The Entity-Relationship Model

Chapter 2

CENG351

Overview of Database Design

- **<u>Conceptual design</u>**: (**ER Model** *is used at this stage.*)
  - What are the **entities** and **relationships** in the enterprise?
  - What information about these entities and relationships should we store in the database?
  - What are the *integrity constraints* or *business rules* that hold?
  - A database "schema" in the ER Model can be represented pictorially (*ER diagrams*).
  - We can map an ER diagram into a relational schema.
- **<u>Schema Refinement:</u>** (Normalization)
  - Check relational schema for redundancies and anomalies.
- **<u>Physical Database Design and Tuning:</u>**
  - Consider typical workloads and further refine the db design.

DB Requirements example

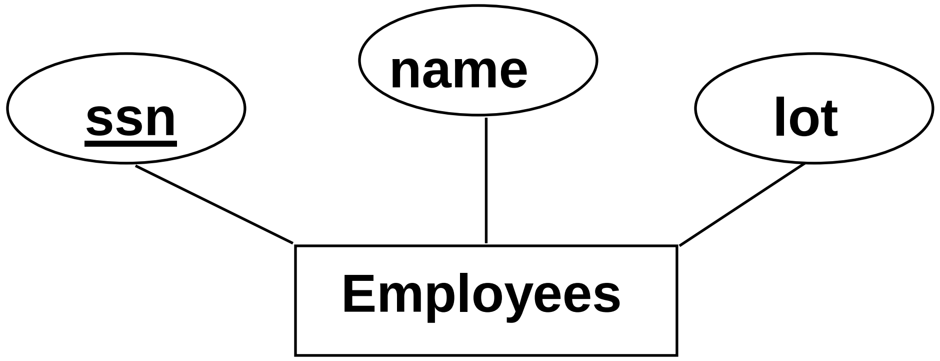
A company database needs to store information about

- employees (identifyied by ssn, with salary and phone as attributes);
- departments (identified by dno, with dname and budget as attributes); and
- children of employees (with name and age as attributes).
- Employees work in departments;
- each department is managed by an employee;
- a child must be identified uniquely by name when the parent (who is an employee; assume that only one parent works for the company) is known. We are not interested in information about a child once the parent leaves the company.

ER Model Basics – Entity Set

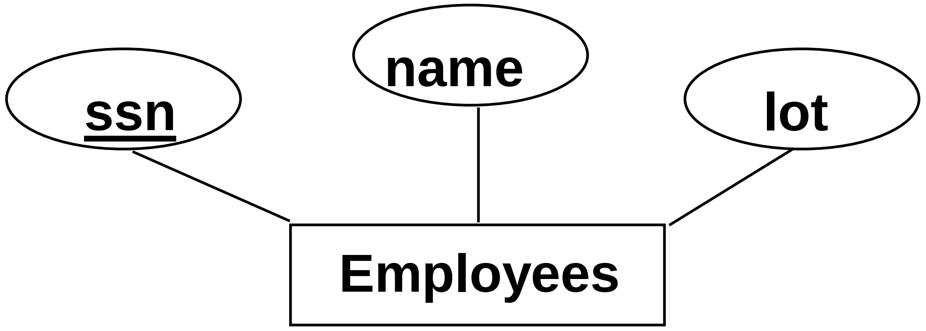
- **Entity:** Real-world object distinguishable from other objects. An entity is described (in DB) using a set of **attributes.**
- **Entity Set:** A collection of similar entities. E.g., all employees.
  - All entities in an entity set have the same set of attributes.
  - Each entity set has a **key**.
  - Each attribute has a **domain.**

Employees Entity Set:



Logical DB Design: ER to Relational Model

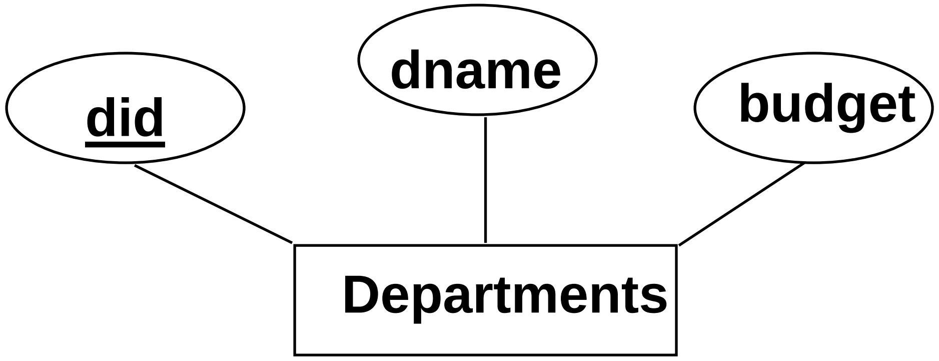
- Entity sets to tables:



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

Logical DB Design: ER to Relational Model

- Entity sets to tables:

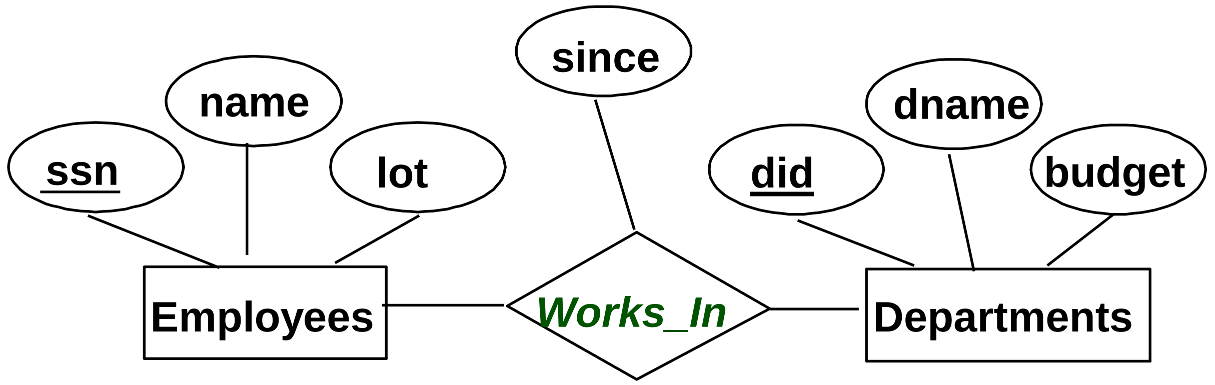


```
CREATE TABLE  Departments(
   did  INTEGER,
   dname  CHAR(20),
   budget  REAL,
   PRIMARY KEY  (did))
```

ER Model Basics- Relationship set

- **Relationship:** Association among two or more entities.
  - e.g., Fred works in Pharmacy department.
- **Relationship Set:** Collection of similar relationships.
  - An n-ary relationship set R relates n entity sets E_1 ... E_n; each relationship in R involves entities $e_1 \in E_1, ..., e_n \in E_n$

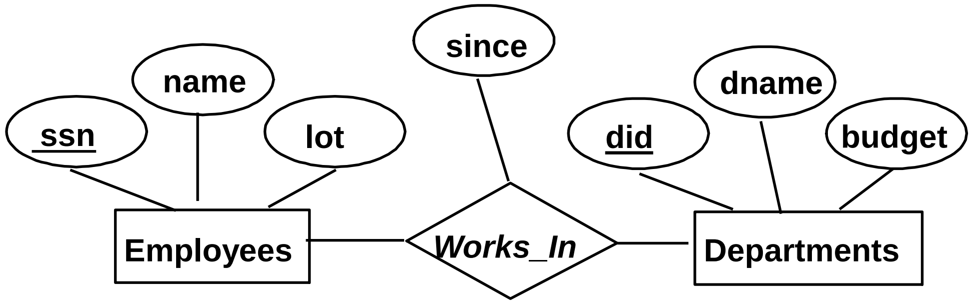
Works_In relationship set:



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).
    - This set of attributes forms a *superkey* for the relation.
  - All descriptive attributes.

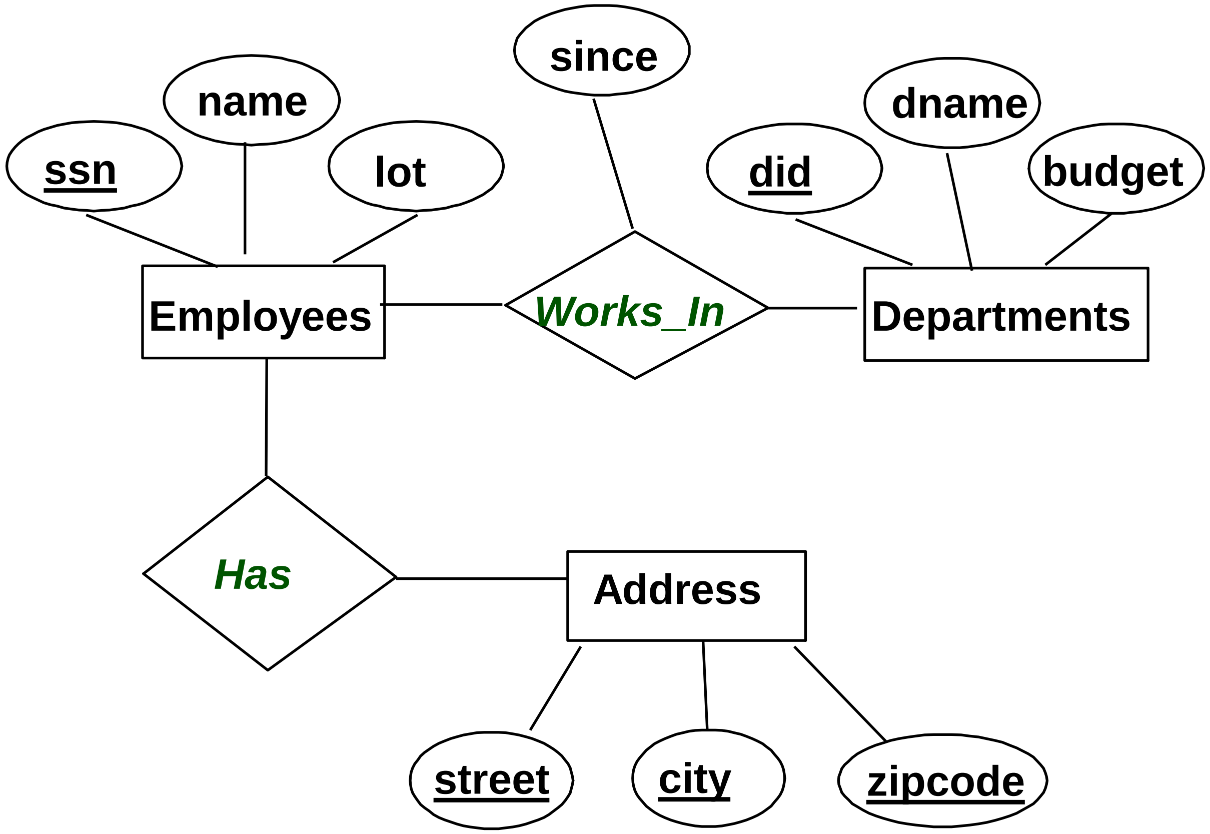
```
CREATE TABLE Works_In(
  ssn  CHAR(11),
  did  INTEGER,
  since  DATE,
  PRIMARY KEY (ssn, did),
  FOREIGN KEY (ssn)
      REFERENCES Employees,
  FOREIGN KEY (did)
      REFERENCES Departments)
```



Relationship set (contd.)

➢ Same entity set could participate in different relationship sets.

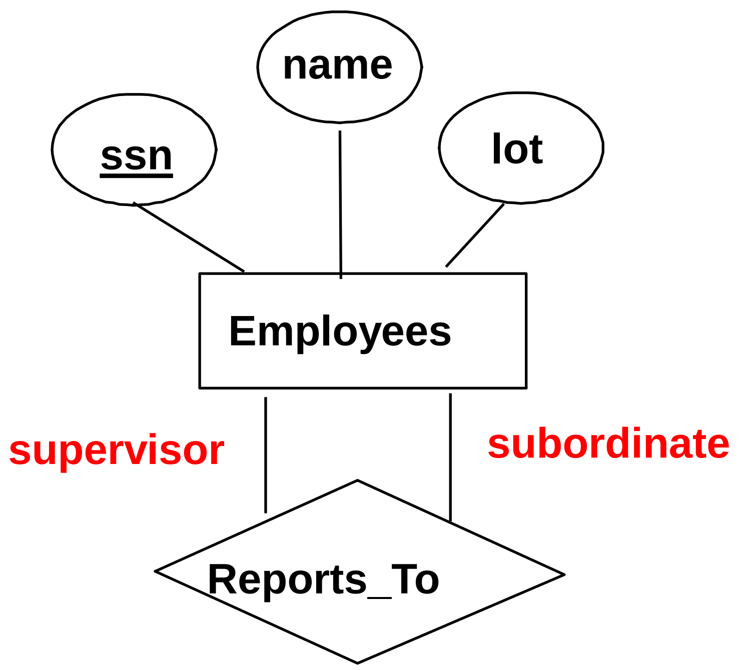
Works_In and *Has* Relationship sets:



Relationship set (contd.)

