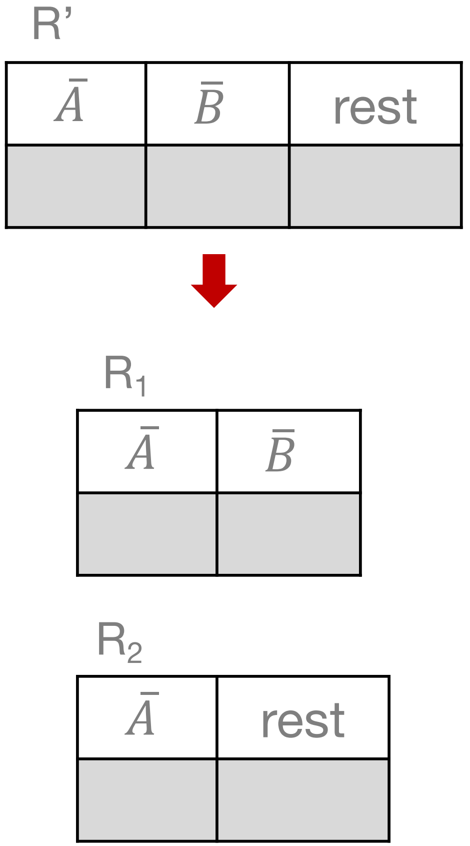
Input: relation R + FDs for R

Output: decomposition of R into BCNF relations with "lossless join"

Compute keys for R

Repeat until all relations are in BCNF:

- Pick any R' with $\bar{A} \rightarrow \bar{B}$ that violates BCNF
- Decompose R' into $R_1(\bar{A}, \bar{B})$ and $R_2(\bar{A}, \text{rest})$
- Compute FDs for R_1 and R_2
- Compute keys for R_1 and R_2



R'

$\bar{A}$	$\bar{B}$	rest

R_1

$\bar{A}$	$\bar{B}$

R_2

$\bar{A}$	rest

BCNF Decomposition Example

Student (SSN, sName, address, HScode, HSname, HScity, GPA, priority)

SSN → sName, address, GPA; GPA → priority; HScode → HSname, HScity

Key: {SSN, HScode}

Pick a BCNF violation

HScode → HSname, HScity

Decompose Student

S1 (HScode, HSname, HScity)

S2 (HScode, SSN, sName, address, GPA, priority)

Compute FDs and keys for S1

HScode → HSname, HScity

Key: {HScode}

S1 is in BCNF

Compute FDs and keys for S2

SSN → sName, address, GPA

GPA → priority

BCNF violations

Key: {SSN, HScode}

S2 is not in BCNF

BCNF Decomposition Example

Student (SSN, sName, address, HScode, HSname, HScity, GPA, priority)

SSN → sName, address, GPA; GPA → priority; HScode → HSname, Hscity

Key: {SSN, HScode}

Pick a BCNF violation

GPA → priority

Decompose S2 (HScode, SSN, sName, address, GPA, priority)

S3 (GPA, priority)

S4 (HScode, SSN, sName, address, GPA)

Compute FDs and keys for S3

GPA → priority

Key: {GPA}

S3 is in BCNF

Compute FDs and keys for S4

SSN → sName, address, GPA } BCNF violation

Key: {SSN, HScode}

S4 is not in BCNF

BCNF Decomposition Example

Student (SSN, sName, address, HScode, HSname, HScity, GPA, priority)

SSN → sName, address, GPA; GPA → priority; HScode → HSname, Hscity

Key: {SSN, HScode}

Pick a BCNF violation

SSN → sName, address, GPA

Decompose S4 (HScode, SSN, sName, address, GPA)

S5 (SSN, sName, address, GPA)

S6 (SSN, HScode)

Compute FDs and keys for S5

SSN → sName, address, GPA

Key: {SSN}

S5 is in BCNF

Compute FDs and keys for S6

Key: {SSN, HScode}

S6 is in BCNF

BCNF Decomposition Example

Student (SSN, sName, address, HScode, HSname, HScity, GPA, priority)

SSN → sName, address, GPA; GPA → priority; HScode → HSname, Hscity

Key: {SSN, HScode}

S1 (HScode, HSname, HScity) → Information about high schools

S3 (GPA, priority) → Information about GPA and priorities

S5 (SSN, sName, address, GPA) → Information about students

S6 (SSN, HScode) → Information about the high schools students went

BCNF decomposition algorithm

Input: relation R + FDs for R

Output: decomposition of R into BCNF relations with “lossless join”

Compute keys for R

Repeat until all relations are in BCNF:

- Pick any R’ with $\bar{A} \rightarrow \bar{B}$ that violates BCNF
    - Different answers depending on the chosen R’
- Extend FD that is used for decomposition (if $A \rightarrow B$ then $A \rightarrow BA^{+}$)
- Decompose R’ into $R_1(\bar{A}, \bar{B})$ and $R_2(\bar{A}$, rest)
- Compute FDs for R_1 and R_2
    - See “Projecting a set of FDs” slides
- Compute keys for R_1 and R_2

Exercise

Consider the following relation and FDs

Movie (title, year, studioName, president, presAddr)

title, year -> studioName
studioName -> president
president -> presAddr

Decompose into BCNF relations.

Exercise

Movie (title, year, studioName, president, presAddr)

title, year -> studioName

studioName -> president

president -> presAddr

Key: {title, year}

Pick a BCNF violation

studioName → president

Decompose Student

S1 (studioName, president)

S2 (studioName, title, year, presAddr)

Compute FDs and keys for S1

studioName → president

Key: {studioName}

S1 is in BCNF

Compute FDs and keys for S2

title, year → studioName

studioName → presAddr

Key: {title, year}

S2 is not in BCNF

BCNF violation

Exercise

Movie (title, year, studioName, president, presAddr)

title, year -> studioName

studioName -> president

president -> presAddr

Key: {title, year}

Pick a BCNF violation

studioName → presAddr

Decompose S2 (studioName, title, year, presAddr)

S3 (studioName, presAddr)

S4 (studioName, title, year)

Compute FDs and keys for S3

studioName → presAddr

Key: {studioName}

S3 is in BCNF

Compute FDs and keys for S4

title, year → studioName

Key: {title, year}

S4 is in BCNF

Exercise

Movie (title, year, studioName, president, presAddr)

title, year -> studioName

studioName -> president

president -> presAddr

Key: {title, year}

S1 (studioName, president)

S3 (studioName, presAddr)

S4 (studioName, title, year)

Kahoot time!

Any doubts?

Readings

Jeffrey Ullman, Jennifer Widom, A first course in Database Systems 3rd Edition

- Section 3.1 – Functional Dependencies
- Section 3.2 – Rules About Functional Dependencies
- Section 3.3 – Design of Relational Database Schemas
- Section 3.4 – Decomposition: The Good, Bad, and Ugly
- Section 3.5 – Third Normal Form