Database Applications (15-415)

The Relational Model
Lecture 3, January 17, 2016

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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 Thursday, Jan 21, 2016 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

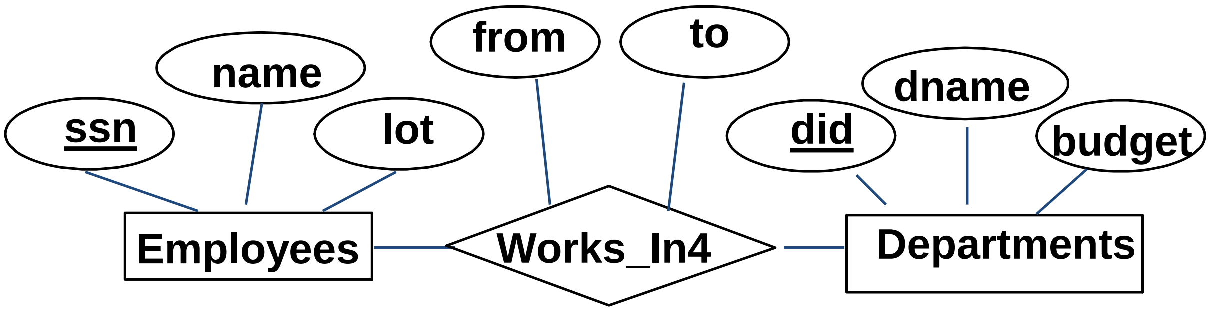
Entity vs. Attribute

- 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

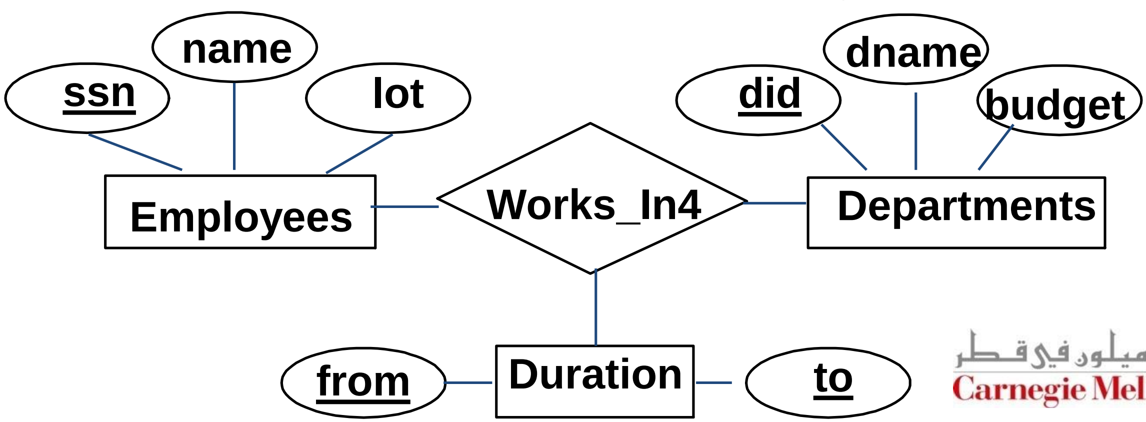
Entity vs. Attribute (Cont'd)

- Consider the following ER diagram:



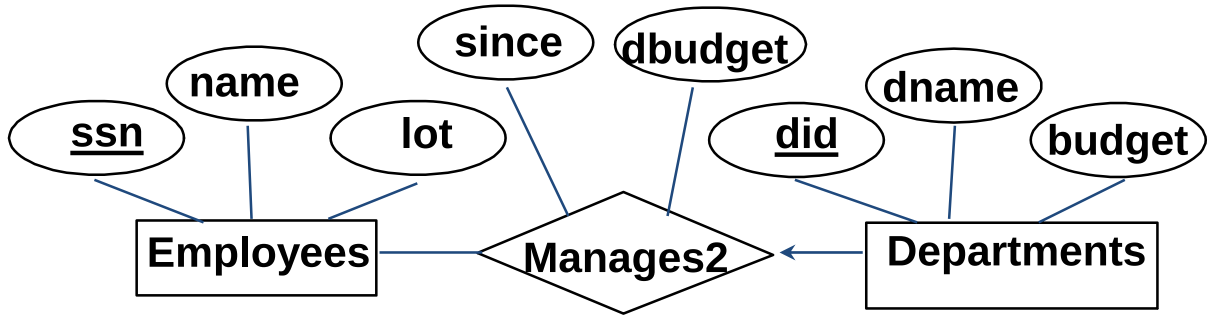
- A problem: Works_In4 does not allow an employee to work in a department for two or more periods

