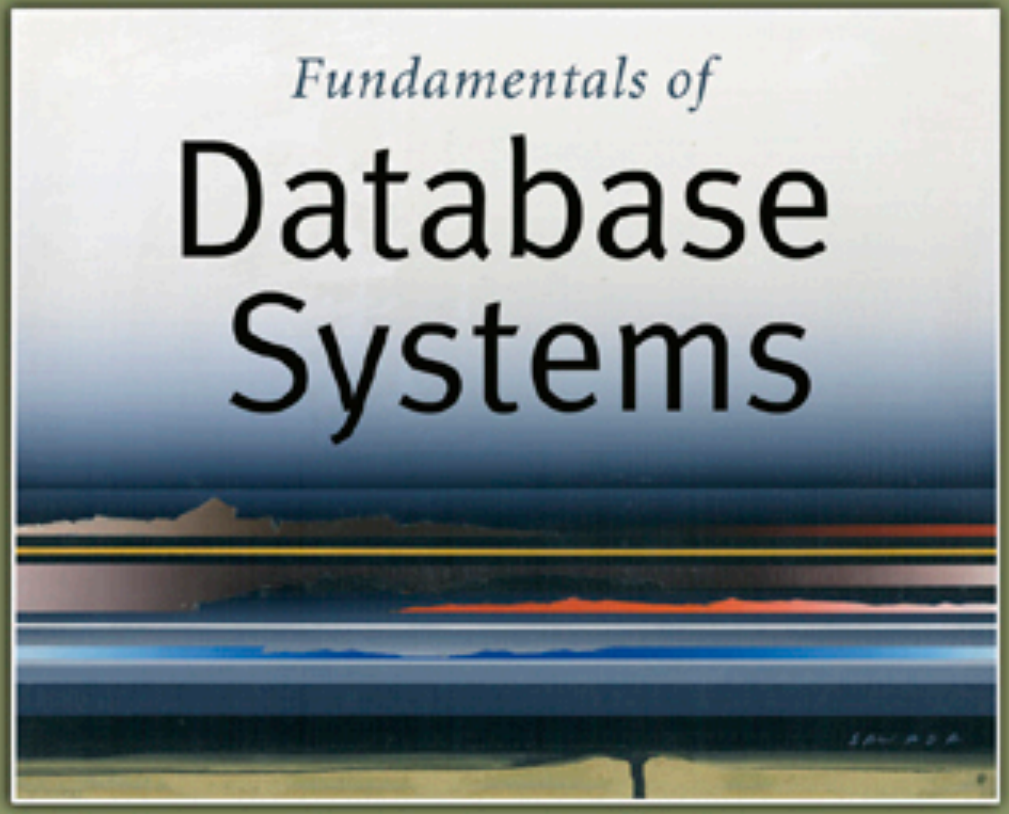
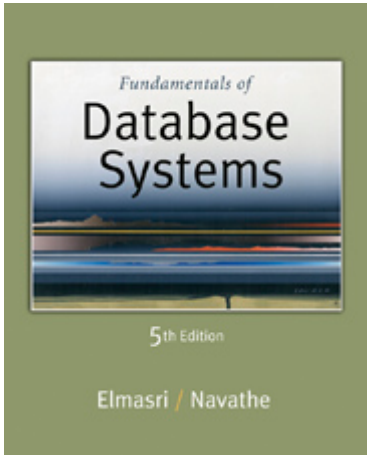


5th Edition

Elmasri / Navathe

Chapter 10

Functional Dependencies and Normalization for Relational Databases



Chapter Outline

- 1 Informal Design Guidelines for Relational Databases
  - 1.1Semantics 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 FD
  - 2.2 Inference Rules for FDs
  - 2.3 Equivalence of Sets of FDs
  - 2.4 Minimal Sets of FDs

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
  - 3.5 Second Normal Form
  - 3.6 Third Normal Form
- 4 General Normal Form Definitions (For Multiple Keys)
- 5 BCNF (Boyce-Codd 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
  - Semantics of the attribute
  - Reducing the redundant values in tuples
  - Reducing the null values in tuples
  - Disallowing the possibility of generating spurious tuples
- Then we discuss formal concepts of functional dependencies and normal forms
  - - 1NF (First Normal Form)
  - - 2NF (Second Normal Form)
  - - 3NF (Third Normal Form)
  - - BCNF (Boyce-Codd Normal Form)
- Additional types of dependencies, further normal forms, relational design algorithms by synthesis are discussed in Chapter 11

