The Relational Model

CMU SCS 15-415/615
C. Faloutsos – A. Pavlo
Lecture #3
R & G, Chap. 3

Outline

- Introduction
- Integrity constraints (IC)
- Enforcing IC
- Querying Relational Data
- ER to tables
- Intro to Views
- Destroying/altering tables

Why Study the Relational Model?

- **Most widely used model.**
  - Vendors: IBM/Informix, Microsoft, Oracle, Sybase, etc.
- **"Legacy systems" in older models**
  - e.g., IBM's IMS
- **Object-oriented concepts have merged in**
  - *object-relational model*
    - Informix->IBM DB2, Oracle

Relational Database: Definitions

- *Relational database:* a set of *relations*
- (relation = table)
- specifically

Relational Database: Definitions

- *Relation:* made up of 2 parts:
  - *Schema* : specifies name of relation, plus name and type of each column.
  - *Instance* : a *table,* with rows and columns.
    - #rows = *cardinality*
    - #fields = *degree / arity*

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

Relational Database: Definitions

- relation: a *set* of rows or *tuples*.
  - all rows are distinct
  - no order among rows (why?)

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

Ex: 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
- Q: do values in a column need 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.
  - E.g.:

```
create table student
    (ssn fixed, name char(20));
```

* Structured Query Language

SQL - A language for Relational DBs

- **Data Manipulation Language (DML)**
  - Specify *queries* to find tuples that satisfy criteria
  - add, modify, remove tuples

```
select * from student ;

update takes set grade=4
    where name='smith'
    and cid = 'db';
```

SQL Overview

- CREATE TABLE <name> (<field> <domain>, …)
- INSERT INTO <name> (<field names>)
  VALUES (<field values>)
- DELETE FROM <name>
  WHERE <condition>

SQL Overview

- UPDATE <name>
  SET <field name> = <value>
  WHERE <condition>
- SELECT <fields>
  FROM <name>
  WHERE <condition>

Creating Relations in SQL

- **Creates the Students relation.**

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

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.

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


Table Creation (continued)

- **Another example:**

```
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)
```

Adding and Deleting Tuples

- 'mass'-delete (**all** Smiths!) :

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


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Keys

- Keys help 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
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sid	name	login	age	gpa
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FOREIGN Key **PRIMARY Key**

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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 :**
  - minimal superkey

```
Student (ssn, name, address)
```

{ssn,name}: superkey
{ssn}: superkey, AND key
{name}: not superkey

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Primary Keys

- **what if >1 key for a relation?**

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Primary Keys

- **what if >1 key for a relation?**
  - one of the keys is chosen (by DBA) to be the ***primary key*****.** Other keys are called ***candidate*** keys..
  - Q: example of >1 superkeys?

Primary Keys

- **what if >1 key for a relation?**
  - one of the keys is chosen (by DBA) to be the ***primary key*****.** Other keys are called ***candidate*** keys..
  - Q: example of >1 superkeys?
  - A1: student: {ssn}, {student-id#}, {driving license#, state}
  - A2: Employee: {ssn}, {phone#}, {room#}
  - A3: computer: {mac-address}, {serial#}

Primary Keys

- **E.g.**
  - *sid* is a key for Students.
  - What about *name*?
  - The set {*sid, gpa*} is a superkey.

Primary and Candidate Keys in SQL

```
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))
```

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Primary and Candidate Keys in SQL

```
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))~~

Q: what does this mean?

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Primary and Candidate Keys in SQL

```
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))~~

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

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Foreign Keys

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 Keys, Referential Integrity

- ***Foreign key*** **: Set of fields `refering' to a tuple in another relation.**
  - Must correspond to the primary key of the other relation.
  - Like a `logical pointer'.
- **foreign key constraints enforce *referential integrity* (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:

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 Keys in SQL

```
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

- **Subtle issues:**
- **What should be done if an Enrolled tuple with a non-existent student id is inserted?**

Enrolled

sid	cid	grade
53666	15-101	C
53666	18-203	B
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Students

sid	name	login	age	gpa
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Enforcing Referential Integrity

- **Subtle issues:**
- **What should be done if an Enrolled tuple with a non-existent student id is inserted? (*Reject it!*)**

Enforcing Referential Integrity

- **Subtle issues, cont'd:**
- **What should be done if a Student's tuple is deleted?**

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

- **Subtle issues, cont'd:**
- **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*'.)

Enforcing Referential Integrity

- **Similar issues arise if primary key of Students tuple is updated.**

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.

Integrity Constraints (ICs)

- **A *legal* instance of a relation: satisfies all specified ICs.**
  - DBMS should not allow illegal instances.
- **we prefer that ICs are enforced by DBMS (as opposed to ?)**
  - Blocks data entry errors, too!

Where do ICs Come From?

Where do ICs Come From?

- the application!

Where do ICs Come From?

- Subtle point: 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!
  - Eg., *name* is not a key,
  - but the assertion that *sid* is a key is given to us.

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@cs	18	3.2
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Where do ICs Come From?

- Key and foreign key ICs are the most common; more general ICs supported too.

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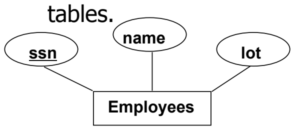
ER to tables outline:

- **strong entities**
- **weak entities**
- **(binary) relationships**
  - 1-to-1, 1-to-many, etc
  - total/partial participation
- **ternary relationships**
- **ISA-hierarchies**
- **aggregation**

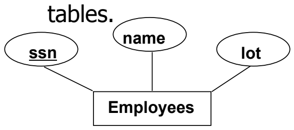
Logical DB Design: ER to Relational

- (strong) entity sets to tables.



Logical DB Design: ER to Relational

- (strong) entity sets to tables.

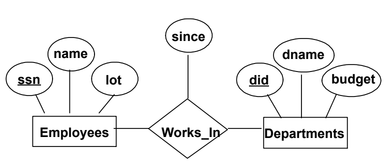


Ssn	Name	Lot
123-22-6666	Attishoo	48
233-31-5363	Smiley	22
131-24-3650	Smethurst	35

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

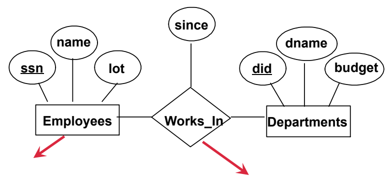

Relationship Sets to Tables

Many-to-many:



Relationship Sets to Tables

Many-to-many:



Ssn	Name	Lot
123-22-6666	Attishoo	48
233-31-5363	Smiley	22
131-24-3650	Smethurst	35

Ssn	did	since
123-22-6666	51	1/1/91
123-22-6666	56	3/3/93
233-31-5363	51	2/2/92

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Relationship Sets to Tables

- key of many-to-many relationships:
  - Keys from participating entity sets (as foreign keys).

```
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)
```

Ssn	did	since
123-22-6666	51	1/1/91
123-22-6666	56	3/3/93
233-31-5363	51	2/2/92

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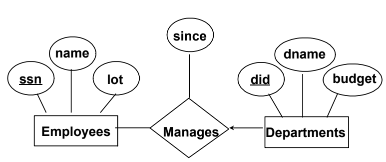
Review: Key Constraints in ER

- **1-to-many:**



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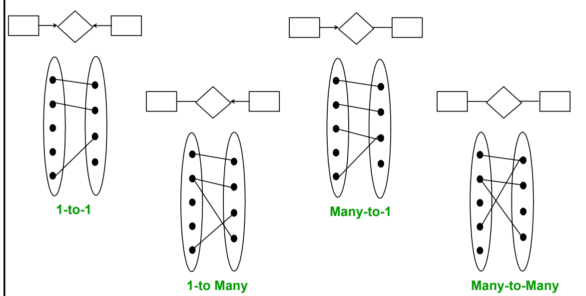
Review: Key Constraints in ER



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ER to tables - summary of basics

- **strong entities:**
  - key -> primary key
- **(binary) relationships:**
  - get keys from all participating entities - pr. key:
  - 1-to-1 -> either key (other: 'cand. key')
  - 1-to-N -> the key of the 'N' part
  - M-to-N -> both keys

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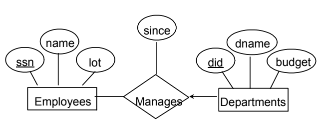
A subtle point (1-to-many)



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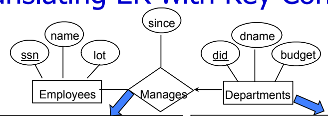
Translating ER with Key Constraints




```
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),
)
```

Two-table-solution

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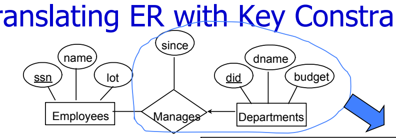
Translating ER with Key Constraints




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

Single-table-solution

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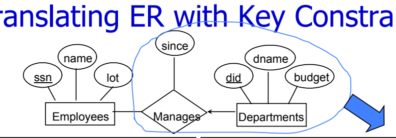
Translating ER with Key Constraints




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

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Pros and cons?

Drill:

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

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


Drill:

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

A: one-table solution can not handle that.

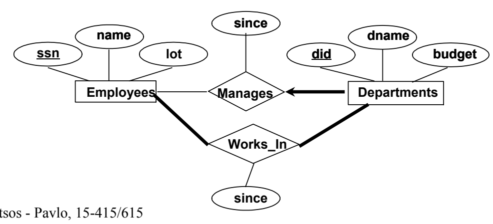
```
CREATE TABLE  Dept_Mgr(
 did    INTEGER,
 dname  CHAR(20),
 budget REAL,
 ssn    CHAR(11),
 since  DATE,
 PRIMARY KEY  (did),
 FOREIGN KEY (ssn)
  REFERENCES Employees)
```

ER to tables outline:

- ✓ **strong entities**
- **weak entities**
- **(binary) relationships**
  - ✓ 1-to-1, 1-to-many, etc
  - total/partial participation
- **ternary relationships**
- **ISA-hierarchies**
- **aggregation**

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)
```

