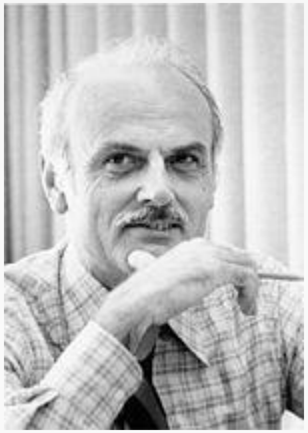
The Relational Model



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Review

- Why use a DBMS? OS provides RAM and disk

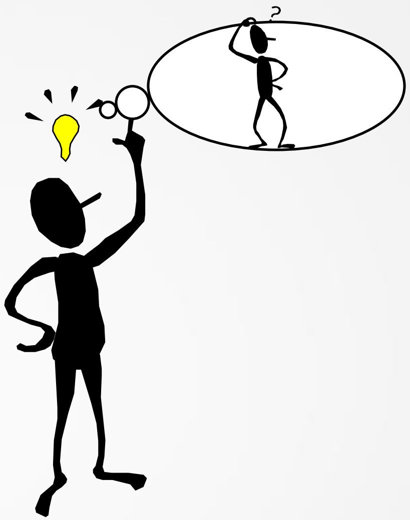
Review

- Why use a DBMS? OS provides RAM and disk
  - Concurrency
  - Recovery
  - Abstraction, Data Independence
  - Query Languages
  - Efficiency (for most tasks)
  - Security
  - Data Integrity

Glossary

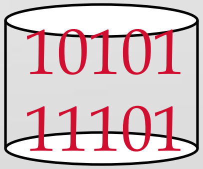
- Byte
- Kilobyte
- Megabyte
- Gigabyte
- Terabyte
  - A handful of these for files in EECS
  - Biggest single online DB is Wal-Mart, >100TB
  - Internet Archive WayBack Machine is > 100 TB
- Petabyte
  - 11 of these in email in 1999
- Exabyte
  - 8 of these projected to be sold in new disks in 2003
- Zettabyte
- Yottabyte

Data Models



- DBMS models real world
- *Data Model* is link between user's view of the world and bits stored in computer
- Many models exist
- We will concentrate on the Relational Model

Student(sid:*Students(sid: string, name: string, login: string, age: integer, gpa:real)*



Why Study the Relational Model?

- Most widely used model.
  - Vendors: IBM, Microsoft, Oracle, Sybase, etc.
- “Legacy systems” in older models
  - e.g., IBM’s IMS
- Object-oriented concepts have recently merged in
  - *object-relational model*
    - IBM DB2, Oracle 9i, IBM Informix
  - Based on POSTGRES research project at Berkeley
    - Postgres still represents the cutting edge on some of these features!

Relational Database: Definitions

- *Relational database:* a set of *relations.*
- *Relation:* made up of 2 parts:
  - *Instance* : a *table,* with rows and columns.
    - #rows = *cardinality*
  - *Schema* : specifies name of relation, plus name and type of each column.
    - E.g. Students(*sid*: string, *name*: string, *login*: string, *age*: integer, *gpa*: real)
    - #fields = *degree / arity*
- Can think of a relation as a *set* of rows or *tuples*.
  - i.e., all rows are distinct

Relational Database Scheme and Instance

Relational database scheme: *D* consist of a finite no. of relation schemes and a set *I* of integrity constraints.

Integrity constraints: Necessary conditions to be satisfied by the data values in the relational instances so that the set

of data values constitute a meaningful database

- domain constraints
- key constraints
- referential integrity constraints

Database instance: Collection of relational instances satisfying the integrity constraints.

Domain and Key Constraints

- **Domain Constraints**: Attributes have associated domains
  Domain – set of atomic data values of a specific type.
  Constraint – stipulates that the actual values of an attribute in any tuple <u>must</u> belong to the declared domain.