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

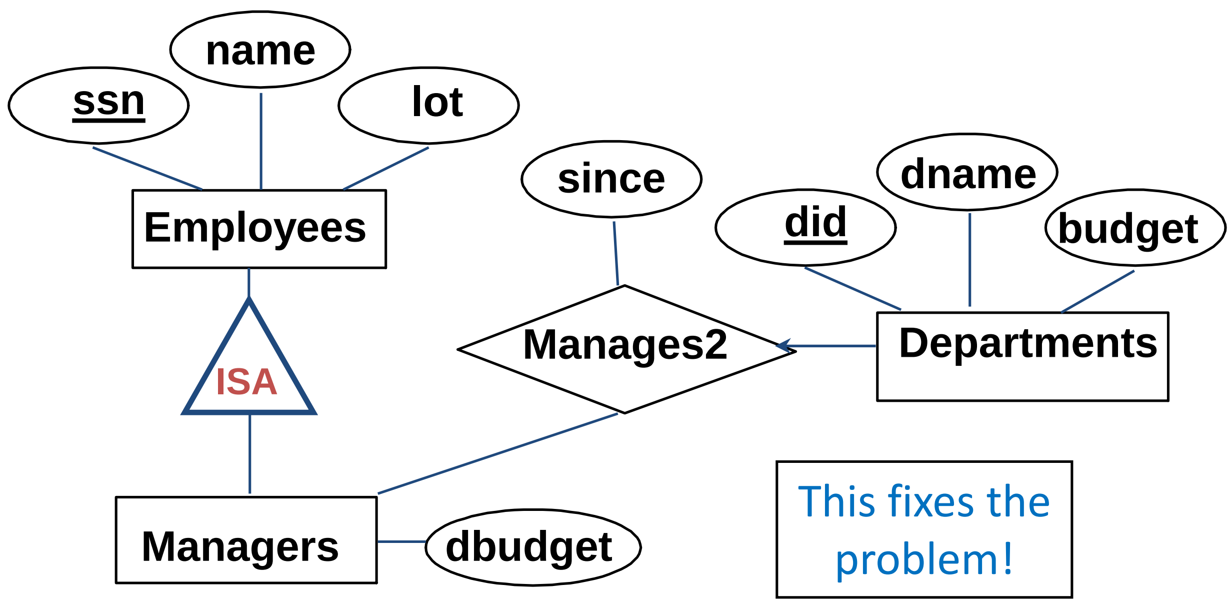


Entity vs. Relationship

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

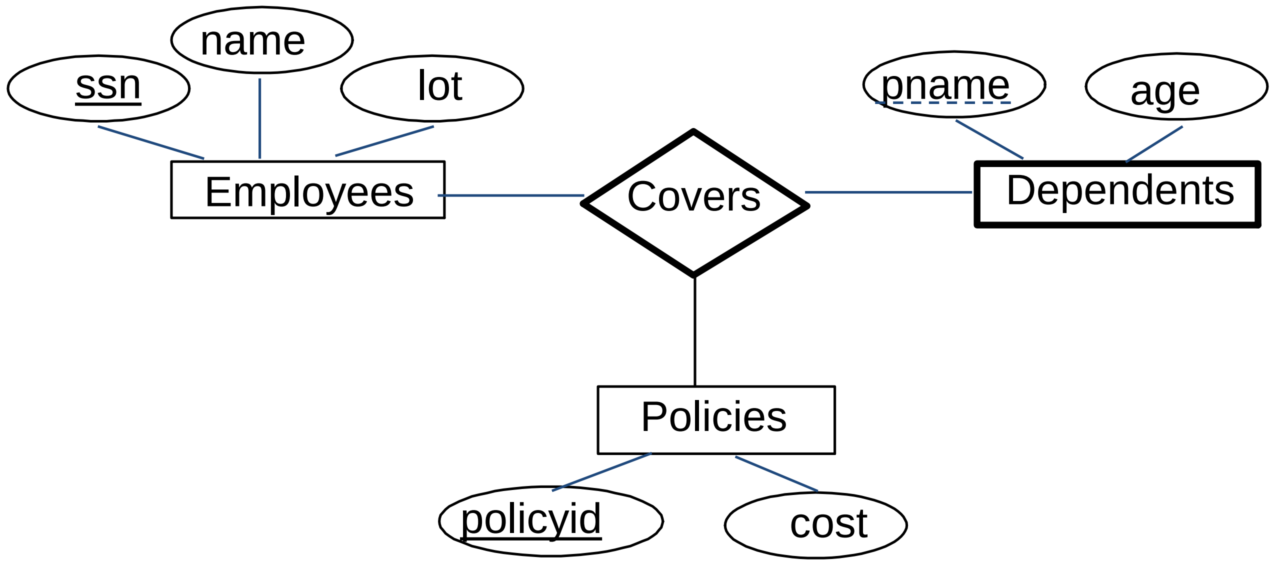


- What if a manager gets a discretionary budget that covers *all* managed departments?
  - Redundant data
  - Misleading



