CS460: Intro to Database Systems

Class 4: *The Relational Model*

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https://bu-disc.github.io/CS460/

Context: Overall Database Design Process

Requirements Analysis

user needs; what must database do?

Last time → Conceptual Design

high level description (often done w/ER model)

Today: Logical Design

translate ER into DBMS data model

Schema Refinement

consistency, normalization

Physical Design

indexes, disk layout

Security Design

who accesses what

The Relational Model

Intro & SQL overview

Keys & Integrity Constraints

ER to Relational

ISA to Relational

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Why the Relational Model?

most widely used model

IBM, Microsoft, Oracle, etc.

”Legacy systems” in older models

e.g., IBM’s IMS

object-relational model incorporates oo concepts

IBM DB2, Oracle 11i

more recently: key-value store

Relational	Key/Value
tables with rows and columns	collections of documents
well-defined schema	schema-less (each document can have different schema)
data model fits data rather than functionality	data stored in an application-friendly way
deduplication	possible duplication

based on a table from http://readwrite.com

Relational Database: Definitions

relational database: a collection (set) of *relations*

each relation: made up of 2 parts

schema: name of relation, name & type of each column

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

instance : a *table,* with rows and columns.

#rows = *cardinality*

#fields = *degree / arity*

can think of a relation as a *set* of rows or *tuples*

(1) all rows are distinct

(2) no order among rows

Instance of Students Relation

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@cs	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* (a.k.a. “Sequel”), 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

* Structured Query Language

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

type (domain) of each field is specified

also enforced whenever tuples are added or modified

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

Table Creation (continued)

Enrolled: holds information about courses students take

```
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@cs’, 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!

The Relational Model

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Keys & Integrity Constraints

ER to Relational

ISA to Relational

Keys

keys: associate tuples in different relations

keys are one form of integrity constraint (IC)

Enrolled

sid	cid	grade
53666	15-101	C
53666	18-203	B
53650	15-112	A
53666	15-105	B

Students

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

FOREIGN Key

PRIMARY Key

Primary Keys

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

A set of fields is a *superkey* if:

No two distinct tuples can have same values in all key fields

Is <sid> a superkey?

What about <sid,name>?

What about <sid,name,age>?

What about <age,name>?

Primary Keys

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

Is <sid> a key? <sid,name>? <sid,name,age>? <age,name>?

Primary Keys

sid	name	login	age	gpa
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A set of fields is a *key* for a relation if :

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No subset of the fields is a superkey

Is <sid> a key? <~~sid,name>? <sid,name,age>?~~ <~~age,name>?~~

Primary Keys

sid	name	login	age	gpa
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A set of fields is a *superkey* if:

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A set of fields is a *key* for a relation if :

It is a superkey

No subset of the fields is a superkey

what if >1 key for a relation?

chose one as the ***primary key*** / rest called ***candidate*** keys

Primary and Candidate Keys in SQL

possibly many *candidate keys* (specified using UNIQUE), one of which is chosen as the *primary key*

keys must be defined carefully!

"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))
```

vs.

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

Primary and Candidate Keys in SQL

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   grade CHAR(2),
   PRIMARY KEY (sid,cid))
```

vs.

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

"students can take only one course, and no two students in a course receive the same grade"

Foreign Keys, Referential Integrity

foreign key: set of fields in one relation that is used to “refer” to a tuple in another

correspond to the primary key of the other relation a “logical pointer”

If all foreign key constraints are enforced, *referential integrity* is achieved (i.e., no dangling references)

Foreign Keys in SQL

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

sid is a foreign key referring to Students

```
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	15-101	C
53666	18-203	B
53650	15-112	A
53666	15-105	B

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
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Enforcing Referential Integrity

Students and Enrolled; *sid* in Enrolled is a FK referencing Students

What to do if a tuple with a non-existent sid is inserted in Enrolled?

What should be done if a Students tuple is deleted?

Enforcing Referential Integrity

Students and Enrolled; *sid* in Enrolled is a FK referencing Students

What to do if a tuple with a non-existent sid is inserted in Enrolled?

