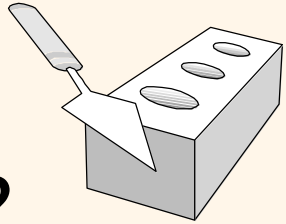
# *The Relational Model*

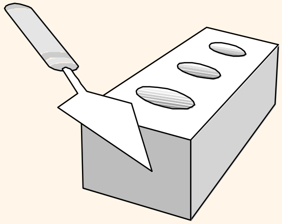
## Chapter 3



# *Why Study the Relational Model?*

- Most widely used model.
  - Vendors: IBM, Informix, Microsoft (Access and SQL Server), Oracle, Sybase, FoxBaseetc.
- "Legacy systems" in older models
  - E.G., IBM's IMS
- Recent competitor: object-oriented model
  - ObjectStore, Versant, Ontos
  - A synthesis emerging: *object-relational model*
    - Informix Universal Server, UniSQL, O2, Oracle, DB2
    - More in scientific computing

# *Relational Database: Definitions*



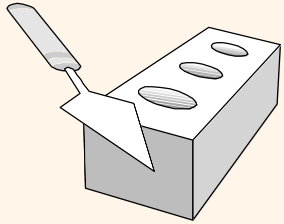
- *Relational database:* a set of *relations*
- *Relation:* made up of 2 parts:
  - *Relation Schema* : specifies name of relation, plus name and type of each column.
    - E.G. Students(*sid*: string, *name*: string, *login*: string, *age*: integer, *gpa*: real).
  - *Relation Instance* : a *table*,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

# *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 |

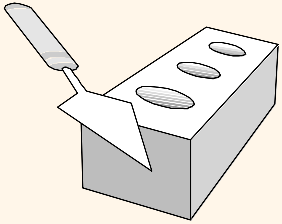
- Cardinality = 3, degree = 5, all rows distinct

# *The SQL Query Language*



- Developed by IBM (system R) in the 1970s
- The most widely used language for creating, manipulating, and querying relational DBMS.
- Need for a standard since it is used by many vendors
- Standards:
  - SQL-86
  - SQL-89 (minor revision)
  - SQL-92 (major revision)
  - SQL-99 (major extensions, current standard)

# *The SQL Query Language*



- 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 (Simple Query)*

| 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 |

- To find the names and login of all 18 year old students:

```
SELECT  name, login
FROM  Students
WHERE  age=18
```

| name | login |
|---|---|
| Jones | jones@cs |
| Smith | smith@eecs |

- To find all student data, replace the first line:

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

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

# *Querying Multiple Relations*

Given the following instances of Enrolled and Students, list all the students who get grade 'A' in any course along with the course id: :

| 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 |

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

Answer:

| S.name | E.cid |
|---|---|
| Smith | Topology112 |

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

# *Creating Relations in SQL*

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

- Creates the Students relation.
  - The type (domain) of each field is specified, and enforced by the DBMS whenever tuples are added or modified.

| sid | name | login | age | gpa |
|---|---|---|---|---|

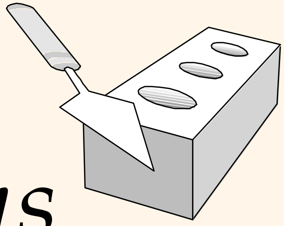
# *Creating Relations in SQL*

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

- The Enrolled table holds information about courses that students take.

| sid | cid | grade |
|---|---|---|

# *Destroying and Altering Relations*



DROP TABLE Students

- Destroys the relation Students. The schema information *and* the tuples are deleted.

ALTER TABLE Students
ADD COLUMN firstYear: integer

- The schema of Students is altered by adding a new field; every tuple in the current instance is extended with a *null* value in the new field.

# *Adding and Deleting Tuples*

- Can insert a single tuple using:

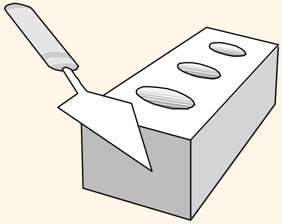
```
INSERT
INTO Students (sid, name, login, age, gpa)
VALUES (53688, 'Smith', 'smith@ee', 18, 3.2)
```

**The list of columns is optional*

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

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

# *Updating Tuples*

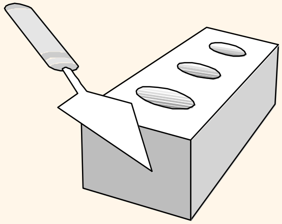


- Update a single tuple

```
UPDATE Students S
SET S.age = S.age +1, S.gpa = S.gpa -1
WHERE S.sid = 54832
```

- Update multiple tuples

```
UPDATE Students S
SET S.age = S.age +1, S.gpa = S.gpa -1
WHERE S.gpa > 3.3
```



# *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!

# *Primary Key Constraints*

- A set of fields is a <u>*key*</u> for a relation if :
  1. No two distinct tuples can have same values in all key fields, and
  2. This is not true for any subset of the key.
     - Part 2 false? A *superkey*.
     - If there are more than one key for a relation, one of the keys is chosen (by DBA) to be the *primary key* while other keys are considered *candidate 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*

- "For a given student and course, there is a single grade."

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

- "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."

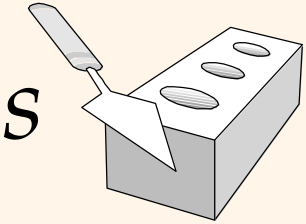
```
CREATE TABLE Enrolled (sid CHAR(20)
                       cid  CHAR(20),
                       grade CHAR(2),
                       PRIMARY KEY  (sid),
                       UNIQUE (cid, grade) )
```

# *Primary and Candidate Keys in SQL*

- Possibly many *candidate keys* (specified using UNIQUE), one of which is chosen as the *primary key (specified using* PRIMARY KEY) .

