CSC 261/461 – Database Systems
Lecture 11

Fall 2017

Announcement

- Read the textbook!
  - Chapter 8:
    - Will cover later; But self-study the chapter
    - Everything except Section 8.4
  - Chapter 14:
    - Section 14.1 – 14.5
  - Chapter 15:
    - Section 15.1 – 15.4

Superkeys and Keys

Keys and Superkeys

A **superkey** is a set of attributes $\mathbf{A_1, \ldots, A_n}$ s.t. for *any other* attribute **B** in R, we have $\mathbf{\{A_1, \ldots, A_n\} \rightarrow B}$

I.e. all attributes are *functionally determined* by a superkey

A **key** is a *minimal* superkey

Meaning that no subset of a key is also a superkey

Finding Keys and Superkeys

- For each set of attributes X

  1. Compute X^+

  2. If X^+ = set of all attributes then X is a **superkey**

  3. If X is minimal, then it is a **key**

Do we need to check all sets of attributes? Which sets?

Example of Finding Keys

```
Product(name, price, category,
color)
```

```
{name, category} → price
{category} → color
```

What is a key?

Example of Keys

Product(name, price, category, color)

{name, category} → price
{category} → color

$\{name, category\}^+ = \{name, price, category, color\}$

= the set of all attributes

$\Longrightarrow$ this is a **superkey**

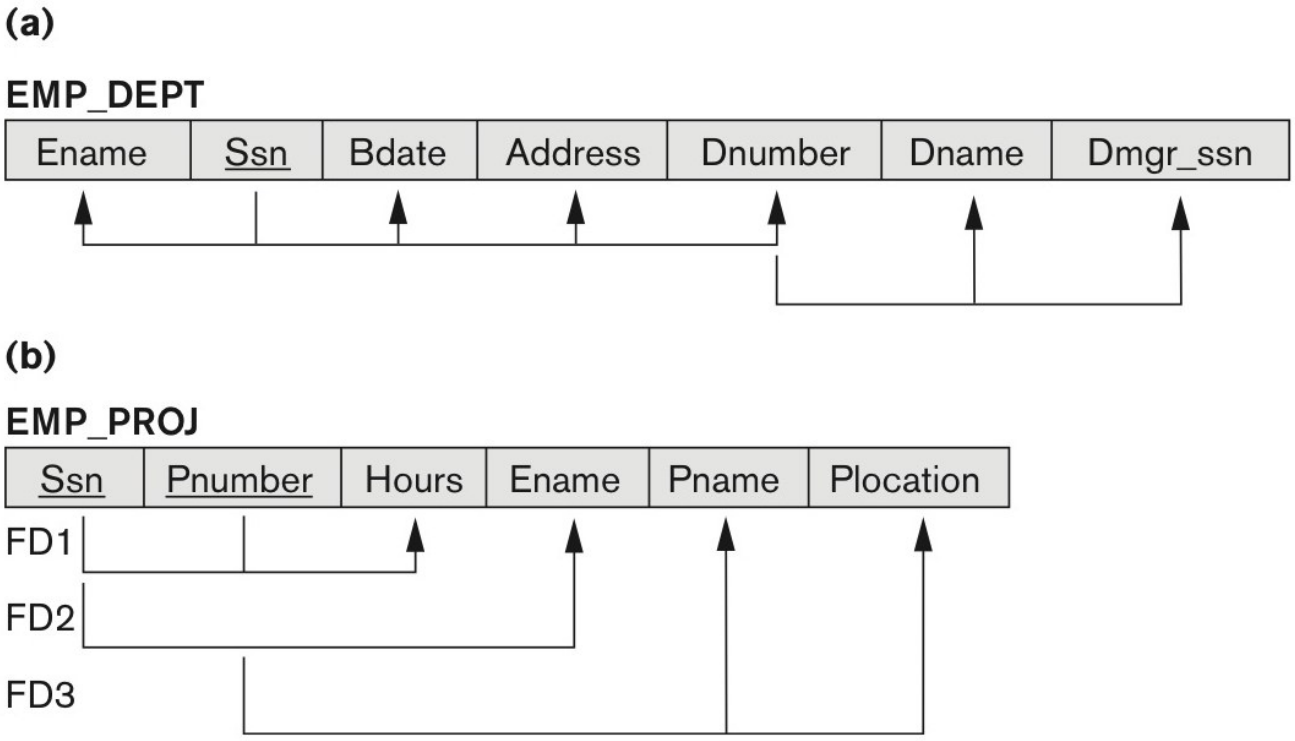
$\Longrightarrow$ this is a **key**, since neither name nor category alone is a superkey