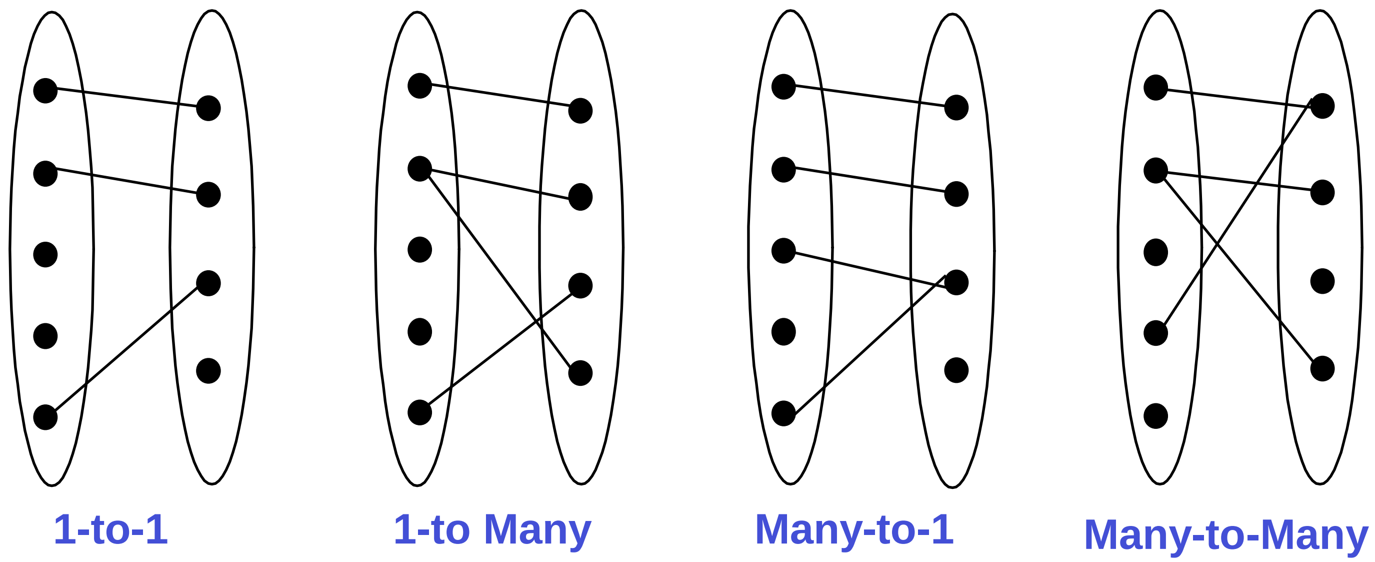
- Same entity set could participate in different “roles” in same relationship set.

Reports_To relationship set:



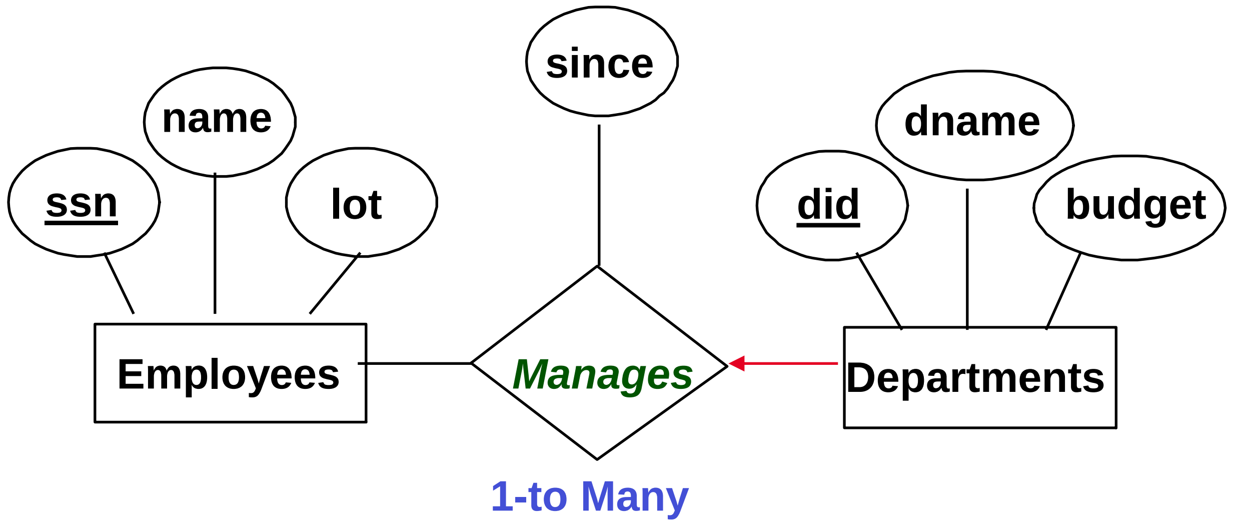
Relationship Types

- Consider ***Works_In***: An employee can work in many departments; a department can have many employees: many-to-many relationship.
- In contrast, each department has at most one employee as manager, but a manager can manage many departments: one-to-many relationship.
  - Similarly we can think of examples of *many-to-one* or *one-to-one* relationships.



Key Constraints

- The restriction that each department has at most one manager is an example of a key constraint.
- It implies that each department entity appears in *at most one* *Manages* relationship.



Translating Relationships with Key Constraints

- How do we translate *Manages* into a table?

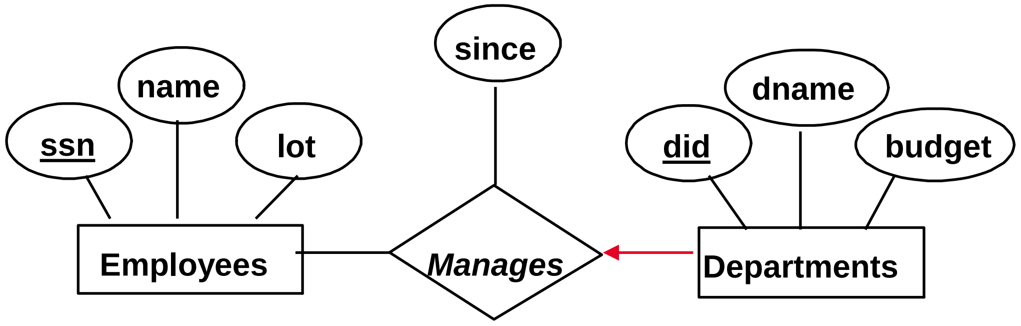
There are two alternative designs:

EITHER:

We could map *Manages* relationship to a separate table (like we did in the previous slide).

OR

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



1-to Many

Alternative 1: Separate Table for *Manages*

- Map *Manages* relationship to a table:
  - Note that did is the key now!
  - There are separate tables for *Employees* and *Departments*.

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

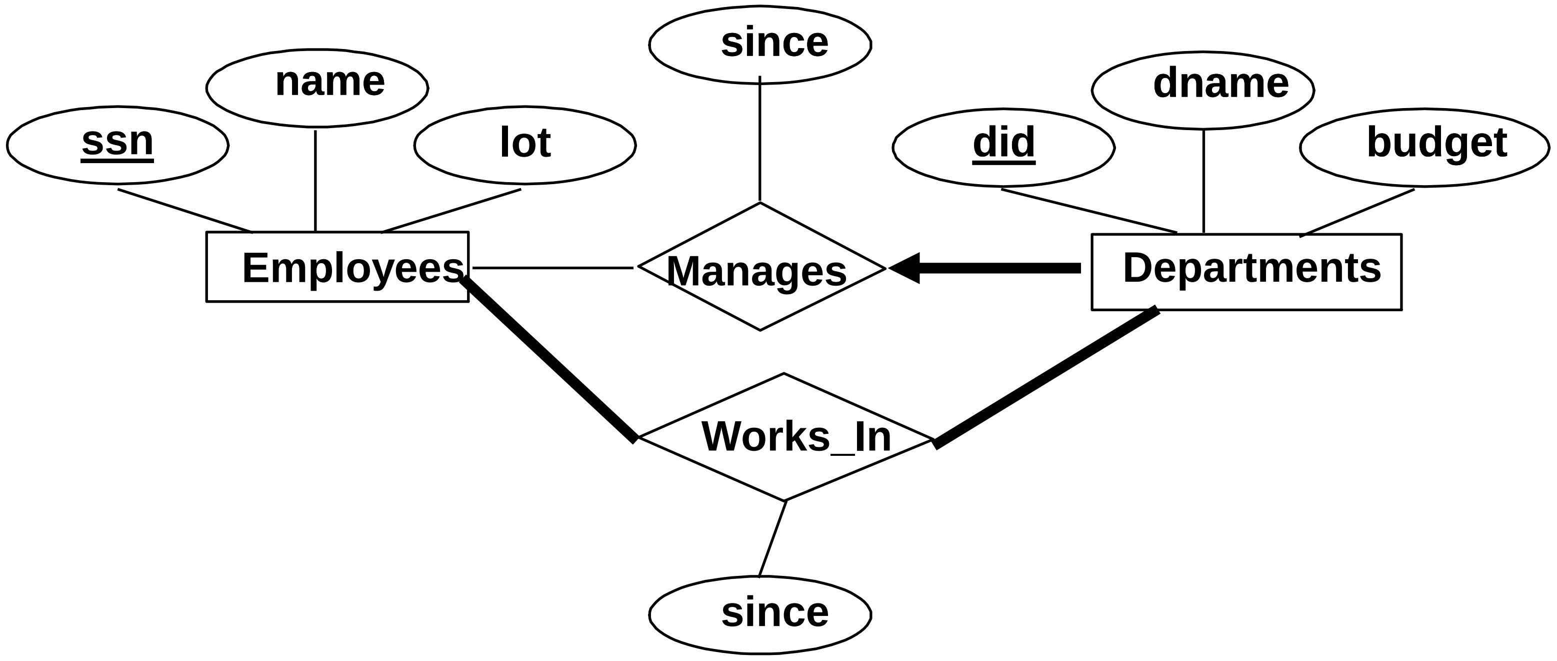
Alternative 2: Embed *Manages* relationship into *Departments* table

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

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

Participation Constraints

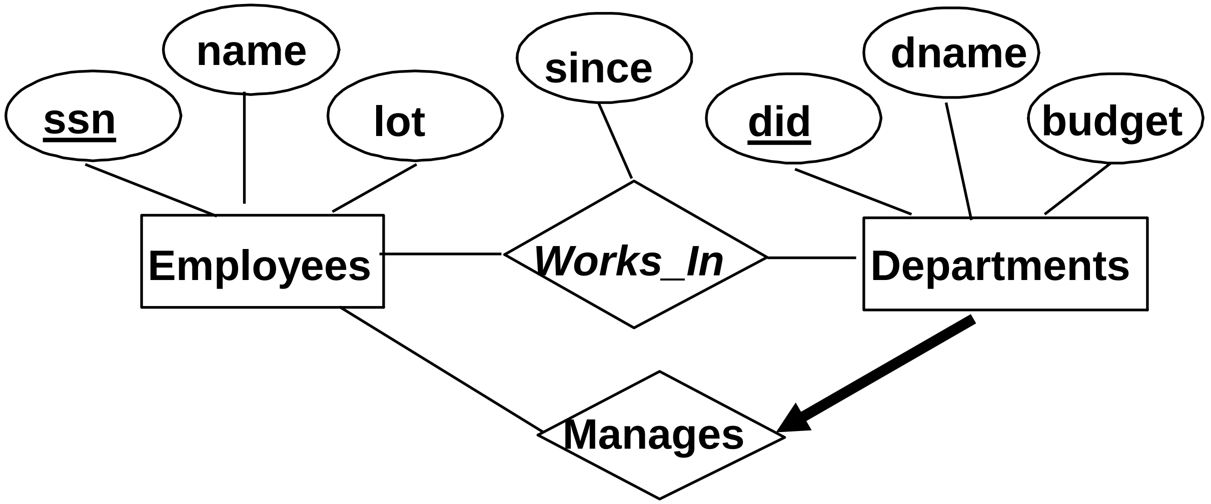
- Does every department have a manager?
  - If so, this is a **participation constraint**: the participation of *Departments* in *Manages* is said to be **total (vs. partial).**
    - Every *did* value in *Departments* table must appear in a row of the *Manages* table (with a non-null *ssn* value!)



Participation Constraints in SQL

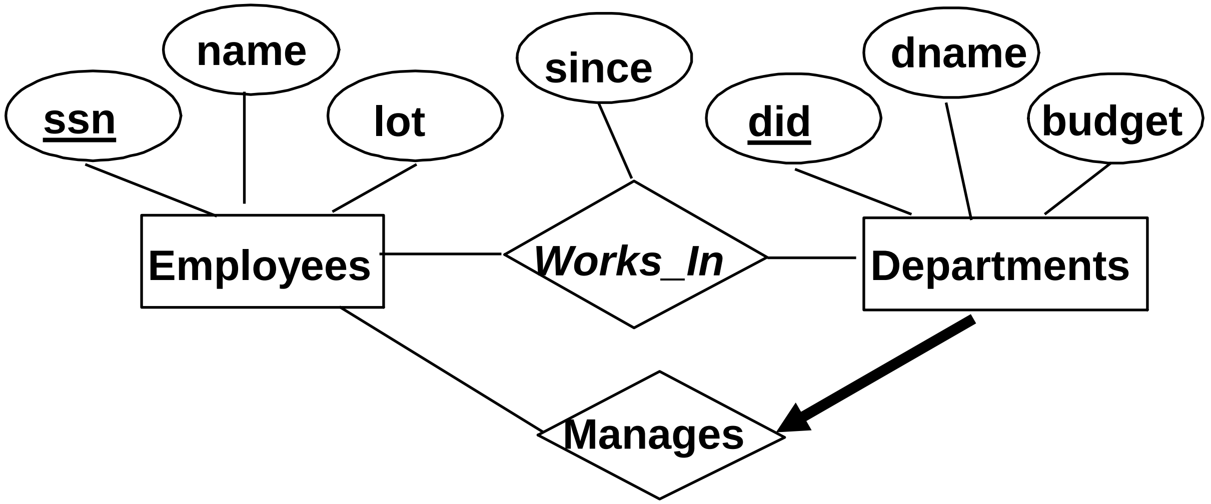
- We can capture participation constraints involving one entity set in a binary relationship, but little else (without resorting to CHECK constraints).

```
CREATE TABLE  Department(
   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)
```



