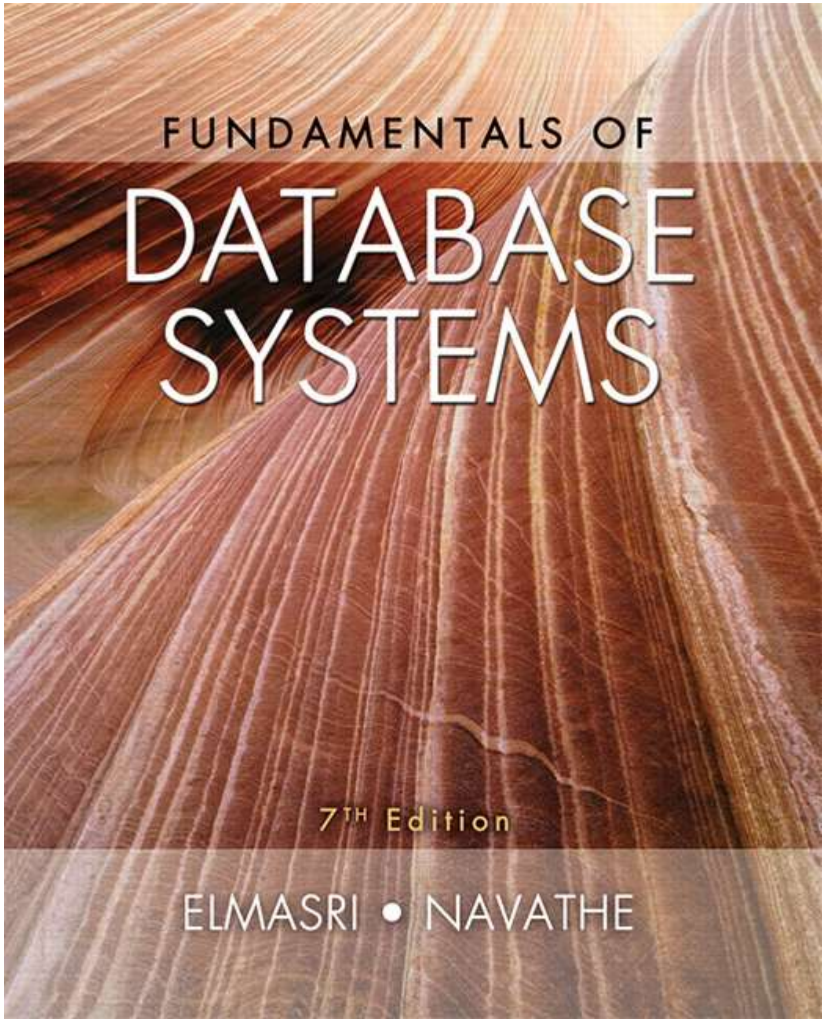
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# CHAPTER 14

# Basics of Functional Dependencies and Normalization for Relational Databases

# Chapter Outline

- 1 Informal Design Guidelines for Relational Databases
  - 1.1 Semantics of the Relation Attributes
  - 1.2 Redundant Information in Tuples and Update Anomalies
  - 1.3 Null Values in Tuples
  - 1.4 Spurious Tuples
- 2 Functional Dependencies (FDs)
  - 2.1 Definition of Functional Dependency

# Chapter Outline

- 3 Normal Forms Based on Primary Keys
  - 3.1 Normalization of Relations
  - 3.2 Practical Use of Normal Forms
  - 3.3 Definitions of Keys and Attributes Participating in Keys
  - 3.4 First Normal Form
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  - 3.6 Third Normal Form
- 4 General Normal Form Definitions for 2NF and 3NF (For Multiple Candidate Keys)
- 5 BCNF (Boyce-Codd Normal Form)

# Chapter Outline

- 6 Multivalued Dependency and Fourth Normal Form
- 7 Join Dependencies and Fifth Normal Form

# 1. Informal Design Guidelines for Relational Databases (1)

- What is relational database design?
  - The grouping of attributes to form "good" relation schemas
- Two levels of relation schemas
  - The logical "user view" level
  - The storage "base relation" level
- Design is concerned mainly with base relations
- What are the criteria for "good" base relations?

# Informal Design Guidelines for Relational Databases (2)

- We first discuss informal guidelines for good relational design
- Then we discuss formal concepts of functional dependencies and normal forms
  - - 1NF (First Normal Form)
  - - 2NF (Second Normal Form)
  - - 3NF (Third Noferferferfewrmal Form)
  - - BCNF (Boyce-Codd Normal Form)
- Additional types of dependencies, further normal forms, relational design algorithms by synthesis are discussed in Chapter 15

# 1.1 Semantics of the Relational Attributes must be clear

- GUIDELINE 1: Informally, each tuple in a relation should represent one entity or relationship instance. (Applies to individual relations and their attributes).
  - Attributes of different entities (EMPLOYEEs, DEPARTMENTs, PROJECTs) should not be mixed in the same relation
  - Only foreign keys should be used to refer to other entities
  - Entity and relationship attributes should be kept apart as much as possible.
- Bottom Line: *Design a schema that can be explained easily relation by relation. The semantics of attributes should be easy to interpret.*