Today's Lecture

1. 2NF, 3NF and Boyce-Codd Normal Form

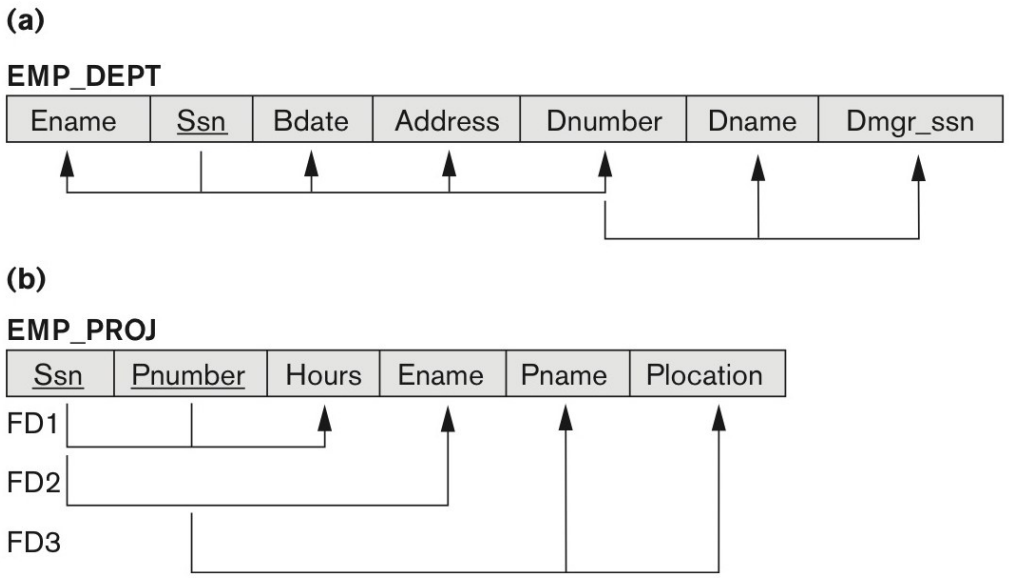
2. Decompositions

Functional Dependencies (Graphical Representation)



Prime and Non-prime attributes

- A **Prime attribute** must be a member of *some* candidate key
- A **Nonprime attribute** is not a prime attribute—that is, it is not a member of any candidate key.



Back to Conceptual Design

Now that we know how to find FDs, it's a straight-forward process:

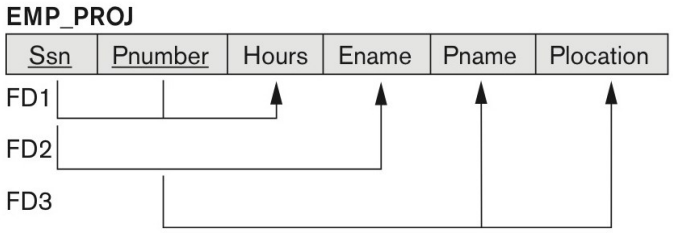
1. Search for "bad" FDs
2. If there are any, then *keep decomposing the table into sub-tables* until no more bad FDs
3. When done, the database schema is *normalized*

Boyce-Codd Normal Form (BCNF)

- Main idea is that we define "good" and "bad" FDs as follows:
  - X → A is a "*good FD" if X is a (super)key*
    - In other words, if A is the set of all attributes
  - X → A is a *"bad FD"* otherwise
- We will try to eliminate the "bad" FDs!
  - Via normalization

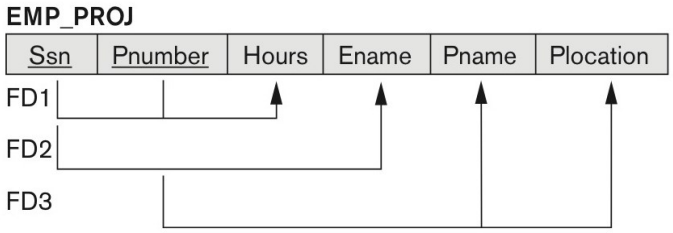
Second Normal Form

- Uses the concepts of **FDs, primary key**
- Definitions
  - **Full functional dependency:**
    - a FD Y → Z where removal of any attribute from Y means the FD does not hold any more



Second Normal Form (cont.)

- Examples:
  - {Ssn, Pnumber} → Hours is a full FD since neither
    - Ssn → Hours nor Pnumber → Hours hold
  - {Ssn, Pnumber} → Ename is not a full FD (it is called a partial dependency) since Ssn → Ename also holds



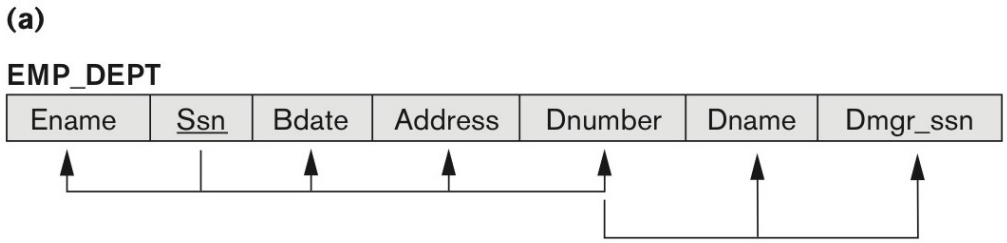
Second Normal Form (2)

