UNIT 3
The Relational Data Model and Relational Database Constraints

The Relational Data Model and Relational Database Constraints and Relational Algebra

UNIT 3

The Relational Data Model and Relational Database Constraints and Relational Algebra Origins

3.1 Relational Model Concepts

- **Domain**: A (usually named) set/universe of atomic values, where by "atomic" we mean simply that, from the point of view of the database, each value in the domain is indivisible (i.e., cannot be broken down into component parts).

  Examples of domains (some taken from page 147):

  - USA_phone_number: string of digits of length ten
  - SSN: string of digits of length nine
  - Name: string of characters beginning with an upper case letter
  - GPA: a real number between 0.0 and 4.0
  - Sex: a member of the set { female, male }
  - Dept_Code: a member of the set { CMPS, MATH, ENGL, PHYS, PSYC, ... }

  These are all logical descriptions of domains. For implementation purposes, it is necessary to provide descriptions of domains in terms of concrete **data types** (or **formats**) that are provided by the DBMS (such as String, int, boolean), in a manner analogous to how programming languages have intrinsic data types.

- **Attribute**: the name of the role played by some value (coming from some domain) in the context of a **relational schema**. The domain of attribute A is denoted dom(A).
- **Tuple**: A tuple is a mapping from attributes to values drawn from the respective domains of those attributes. A tuple is intended to describe some entity (or relationship between entities) in the miniworld.

  As an example, a tuple for a PERSON entity might be

  { Name --> "Rumpelstiltskin", Sex --> Male, IQ --> 143 }

- **Relation**: A (named) set of tuples all of the same form (i.e., having the same set of attributes). The term **table** is a loose synonym. (Some database purists would argue that a table is "only" a physical manifestation of a relation.)
- **Relational Schema**: used for describing (the structure of) a relation. E.g., $R(A_1, A_2, ..., A_n)$ says that R is a relation with attributes $A_1, ... A_n$. The **degree** of a relation is the number of attributes it has, here n.

  Example: STUDENT(Name, SSN, Address)

  (See Figure 5.1, page 149, for an example of a STUDENT relation/table having several tuples/rows.)

One would think that a "complete" relational schema would also specify the domain of each attribute.

- **Relational Database**: A collection of **relations**, each one consistent with its specified relational schema.

3.1.2 Characteristics of Relations

Ordering of Tuples: A relation is a set of tuples; hence, there is no order associated with them. That is, it makes no sense to refer to, for example, the 5th tuple in a relation. When a relation is depicted as a table, the tuples are necessarily listed in some order, of course, but you should attach no significance to that order. Similarly, when tuples are represented on a storage device, they must be organized in some fashion, and it may be advantageous, from a performance standpoint, to organize them in a way that depends upon their content.

Ordering of Attributes: A tuple is best viewed as a mapping from its attributes (i.e., the names we give to the roles played by the values comprising the tuple) to the corresponding values. Hence, the order in which the attributes are listed in a table is irrelevant. (Note that, unfortunately, the set theoretic operations in relational algebra (at least how E&N define them) make implicit use of the order of the attributes. Hence, E&N view attributes as being arranged as a sequence rather than a set.)

Values of Attributes: For a relation to be in First Normal Form, each of its attribute domains must consist of atomic (neither composite nor multi-valued) values. Much of the theory underlying the relational model was based upon this assumption. Chapter 10 addresses the issue of including non-atomic values in domains. (Note that in the latest edition of C.J. Date's book, he explicitly argues against this idea, admitting that he has been mistaken in the past.)

The **Null** value: used for don't know, not applicable.

Interpretation of a Relation: Each relation can be viewed as a **predicate** and each tuple in that relation can be viewed as an assertion for which that predicate is satisfied (i.e., has value **true**) for the combination of values in it. In other words, each tuple represents a fact. Example (see Figure 5.1): The first tuple listed means: There exists a student having name Benjamin Bayer, having SSN 305-61-2435, having age 19, etc.

Keep in mind that some relations represent facts about entities (e.g., students) whereas others represent facts about relationships (between entities). (e.g., students and course sections).

The **closed world assumption** states that the only true facts about the miniworld are those represented by whatever tuples currently populate the database.

3.1.3 Relational Model Notation:

- $R(A_1, A_2, ..., A_n)$ is a relational schema of degree n denoting that there is a relation R having as its attributes $A_1, A_2, ..., A_n$.