- **Key Constraint**: Relation scheme – associated keys Constraint – if *K* is supposed to be a key for scheme *R*,

any relation instance *r* on *R* should not have two tuples that have identical values for attributes in *K*.

Also, none of the key attributes can have <u>null</u> value.

Example Instance of Students Relation

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@eecs	18	3.2
53650	Smith	smith@math	19	3.8

- Cardinality = 3, arity = 5 , all rows distinct
- Do all values in each column of a relation instance have to be distinct?

SQL - A language for Relational DBs

- SQL: standard language
- Data Definition Language (DDL)
  - create, modify, delete relations
  - specify constraints
  - administer users, security, etc.
- Data Manipulation Language (DML)
  - Specify *queries* to find tuples that satisfy criteria
  - add, modify, remove tuples

SQL Overview

- ```
  CREATE TABLE <name> ( <field> <domain>, … )
  ```
- ```
  INSERT INTO <name> (<field names>)
       VALUES (<field values>)
  ```
- ```
  DELETE FROM <name>
        WHERE <condition>
  ```
- ```
  UPDATE <name>
     SET <field name> = <value>
   WHERE <condition>
  ```
- ```
  SELECT <fields>
    FROM <name>
   WHERE <condition>
  ```
  ```

Creating Relations in SQL

- Creates the Students relation.
- Note: the type (domain) of each field is specified, and enforced by the DBMS
  - whenever tuples are added or modified.
- Another example: the Enrolled table holds information about courses students take.

```
CREATE TABLE Students
      (sid CHAR(20),
       name CHAR(20),
       login CHAR(10),
       age INTEGER,
       gpa FLOAT)
```

```
CREATE TABLE Enrolled
      (sid CHAR(20),
       cid CHAR(20),
       grade CHAR(2))
```

Adding and Deleting Tuples

- Can insert a single tuple using:

```
INSERT INTO  Students (sid, name, login, age, gpa)
     VALUES  ('53688', 'Smith', 'smith@ee', 18, 3.2)
```

- **Can delete all tuples satisfying some condition (e.g., name = Smith):**

```
DELETE
  FROM Students S
 WHERE S.name = 'Smith'
```

☞ **Powerful variants of these commands are available; more later!**

Keys

- Keys are a way to associate tuples in different relations
- Keys are one form of integrity constraint (IC)

Enrolled

sid	cid	grade
53666	Carnatic101	C
53666	Reggae203	B
53650	Topology112	A
53666	History105	B

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@eecs	18	3.2
53650	Smith	smith@math	19	3.8

Primary Keys

- A set of fields is a *superkey* if:
  - No two distinct tuples can have same values in all key fields
- A set of fields is a *key* for a relation if :
  - It is a superkey
  - No subset of the fields is a superkey
- >1 key for a relation?
  - one of the keys is chosen (by DBA) to be the *primary key*.
- E.g.
  - *sid* is a key for Students.
  - What about *name*?
  - The set {*sid, gpa*} is a superkey.

Primary and Candidate Keys in SQL

- Possibly many *candidate keys* (specified using UNIQUE), one of which is chosen as the *primary key*.
  - "For a given student and course, there is a single grade."
    vs.
    "Students can take only one course, and receive a single grade for that course; further, no two students in a course receive the same grade."
  - Used carelessly, an IC can prevent the storage of database instances that should arise in practice!

```
CREATE TABLE Enrolled
   (sid CHAR(20)
     cid  CHAR(20),
     grade CHAR(2),
     PRIMARY KEY (sid,cid))
```

```
CREATE TABLE Enrolled
   (sid CHAR(20)
     cid  CHAR(20),
     grade CHAR(2),
     PRIMARY KEY  (sid),
     UNIQUE (cid, grade))
```

Foreign Keys

- A Foreign Key is a field whose values are keys in another relation.

Enrolled

sid	cid	grade
53666	Carnatic101	C
53666	Reggae203	B
53650	Topology112	A
53666	History105	B

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@eecs	18	3.2
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Foreign Keys, Referential Integrity

- *Foreign key* : Set of fields in one relation that is used to `refer' to a tuple in another relation.
  - Must correspond to primary key of the second relation.
  - Like a `logical pointer'.
- E.g. *sid* is a foreign key referring to Students:
  - Enrolled(*sid*: string, *cid*: string, *grade*: string)
  - If all foreign key constraints are enforced, *referential integrity* is achieved (i.e., no dangling references.)

Foreign Keys in SQL

- Only students listed in the Students relation should be allowed to enroll for courses.