1.1 Semantics of the Relation Attributes

- 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 10.1 A simplified COMPANY relational database schema

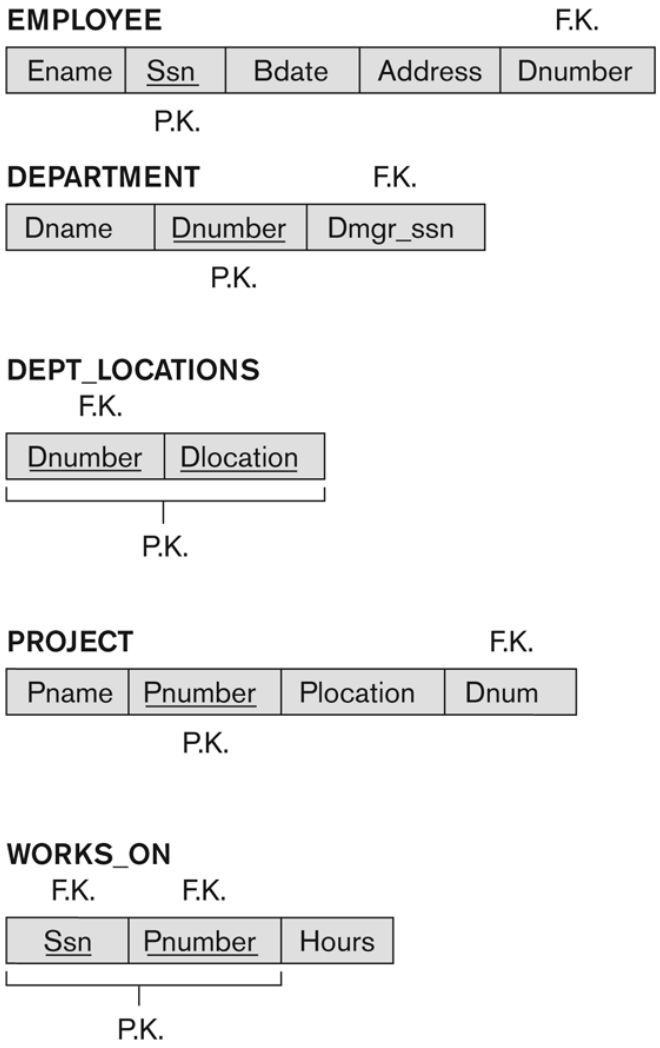


Figure 10.1
A simplified COMPANY relational database schema.

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 A MODIFICATION 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)
- Insertion 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 AN DELETE ANOMALY

- Consider the relation:
  - EMP_PROJ(Emp#, Proj#, Ename, Pname, No_hours)
- Deletion 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 10.3 Two relation schemas suffering from update anomalies

Figure 10.3
Two relation schemas suffering from update anomalies.
(a) EMP_DEPT and
(b) EMP_PROJ.

