Database Applications (15-415)

The Relational Model (Cont'd) & Relational Algebra (Intro)
Lecture 4, January 19, 2016

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Today…

- Last Session:
  - The relational model

- Today's Session:
  - The relational model (*Cont'd*)
    - Basic SQL
    - ER to relational databases
  - Relational algebra
    - Relational query languages (in general)

- Announcements:
  - PS1 is due on Thursday, Jan 21st by midnight
  - In the next recitation we will practice on translating ER designs into relational databases

Outline

- The Relational Model: Basic SQL ✓
- Translating ER Diagrams to Tables and Summary
- Query Languages

SQL - A Language for Relational DBs

- SQL (a.k.a. "Sequel") stands for Structured Query Language
- SQL was developed by IBM (system R) in the 1970s
- There is a need for a standard since SQL is used by many vendors
- Standards:
  - SQL-86
  - SQL-89 (minor revision)
  - SQL-92 (major revision)
  - SQL-99 (major extensions)
  - SQL-2003 (minor revision)
  - SQL-2011

DDL and DML

- The SQL language has two main aspects (*there are other aspects which we discuss next week*)
  - Data Definition Language (DDL)
    - Allows creating, modifying, and deleting relations and views
    - Allows specifying constraints
    - Allows administering users, security, etc.
  - Data Manipulation Language (DML)
    - Allows posing *queries* to find tuples that satisfy criteria
    - Allows adding, modifying, and removing tuples

Creating Relations in SQL

- S1 can be used to create the “Students” relation
- S2 can be used to create the “Enrolled” relation

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

S1

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

S2

The DBMS enforces domain constraints whenever tuples are added or modified

Adding and Deleting Tuples

- We can insert a single tuple to the "Students" relation using:

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

- We can delete all tuples from the "Students" relation which satisfy some condition (e.g., name = Smith):

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

Powerful variants of these commands are available; more next week!

Querying a Relation

- How can we find all 18-year old 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

```
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

- How can we find just names and logins?

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

Querying Multiple Relations

- What does the following query compute assuming S and E?

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

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

S

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

E

We get:

S.name	E.cid
Smith	Topology112

Destroying and Altering Relations

- How to destroy the relation "Students"?

```
DROP TABLE Students
```

The schema information *and* the tuples are deleted

- How to alter the schema of "Students" in order to add a new field?

```
ALTER TABLE Students
        ADD COLUMN firstYear: integer
```

Every tuple in the current instance is extended with a ***null*** value in the new field!

Integrity Constraints (ICs)

- An IC is a condition that must be true for *any* instance of the database (e.g., *domain constraints*)
  - ICs are specified when schemas are 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!

Keys

- Keys help associate tuples in different relations

- Keys are one form of integrity constraints (ICs)

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
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FOREIGN Key

Students

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53650	Smith	smith@math	19	3.8

PRIMARY Key

Superkey, Primary and Candidate 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 *primary key* for a relation if:
  - It is a *minimal* superkey

- What if there is more than one key for a relation?
  - One of the keys is chosen (by DBA) to be the primary key
  - Other keys are called *candidate keys*

- Examples:
  - *sid* is a key for Students (what about *name*?)
  - The set {*sid, name*} is a superkey (or a set of fields that contains a key)

Primary and Candidate Keys in SQL

- Many candidate keys (specified using UNIQUE) can be designated and one is chosen as a *primary key*
- Keys must be used carefully!
- "For a given student and course, there is a single grade"

Primary and Candidate Keys in SQL

- Many candidate keys (specified using UNIQUE) can be designated and one is chosen as a *primary key*
- Keys must be used 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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```

Q: What does this mean?

Primary and Candidate Keys in SQL

- Many candidate keys (specified using UNIQUE) can be designated and one is chosen as a *primary key*

- Keys must be used carefully!

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

```
CREATE TABLE Enrolled
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   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))
```

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

Foreign Keys and Referential Integrity

- A foreign key is a set of fields referring to a tuple in another relation
  - It must correspond to the primary key of the other relation
  - It acts like a `logical pointer’
- If all foreign key constraints are enforced, referential integrity is said to be achieved (i.e., no dangling references)

Foreign Keys in SQL

- Example: Only existing students may enroll for courses
  - *sid* is a foreign key referring to Students
  - How can we write this in SQL?

Enrolled

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

Students

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Foreign Keys in SQL

- Example: Only existing students may 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
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Students

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Enforcing Referential Integrity

- 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?
  - Disallow its deletion
  - Delete all Enrolled tuples that refer to it
  - Set sid in Enrolled tuples that refer to it to a *default sid*
  - Set sid in Enrolled tuples that refer to it to a special value *null*, denoting *`unknown'* or *`inapplicable'*

- What if a "Students" tuple is updated?

Referential Integrity in SQL

- SQL/92 and SQL:1999 support all 4 options on deletes and updates
  - Default is NO ACTION (i.e., *delete/update is rejected*)
  - CASCADE (also delete all tuples that refer to the 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 )
```

What does this mean?

