Database Systems

Chapter # 14

Database Design Theory and Normalization

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Normalization

- Normalization is the process of reorganizing/restructuring data in a database with a series of so called normal-forms, so that it meets two basic requirements:
  - There is no redundancy of data (all data is stored in only one place)
  - data dependencies are logical (all related data items are stored together).
- Normalization is important for many reasons, but chiefly because it allows databases to take up as little disk space as possible, resulting in increased performance.

Four informal guidelines

- Four informal guidelines used to determine the quality of relation schema design:
  - Making sure that the semantics of the attributes is clear in the schema
  - Reducing the redundant information in tuples
  - Reducing the NULL values in tuples
  - Disallowing the possibility of generating spurious tuples.

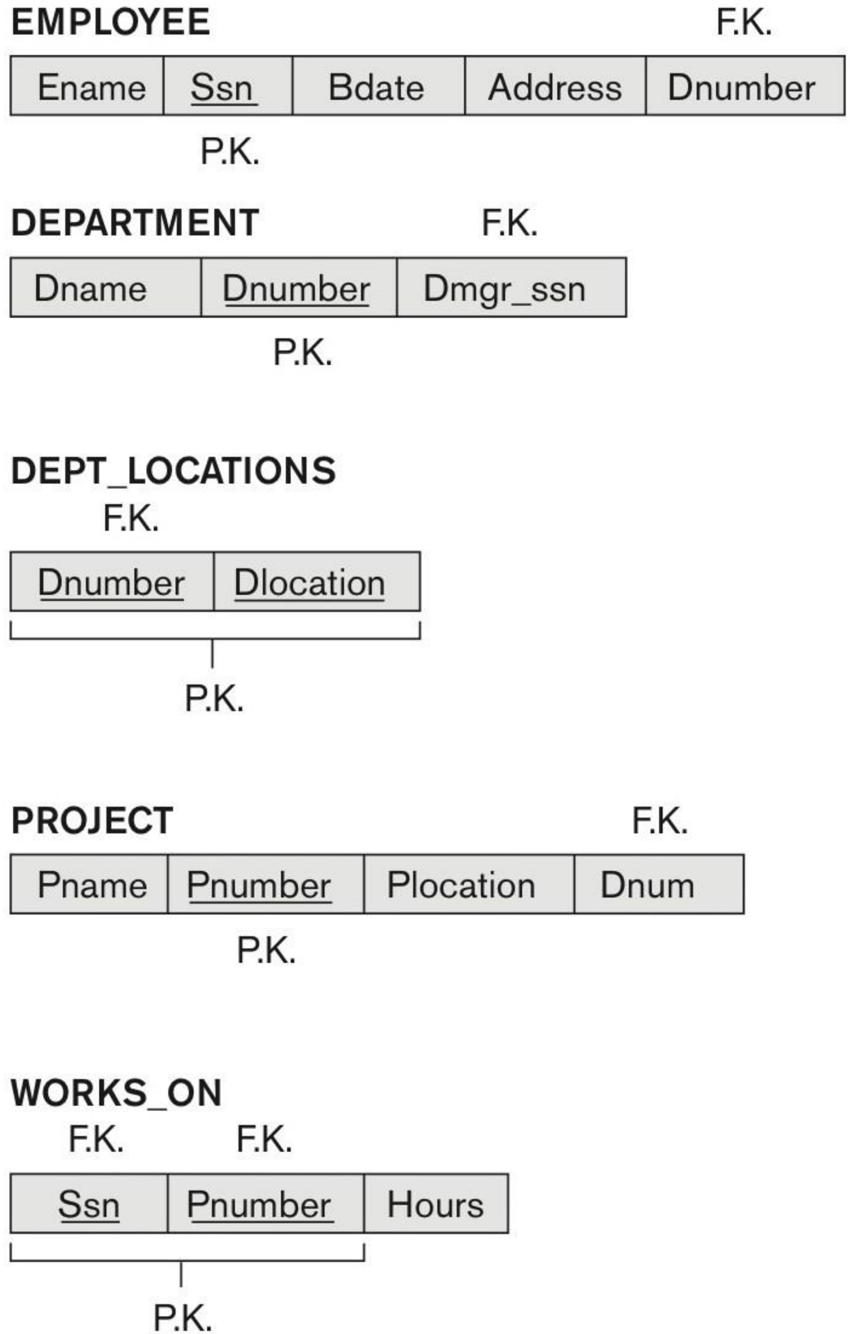


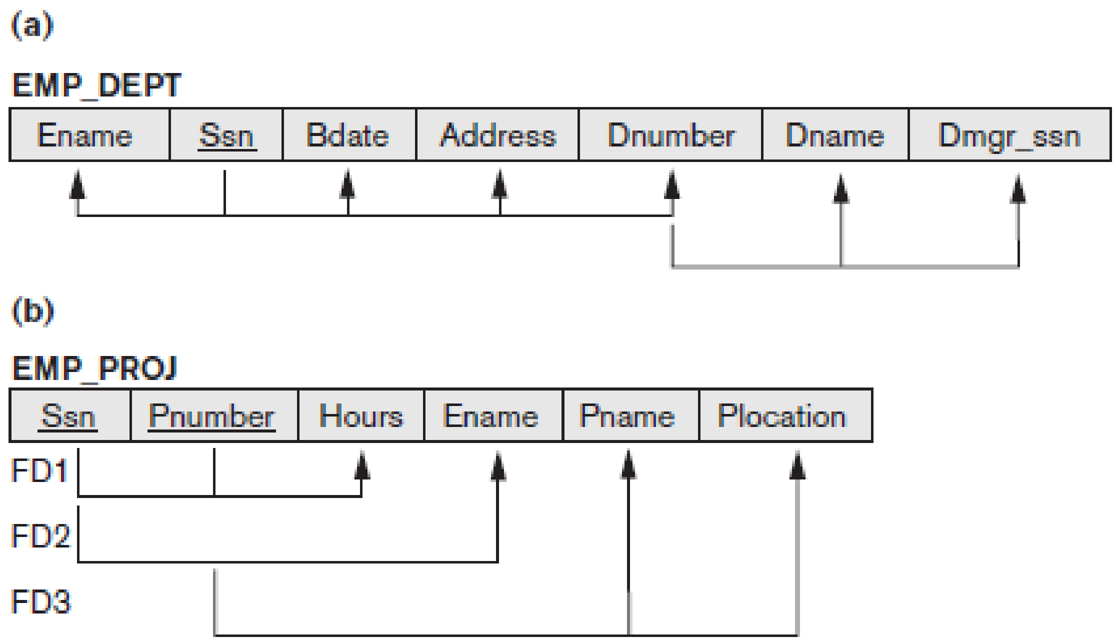
Figure 14.1 A simplified COMPANY relational database schema.