Binary vs. Ternary Relationships

If each policy is owned by just 1 employee:



Binary vs. Ternary Relationships

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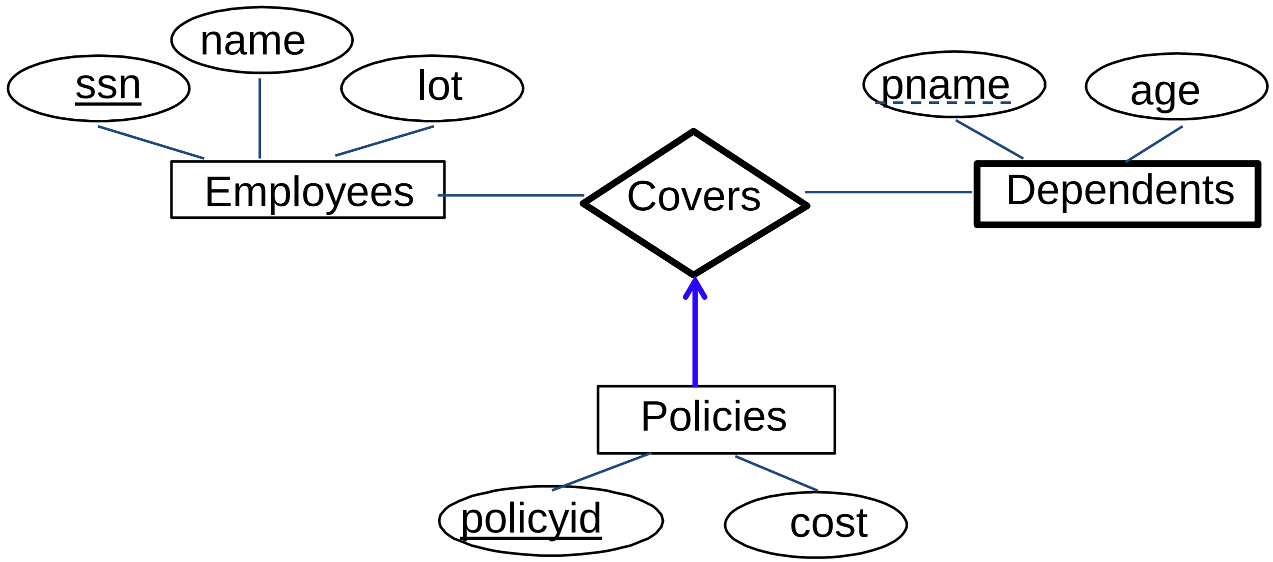
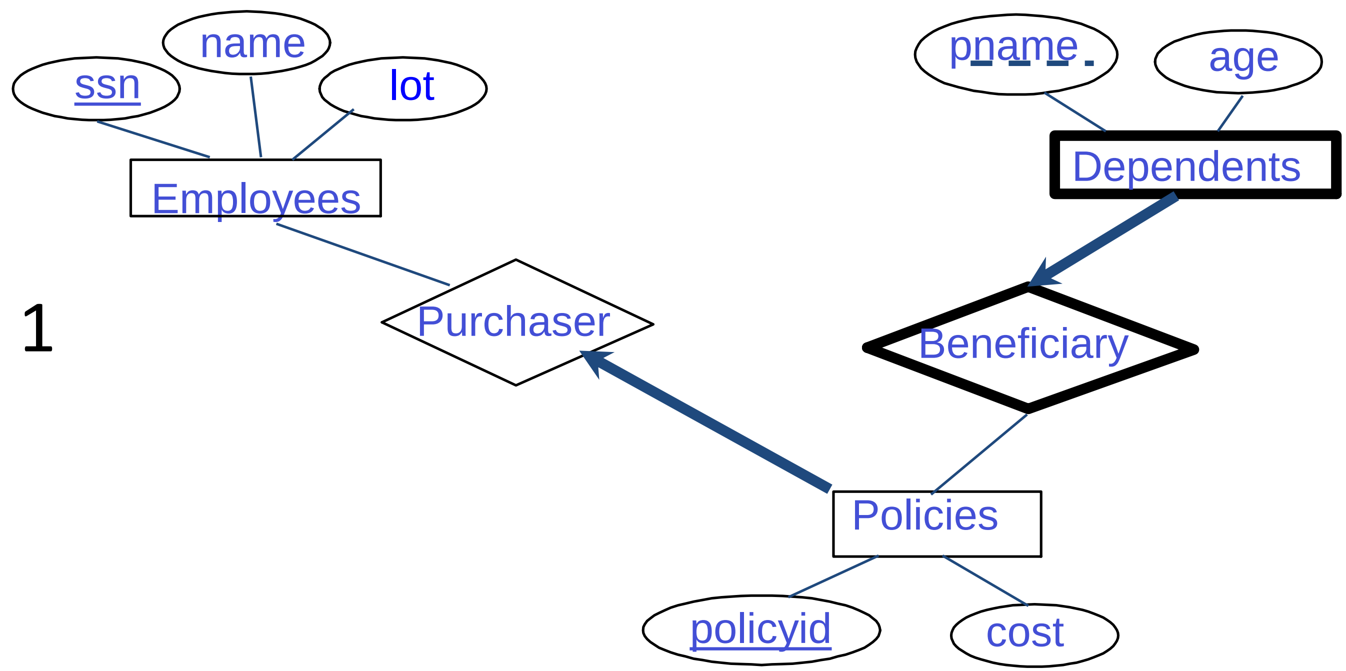