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 we can set sid to be equal to *null*, denoting *"unknown"* or *"inapplicable")*

Similar issues arise if primary key of Students tuple is updated

Integrity Constraints (ICs)

IC: 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 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 *real-world semantics*

we can check a database instance to see if an IC is violated, but we cannot infer that an IC hold

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

key and foreign key ICs are the most common

(more general ICs supported too)

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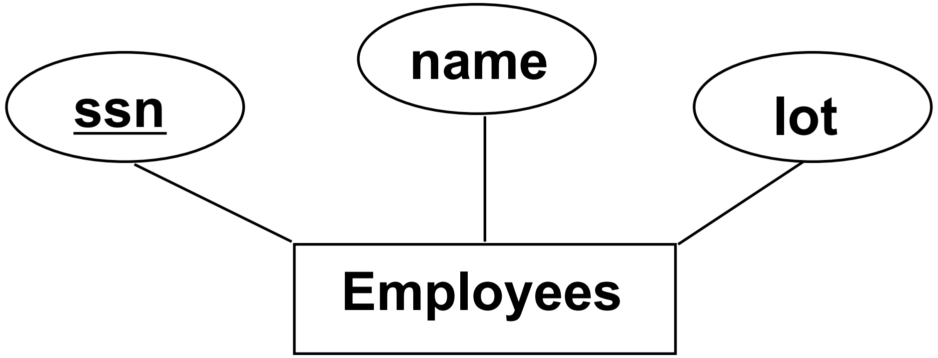
Logical DB Design: ER to Relational

Entity sets to tables

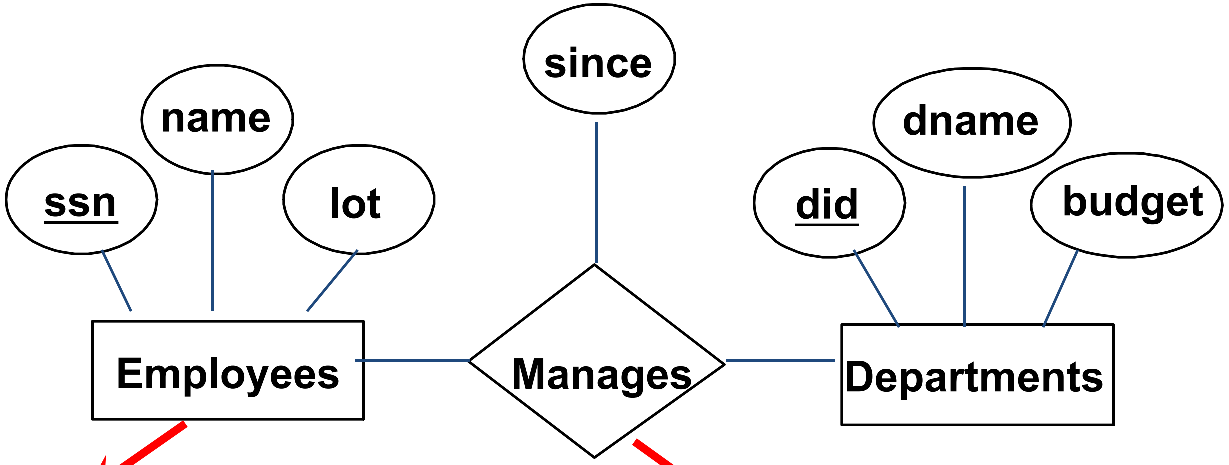


ssn	name	lot
123-22-3666	Attishoo	48
231-31-5368	Smiley	22
131-24-3650	Smethurst	35

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

Relationship Sets to Tables

Our favorite example:



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

ssn	did	since
123-22-3666	51	1/1/91
123-22-3666	56	3/3/93
231-31-5368	51	2/2/92

Relationship Sets to Tables

In translating a many-to-many relationship set to a relation, attributes of the relation must include:

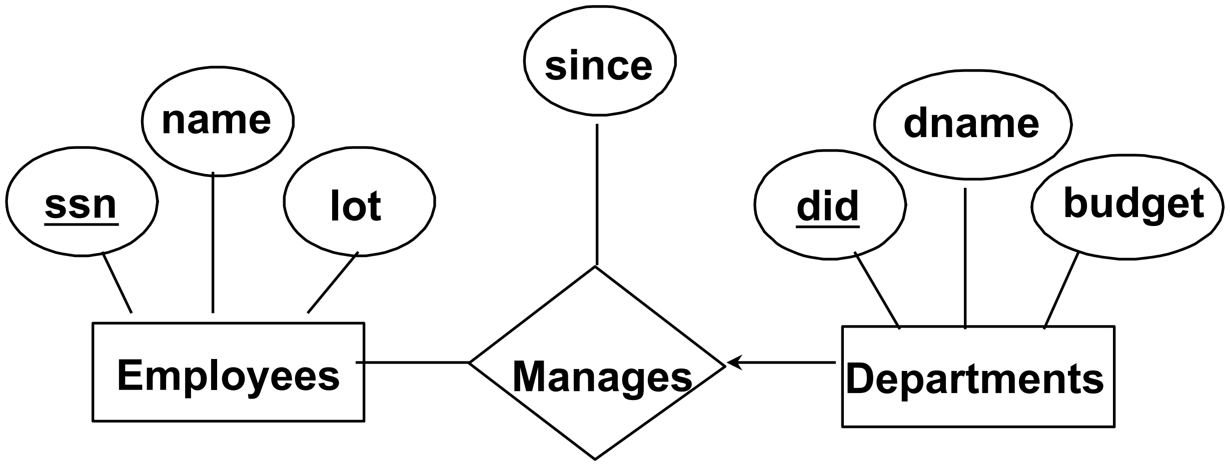
- Keys for each participating entity set (as foreign keys). This set of attributes forms a *superkey* for the relation.
- All descriptive attributes.

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

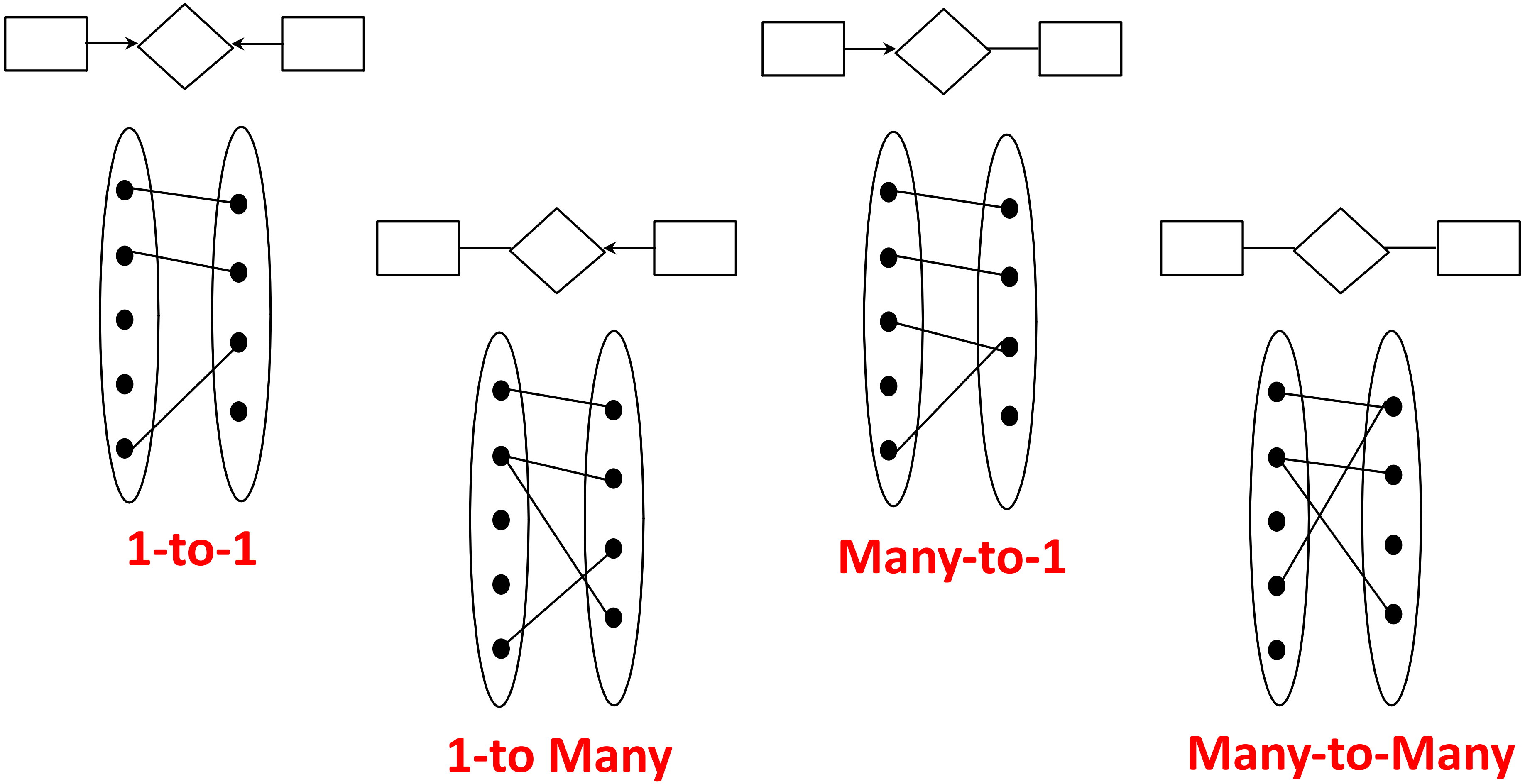
ssn	did	since
123-22-3666	51	1/1/91
123-22-3666	56	3/3/93
231-31-5368	51	2/2/92