Guideline 1

- Design a relation schema so that it is easy to explain its meaning.
- Do not combine attributes from multiple entity types and relationship types into a single relation.
- If the relation corresponds to a mixture of multiple entities and relationships, semantic ambiguities will result and the relation cannot be easily explained.

Examples of Violating Guideline 1.

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



They fare poorly
Against the above measure of design quality. They may be used as views, but they
Cause problems when used as base relations,

Redundant Information in Tuples and Update Anomalies

- **Goal of schema design:** to minimize the storage space used by the base relations
  - Grouping attributes into relation schemas has a significant effect on storage space.

EMPLOYEE

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

DEPARTMENT

Dname	Dnumber	Dmgr_ssn
Research	5	333445555
Administration	4	987654321
Headquarters	1	888665555

Natural join of Employee and Department Tables

Redundancy

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

Anomalies

- Storing natural joins of base relations leads to an additional problem referred to as update anomalies.
  - Classified into:
    - **Insertion Anomalies**
    - **Deletion Anomalies**
    - **Modification Anomalies**

Insertion Anomalies.

- Insertion anomalies can be differentiated into two types:
- To insert a new employee tuple into EMP_DEPT, we must include either the attribute values for the department that the employee works for, or NULLs (if the employee does not work for a department as yet).
  - For example, to insert a new tuple for an employee who works in department number 5, we must enter all the attribute values of department 5 correctly so that they are *consistent*

Insertion Anomalies.

EMPLOYEE

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

DEPARTMENT

Dname	Dnumber	Dmgr_ssn
Research	5	333445555
Administration	4	987654321
Headquarters	1	888665555

For example, to insert a new tuple for an employee who works in department number 5, we must enter all the attribute values of department 5 correctly so that they are *consistent*

Redundancy

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
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Borg, James E.	888665555	1937-11-10	450 Stone, Houston, TX	1	Headquarters	888665555

In the design of Figure 14.2, we do not have to worry about this consistency problem because we enter only the department number in the employee tuple; once in the database, as a single tuple in the DEPARTMENT relation.

Insertion Anomalies.

- **It is difficult to insert a new department that has no employees as yet in the EMP_DEPT relation.**
  - The only way to do this is to place NULL values in the

Redundancy

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
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Jabbar, Ahmad V.	987987987	1969-03-29	980 Dallas, Houston, TX	4	Administration	987654321
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This violates the entity integrity for EMP_DEPT because its primary key Ssn cannot be null.

EXAMPLE OF AN INSERT ANOMALY

- **Consider the relation:**
  - EMP_PROJ(Emp#, Proj#, Hours, Ename, Pname,Plocation)
- **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.

Redundancy Redundancy

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

EXAMPLE OF AN UPDATE ANOMALY(Repeated Update)

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

EMP_PROJ

Ssn	Pnumber	Hours	Ename (Redundancy)	Pname (Redundancy)	Plocation (Redundancy)
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

EXAMPLE OF A DELETE ANOMALY

- **Consider the relation:**
- EMP_PROJ(Emp#, Proj#, Hours Ename, Pname,Plocation)
- **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.

EMP_PROJ

Ssn	Pnumber	Hours	Ename	Pname	Plocation
			Redundancy	Redundancy	
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
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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 2.

- **Guideline 2.** Design the base relation schemas so that no insertion, deletion, or modification anomalies are not present in the relations.

Null Values

- If many of the attributes do not apply to all tuples in the relation, we end up with many NULLs in those tuples.
- This can waste space at the storage level and may also lead to problems with understanding the meaning of the attributes.
- Another problem with NULLs is how to account for them when aggregate operations such as COUNT or SUM are applied.

Reasons for NULLS

- **Attribute not applicable or invalid** (e.g. Visa_Status may not apply to local students)
- **Attribute value unknown** (may exist) (e.g. Date_of_birth may be unknown for an employee)
- **Value known to exist, but unavailable** (e.g. Home_Phone_Number for an employee may exist, but may not be available and recorded yet.
- **Guideline 3.** As far as possible, avoid placing attributes in a base relation whose values may frequently be NULL.
- If NULLs are unavoidable, make sure that they apply in exceptional cases only and do not apply to a majority of tuples in the relation.

Generation of Spurious Tuples

Additional tuples that are not present in original table are called spurious tuples because they represent spurious information that is not valid.

