Relational Database Design using E/R

Introduction to Databases

CompSci 316 Fall 2020

DUKE
COMPUTER SCIENCE

Announcements (Thu. Aug. 27)

- Reminder: HW1 due Tuesday, 9/1, 11:59 pm
  - Finish on time!

- Project team formation: by Tuesday 9/8
  - Read the pdf on project details and choose fixed/open
  - See the email sent on sakai and piazza for shared google spreadsheet
  - If you have formed a group – add it to the spreadsheet
  - If you are looking for members – add your project to the spreadsheet
  - Each project team should have 5 members
  - By default, all group members from the same discussions
  - Need help? Reach out to Yesenia and Sudeepa

- Lecture video watch policy update (extended):
  - You can watch the video by the next day, e.g., Tuesday 9/2's lecture can be watched by Wednesday 9/3 11:59 pm Eastern.
  - Gives you 24 + 9 = 33 hours instead of 24

- Anonymous feedback form posted on Piazza
  - If you would like us to repeat a concept next week in discussions/lectures, please write it there and submit
  - Any comments/feedback/difficulties: let us know!

Where are we now?

Relational model and queries
- 🟩 Relational Model
- 🟩🟨 Query in SQL
- 🟩 Query in RA

Database Design
- ★ 🟦 E/R diagram (design from scratch)
- 🟨 Normal Forms (refine design)

Beyond Relational Model
- 🟨 XML
- 🟨 NOSQL JSON/MongoDB

DBMS Internals and Query Processing
- 🟨 Storage
- 🟨 Index
- 🟨 Join algo/Sorting
- 🟨 Execution/ Optimization

Transactions
- 🟨 Basics
- 🟨 Concurrency Control
- 🟨 Recovery

(Basic) Big Data Processing
- 🟨 Map-Reduce
- 🟨 Parallel DBMS

🟩 Covered

🟨 To be covered

🟦 Next

Relational model: review

- A database is a collection of relations (or tables)
- Each relation has a set of attributes (or columns)
- Each attribute has a name and a domain (or type)
- Each relation contains a set of tuples (or rows)

How do we know which relations and attributes to have?

Example: Users, Groups, Members

Groups

Each has gid (unique id), name

Users

Each has uid (unique id), name, age, pop (popularity)

Member

Records fromDate (when a user joined a group)

Keys

- A set of attributes K is a key for a relation R if
  - In no instance of R will two different tuples agree on all attributes of K
    - That is, K can serve as a "tuple identifier"
  - No proper subset of K satisfies the above condition
    - That is, K is minimal

- Example: *User (uid, name, age, pop)*
  - *uid* is a key of *User*
  - *age* is not a key (not an identifier)
  - {*uid*, *name*} is not a key (not minimal)

Schema vs. instance

uid	*name*	*age*	*pop*
142	Bart	10	0.9
123	Milhouse	10	0.2
857	Lisa	8	0.7
456	Ralph	8	0.3

- Is *name* a key of *User*?
  - Yes? Seems reasonable for this instance
  - No! User names are not unique in general
- Key declarations are part of the schema

More examples of keys

- *Member (uid, gid)*
  - *{uid, gid}*

  ☞A key can contain multiple attributes
- *Address (street_address, city, state, zip)*
  - *{street_address, city, state}*
  - *{street_address, zip}*

  ☞A relation can have multiple keys!
    - We typically pick one as the "primary" key, and underline all its attributes, e.g., *Address (street_address, city, state, zip)*

Announcements (Tue. Sep. 1)

- Reminder: HW1 due TODAY, 9/1, 11:59 pm
  - Still some OH!

- Project team formation: by Tuesday 9/8
  - We are inviting some 6 member groups! Please let Yesenia and me know!
  - See last Thu Announceement

- Thursday's Project Mixer Class
  - Presentation by CoLab and Your UTAs from their Spring'20 project experience (if more time, will continue with lectures)
- RATest – research tool for debugging your RA queries
  - we would appreciate if you give give us consent to analyze your anonymous/aggregate data to improve the tool

Use of keys

- More constraints on data, fewer mistakes
- Look up a row by its key value
  - Many selection conditions are "key = value"
- "Pointers" to other rows (often across tables)
  - Example: *Member* (*uid*, *gid*)
    - *uid* is a key of *User*
    - *gid* is a key of *Group*
    - A *Member* row "links" a *User* row with a *Group* row
  - Many join conditions are "key = key value stored in another table"