- Used carelessly, an IC can prevent the storage of database instances that arise in practice!

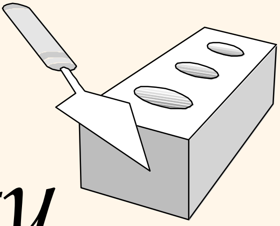
# *Enforcing Primary Key Constrains*



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 |

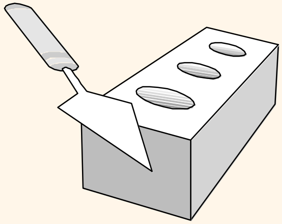
- Having this table: The following transactions are ***REJECTED:***
  - INSERT INTO Students (sid, name, login, age, gpa) VALUES (53688, 'Mike', 'Mike@cs', 17, 3.4)
  - INSERT INTO Students (sid, name, login, age, gpa) VALUES (*null*, 'Mike', 'Mike@cs', 17, 3.4)
  - INSERT INTO Students (sid, name, login, age, gpa) VALUES (53784, 'Mike', 'Mike@cs', 'twenty', 3.4)
  - UDPATE Students S SET S.sid = 53688 WHERE S.sid = 53666
- There are no problems for *Deletion*



# *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.
- Can you name a data model w/o referential integrity?

# *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 |

# *Enforcing Referential Integrity*

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 |

- What should be done if an Enrolled tuple with a non-existent student id is inserted?
  - INSERT INTO Enrolled (sid, cid, grade) VALUES (53611, 'History105', 'A')
    - *(Reject it!)*

# *Enforcing Referential Integrity*

Enrolled

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

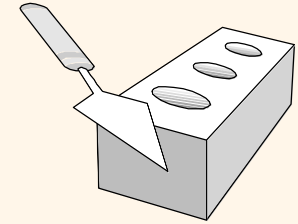
Students

| 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 |

- What should be done if a Students tuple is deleted?
  - OPTION 1: Also delete all Enrolled tuples that refer to it.
  - OPTION 2: Disallow deletion of a Students tuple that is referred to.
  - OPTION 3: Set sid in Enrolled tuples that refer to it to a *default sid*.
  - OPTION 4: Set sid in Enrolled tuples that refer to it to *null*.

- Similar if primary key of Students tuple is updated.

# *Referential Integrity in SQL*

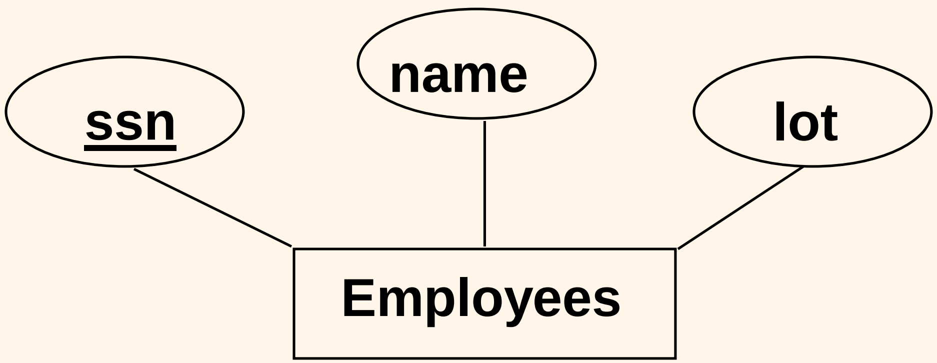


- SQL/92 and SQL:1999 support all four options on deletes and updates.
  - Default is NO ACTION (*delete/update is rejected*)
  - CASCADE (also delete all tuples that refer to deleted tuple)
  - SET NULL / SET DEFAULT (sets foreign key value of referencing tuple)

```
CREATE TABLE Enrolled (sid CHAR(20),
                       cid CHAR(20),
                       grade CHAR(2),
                       PRIMARY KEY (sid,cid),
                       FOREIGN KEY (sid)
                            REFERENCES Students
                                ON DELETE CASCADE
                                ON UPDATE SET DEFAULT )
```

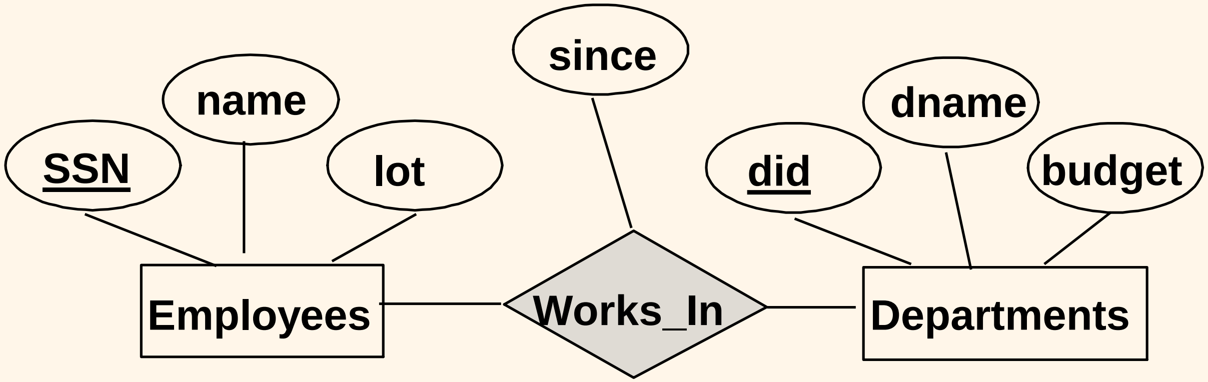
# *Logical DB Design: ER to Relational*

- Entity sets to tables:




```
CREATE TABLE Employees (ssn CHAR(11),
                        name CHAR(20),
                        lot  INTEGER,
                        PRIMARY KEY  (ssn))
```

