Database Applications (15-415)

The Relational Model
Lecture 3, January 18, 2015

Mohammad Hammoud

جامعة كارنيجي ميلون في قطر
Carnegie Mellon University Qatar

Today…

- Last Session:
  - The entity relationship (ER) model
- Today's Session:
  - ER model (Cont'd): conceptual design choices
  - The relational model
    - Basic Constructs of the relational model
    - Basic SQL
- Announcement:
  - PS1 is due on Jan 22, 2015 (i.e., Thursday) by midnight

Outline

- ER Model: Conceptual Design Choices and Summary ✓
- The Relational Model: Introduction
- The Relational Model: Basic SQL

Conceptual Design Choices

- Should a concept be modeled as an *entity* or an *attribute*?
- Should a concept be modeled as an *entity* or a *relationship*?
- How should we identify relationships?
  - *Binary* or *ternary*?
  - *Ternary* or *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

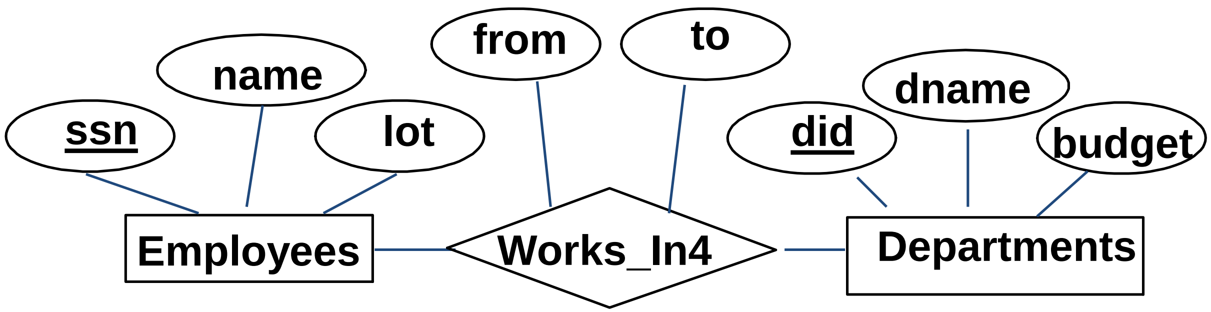
Entity vs. Attribute

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

- This depends upon the use we want to make of address information, and the semantics of the data
  - If we have several addresses per an 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

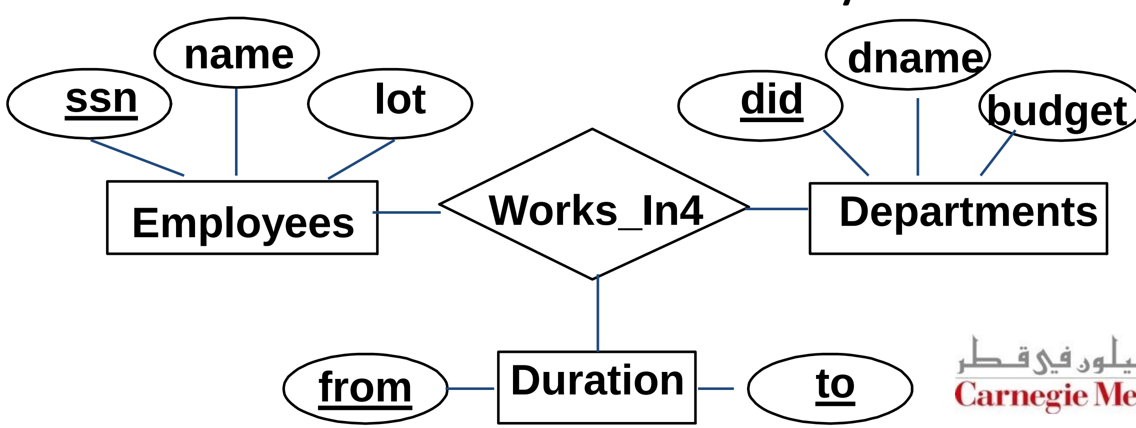
Entity vs. Attribute (Cont'd)

- Consider the following ER diagram:



- A problem: Works_In4 does not allow an employee to work in a department for two or more periods

