The Relational Model

Ramakrishnan & Gehrke, Chapter 3

A SQL query walks up to two tables in a restaurant and asks: "Mind if I join you?"

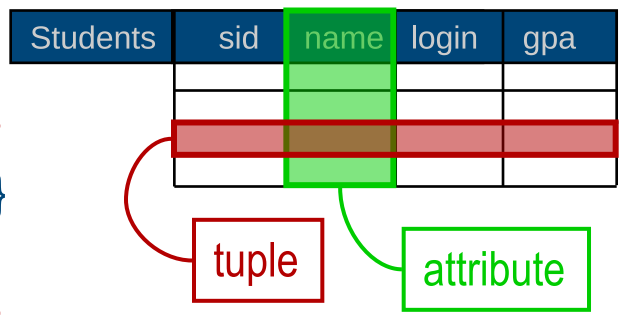
Relational Database: Definitions

- Technically: Relation made up of 2 parts:
  - Schema: specifies name of relation, plus name and type of each column
    - Ex: Students(sid: string, name: string, login: string, gpa: real)
  - Instance: a table, with rows and columns
    - *# rows = cardinality, # fields = degree / arity*

does not change often

changes all the time

- Mathematically:
  - Let A1, …, An (n>0) be value sets, called attribute domains
  - relation $R \subseteq A_1 \times \ldots \times A_n = \{ (a_1,\ldots,a_n) \mid a_1 \in A_1, \ldots, a_n \in A_n \}$



- Can think of a relation as a set of rows or tuples
  - NO!!! Duplicates allowed → multi-set
  - atomic attribute types only – no fancies like sets, trees, …
- Relational database: a set of relations

Example Instance of Students Relation

Sid	Name	Login	Gpa
53666	Jones	jones@cs	3.4
53688	Smith	smith@eecs	3.2
53650	Smith	smith@math	3.8

- Cardinality = 3, degree = 4, all rows distinct
- Do all *columns* in a relation instance have to be distinct?

Querying Relational Databases

- A major strength of the relational model: simple, powerful *querying* of data
  - Data organised in tables, query results are tables as well
  - Small set of generic operations, work on any table structure
- Query describes structure of result ("what"),
  not algorithm how this result is achieved ("how")
  - data independence, optimizability
- Queries can be written intuitively,
  and the DBMS is responsible for efficient evaluation
  - The key: precise (mathematical) semantics for relational queries
  - Allows the optimizer to extensively re-order operations,
    and still ensure that the answer does not change

SQL, Structured English Query Language

- "all students with GPA less than 3.6"

```
SELECT *
FROM Students S
WHERE S.gpa < 3.6
```

sid	name	login	gpa
53666	Jones	jones@cs	3.4
53688	Smith	smith@eecs	3.2
~~53650~~	~~Smith~~	~~smith@math~~	~~3.8~~

- "…names and logins…":

```
SELECT S.name, S.login
…
```

~~sid~~	name	login	~~gpa~~
~~53666~~	Jones	jones@cs	~~3.4~~
~~53688~~	Smith	smith@eecs	~~3.2~~

name	login
Jones	jones@cs
Smith	smith@eecs

SQL Joins: Querying Multiple Relations

- What does the following query compute?
  - ```
    SELECT  S.name, E.cid
    FROM  Students S, Enrolled E
    WHERE  S.sid=E.sid AND E.grade="A"
    ```
- Given the following instances of Students and Enrolled:

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

sid	cid	grade
53831	Carnatic101	C
53831	Reggae203	B
53666	Topology112	A
53688	History105	B

- we get:

S.name	E.cid
Jones	Topology112
    ```

DML: Adding and Deleting Tuples

- DML = Data Manipulation Language = SELECT + …
- insert a single tuple:

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

- delete all tuples satisfying some condition:

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

- change all tuples satisfying some condition:

```
UPDATE Students S
SET gpa = 3.0
WHERE S.name = 'Smith'
```

SQL = DML ∪ DDL

DDL: Maintaining the Schema

- DDL = Data Definition Language
  - Create / delete / change relation definitions; inspect schema
  - type (domain) of each attribute is specified, enforced by DBMS
  - Standard attribute types: integer, float(p), char(n), varchar(n), long
- Example 1: Create Students relation