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

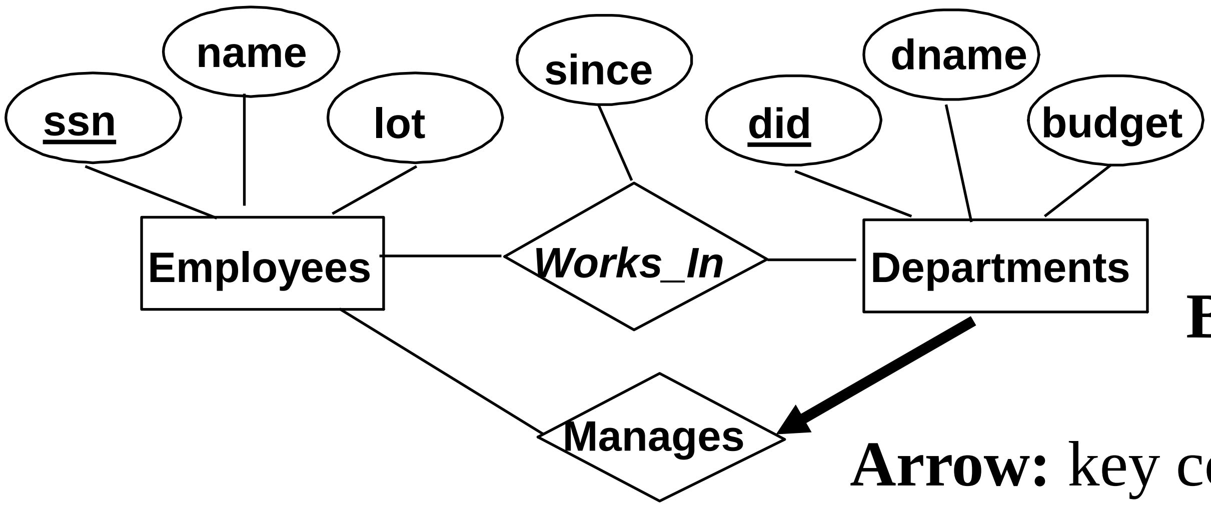
```
CREATE TABLE  Departments(
   did  INTEGER,
   dname  CHAR(20),
   budget  REAL,
   PRIMARY KEY  (did))
```



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

```
CREATE TABLE  Departments(
  did  INTEGER,
  dname  CHAR(20),
  budget  REAL,
  PRIMARY KEY  (did))
```

```
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)
```



Bold: total participation
at least one manager

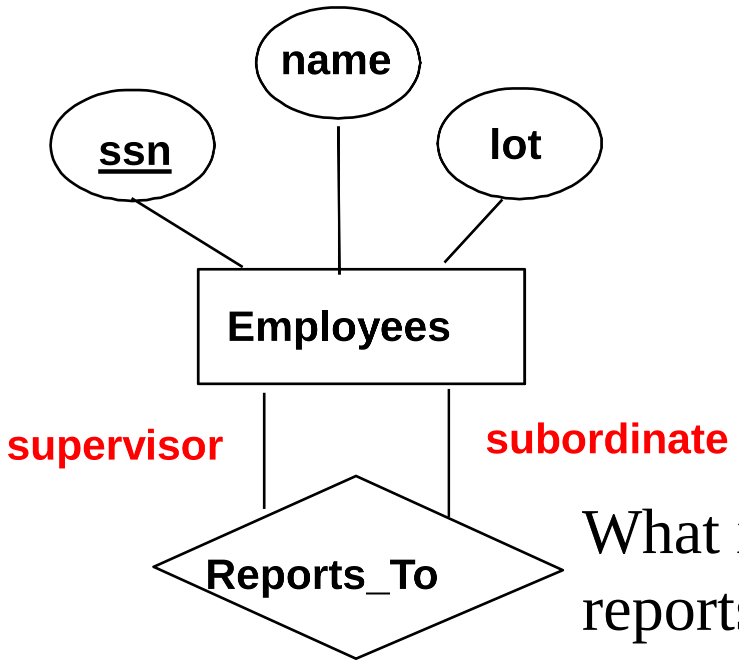
Arrow: key constraint
(1-M relationship); at most one manager

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

```
CREATE TABLE  Dept_Mans(
  did  INTEGER,
  dname  CHAR(20),
  budget  REAL,
  ssn  CHAR(11) NOT NULL,
  since  DATE,
  PRIMARY KEY  (did),
  FOREIGN KEY (ssn) REFERENCES Employees)
```

```
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)
```

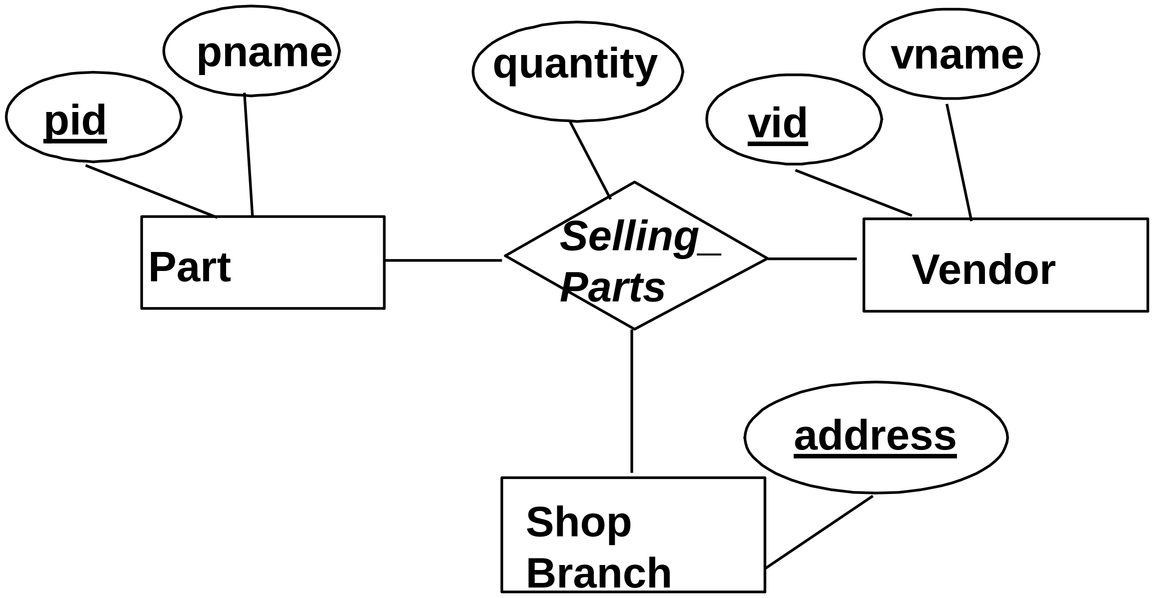
A binary relationship with roles



What if each employee (subordinate) reports to at most one employee (supervisor)?

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

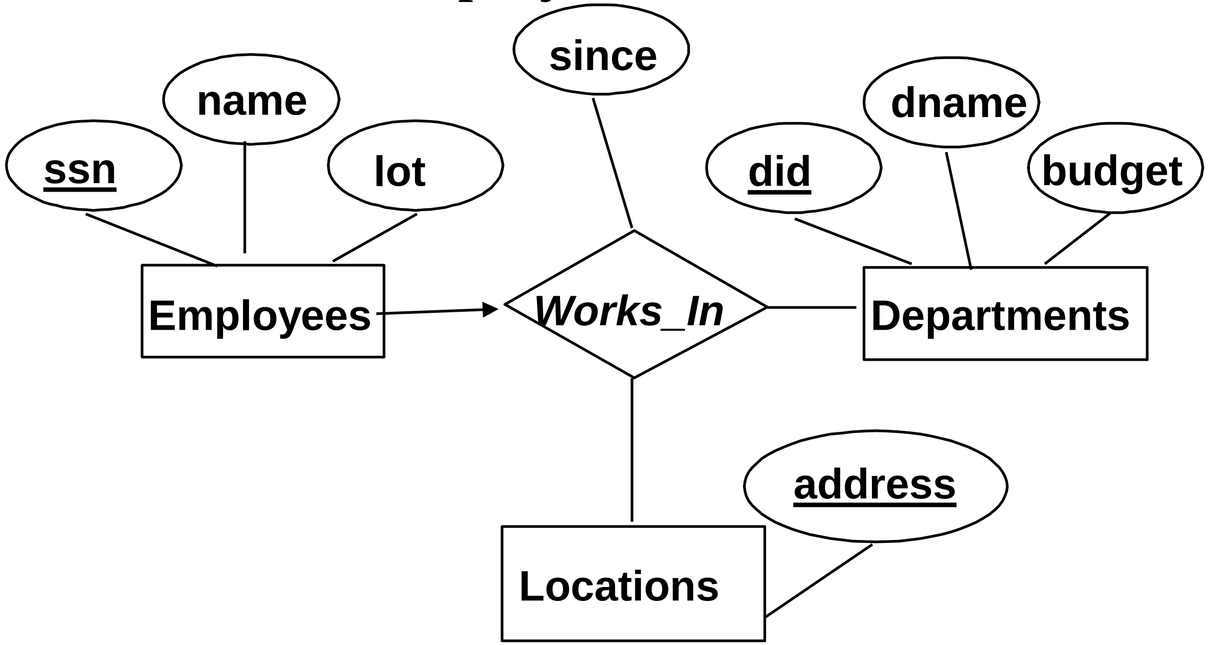
Translating a ternary relationship



<u>Selling_parts(pid, vid, address</u>, quantity)

Translating a ternary relationship

- Assume each employee *works in* at most one department and at a single location (but:
  - each dept can be associated with several locations and employees, and
  - each location can be associated with several departments and employees,

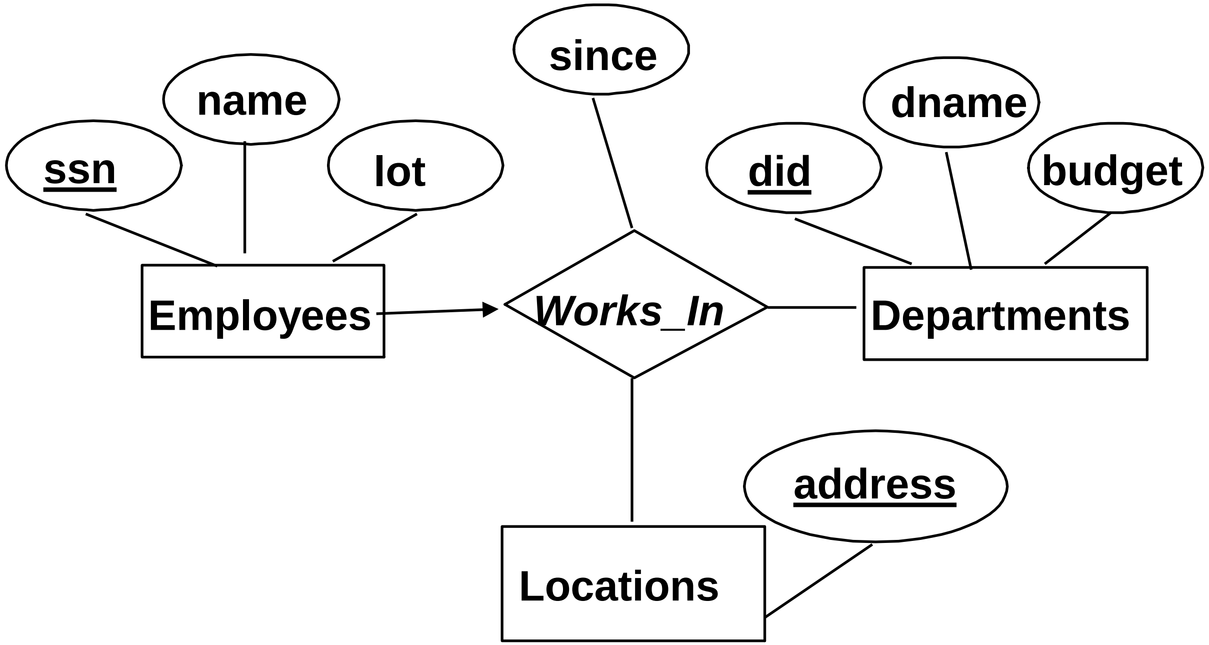


WorksIn

<u>ssn</u>	did	location
100	1	Ankara
200	1	Ankara
300	2	Ankara
400	2	İstanbul
500	3	İstanbul

Translating a ternary relationship

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

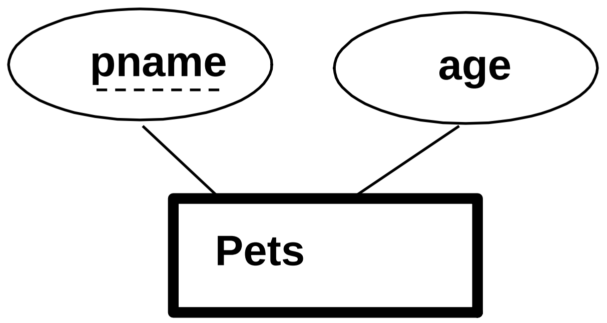


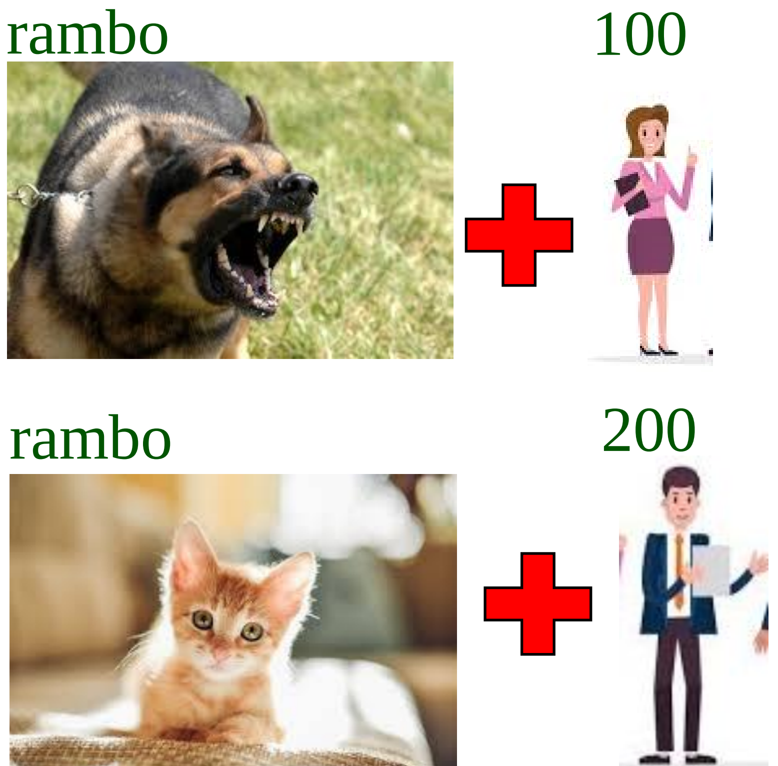
WorksIn

ssn	did	location
100	1	Ankara
200	1	Ankara
300	2	Ankara
400	2	İstanbul
500	3	İstanbul