- A relation schema R is in **second normal form (2NF)** if every non-prime attribute A in R is fully functionally dependent on the primary key

- R can be decomposed into 2NF relations via the process of 2NF normalization or "second normalization"

Third Normal Form (1)

- Definition:
  - **Transitive functional dependency**:
    - a FD X → Z that can be derived from two FDs X → Y and Y → Z
- Examples:
  - Ssn -> Dmgr_ssn is a **transitive** FD
    - Since Ssn -> Dnumber and Dnumber -> Dmgr_ssn hold
  - Ssn -> Ename is **non-transitive**
    - Since there is no set of attributes X where Ssn → X and X → Ename



Third Normal Form (2)

- A relation schema R is in **third normal form** (3NF) if it is in 2NF *and* no non-prime attribute A in R is transitively dependent on the primary key
- R can be decomposed into 3NF relations via the process of 3NF normalization

Normalizing into 2NF and 3NF

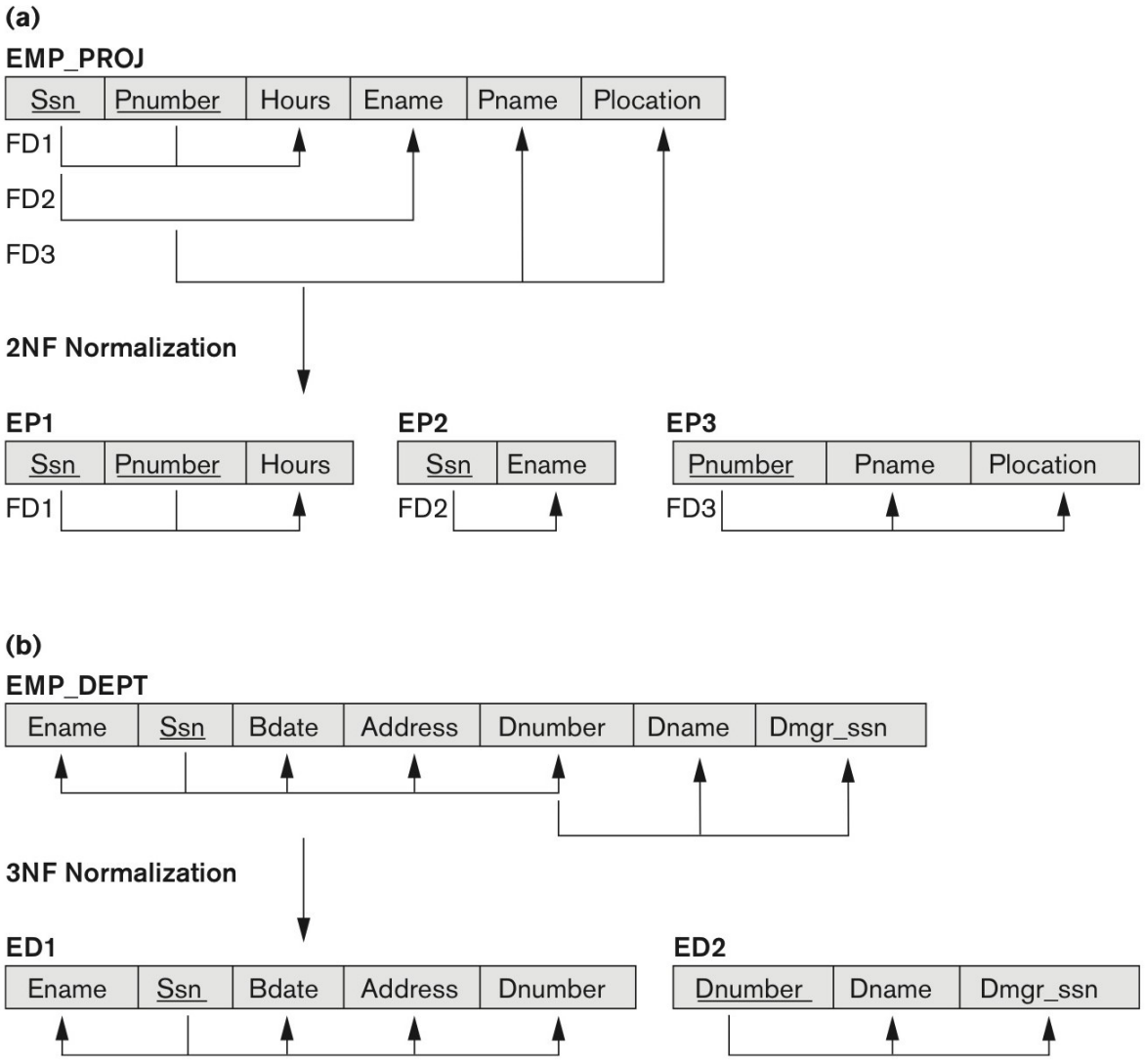
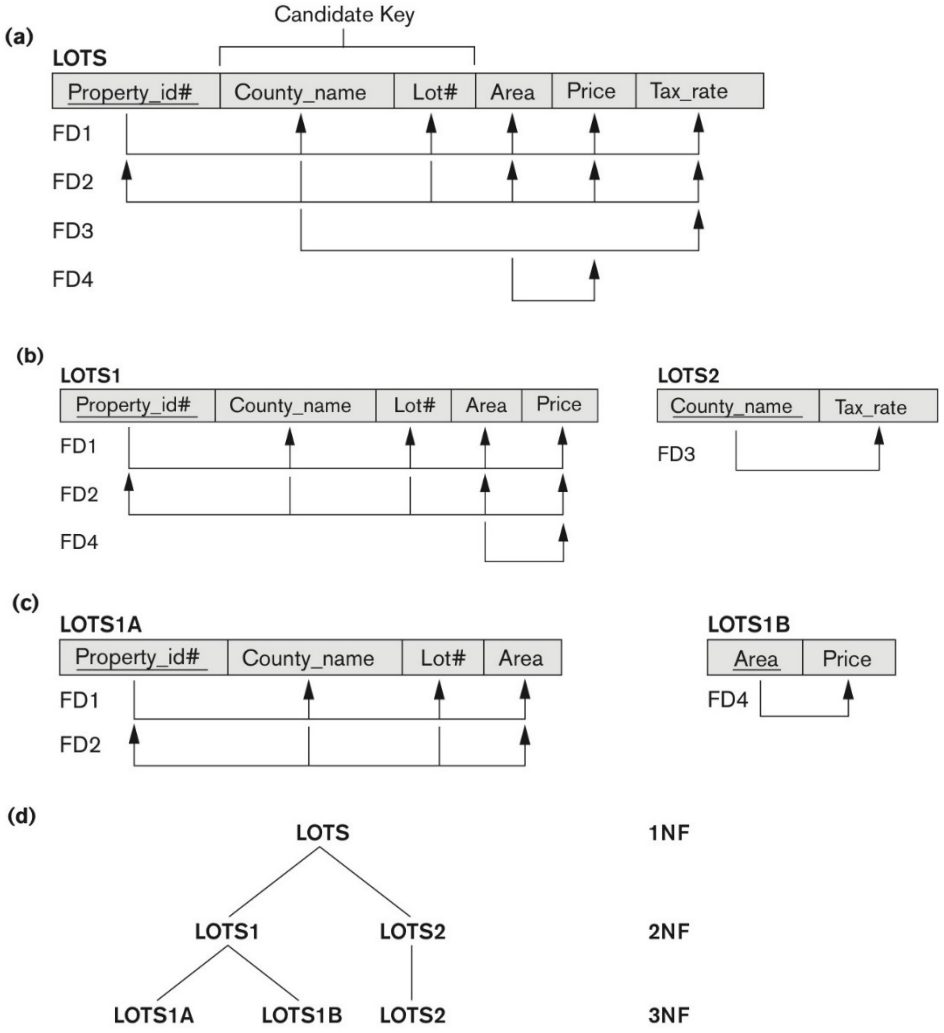