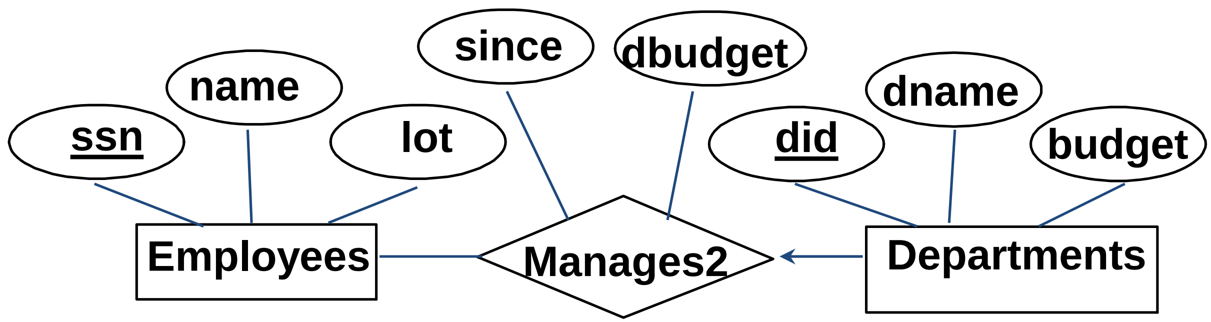
- Solution: introduce "Duration" as a new entity set



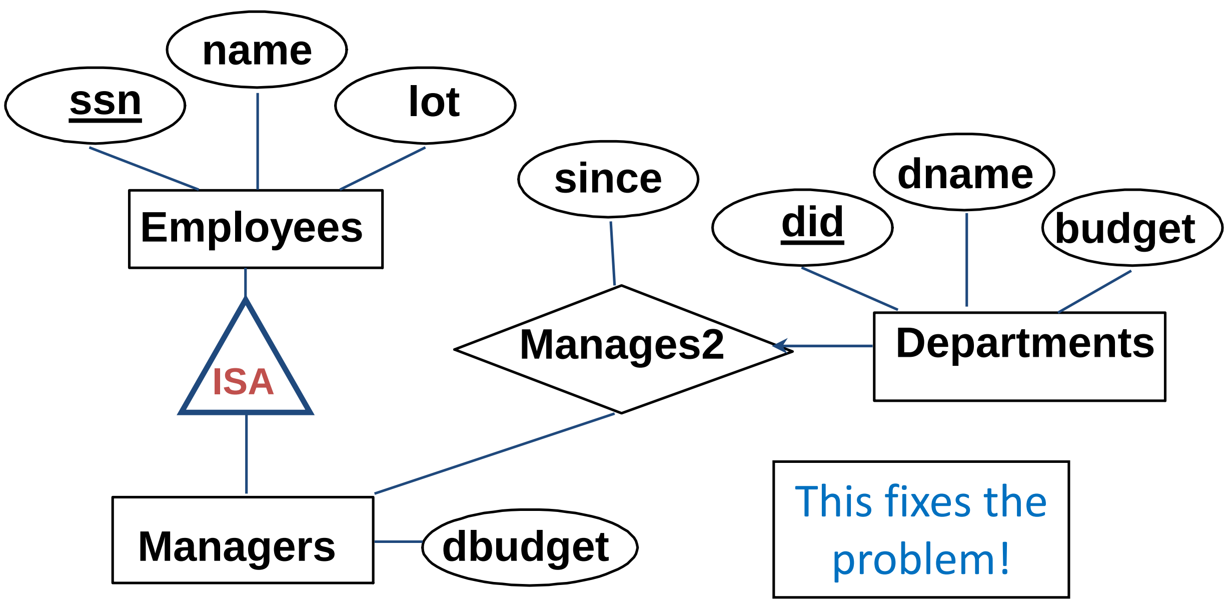
جامعة كارنيجي ميلون في قطر
Carnegie Mellon University Qatar

Entity vs. Relationship

- Consider the following ER diagram whereby a manager gets a separate discretionary budget for each department



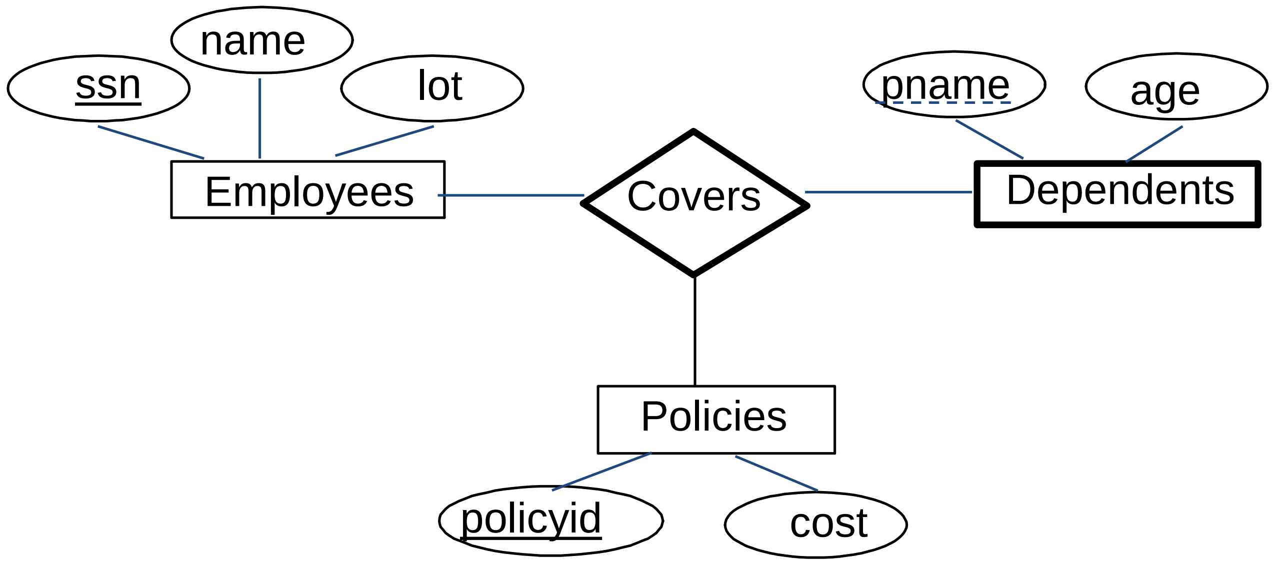
- What if a manager gets a discretionary budget that covers *all* managed departments?
  - Redundant data
  - Misleading