Database design

- Understand the real-world domain being modeled
- Specify it using a database design model
  - More intuitive and convenient for schema design
  - But not necessarily implemented by DBMS
  - We will cover
    - Entity/Relationship (E/R) model
- Then
  1. Translate specification to the data model of DBMS
     - Relational, XML, object-oriented, etc.
  2. Create DBMS schema

Entity-relationship (E/R) model

- Historically and still very popular

- Designs represented by E/R diagrams
  - We use the style of E/R diagram covered by the GMUW book; there are other styles/extensions

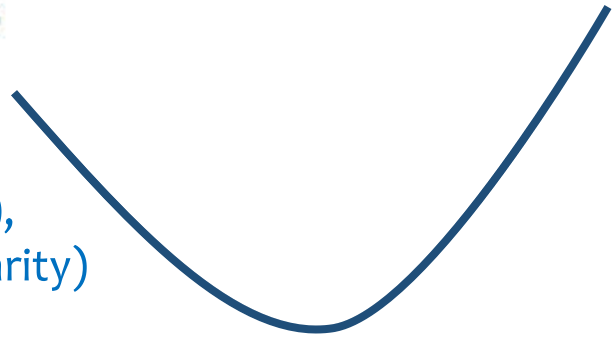
Example: Users, Groups, Members

Users

Each has uid (unique id), name, age, pop (popularity)

Groups

Each has gid (unique id), name

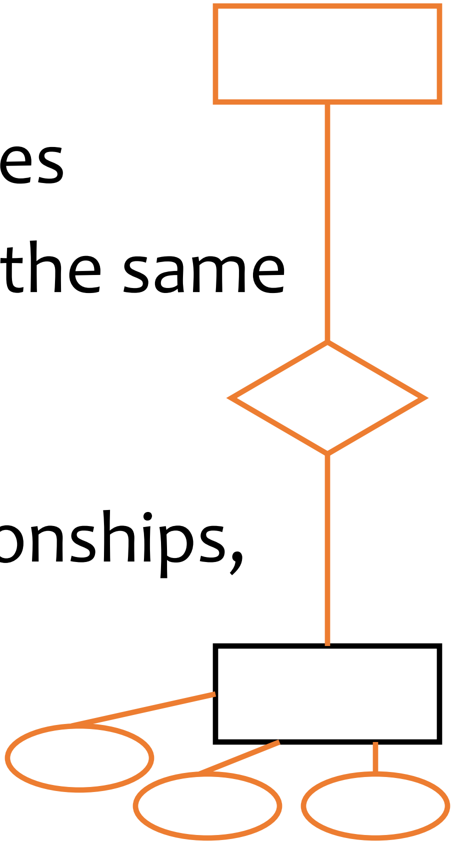


Member

Records fromDate
(when a user joined a group)

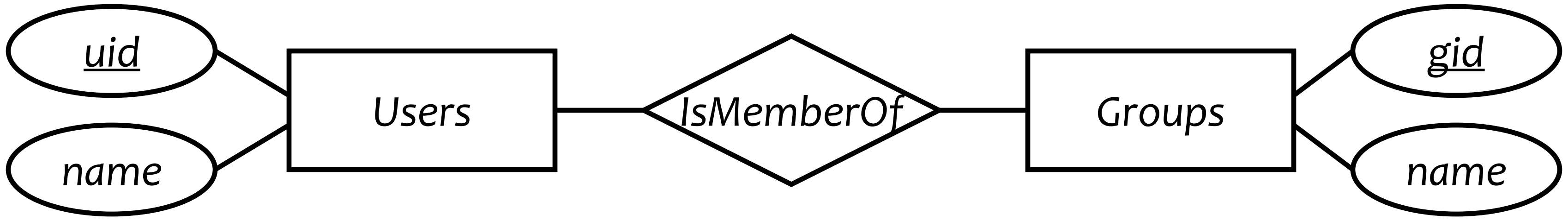
E/R basics

- Entity: a "thing," like an object
- Entity set: a collection of things of the same type, like a relation of tuples or a class of objects
  - Represented as a rectangle
- Relationship: an association among entities
- Relationship set: a set of relationships of the same type (among same entity sets)
  - Represented as a diamond
- Attributes: properties of entities or relationships, like attributes of tuples or objects
  - Represented as ovals