- By convention, Q, R, and S denote relation names.
- By convention, q, r, and s denote relation states. For example, r(R) denotes one possible state of relation R. If R is understood from context, this could be written, more simply, as r.
- By convention, t, u, and v denote tuples.
- The "dot notation" R.A (e.g., STUDENT.Name) is used to qualify an attribute name, usually for the purpose of distinguishing it from a same-named attribute in a different relation (e.g., DEPARTMENT.Name).
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3.2 Relational Model Constraints and Relational Database Schemas

Constraints on databases can be categorized as follows:

- **inherent model-based:** Example: no two tuples in a relation can be duplicates (because a relation is a set of tuples)
- **schema-based:** can be expressed using DDL; this kind is the focus of this section.
- **application-based:** are specific to the "business rules" of the miniworld and typically difficult or impossible to express and enforce within the data model. Hence, it is left to application programs to enforce.

Elaborating upon **schema-based constraints**:

3.2.1 Domain Constraints: Each attribute value must be either **null** (which is really a non-value) or drawn from the domain of that attribute. Note that some DBMS's allow you to impose the **not null** constraint upon an attribute, which is to say that that attribute may not have the (non-)value **null**.

3.2.2 Key Constraints: A relation is a set of tuples, and each tuple's "identity" is given by the values of its attributes. Hence, it makes no sense for two tuples in a relation to be identical (because then the two tuples are actually one and the same tuple). That is, no two tuples may have the same combination of values in their attributes.

Usually the miniworld dictates that there be (proper) subsets of attributes for which no two tuples may have the same combination of values. Such a set of attributes is called a **superkey** of its relation. From the fact that no two tuples can be identical, it follows that the set of all attributes of a relation constitutes a superkey of that relation.

A **key** is a minimal superkey, i.e., a superkey such that, if we were to remove any of its attributes, the resulting set of attributes fails to be a superkey.

Example: Suppose that we stipulate that a faculty member is uniquely identified by Name and Address and also by Name and Department, but by no single one of the three attributes mentioned. Then { Name, Address, Department } is a (non-minimal) superkey and each of { Name, Address } and { Name, Department } is a key (i.e., minimal superkey).

Candidate key: any key! (Hence, it is not clear what distinguishes a key from a candidate key.)

Primary key: a key chosen to act as the means by which to identify tuples in a relation. Typically, one prefers a primary key to be one having as few attributes as possible.

3.2.3 Relational Databases and Relational Database Schemas

A **relational database schema** is a set of schemas for its relations (see Figure 5.5, page 157) together with a set of **integrity constraints**.

A **relational database state/instance/snapshot** is a set of states of its relations such that no integrity constraint is violated. (See Figure 5.6, page 159, for a snapshot of COMPANY.)

3.2.4 Entity Integrity, Referential Integrity, and Foreign Keys

Entity Integrity Constraint: In a tuple, none of the values of the attributes forming the relation's primary key may have the (non-)value **null**. Or is it that at least one such attribute must have a non-null value? In my opinion, E&N do not make it clear!

Referential Integrity Constraint: (See Figure 5.7) A **foreign key** of relation R is a set of its attributes intended to be used (by each tuple in R) for identifying/referring to a tuple in some relation S. (R is called the referencing relation and S the referenced relation.) For this to make sense, the set of attributes of R forming the foreign key should "correspond to" some superkey of S. Indeed, by definition we require this superkey to be the primary key of S.

This constraint says that, for every tuple in R, the tuple in S to which it refers must actually be in S. Note that a foreign key may refer to a tuple in the same relation and that a foreign key may be part of a primary key (indeed, for weak entity types, this will always occur). A foreign key may have value **null** (necessarily in all its attributes??), in which case it does not refer to any tuple in the referenced relation.

Semantic Integrity Constraints: application-specific restrictions that are unlikely to be expressible in DDL. Examples:

- salary of a supervisee cannot be greater than that of her/his supervisor
- salary of an employee cannot be lowered

3.3 Update Operations and Dealing with Constraint Violations

For each of the update operations (Insert, Delete, and Update), we consider what kinds of constraint violations may result from applying it and how we might choose to react.

3.3.1 Insert:

- domain constraint violation: some attribute value is not of correct domain
- entity integrity violation: key of new tuple is **null**

- key constraint violation: key of new tuple is same as existing one
- referential integrity violation: foreign key of new tuple refers to non-existent tuple

Ways of dealing with it: reject the attempt to insert! Or give user opportunity to try again with different attribute values.

3.3.2 Delete:

- Referential integrity violation: a tuple referring to the deleted one exists.