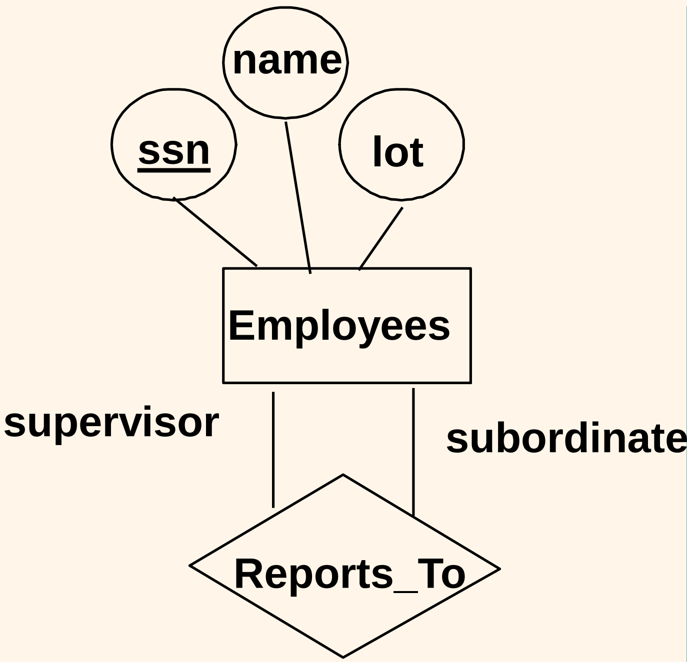
# Relationship Sets to Tables

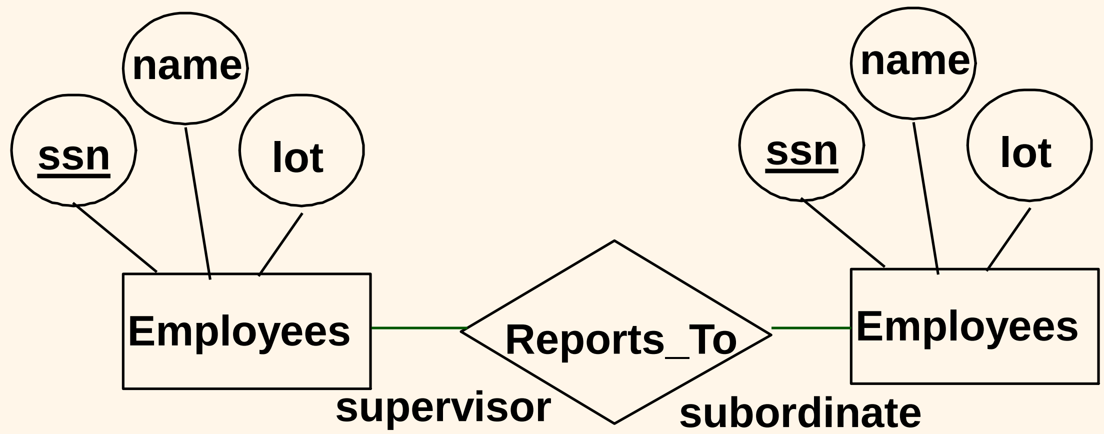



- In translating a relationship set to a relation, attributes of the relation must include:
  - Keys for each participating entity set (as foreign keys).
  - All descriptive attributes.

```
CREATE TABLE Works_In( ssn  CHAR(11),
                       did  INTEGER,
                       since  DATE,
                    PRIMARY KEY (ssn, did),
                    FOREIGN KEY (ssn) REFERENCES Employees,
                    FOREIGN KEY (did) REFERENCES Departments)
```