```
CREATE TABLE Enrolled
    (sid CHAR(20), cid CHAR(20), grade CHAR(2),
     PRIMARY KEY (sid,cid),
     FOREIGN KEY (sid) REFERENCES Students )
```

Enrolled

sid	cid	grade
53666	Carnatic101	C
53666	Reggae203	B
53650	Topology112	A
53666	History105	B

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@eecs	18	3.2
53650	Smith	smith@math	19	3.8

Integrity Constraints (ICs)

- IC: condition that must be true for *any* instance of the database; e.g., *domain constraints.*
  - ICs are specified when schema is defined.
  - ICs are checked when relations are modified.
- A *legal* instance of a relation is one that satisfies all specified ICs.
  - DBMS should not allow illegal instances.
- If the DBMS checks ICs, stored data is more faithful to real-world meaning.
  - Avoids data entry errors, too!

Where do ICs Come From?

- ICs are based upon the semantics of the real-world that is being described in the database relations.
- We can check a database instance to see if an IC is violated, but we can NEVER infer that an IC is true by looking at an instance.
  - An IC is a statement about *all possible* instances!
  - From example, we know *name* is not a key, but the assertion that *sid* is a key is given to us.
- Key and foreign key ICs are the most common; more general ICs supported too.

Enrolled

sid	cid	grade
53666	Carnatic101	C
53666	Reggae203	B
53650	Topology112	A
53666	History105	B

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@eecs	18	3.2
53650	Smith	smith@math	19	3.8

Enforcing Referential Integrity

- Remember Students and Enrolled; *sid* in Enrolled is a foreign key that references Students.
- What should be done if an Enrolled tuple with a non-existent student id is inserted?
    - *(Reject it!)*
- What should be done if a Students tuple is deleted?
    - Also delete all Enrolled tuples that refer to it.
    - Disallow deletion of a Students tuple that is referred to.
    - Set sid in Enrolled tuples that refer to it to a *default sid*.
    - (In SQL, also: Set sid in Enrolled tuples that refer to it to a special value *null*, denoting `*unknown*' or `*inapplicable*'.)
- Similar if primary key of Students tuple is updated.

Relational Query Languages

- A major strength of the relational model: supports simple, powerful *querying* of data.
- Queries can be written intuitively, and the DBMS is responsible for efficient evaluation.
  - The key: precise semantics for relational queries.
  - Allows the optimizer to extensively re-order operations, and still ensure that the answer does not change.

The SQL Query Language

```
SELECT *
  FROM Students S
 WHERE S.age=18
```

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2

- The most widely used relational query language.
  - Current std is SQL99; SQL92 is a basic subset
- To find all 18 year old students, we can write:
- **To find just names and logins, replace the first line:**