```
CREATE TABLE Students(
   sid: char(20), name: char(20), login: char(10), gpa: float(2)
)
```

- Example 2: Enrolled table for students' courses

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

SQL = DML ∪ DDL

Integrity Constraints

- Integrity constraint = 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 key 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 → superkey
  - If >1 key for relation,
    one of the keys is chosen (by DBA) to be primary key
- Example:
  - sid key for Students (what about name?)
  - The set {sid, gpa} is a superkey

Primary and Candidate Keys in SQL

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

- "*For a given student and course, there is a single grade*"
  vs.
  "*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.*"
  - Used carelessly, an IC can prevent the storage of database instances that arise in practice!

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

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

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'
- Example: 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.
- 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 )
```

Problem?

Enrolled

sid	cid	grade
53831	Carnatic101	C
53831	Reggae203	B
53666	Topology112	A
53688	History105	B

Students

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

Problem?

Enforcing Referential Integrity

- *Students* and *Enrolled*:
  Enrolled. *sid* = foreign key referencing *Students*
- What if *Enrolled* tuple with non-existent student id is inserted?
  - Reject it
- 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 *Enrolled.sid* tuples that refer to it to a *default sid*
  - Set *Enrolled.sid* tuples that refer to it to a special value NULL, aka *`unknown'* or *`inapplicable'*
- Similar if primary key of *Students* tuple is updated
  - Never ever do that, anyway!

Referential Integrity in SQL

- SQL/92 and SQL:1999 support all 4 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 )
```

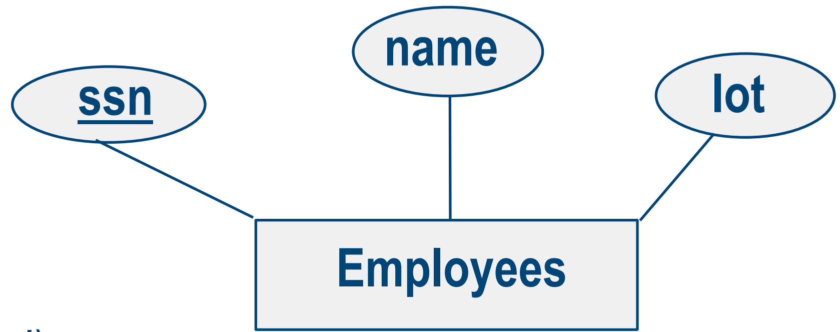
treat corresponding Enrolled tuple when Students (!) tuple is deleted

Where do ICs Come From?

- based upon the semantics of the real-world enterprise that is being described in the database relations
- can check a database instance to see if an IC is violated, but can NEVER infer that an IC is true by looking at an instance
  - 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 to us
- Key and foreign key ICs are the most common; more general ICs supported too

Logical DB Design: ER to Relational

- Entity sets to tables:
  - ER attribute → table attribute (can do that because ER constrained to simple types, same as in relational model)
  - Declare key attribute "Primary key"




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

- Best practice (not followed by some books): Add "abstract" identifying key attribute
  - No further semantics
  - System generated, no change, no reuse
  - use only this as primary key & for referencing