Figure 14.12 Normalization into 2NF and 3NF

Figure 14.12
Normalization into 2NF and 3NF. (a) The LOTS relation with its functional dependencies FD1 through FD4. (b) Decomposing into the 2NF relations LOTS1 and LOTS2. (c) Decomposing LOTS1 into the 3NF relations LOTS1A and LOTS1B. (d) Progressive normalization of LOTS into a 3NF design.



Normal Forms Defined Informally

- 1st normal form
  - All attributes depend on **the key**
- 2nd normal form
  - All attributes depend on **the whole key**
- 3rd normal form
  - All attributes depend on **nothing but the key**

General Definition of 2NF and 3NF (For Multiple Candidate Keys)

- A relation schema R is in **second normal form (2NF)** if every non-prime attribute A in R is fully functionally dependent on ***every*** key of R

- A relation schema R is in **third normal form (3NF)** if it is in 2NF *and* no non-prime attribute A in R is transitively dependent on ***any*** key of R

1. BOYCE-CODD NORMAL FORM

What you will learn about in this section

1. Conceptual Design
2. Boyce-Codd Normal Form
3. The BCNF Decomposition Algorithm

5. BCNF (Boyce-Codd Normal Form)

- A relation schema R is in Boyce-Codd Normal Form (BCNF) if whenever an **FD X → A** holds in R, then **X is a superkey** of R
- Each normal form is strictly stronger than the previous one
  - Every 2NF relation is in 1NF
  - Every 3NF relation is in 2NF
  - Every BCNF relation is in 3NF