This fixes the problem!

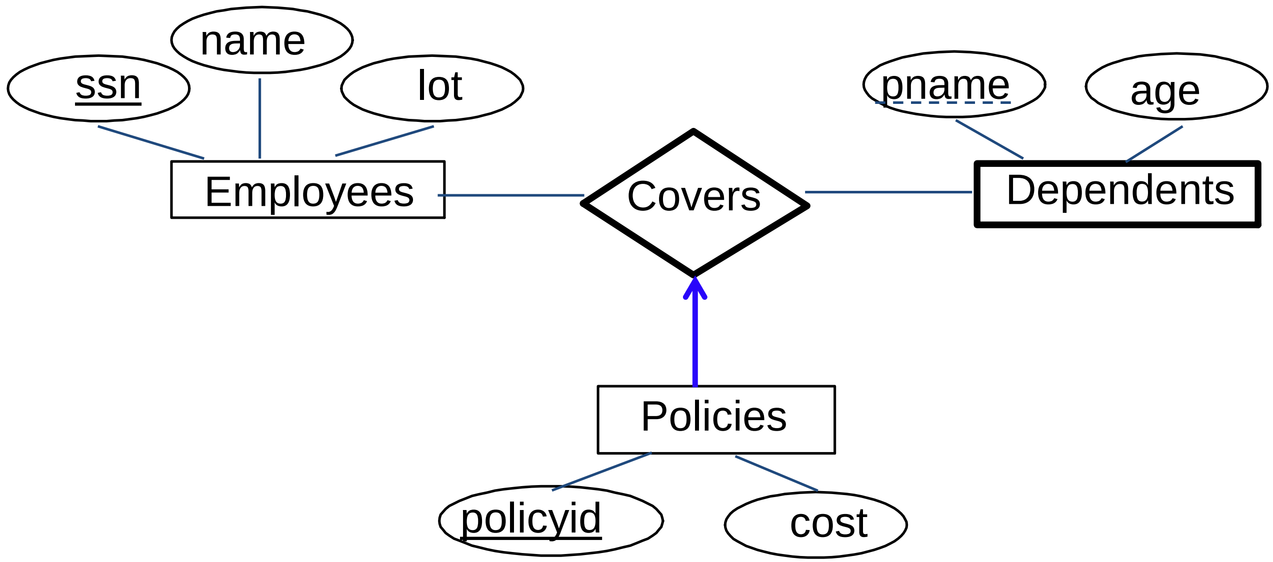
Binary vs. Ternary Relationships

If each policy is owned by just 1 employee:



Binary vs. Ternary Relationships

If each policy is owned by just 1 employee:

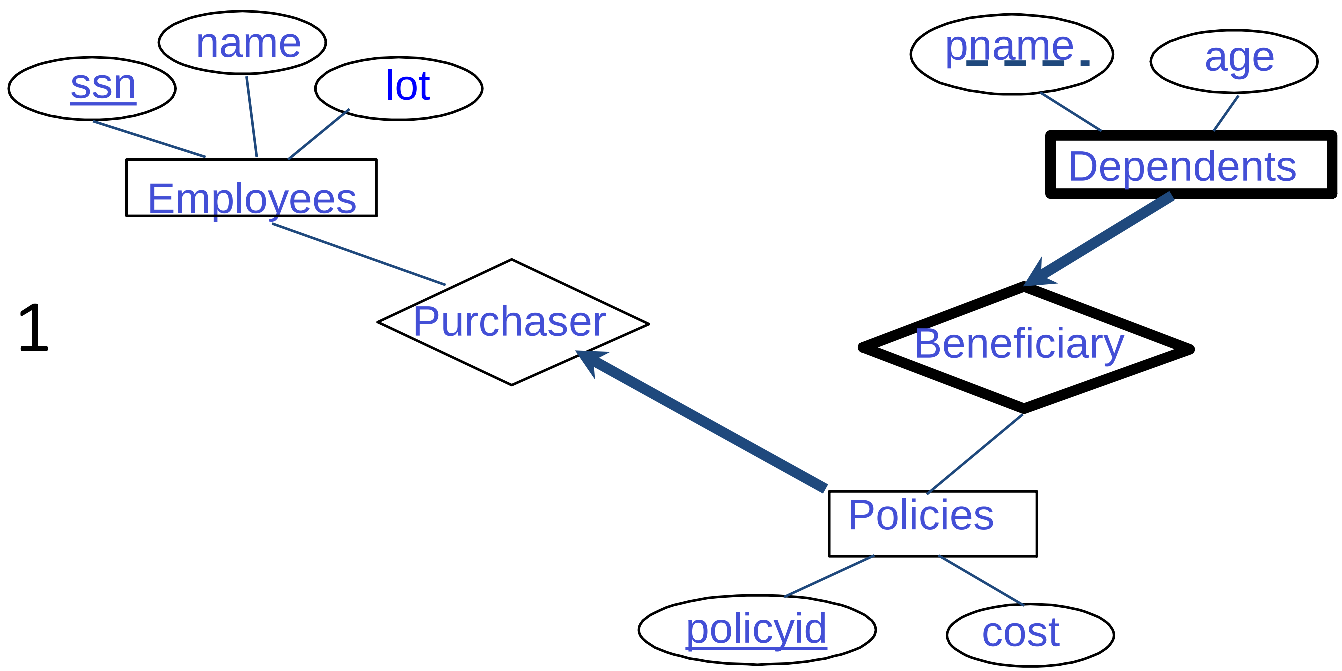


Bad design!

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

Binary vs. Ternary Relationships

If each policy is owned by just 1 employee:



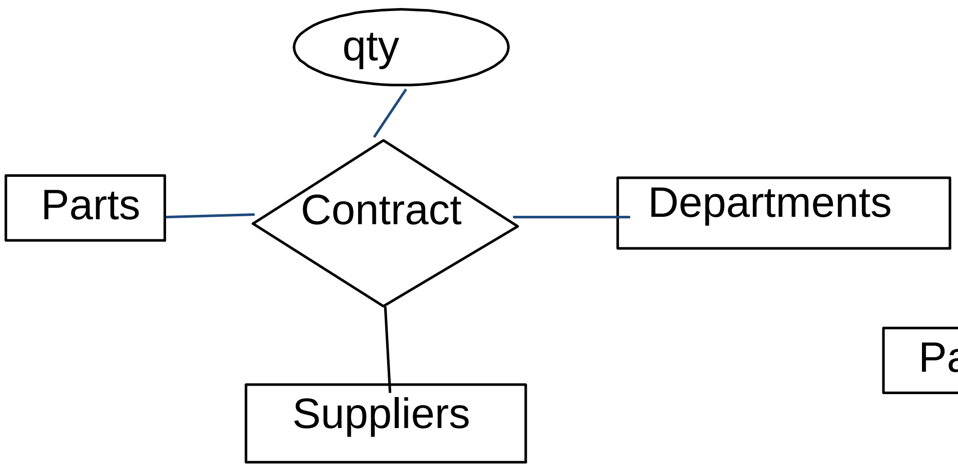
Better design!

Binary vs. Ternary Relationships

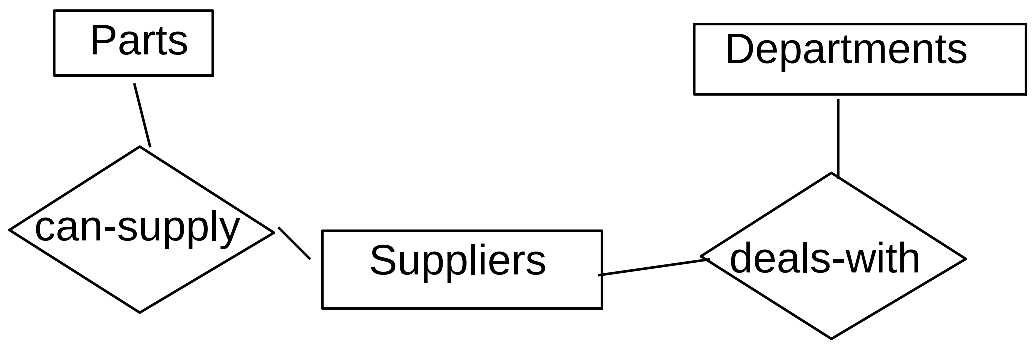
- But sometimes ternary relationships cannot be replaced by a set of binary relationships