```
CREATE TABLE Employees
 ( sid INTEGER,
   ssn CHAR(11) UNIQUE,
   …,
   PRIMARY KEY (sid) )
```

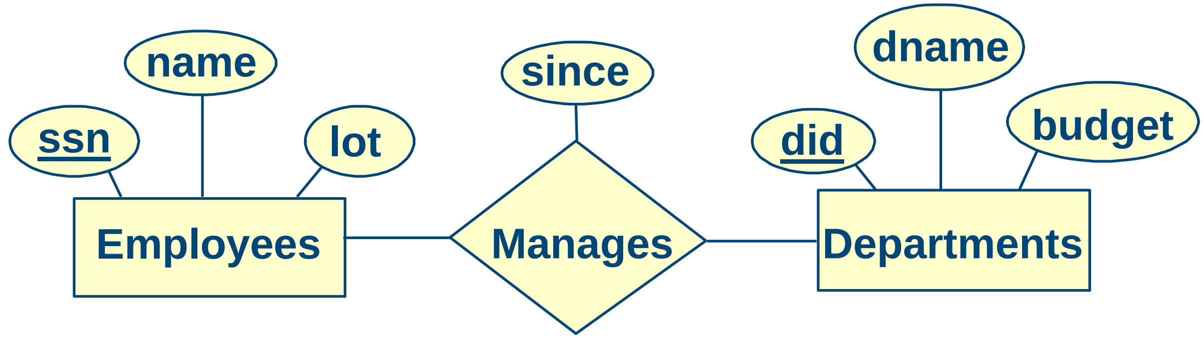
Relationship Sets to Tables

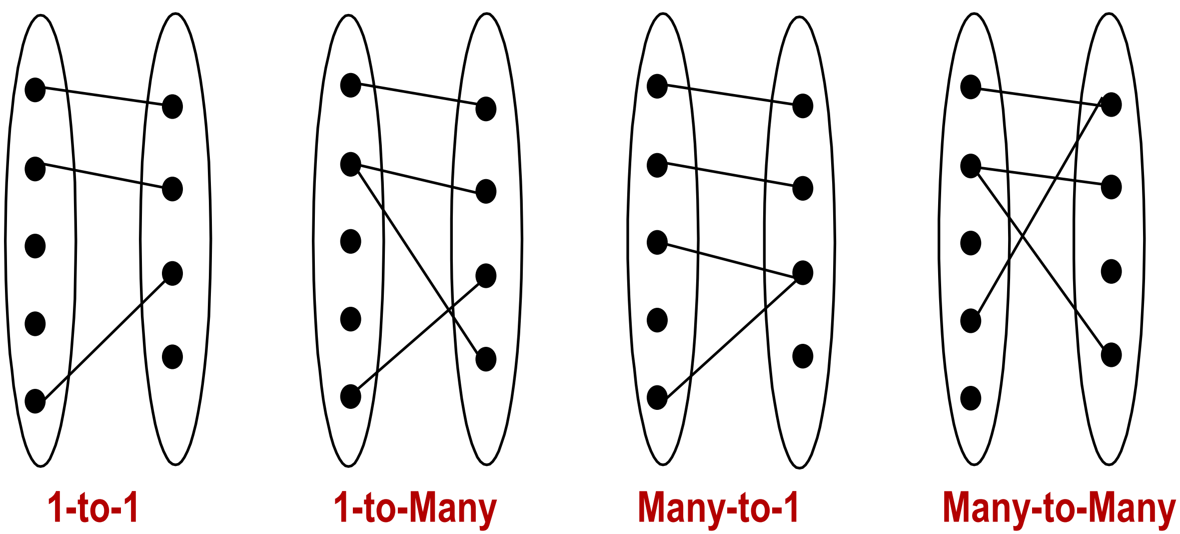
- In translating a relationship set to a relation, attributes of the relation must include:
  - Keys for each participating entity set (as foreign keys)
    - *a superkey for the relation*
  - All descriptive attributes

```
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 )
```

Review: Key Constraints

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

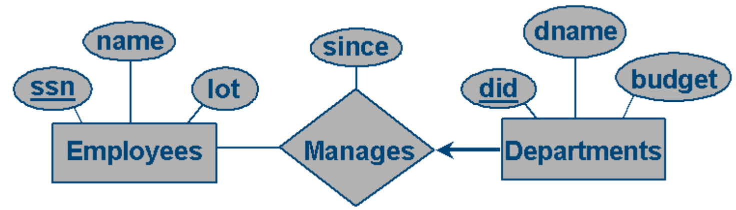




Translation to relational model? …see next!

ER Diagrams with Key Constraints

- Map relationship to table:
  - *did* key now
  - Separate tables for Employees and Departments



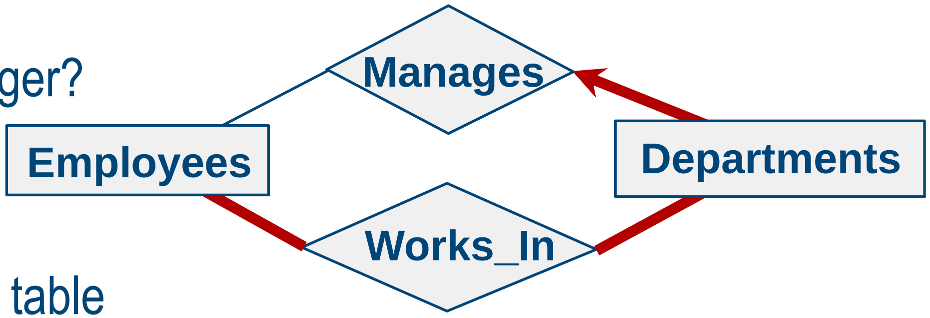