Participation Constraints in SQL

- **Total participation ('no action' -> do NOT do the delete)**
- **Ie, a department MUST have a nanager**

```
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)
```

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Participation Constraints in SQL

- **Partial partipation, ie, a department may be headless**

```
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)
```

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ER to tables outline:

- ✓ **strong entities**
- ➡ **weak entities**
- **(binary) relationships**
  - ✓ 1-to-1, 1-to-many, etc
  - ✓ total/partial participation
- **ternary relationships**
- **ISA-hierarchies**
- **aggregation**

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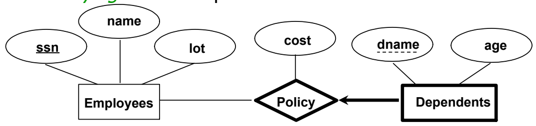
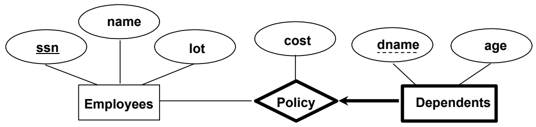
Review: Weak Entities

- **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.



Review: Weak Entities

How to turn 'Dependents' into a table?



Translating Weak Entity Sets

- **Weak entity set and identifying relationship set are translated into a single table.**

```
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 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 (-> 'CASCADE')

```
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)
```

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ER to tables outline:

- ✓ **strong entities**
- ✓ **weak entities**
- ✓ **(binary) relationships**
  - ✓ 1-to-1, 1-to-many, etc
  - ✓ total/partial participation
- **ternary relationships**
- ➡ **ISA-hierarchies**
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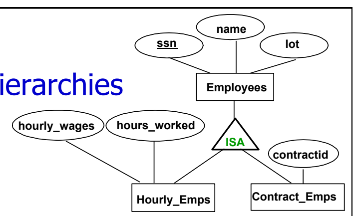
Review: ISA Hierarchies



- ***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)***

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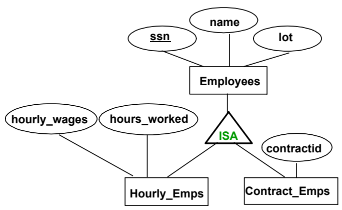
Drill:

- **What would you do?**



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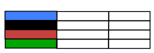
Translating ISA Hierarchies to Relations

- General approach: 3 relations: Employees, Hourly_Emps and Contract_Emps.
  - how many times do we record an employee?
  - what to do on deletion?
  - how to retrieve **all** info about an employee?

EMP (ssn, name, lot)



H_EMP(ssn, h_wg, h_wk)

CONTR(ssn, cid)

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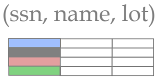
Translating ISA Hierarchies to Relations

- 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.

EMP (ssn, name, lot)



H_EMP(ssn, h_wg, h_wk, name, lot)

CONTR(ssn, cid, name, lot)

Notice: 'black' is gone!

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ER to tables outline:

- ✓ strong entities
- ✓ weak entities
- ✓ (binary) relationships
  - ✓ 1-to-1, 1-to-many, etc
  - ✓ total/partial participation
- ➡ ternary relationships
- ✓ ISA-hierarchies
- aggregation

Ternary relationships; aggregation

- **rare**
- **keep keys of all participating entity sets**

(or: avoid such situations:
break into 2-way relationships or
add an auto-generated key
)

Outline

- **Introduction**
- **Integrity constraints (IC)**
- **Enforcing IC**
- **Querying Relational Data**
- **ER to tables**
- **Intro to Views**
- **Destroying/altering tables**

Views

- **Virtual tables**

```
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
```

- DROP VIEW

Views and Security

- **DBA: grants authorization to a view for a user**
- **user can only see the view - nothing else**

Outline

- **Introduction**
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Table changes

- `DROP TABLE`
- `ALTER TABLE`, **e.g.**

```
ALTER TABLE students
  ADD COLUMN maiden-name CHAR(10)
```


Relational Model: Summary

- A tabular representation of data.
- Simple and intuitive; most widely used (plus object-relational)
- Integrity constraints can be specified by the DBA, based on customer specs. 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 - pr. key:
  - 1:1 -> either key
  - 1:N -> the key of the 'N' part
  - M:N -> both keys
- **weak entities:**
  - strong key + partial key -> primary key
  - ..... ON DELETE CASCADE

ER to tables - summary of advanced

- **total/partial participation:**
  - NOT NULL; ON DELETE NO ACTION
- **ternary relationships:**
  - get keys from all; decide which one(s) -> prim. key
- **aggregation: like relationships**
- **ISA:**
  - 2 tables ('total coverage')
  - 3 tables (most general)