Review: Key Constraints in ER

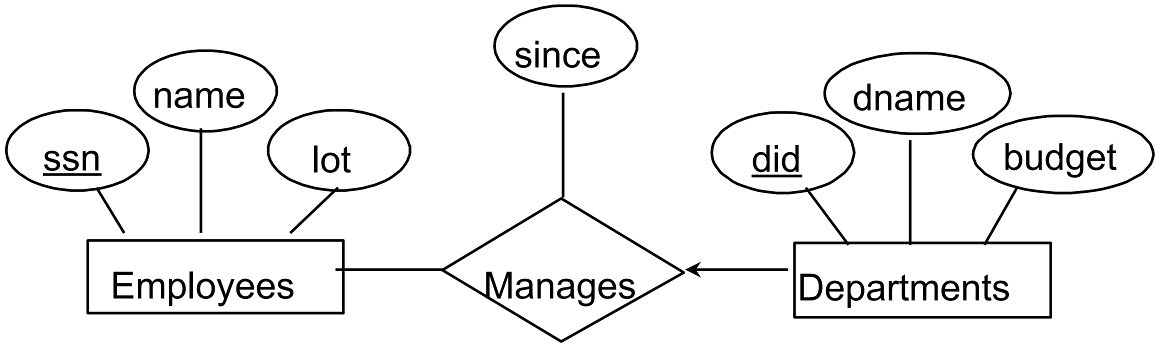
Each dept has at most one manager, according to the *key constraint* on Manages



Review: Key Constraints in ER



Translating ER with Key Constraints



since each department has a unique manager, we could instead combine Manages 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)
```

Vs.

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

What if the toy department has no manager (yet) ?

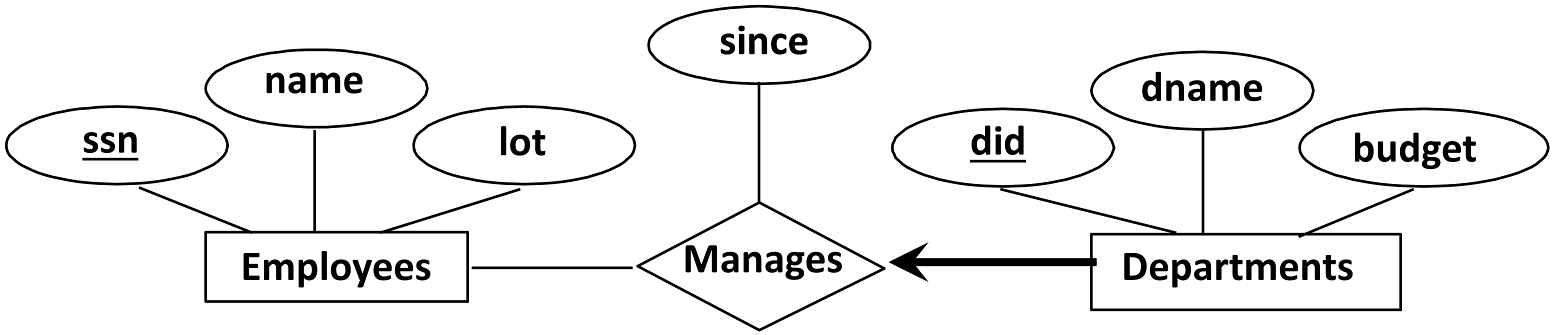
Can be NULL! → (ssn)

```
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

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 (PC) in SQL

PCs of one entity set in a binary relationship, yes!