Bad design!

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

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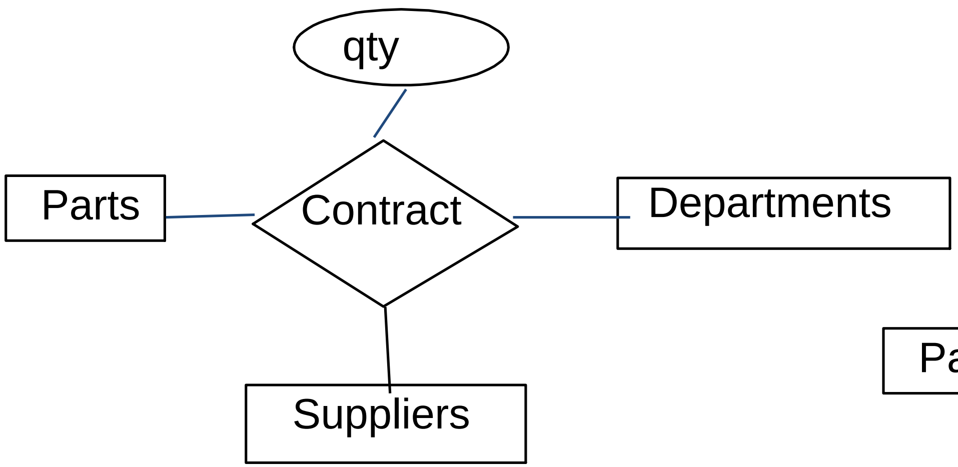
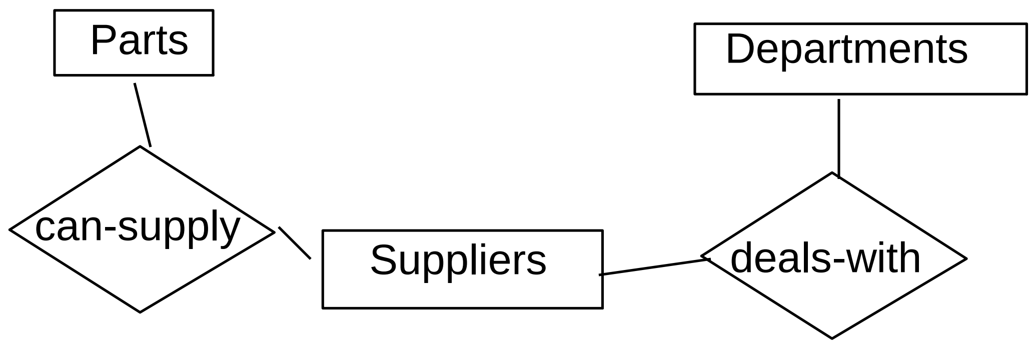


vs.