# *Relationship Sets to Tables*

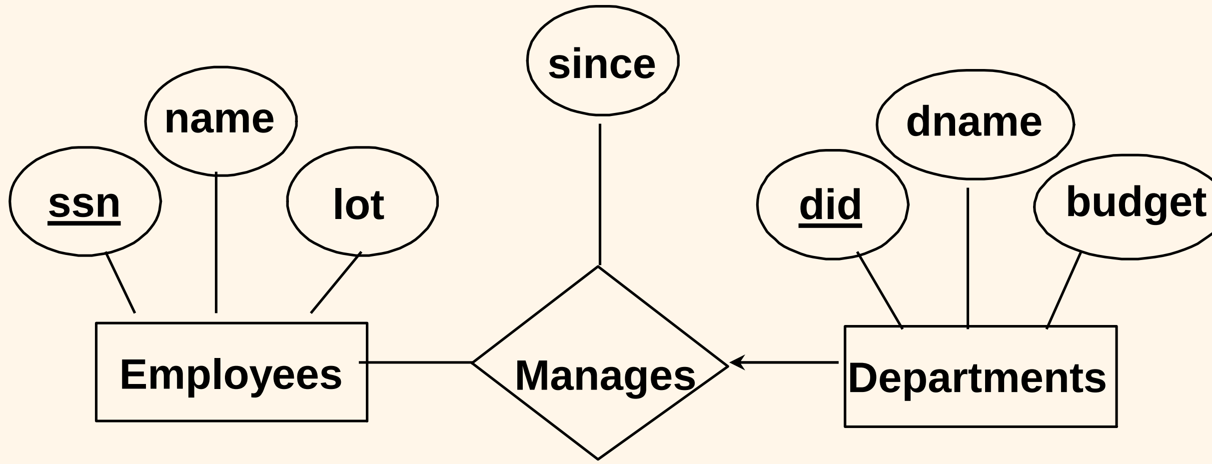


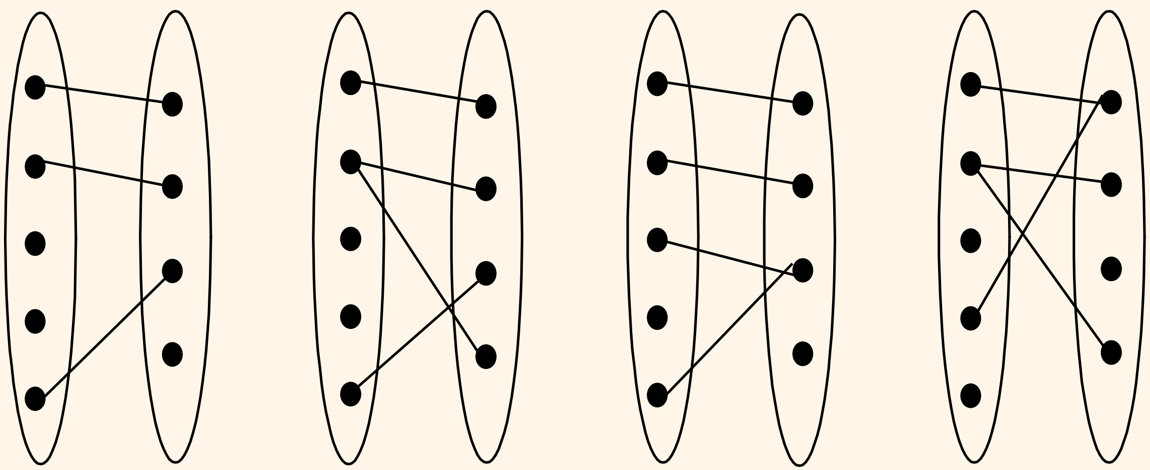




```
CREATE TABLE Reports_To( supervisor_ssn  CHAR(11),
                         subordinate_ssn  CHAR(11),
        PRIMARY KEY (supervisor_ssn, subordinate_ssn),
        FOREIGN KEY (supervisor_ssn)   REFERENCES Employees(ssn),
        FOREIGN KEY (subordinate_ssn) REFERENCES Employees(ssn))
```

# *Review: Key Constraints*

- Each dept has at most one manager, according to the *key constraint* on Manages.



1-to-1 | 1-to Many | Many-to-1 | Many-to-Many

*Translation to relational model?*

# *Translating ER Diagrams with Key Constraints*

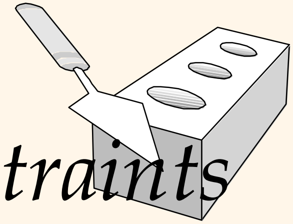
- Map relationship to a table:
  - Separate tables for Employees and Departments.

```
CREATE TABLE  Manages(
   ssn  CHAR(11),
   did  INTEGER,
   since  DATE,
   PRIMARY KEY  (ssn,did),
   FOREIGN KEY (ssn) REFERENCES Employees,
   FOREIGN KEY (did) REFERENCES Departments)
```

- Note that did is the key now!

```
CREATE TABLE  Manages(
   ssn  CHAR(11),
   did  INTEGER,
   since  DATE,
   PRIMARY KEY  (did),
   FOREIGN KEY (ssn) REFERENCES Employees,
   FOREIGN KEY (did) REFERENCES Departments)
```