Figure 14.13 Boyce-Codd normal form

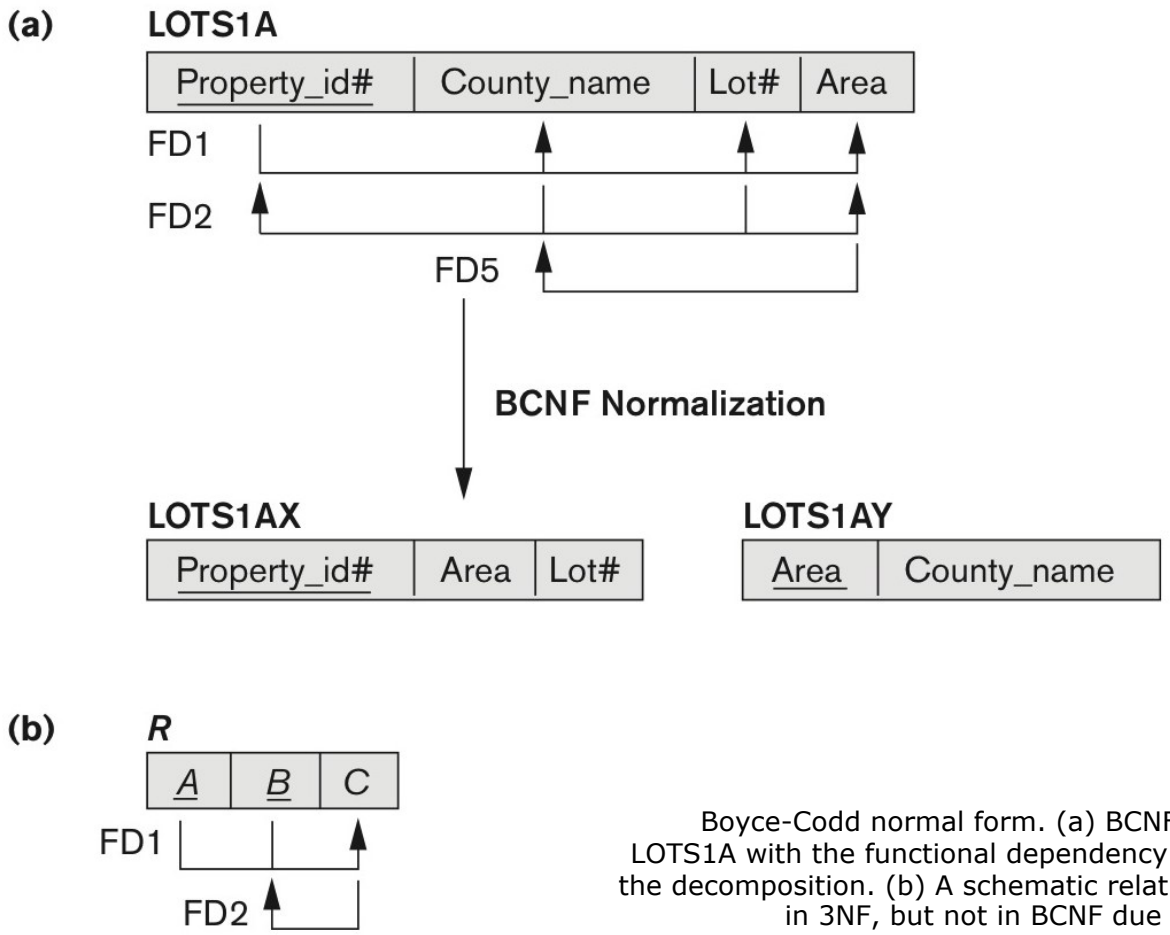


Figure 14.13
Boyce-Codd normal form. (a) BCNF normalization of LOTS1A with the functional dependency FD2 being lost in the decomposition. (b) A schematic relation with FDs; it is in 3NF, but not in BCNF due to the f.d. C → B.

General Definition of 2NF and 3NF (For Multiple Candidate Keys)

- A relation schema R is in **second normal form (2NF)** if every non-prime attribute A in R is fully functionally dependent on ***every*** key of R

- A relation schema R is in **third normal form (3NF)** if it is in 2NF *and* no non-prime attribute A in R is transitively dependent on ***any*** key of R

4.3 Interpreting the General Definition of Third Normal Form (2)

- **ALTERNATIVE DEFINITION of 3NF: We can restate the definition as:**

  A relation schema R is in **third normal form** (3NF) if, whenever a nontrivial FD X→A holds in R, either