```
CREATE TABLE  Manages
(  ssn  CHAR(11),
   did  INTEGER,
   since  DATE,
   PRIMARY KEY  (did),
   FOREIGN KEY (ssn) REFERENCES Employees,
   FOREIGN KEY (did) REFERENCES Departments )
```

- We know each department has unique manager
  → can 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 )
```

Participation Constraints in SQL

- Review: Participation Constraints
  - Does every department have a manager?
    → participation constraint
  - Every *did* value in *Departments* table must appear in a row of the *Manages* table (with non-null ssn value!)



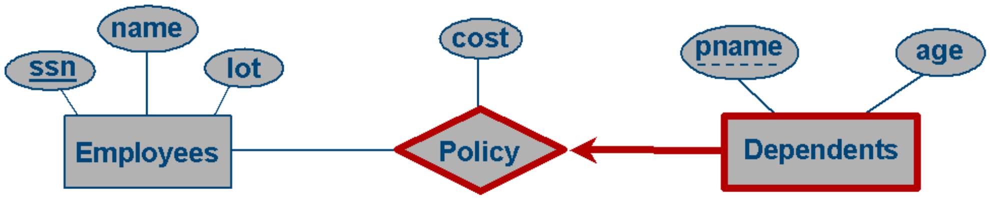

```
CREATE TABLE  Manages
(  did  INTEGER,
   dname  CHAR(20),
   budget  REAL,
   ssn  CHAR(11) NOT NULL,
   since  DATE,
   PRIMARY KEY  (did),
   FOREIGN KEY  (ssn)
     REFERENCES Employees
     ON DELETE NO ACTION )
```

- can capture participation constraints involving one entity set in a binary relationship
  - but little else (w/o CHECK constraints)
- caution about hacks!

Translating Weak Entity Sets

forget this slide!

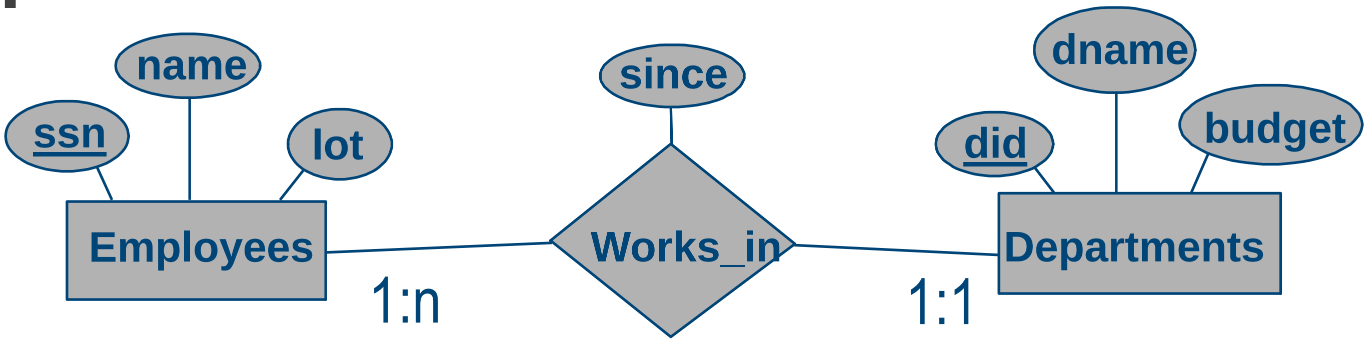
- Review: weak entity:
  identifiable uniquely only by *owner* entity
  - one-to-many relationship set
    (1 owner, many weak entities)
  - Weak entity:
    total participation in identifying relationship set



