Database Systems

Lecture #12

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Objectives

- To learn design guidelines for relation schemas and functional dependency
  - Discuss *goodness* of database schemas
  - Designing good database schemas
  - Concepts of functional dependency

Outline

- *Informal* Design Guidelines for Relation Schemas
  - Semantics of Attributes in Relations
  - Redundant Information and Update Anomalies
  - NULL Values in Tuples
  - Spurious Tuples
- Functional Dependencies

Informal Design Guidelines for Relation Schemas

- Designing a relational database
  - Process to define a set of *good table schemas* for a given application
  - Decide the attributes to be included in each table

Informal Design Guidelines for Relation Schemas

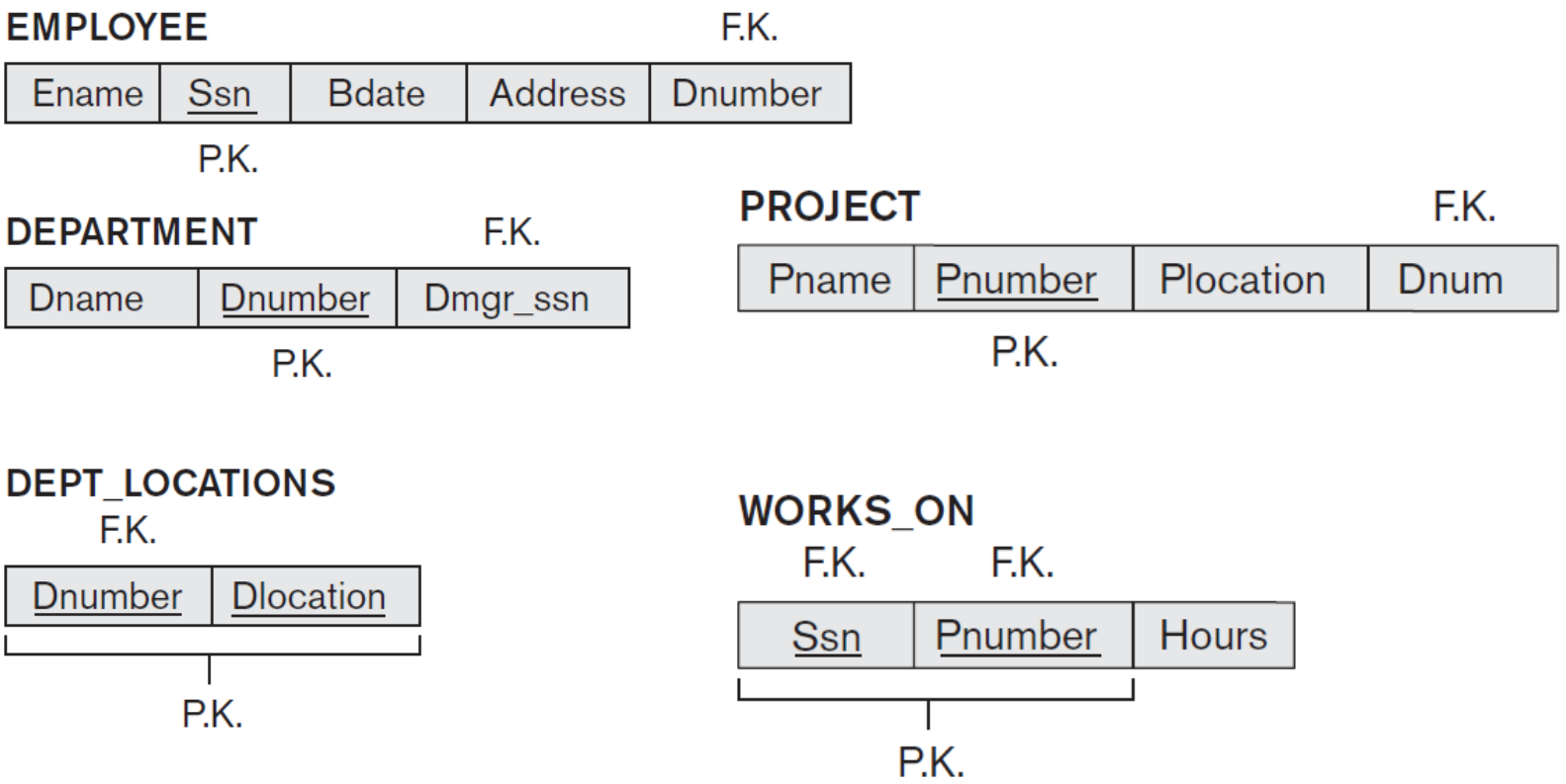
- Rough criteria for a *good table schema*
  - Semantics of attributes
  - Redundant information in tuples
  - NULL values in tuples
  - Spurious tuples
- Formal criteria
  - *Normalization*