# Figure 14.1 A simplified COMPANY relational database schema

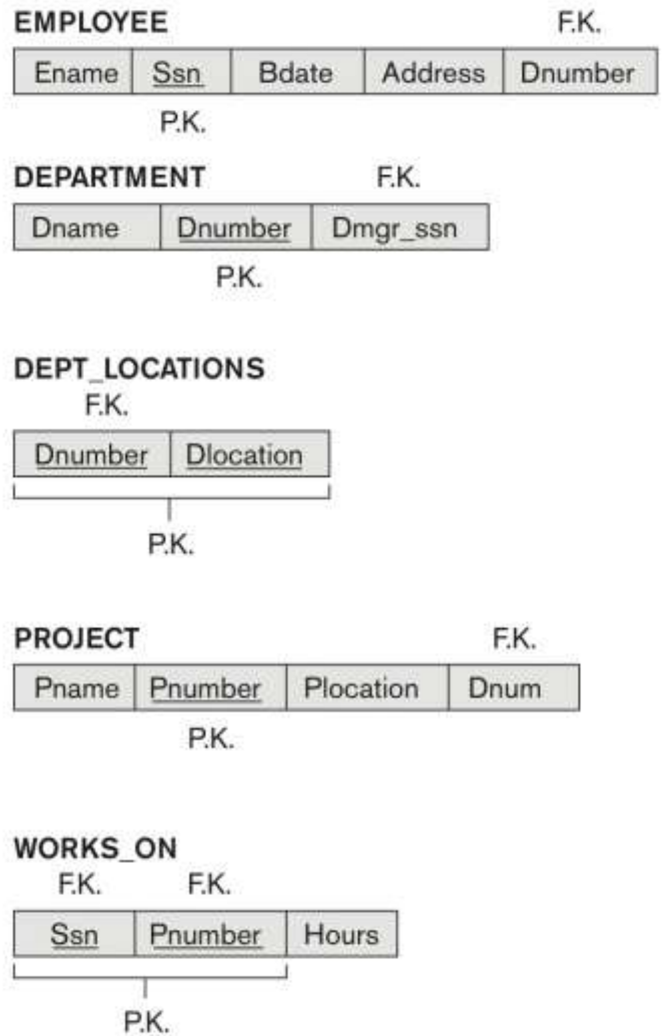



**Figure 14.1** A simplified COMPANY relational database schema.

# 1.2 Redundant Information in Tuples and Update Anomalies

- Information is stored redundantly
  - Wastes storage
  - Causes problems with update anomalies
    - Insertion anomalies
    - Deletion anomalies
    - Modification anomalies

# EXAMPLE OF AN UPDATE ANOMALY

- Consider the relation:
  - EMP_PROJ(Emp#, Proj#, Ename, Pname, No_hours)
- Update Anomaly:
  - Changing the name of project number P1 from “Billing” to “Customer-Accounting” may cause this update to be made for all 100 employees working on project P1.

# EXAMPLE OF AN INSERT ANOMALY

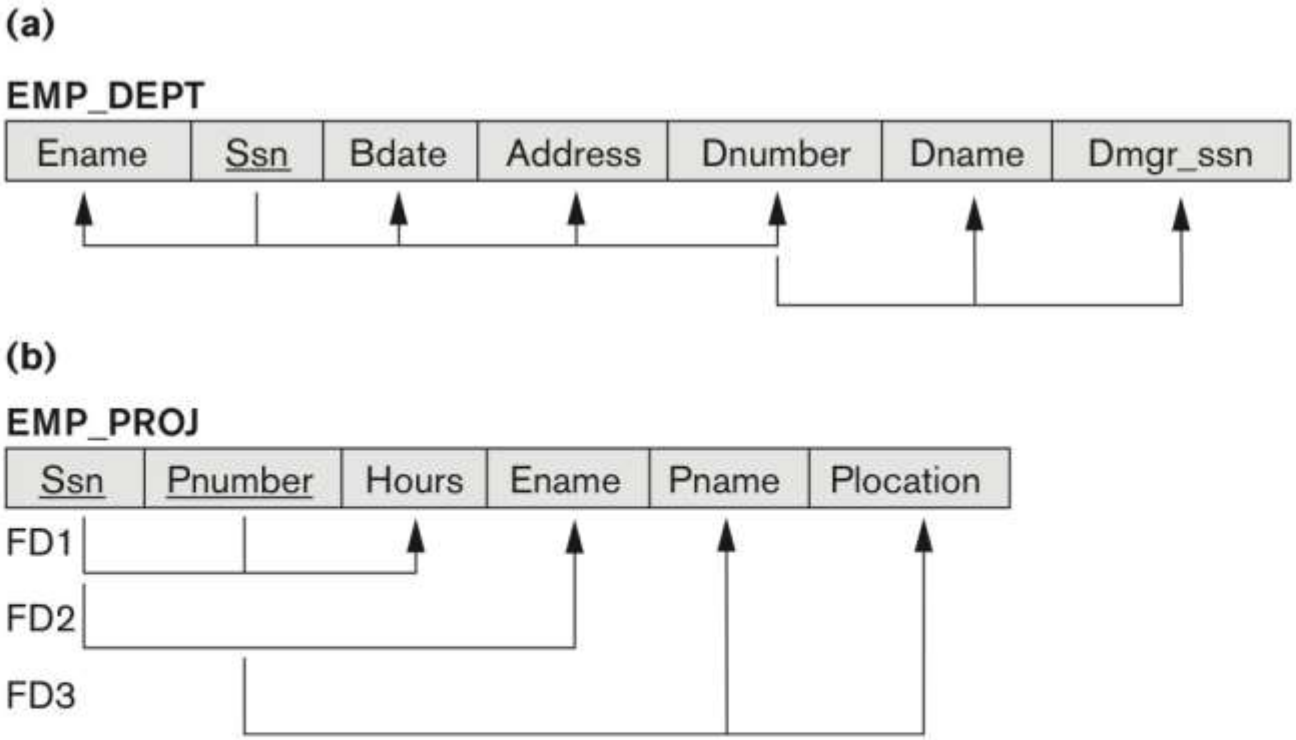
- Consider the relation:
  - EMP_PROJ(Emp#, Proj#, Ename, Pname, No_hours)
- Insert  Anomaly:
  - Cannot insert a project unless an employee is assigned to it.
- Conversely
  - Cannot insert an employee unless an he/she is assigned to a project.