Three options for dealing with it:

- Reject the deletion
- Attempt to **cascade** (or **propagate**) by deleting any referencing tuples (plus those that reference them, etc., etc.)
- modify the foreign key attribute values in referencing tuples to **null** or to some valid value referencing a different tuple

3.3.3 Update:

- Key constraint violation: primary key is changed so as to become same as another tuple's
- referential integrity violation:
    - foreign key is changed and new one refers to nonexistent tuple
    - primary key is changed and now other tuples that had referred to this one violate the constraint

3.3.4 Transactions: This concept is relevant in the context where multiple users and/or application programs are accessing and updating the database concurrently. A transaction is a logical unit of work that may involve several accesses and/or updates to the database (such as what might be required to reserve several seats on an airplane flight). The point is that, even though several transactions might be processed concurrently, the end result must be as though the transactions were carried out sequentially. (Example of simultaneous withdrawals from same checking account.)

he Relational Algebra

- Operations to manipulate relations.
- Used to specify retrieval requests (queries).
- Query result is in the form of a relation

3.4 Relational Operations:

SELECT σ and PROJECT π operations.

Set operations: These include UNION U, INTERSECTION | |, DIFFERENCE -, CARTESIAN PRODUCT X.

JOIN operations $\bowtie$.

Other relational operations: DIVISION, OUTER JOIN, AGGREGATE FUNCTIONS.

3.4.1 SELECT σ and PROJECT π

SELECT operation (denoted by σ):

- Selects the tuples (rows) from a relation R that satisfy a certain selection condition c
- Form of the operation: σ_c
- The condition c is an arbitrary Boolean expression on the attributes of R
- Resulting relation has the same attributes as R
- Resulting relation includes each tuple in r(R) whose attribute values satisfy the condition

Examples:

$\sigma_{DNO=4}(EMPLOYEE)$

$\sigma_{SALARY>30000}(EMPLOYEE)$

$\sigma_{(DNO=4 \text{ AND } SALARY>25000) \text{ OR } DNO=5}(EMPLOYEE)$

PROJECT operation (denoted by π):

- Keeps only certain attributes (columns) from a relation R specified in an attribute list L
- Form of operation: $\pi_L(R)$
- Resulting relation has only those attributes of R specified in L
- The PROJECT operation eliminates duplicate tuples in the resulting relation so that it remains a mathematical set (no duplicate elements).

Example: $\pi_{SEX,SALARY}(EMPLOYEE)$

If several male employees have salary 30000, only a single tuple <M, 30000> is kept in the resulting relation.

Figure 7.8 Results of SELECT and PROJECT operations.
(a) $\sigma_{(DNO=4 \text{ AND } SALARY>25000) \text{ OR } (DNO=5 \text{ AND } SALARY>30000)}$(EMPLOYEE).
(b) $\pi_{LNAME,\ FNAME,\ SALARY}$(EMPLOYEE). (c) $\pi_{SEX,\ SALARY}$(EMPLOYEE)

(a)

FNAME	MINIT	LNAME	SSN	BDATE	ADDRESS	SEX	SALARY	SUPERSSN	DNO
Franklin	T	Wong	333445555	1955-12-08	638 Voss,Houston,TX	M	40000	888665555	5
Jennifer		Wallace	987654321	1941-06-20	291 Berry,Bellaire,TX	F	43000	888665555	4
Ramesh		Narayan	666884444	1962-09-15	975 FireOak,Humble,TX	M	38000	333445555	5

(b)

LNAME	FNAME	SALARY
Smith	John	30000
Wong	Franklin	40000
Zelaya	Alicia	25000
Wallace	Jennifer	43000
Narayan	Ramesh	38000
English	Joyce	25000
Jabbar	Ahmad	25000
Borg	James	55000

(c)

SEX	SALARY
M	30000
M	40000
F	25000
F	43000
M	38000
M	25000
M	55000

Duplicate tuples are eliminated by the π operation.

Sequences of operations:

Several operations can be combined to form a relational algebra expression (query)

Example: Retrieve the names and salaries of employees who work in department 4:

$\pi_{FNAME,LNAME,SALARY}$ ($\sigma_{DNO=4(EMPLOYEE)}$)

Alternatively, we specify explicit intermediate relations for each step:

DEPT4_EMPS $\leftarrow \sigma_{DNO=4}$(EMPLOYEE)

$\rho \leftarrow \pi_{FNAME,LNAME,SALARY}$(DEPT4_EMPS)

Attributes can optionally be renamed in the resulting left-hand-side relation (this may be required for some operations that will be presented later):

DEPT4_EMPS $\leftarrow \sigma_{DNO=4}$(EMPLOYEE)

$\rho_{(FIRSTNAME,LASTNAME,SALARY)} \leftarrow \pi_{FNAME,LNAME,SALARY}$(DEPT4_EMPS)

Figure 7.9 Results of relational algebra expressions.
(a) $\pi_{\text{LNAME, FNAME, SALARY}}(\sigma_{\text{DNO=5}}(\text{EMPLOYEE}))$. (b) The same expression using intermediate relations and renaming of attributes.