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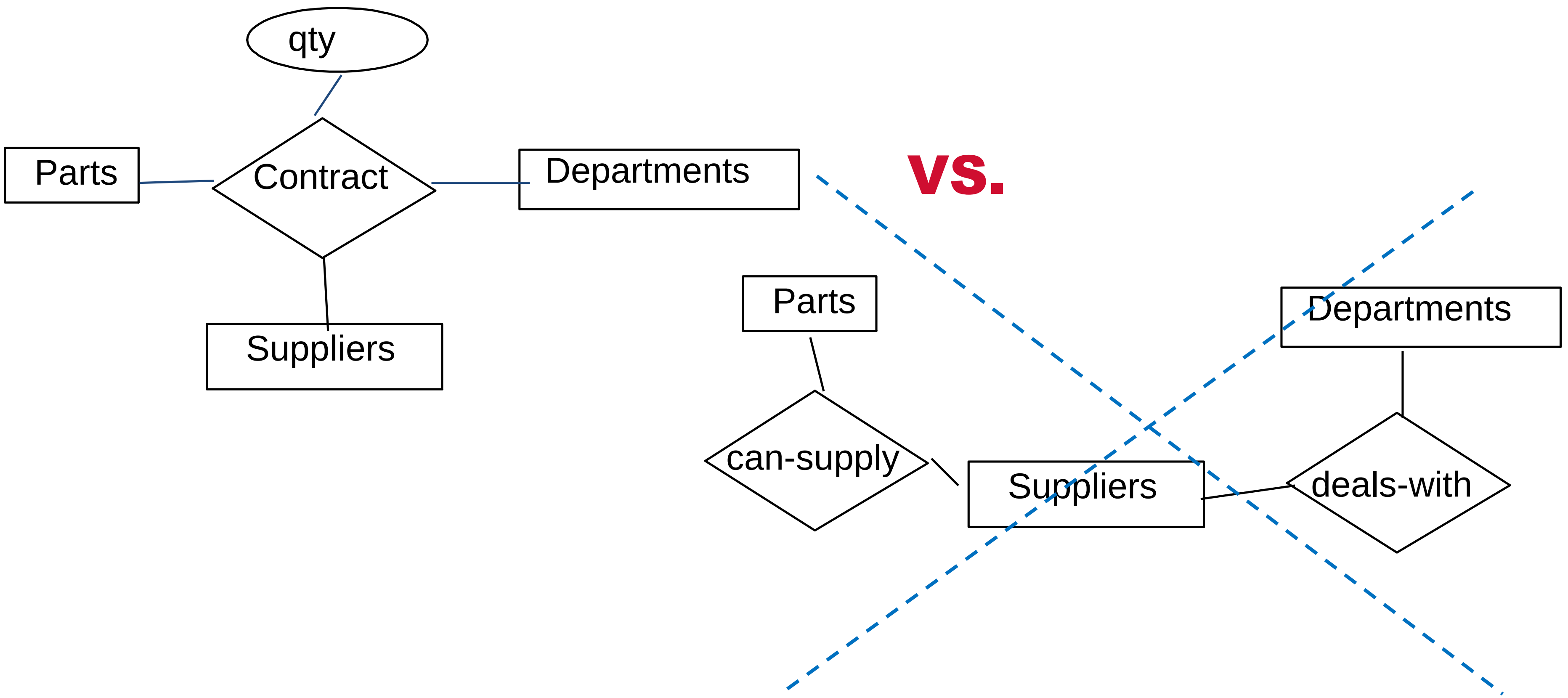