# EXAMPLE OF A DELETE ANOMALY

- Consider the relation:
  - EMP_PROJ(Emp#, Proj#, Ename, Pname, No_hours)
- Delete Anomaly:
  - When a project is deleted, it will result in deleting all the employees who work on that project.
  - Alternately, if an employee is the sole employee on a project, deleting that employee would result in deleting the corresponding project.

# Figure 14.3 Two relation schemas suffering from update anomalies

**Figure 14.3**
Two relation schemas suffering from update anomalies. (a) EMP_DEPT and (b) EMP_PROJ.



# Figure 14.4 Sample states for EMP_DEPT and EMP_PROJ

**Figure 14.4**
Sample states for EMP_DEPT and EMP_PROJ resulting from applying NATURAL JOIN to the relations in Figure 14.2. These may be stored as base relations for performance reasons.

Redundancy (Dname, Dmgr_ssn)

**EMP_DEPT**

| Ename | Ssn | Bdate | Address | Dnumber | Dname | Dmgr_ssn |
|---|---|---|---|---|---|---|
| Smith, John B. | 123456789 | 1965-01-09 | 731 Fondren, Houston, TX | 5 | Research | 333445555 |
| Wong, Franklin T. | 333445555 | 1955-12-08 | 638 Voss, Houston, TX | 5 | Research | 333445555 |
| Zelaya, Alicia J. | 999887777 | 1968-07-19 | 3321 Castle, Spring, TX | 4 | Administration | 987654321 |
| Wallace, Jennifer S. | 987654321 | 1941-06-20 | 291 Berry, Bellaire, TX | 4 | Administration | 987654321 |
| Narayan, Ramesh K. | 666884444 | 1962-09-15 | 975 FireOak, Humble, TX | 5 | Research | 333445555 |
| English, Joyce A. | 453453453 | 1972-07-31 | 5631 Rice, Houston, TX | 5 | Research | 333445555 |
| Jabbar, Ahmad V. | 987987987 | 1969-03-29 | 980 Dallas, Houston, TX | 4 | Administration | 987654321 |
| Borg, James E. | 888665555 | 1937-11-10 | 450 Stone, Houston, TX | 1 | Headquarters | 888665555 |

Redundancy (Ename) Redundancy (Pname, Plocation)

**EMP_PROJ**

| Ssn | Pnumber | Hours | Ename | Pname | Plocation |
|---|---|---|---|---|---|
| 123456789 | 1 | 32.5 | Smith, John B. | ProductX | Bellaire |
| 123456789 | 2 | 7.5 | Smith, John B. | ProductY | Sugarland |
| 666884444 | 3 | 40.0 | Narayan, Ramesh K. | ProductZ | Houston |
| 453453453 | 1 | 20.0 | English, Joyce A. | ProductX | Bellaire |
| 453453453 | 2 | 20.0 | English, Joyce A. | ProductY | Sugarland |
| 333445555 | 2 | 10.0 | Wong, Franklin T. | ProductY | Sugarland |
| 333445555 | 3 | 10.0 | Wong, Franklin T. | ProductZ | Houston |
| 333445555 | 10 | 10.0 | Wong, Franklin T. | Computerization | Stafford |
| 333445555 | 20 | 10.0 | Wong, Franklin T. | Reorganization | Houston |
| 999887777 | 30 | 30.0 | Zelaya, Alicia J. | Newbenefits | Stafford |
| 999887777 | 10 | 10.0 | Zelaya, Alicia J. | Computerization | Stafford |
| 987987987 | 10 | 35.0 | Jabbar, Ahmad V. | Computerization | Stafford |
| 987987987 | 30 | 5.0 | Jabbar, Ahmad V. | Newbenefits | Stafford |
| 987654321 | 30 | 20.0 | Wallace, Jennifer S. | Newbenefits | Stafford |
| 987654321 | 20 | 15.0 | Wallace, Jennifer S. | Reorganization | Houston |
| 888665555 | 20 | Null | Borg, James E. | Reorganization | Houston |

# Guideline for Redundant Information in Tuples and Update Anomalies

- GUIDELINE 2:
  - Design a schema that does not suffer from the insertion, deletion and update anomalies.
  - If there are any anomalies present, then note them so that applications can be made to take them into account.

# 1.3 Null Values in Tuples

- GUIDELINE 3:
  - Relations should be designed such that their tuples will have as few NULL values as possible
  - Attributes that are NULL frequently could be placed in separate relations (with the primary key)
- Reasons for nulls:
  - Attribute not applicable or invalid
  - Attribute value unknown (may exist)
  - Value known to exist, but unavailable

# 1.4 Generation of Spurious Tuples – avoid at any cost

- Bad designs for a relational database may result in erroneous results for certain JOIN operations
- The "lossless join" property is used to guarantee meaningful results for join operations

- GUIDELINE 4:
  - The relations should be designed to satisfy the lossless join condition.
  - No spurious tuples should be generated by doing a natural-join of any relations.

# Spurious Tuples (2)

- There are two important properties of decompositions:
  a) Non-additive or losslessness of the corresponding join
  b) Preservation of the functional dependencies.

- Note that:
  - Property (a) is extremely important and *cannot* be sacrificed.
  - Property (b) is less stringent and may be sacrificed. (See Chapter 15).