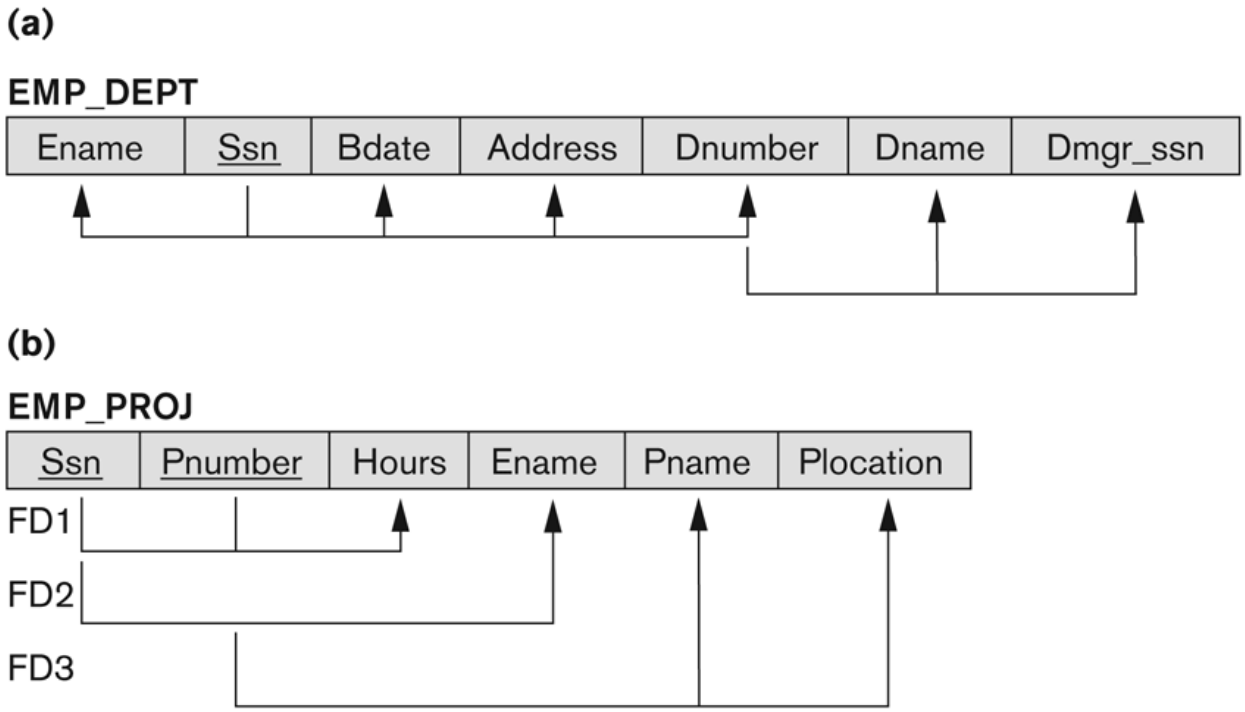


Figure 10.4 Example States for EMP_DEPT and EMP_PROJ

Figure 10.4

Example states for EMP_DEPT and EMP_PROJ resulting from applying NATURAL JOIN to the relations in Figure 10.2. These may be stored as base relations for performance reasons.

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

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

Guideline to 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
  - Value known to exist, but unavailable

1.4 Spurious Tuples

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

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
333445555	3	10.0	ProductZ	Houston
333445555	10	10.0	Computerization	Stafford
333445555	20	10.0	Reorganization	Houston
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

1.4 Spurious Tuples

	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.

* * *

Figure 15.6
Result of applying NATURAL JOIN to the tuples above the dashed lines in EMP_PROJ1 and EMP_LOCS of Figure 15.5. Generated spurious tuples are marked by asterisks.

1.4 Spurious Tuples

- 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:
  - Design relation schemas so that they can be JOINed with equality conditions on attributes that are either primary keys or foreign keys in a way that guarantees that no spurious tuples are generated.
  - Do not have relations that contain matching attributes other than foreign key – primary key combinations.
  - 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 11).

2.1 Functional Dependencies (1)

- 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

Functional Dependencies (2)

- 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

Functional Dependencies (3)

- if X is a candidate key of R – then X→ Y for any subset of attributes Y of R (because the key constraint implies that no two tuples in any legal state r(R) will have the same value of X).
- If X→ Y in R this does not imply that Y → X in R.
- A functional dependency is the property of the semantics or meaning of the attributes.
- Relation extensions r(R) that satisfy the functional dependency constraint are called legal extensions (or legal relation states) of R.

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])

FD Constraint

- FD is a property of the relation schema (intension) R, not of a particular legal relation state (extension) r of R.
- Thus, FD cannot be automatically inferred from a given relation extension r but must be defined explicitly by someone who knows the semantics of the attributes of R.

Project table

ProjectID	Budget
P1	32
P2	40
P3	27
P4	17

Employee table

EmpID	ProjectID	Hours
S75	P1	7
S75	P2	3
S79	P1	4
S79	P3	1
S80	P2	5

2.2 Inference Rules for FDs (1)

- Schema designer specifies FDs that are semantically obvious.
- Other dependencies can be inferred or deduced from the FDs in F. For example:
  - F={SSN → {ENAME, BDATE, ADDRESS, DNUMBER}, DNUMBER → {DNAME, DMGRSSN}}
  - We can infer the following from F:
    - SSN → {DNAME, DMGRSSN}
    - SSN → SSN
    - DNUMBER → DNAME