  a) X is a superkey of R or

  b) A is a prime attribute of R

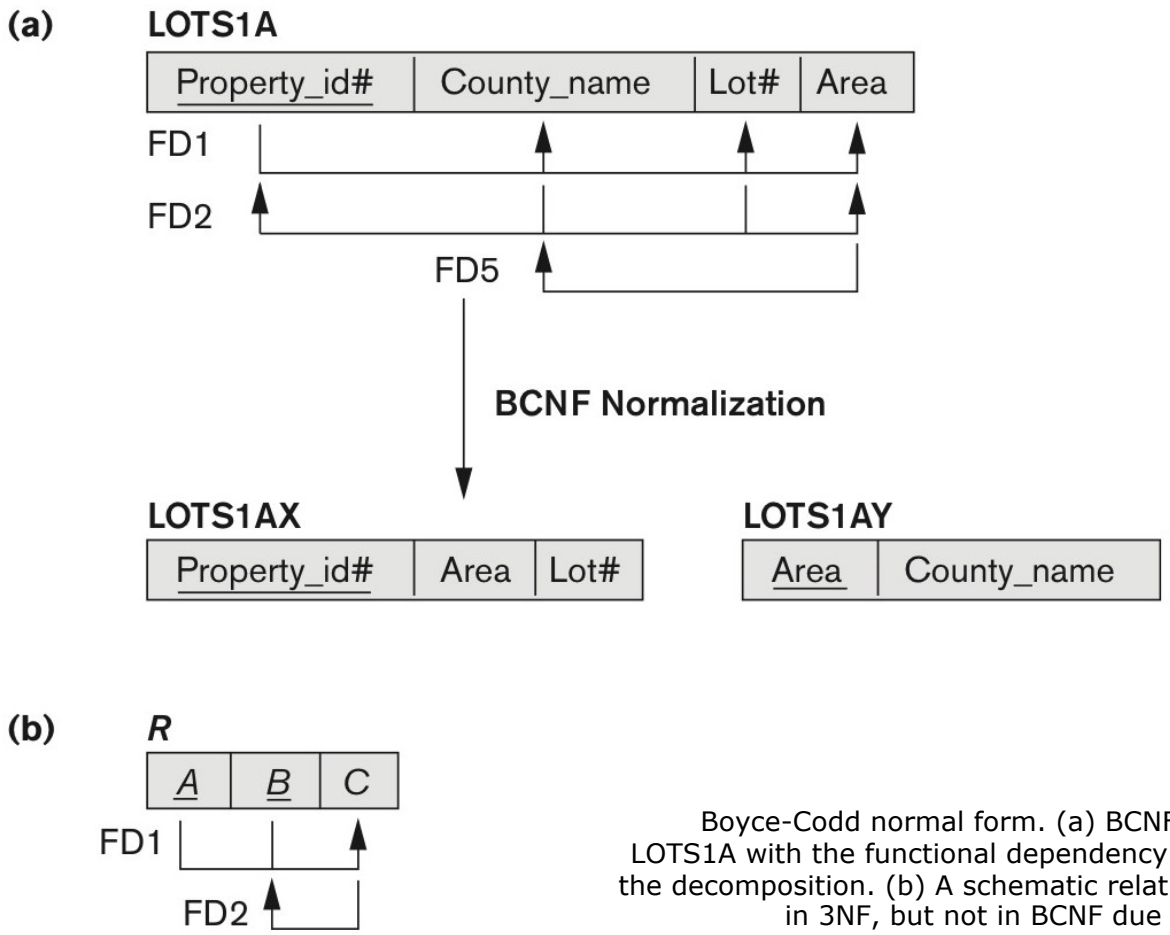
  The condition (b) takes care of the dependencies that "slip through" (are allowable to) 3NF but are "caught by" BCNF which we discuss next.

5. BCNF (Boyce-Codd Normal Form)

- **Definition of 3NF:**
- A relation schema R is in **3NF** if, whenever a nontrivial FD X→A holds in R, either
  a) X is a superkey of R or
  b) A is a prime attribute of R

- A relation schema R is in **Boyce-Codd Normal Form** (**BCNF**) if whenever an FD X → A holds in R, then
  a) X is a superkey of R
  ~~b) There is no b~~
- Each normal form is strictly stronger than the previous one
  - Every 2NF relation is in 1NF
  - Every 3NF relation is in 2NF
  - Every BCNF relation is in 3NF

Boyce-Codd normal form



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A relation TEACH that is in 3NF but not in BCNF

TEACH

Student	Course	Instructor
Narayan	Database	Mark
Smith	Database	Navathe
Smith	Operating Systems	Ammar
Smith	Theory	Schulman
Wallace	Database	Mark
Wallace	Operating Systems	Ahamad
Wong	Database	Omiecinski
Zelaya	Database	Navathe
Narayan	Operating Systems	Ammar

- Two FDs exist in the relation TEACH:

X	→ A
– {student, course}	→ instructor
– instructor	→ course

- {student, course} is a candidate key for this relation
- So this relation is in 3NF *but not in* BCNF
- A relation **NOT** in BCNF should be decomposed
  - while possibly forgoing the preservation of all functional dependencies in the decomposed relations.