(a)

FNAME	LNAME	SALARY
John	Smith	30000
Franklin	Wong	40000
Ramesh	Narayan	38000
Joyce	English	25000

(b)

TEMP	FNAME	MINIT	LNAME	SSN	BDATE	ADDRESS	SEX	SALARY	SUPERSSN	DNO
	John	B	Smith	123456789	1965-01-09	731 Fondren,Houston,TX	M	30000	333445555	5
	Franklin	T	Wong	333445555	1955-12-08	638 Voss,Houston,TX	M	40000	888665555	5
	Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak,Humble,TX	M	38000	333445555	5
	Joyce	A	English	453453453	1972-07-31	5631 Rice,Houston,TX	F	25000	333445555	5

	FIRSTNAME	LASTNAME	SALARY
	John	Smith	30000
	Franklin	Wong	40000
	Ramesh	Narayan	38000
	Joyce	English	25000

3.5 Relational algebra operation Set theory Operations

Binary operations from mathematical set theory:

UNION: $R_1 \cup R_2$,

INTERSECTION: $R_1 \cap R_2$,

SET DIFFERENCE: $R_1 - R_2$,

CARTESIAN PRODUCT: $R_1 \times R_2$.

For ∪, ∩, -, the operand relations R1(A1, A2, ..., An) and R2(B1, B2, ..., Bn) must have the same number of attributes, and the domains of corresponding attributes must be compatible; that is, dom(Ai) = dom(Bi) for i=1, 2, ..., n. This condition is called union compatibility. The resulting relation for ∪, ∩, or - has the same attribute names as the first operand relation R1 (by convention).

Figure 7.11 Illustrating the set operations union, intersection, and difference. (a) Two union compatible relations. (b) STUDENT ∪ INSTRUCTOR. (c) STUDENT ∪ INSTRUCTOR. (d) STUDENT − INSTRUCTOR. (e) INSTRUCTOR − STUDENT.

(a)

STUDENT	FN	LN
	Susan	Yao
	Ramesh	Shah
	Johnny	Kohler
	Barbara	Jones
	Amy	Ford
	Jimmy	Wang
	Ernest	Gilbert

INSTRUCTOR	FNAME	LNAME
	John	Smith
	Ricardo	Browne
	Susan	Yao
	Francis	Johnson
	Ramesh	Shah

(b)

FN	LN
Susan	Yao
Ramesh	Shah
Johnny	Kohler
Barbara	Jones
Amy	Ford
Jimmy	Wang
Ernest	Gilbert
John	Smith
Ricardo	Browne
Francis	Johnson

(c)

FN	LN
Susan	Yao
Ramesh	Shah

(d)

FN	LN
Johnny	Kohler
Barbara	Jones
Amy	Ford
Jimmy	Wang
Ernest	Gilbert

(e)

FNAME	LNAME
John	Smith
Ricardo	Browne
Francis	Johnson

CARTESIAN PRODUCT

$R(A_1, A_2, ..., A_m, B_1, B_2, ..., B_n) \leftarrow R_1(A_1, A_2, ..., A_m) \text{ X } R_2 (B_1, B_2, ..., B_n)$

A tuple t exists in R for each combination of tuples t_1 from R_1 and t_2 from R_2 such that:

$t[A_1, A_2, ..., A_m] = t_1$ and $t[B_1, B_2, ..., B_n] = t_2$

If R_1 has n_1 tuples and R_2 has n_2 tuples, then R will have $n_1 * n_2$ tuples.

CARTESIAN PRODUCT is a meaningless operation on its own. It can combine related tuples from two relations if followed by the appropriate SELECT operation.

Example: Combine each DEPARTMENT tuple with the EMPLOYEE tuple of the manager.

DEP_EMP ← DEPARTMENT X EMPLOYEE

DEPT_MANAGER ← $\sigma_{MGRSSN=SSN}$(DEP_EMP)

Figure 7.12 An illustration of the CARTESIAN PRODUCT operation.