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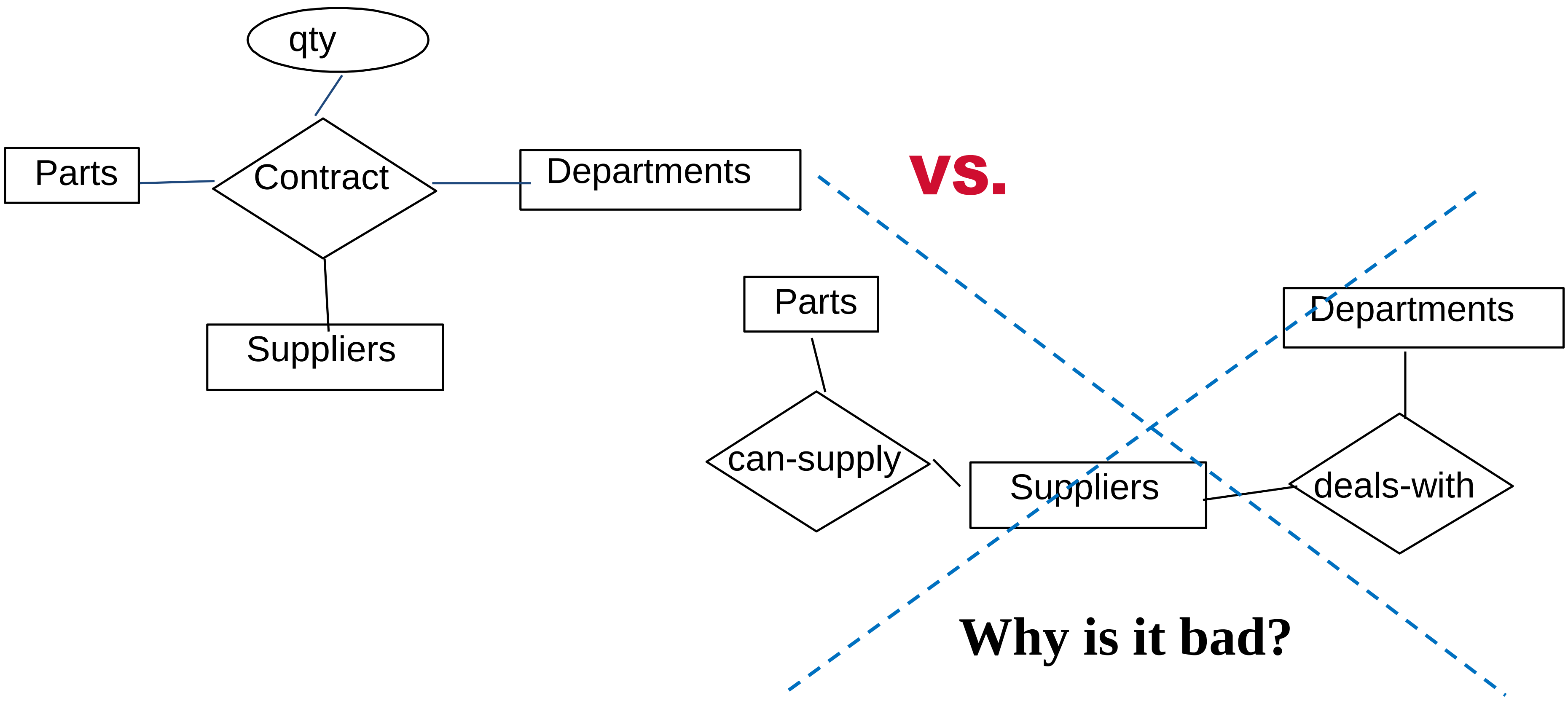
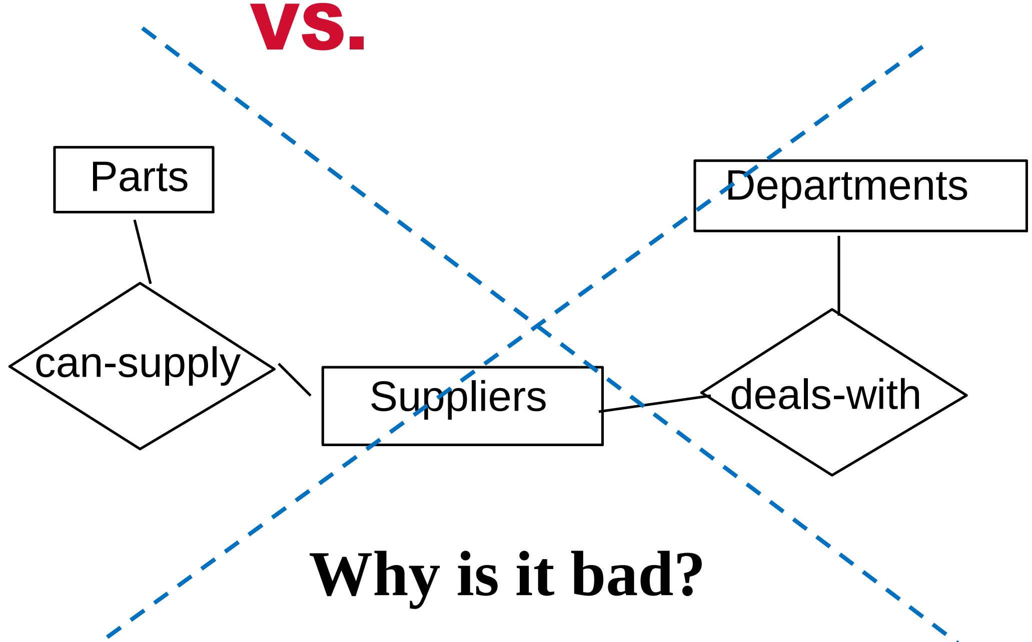


Binary vs. Ternary Relationships

- 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*?