Binary vs. Ternary Relationships

- But sometimes ternary relationships cannot be replaced by a set of binary relationships

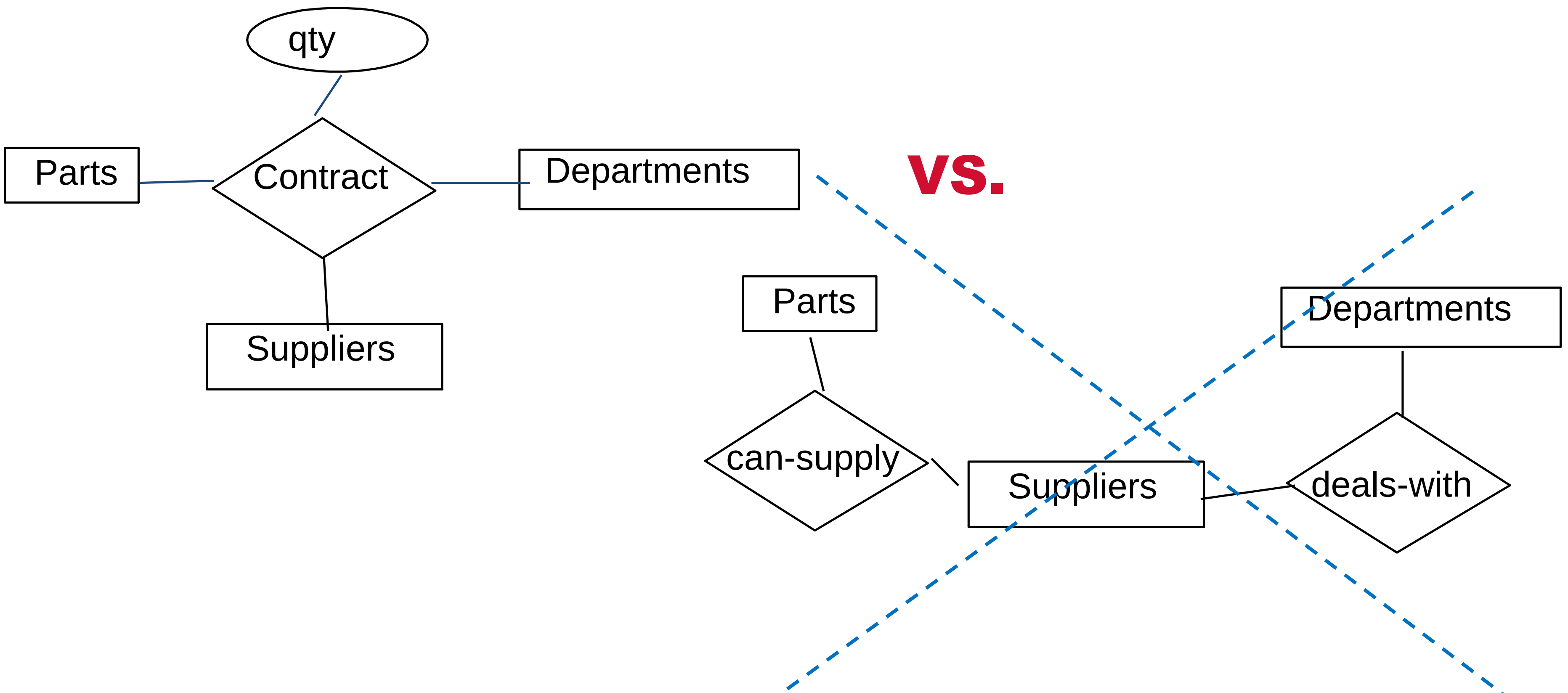


vs.



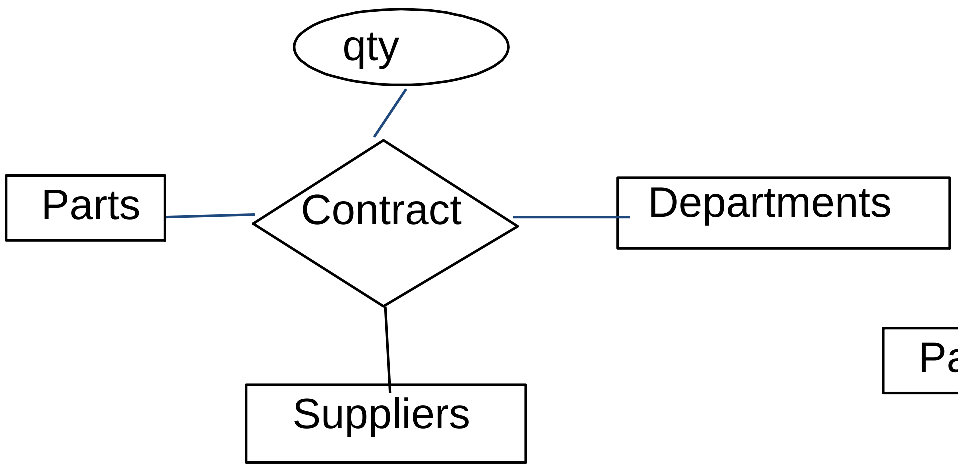
Binary vs. Ternary Relationships

- But sometimes ternary relationships cannot be replaced by a set of binary relationships