Semantics of Attributes in Relations

- Determining a table schema
  - All the attributes belonging to one relation should have meanings mutually-related in the real-world
  - Ex: STUDENT (name, age, gender, address)

Semantics of Attributes in Relations

- Example of a good design



Guideline 1

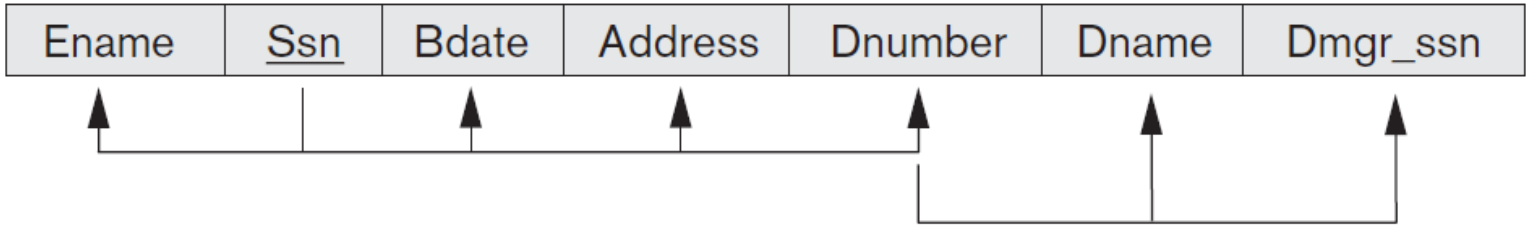
- Each tuple should *correspond to only one* entity instance or relationship instance
- Do not combine attributes from multiple entity types and relationship types into a single relation

Guideline 1

- Example of violating Guideline 1

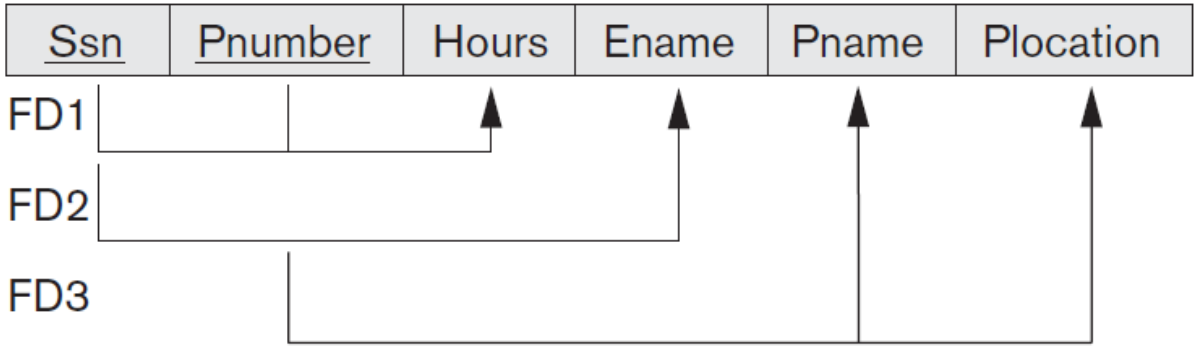
(a)

EMP_DEPT



(b)

EMP_PROJ



Redundant Information

- Minimizing storage space
  - One of main goals of table schema design
  - By eliminating redundant information

Redundant Information

- Example of a database instance

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

DEPT_LOCATIONS

Dnumber	Dlocation
1	Houston
4	Stafford
5	Bellaire
5	Sugarland
5	Houston

Redundant Information

- Example of a database instance

WORKS_ON

Ssn	Pnumber	Hours
123456789	1	32.5
123456789	2	7.5
666884444	3	40.0
453453453	1	20.0
453453453	2	20.0
333445555	2	10.0
333445555	3	10.0
333445555	10	10.0
333445555	20	10.0
999887777	30	30.0
999887777	10	10.0
987987987	10	35.0
987987987	30	5.0
987654321	30	20.0
987654321	20	15.0
888665555	20	Null

PROJECT

Pname	Pnumber	Plocation	Dnum
ProductX	1	Bellaire	5
ProductY	2	Sugarland	5
ProductZ	3	Houston	5
Computerization	10	Stafford	4
Reorganization	20	Houston	1
Newbenefits	30	Stafford	4

Redundant Information

- Example of tables with redundancy (1:N)

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

Redundant Information

- Example of tables with redundancy (N:M)