- Weak entity set & identifying relationship set
  → single table
- When owner entity is deleted:
  delete all owned weak entities

```
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 )
```

Example

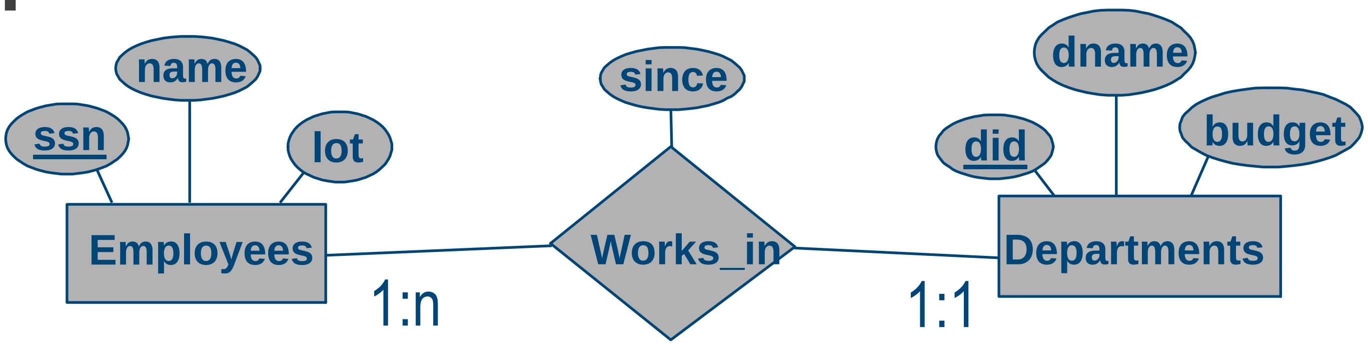



```
Create table Employees(
  eid: int,
  ssn: int unique,
  name: char(100),
  lot: int
  primary key (eid)
)
```

```
Create table Works_in(
  eid: int unique,
  did_ int,
  since: date
  primary key(eid,did_)
  foreign key (eid) references Employees
  foreign key (did_) references Departments
)
```

```
Create table Departments(
  did_: int,
  did: int unique,
  dname: char(100),
  budget: money
  primary key (did_)
)
```

Example




```
Create table Employees(
  eid: int,
  ssn: int unique,
  name: char(100),
  lot: int
  primary key (eid)
)
```

```
Create table Works_in(
  eid: int unique,
  did_ int,
  since: date
  primary key(eid,did_)
  foreign key (eid) references Employees
  foreign key (did_) references Departments
)
```

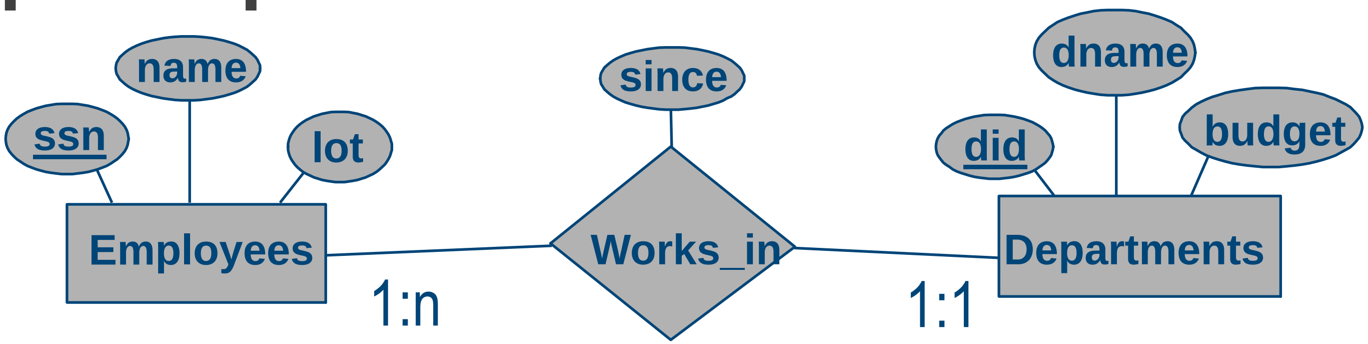
```
Create table Departments(
  did_: int,
  did: int unique,
  dname: char(100),
  budget: money
  primary key (did_)
)
```