Weak Entities

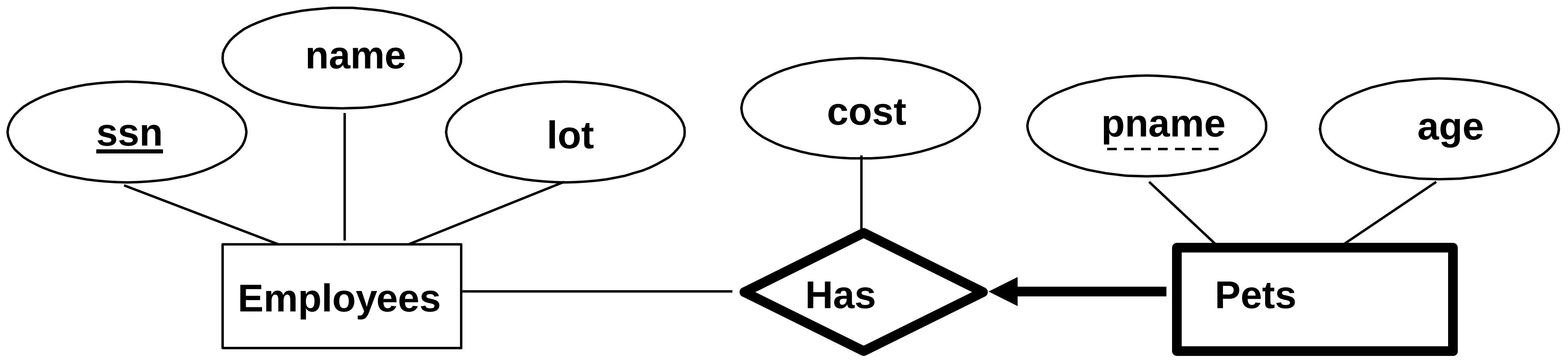
- A **weak entity** can be identified uniquely only by considering the primary key of another (*owner*) entity.
  - identified by its discriminator attributes (partial key) + PK of another (owner) entity
- Suppose our employees have pets, each pet has a name!





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 (one owner, many weak entities).
  - Weak entity set must have **total participation** in this **identifying** relationship set.



Translating Weak Entity Sets

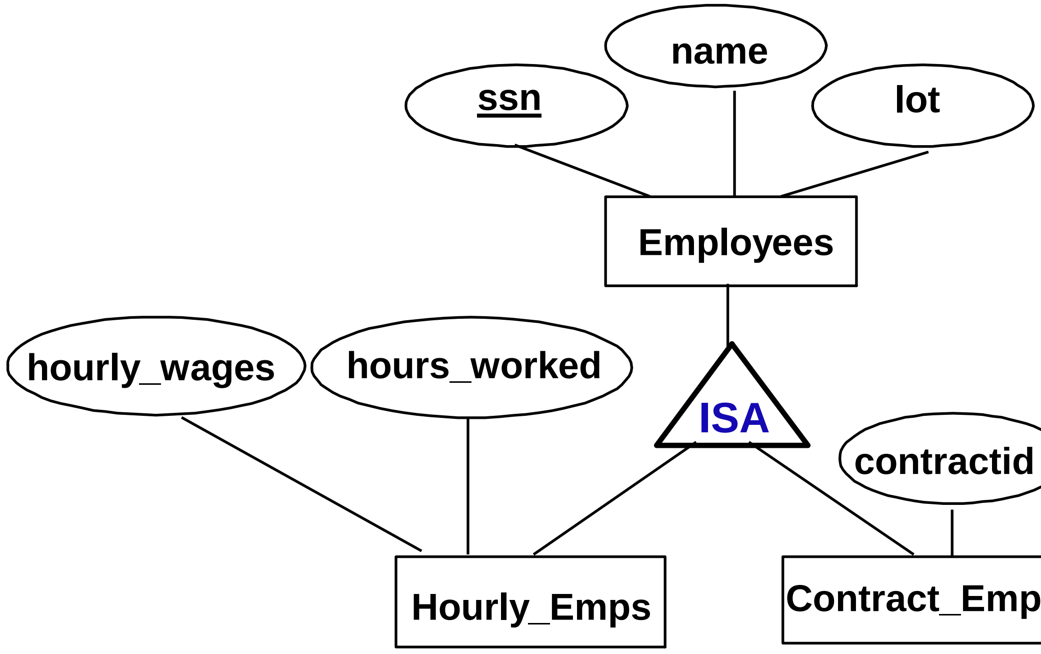
- Weak entity set and identifying relationship set are translated into a single table.
  - When the owner entity is deleted, all owned weak entities must also be deleted.

Do I need this?

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

ISA (`is a´) Hierarchies

- As in object-oriented programming languages, attributes are inherited.
  - If we declare A ISA B, every A entity is also considered to be a B entity.
- Reasons for using ISA:
  - To add descriptive attributes specific to a subclass.
  - To identify entities that participate in a relationship.



ISA (`is a´) Hierarchies

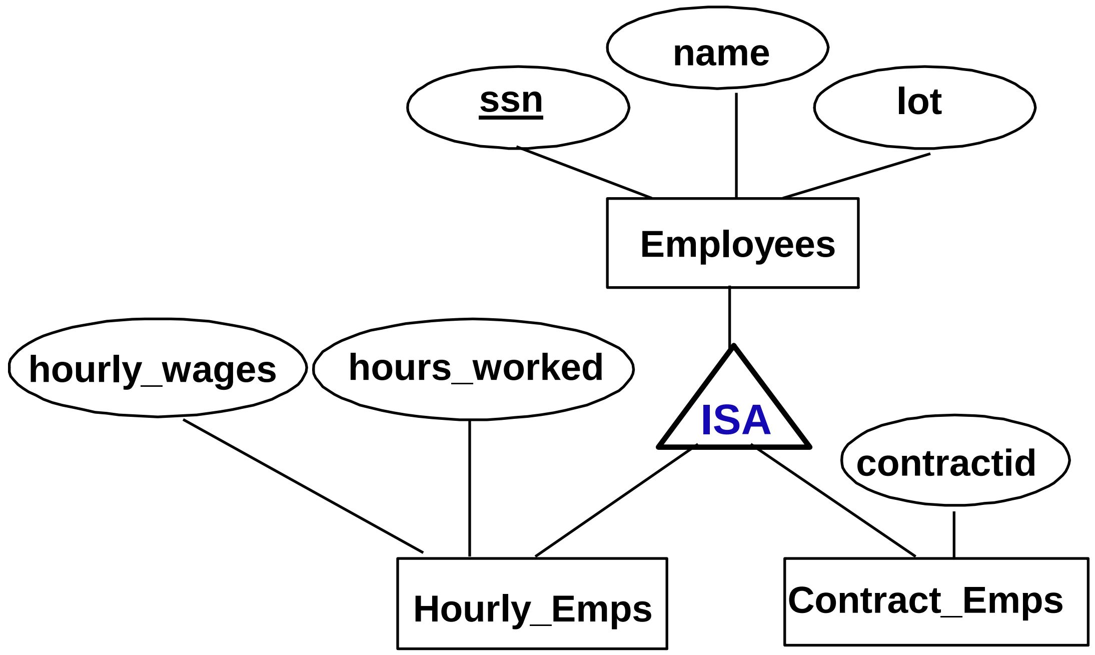
- **Overlap constraints**: Can Joe be an *Hourly_Emps* as well as a *Contract_Emps* entity? **(Allowed/disallowed)**

- **Covering constraints**: Does every *Employees* entity also have to be an *Hourly_Emps* or a *Contract_Emps* entity? **(Yes/no)**

Translating ISA Hierarchies to Relations

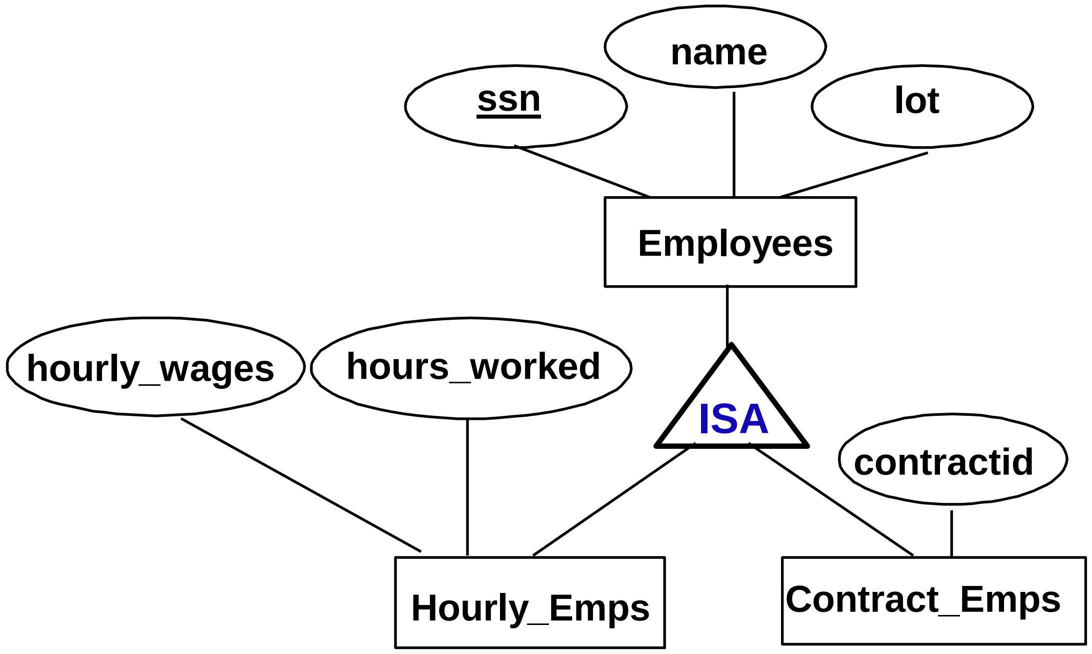
- **General approach:**
  - 3 relations: <u>Employees</u>, <u>Hourly_Emps</u> and <u>Contract_Emps</u>.
    - Hourly_Emps: Every employee is recorded in Employees. For hourly emps, extra info recorded in Hourly_Emps (hourly_wages, hours_worked, <u>ssn</u>); must delete Hourly_Emps tuple if referenced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

Translating ISA Hierarchies to Relations



- **First approach:**
  - 3 relations.
    - Employees(<u>ssn</u>, name, lot)
    - Hourly_Emps(<u>ssn</u>, hourly_wages, hours_worked)
    - Contract_Emps(<u>ssn</u>, contractid)
  - In Hourly_Emps & Contract_Emps tables:
    - FOREIGN KEY (ssn) REFERENCES Employees ON DELETE CASCADE

Translating ISA Hierarchies to Relations

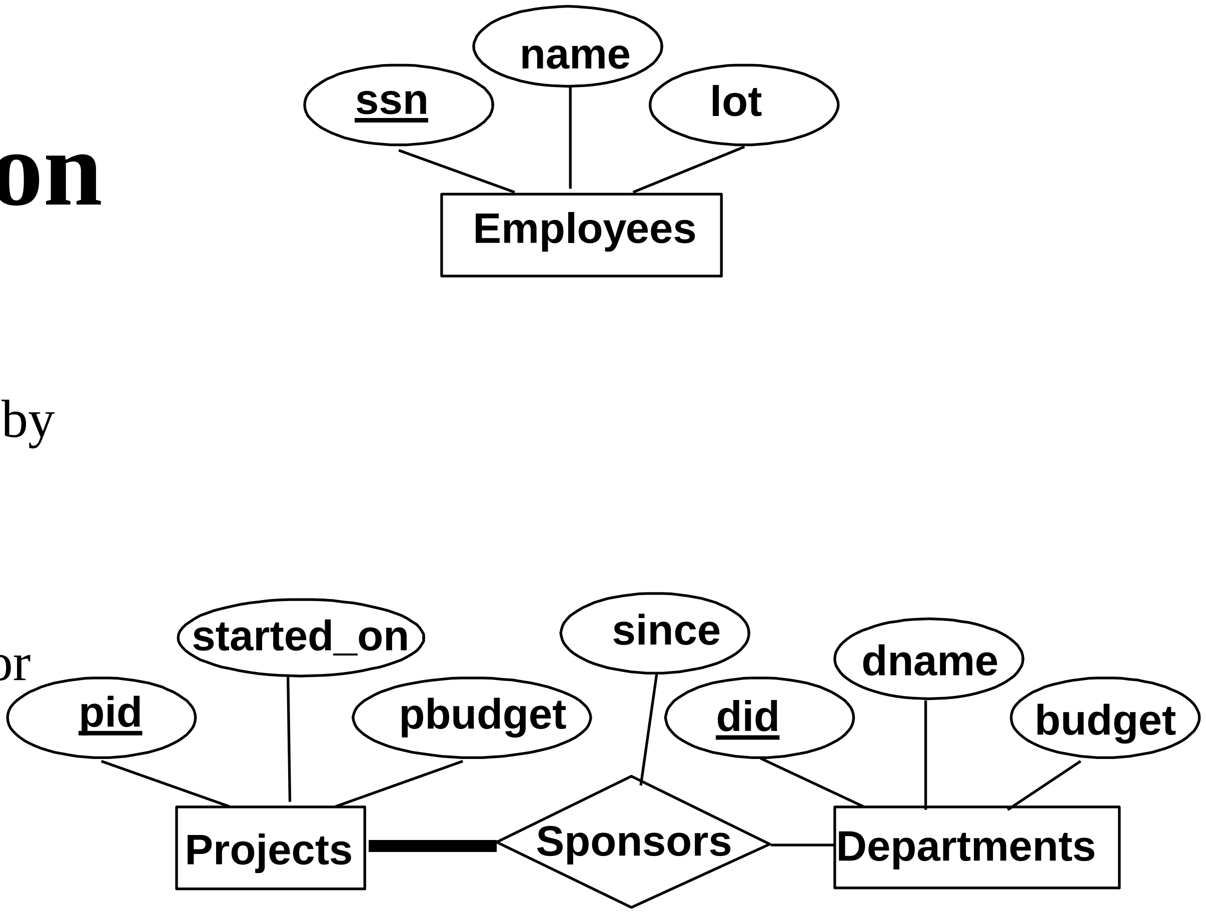


- **Second approach:**
  - 2 relations.
    - Hourly_Emps(ssn, name, lot, hourly_wages, hours_worked)
    - Contract_Emps(ssn, name, lot, contractid)
  - Not applicable if not "covering"