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

Update Anomalies

- Updating tuples won't work as expected
  - Insertion
  - Deletion
  - Modification

Update Anomalies

- Insertion anomalies
  - Difficult to insert a new department that *has no employees yet* in the EMP_DEPT table
  - This problem will not occur if we build *separate tables* DEPARTMENT and EMPLOYEE

Update Anomalies

- Deletion anomalies
  - When deleting the last employee working for a particular department from the EMP_DEPT table
    - Information concerning that department is lost from the database
  - This problem will not occur if we build *separate tables* DEPARTMENT and EMPLOYEE

Update Anomalies

- Modification anomalies
  - If we change the manager of a particular department in the EMP_DEPT table
    - Must update those tuples of all employees who work in that department
  - This problem will not occur if we build *separate tables* DEPARTMENT and EMPLOYEE

Guideline 2

- Design base relation schemas so that no update anomalies are present in the relations
- If any anomalies are present:
  - Note them clearly
  - Make sure that the programs updating the database will operate correctly

NULL Values in Tuples

- Meanings of NULLs
  - Unknown value
  - Unavailable or withheld value
  - Not applicable attribute

NULL Values in Tuples

- Problems with NULL values
  - Wasted storage space
  - Ambiguous meaning
  - Difficult to use aggregate functions
    - Each individual NULL value considered to be different

Guideline 3

- Avoid placing attributes in a base relation of their values may frequently be NULL
- If NULLs are unavoidable:
  - Make sure that they apply in exceptional cases only, not to a majority of tuples
  - Create a *new relation for only those tuples* with NULL values

Guideline 3

- Example
  - If only 10 percent of employees have their own individual offices
  - Method 1:
    - Include Office_number attribute to EMPLOYEE relation
    - 90% of tuples will have NULLs

Guideline 3

- Example
  - If only 10 percent of employees have their own individual offices
  - Method 2:
    - Create EMP_OFFICES (Essn, Office_number) relation
    - EMP_OFFICES will have tuples for only the employees with office

Spurious Tuples

- NATURAL JOIN can produce tuples with invalid information
  - Called spurious tuples
  - Caused by inappropriately designed relations

Spurious Tuples

- Example

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

Spurious Tuples

- Example
  - Join EMP_LOCS and EMP_PROJ1 with Plocation

	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.

*
*
*

Guideline 4

- Avoid relations that contain join attributes that are *not (foreign key, primary key) combinations*

Functional Dependencies

- Concepts
  - Formal tool for analysis of relational schemas
  - Used to define *normal forms* along with keys

Functional Dependencies

- Format
  - Denoted by $X \rightarrow Y$
    - X, Y: set of attributes that are subset of R
  - Values of X *functionally determine* the values of Y
  - Or Y is *functionally dependent on* X

Functional Dependencies

Meanings

- For any two tuples t_1 and t_2 in a particular relation that have $t_1[X] = t_2[X]$, then $t_1[Y] = t_2[Y]$
  - Thus the tuples with same values for X also have same values for Y
  - A value of attribute set X uniquely determines the value of attribute set Y
- Derived from the constraints required in the real-world application
  - Major -> Department
  - Department -> School

Functional Dependencies

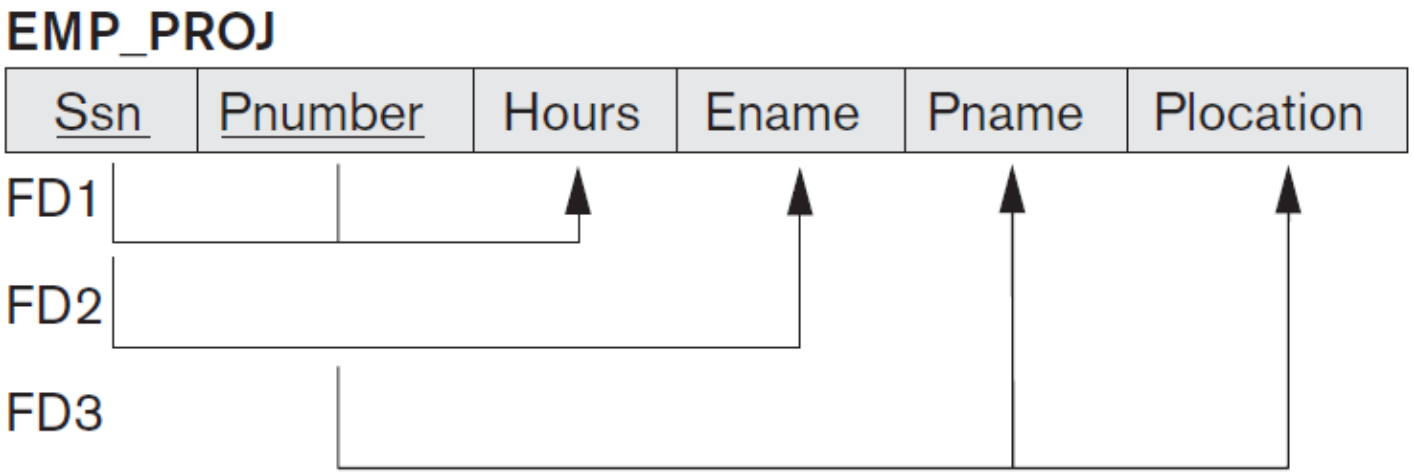
- Note that…
  - If X is a *candidate key* of R
    - Then $X \rightarrow Y$
    - For any subset of attributes Y of R
  - If $X \rightarrow Y$ in R
    - This does not say whether or not $Y \rightarrow X$ in R