# 2. Functional Dependencies

- Functional dependencies (FDs)
  - Are used to specify *formal measures* of the "goodness" of relational designs
  - And keys are used to define **normal forms** for relations
  - Are **constraints** that are derived from the *meaning* and *interrelationships* of the data attributes
- A set of attributes X *functionally determines* a set of attributes Y if the value of X determines a unique value for Y

# 2.1 Defining Functional Dependencies

- X → Y holds if whenever two tuples have the same value for X, they *must have* the same value for Y
  - For any two tuples t1 and t2 in any relation instance r(R): If t1[X]=t2[X], *then* t1[Y]=t2[Y]
- X → Y in R specifies a *constraint* on all relation instances r(R)
- Written as X → Y; can be displayed graphically on a relation schema as in Figures. ( denoted by the arrow: ).
- FDs are derived from the real-world constraints on the attributes

# Examples of FD constraints (1)

- Social security number determines employee name
  - SSN → ENAME
- Project number determines project name and location
  - PNUMBER → {PNAME, PLOCATION}
- Employee ssn and project number determines the hours per week that the employee works on the project
  - {SSN, PNUMBER} → HOURS

# Examples of FD constraints (2)

- An FD is a property of the attributes in the schema R
- The constraint must hold on *every* relation instance r(R)
- If K is a key of R, then K functionally determines all attributes in R
  - (since we never have two distinct tuples with t1[K]=t2[K])

# Defining FDs from instances

- Note that in order to define the FDs, we need to understand the meaning of the attributes involved and the relationship between them.
- An FD is a property of the attributes in the schema R
- Given the instance (population) of a relation, all we can conclude is that an FD *may exist* between certain attributes.
- What we can definitely conclude is – that certain FDs *do not exist* because there are tuples that show a violation of those dependencies.

# Figure 14.7 Ruling Out FDs

*Note that given the state of the TEACH relation, we can say that the FD: Text → Course may exist. However, the FDs Teacher → Course, Teacher → Text and Couse → Text are ruled out.*

**TEACH**

| Teacher | Course | Text |
|---|---|---|
| Smith | Data Structures | Bartram |
| Smith | Data Management | Martin |
| Hall | Compilers | Hoffman |
| Brown | Data Structures | Horowitz |

# Figure 14.8 What FDs may exist?

- A relation *R*(A, B, C, D) with its extension.
- Which FDs *may exist* in this relation?

| A | B | C | D |
|---|---|---|---|
| a1 | b1 | c1 | d1 |
| a1 | b2 | c2 | d2 |
| a2 | b2 | c2 | d3 |
| a3 | b3 | c4 | d3 |

# 3 Normal Forms Based on Primary Keys

- 3.1 Normalization of Relations
- 3.2 Practical Use of Normal Forms
- 3.3 Definitions of Keys and Attributes Participating in Keys
- 3.4 First Normal Form
- 3.5 Second Normal Form
- 3.6 Third Normal Form

# 3.1 Normalization of Relations (1)

- **Normalization:**
  - The process of decomposing unsatisfactory "bad" relations by breaking up their attributes into smaller relations

- **Normal form:**
  - Condition using keys and FDs of a relation to certify whether a relation schema is in a particular normal form

# Normalization of Relations (2)

- 2NF, 3NF, BCNF
  - based on keys and FDs of a relation schema
- 4NF
  - based on keys, multi-valued dependencies : MVDs;
- 5NF
  - based on keys, join dependencies : JDs
- Additional properties may be needed to ensure a good relational design (lossless join, dependency preservation; see Chapter 15)

# 3.2 Practical Use of Normal Forms

- **Normalization** is carried out in practice so that the resulting designs are of high quality and meet the desirable properties

- The practical utility of these normal forms becomes questionable when the constraints on which they are based are *hard to understand* or to *detect*
- The database designers *need not* normalize to the highest possible normal form
  - (usually up to 3NF and BCNF. 4NF rarely used in practice.)
- **Denormalization**:
  - The process of storing the join of higher normal form relations as a base relation—which is in a lower normal form

# 3.3 Definitions of Keys and Attributes Participating in Keys (1)

- A **superkey** of a relation schema R = {A1, A2, ...., An} is a set of attributes S *subset-of* R with the property that no two tuples t1 and t2 in any legal relation state r of R will have t1[S] = t2[S]

- A **key** K is a **superkey** with the *additional property* that removal of any attribute from K will cause K not to be a superkey any more.

# Definitions of Keys and Attributes Participating in Keys (2)

- If a relation schema has more than one key, each is called a **candidate** key.
  - One of the candidate keys is *arbitrarily* designated to be the **primary key**, and the others are called **secondary keys**.
- 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.

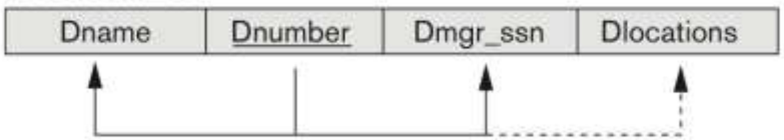
# 3.4 First Normal Form

- Disallows
  - composite attributes
  - multivalued attributes
  - **nested relations**; attributes whose values for an *individual tuple* are non-atomic
- Considered to be part of the definition of a relation
- Most RDBMSs allow only those relations to be defined that are in First Normal Form

# Figure 14.9 Normalization into 1NF

(a)

DEPARTMENT




(b)

DEPARTMENT

| Dname | Dnumber | Dmgr_ssn | Dlocations |
|---|---|---|---|
| Research | 5 | 333445555 | {Bellaire, Sugarland, Houston} |
| Administration | 4 | 987654321 | {Stafford} |
| Headquarters | 1 | 888665555 | {Houston} |

(c)

DEPARTMENT

| Dname | Dnumber | Dmgr_ssn | Dlocation |
|---|---|---|---|
| Research | 5 | 333445555 | Bellaire |
| Research | 5 | 333445555 | Sugarland |
| Research | 5 | 333445555 | Houston |
| Administration | 4 | 987654321 | Stafford |
| Headquarters | 1 | 888665555 | Houston |

**Figure 14.9**
Normalization into 1NF. (a) A relation schema that is not in 1NF. (b) Sample state of relation DEPARTMENT. (c) 1NF version of the same relation with redundancy.