Where do ICs Come From?

- ICs are based upon the semantics of the real-world enterprise 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 the "Students" relation, 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 are supported too

Views

- A view is a table whose rows are not explicitly stored but computed as needed

```
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 queried
  - Querying YoungActiveStudents would necessitate computing it first then applying the query on the result as being like any other relation
- 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

Views and Security

- Views can be used to present necessary information, while hiding details in underlying relation(s)
  - If the schema of an old relation is *changed*, a view can be defined to represent the old schema
    - This allows applications to *transparently* assume the old schema

  - Views can be defined to give a group of users access to just the information they are allowed to see
    - E.g., we can define a view that allows students to see other students' names and ages, but not GPAs (also students can be prevented from accessing the underlying "Students" relation)

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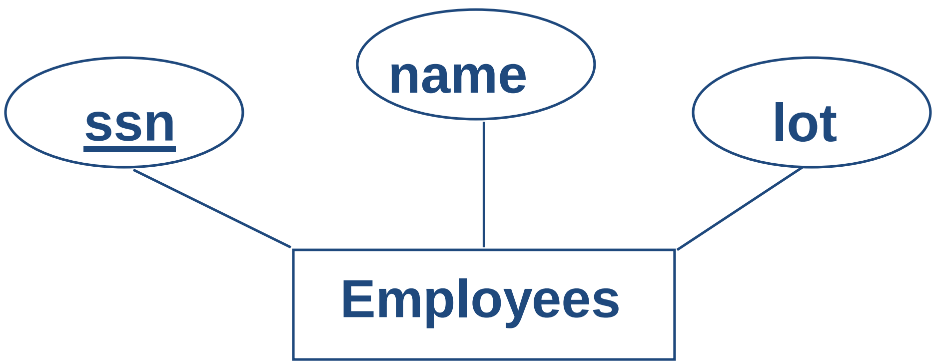
Security!

Outline

- The Relational Model: Basic SQL
- Translating ER Diagrams to Tables and Summary ✓
- Query Languages

Strong Entity Sets to Tables

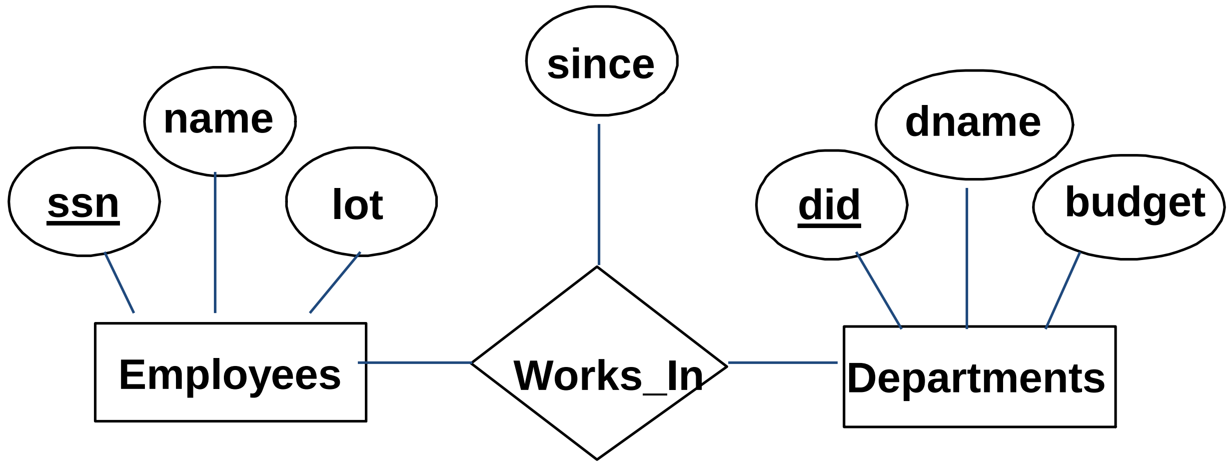