2.2 Inference Rules for FDs (2)

- Given a set of FDs F, we can **infer** additional FDs that hold whenever the FDs in F hold
- We use F |= X → Y to denote that FD X → Y is inferred from F
- Armstrong's inference rules:
  - IR1. (**Reflexive**) If Y *subset-of* X, then X -> Y
  - IR2. (**Augmentation**) If X -> Y, then XZ -> YZ
    - (Notation: XZ stands for X U Z)
  - IR3. (**Transitive**) If X -> Y and Y -> Z, then X -> Z
- A FD X → Y is *trivial* if X superset-of Y; otherwise it is *nontrivial.*
- IR1, IR2, IR3 form a **sound** and **complete** set of inference rules
  - These are rules hold and all other rules that hold can be deduced from these

Inference Rules for FDs (3)

- Some additional inference rules that are useful:
  - **IR4. Decomposition:** If X -> YZ, then X -> Y and X -> Z
  - **IR5. Union:** If X -> Y and X -> Z, then X -> YZ
  - **IR6. Psuedotransitivity:** If X -> Y and WY -> Z, then WX -> Z

- The last three inference rules, as well as any other inference rules, can be deduced from IR1, IR2, and IR3 (completeness property)

Inference Rules for FDs (4)

- **Closure** of a set F of FDs is the set F^+ of all FDs that can be inferred from F
- **Closure** of a set of attributes X with respect to F is the set X^+ of all attributes that are functionally determined by X
- X^+ can be calculated by repeatedly applying IR1, IR2, IR3 using the FDs in F

2.3 Equivalence of Sets of FDs

- Two sets of FDs F and G are **equivalent** if:
  - Every FD in F can be inferred from G, and
  - Every FD in G can be inferred from F
  - Hence, F and G are equivalent if $F^+ = G^+$
- Definition (**Covers**):
  - F **covers** G if every FD in G can be inferred from F
    - (i.e., if G^+ *subset-of* F^+)
- F and G are equivalent if F covers G and G covers F
- There is an algorithm for checking equivalence of sets of FDs

2.4 Minimal Sets of FDs (1)

- A set of FDs is **minimal** if it satisfies the following conditions:
  1. Every dependency in F has a single attribute for its RHS.
  2. We cannot replace any dependency X -> A in F with a dependency Y -> A, where Y proper-subset-of X (Y subset-of X) and still have a set of dependencies that is equivalent to F.
  3. We cannot remove any dependency from F and have a set of dependencies that is equivalent to F.

Minimal Sets of FDs (2)

- Every set of FDs has an equivalent minimal set
- There can be several equivalent minimal sets
- There is no simple algorithm for computing a minimal set of FDs that is equivalent to a set F of FDs. This is called a minimal cover of F.
- To synthesize a set of relations, we assume that we start with a set of dependencies that is a minimal set

Minimal Sets of FDs (3)

- Minimal set of FDs are a set of dependencies in a *standard or canonical form* and with *no redundancies.*
- Condition 1 ensures that every dependency is in a canonical form with a single attribute on the RHS.
- Conditions 2 and 3 ensure that there are no redundancies in the dependencies:
  - Either having redundant attributes on the LHS of the dependency (condition 2)
  - Or by having a dependency that can be inferred from the remaining FDs in F (condition 3)

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

3.1 Normalization of Relations (2)

- First proposed by Codd in 1972.
- The process which proceeds in top down fashion by evaluating each relation against the criteria for normal forms and decomposing relations as necessary can be considered as *relational design by analysis.*
- Relations in a particular normal form can be synthesized from a given set of FDs . This approach is called *relational design by synthesis.*

3.1 Normalization of Relations (3)

- **Normalization of data** can be looked upon as a process of analyzing the given relation schemas based on their FDs and primary keys to achieve the desirable properties of:
  - Minimizing redundancy
  - Minimizing update anomalies
- Unsatisfactory relations that do not meet certain conditions – the **normal form tests** – are decomposed into smaller relation schemas that meet the tests and hence posses the desirable properties.

Normalization of Relations (4)

- Normalization procedure provides database designers with:
  - A formal framework for analyzing relation schemas based on their keys and on the functional dependencies among their attributes.
  - A series of normal form tests that can be carried out on individual relation schemas so that the relational database can be normalized to any desired degree.
- A normal form of a relation refers to the highest normal form condition that it meets.