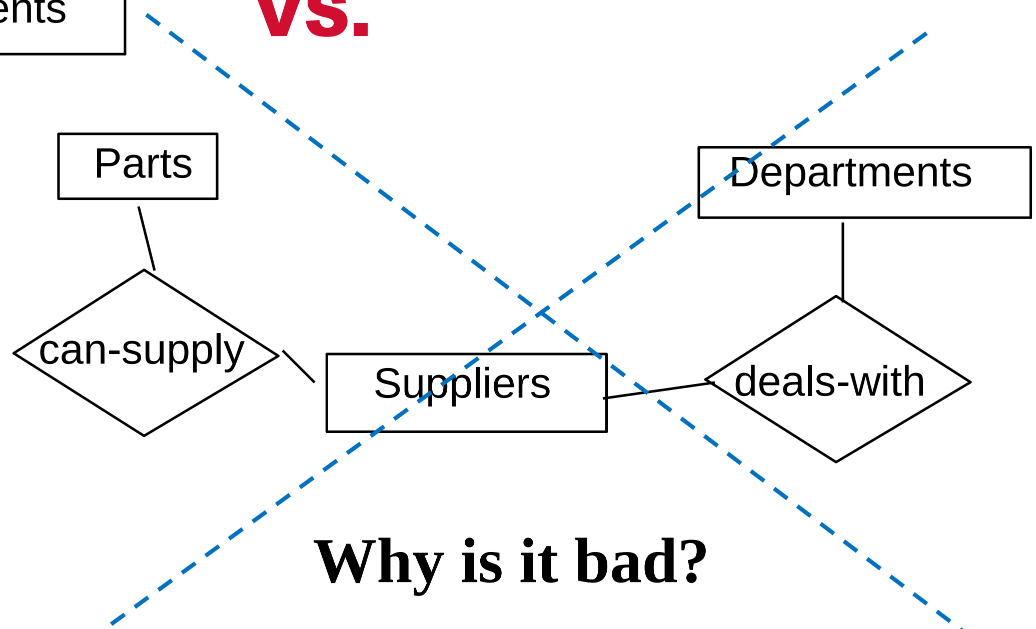


Binary vs. Ternary Relationships

- But sometimes ternary relationships cannot be replaced by a set of binary relationships



vs.

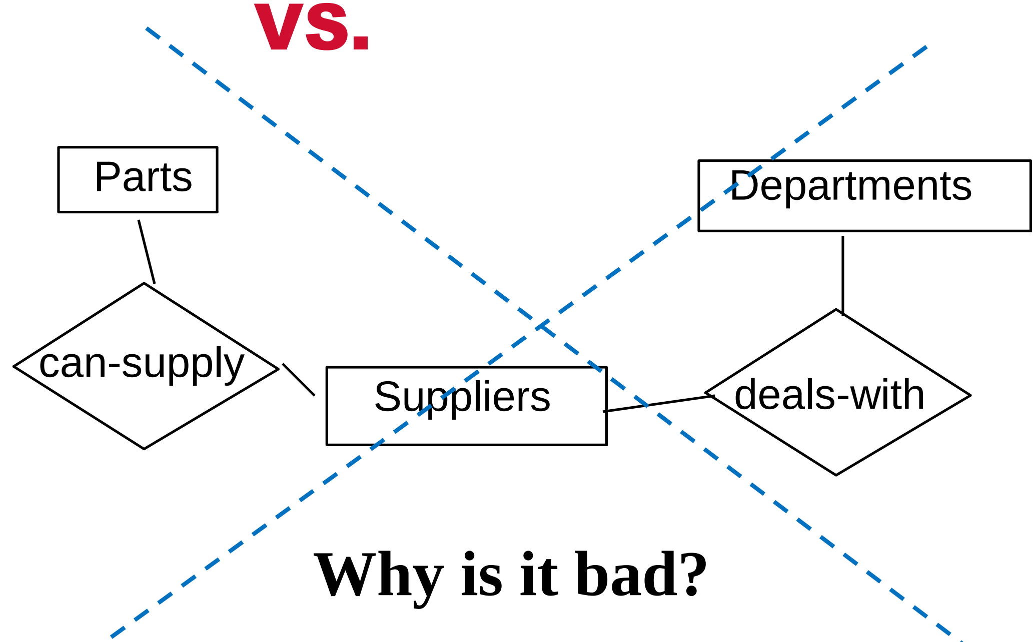


Why is it bad?