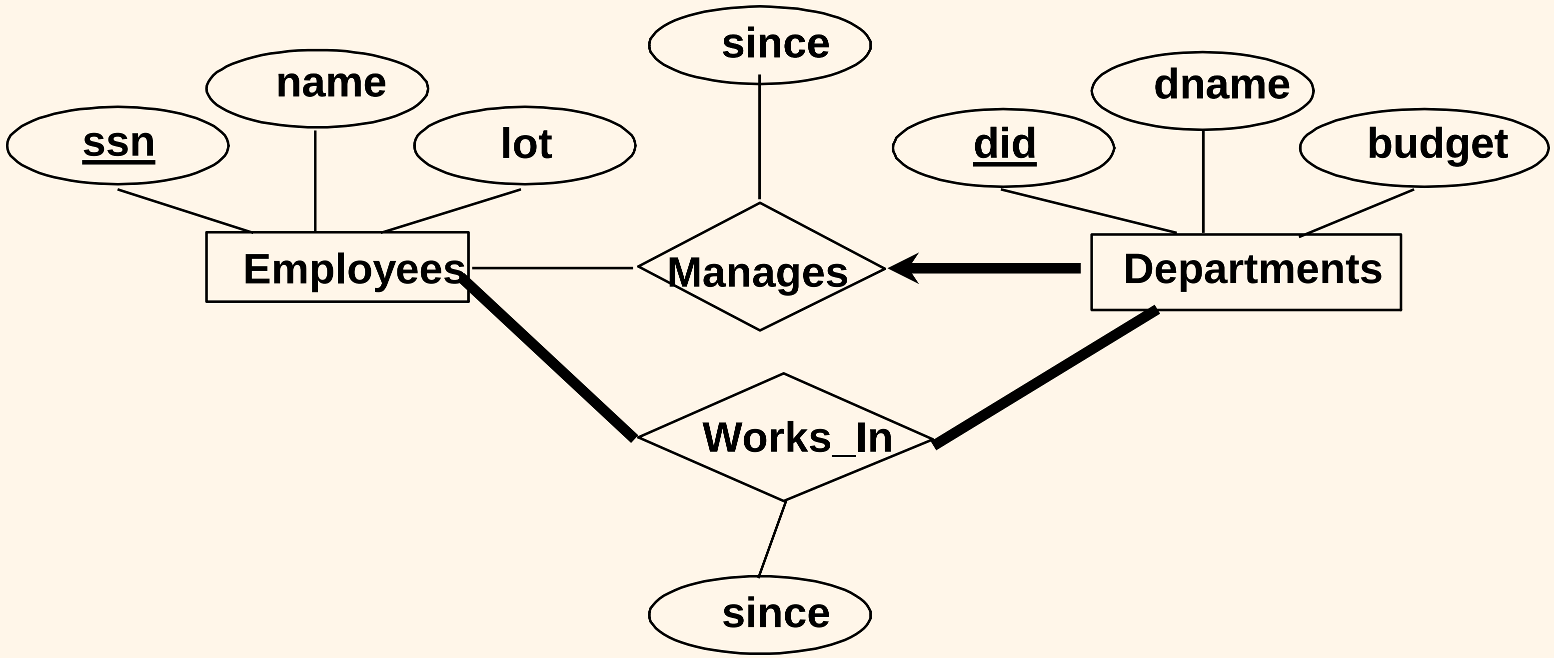
# *Translating ER Diagrams with Key Constraints*



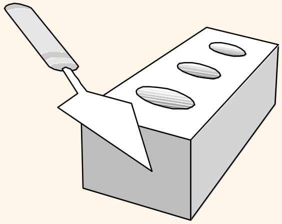
- Since each department has a unique manager, we could instead combine Manages and Departments.

```
CREATE TABLE  Dept_Mgr(
   did  INTEGER,
   dname  CHAR(20),
   budget  REAL,
   ssn  CHAR(11),
   since  DATE,
   PRIMARY KEY  (did),
   FOREIGN KEY (ssn) REFERENCES Employees)
```

# Review: Participation Constraints




- Does every department have a manager?
  - If so, this is a *participation constraint*: the participation of Departments in Manages is said to be *total* (vs. *partial*).
    - Every *did* value in Departments table must appear in a row of the Manages table (with a non-null *ssn* value!)

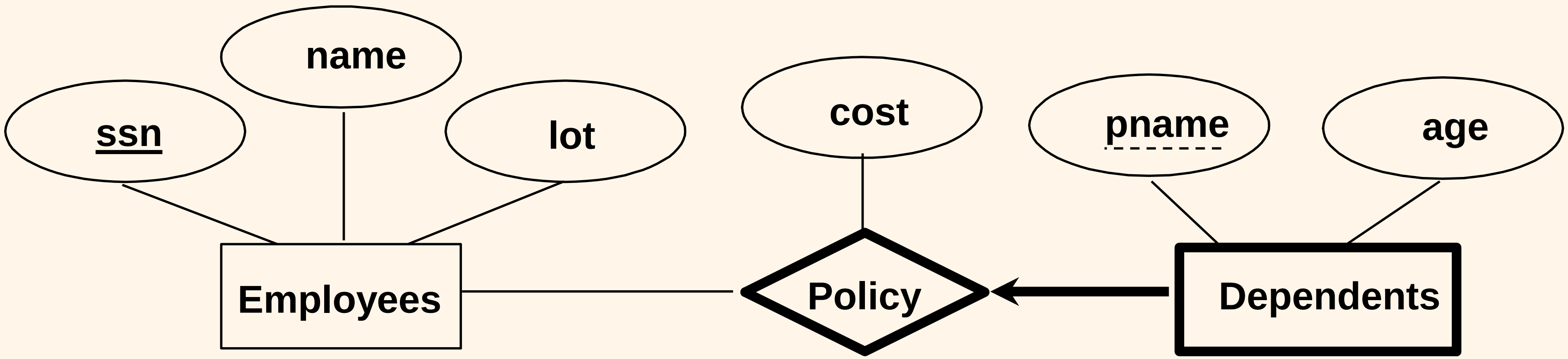


# *Participation Constraints in SQL*

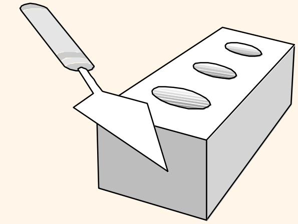
- We can capture participation constraints involving one entity set in a binary relationship, but little else (without resorting to CHECK constraints).

```
CREATE TABLE Dept_Mgr(
  did INTEGER,
  dname CHAR(20),
  budget REAL,
  ssn CHAR(11) NOT NULL,
  since DATE,
  PRIMARY KEY (did),
  FOREIGN KEY (ssn) REFERENCES Employees,
    ON DELETE NO ACTION)
```

# *Review: Weak Entities*




- A *weak entity* can be identified uniquely only by considering the primary key of another (*owner*) entity.
  - Owner entity set and weak entity set must participate in a one-to-many relationship set (1 owner, many weak entities).
  - Weak entity set must have total participation in this *identifying* relationship set.