```
SELECT S.name, S.login
```

Querying Multiple Relations

```
SELECT S.name, E.cid
  FROM Students S, Enrolled E
 WHERE S.sid=E.sid AND E.grade='A'
```

Given the following instance of Enrolled

sid	cid	grade
53831	Carnatic101	C
53831	Reggae203	B
53650	Topology112	A
53666	History105	B

- What does the following query compute?

we get:

S.name	E.cid
Smith	Topology112

Semantics of a Query

- A *conceptual evaluation method* for the previous query:
  1. do FROM clause: compute *cross-product* of Students and Enrolled
  2. do WHERE clause: Check conditions, discard tuples that fail
  3. do SELECT clause: Delete unwanted fields
- Remember, this is *conceptual*. Actual evaluation will be *much* more efficient, but must produce the same answers.

Cross-product of Students and Enrolled Instances

S.sid	S.name	S.login	S.age	S.gpa	E.sid	E.cid	E.grade
53666	Jones	jones@cs	18	3.4	53831	Carnatic101	C
53666	Jones	jones@cs	18	3.4	53832	Reggae203	B
53666	Jones	jones@cs	18	3.4	53650	Topology112	A
53666	Jones	jones@cs	18	3.4	53666	History105	B
53688	Smith	smith@ee	18	3.2	53831	Carnatic101	C
53688	Smith	smith@ee	18	3.2	53831	Reggae203	B
53688	Smith	smith@ee	18	3.2	53650	Topology112	A
53688	Smith	smith@ee	18	3.2	53666	History105	B
53650	Smith	smith@math	19	3.8	53831	Carnatic101	C
53650	Smith	smith@math	19	3.8	53831	Reggae203	B
53650	Smith	smith@math	19	3.8	**53650**	Topology112	**A**
53650	Smith	smith@math	19	3.8	53666	History105	B

Relational Model: Summary

- A tabular representation of data.
- Simple and intuitive, currently the most widely used
  - Object-relational variant gaining ground
  - XML support being added
- Integrity constraints can be specified by the DBA, based on application semantics. DBMS checks for violations.
  - Two important ICs: primary and foreign keys
  - In addition, we *always* have domain constraints.
- Powerful and natural query languages exist.

Example Relational Scheme

student (rollNo, name, degree, year, sex, deptNo, advisor)