Aggregation

Suppose:

- entity set *Projects*
- each *Projects* is sponsored by at least one *Departments*
- each *Departments* that sponsors a *Projects* might assign employees to monitor sponsorship

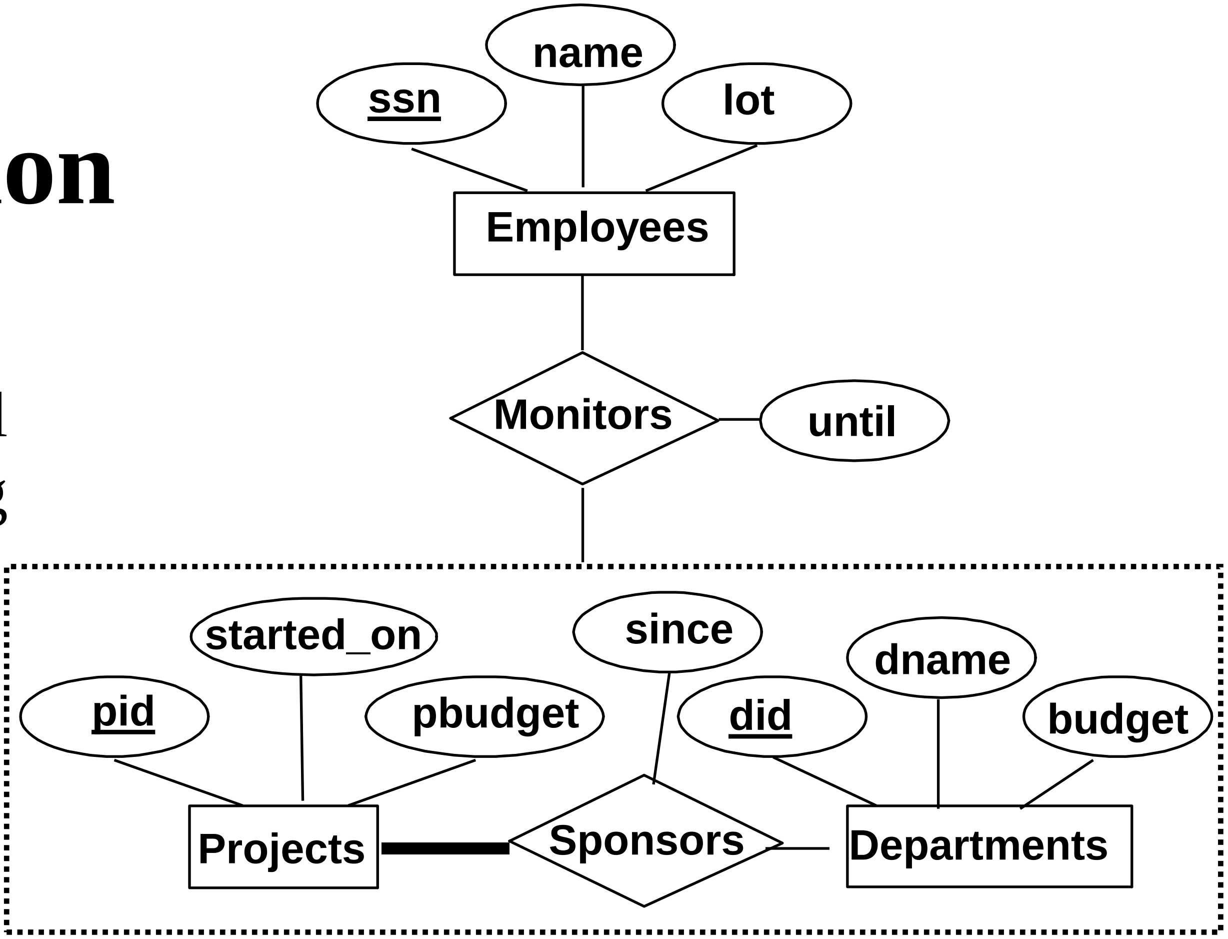


Intuitively…

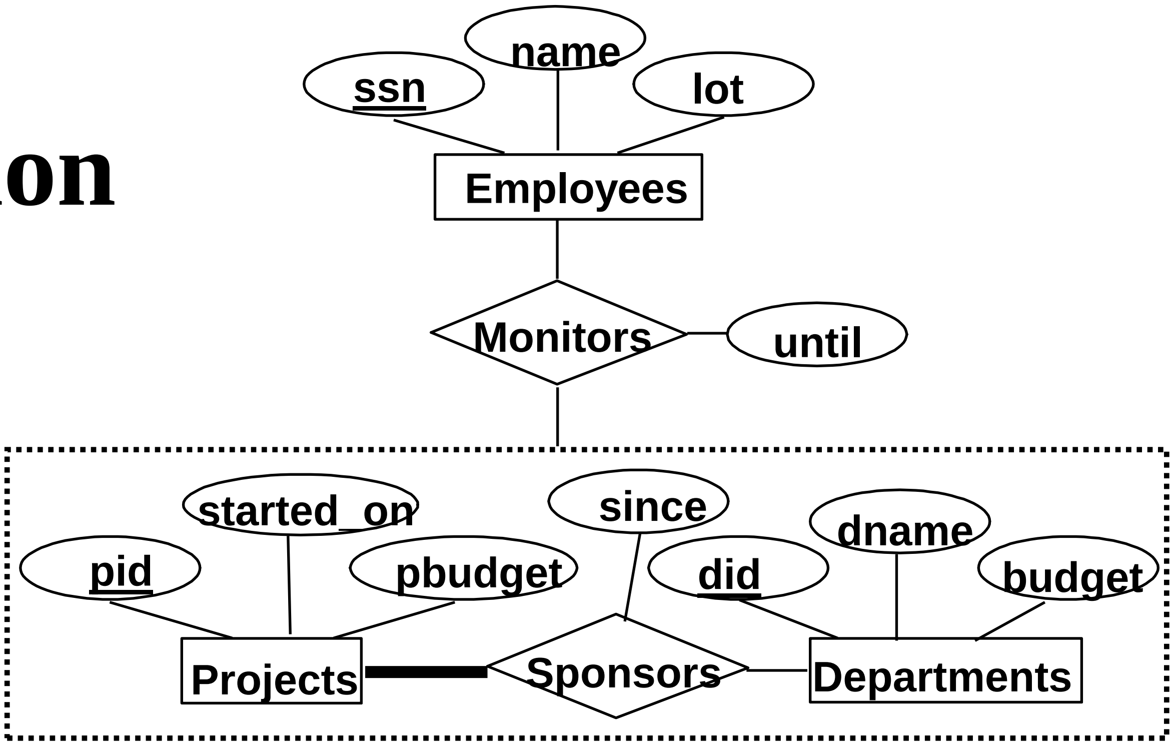
- *Monitors* should be a relationship set that associates a *Sponsors* relation (versus a *Projects* or *Departments*) with an *Employees* entity.

Aggregation

- Aggregation is used when we have to model a relationship involving (entity sets and) a relation: a *relationship set*.
- **Aggregation** allows us to treat a relationship set as an entity set for purposes of participation in (other) relationships.



Aggregation



- Mapping to Relational Model:

Employees(<u>ssn</u>, name, lot)

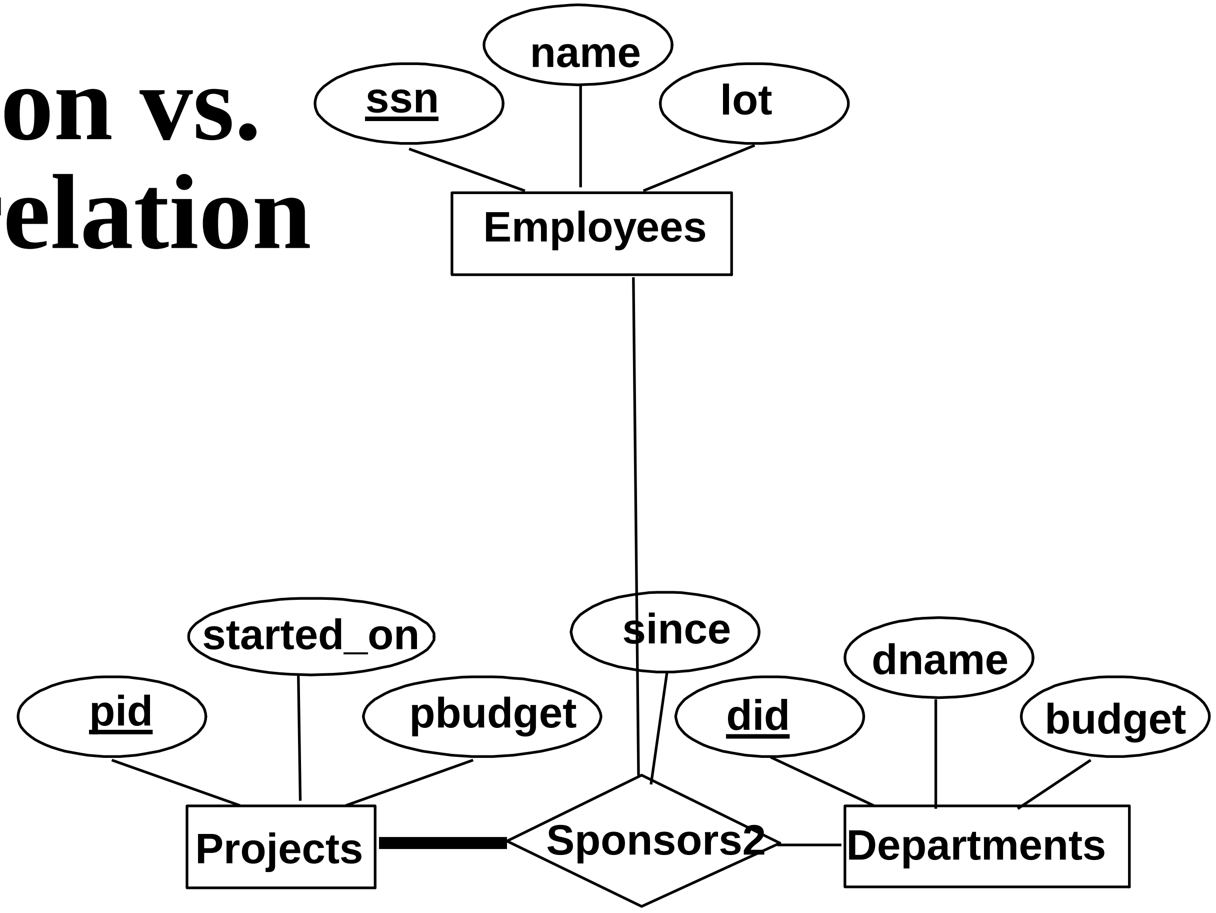
Projects(<u>pid</u>, started_on, pbudget)

Departments(<u>did</u>, dname, budget)

Sponsors(<u>pid, did</u>, since)

Monitors(<u>ssn, pid, did</u>, until)

Aggregation vs. Ternary relation



Suppose:

- No need to record *until* attribute of *Monitors*

- Then…
  - Can use ternary relationship *Sponsors2*

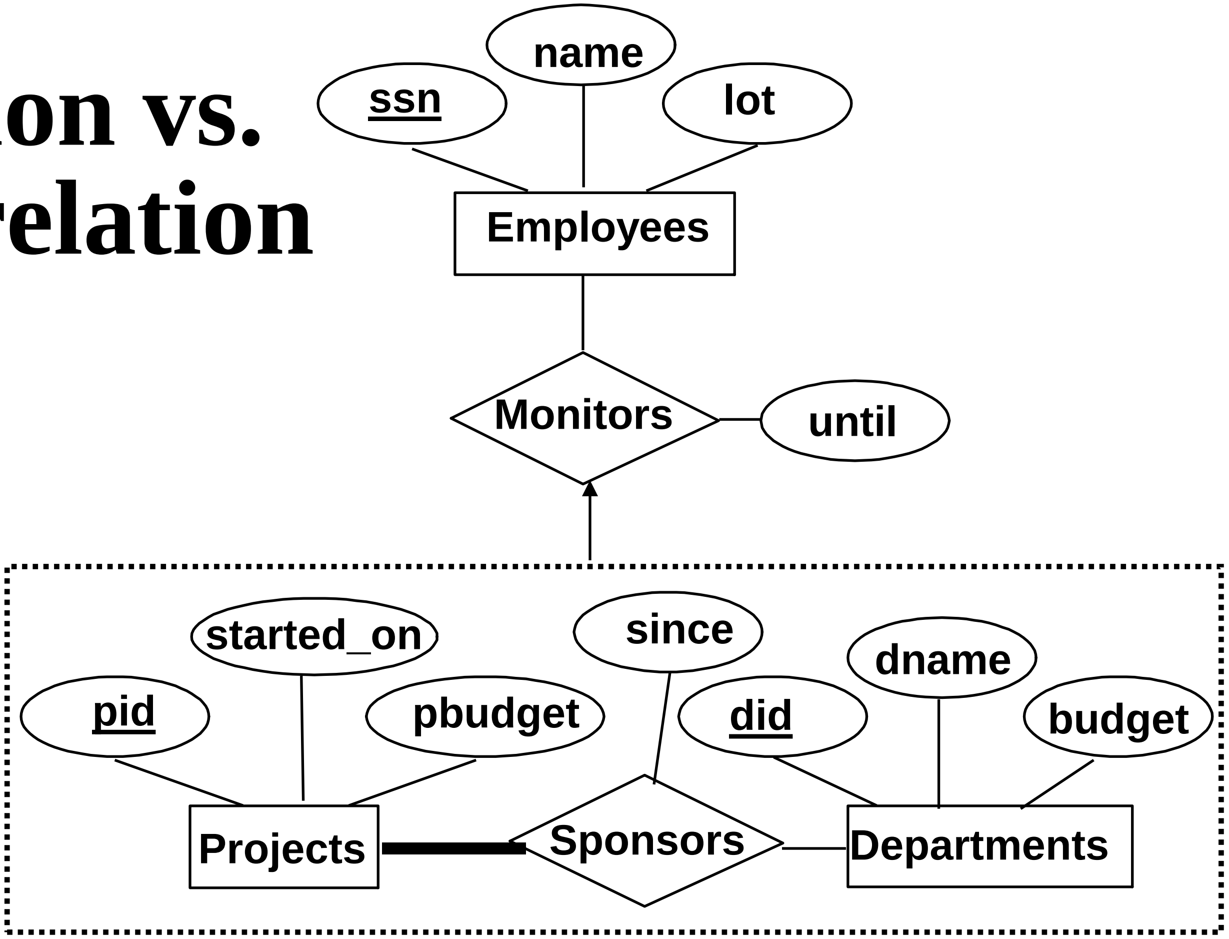
But suppose we have constraint that:

Each sponsorship (of a project by a department) be monitored by at most one employee?