Achieving the BCNF by Decomposition

- Three possible decompositions for relation TEACH
  - D1: {student, instructor} and {student, course}
  - D2: {course, instructor } and {course, student}
  - ✓ D3: {instructor, course } and {instructor, student}

Boyce-Codd Normal Form

BCNF is a simple condition for removing anomalies from relations:

A relation R is **in BCNF** if:

if $\{X_1, ..., X_n\} \rightarrow A$ is a *non-trivial* FD in R

then $\{X_1, ..., X_n\}$ **is a superkey** for R

In other words: there are no "bad" FDs

Example

Name	SSN	PhoneNumber	City
Fred	123-45-6789	206-555-1234	Seattle
Fred	123-45-6789	206-555-6543	Seattle
Joe	987-65-4321	908-555-2121	Westfield
Joe	987-65-4321	908-555-1234	Westfield

`{SSN} → {Name,City}`

This FD is *bad* because it is **not** a superkey

⟹ **Not** in BCNF

What is the key?
{SSN, PhoneNumber}

Example

Name	SSN	City
Fred	123-45-6789	Seattle
Joe	987-65-4321	Madison

SSN	PhoneNumber
123-45-6789	206-555-1234
123-45-6789	206-555-6543
987-65-4321	908-555-2121
987-65-4321	908-555-1234

Now in BCNF!

{SSN} → {Name,City}

This FD is now *good* because it is the key

Let's check anomalies:

- Redundancy ?
- Update ?
- Delete ?

BCNF Decomposition Algorithm

BCNFDecomp(R):

BCNF Decomposition Algorithm

BCNFDecomp(R):

Find *a set of attributes* X s.t.: $X^+ \neq X$ and $X^+ \neq$ [all attributes]

Find a set of attributes X which has non-trivial "bad" FDs, i.e. is not a superkey, using closures

BCNF Decomposition Algorithm

BCNFDecomp(R):

Find a *set of attributes* X s.t.: $X^+ \neq X$ and $X^+ \neq$ [all attributes]

if (not found) **then Return** R

If no "bad" FDs found, in BCNF!

BCNF Decomposition Algorithm

BCNFDecomp(R):

Find a *set of attributes* X s.t.: $X^+ \neq X$ and $X^+ \neq$ [all attributes]

if (not found) **then Return** R

let $Y = X^+ - X$, $Z = (X^+)^C$

Let Y be the attributes that ***X functionally determines*** (+ that are not in X)

And let Z be **the other attributes that it *doesn't***

BCNF Decomposition Algorithm

BCNFDecomp(R):

Find a *set of attributes* X s.t.: $X^+ \neq X$ and $X^+ \neq$ [all attributes]

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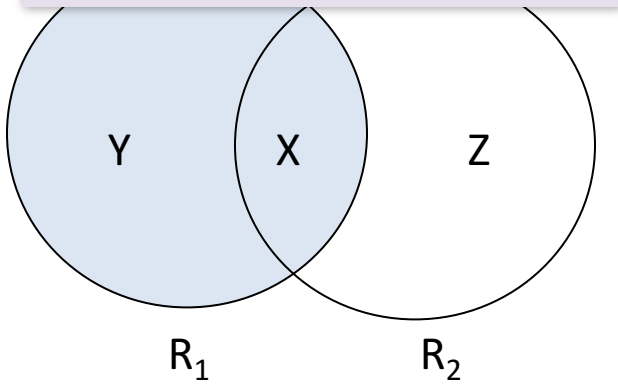
let $Y = X^+ - X$, $Z = (X^+)^C$

decompose R into $\mathbf{R_1(X \cup Y)}$ and $\mathbf{R_2(X \cup Z)}$

Split into one relation (table) with X plus the attributes that X determines (Y)…



BCNF Decomposition Algorithm

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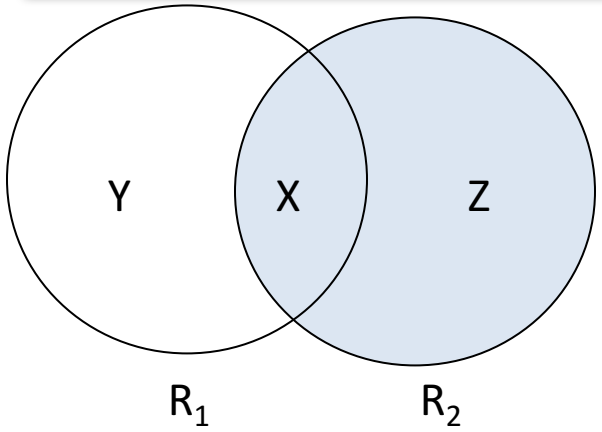
let $Y = X^+ - X$, $Z = (X^+)^C$

decompose R into $\mathbf{R_1(X \cup Y)}$ and $\mathbf{R_2(X \cup Z)}$

And one relation with X plus the attributes it *does not* determine (Z)



BCNF Decomposition Algorithm

BCNFDecomp(R):

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if (not found) **then Return** R

let $Y = X^+ - X$, $Z = (X^+)^C$

decompose R into $\mathbf{R_1(X \cup Y)}$ and $\mathbf{R_2(X \cup Z)}$

Return BCNFDecomp(R_1), BCNFDecomp(R_2)

Proceed recursively until no more "bad" FDs!