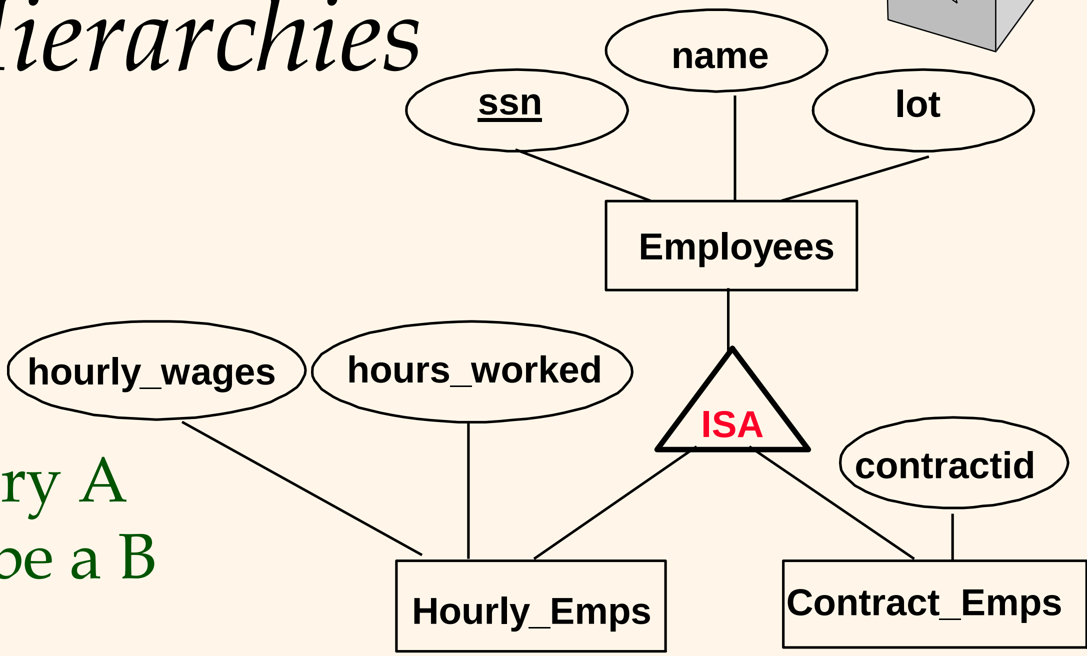


# Translating Weak Entity Sets

- Weak entity set and identifying relationship set are translated into a single table.
  - When the owner entity is deleted, all owned weak entities must also be deleted.

```
CREATE TABLE Dep_Policy (
  pname CHAR(20),
  age INTEGER,
  cost REAL,
  ssn CHAR(11) NOT NULL,
  PRIMARY KEY (pname, ssn),
  FOREIGN KEY (ssn) REFERENCES Employees,
    ON DELETE CASCADE)
```