Then…

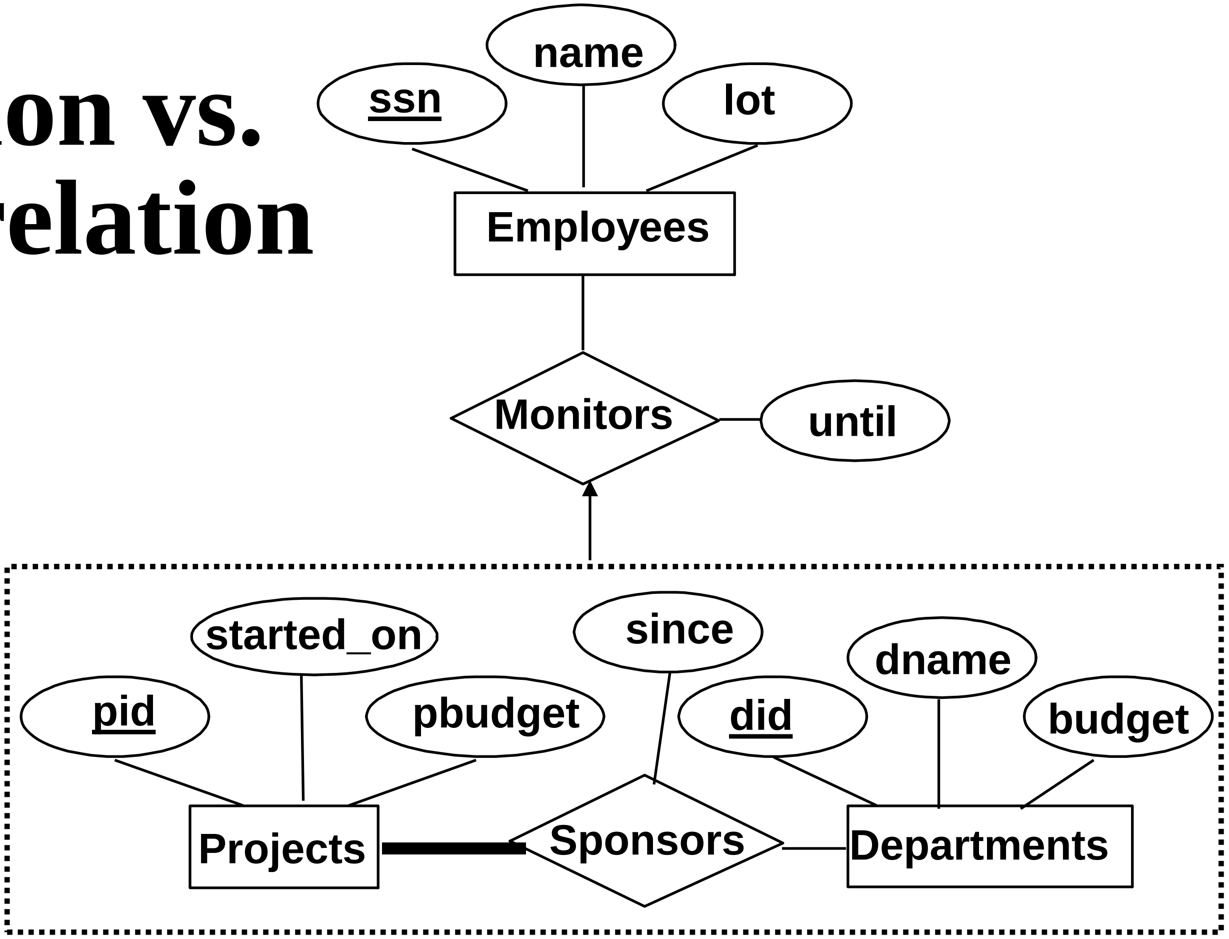
Can’t do it with *Sponsors2* → Need aggregated relationship *Sponsors*

Aggregation vs. Ternary relation (Contd.)



- *Monitors* is a distinct relationship, with a descriptive attribute (*until*).
- Also, can say that each sponsorship is monitored by at most one employee.

Aggregation vs. Ternary relation (Contd.)



- Mapping:

Projects(<u>pid</u>, started_on, pbudget)

Departments(<u>did</u>, dname, budget)

Sponsors(<u>pid, did</u>, since)

Employees(<u>ssn</u>, name, lot)

Monitors(<u>pid, did</u>, ssn, until) Where does pid and did refer to?

Conceptual Design Using the ER Model

- **Design choices:**
  - Should a concept be modeled as an entity or an attribute?
  - Should a concept be modeled as an entity or a relationship?
  - Identifying relationships: Binary or ternary? Aggregation?
- Constraints in the ER Model:
  - A lot of data semantics can (and should) be captured.
  - But some constraints cannot be captured in ER diagrams.

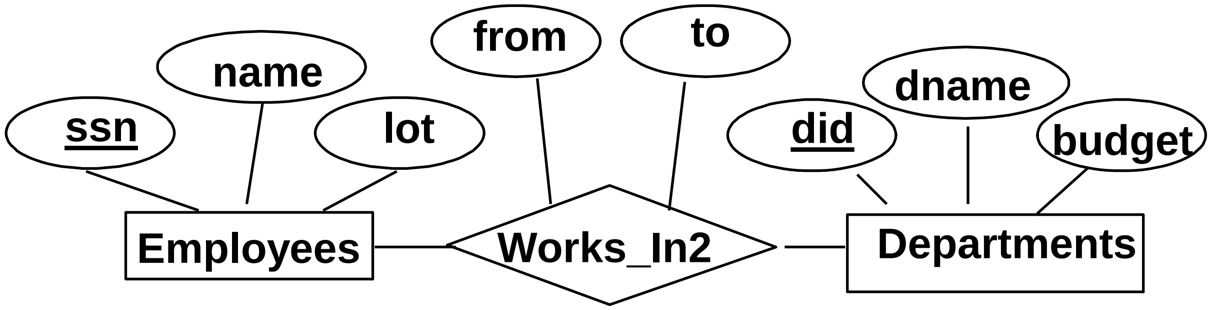
Entity vs. Attribute

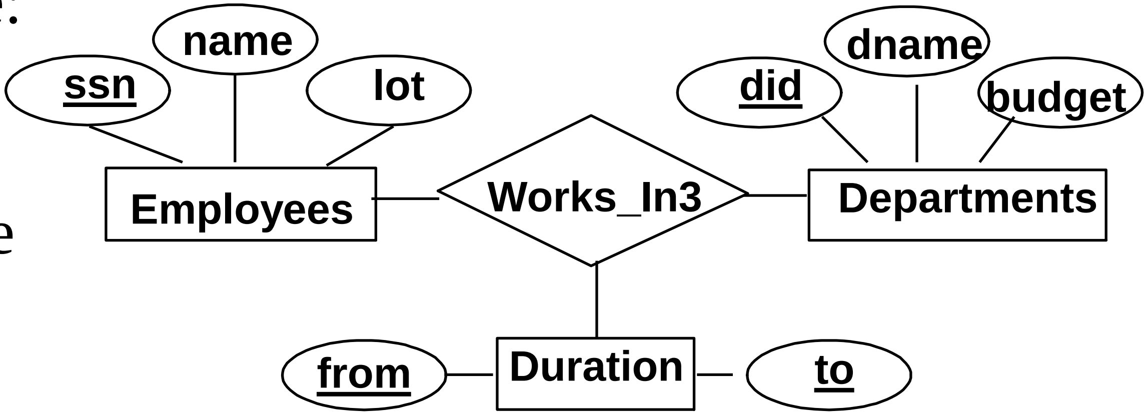
- Should **address** be an attribute of Employees or an entity (connected to Employees by a relationship)?

- Depends upon the use we want to make of address information, and the semantics of the data:
    - If we have several addresses per employee, *address* must be an entity (since attributes cannot be set-valued).
    - If the structure (city, street, etc.) is important, e.g., we want to retrieve employees in a given city, *address* must be modeled as an entity (since attribute values are atomic).

Entity vs. Attribute (Cont.)

- Works_In2 does not allow an employee to work in a department for two or more periods.
- Similar to the problem of wanting to record several addresses for an employee: we want to record several values of the descriptive attributes for each instance of this relationship.

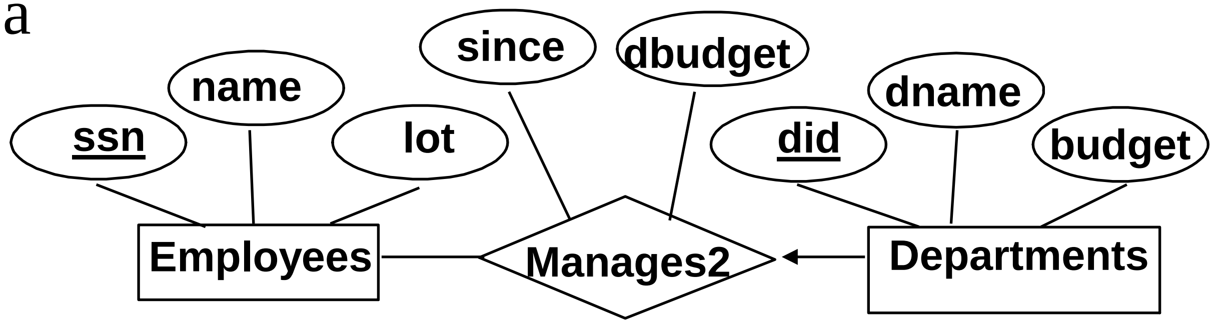


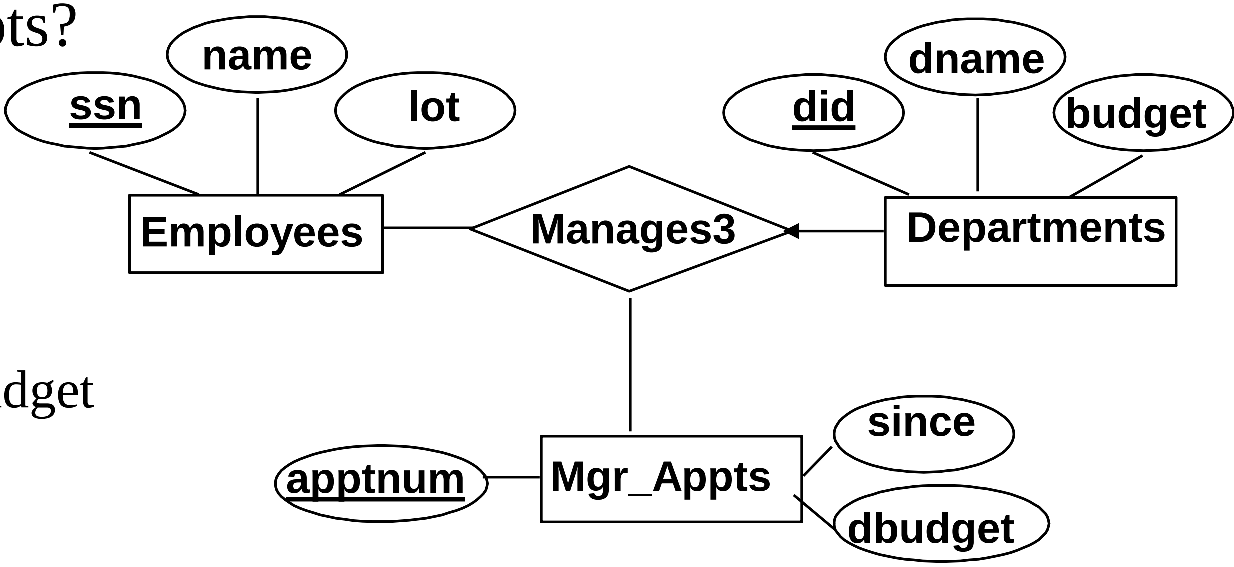


Entity vs. Relationship

- First ER diagram OK if a manager gets a separate discretionary budget for each dept.
- What if a manager gets a discretionary budget that covers all managed depts?
  - Redundancy of budget, which is stored for each dept managed by the manager.

Misleading: suggests dbudget tied to managed dept.