Functional Dependencies

- FD is a *property of table schema R*
  - Not of a particular table instance *r*
    - The constraint must hold for all instance *r*(*R*)
  - Cannot be inferred automatically from a given *r*
    - Must defined explicitly before the database is built

Functional Dependencies

- Example
  - For EMP_PROJ table
    a. Ssn → Ename
    b. Pnumber →{Pname, Plocation}
    c. {Ssn, Pnumber} → Hours



Inference Rules for FDs

- *F*:
  - Set of functional dependencies that are specified on table schema *R*
- F^+:
  - Set of all dependencies that can be inferred from *F*
  - Also include *F*
  - Called the *closure* of *F*

Inference Rules for FDs

- Example
  - *F* = {Ssn → {Ename, Bdate, Address, Dnumber},
    Dnumber → {Dname, Dmgr_ssn} }
  - Additional FDs that can be inferred from *F*:
    - Ssn → {Dname, Dmgr_ssn}
    - Ssn → Ssn
    - Dnumber → Dname

Inference Rules for FDs

- Armstrong's inference rules
  - IR1 (reflexive rule): If $X \supseteq Y$, then $X \rightarrow Y$
  - IR2 (augmentation rule): $\{X \rightarrow Y\} \models XZ \rightarrow YZ$
  - IR3 (transitive rule): $\{X \rightarrow Y, Y \rightarrow Z\} \models X \rightarrow Z$
  - *Sound* and *complete (Proof?)*

Inference Rules for FDs

- Other inference rules
  - IR4 (decomposition rule): $\{X \rightarrow YZ\} \models X \rightarrow Y$
  - IR5 (union rule): $\{X \rightarrow Y,\ X \rightarrow Z\} \models X \rightarrow YZ$
  - IR6 (pseudo-transitive rule): $\{X \rightarrow Y,\ WY \rightarrow Z\} \models WX \rightarrow Z$
  - Can prove IR4~6 by using IR1~3

Systematic Way to Determine Additional FDs

- X:
  - Set of attributes that appear as a left-hand side of some FD in F
- X^+:
  - Set of all the attributes that are *functionally determined* by X based on F
  - Called *closure of X under F*
  - Determined for each X
  - Can be calculated by applying inference rules repeatedly

Systematic Way to Determine Additional FDs

- Algorithm for determining X^+

$X^+ := X;$
repeat
    old$X^+ := X^+;$
    for each functional dependency $Y \rightarrow Z$ in F do
        if $X^+ \supseteq Y$ then $X^+ := X^+ \cup Z;$
until $(X^+ = \text{old}X^+);$

Systematic Way to Determine Additional FDs

- Example

$$F = \{\text{Ssn} \rightarrow \text{Ename},$$
$$\text{Pnumber} \rightarrow \{\text{Pname}, \text{Plocation}\},$$
$$\{\text{Ssn}, \text{Pnumber}\} \rightarrow \text{Hours}\}$$

Systematic Way to Determine Additional FDs

- Example

$\{Ssn\}^{+} = \{Ssn, Ename\}$

$\{Pnumber\}^{+} = \{Pnumber, Pname, Plocation\}$

$\{Ssn, Pnumber\}^{+} = \{Ssn, Pnumber, Ename, Pname, Plocation, Hours\}$

Summary

- Informal guidelines for good design
- Functional dependency
  - Basic tool for analyzing relational schemas
  - Inference rules

References

1. Codd, Edgar F. "A relational model of data for large shared data banks." *Communications of the ACM* 13.6 (1970): 377-387.
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Have a nice day!