(b)

EMP_LOCS

Ename	Plocation
Smith, John B.	Bellaire
Smith, John B.	Sugarland
Narayan, Ramesh K.	Houston
English, Joyce A.	Bellaire
English, Joyce A.	Sugarland
Wong, Franklin T.	Sugarland
Wong, Franklin T.	Houston
Wong, Franklin T.	Stafford
Zelaya, Alicia J.	Stafford
Jabbar, Ahmad V.	Stafford
Wallace, Jennifer S.	Stafford
Wallace, Jennifer S.	Houston
Borg, James E.	Houston

Natural Join

EMP_PROJ1

Ssn	Pnumber	Hours	Pname	Plocation
123456789	1	32.5	ProductX	Bellaire
123456789	2	7.5	ProductY	Sugarland
666884444	3	40.0	ProductZ	Houston
453453453	1	20.0	ProductX	Bellaire
453453453	2	20.0	ProductY	Sugarland
333445555	2	10.0	ProductY	Sugarland
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999887777	30	30.0	Newbenefits	Stafford
999887777	10	10.0	Computerization	Stafford
987987987	10	35.0	Computerization	Stafford
987987987	30	5.0	Newbenefits	Stafford
987654321	30	20.0	Newbenefits	Stafford
987654321	20	15.0	Reorganization	Houston
888665555	20	NULL	Reorganization	Houston

	Ssn	Pnumber	Hours	Pname	Plocation	Ename
	123456789	1	32.5	ProductX	Bellaire	Smith, John B.
*	123456789	1	32.5	ProductX	Bellaire	English, Joyce A.
	123456789	2	7.5	ProductY	Sugarland	Smith, John B.
*	123456789	2	7.5	ProductY	Sugarland	English, Joyce A.
*	123456789	2	7.5	ProductY	Sugarland	Wong, Franklin T.
	666884444	3	40.0	ProductZ	Houston	Narayan, Ramesh K.
*	666884444	3	40.0	ProductZ	Houston	Wong, Franklin T.
*	453453453	1	20.0	ProductX	Bellaire	Smith, John B.
	453453453	1	20.0	ProductX	Bellaire	English, Joyce A.
*	453453453	2	20.0	ProductY	Sugarland	Smith, John B.
	453453453	2	20.0	ProductY	Sugarland	English, Joyce A.
*	453453453	2	20.0	ProductY	Sugarland	Wong, Franklin T.
*	333445555	2	10.0	ProductY	Sugarland	Smith, John B.
*	333445555	2	10.0	ProductY	Sugarland	English, Joyce A.
	333445555	2	10.0	ProductY	Sugarland	Wong, Franklin T.
*	333445555	3	10.0	ProductZ	Houston	Narayan, Ramesh K.
	333445555	3	10.0	ProductZ	Houston	Wong, Franklin T.
	333445555	10	10.0	Computerization	Stafford	Wong, Franklin T.
*	333445555	20	10.0	Reorganization	Houston	Narayan, Ramesh K.
	333445555	20	10.0	Reorganization	Houston	Wong, Franklin T.

*

Guideline 4

- Design relation schemas so that they can be joined with equality conditions on attributes that are appropriately related (primary key, foreign key) pairs in a way that guarantees that no spurious tuples are generated.
- Avoid relations that contain matching attributes that are not (foreign key, primary key) combinations because joining on such attributes may produce spurious tuples.

Spurious Tuples

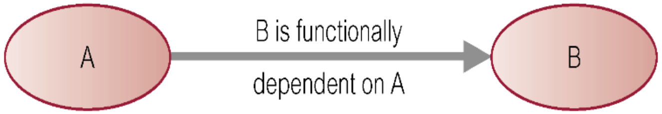
- There are two important properties of decompositions:
  - **Non-additive or lossless ness of the corresponding join**
  - **Preservation of the functional dependencies.**
- **Note that:**
  - Property (a) is extremely important and *cannot* be sacrificed.
  - Property (b) is less stringent and may be sacrificed.

Functional Dependencies

- A functional dependency is a constraint between two sets of attributes from the database.
- **Definition.**
- A functional dependency, denoted by $X \rightarrow Y$, between two sets of attributes X and Y that are subsets of R specifies a constraint on the possible tuples that can form a relation state r of R. The constraint is that, for any two tuples t1 and t2 in r that have
- $t1[X] = t2[X]$, they must also have $t1[Y] = t2[Y]$.

Defining Functional Dependencies

- **If A and B are attributes of relation R, B is functionally dependent on A (denoted A $\rightarrow$ B), if each value of A in R is associated with exactly one value of B in R.**



- 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

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.

Determining Functional Dependencies

TEACH

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

Figure 14.7
A relation state of TEACH with a *possible* functional dependency TEXT → COURSE. However, TEACHER → COURSE, TEXT → TEACHER and COURSE → TEXT are ruled out.

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

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

FD holds

B -> C
C -> B
{A,B} -> C
{A,B} -> D
{A,C} -> B
{A,C} -> D
{A,D} -> B
{A,D} -> C
{B,D} -> A
{B,D} -> C
{C,D} -> A
{C,D} -> B
{A,B,C} -> D
{A,B,D} -> C
{B,C,D} -> A

FD not holds

A -> B
A -> C
A -> D
B -> A
B -> D
C -> A
C -> D
D -> A
D -> B
D -> C
{B,C} -> A
{B,C} -> D

Important Definitions

- **Determinant**
  - Refers to the attribute, or group of attributes, on the left-hand side of the arrow of a functional dependency.
- **Full Functional dependency:**
  - Indicates that if A and B are attributes of a relation, B is fully functionally dependent on A if B is functionally dependent on A, but not on any proper subset of A.
    - {StaffNo, StaffName} → BranchNo
    - StaffNo → BranchNo
- **Transitive Dependency**
  - A condition where A, B, and C are attributes of a relation such that if A → B and B → C, then C is transitively dependent on A via B (provided that A is not functionally dependent on B or C).