# Figure 14.10 Normalizing nested relations into 1NF

(a)

EMP_PROJ

| | | Projs | |
|---|---|---|---|
| Ssn | Ename | Pnumber | Hours |

(b)

EMP_PROJ

| Ssn | Ename | Pnumber | Hours |
|---|---|---|---|
| 123456789 | Smith, John B. | 1 | 32.5 |
| | | 2 | 7.5 |
| 666884444 | Narayan, Ramesh K. | 3 | 40.0 |
| 453453453 | English, Joyce A. | 1 | 20.0 |
| | | 2 | 20.0 |
| 333445555 | Wong, Franklin T. | 2 | 10.0 |
| | | 3 | 10.0 |
| | | 10 | 10.0 |
| | | 20 | 10.0 |
| 999887777 | Zelaya, Alicia J. | 30 | 30.0 |
| | | 10 | 10.0 |
| 987987987 | Jabbar, Ahmad V. | 10 | 35.0 |
| | | 30 | 5.0 |
| 987654321 | Wallace, Jennifer S. | 30 | 20.0 |
| | | 20 | 15.0 |
| 888665555 | Borg, James E. | 20 | NULL |

(c)

EMP_PROJ1

| Ssn | Ename |
|---|---|

EMP_PROJ2

| Ssn | Pnumber | Hours |
|---|---|---|

**Figure 14.10**
Normalizing nested relations into 1NF. (a) Schema of the EMP_PROJ relation with a *nested relation* attribute PROJS. (b) Sample extension of the EMP_PROJ relation showing nested relations within each tuple. (c) Decomposition of EMP_PROJ into relations EMP_PROJ1 and EMP_PROJ2 by propagating the primary key.

# 3.5 Second Normal Form (1)

- Uses the concepts of **FDs, primary key**
- Definitions
  - **Prime attribute:** An attribute that is member of the primary key K
  - **Full functional dependency:** a FD Y -> Z where removal of any attribute from Y means the FD does not hold any more
- 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"

# Figure 14.11 Normalizing into 2NF and 3NF

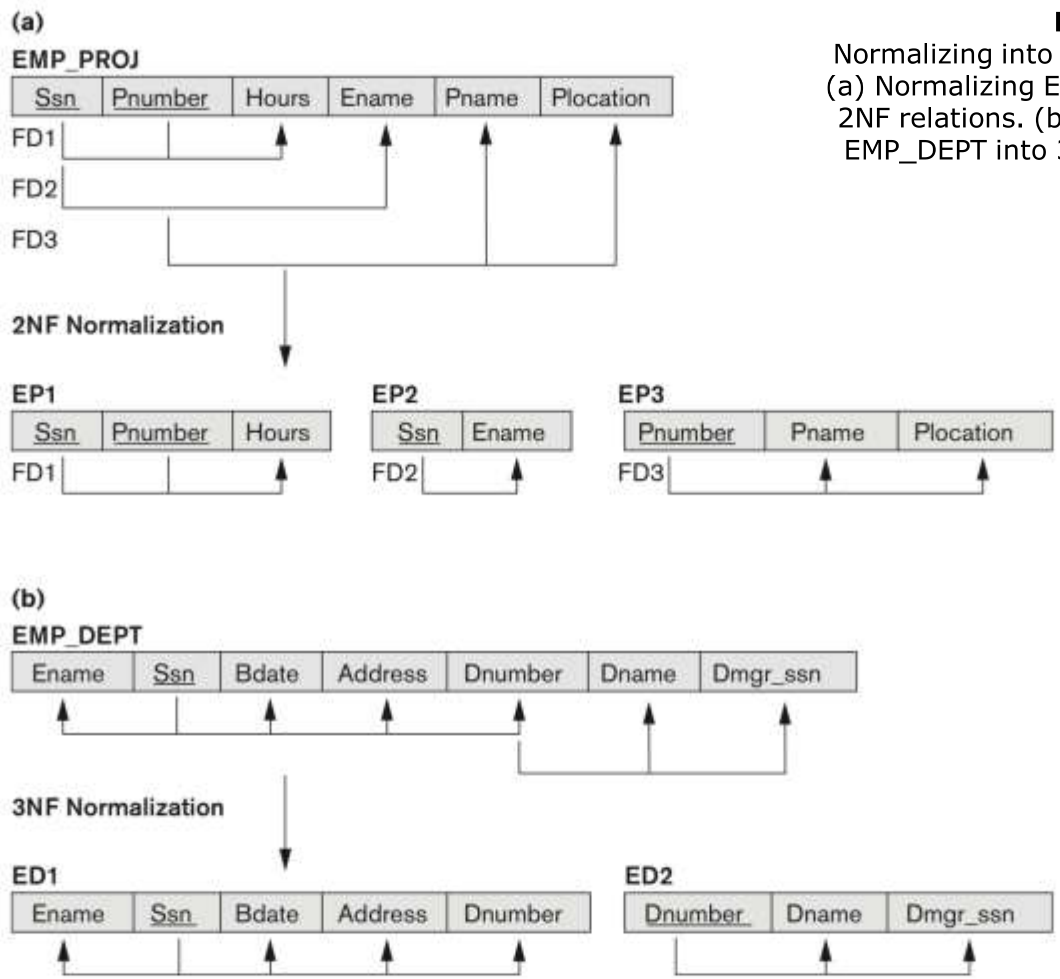
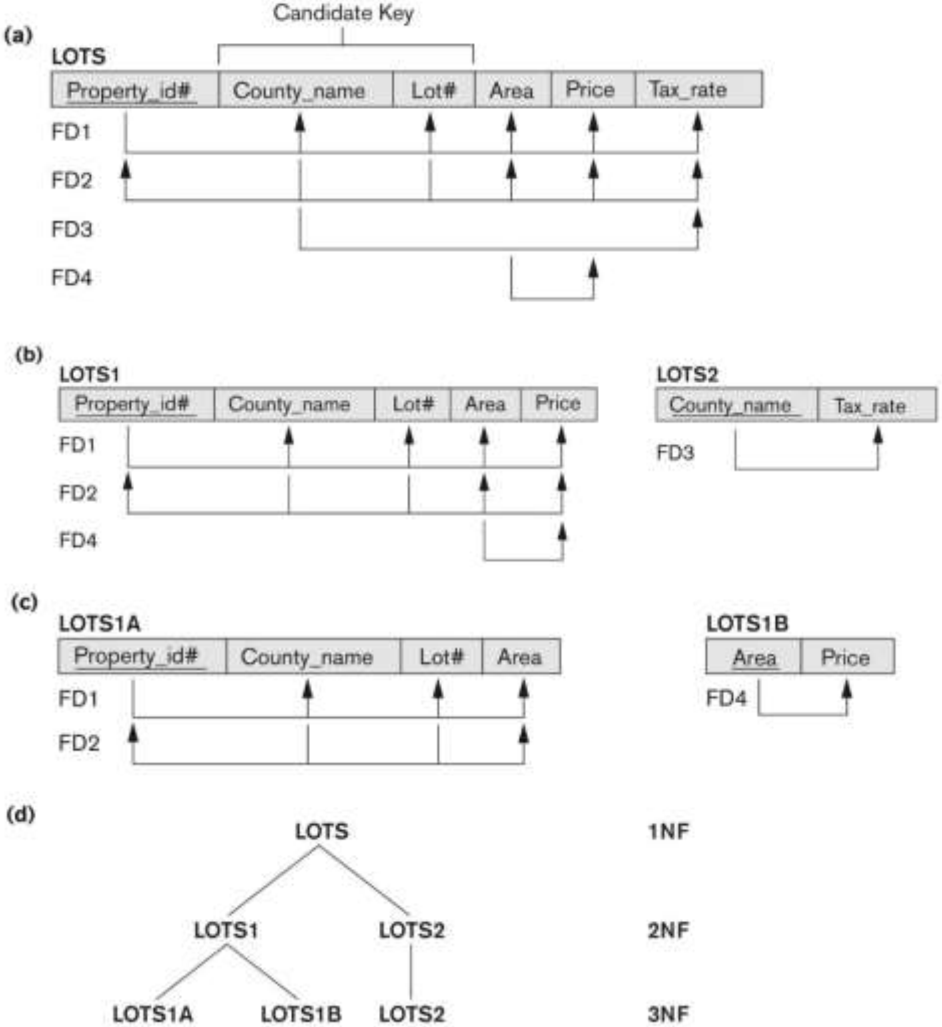