```
CREATE TABLE Employees
        (ssn CHAR(11),
        name CHAR(20),
        lot  INTEGER,
        PRIMARY KEY  (ssn))
```

Relationship Sets to Tables

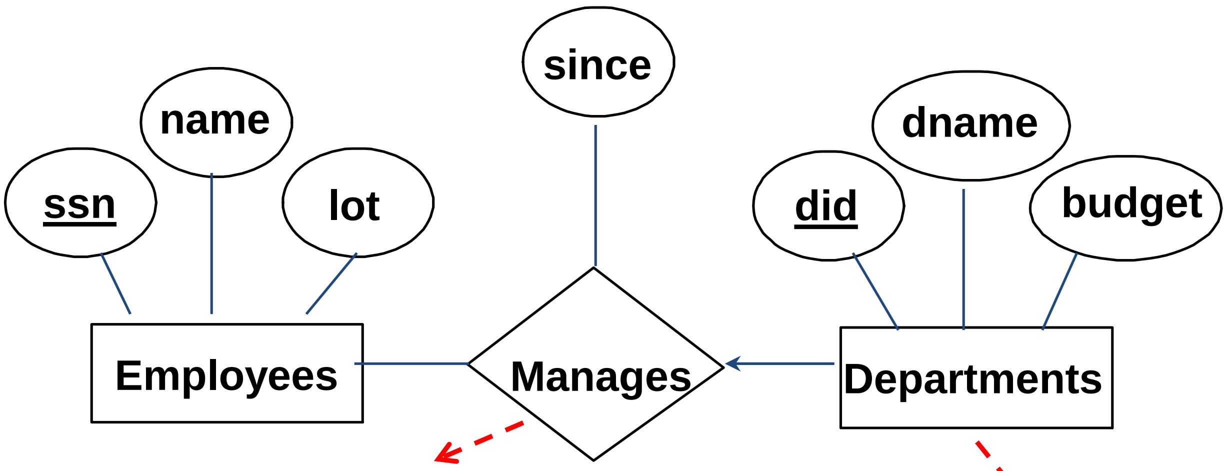
- In translating a relationship set to a relation, attributes of the relation must include:
  1. Keys for each participating entity set (as foreign keys)
     - This set of attributes forms a *superkey* for the relation
  2. All descriptive attributes
- Relationship sets
  - 1-to-1, 1-to-many, and many-to-many
  - Key/Total/Partial participation

M-to-N Relationship Sets to Tables




```
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)
```

1-to-M Relationship Sets to Tables