FEMALE_EMPS	FNAME	MINIT	LNAME	SSN	BDATE	ADDRESS	SEX	SALARY	SUPERSSN	DNO
	Alicia	J	Zelaya	999887777	1968-07-19	3321 Castle,Spring,TX	F	25000	987654321	4
	Jennifer	S	Wallace	987654321	1941-06-20	291 Berry,Bellaire,TX	F	43000	888665555	4
	Joyce	A	English	453453453	1972-07-31	5631 Rice,Houston,TX	F	25000	333445555	5

EMPNAMES	FNAME	LNAME	SSN
	Alicia	Zelaya	999887777
	Jennifer	Wallace	987654321
	Joyce	English	453453453

EMP_DEPENDENTS	FNAME	LNAME	SSN	ESSN	DEPENDENT_NAME	SEX	BDATE	...
	Alicia	Zelaya	999887777	333445555	Alice	F	1986-04-05	...
	Alicia	Zelaya	999887777	333445555	Theodore	M	1983-10-25	...
	Alicia	Zelaya	999887777	333445555	Joy	F	1958-05-03	...
	Alicia	Zelaya	999887777	987654321	Abner	M	1942-02-28	...
	Alicia	Zelaya	999887777	123456789	Michael	M	1988-01-04	...
	Alicia	Zelaya	999887777	123456789	Alice	F	1988-12-30	...
	Alicia	Zelaya	999887777	123456789	Elizabeth	F	1967-05-05	...
	Jennifer	Wallace	987654321	333445555	Alice	F	1986-04-05	...
	Jennifer	Wallace	987654321	333445555	Theodore	M	1983-10-25	...
	Jennifer	Wallace	987654321	333445555	Joy	F	1958-05-03	...
	Jennifer	Wallace	987654321	987654321	Abner	M	1942-02-28	...
	Jennifer	Wallace	987654321	123456789	Michael	M	1988-01-04	...
	Jennifer	Wallace	987654321	123456789	Alice	F	1988-12-30	...
	Jennifer	Wallace	987654321	123456789	Elizabeth	F	1967-05-05	...
	Joyce	English	453453453	333445555	Alice	F	1986-04-05	...
	Joyce	English	453453453	333445555	Theodore	M	1983-10-25	...
	Joyce	English	453453453	333445555	Joy	F	1958-05-03	...
	Joyce	English	453453453	987654321	Abner	M	1942-02-28	...
	Joyce	English	453453453	123456789	Michael	M	1988-01-04	...
	Joyce	English	453453453	123456789	Alice	F	1988-12-30	...
	Joyce	English	453453453	123456789	Elizabeth	F	1967-05-05	...

ACTUAL_DEPENDENTS	FNAME	LNAME	SSN	ESSN	DEPENDENT_NAME	SEX	BDATE
	Jennifer	Wallace	987654321	987654321	Abner	M	1942-02-28

RESULT	FNAME	LNAME	DEPENDENT_NAME
	Jennifer	Wallace	Abner

3.6 JOIN Operations

THETA JOIN: Similar to a CARTESIAN PRODUCT followed by a SELECT. The condition c is called a join condition.

$R(A_1, A_2, ..., A_m, B_1, B_2, ..., B_n) \leftarrow R_1(A_1, A_2, ..., A_m) \bowtie_c R_2 (B_1, B_2, ..., B_n)$

EQUIJOIN: The join condition c includes one or more equality comparisons involving attributes from R_1 and R_2. That is, c is of the form:

$(A_i=B_j)$ AND ... AND $(A_h=B_k)$; $1\leq i,h\leq m$, $1\leq j,k\leq n$

In the above EQUIJOIN operation:

$A_i, ..., A_h$ are called the **join attributes** of R_1

$B_j, ..., B_k$ are called the **join attributes** of R_2

Example of using EQUIJOIN:

Retrieve each DEPARTMENT's name and its manager's name:

$T \leftarrow DEPARTMENT \bowtie_{MGRSSN = SSN} EMPLOYEE$

RESULT $\leftarrow \pi_{DNAME,FNAME,LNAME}$ (T)

NATURAL JOIN (*):

In an EQUIJOIN R $\leftarrow R_1 \bowtie_c R_2$, the join attribute of R_2 appear redundantly in the result relation R. In a NATURAL JOIN, the redundant join attributes of R_2 are eliminated from R. The equality condition is implied and need not be specified.

R $\leftarrow R_1 *^{\text{(join attributes of R1),(join attributes of R2)}} R_2$

Example: Retrieve each EMPLOYEE's name and the name of the DEPARTMENT he/she works for:

T$\leftarrow$ EMPLOYEE $*_{(DNO),(DNUMBER)}$ DEPARTMENT

RESULT $\leftarrow \pi_{FNAME,LNAME,DNAME}$ (T)

If the join attributes have the same names in both relations, they need not be specified and we can write R $\leftarrow R_1 * R_2$.

Example: Retrieve each EMPLOYEE's name and the name of his/her SUPERVISOR:

SUPERVISOR(SUPERSSN,SFN,SLN)$\leftarrow \pi_{SSN,FNAME,LNAME}$(EMPLOYEE)
T$\leftarrow$EMPLOYEE * SUPERVISOR
RESULT $\leftarrow \pi_{FNAME,LNAME,SFN,SLN}$(T)

Figure 7.14 An illustration of the NATURAL JOIN operation. (a) PROJ_DEPT ← PROJECT * DEPT. (b) DEPT_LOCS ← DEPARTMENT * DEPT_LOCATIONS.