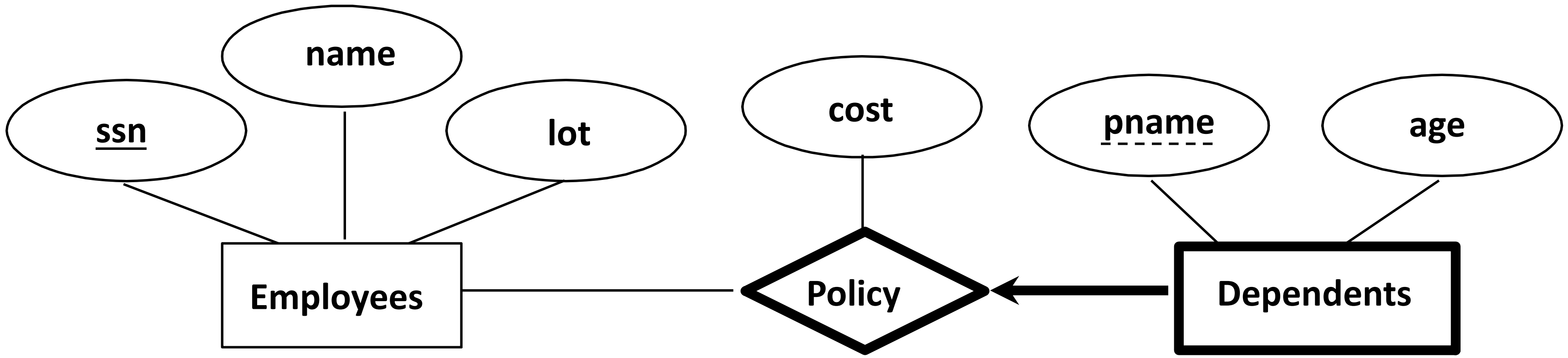
but little else (without resorting to CHECK constraints)

```
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 by the primary key of another (*owner*) entity (+ some of its attributes)

- 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.