```
CREATE TABLE  Manages(
 ssn    CHAR(11),
 did    INTEGER,
 since  DATE,

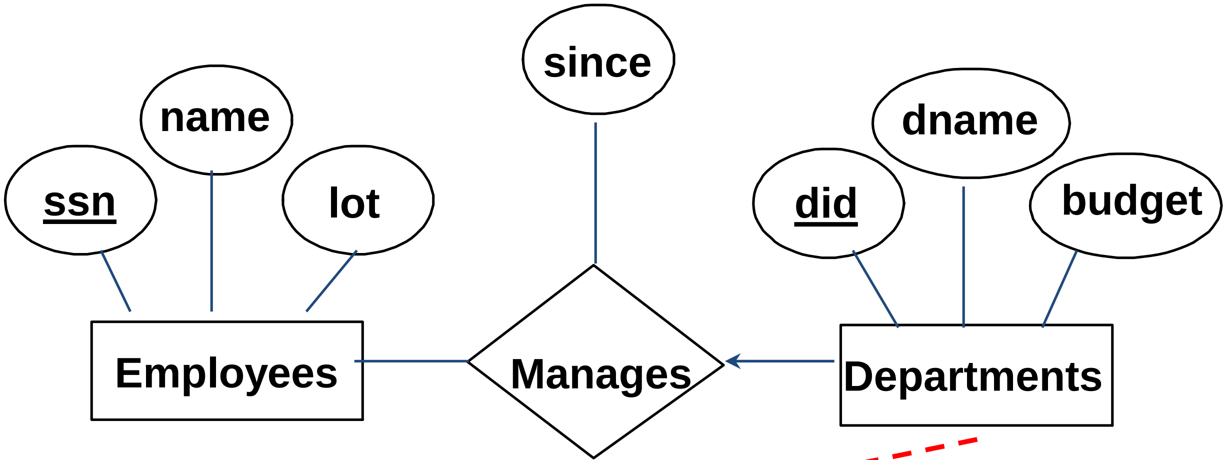
 PRIMARY KEY  (did),
 FOREIGN KEY (ssn)
REFERENCES Employees,
 FOREIGN KEY (did)
REFERENCES Departments)
```

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

Approach 1:

Create separate tables for Manages and Departments

1-to-M Relationship Sets to Tables




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

Can ssn take a *null* value?

Approach 2:

Create a table for only the Departments entity set (i.e., take advantage of the key constraint)

One-Table vs. Two-Table Approaches

- The one-table approach:

  (+) Eliminates the need for a separate table for the involved relationship set (e.g., Manages)

  (+) Queries can be answered without combining information from two relations

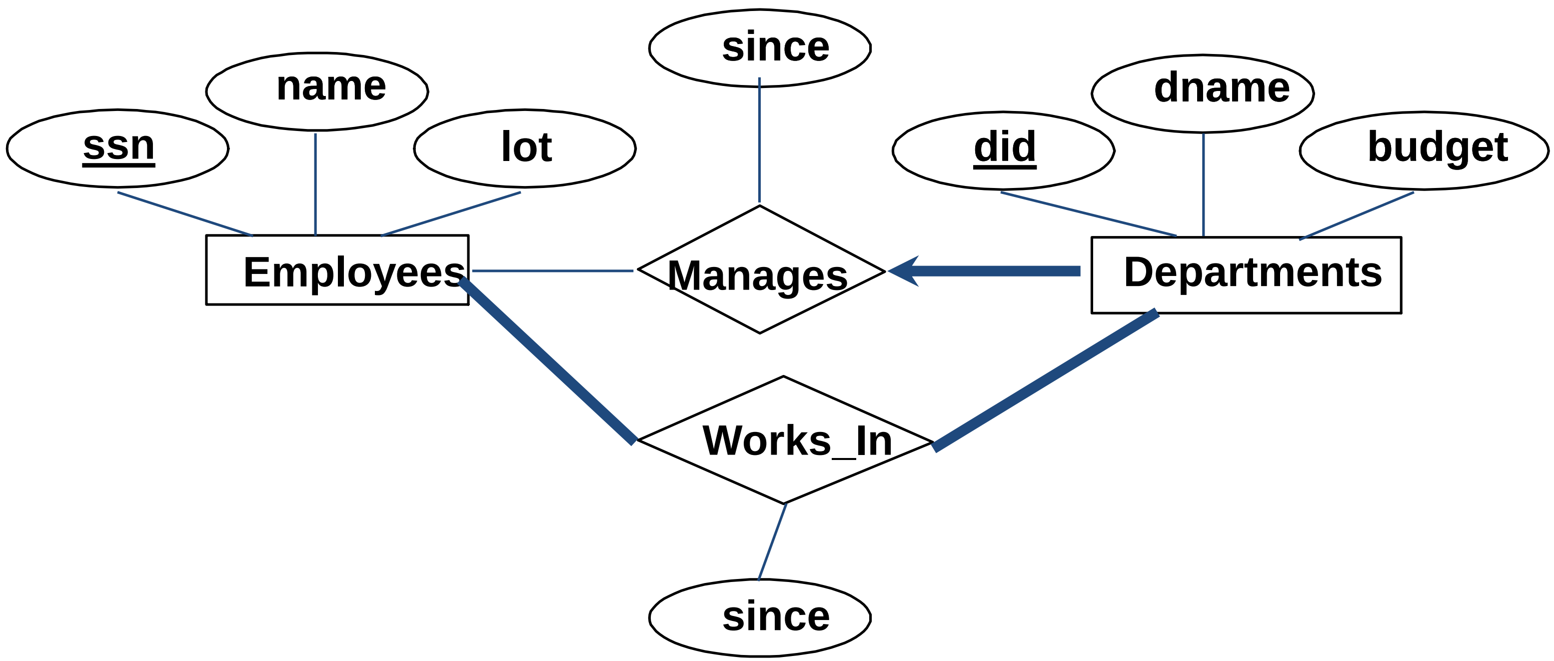
  (-) Space could be wasted!

    - What if several departments have no managers?

- The two-table approach:
  - The opposite of the one-table approach!

Translating Relationship Sets with Participation Constraints

- What does the following ER diagram entail (with respect to Departments and Managers)?



Every *did* value in Departments table must appear in a row of the Manages table- *if defined*- (with a non-null *ssn* value!)

Translating Relationship Sets with Participation Constraints

- Here is how to create the "Dept_Mgr" table using the one-table approach:

```
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)
```

Can this be captured using the two-table approach?

Translating Relationship Sets with Participation Constraints

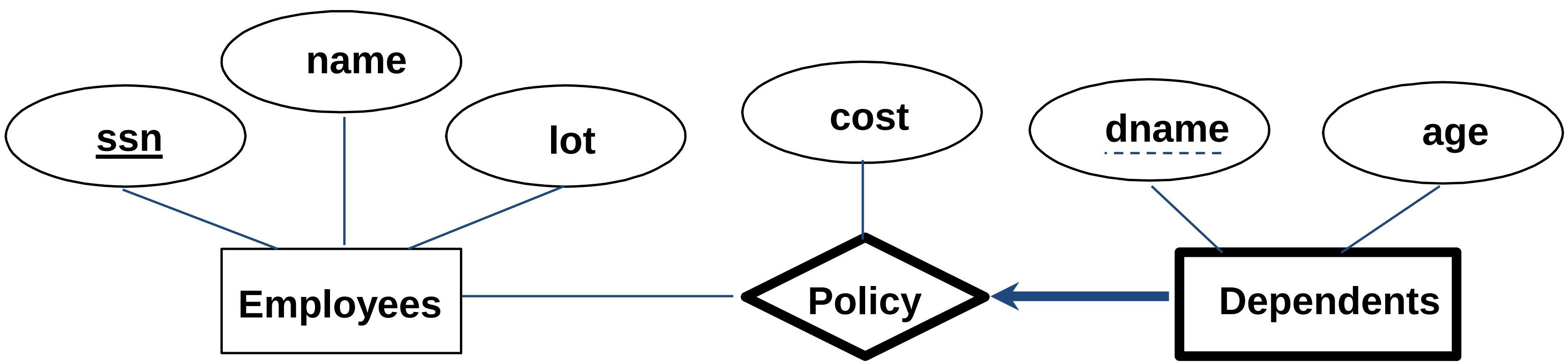
- Here is how to create the "Dept_Mgr" table using the one-table approach:

```
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 SET  NULL)
```

Would this work?

Translating Weak Entity Sets

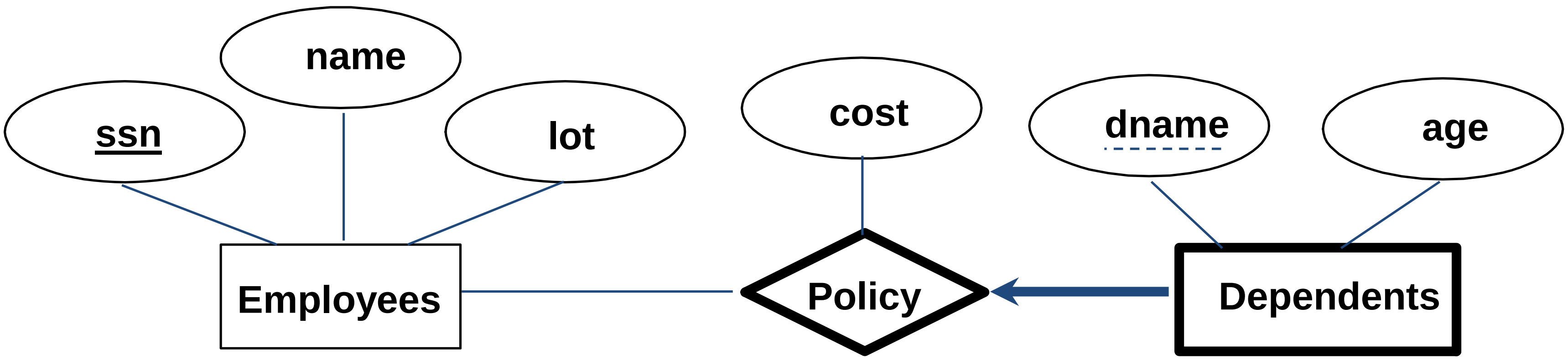
- A weak entity set always:
  - Participates in a one-to-many binary relationship
  - Has a key constraint and total participation



- Which approach is ideal for that?
  - The one-table approach

Translating Weak Entity Sets

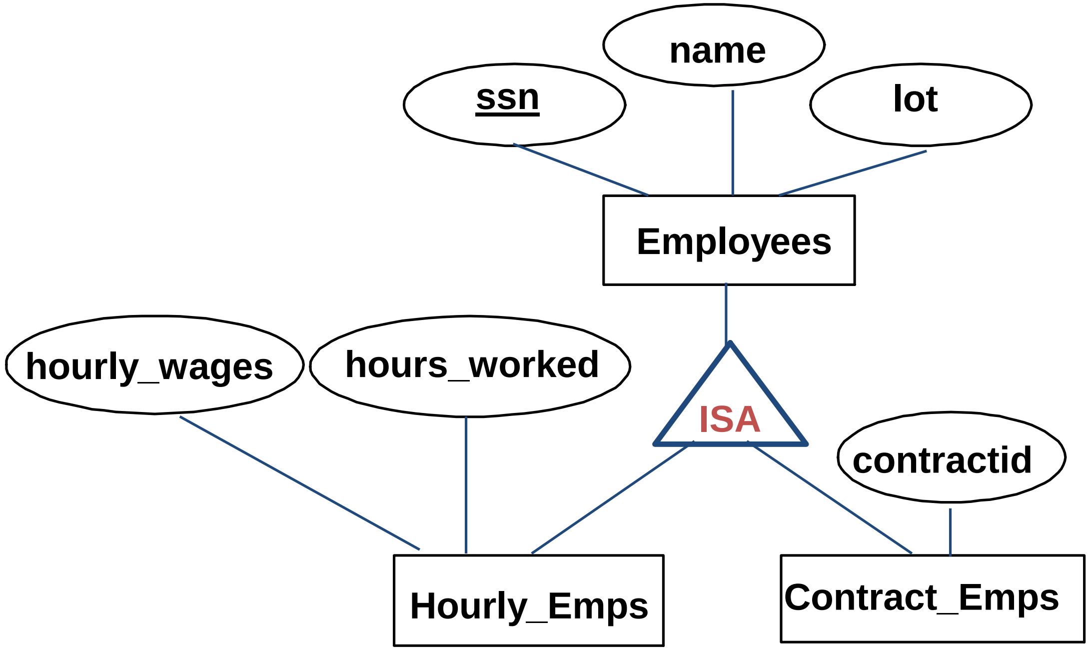
- Here is how to create “Dep_Policy” using the one-table approach




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

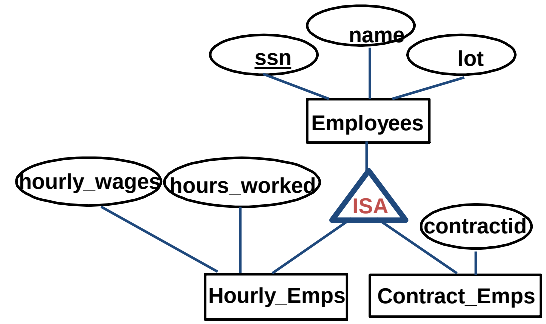
Translating ISA Hierarchies to Relations

- Consider the following example:

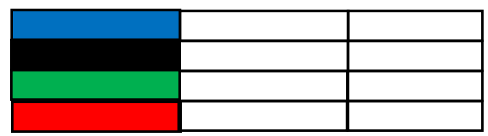


Translating ISA Hierarchies to Relations

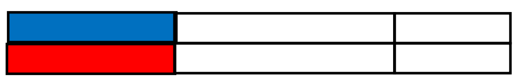
- General approach:
  - *Create* 3 relations: “Employees”, “Hourly_Emps” and “Contract_Emps”



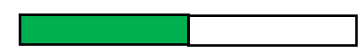
EMP (<u>ssn</u>, name, lot)



H_EMP(<u>ssn</u>, h_wg, h_wk)

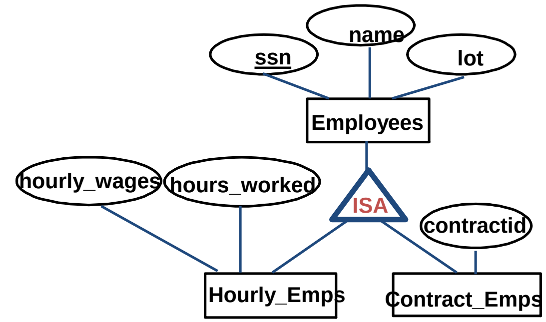


CONTR(<u>ssn</u>, cid)

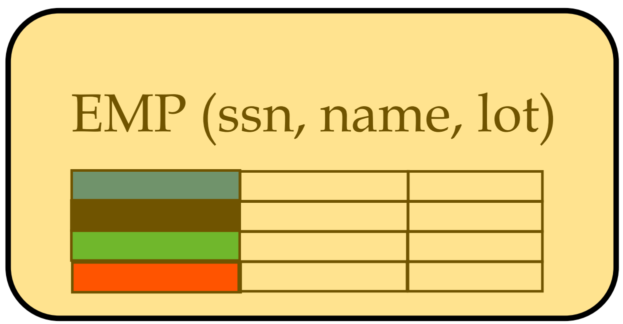


- How many times do we record an employee?
- What to do on deletions?
- How to retrieve ***all*** info about an employee?

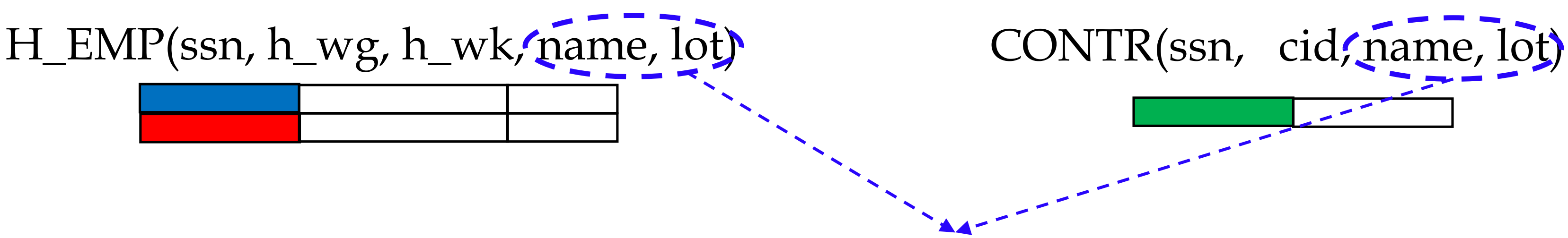
Translating ISA Hierarchies to Relations



- Alternatively:
  - Just create 2 relations “Hourly_Emps” and “Contract_Emps”
    - Each employee **must be** in one of these two subclasses