Here, *degree* is the program (B Tech, M Tech, M S, Ph D etc) for which the student has joined. *Year* is the year of admission and *advisor* is the EmpId of a faculty member identified as the student's advisor.

department (deptId, name, hod, phone)
Here, *phone* is that of the department's office.

professor (empId, name, sex, startYear, deptNo, phone)
Here, *startYear* is the year when the faculty member has joined the department *deptNo*.

Example Relational Scheme

course (<u>courseId</u>, cname, credits, deptNo)

Here, *deptNo* indicates the department that offers the course.

enrollment (<u>rollNo, courseId, sem, year</u>, grade)
Here, *sem* can be either “odd” or “even” indicating the two semesters of an academic year. The value of *grade* will be null for the current semester and non-null for past semesters.

teaching (<u>empId, courseId, sem, year</u>, classRoom) preRequisite

(<u>preReqCourse, courseID</u>)

Here, if (c1, c2) is a tuple, it indicates that c1 should be successfully completed before enrolling for c2.

Example Relational Scheme

student (<u>rollNo</u>, name, degree, year, sex, deptNo, advisor)

department (<u>deptId</u>, name, hod, phone)

professor (<u>empId</u>, name, sex, startYear, deptNo, phone)

course (<u>courseId</u>, cname, credits, deptNo)

enrollment (<u>rollNo, courseId, sem, year</u>, grade)

teaching (<u>empId, courseId, sem, year</u>, classRoom)

preRequisite (<u>preReqCourse, courseID</u>)

queries-1

queries-2

queries-3

TCQuery

Example Relational Scheme with RIC's shown

student (rollNo, name, degree, year, sex, deptNo, advisor)

department (deptId, name, hod, phone)

professor (empId, name, sex, startYear, deptNo, phone)

course (courseId, cname, credits, deptNo)

enrollment (rollNo, courseId, sem, year, grade) teaching

(empId, courseId, sem, year, classRoom)

preRequisite (preReqCourse, courseID)

Querying Relational Data