Example Transitive Dependency

Staff Branch

staffNo	sName	position	salary	branchNo	bAddress
SL21	John White	Manager	30000	B005	22 Deer Rd, London
SG37	Ann Beech	Assistant	12000	B003	163 Main St, Glasgow
SG14	David Ford	Supervisor	18000	B003	163 Main St, Glasgow
SA9	Mary Howe	Assistant	9000	B007	16 Argyll St, Aberdeen
SG5	Susan Brand	Manager	24000	B003	163 Main St, Glasgow
SL41	Julie Lee	Assistant	9000	B005	22 Deer Rd, London

- **Consider functional dependencies in the Staff-Branch relation**

  staffNo → sName, position, salary, branchNo, bAddress

  branchNo → bAddress

- **Transitive dependency,**
  - **branchNo → bAddress exists on staffNo via branchNo**

Normalization of Relations

- **Definition.** The normal form of a relation refers to the highest normal form condition that it meets, and hence indicates the degree to which it has been normalized.
- **Normalization of data:** process of analyzing the given relation schemas based on their FDs and primary keys to achieve the desirable properties of
  (1) minimizing redundancy
  (2) minimizing the insertion, deletion, and update anomalies
- **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

- 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)

Practical Use of Normal Forms

- The database designers *need not* normalize to the highest possible normal form
  - (usually up to 3NF and BCNF. 4NF rarely used in practice.)
- **DE normalization**:
  - The process of storing the join of higher normal form relations as a base relation—which is in a lower normal form

Definitions of Keys and Attributes Participating in Keys

- 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.

Non-additive or Lossless Join Decomposition

- If we decompose a relation R into relations R1 and R2,
  - Decomposition is lossy if R1 ⋈ R2 ⊃ R
  - Decomposition is lossless if R1 ⋈ R2 = R
- To check for lossless join decomposition using FD set, following conditions must hold:
  - Union of Attributes of R1 and R2 must be equal to attribute of R. Each attribute of R must be either in R1 or in R2.
    - **Att(R1) U Att(R2) = Att(R)**
  - Intersection of Attributes of R1 and R2 must not be NULL.
    - **Att(R1) ∩ Att(R2) ≠ Φ**
  - Common attribute must be a key for at least one relation (R1 or R2)
  - **Att(R1) ∩ Att(R2) -> Att(R1) or Att(R1) ∩ Att(R2) -> Att(R2)**

Example

- R (A, B, C, D)
- FD: {A->BC} is decomposed into R1(ABC) and R2(AD) which is a lossless join decomposition as:
- First condition holds true as Att(R1) U Att(R2) = (ABC) U (AD) = (ABCD) = Att(R).
- Second condition holds true as Att(R1) ∩ Att(R2) = (ABC) ∩ (AD) ≠ Φ
- Third condition holds true as Att(R1) ∩ Att(R2) = A is a key of R1(ABC) because A->BC is given.

Dependency Preserving Decomposition

- If we decompose a relation R into relations R1 and R2, All dependencies of R either must be a part of R1 or R2 or must be ***derivable*** from combination of FD's of R1 and R2.
- **For Example**,
- **R (A, B, C, D)** with **FD set{A->BC}** is decomposed into **R1(ABC)** and **R2(AD)** which is dependency preserving because FD **A->BC** is a part of **R1(ABC)**.

FIRST NORMAL FORM

It states that
the domain of an attribute
must include only *atomic*
(simple, indivisible) *values*
and
that the value of any
attribute in a tuple must be
a *single value* from the
domain of
that attribute.

(a)

DEPARTMENT

Dname	Dnumber	Dmgr_ssn	Dlocations

(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.

Normalizing into 1NF.

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.

(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

Second Normal Form

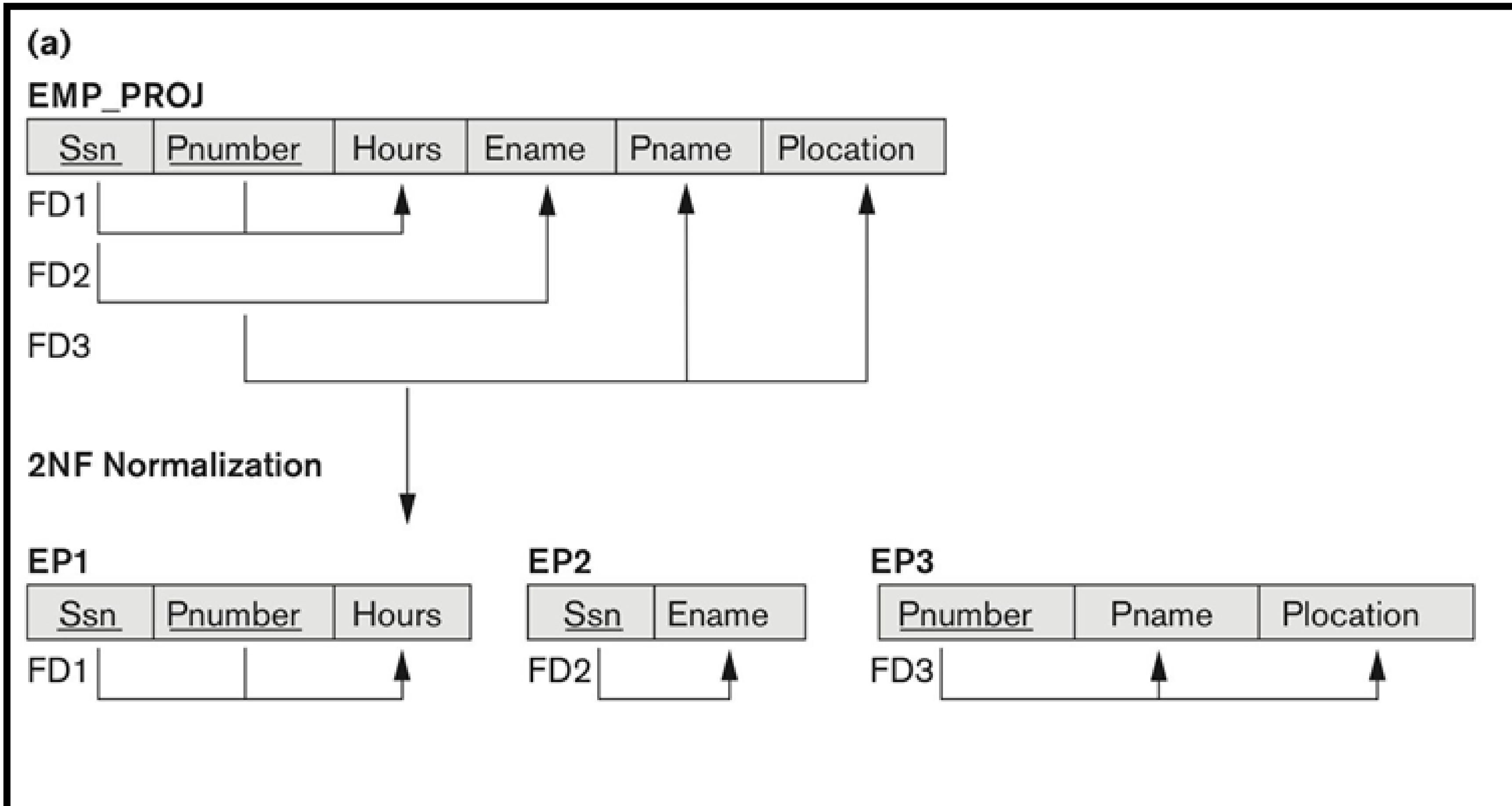
- Uses the concepts of **FDs, primary key**
- Definitions
  - **Prime attribute:** An attribute that is member of the primary key K
  - **Full functional dependency:** a FD Y -> Z where removal of any attribute from Y means the FD does not hold any more
- Examples:
  - {SSN, PNUMBER} -> HOURS is a full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