```
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)
```

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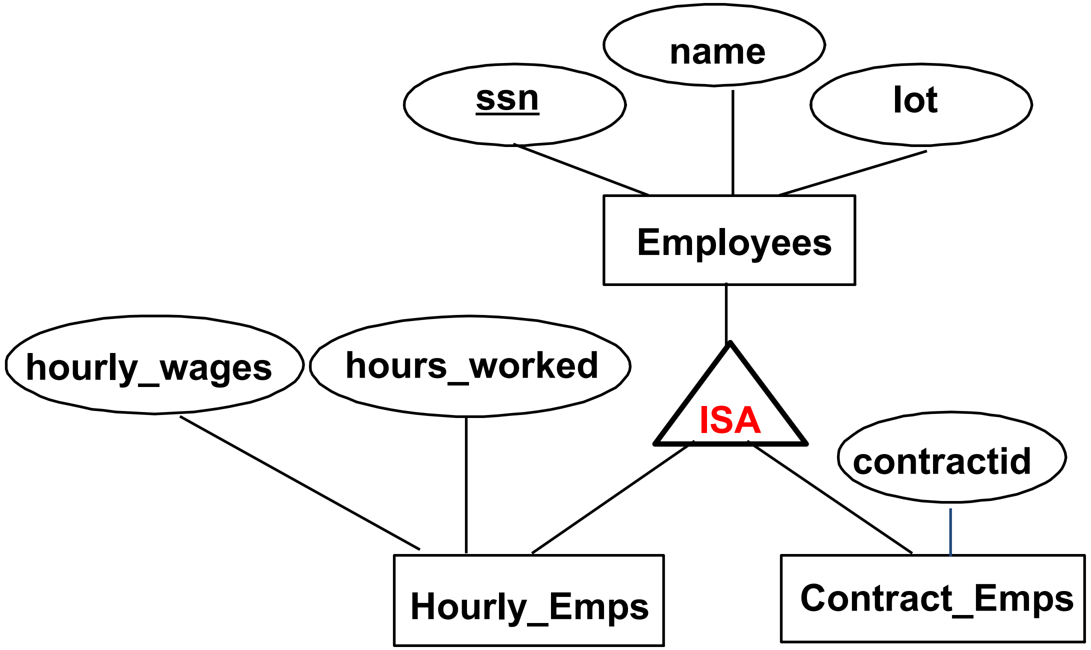
Review: ISA Hierarchies

As in C++, or other PLs, attributes are inherited.

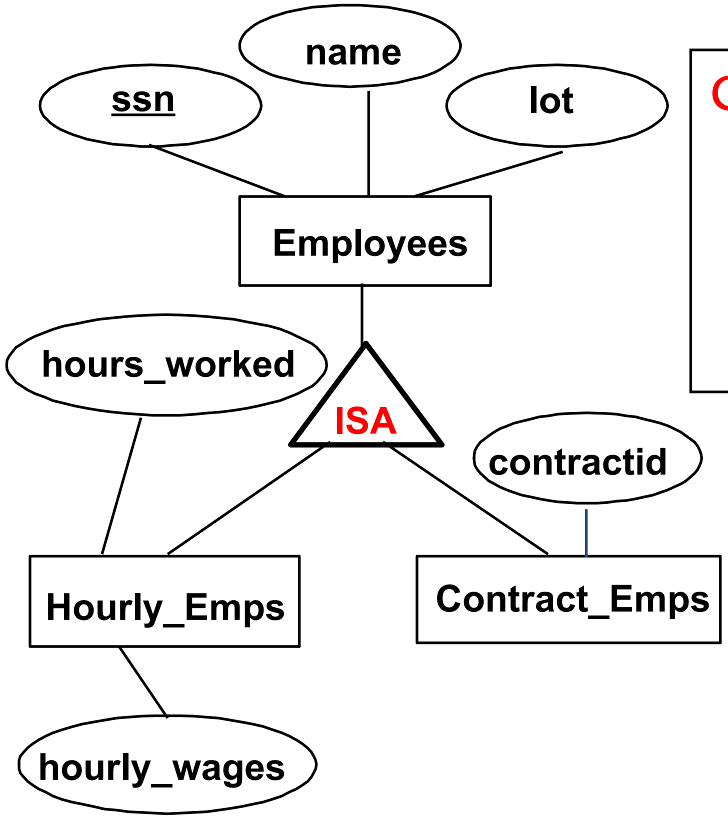
If we declare A **ISA** B, every A entity is also considered to be a B entity.



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

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




```
CREATE TABLE Employees (
    ssn CHAR(11) NOT NULL,
    name CHAR(20),
    lot  INTEGER,
    PRIMARY KEY  (ssn))
```

```
CREATE TABLE Contract_Emps (
    ssn CHAR(11) NOT NULL,
    contractid INTEGER,
    PRIMARY KEY  (ssn),
    FOREIGN KEY  (ssn)
        REFERENCES Employees)
```

```
CREATE TABLE Hourly_Emps (
    ssn  CHAR(11) NOT NULL,
    hourly_wages REAL,
    hours_worked REAL,
    PRIMARY KEY  (ssn),
    FOREIGN KEY  (ssn) REFERENCES Employees)
```

what should happen if I delete an entry from Employees?

can we use ON DELETE CASCADE?

how to access name and hours worked ? Join!

Alternative approach for ISA Hierarchies

```
CREATE TABLE Hourly_Emps (
   ssn  CHAR(11) NOT NULL,
   name CHAR(20),
   lot  INTEGER,
   hourly_wages REAL,
   hours worked REAL,
   PRIMARY KEY  (ssn))
```

```
CREATE TABLE Contract_Emps
  (ssn CHAR(11) NOT NULL,
   name CHAR(20),
   lot  INTEGER,
   contractid INTEGER,
   PRIMARY KEY  (ssn))
```

how to ensure that every employee is only in one of the two? 

what about Employees that are neither? 

what about querying for all employees?  Query 2 tables!

Relational Model: Summary

tabular representation of data

simple & intuitive, currently the most widely used

Integrity Constraints can be specified based on app semantics & DBMS checks for violations

two important ICs: primary and foreign keys

in addition, we *always* have domain constraints

ER to Relational is (fairly) straightforward