- A relational database query (query, for short) is a question about the data, and the answer consists of a new relation containing the result. For example, we might want to find all students younger than 18 or all students enrolled in Reggae203. A query language is a specialized language for writing queries.
- SELECT * FROM Students S WHERE S.age < 18
- * means here to retain all the fields.

Querying Relational Data

- The condition *S. age* < 18 involves an arithmetic comparison of an *age* value with an integer and is permissible because the domain of *age* is the set of integers.

- On the other hand, a condition such as *S.age* = *S.id* does not make sense because it compares an integer value with a string value, and this comparison is defined to fail in SQL; a query containing this condition produces no answer tuples.

Querying Relational Data

- In addition to selecting a subset of tuples, a query can extract a subset of the fields of each selected tuple. We can compute the names and logins of students who are younger than 18 with the following query:
- SELECT S.name, S.login FROM Students S WHERE S.age < 18
- Note that the order in which we perform these operations does matter-if we remove unwanted fields first, we cannot check the condition *S. age* < 18, which involves one of those fields.

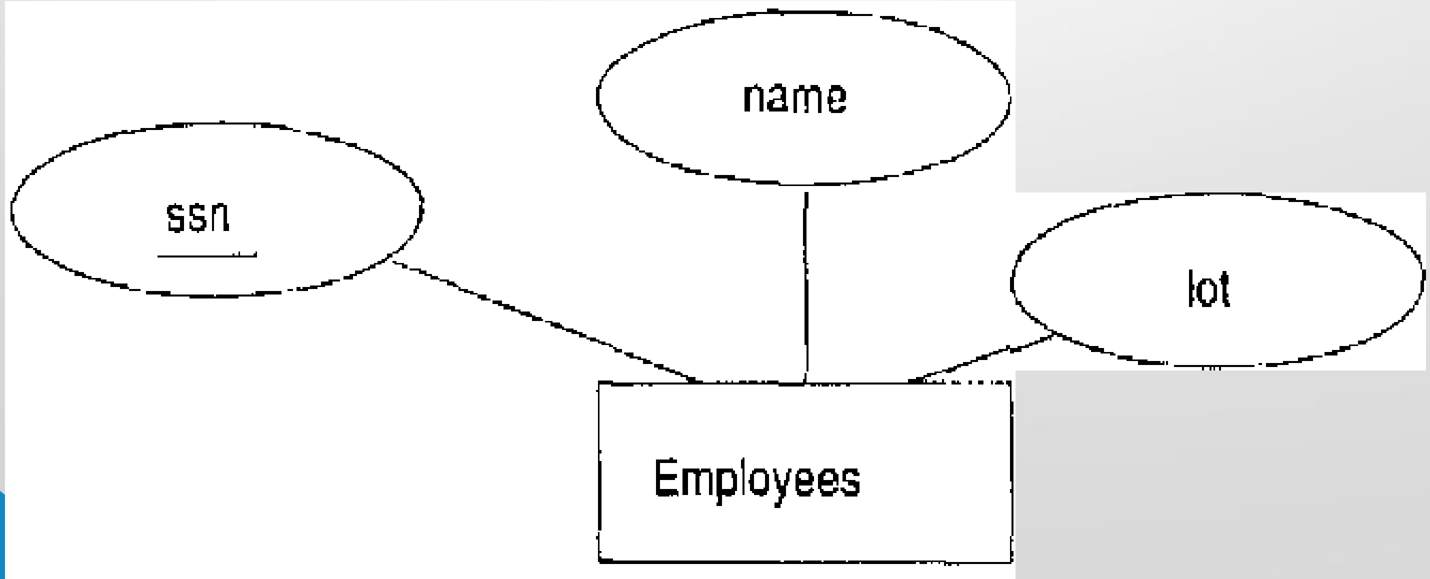
LOGICAL DATABASE DESIGN: ER TO RELATIONAL

- The ER model is convenient for representing an initial, high-level database design. Given an ER diagram describing a database, a standard approach is taken to generating a relational database schema that closely approximates the ER design.

We describe how to translate an ER diagram into a collection of tables with associated constraints, that is, a relational database schema.

LOGICAL DATABASE DESIGN: ER TO RELATIONAL

- **Entity Sets to Tables**
- An entity set is mapped to a relation in a straightforward way: Each attribute of the entity set becomes an attribute of the table. Note that we know both the domain of each attribute and the (primary) key of an entity set.



LOGICAL DATABASE DESIGN: ER TO RELATIONAL