(a)

PROJ_DEPT	PNAME	PNUMBER	PLOCATION	DNUM	DNAME	MGRSSN	MGRSTARTDATE
	ProductX	1	Bellaire	5	Research	333445555	1988-05-22
	ProductY	2	Sugarland	5	Research	333445555	1988-05-22
	ProductZ	3	Houston	5	Research	333445555	1988-05-22
	Computerization	10	Stafford	4	Administration	987654321	1995-01-01
	Reorganization	20	Houston	1	Headquarters	888665555	1981-06-19
	Newbenefits	30	Stafford	4	Administration	987654321	1995-01-01

(b)

DEPT_LOCS	DNAME	DNUMBER	MGRSSN	MGRSTARTDATE	LOCATION
	Headquarters	1	888665555	1981-06-19	Houston
	Administration	4	987654321	1995-01-01	Stafford
	Research	5	333445555	1988-05-22	Bellaire
	Research	5	333445555	1988-05-22	Sugarland
	Research	5	333445555	1988-05-22	Houston

Note: In the original definition of NATURAL JOIN, the join attributes were required to have the same names in both relations.

There can be a more than one set of join attributes with a different meaning between the same two relations. For example:

JOIN ATTRIBUTES
RELATIONSHIP

EMPLOYEE.SSN=	EMPLOYEE manages
	DEPARTMENT.MGRSSN
the DEPARTMENT	
EMPLOYEE.DNO=	EMPLOYEE works for
DEPARTMENT.DNUMBER	the DEPARTMENT

Example: Retrieve each EMPLOYEE's name and the name of the DEPARTMENT he/she works for:

T ← EMPLOYEE $\bowtie_{DNO=DNUMBER}$ DEPARTMENT

RESULT ← $\pi_{FNAME,LNAME,DNAME}(T)$

A relation can have a set of join attributes to join it with itself :

JOIN ATTRIBUTES	RELATIONSHIP
EMPLOYEE(1).SUPERSSN= EMPLOYEE(2).SSN	EMPLOYEE(2) supervises EMPLOYEE(1)

One can think of this as joining two distinct copies of the relation, although only one relation actually exists In this case, renaming can be useful.

Example: Retrieve each EMPLOYEE's name and the name of his/her SUPERVISOR:

SUPERVISOR(SSSN,SFN,SLN) $\leftarrow \pi_{\text{SSN,FNAME,LNAME}}$(EMPLOYEE)

T $\leftarrow$ EMPLOYEE $\bowtie_{\text{SUPERSSN=SSSN}}$ SUPERVISOR

RESULT $\leftarrow \pi_{\text{FNAME,LNAME,SFN,SLN}}$(T)

Complete Set of Relational Algebra Operations:

All the operations discussed so far can be described as a sequence of only the operations SELECT, PROJECT, UNION, SET DIFFERENCE, and CARTESIAN PRODUCT.

Hence, the set {σ , π , , - , X } is called a complete set of relational algebra operations. Any query language equivalent to these operations is called **relationally complete**.

For database applications, additional operations are needed that were not part of the original relational algebra. These include:

1. Aggregate functions and grouping.
2. OUTER JOIN and OUTER UNION.

3.7 Additional Relational Operations

AGGREGATE FUNCTIONS ($\mathfrak{I}$)

Functions such as SUM, COUNT, AVERAGE, MIN, MAX are often applied to sets of values or sets of tuples in database applications

<grouping attributes> $\mathfrak{I}_{\text{<function list>}}$(R)

The grouping attributes are optional

Example 1: Retrieve the average salary of all employees (no grouping needed):

ρ(AVGSAL)$\leftarrow \mathfrak{F}_{\text{AVERAGE SALARY}}$ (EMPLOYEE)

Example 2: For each department, retrieve the department number, the number of employees, and the average salary (in the department):

$\rho_{\text{(DNO,NUMEMPS,AVGSAL)}} \leftarrow$ DNO $\mathfrak{F}_{\text{COUNT SSN, AVERAGE SALARY}}$ (EMPLOYEE)

DNO is called the grouping attribute in the above example

Figure 7.16 An illustration of the AGGREGATE FUNCTION operation. (a) R(DNO, NO_OF_EMPLOYEES, AVERAGE_SAL) $\leftarrow$ $_{\text{DNO}}\mathfrak{F}_{\text{COUNT SSN,AVERAGE SALARY}}$ (EMPLOYEE). (b) $_{\text{DNO}}\mathfrak{F}_{\text{COUNT SSN,AVERAGE SALARY}}$(EMPLOYEE). (c) $\mathfrak{F}_{\text{COUNT SSN,AVERAGE SALARY}}$(EMPLOYEE).