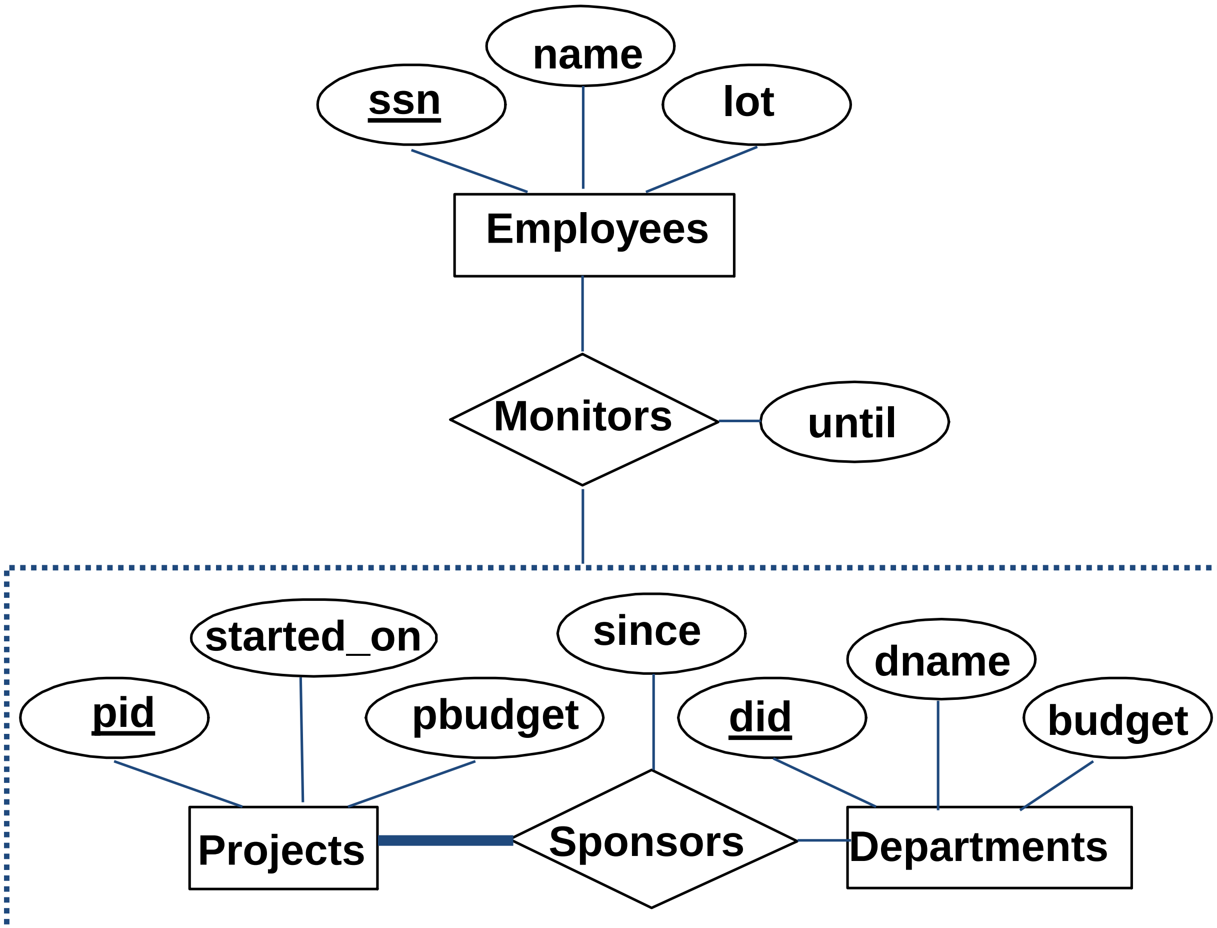
‘black’ is gone!



Duplicate Values!

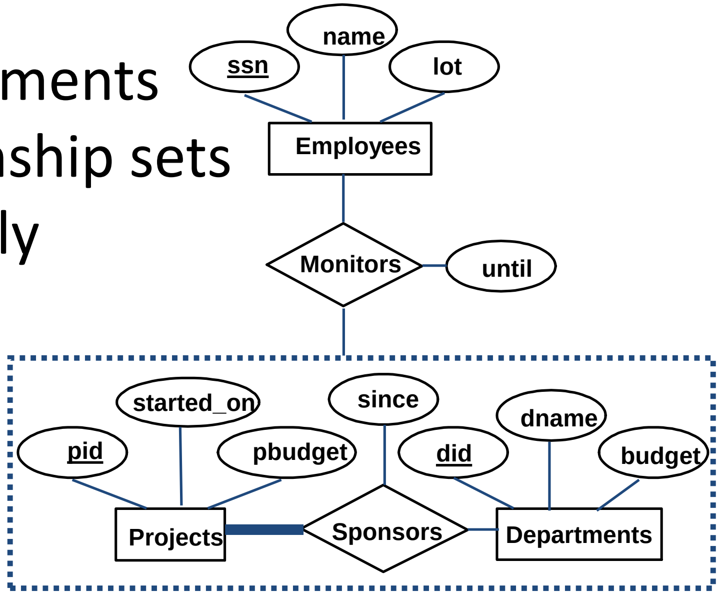
Translating Aggregations

- Consider the following example:



Translating Aggregations

- Standard approach:
  - The Employees, Projects and Departments entity sets and the Sponsors relationship sets are translated as described previously



  - For the Monitors relationship, we create a relation with the following attributes:
    - The key attribute of Employees (i.e., ssn)
    - The key attributes of Sponsors (i.e., did, pid)
    - The descriptive attributes of Monitors (i.e., until)

The Relational Model: A Summary

- A tabular representation of data
- Simple and intuitive, currently one of the most widely used
  - Object-relational variant is gaining ground
- Integrity constraints can be specified (by the DBA) based on application semantics (DBMS checks for violations)
  - Two important ICs: primary and foreign keys
  - Also: not null, unique
  - In addition, we *always* have domain constraints
- Mapping from ER to Relational is (fairly) straightforward!

ER to Tables - Summary of Basics

- Strong entities:
  - Key -> primary key
- (Binary) relationships:
  - Get keys from all participating entities:
    - 1:1 -> either key can be the primary key
    - 1:N -> the key of the 'N' part will be the primary key
    - M:N -> both keys will be the primary key
- Weak entities:
  - Strong key + partial key -> primary key
  - ..... ON DELETE CASCADE

ER to Tables - Summary of Advanced

- Total/Partial participation:
  - NOT NULL
- Ternary relationships:
  - Get keys from all; decide which one(s) -> primary Key
- Aggregation: like relationships
- ISA:
  - 3 tables (most general)
  - 2 tables (‘total coverage’)

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- Query Languages ✓

Relational Query Languages

- Query languages (QLs) allow *manipulating* and *retrieving* data from databases

- The relational model supports simple and powerful QLs:
  - Strong formal foundation based on logic
  - High amenability for effective optimizations

- Query Languages **!=** programming languages!
  - QLs are not expected to be “Turing complete”
  - QLs are not intended to be used for complex calculations
  - QLs support easy and efficient access to large datasets

Formal Relational Query Languages

- There are two mathematical Query Languages which form the basis for commercial languages (e.g., SQL)
  - Relational Algebra
    - Queries are composed of operators
    - Each query describes a step-by-step procedure for computing the desired answer
    - Very useful for representing *execution plans*
  - Relational Calculus
    - Queries are subsets of first-order logic
    - Queries describe desired answers without specifying how they will be computed
    - A type of *non-procedural* (or *declarative*) formal query language

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Next Class

Relational Algebra