Normalization of Relations (5)

- 2NF, 3NF, BCNF
  - based on keys and FDs of a relation schema
- 4NF
  - based on keys, multi-valued dependencies; 5NF based on keys, join dependencies (Chapter 11)
- Normal forms when considered in isolation from other factors do not guarantee a good database design
- Additional properties may be needed to ensure a good relational design
  - lossless join or nonadditive join property
  - dependency preservation property

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, BCNF or 4NF)
- **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.

3.2 First Normal Form

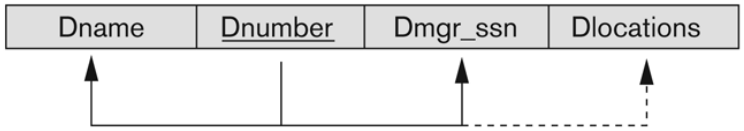
- Disallows
  - composite attributes
  - multivalued attributes
  - **nested relations**; attributes whose values for an *individual tuple* are non-atomic

- Considered to be part of the definition of relation

Figure 10.8 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 10.8
Normalization into 1NF. (a) A relation schema that is not in 1NF. (b) Example state of relation DEPARTMENT. (c) 1NF version of the same relation with redundancy.

Figure 10.9 Normalization 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, AliciaJ.	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 10.9
Normalizing nested relations into 1NF. (a) Schema of the EMP_PROJ relation with a *nested relation* attribute PROJS. (b) Example 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.

3.3 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

Figure 10.10 Normalizing into 2NF and 3NF

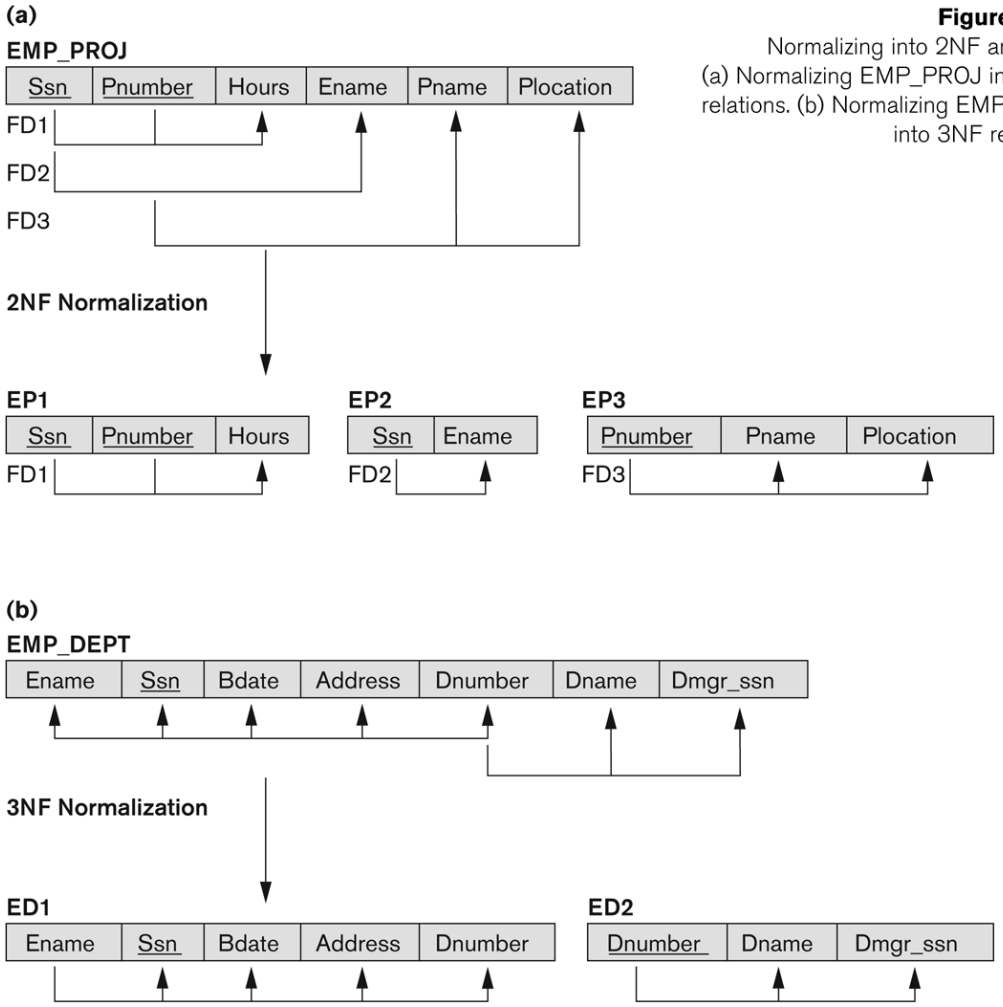


Figure 10.10
Normalizing into 2NF and 3NF. (a) Normalizing EMP_PROJ into 2NF relations. (b) Normalizing EMP_DEPT into 3NF relations.