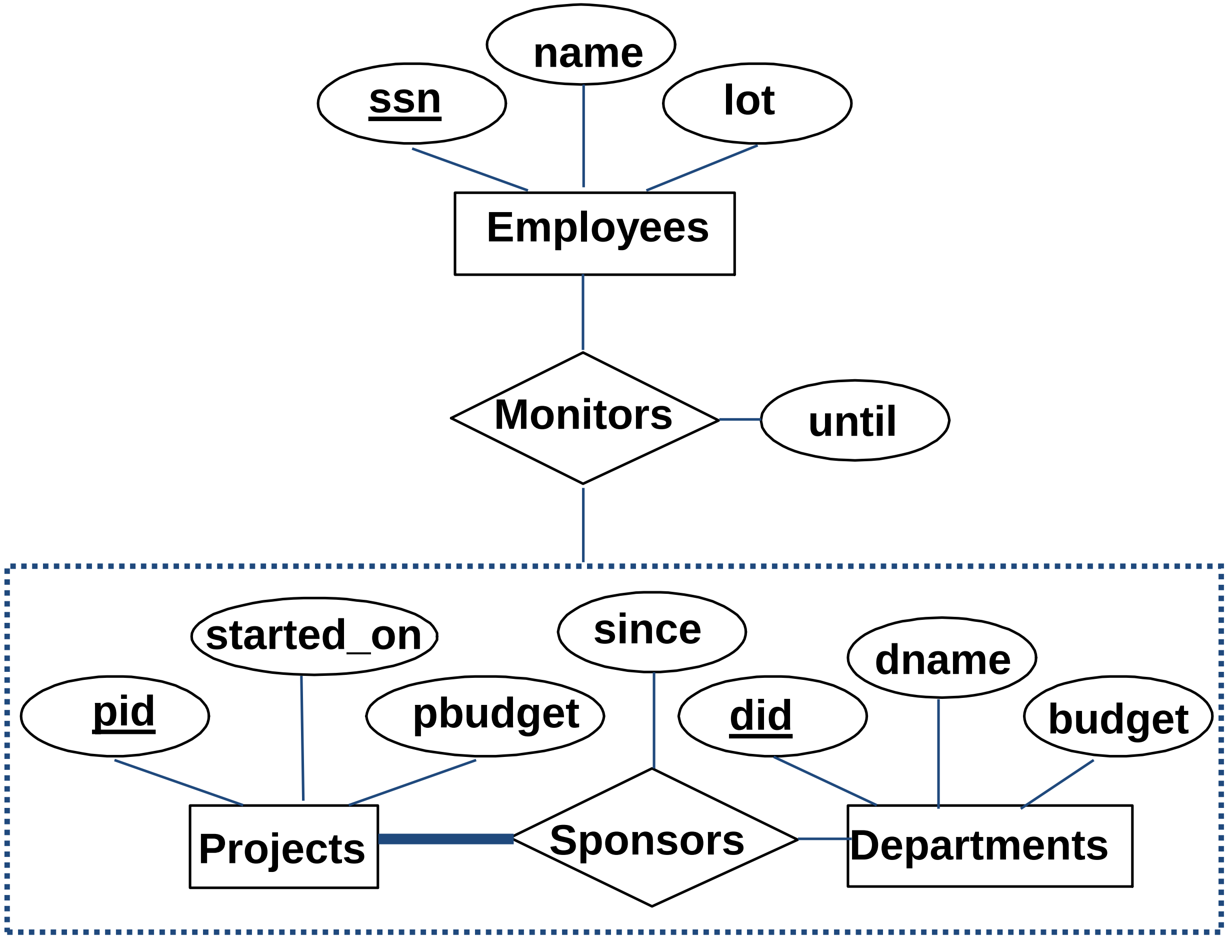
vs.



Why is it bad?