(a)

	DNO	NO_OF_EMPLOYEES	AVERAGE_SAL
	5	4	33250
	4	3	31000
	1	1	55000

OUTER JOIN

In a regular EQUIJOIN or NATURAL JOIN operation, tuples in R_1 or R_2 that do not have matching tuples in the other relation do not appear in the result

Some queries require all tuples in R_1 (or R_2 or both) to appear in the result

When no matching tuples are found, **null**s are placed for the missing attributes

LEFT OUTER JOIN: R_1 X R_2 lets every tuple in R_1 appear in the result

RIGHT OUTER JOIN: R_1 X R_2 lets every tuple in R_2 appear in the result

FULL OUTER JOIN: R_1 X R_2 lets every tuple in R_1 or R_2 appear in the result

Figure 7.18 The LEFT OUTER JOIN operation.

RESULT	FNAME	MINIT	LNAME	DNAME
	John	B	Smith	null
	Franklin	T	Wong	Research
	Alicia	J	Zelaya	null
	Jennifer	S	Wallace	Administration
	Ramesh	K	Narayan	null
	Joyce	A	English	null
	Ahmad	V	Jabbar	null
	James	E	Borg	Headquarters

3.8 Examples of Queries in Relational Algebra

- **Q1: Retrieve the name and address of all employees who work for the 'Research' department.**

  RESEARCH_DEPT ← σ DNAME='Research' (DEPARTMENT)

  RESEARCH_EMPS ← (RESEARCH_DEPT DNUMBER= DNOEMPLOYEEEMPLOYEE)

  RESULT ← π FNAME, LNAME, ADDRESS (RESEARCH_EMPS)

- **Q6: Retrieve the names of employees who have no dependents.**

  ALL_EMPS ← π SSN(EMPLOYEE)

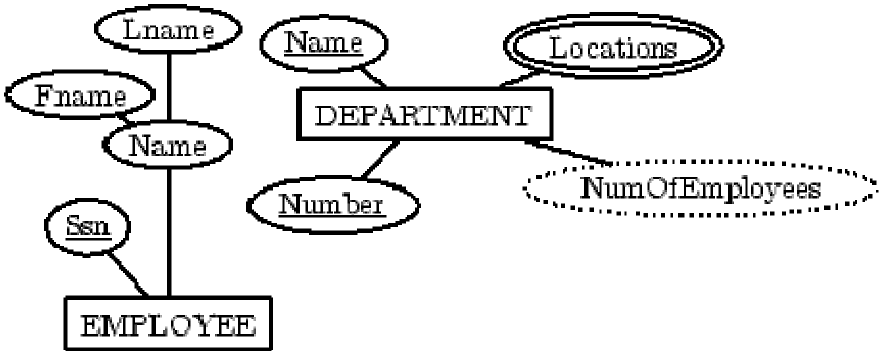
  EMPS_WITH_DEPS(SSN) ← π ESSN(DEPENDENT)

  EMPS_WITHOUT_DEPS ← (ALL_EMPS - EMPS_WITH_DEPS)

  RESULT ← π LNAME, FNAME (EMPS_WITHOUT_DEPS * EMPLOYEE)

3.9 Relational Database Design Using ER-to-Relational Mapping

Step 1: For each **regular (strong) entity type** E in the ER schema, create a relation R that includes all the simple attributes of E.