**Figure 14.11**
Normalizing into 2NF and 3NF. (a) Normalizing EMP_PROJ into 2NF relations. (b) Normalizing EMP_DEPT into 3NF relations.

# 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.



# 3.6 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 -> DMGRSSN is a **transitive** FD
    - Since SSN -> DNUMBER and DNUMBER -> DMGRSSN 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
- NOTE:
  - In X -> Y and Y -> Z, with X as the primary key, we consider this a problem only if Y is not a candidate key.
  - When Y is a candidate key, there is no problem with the transitive dependency .
  - E.g., Consider EMP (SSN, Emp#, Salary ).
    - Here, SSN -> Emp# -> Salary and Emp# is a candidate key.

# 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**

# 4. General Normal Form Definitions (For Multiple Keys) (1)

- The above definitions consider the primary key only
- The following more general definitions take into account relations with multiple candidate keys
- Any attribute involved in a candidate key is a *prime attribute*
- All other attributes are called *non-prime attributes.*

# 4.1 General Definition of 2NF (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
- In Figure 14.12 the FD

  County_name → Tax_rate violates 2NF.

So second normalization converts LOTS into

LOTS1 (Property_id#, County_name, Lot#, Area, Price)

LOTS2 ( County_name, Tax_rate)

# 4.2 General Definition of Third Normal Form

- Definition:
  - **Superkey** of relation schema R - a set of attributes S of R that contains a key of R
  - A relation schema R is in **third normal form (3NF)** if whenever a FD X → A holds in R, then either:
    - (a) X is a superkey of R, or
    - (b) A is a prime attribute of R
- LOTS1 relation violates 3NF because

Area → Price ; and Area is not a superkey in LOTS1. (see Figure 14.12).

# 4.3 Interpreting the General Definition of Third Normal Form

- Consider the 2 conditions in the Definition of 3NF:

  A relation schema R is in **third normal form (3NF)** if whenever a FD $X \rightarrow A$ holds in R, then either:

  - (a) X is a superkey of R, or
  - (b) A is a prime attribute of R

- Condition (a) catches two types of violations :

  \- one where a prime attribute functionally determines a non-prime attribute. This catches 2NF violations due to non-full functional dependencies.

  -second, where a non-prime attribute functionally determines a non-prime attribute. This catches 3NF violations due to a transitive dependency.

# 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 every non-prime attribute in R meets both of these conditions:

  - It is fully functionally dependent on every key of R
  - It is non-transitively dependent on every key of R

  Note that stated this way, a relation in 3NF also meets the requirements for 2NF.

- The condition (b) from the last slide 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)

- A relation schema R is in **Boyce-Codd Normal Form (BCNF)** if whenever an **FD X** $\longrightarrow$ **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
- There exist relations that are in 3NF but not in BCNF
- Hence BCNF is considered a stronger form of 3NF
- The goal is to have each relation in BCNF (or 3NF)