Aggregation

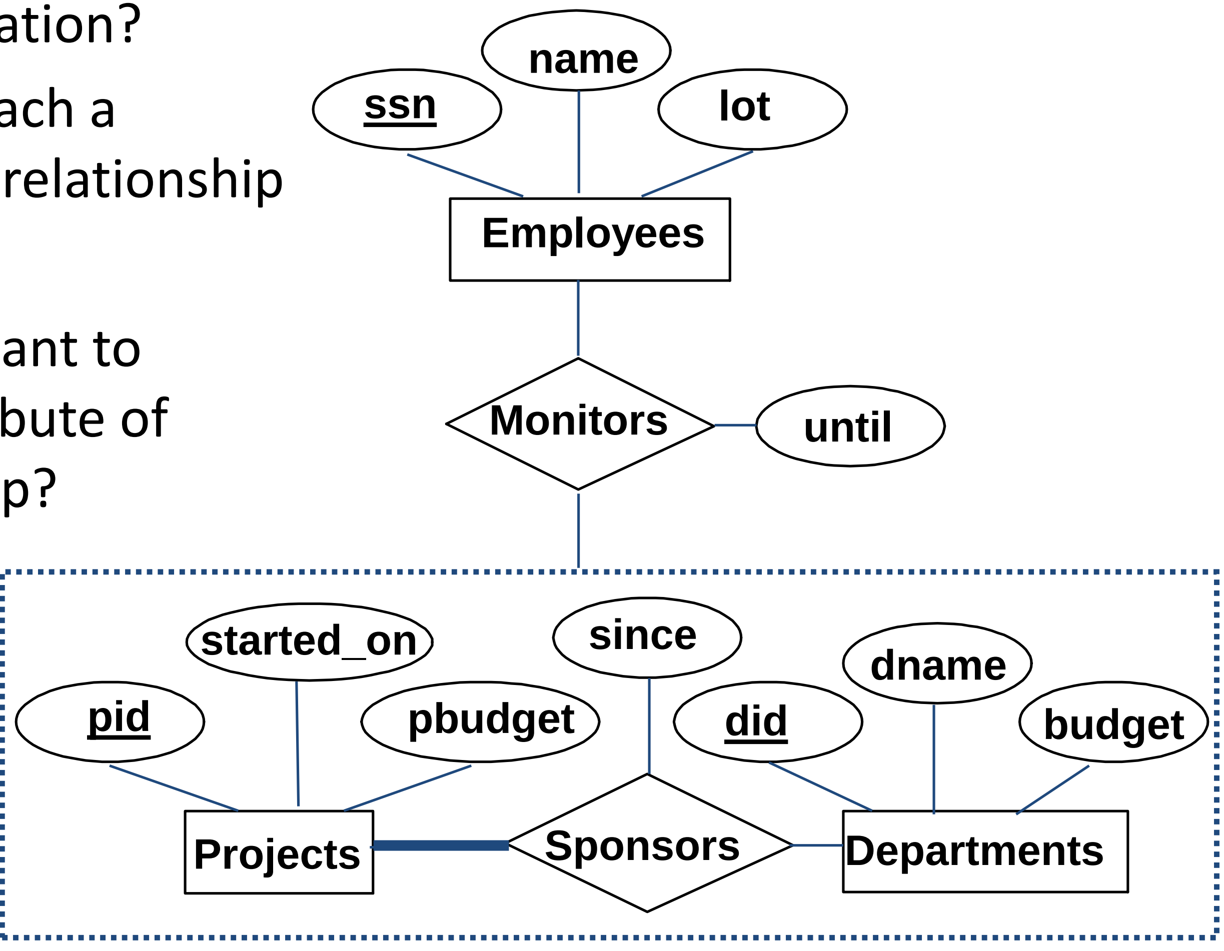
- Aggregation allows indicating that a relationship set (identified through a *dashed box*) participates in another relationship set



Ternary vs. Aggregation Relationships

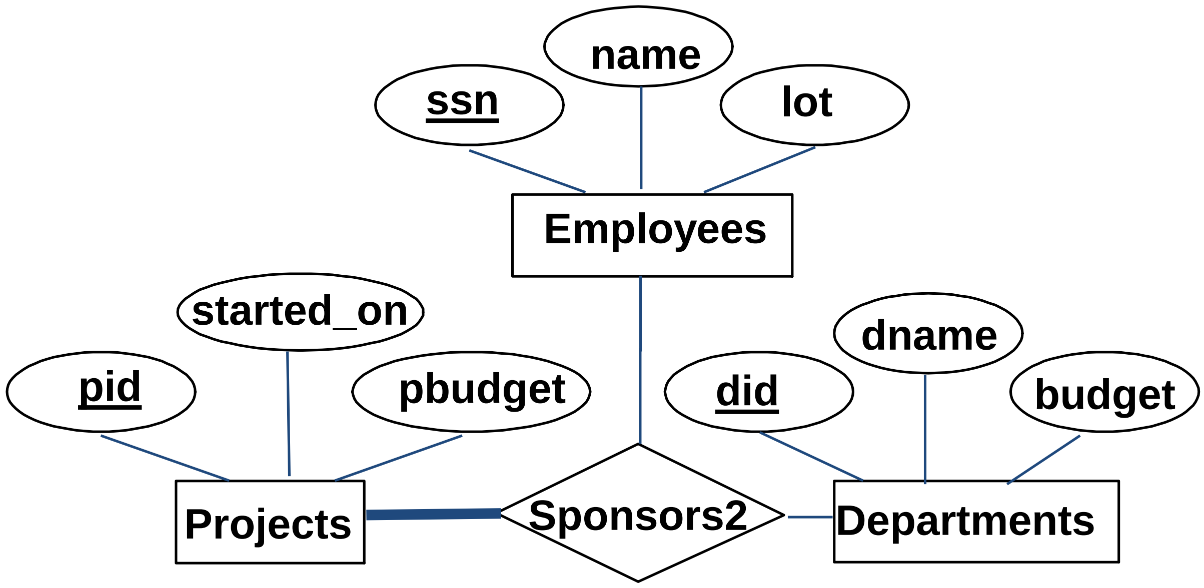
- When to use aggregation?
  - If we want to attach a relationship to a relationship

- 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

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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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sid	cid	grade
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FOREIGN Key

Students

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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

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

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```

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
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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
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

- 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 <u>updated</u>?

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!

Next Class

The Relational Model (Cont'd) and Relational Algebra