eid	ssn	name	lot
1	123	John Doe	5
2	456	Jane Fox	17
3	789	Charlie Brown	42

eid	did_	since
1	2	2018-12-01
3	1	2017-01-01
2	2	2015-06-01

did_	did	name	budget
1	5	Sales	500
2	17	Accounting	170
3	99	Production	420

Example / Optimized

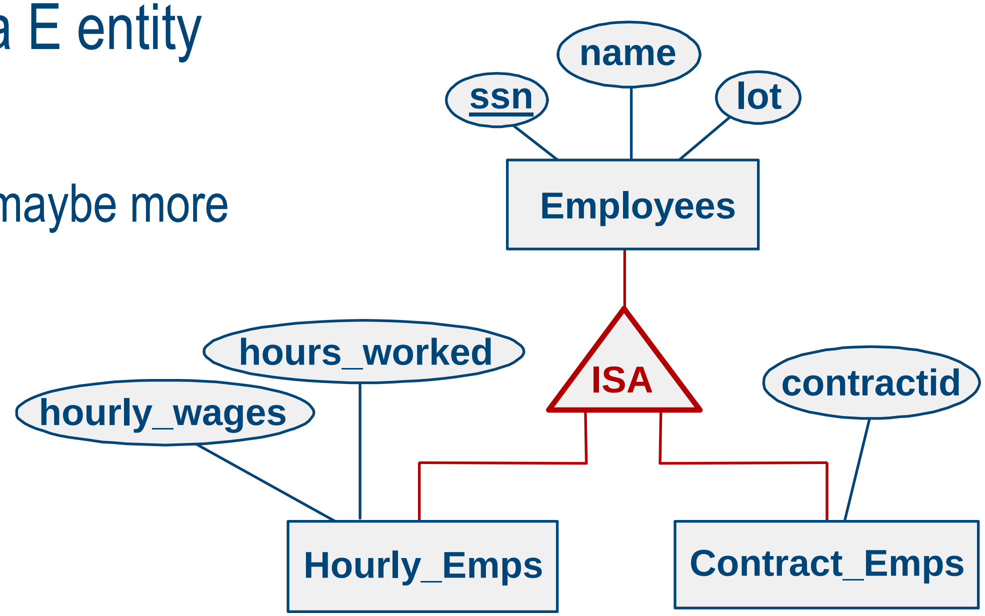


- Create table Employees(
  eid: int,
  ssn: int unique,
  name: char(100),
  lot: int,
  since: date
  did_: int
  primary key (eid)
  foreign key (did_)
  references Departments
)

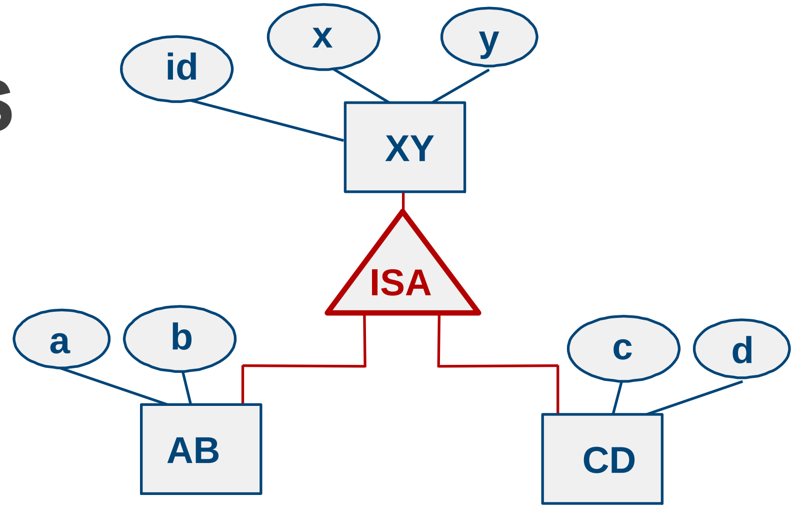
- Create table Departments(
  did_: int,
  did: int unique,
  dname: char(100),
  budget: money
  primary key (did_)
)