# Figure 14.13 Boyce-Codd normal form

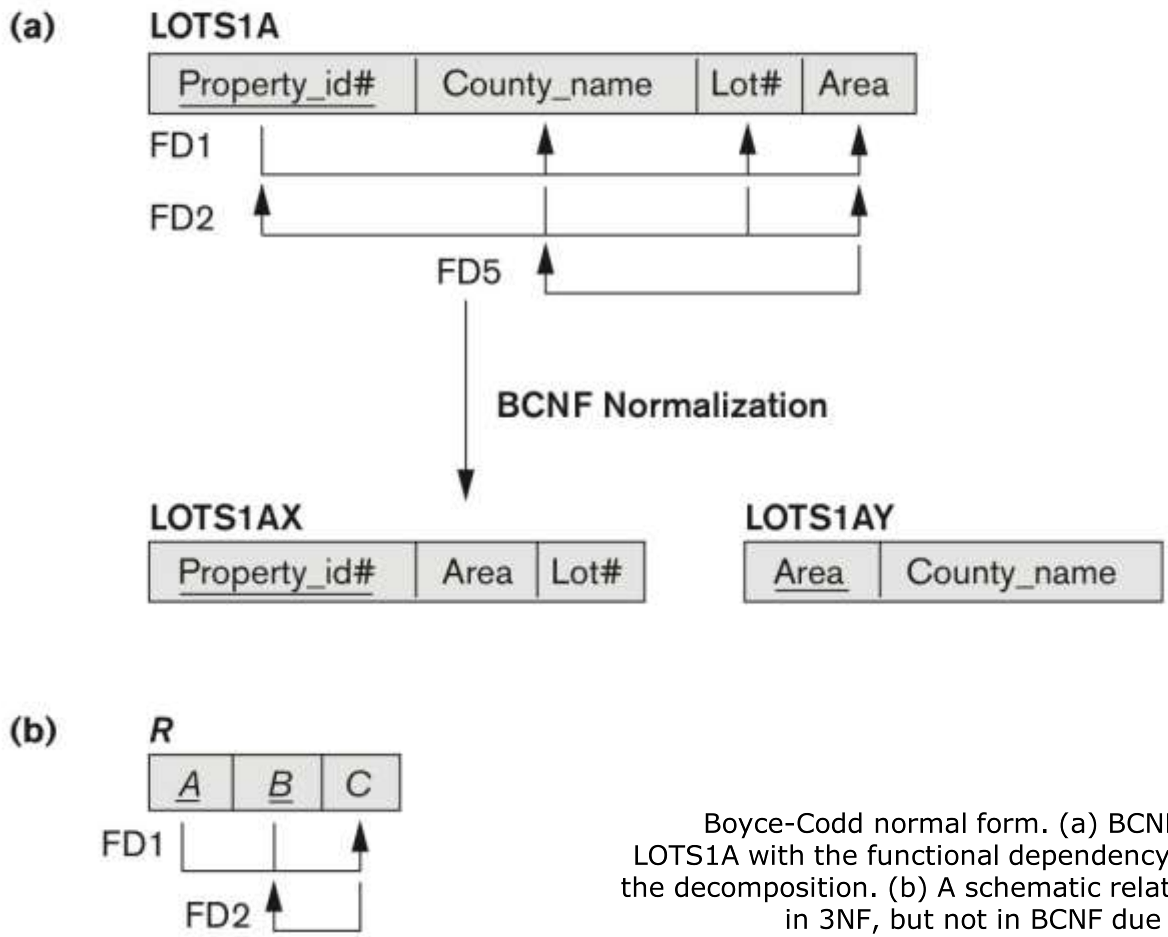



**Figure 14.13**
Boyce-Codd normal form. (a) BCNF normalization of LOTS1A with the functional dependency FD2 being lost in the decomposition. (b) A schematic relation with FDs; it is in 3NF, but not in BCNF due to the f.d. $C \rightarrow B$.

# Figure 14.14 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 |

**Figure 14.14**
A relation TEACH that is in 3NF but not BCNF.

# Achieving the BCNF by Decomposition (1)

- Two FDs exist in the relation TEACH:
  - fd1: { student, course} -> instructor
  - fd2: instructor -> course
- {student, course} is a candidate key for this relation and that the dependencies shown follow the pattern in Figure 14.13 (b).
  - So this relation is in 3NF *but not in* BCNF
- A relation **NOT** in BCNF should be decomposed so as to meet this property, while possibly forgoing the preservation of all functional dependencies in the decomposed relations.
  - (See Algorithm 15.3)

# Achieving the BCNF by Decomposition (2)

- Three possible decompositions for relation TEACH
  - D1: {student, instructor} and {student, course}
  - D2: {course, instructor } and {course, student}
  - D3: {instructor, course } and {instructor, student} ✓
- All three decompositions will lose fd1.
  - We have to settle for sacrificing the functional dependency preservation. But we cannot sacrifice the non-additivity property after decomposition.
- Out of the above three, only the 3rd decomposition will not generate spurious tuples after join.(and hence has the non-additivity property).
- A test to determine whether a binary decomposition (decomposition into two relations) is non-additive (lossless) is discussed under Property NJB on the next slide. We then show how the third decomposition above meets the property.

# Test for checking non-additivity of Binary Relational Decompositions

- **Testing Binary Decompositions for Lossless Join (Non-additive Join) Property**
  - **Binary Decomposition:** Decomposition of a relation R into two relations.
  - **PROPERTY NJB (non-additive join test for binary decompositions):** A decomposition D = {R1, R2} of R has the lossless join property with respect to a set of functional dependencies F on R *if and only if* either
    - The f.d. ((R1 ∩ R2) → (R1- R2)) is in $F^+$, or
    - The f.d. ((R1 ∩ R2) → (R2 - R1)) is in $F^+$.

# Test for checking non-additivity of Binary Relational Decompositions

**If you apply the NJB test to the 3 decompositions of the TEACH relation:**

- D1 gives **Student** → Instructor or **Student** → Course, none of which is true.
- D2 gives **Course** → Instructor or **Course** → Student, none of which is true.
- However, in D3 we get **Instructor** → Course or **Instructor** → Student.

Since **Instructor** → Course is indeed true, the NJB property is satisfied and D3 is determined as a non-additive (good) decomposition.