Figure 10.11 Normalization into 2NF and 3NF

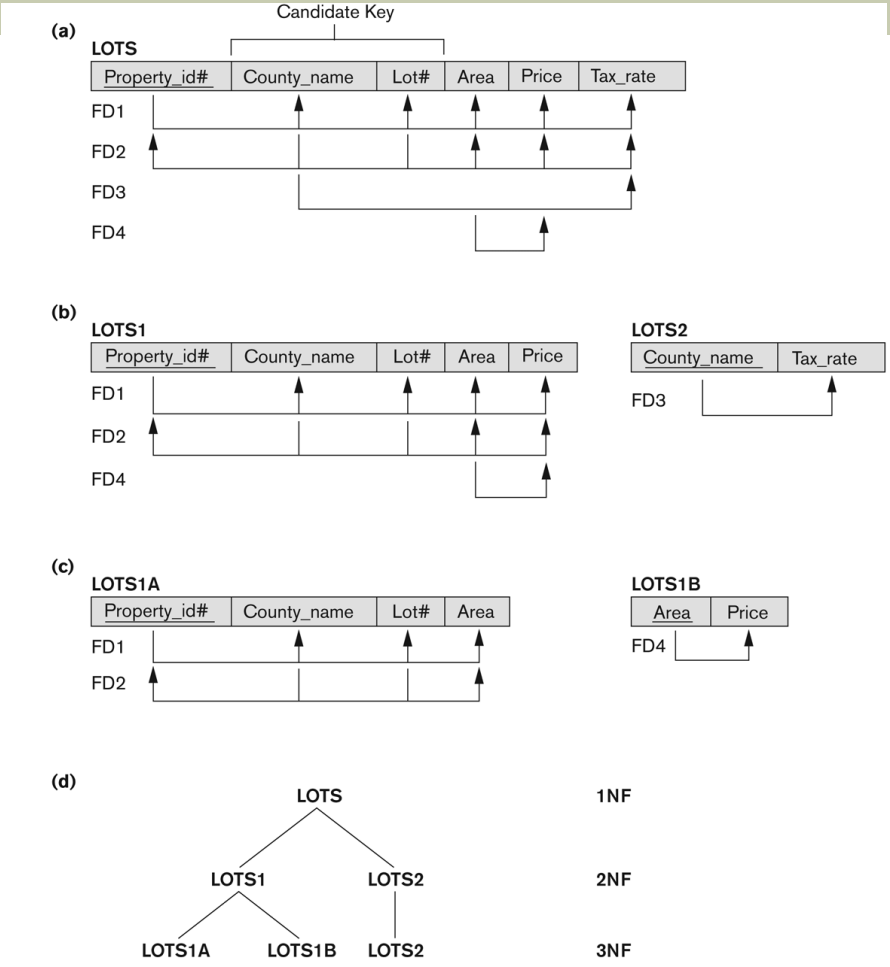


Figure 10.11
Normalization into 2NF and 3NF. (a) The LOTS relation with its functional dependencies FD1 through FD4. (b) Decomposing into the 2NF relations LOTS1 and LOTS2. (c) Decomposing LOTS1 into the 3NF relations LOTS1A and LOTS1B. (d) Summary of the progressive normalization of LOTS.