- **Definition.** A relation schema R is in 2NF if every nonprime attribute A in R is fully functionally dependent on the primary key of R.

Second Normal Form

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



Example Transitive Dependency

StaffBranch

staffNo	sName	position	salary	branchNo	bAddress
SL21	John White	Manager	30000	B005	22 Deer Rd, London
SG37	Ann Beech	Assistant	12000	B003	163 Main St, Glasgow
SG14	David Ford	Supervisor	18000	B003	163 Main St, Glasgow
SA9	Mary Howe	Assistant	9000	B007	16 Argyll St, Aberdeen
SG5	Susan Brand	Manager	24000	B003	163 Main St, Glasgow
SL41	Julie Lee	Assistant	9000	B005	22 Deer Rd, London

- **Consider functional dependencies in the Staff-Branch relation**

  staffNo → sName, position, salary, branchNo, bAddress

  branchNo → bAddress

- **Transitive dependency,**
  - **branchNo → bAddress exists on staffNo via branchNo**

Third Normal Form

- **Definition.** a relation schema R is in 3NF if it satisfies 2NF and no nonprime attribute of R is transitively dependent on the primary key.
- **Definition of Transitive functional dependency:**
  - **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

General Definition. A relation schema R is in third normal form (3NF) if, whenever a nontrivial functional dependency X → A holds in R, either
(a) X is a super key/Candidate key of R,
OR
(b) A is a prime attribute of R.