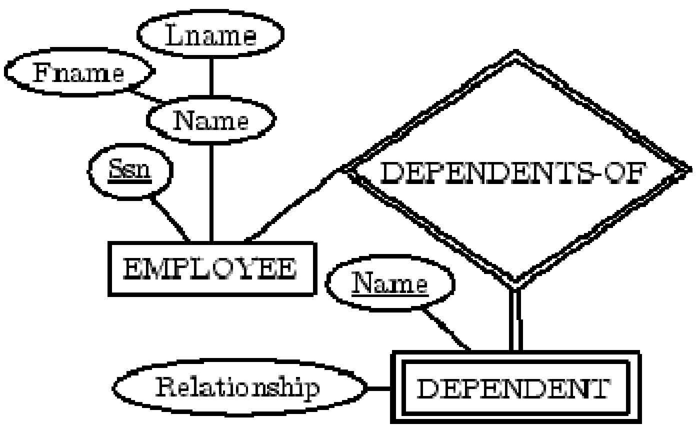
EMPLOYEE

SSN	Lname	Fname

DEPARTMENT

NUMBER	NAME

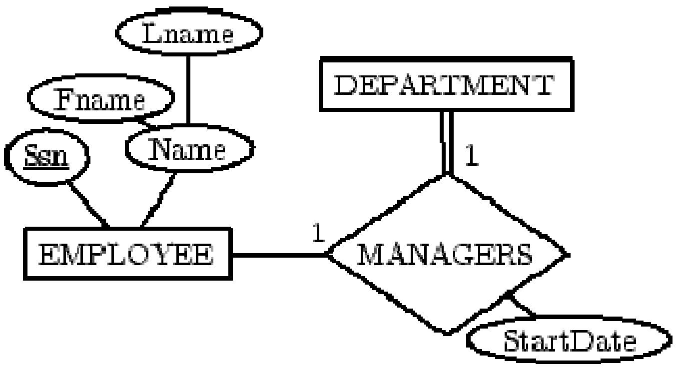
Step 2: For each **weak entity type** W in the ER schema with owner entity type E, create a relation R, and include all simple attributes (or simple components of composite attributes) of W as attributes. In addition, include as foreign key attributes of R the primary key attribute(s) of the relation(s) that correspond to the owner entity type(s).



DEPENDENT

EMPL-SSN	NAME	Relationship

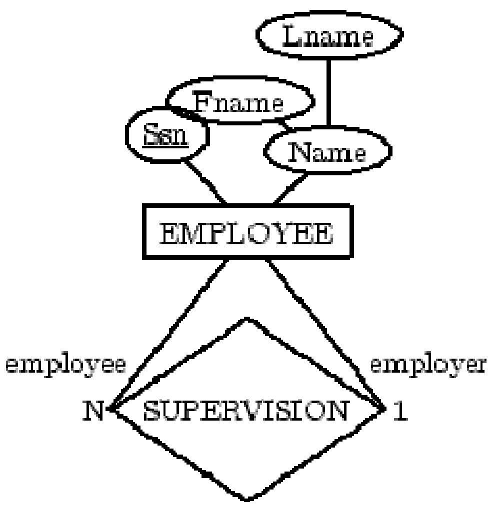
Step 3: For each **binary 1:1 relationship type** R in the ER schema, identify the relations S and T that correspond to the entity types participating in R. Choose one of the relations, say S, and include the primary key of T as a foreign key in S. Include all the simple attributes of R as attributes of S.



DEPARTMENT

MANAGER-SSN	StartDate

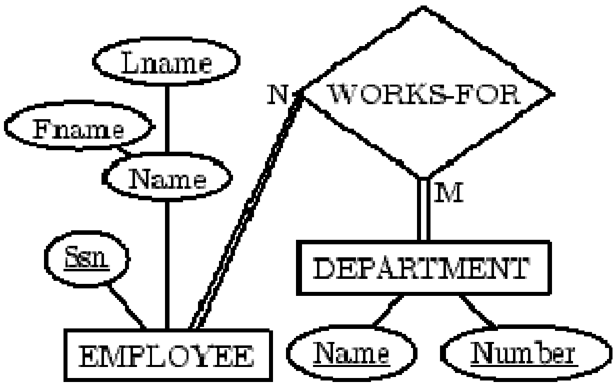
Step 4: For each regular **binary 1:N relationship type** R identify the relation (N) relation S. Include the primary key of T as a foreign key of S. Simple attributes of R map to attributes of S.



EMPLOYEE

SupervisorSSN

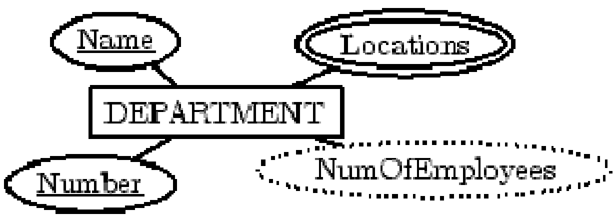
Step 5: For each **binary M:N relationship type** R, create a relation S. Include the primary keys of participant relations as foreign keys in S. Their combination will be the primary key for S. Simple attributes of R become attributes of S.



WORKS-FOR

EmployeeSSN	DeptNumber

Step 6: For each **multi-valued attribute A**, create a new relation R. This relation will include an attribute corresponding to A, plus the primary key K of the parent relation (entity type or relationship type) as a foreign key in R. The primary key of R is the combination of A and K.



DEP-LOCATION

Location	DEP-NUMBER

Step 7: For each **n-ary relationship type R**, where n>2, create a new relation S to represent R. Include the primary keys of the relations participating in R as foreign keys in S. Simple attributes of R map to attributes of S. The primary key of S is a combination of all the foreign keys that reference the participants that have cardinality constraint > 1.

For a recursive relationship, we will need a new relation.