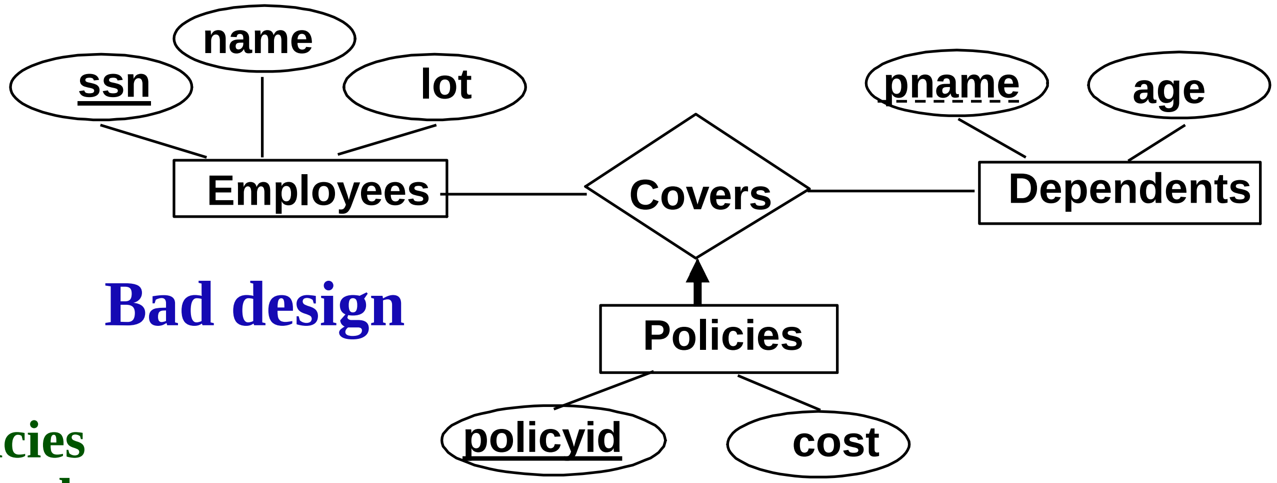




Binary vs. Ternary Relationships

Suppose that:

- a policy cannot be owned jointly by two or more Employee:



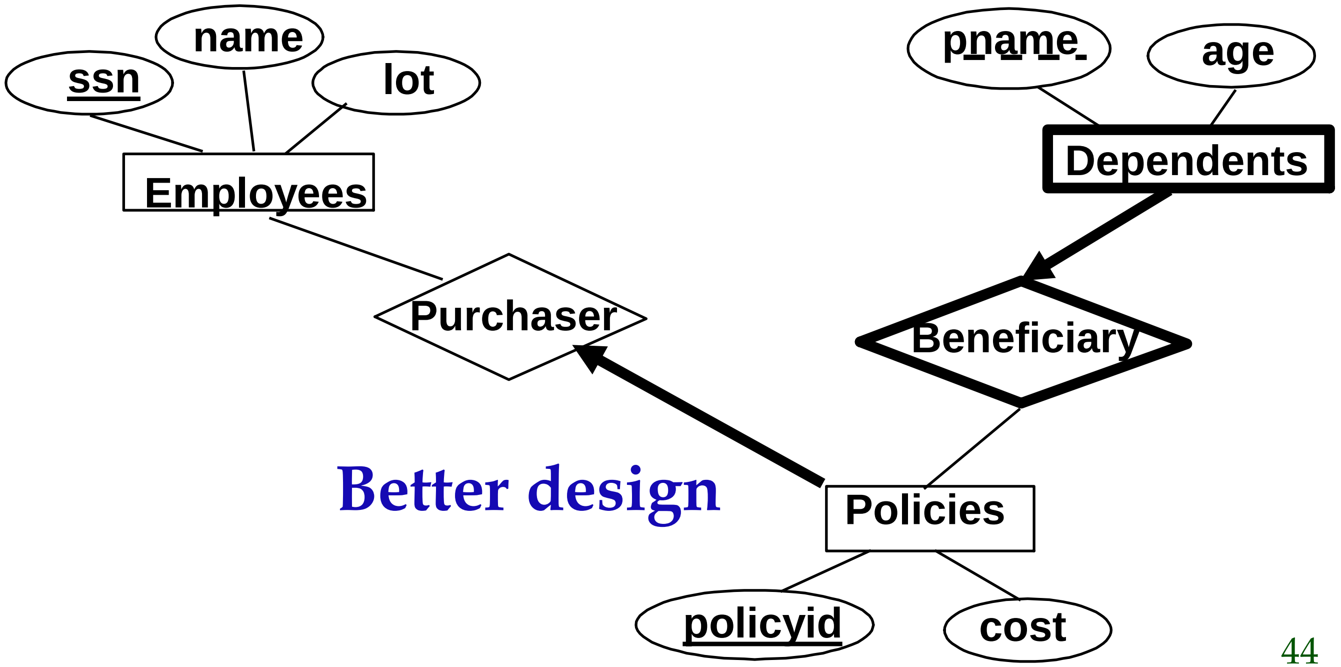
Bad design

–Key constraint on Policies would mean policy can only cover 1 dependent!

- Suppose that:
  - Every policy must be owned by some employee
- Acceptable if each policy covers at least one dependent

Binary vs. Ternary Relationships (Cont.)

- What are the additional constraints in this 2nd diagram?
  - –Policy cannot be owned jointly by two or more employees
  - –Every policy must be owned by some employee
  - –Dependent is a weak entity set, and each dependent entity is uniquely identified by taking pname in conjunction with the policyid of a policy.
  - –Dependents cannot be beneficiary of more than one policy.