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

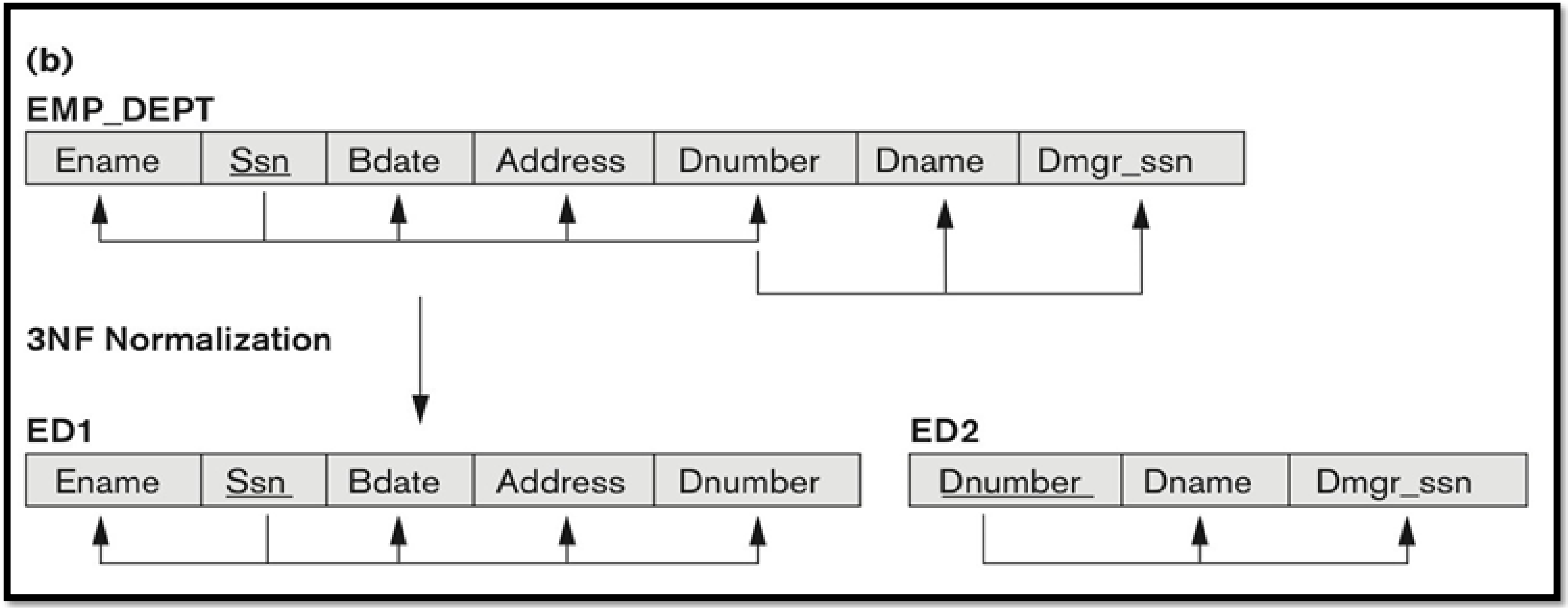
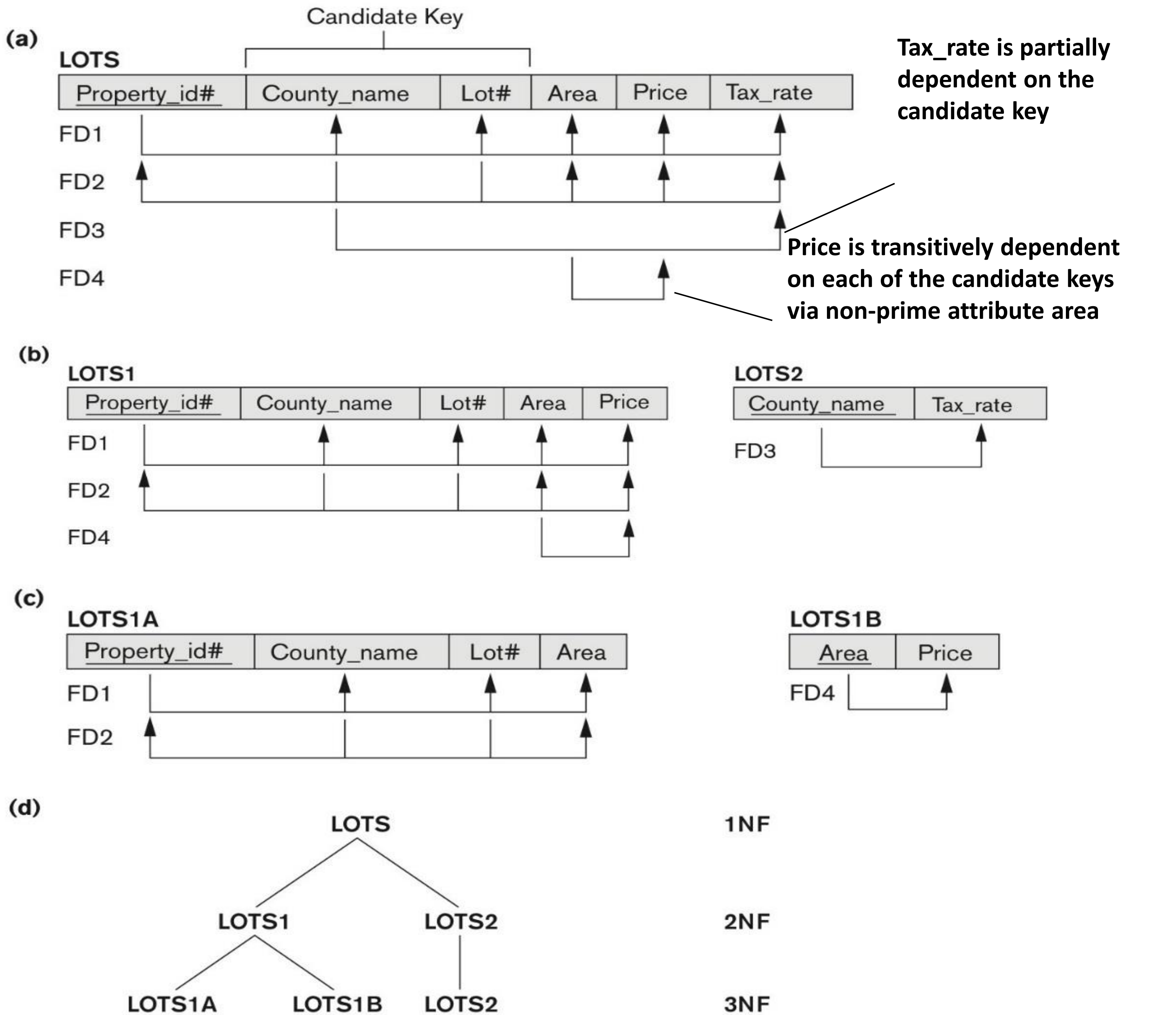


Figure 14.12
Normalization into 2NF and 3NF. (a) The LOTS relation with its functional dependencies FD1 through FD4.
(b) Decomposing into the 2NF relations LOTS1 and LOTS2. (c) Decomposing LOTS1 into the 3NF relations LOTS1A and LOTS1B.
(d) Progressive normalization of LOTS into a **3NF** design.



Boyce-Codd Normal Form

- **Definition.** A relation schema R is in BCNF if whenever a nontrivial functional dependency X → A holds in R, then X is a superkey of R.