ssn	*name*	*lot*
123-22-3666	Attishoo	48
231-31-5368	Smiley	22
131-24-3650	Smethurst	35

LOGICAL DATABASE DESIGN: ER TO RELATIONAL

- **Relationship Sets (without Constraints) to Tables**
- A relationship set, like an entity set, is mapped to a relation in the relational model.
- To represent a relationship, we must be able to identify each participating entity and give values to the descriptive attributes of the relationship. Thus, the attributes of the relation include:
- • The primary key attributes of each participating entity set, as foreign key fields.
- • The descriptive attributes of the relationship set.
- The set of non-descriptive attributes is a superkey for the relation.

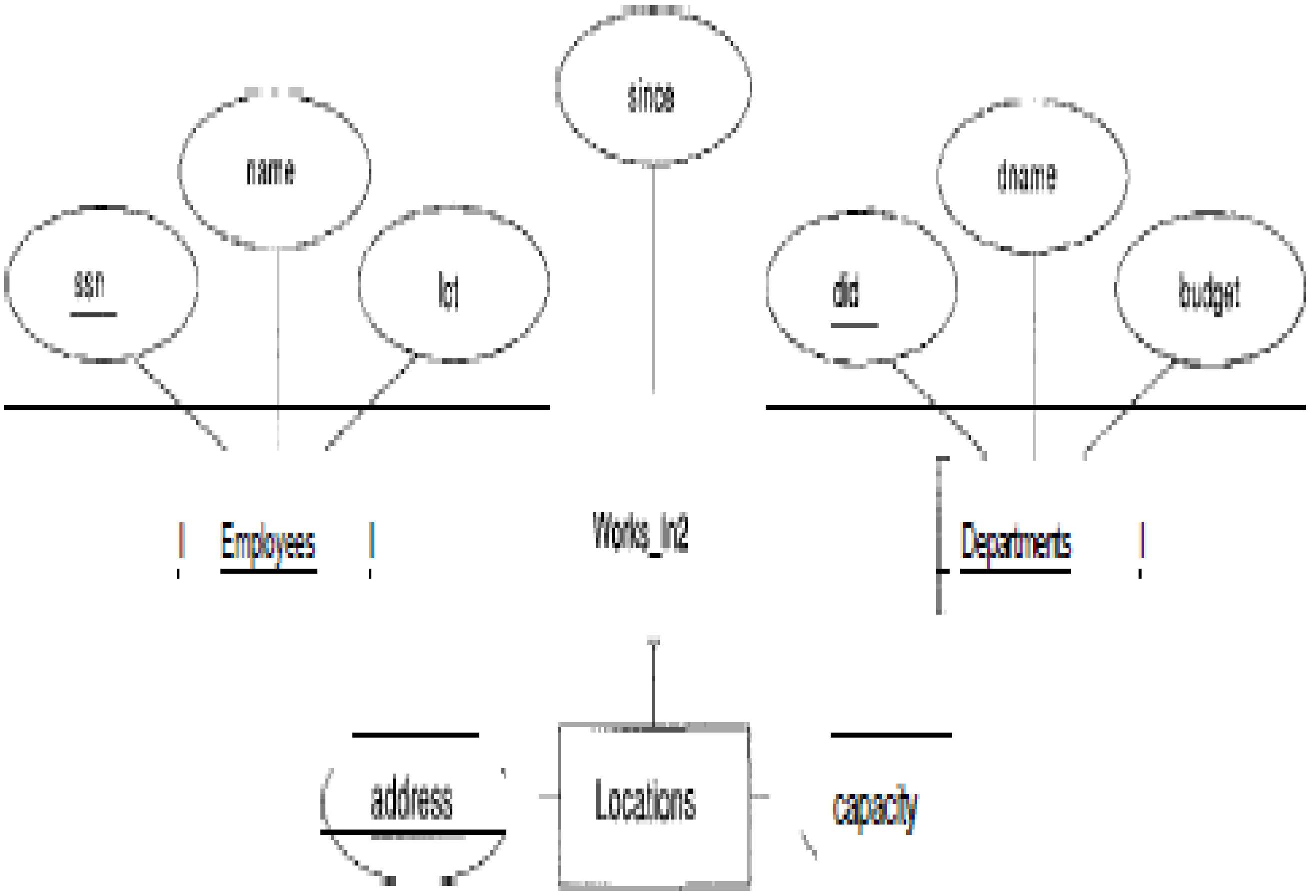
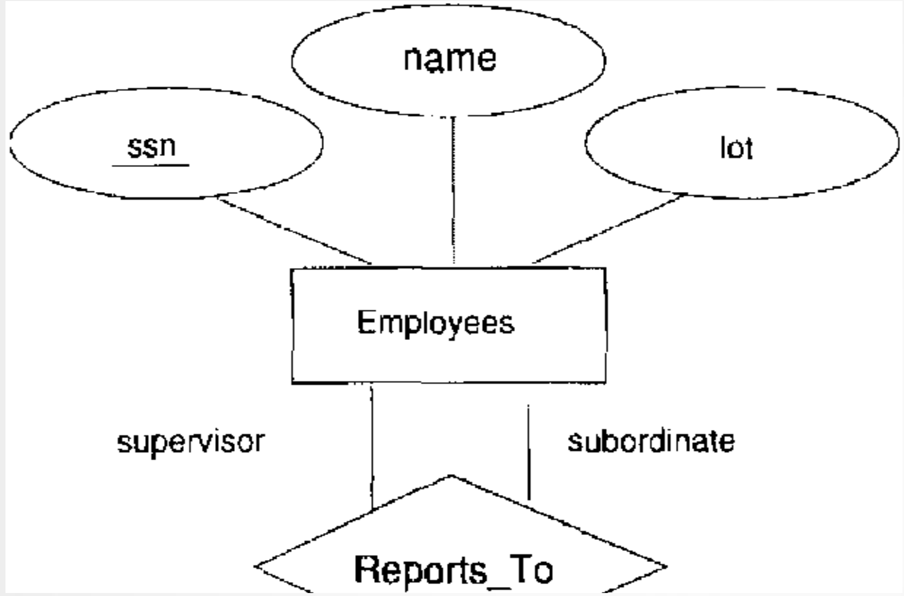


Figure 3.10 A Ternary Relationship Set

```
CREATE TABLE Works_In2 ( ssn      CHAR(11),
                         did      INTEGER,
                         address  CHAR(20),
                         since    DATE,
                         PRIMARY KEY (8sn, did, address),
                         FOREIGN KEY (ssn) REFERENCES Employees,
FOREIGN KEY (address) REFERENCES Locations,
FOREIGN KEY (did) REFERENCES Departments)
```

Note that the *address, did.* and *ssn* fields cannot take on *n'ull* values. Because these fields are part of the primary key for Works_In2, a NOT NULL constraint is implicit for each of these fields. This constraint ensures that these fields uniquely identify a department, an employee, and a location in each tuple of Works_In2



role indicators *supervisor* and *subordinate* are used to create meaningful field names in the CREATE statement for the Reports..To table

```
CREATE TABLE Reports_To (
        supervisor...ssn    CHAR(11),
        subordinate...ssn  CHAR(11),
        PRIMARY KEY (supervisor_ssn, subordinate_ssn),
        FOREIGN KEY (supervisor...ssn) REFERENCES Employees(ssn),
        FOREIGN KEY (subordinate...ssn) REFERENCES Employees(ssn) )
```