ISA Hierarchies

- H ISA E: every H entity is also a E entity ("H inherits from E")
  - H attributes = E attributes + plus maybe more
  - H subclass, E superclass
- Mapping to Relations
  - Several choices
  - Constraints determine



ISA → Tables



- Alt 1:

AB	id	a	b
	1	.	.
	3	.	.

XY	id	x	y
	1	.	.
	2	.	.
	3		
	4		

CD	id	c	d
	2	.	.
	4	.	.

- Alt 2:

ABXY	id	a	b	x	y
	1	.	.	.	.
	3	.	.	.	.

CDXY	id	c	d	x	y
	2	.	.	.	.
	4	.	.	.	.

- Alt 3:

ABCDXY	id	a	b	c	d	x	y
	1	5	7	n	n	3	4
	2	n	n	9	8	6	7

Insert?
Select AB?
Select XY?

ISA → Relations: Discussion

- Alt 1: separate relation per entity set
  → 3 relations: Employees, Hourly_Emps, Contract_Emps
  - Every employee recorded in Employees
  - must delete Hourly_Emps tuple if referenced Employees tuple is deleted
  - Queries on all Employees easy, on Hourly_Emps require join
- Alt 2: relations only for subclass entity sets
  → 2 relations: Hourly_Emps, Contract_Emps
  - Hourly_Emps: ssn, name, lot, hourly_wages, hours_worked
  - Each employee must be in one of these two subclasses

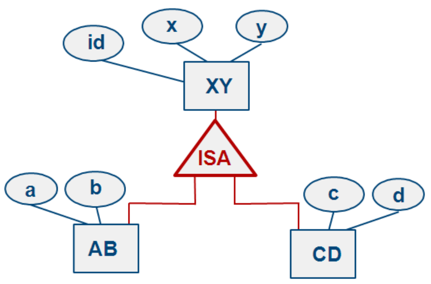
Overlap?
Covering?

- Alt 3: one big relation → 1 relation: Emps
- Alt 4: PostgreSQL inheritance:

  CREATE TABLE Contract_Emps (contractid: int) INHERITS (Employees)

Not a solution in exam!

ISA → Relations: Schemas



- Alt 1: separate relation per entity set

  XY (id, x, y)
  AB (id, a, b, FOREIGN KEY (id) REFERENCES XY(id))
  CD (id, c, d, FOREIGN KEY (id) REFERENCES XY(id))

- Alt 2: relations only for subclass entity sets

  XYAB (id, x, y, a, b)
  XYCD (id, x, y, c, d)

- Alt 3: one big relation

  XYABCD (id, x, y, a, b c, d)

Views

- like a table, but stores query rather than data
- Definition:

```
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
```

- Use like any table:

```
SELECT name
FROM YoungActiveStudents
WHERE grade < 3.00
```

- Security: hiding details of underlying relation(s)
  - Given YoungActiveStudents, but not Students or Enrolled, can find students enrolled
  - …but not courses they are enrolled in

Relational Model: Summary

- Tabular representation of data
  - Simple & intuitive, most widely used
- Rules ER → relational model
  - Sometimes direct mapping: attributes, keys & foreign keys, …
  - Sometimes no direct support: inheritance, multiplicities, …
- Integrity constraints based on application semantics; DBMS enforces
  - primary + foreign keys; domain constraints; …
  - Sometimes inherent from modelling approach, ex: multiplicities
- SQL query language for generic set-oriented table handling (see next)