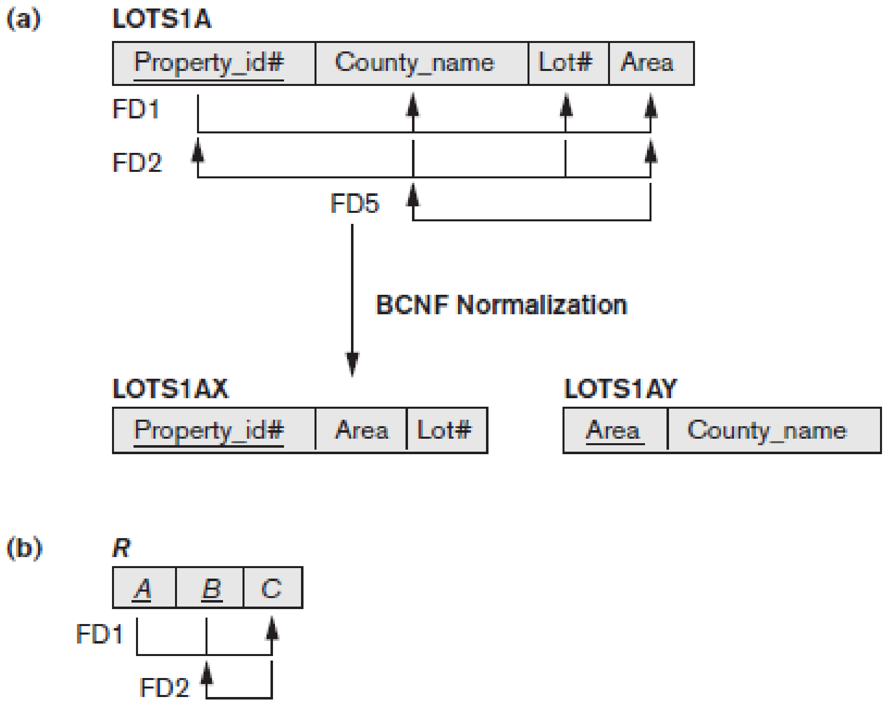


Figure 14.13
Boyce-Codd normal form. (a) BCNF normalization of LOTS1A with the functional dependency FD2 being lost in the decomposition. (b) A schematic relation with FDs; it is in 3NF, but not in BCNF due to the f.d. $C \rightarrow B$.

Decomposition of Relations not in BCNF

FD1: {Student, Course} → Instructor
FD2:14 Instructor → Course

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

Decomposition of Relations not in BCNF

FD1: {Student, Course} $\rightarrow$ Instructor
FD2:14 Instructor $\rightarrow$ Course

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

Normalized Relations:

R1 (Instructor, Course) and R2(Instructor, Student)

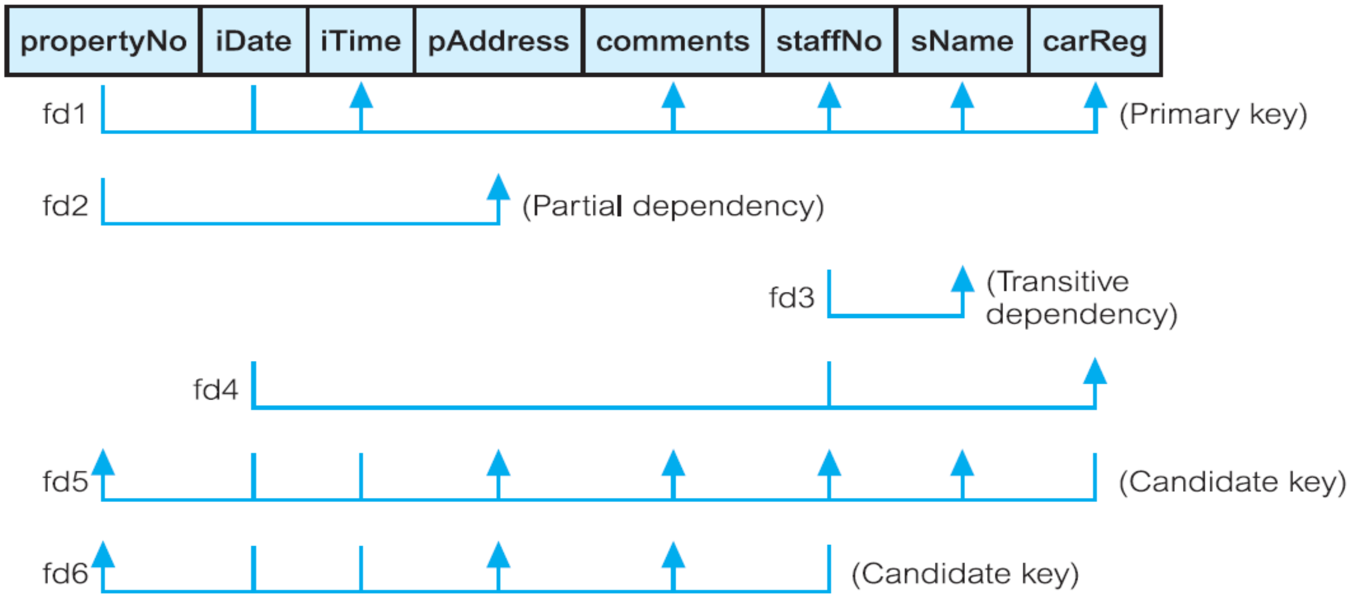
StaffPropertyInspection

propertyNo	iDate	iTime	pAddress	comments	staffNo	sName	carReg
PG4	18-Oct-12	10.00	6 Lawrence St, Glasgow	Need to replace crockery	SG37	Ann Beech	M231 JGR
PG4	22-Apr-13	09.00	6 Lawrence St, Glasgow	In good order	SG14	David Ford	M533 HDR
PG4	1-Oct-13	12.00	6 Lawrence St, Glasgow	Damp rot in bathroom	SG14	David Ford	N721 HFR
PG16	22-Apr-13	13.00	5 Novar Dr, Glasgow	Replace living room carpet	SG14	David Ford	M533 HDR
PG16	24-Oct-13	14.00	5 Novar Dr, Glasgow	Good condition	SG37	Ann Beech	N721 HFR

The First Normal Form(1NF) StaffPropertyInspection relation.