Binary vs. Ternary Relationships

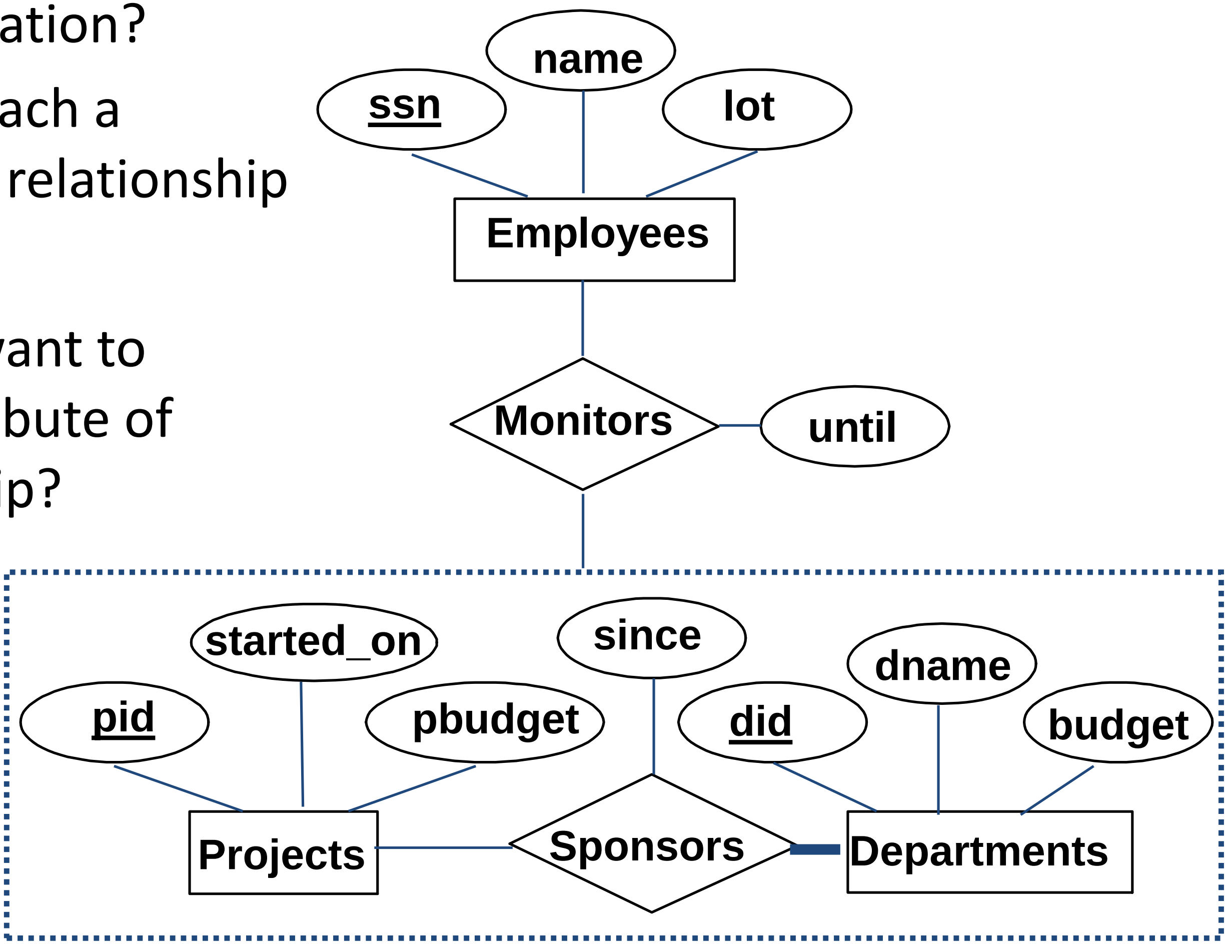
- But sometimes ternary relationships cannot be replaced by a set of binary relationships
  - ***S*** "can-supply" ***P***, ***D*** "needs" ***P***, and ***D*** "deals-with" ***S*** do not imply that ***D*** has agreed to buy ***P*** from ***S***
  - How do we record *qty*?

vs.