3.4 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
- 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

General Normal Form Definitions (2)

- 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
- NOTE: Boyce-Codd normal form disallows condition (b) above

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
- There exist relations that are in 3NF but not in BCNF
- The goal is to have each relation in BCNF (or 3NF)

Figure 10.12 Boyce-Codd normal form

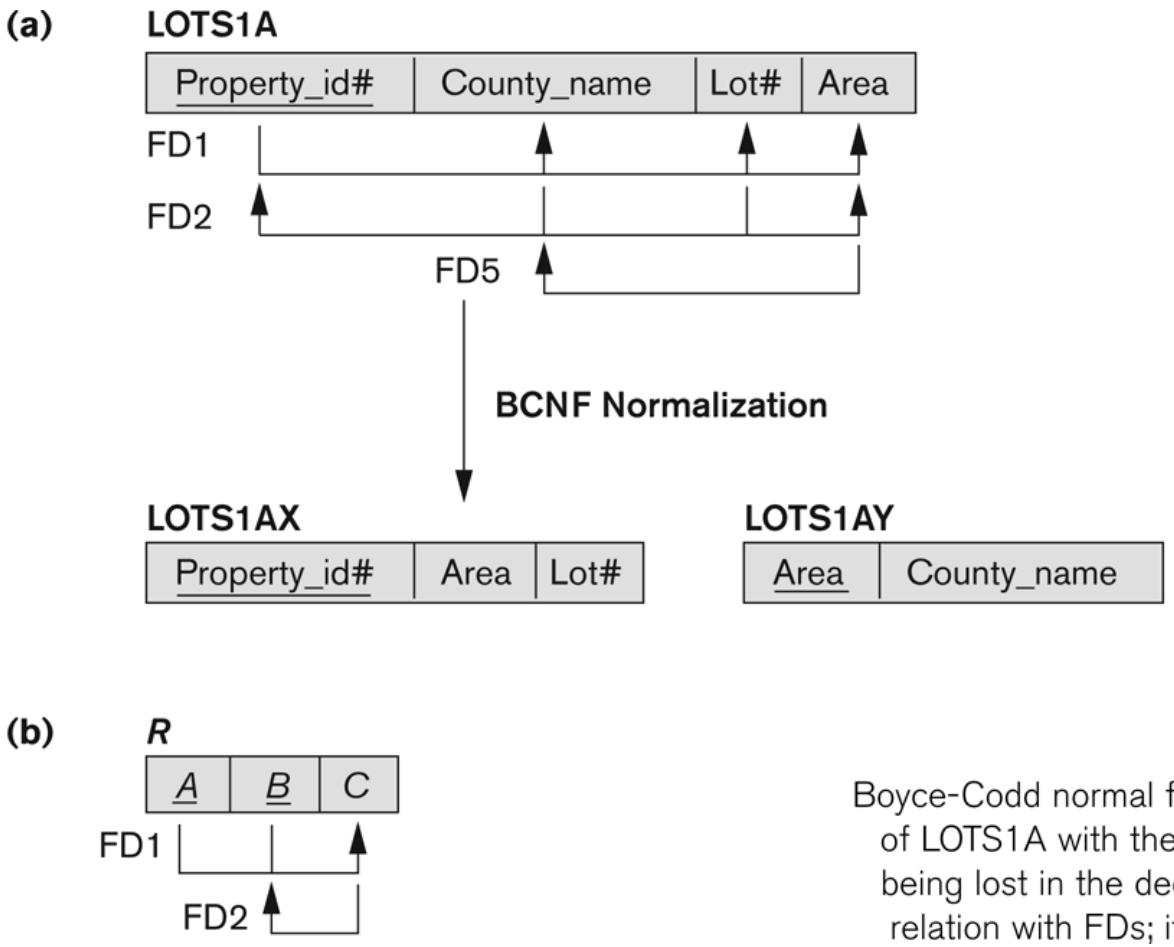


Figure 10.12
Boyce-Codd normal form. (a) BCNF normalization of LOTS1A with the functional dependency FD2 being lost in the decomposition. (b) A schematic relation with FDs; it is in 3NF, but not in BCNF.

Figure 10.13 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 10.13
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 10.12 (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 11.3)

Achieving the BCNF by Decomposition (2)

- Three possible decompositions for relation TEACH
  - {student, instructor} and {student, course}
  - {course, instructor } and {course, student}
  - {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 in section 11.1.4 under Property LJ1. Verify that the third decomposition above meets the property.

Chapter Outline

- Informal Design Guidelines for Relational Databases
- Functional Dependencies (FDs)
  - Definition, Inference Rules, Equivalence of Sets of FDs, Minimal Sets of FDs
- Normal Forms Based on Primary Keys
- General Normal Form Definitions (For Multiple Keys)
- BCNF (Boyce-Codd Normal Form)