# General Procedure for achieving BCNF when a relation fails BCNF

**Here we make use the algorithm from Chapter 15 (Algorithm 15.5):**

- Let R be the relation not in BCNF, let X be a subset-of R, and let $X \rightarrow A$ be the FD that causes a violation of BCNF. Then R may be decomposed into two relations:
- (i) *R –A* and (ii) *X* **U** *A*.
- If either *R –A* or *X* u *A*. is not in BCNF, repeat the process.

Note that the f.d. that violated BCNF in TEACH was Instructor $\rightarrow$Course. Hence its BCNF decomposition would be :

(TEACH – COURSE) and (Instructor u Course), which gives

the relations: (Instructor, Student) and (Instructor, Course) that we obtained before in decomposition D3.

# 5. Multivalued Dependencies and Fourth Normal Form (1)

**Definition:**

- A **multivalued dependency** (**MVD**) $X \twoheadrightarrow Y$ specified on relation schema $R$, where $X$ and $Y$ are both subsets of $R$, specifies the following constraint on any relation state $r$ of $R$: If two tuples $t_1$ and $t_2$ exist in $r$ such that $t_1[X] = t_2[X]$, then two tuples $t_3$ and $t_4$ should also exist in $r$ with the following properties, where we use $Z$ to denote $(R\ {}_2\ (X \cup Y))$:
  - $t_3[X] = t_4[X] = t_1[X] = t_2[X]$.
  - $t_3[Y] = t_1[Y]$ and $t_4[Y] = t_2[Y]$.
  - $t_3[Z] = t_2[Z]$ and $t_4[Z] = t_1[Z]$.
- An MVD $X \twoheadrightarrow Y$ in $R$ is called a **trivial MVD** if (a) $Y$ is a subset of $X$, or (b) $X \cup Y = R$.

# Multivalued Dependencies and Fourth Normal Form (3)

**Definition:**

- A relation schema *R* is in **4NF** with respect to a set of dependencies *F* (that includes functional dependencies and multivalued dependencies) if, for every *nontrivial* multivalued dependency $X \rightarrow\rightarrow Y$ in $F^+$, *X* is a superkey for R.
  - Note: $F^+$ is the (complete) set of all dependencies (functional or multivalued) that will hold in every relation state *r* of *R* that satisfies *F*. It is also called the **closure** of *F*.

# Figure 14.15 Fourth and fifth normal forms.

**(a)** **EMP**

| Ename | Pname | Dname |
|---|---|---|
| Smith | X | John |
| Smith | Y | Anna |
| Smith | X | Anna |
| Smith | Y | John |

**(b)** **EMP_PROJECTS**

| Ename | Pname |
|---|---|
| Smith | X |
| Smith | Y |

**EMP_DEPENDENTS**

| Ename | Dname |
|---|---|
| Smith | John |
| Smith | Anna |

**(c)** **SUPPLY**

| Sname | Part_name | Proj_name |
|---|---|---|
| Smith | Bolt | ProjX |
| Smith | Nut | ProjY |
| Adamsky | Bolt | ProjY |
| Walton | Nut | ProjZ |
| Adamsky | Nail | ProjX |
| Adamsky | Bolt | ProjX |
| Smith | Bolt | ProjY |

**(d)** $R_1$

| Sname | Part_name |
|---|---|
| Smith | Bolt |
| Smith | Nut |
| Adamsky | Bolt |
| Walton | Nut |
| Adamsky | Nail |

$R_2$

| Sname | Proj_name |
|---|---|
| Smith | ProjX |
| Smith | ProjY |
| Adamsky | ProjY |
| Walton | ProjZ |
| Adamsky | ProjX |

$R_3$

| Part_name | Proj_name |
|---|---|
| Bolt | ProjX |
| Nut | ProjY |
| Bolt | ProjY |
| Nut | ProjZ |
| Nail | ProjX |

**Figure 14.15**
Fourth and fifth normal forms. (a) The EMP relation with two MVDs: Ename –>> Pname and Ename –>> Dname. (b) Decomposing the EMP relation into two 4NF relations EMP_PROJECTS and EMP_DEPENDENTS. (c) The relation SUPPLY with no MVDs is in 4NF but not in 5NF if it has the JD(R1, R2, R3). (d) Decomposing the relation SUPPLY into the 5NF relations R1, R2, R3.

# 6. Join Dependencies and Fifth Normal Form (1)

**Definition:**

- A **join dependency** (**JD**), denoted by JD($R_1$, $R_2$, ..., $R_n$), specified on relation schema *R*, specifies a constraint on the states *r* of *R*.
  - The constraint states that every legal state *r* of *R* should have a non-additive join decomposition into $R_1$, $R_2$, ..., $R_n$; that is, for every such *r* we have
  - $* (\pi_{R1}(r), \pi_{R2}(r), ..., \pi_{Rn}(r)) = r$

  ***Note**: an MVD is a special case of a JD where n = 2.*
- A join dependency JD($R_1$, $R_2$, ..., $R_n$), specified on relation schema *R*, is a **trivial JD** if one of the relation schemas $R_i$ in JD($R_1$, $R_2$, ..., $R_n$) is equal to *R*.

# Join Dependencies and Fifth Normal Form (2)

**Definition:**

- A relation schema $R$ is in **fifth normal form (5NF)** (or **Project-Join Normal Form (PJNF)**) with respect to a set $F$ of functional, multivalued, and join dependencies if,
  - for every nontrivial join dependency JD($R_1$, $R_2$, ..., $R_n$) in $F^+$ (that is, implied by $F$),
    - every $R_i$ is a superkey of $R$.
- Discovering join dependencies in practical databases with hundreds of relations is next to impossible. Therefore, 5NF is rarely used in practice.

# Chapter Summary

- Informal Design Guidelines for Relational Databases
- Functional Dependencies (FDs)
- Normal Forms (1NF, 2NF, 3NF)Based on Primary Keys
- General Normal Form Definitions of 2NF and 3NF (For Multiple Keys)
- BCNF (Boyce-Codd Normal Form)
- Fourth and Fifth Normal Forms