StaffPropertyInspection (propertyNo, iDate, iTime, pAddress, comments, staffNo, sName, carReg)

StaffPropertyInspection



fd1	propertyNo, iDate → iTime, comments, staffNo, sName, carReg	(Primary key)
fd2	propertyNo → pAddress	(Partial dependency)
fd3	staffNo → sName	(Transitive dependency)
fd4	staffNo, iDate → carReg	
fd5	carReg, iDate, iTime → propertyNo, pAddress, comments, staffNo, sName	(Candidate key)
fd6	staffNo, iDate, iTime → propertyNo, pAddress, comments	(Candidate key)

Second Normal Form (2NF)

Property	(propertyNo, pAddress)
PropertyInspection	(propertyNo, iDate, iTime, comments, staffNo, sName, carReg)

Third Normal Form (3NF)

Property	(propertyNo, pAddress)
Staff	(staffNo, sName)
PropertyInspect	(propertyNo, iDate, iTime, comments, staffNo, carReg)

Boyce–Codd Normal Form (BCNF)

StaffCar	(staffNo, iDate, carReg)
Inspection	(propertyNo, iDate, iTime, comments, staffNo)

Property Relation

fd2 propertyNo $\rightarrow$ pAddress

Staff Relation

fd3 staffNo $\rightarrow$ sName

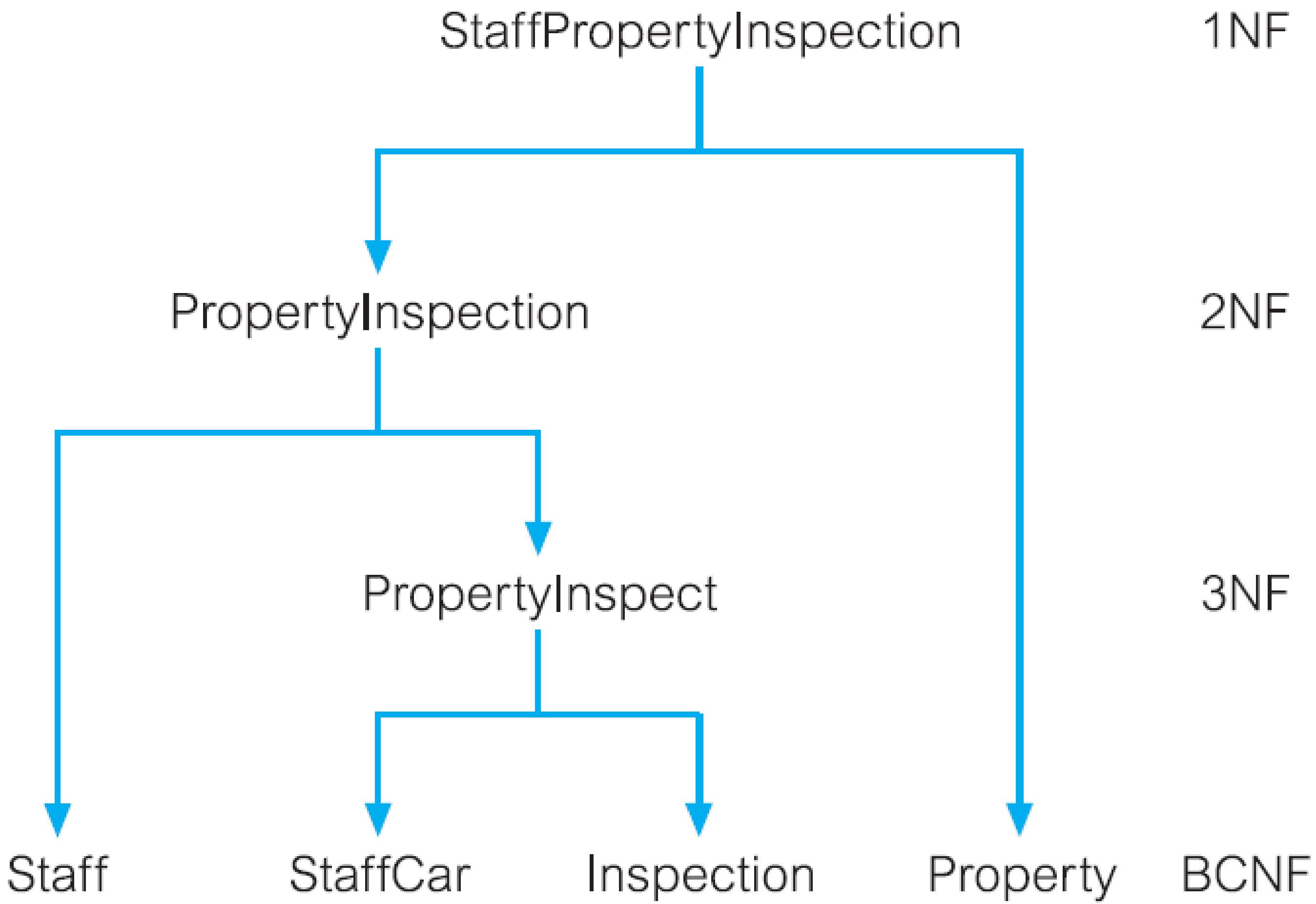
PropertyInspect Relation

fd1′ propertyNo, iDate $\rightarrow$ iTime, comments, staffNo, carReg

fd4 staffNo, iDate $\rightarrow$ carReg

fd5′ carReg, iDate, iTime $\rightarrow$ propertyNo, comments, staffNo

fd6′ staffNo, iDate, iTime $\rightarrow$ propertyNo, comments


StaffPropertyInspection
1NF
PropertyInspection
2NF
PropertyInspect
3NF
Staff
StaffCar
Inspection
Property
BCNF