# *Review: ISA Hierarchies*



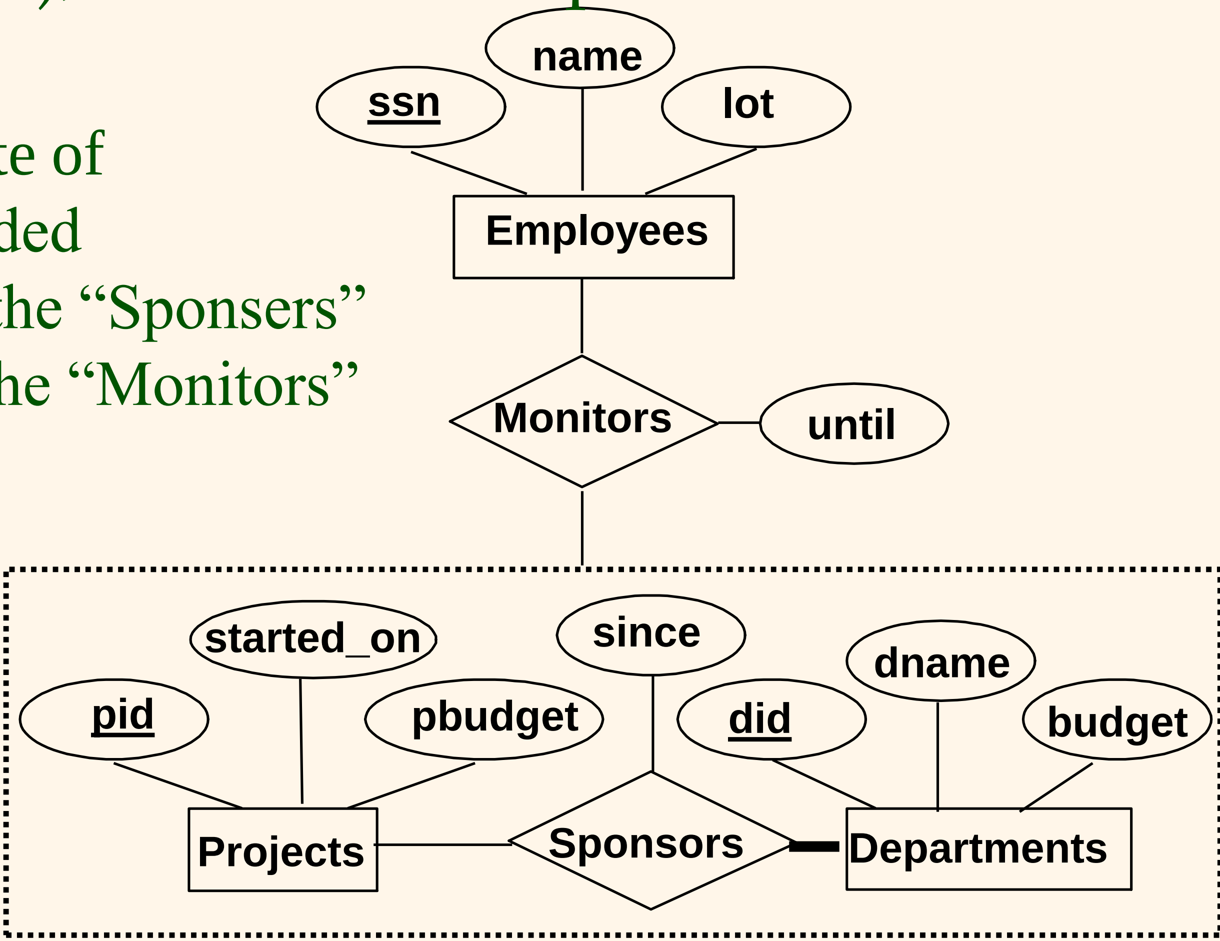

- As in C++, or other PLs, attributes are inherited.
- If we declare A **ISA** B, every A entity is also considered to be a B entity.
- *Overlap constraints*: Can Joe be an Hourly_Emps as well as a Contract_Emps entity? (*Allowed/disallowed*)
  - Hourly_Emps OVERLAPS Senior_Emps
- *Covering constraints*: Does every Employees entity also have to be an Hourly_Emps or a Contract_Emps entity? (*Yes/no*)
  - Hourly_Emps AND Contract_Emps COVERS Employees

# *Translating ISA Hierarchies to Relations*

- ***General approach:***
  - 3 relations: Employees, Hourly_Emps and Contract_Emps.
    - *Hourly_Emps*: Every employee is recorded in Employees. For hourly emps, extra info recorded in Hourly_Emps (*hourly_wages, hours_worked, ssn*); must delete Hourly_Emps tuple if referenced Employees tuple is deleted).
    - Queries involving all employees easy, those involving just Hourly_Emps require a join to get some attributes.
- Alternative: Just Hourly_Emps and Contract_Emps.
  - *Hourly_Emps*: *ssn, name, lot, hourly_wages, hours_worked.*
  - Each employee must be in one of these two subclasses.

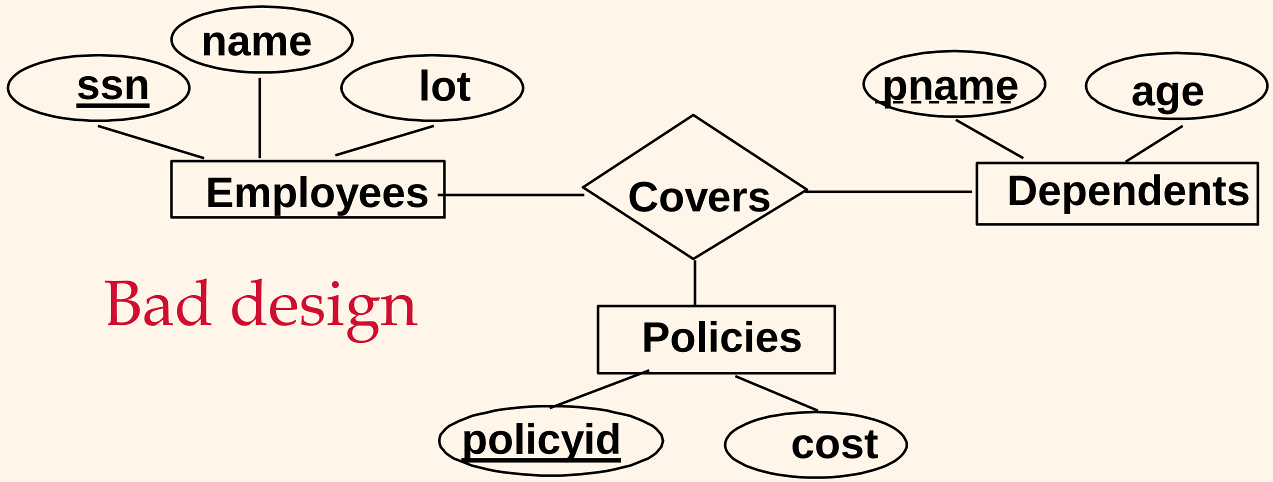
# Aggregation

- *Monitors:* Create a relation with the key attribute of "Employee" (ssn) and the key attribute for "Sponsers" (did,pid), and the descriptive attribute of "Monitors" (until)
  - The descriptive attribute of "sponsers" is not included
  - Not every (pid,did) in the "Sponsers" relation participate in the "Monitors" relation
  - If "Sponsers" has no descriptive attributes and has total participation in "Monitors", we can drop "Sponsers"