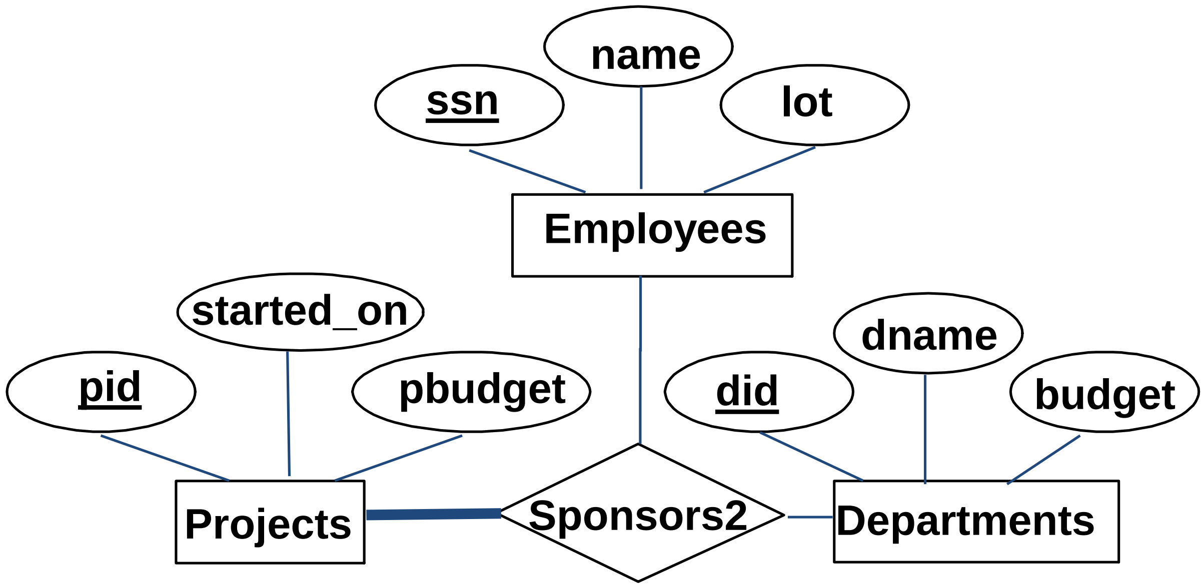
Ternary vs. Aggregation Relationships

- When to use aggregation?
  - If we want to attach a relationship to a relationship
- What if we do not want to record the *until* attribute of Monitors relationship?



Ternary vs. Aggregation Relationships (Cont'd)

- We might reasonably use a ternary relationship instead of an aggregation



What if each sponsorship (of a project by a department) is to be monitored by at most one employee?

ER Model: Summary

- *Conceptual design* follows *requirements analysis*
  - Yields a high-level description of data to be stored

- The ER model is popular for conceptual design
  - Its constructs are expressive, close to the way people think about their applications

- The basic constructs of the ER model are:
  - *Entities*, *relationships*, and *attributes* (of entities and relationships)

ER Model: Summary

- Some additional constructs of the ER model are:
  - *Weak entities*, *ISA hierarchies*, and *aggregation*

- Several kinds of integrity constraints can be expressed in the ER model
  - *Key constraints*, *participation constraints*, and *overlap/covering constraints* for ISA hierarchies

- Note: there are many variations on the ER model

ER Model: Summary

- 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 (e.g., ternary)
    - Whether or not to use ISA hierarchies
    - Whether or not to use aggregation

Outline

- ER Model: Conceptual Design Choices and Summary
- The Relational Model: Introduction ✓
- The Relational Model: Basic SQL

Why Studying 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 into
  - An *object-relational model*
    - Informix->IBM DB2, Oracle 8i

What is the Relational Model?

- The relational model adopts a "tabular" representation
  - A database is a *collection* of one or more relations
  - Each relation is a *table* with rows and columns

- What is unique about the relational model as opposed to older data models?
  - Its simple data representation
  - Ease with which complex queries can be expressed

Basic Constructs

- The main construct in the relational model is the *relation*

- A relation consists of:
  1. A schema which includes:
     - The relation's name
     - The name of each column
     - The *domain* of each column

  2. An instance which is a set of tuples
     - Each tuple has the same number of columns as the relation schema

The Domain Constraints

- A relation schema specifies the *domain* of each column which entails domain constraints

- A domain constraint specifies a condition by which each instance of a relation should satisfy
  - The values that appear in a column must be drawn from the domain associated with that column

- Who defines a domain constraint?
  - DBA
- Who enforces a domain constraint?
  - DBMS

More Details on the Relational Model

Degree (or arity) = # of fields

Cardinality = # of tuples

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

An instance of the "Students" relation

- What is the relational database schema (*not* the relation schema)?
  - A collection of schemas for the relations in the database
- What is the instance of a relational database (*not* the instance of a relation)?
  - A collection of relation instances

Outline

- ER Model: Conceptual Design Choices and Summary
- The Relational Model: Introduction
- The Relational Model: Basic SQL ✓

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
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@cs	18	3.2
53650	Smith	smith@math	19	3.8

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
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

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

- 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))
```

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
  (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))
```

"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

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

- 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
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

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)

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

Logical Data Independence!

  - 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)

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

    Logical Data Independence!
    - 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

    Security!
    - 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)

Next Class

The Relational Model (Cont'd) and Relational Algebra