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.
- What if Policies is a weak entity set?

```
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 (Cont.)

- Previous example illustrated a case when two binary relationships were better than one ternary relationship.
- An example in the other direction: a ternary relation **Contracts** relates entity sets **Parts, Departments** and **Suppliers,** and has descriptive attribute *qty*.
- No combination of binary relationships is an adequate substitute for at least two reasons:
  - S "can-supply" P, D "needs" P, and D "deals-with" S does not imply that D has agreed to buy P from S.
  - How do we record *qty*?

Summary of Conceptual Design

- *Conceptual design* follows *requirements analysis*,
  - Yields a high-level description of data to be stored
- ER model popular for conceptual design
  - Constructs are expressive, close to the way people think about their applications.
- Basic constructs: *entities*, *relationships*, and *attributes* (of entities and relationships).
- Some additional constructs: *weak entities*, *ISA hierarchies*, and *aggregation*.
- Note: There are many variations on ER model.

Summary of ER (Contd.)

- Several kinds of integrity constraints can be expressed in the ER model: **key constraints, participation constraints, and overlap/covering constraints** for ISA hierarchies. Some **foreign key constraints** are also implicit in the definition of a relationship set.
  - Some constraints (notably, **functional dependencies**) cannot be expressed in the ER model.
  - Constraints play an important role in determining the best database design for an enterprise.

Summary of ER (Contd.)

- ER design is *subjective*. There are often many ways to model a given scenario! Analyzing alternatives can be tricky, especially for a large enterprise. Common choices include:
  - Entity vs. attribute, entity vs. relationship, binary or n-ary relationship, whether or not to use ISA hierarchies, and whether or not to use aggregation.
- Ensuring good database design: resulting relational schema should be analyzed and refined further. FD information and normalization techniques are especially useful.

Example

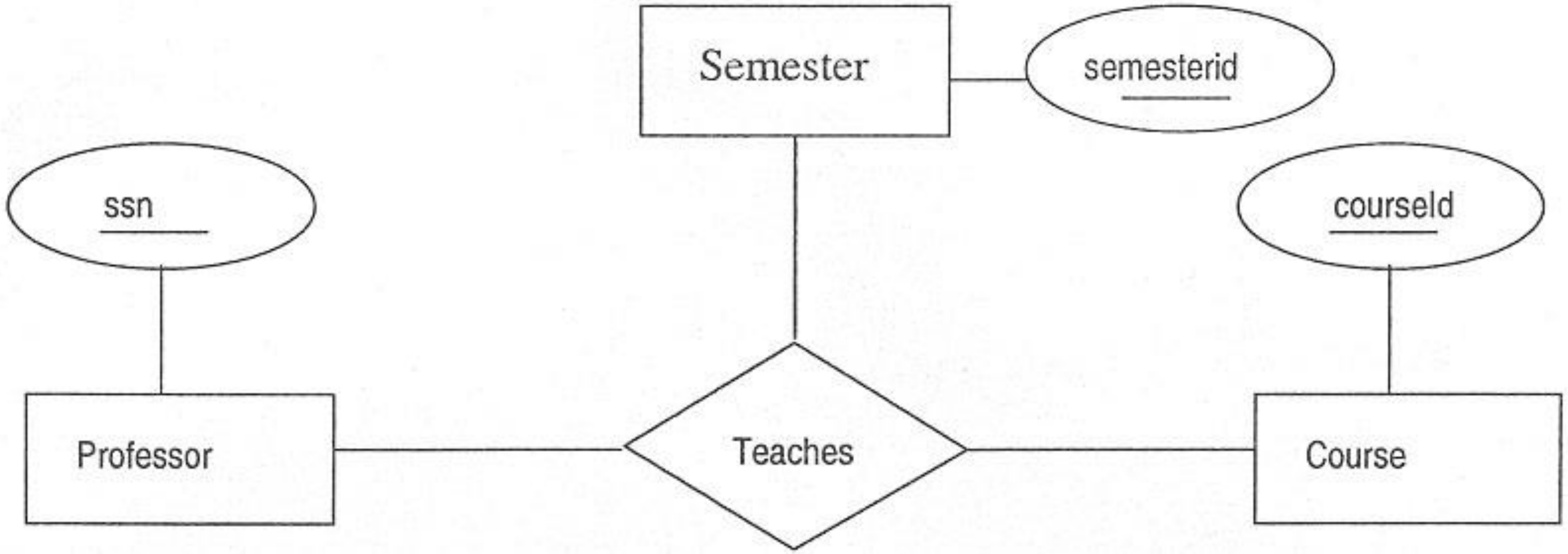
- A University database contains information about **professors** (identified by social security number, or *SSN*) and **courses** (identified by *courseid*). Professors teach courses.
- Each of the following situations concerns the **Teaches** relationship set. For each situation, draw an ER diagram that describes it (assuming that no further constraints hold).

Example (cont')

1) Professors can teach the same course in several semesters, and each offering must be recorded.
2) Professors can teach the same course in several semesters, and only the most recent such offering needs to be recorded. (Assume this condition applies to all subsequent questions.)
3) Every professor must teach some course
4) Every professor teaches exactly one course (no more, no less).
5) Every professor teaches exactly one course (no more no less), and every course must be taught by some professor.
6) Now assume that certain courses can be taught by a team of professors jointly, but it is possible that no one professor in a team can teach the course. Model this situation introducing additional entity sets and relationship sets if necessary.

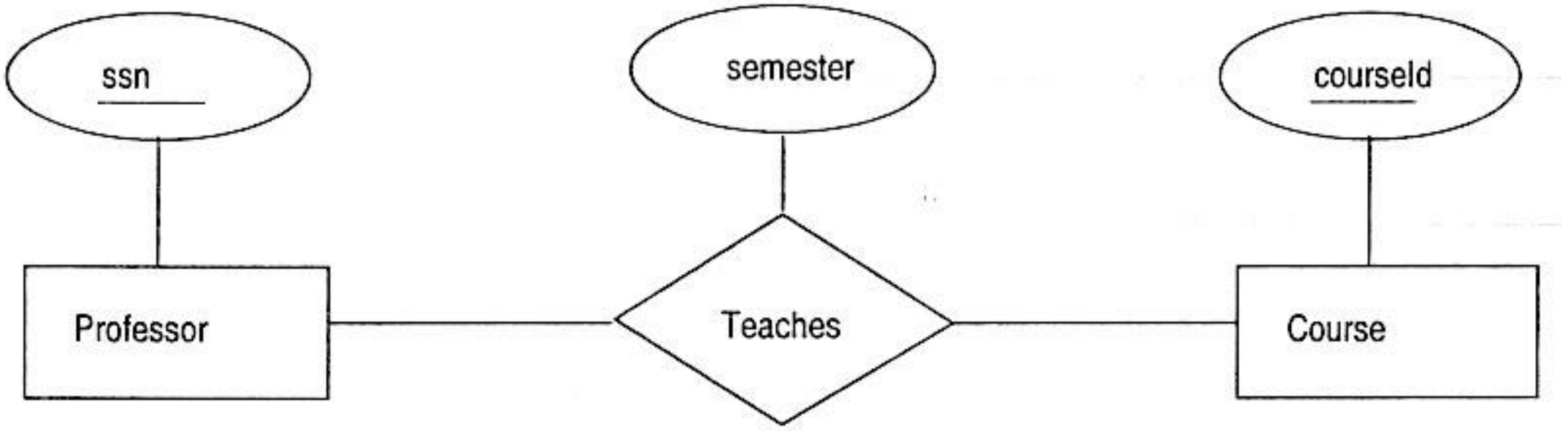
Example (cont')

1) Professors can teach the same course in several semesters, and each offering must be recorded.



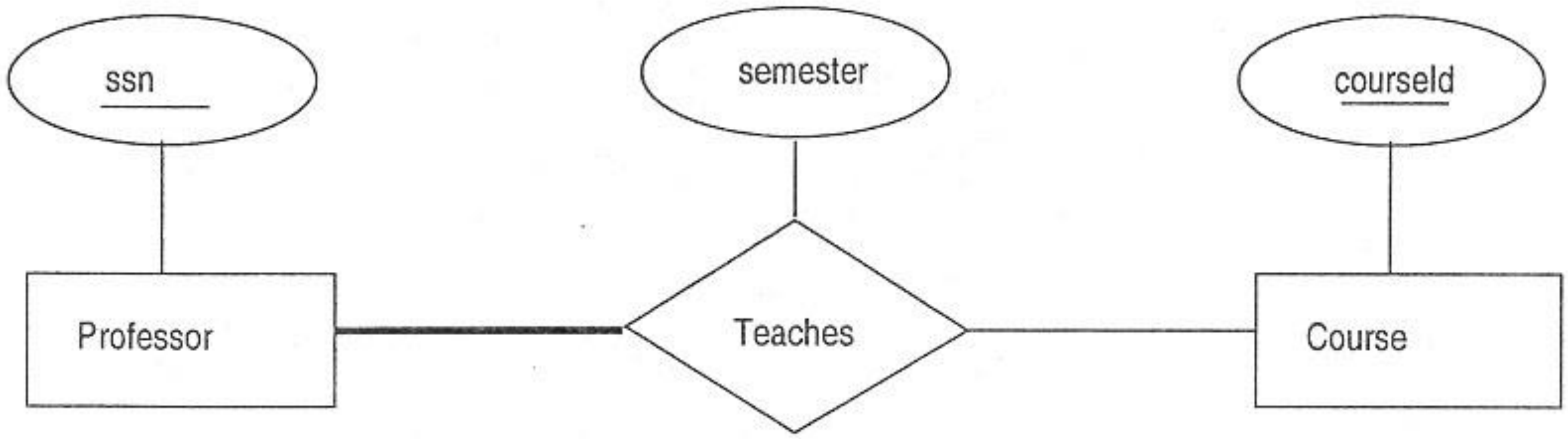
Example (cont')

2) Professors can teach the same course in several semesters, and only the most recent such offering needs to be recorded. (Assume this condition applies to all subsequent questions.)



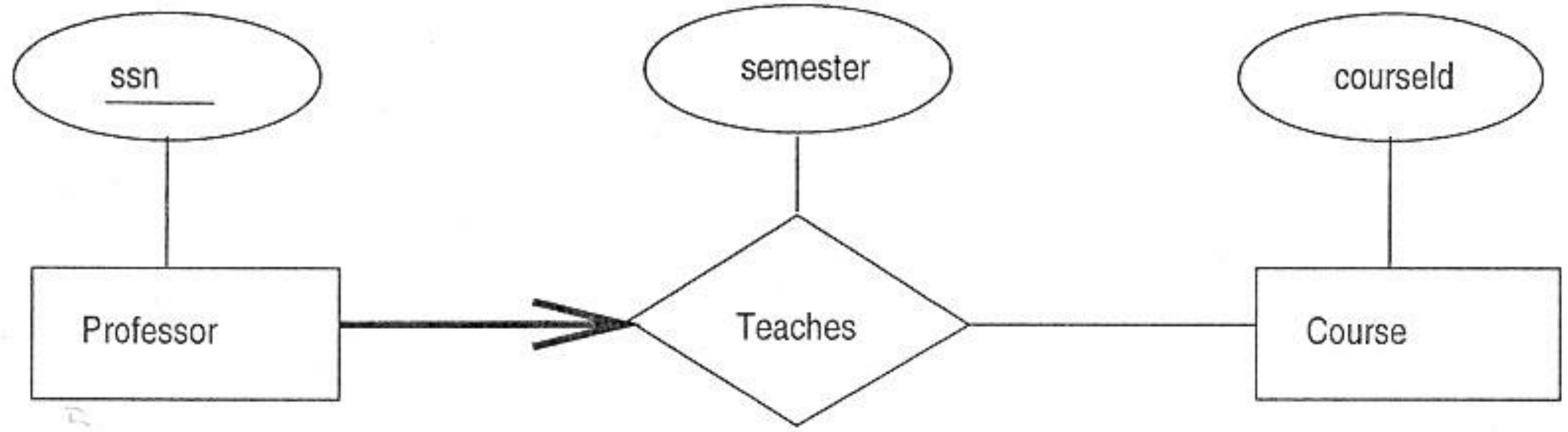
Example (cont')

3) Every professor must teach some course



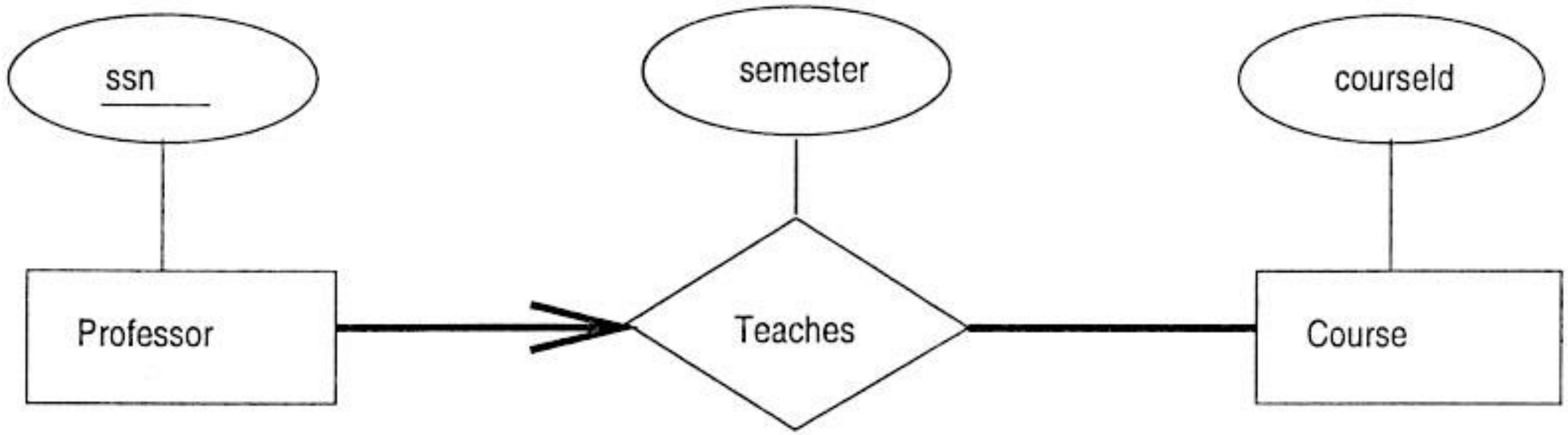
Example (cont')

4) Every professor teaches exactly one course (no more, no less).



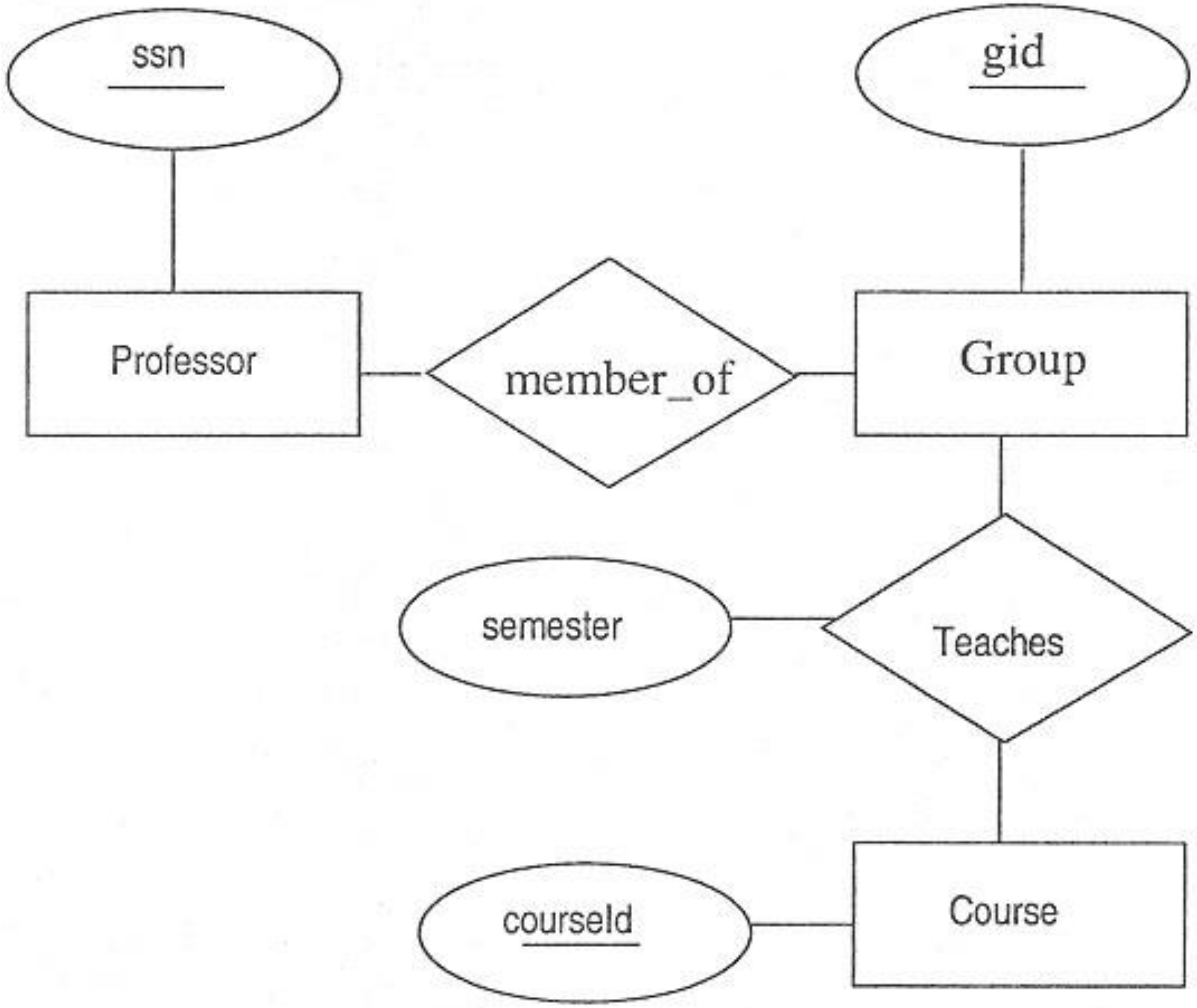
Example (cont')

5) Every professor teaches exactly one course (no more no less), and every course must be taught by some professor.



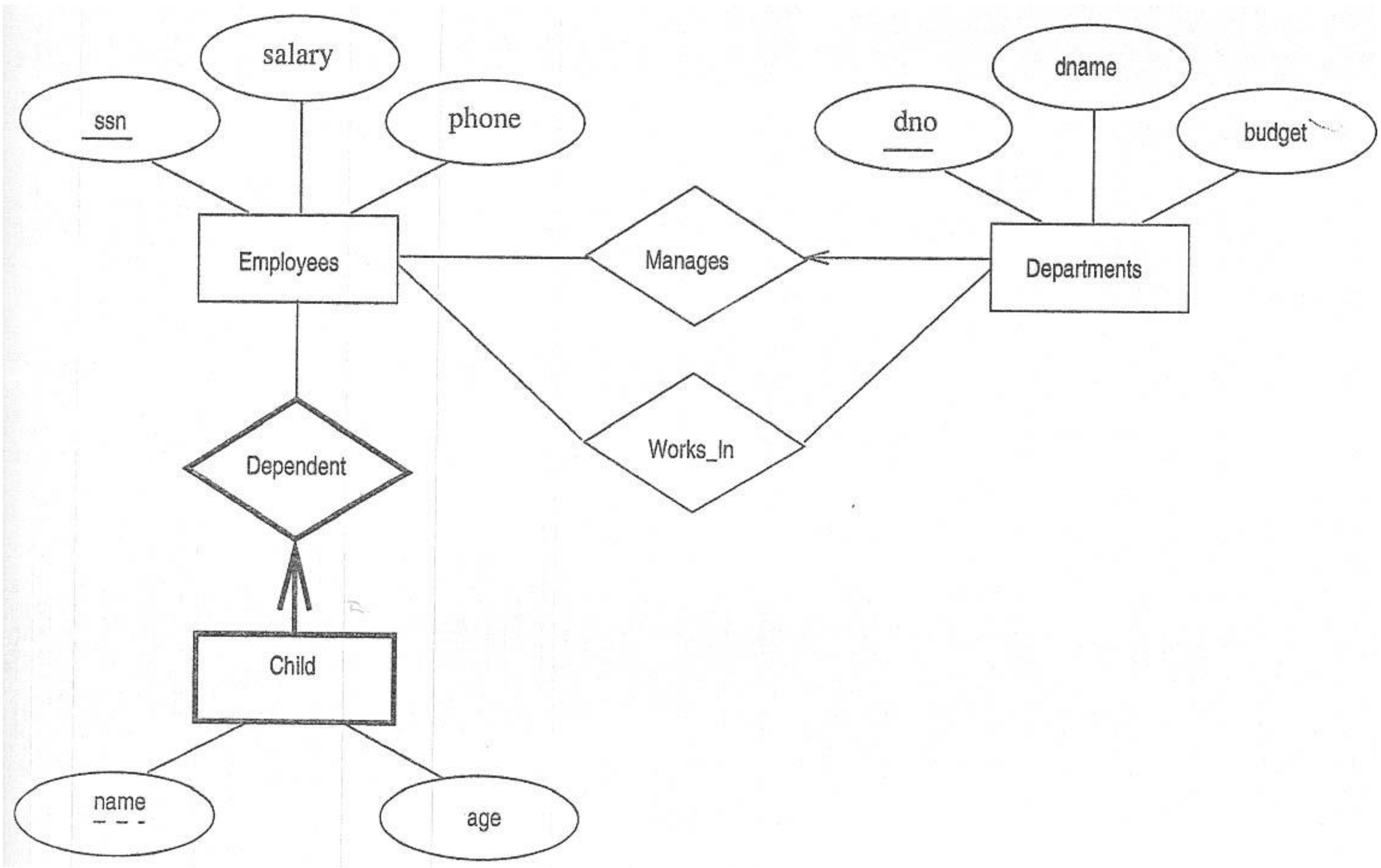
Example (cont')

6) Now assume that certain courses can be taught by a team of professors jointly, but it is possible that no one professor in a team can teach the course. Model this situation introducing additional entity sets and relationship sets if necessary.


ssn
gid
Professor
member_of
Group
semester
Teaches
courseId
Course

Example

- A company database needs to store information about employees (identifyied by ssn, with salary and phone as attributes); departments (identified by dno, with dname and budget as attributes); and children of employees (with name and age as attributes). Employees work in departments; each department is managed by an employee; a child must be identified uniquely by name when the parent (who is an employee; assume that only one parent works for the company) is known. We are not interested in information about a child once the parent leaves the company.


salary
ssn
phone
dname
dno
budget
Employees
Manages
Departments
Works_In
Dependent
Child
name
age