Another way of representing the same concept

BCNFDecomp(R):
If X→ A causes BCNF violation:

Decompose R into

R1= XA
R2 = R –A

(Note: X is present in both R1 and R2)

Example

BCNFDecomp(R):
Find a *set of attributes* X s.t.: $X^+ \neq X$ and $X^+ \neq$ [all attributes]

if (not found) **then Return** R

let $Y = X^+ - X$, $Z = (X^+)^C$
decompose R into $\mathbf{R_1(X \cup Y)}$ and $\mathbf{R_2(X \cup Z)}$

Return BCNFDecomp(R_1), BCNFDecomp(R_2)

R(A,B,C,D,E)

{A} → {B,C}
{C} → {D}

BCNFDecomp(R):
If X→ A causes BCNF violation:

Decompose R into

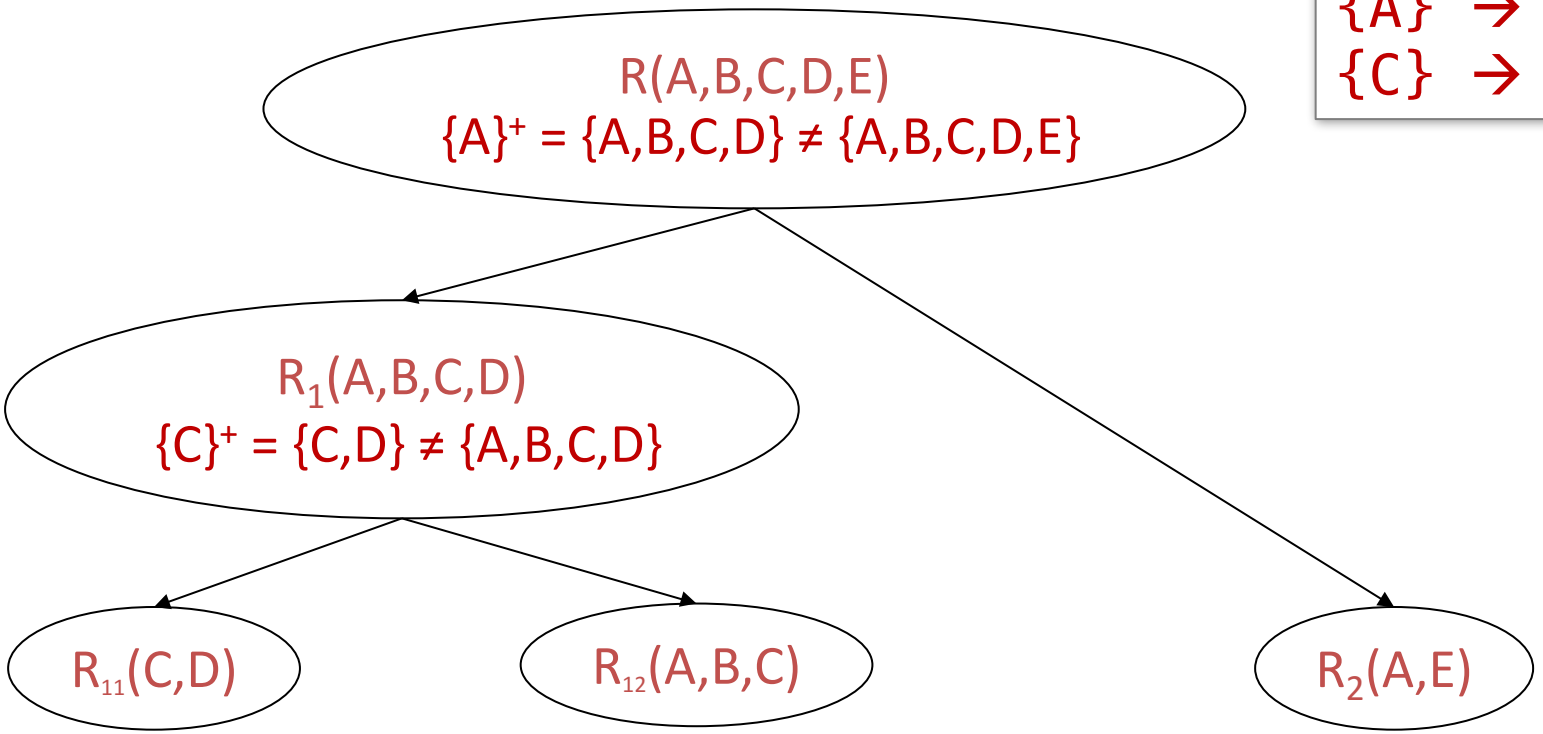
R1= XA
R2 = R –A

(Note: X is present in both R1 and R2)

Example

R(A,B,C,D,E)

{A} → {B,C}
{C} → {D}



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