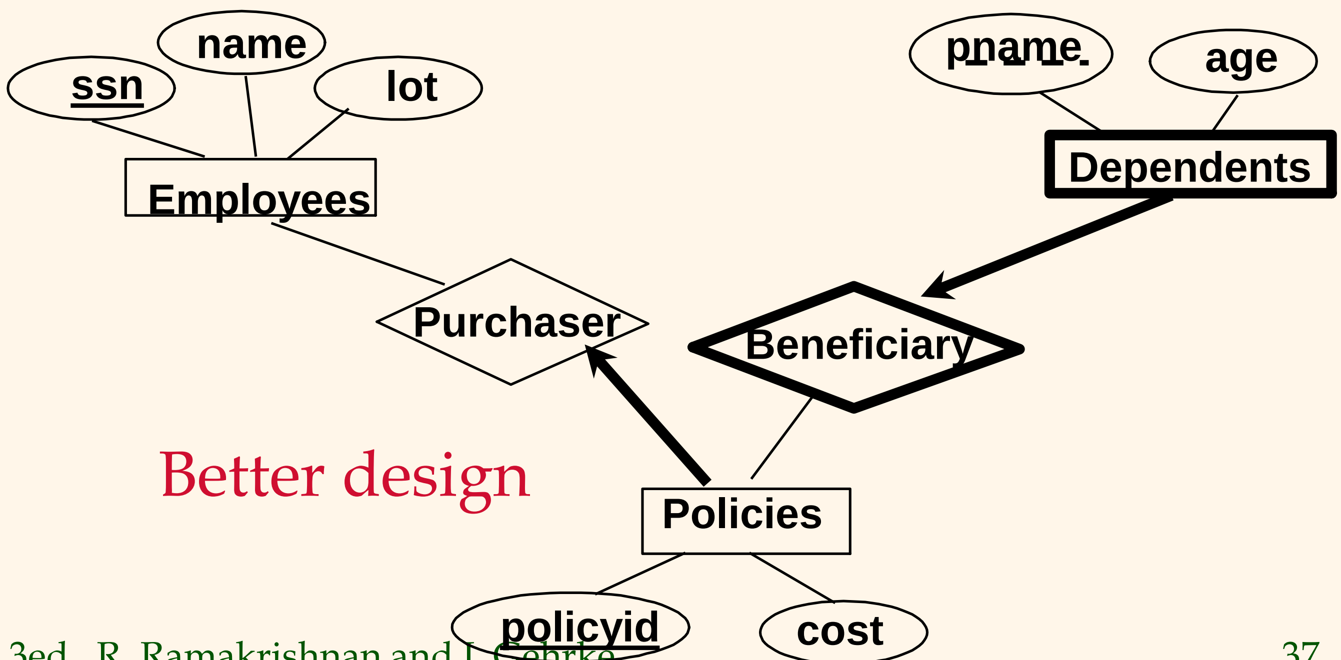


# *Review: Binary vs. Ternary Relationships*

- If each policy is owned by just one employee, and each dependent is tied to the covering policy, first diagram is inaccurate.




Bad design




Better design

# *Binary vs. Ternary Relationships (Contd.)*

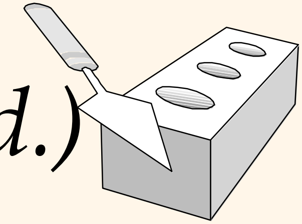
- The key constraints allow us to combine Purchaser with Policies and Beneficiary with Dependents.

- Participation constraints lead to NOT NULL constraints.

```
CREATE TABLE Policies (
  policyid INTEGER,
  cost REAL,
  ssn CHAR(11) NOT NULL,
  PRIMARY KEY (policyid).
  FOREIGN KEY (ssn) REFERENCES Employees,
    ON DELETE CASCADE)
```

```
CREATE TABLE Dependents (
  pname CHAR(20),
  age INTEGER,
  policyid INTEGER,
  PRIMARY KEY (pname, policyid).
  FOREIGN KEY (policyid) REFERENCES Policies,
    ON DELETE CASCADE)
```

# *Binary vs. Ternary Relationships (Contd.)*



- What if Policies is a weak entity set?
  - Cascaded weak entities

```
CREATE TABLE Policies (
  policyid INTEGER,
  cost REAL,
  ssn CHAR(11),
  PRIMARY KEY (policyid,ssn).
  FOREIGN KEY (ssn) REFERENCES
  Employees ON DELETE CASCADE)
```

```
CREATE TABLE Dependents (
  pname CHAR(20),
  ssn CHAR(11),
  age INTEGER,
  policyid INTEGER,
  PRIMARY KEY (pname, policyid,ssn).
  FOREIGN KEY (policyid,ssn) REFERENCES
Policies
  ON DELETE CASCADE)
```

# *Views*

- A *view* is just a relation, but we store a *definition*, rather than a set of tuples.

```
CREATE VIEW YoungActiveStudents (name, grade)
    AS SELECT S.name, E.grade
    FROM Students S, Enrolled E
    WHERE S.sid = E.sid and S.age<21
```

- Views can be dropped using the DROP VIEW command.
- How to handle DROP TABLE if there's a view on the table?
  - DROP TABLE command has options to let the user specify this.

# *Updates on Views*

- SQL-92 allows updates to be specified only on views defined on a single table

```
CREATE VIEW GoodStudents (sid, gpa)
    AS SELECT sid,gpa
    FROM Students
    WHERE gpa > 3.0
```

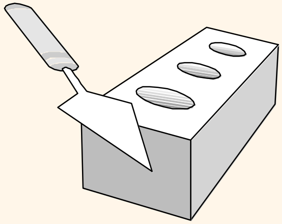
- Deleting a tuple from GoodStudent would delete the corresponding tuple from the original table
- What would happen if “sid” is replaced by “sname” in the view

# *Updates on Views*

- A tuple can be inserted into the view

```
INSERT INTO GoodStudents (sid, gpa)
VALUES (34261,3.5)
```

- What would happen to the other fields ➔ NULL
- Can we insert a GPA less than 3 ➔ YES
- To prevent this ➔ Add "WITH CHECK OPTION" to the view definition



# *Relational Model: Summary*

- A tabular representation of data.
- Simple and intuitive, currently the most widely used.
- 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.
- Rules to translate ER to relational model