An example E/R diagram

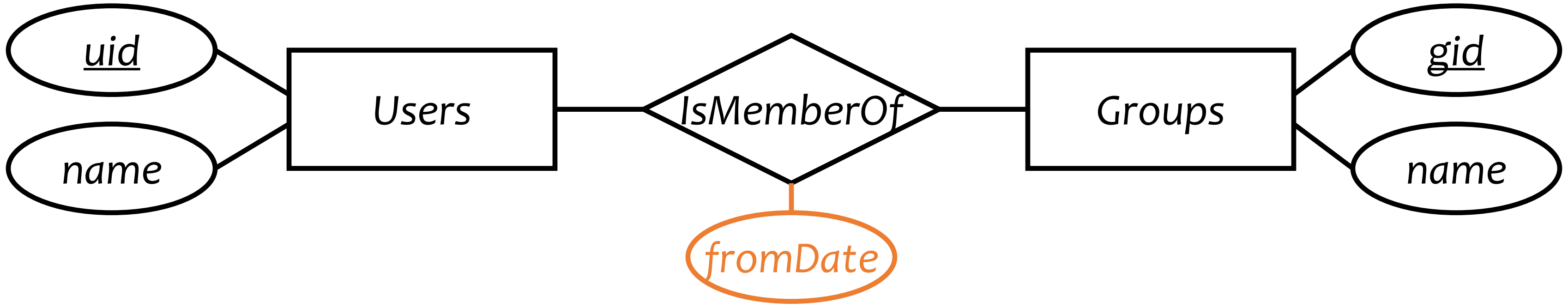
- Users are members of groups



- A key of an entity set is represented by underlining all attributes in the key
    - A key is a set of attributes whose values can belong to at most one entity in an entity set—like a key of a relation

Attributes of relationships

- Example: a user belongs to a group since a particular date



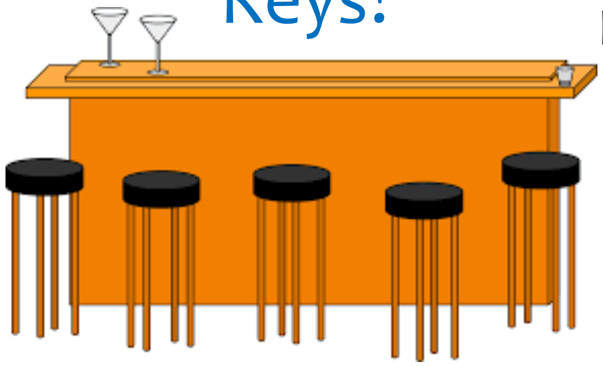
- Where do the dates go?
  - With *Users*?
    - But a user can join multiple groups on different dates
  - With *Groups*?
    - But different users can join the same group on different dates
  - With *IsMemberOf*!

E/R diagram for Beers Database?

Keys?

Bars
Each has an address

Drinkers **Frequent** Bars
"X" times a week



Bars **Serve** Beers
At price "Y"

Drinkers
Each has an address

Drinkers **Likes** Beers

Beers
Each has a brewer

More on relationships

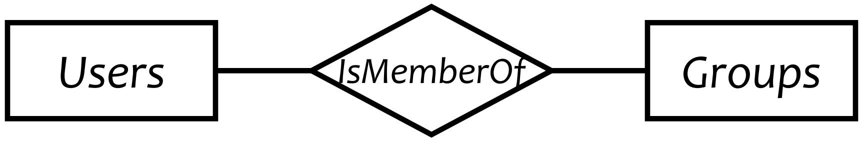
- There could be multiple relationship sets between the same entity sets
  - Example: *Users IsMemberOf Groups*; *Users Likes Groups*
- In a relationship set, each relationship is uniquely identified by the entities it connects
  - Example: Between Bart and "Dead Putting Society", there can be at most one *IsMemberOf* relationship and at most one *Likes* relationship

  ☞What if Bart joins DPS, leaves, and rejoins? How can we modify the design to capture historical membership information?

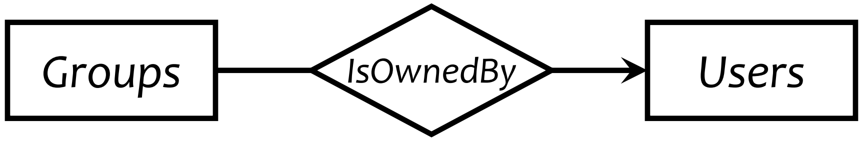
    ☞Make an entity set of *MembershipRecords*

Multiplicity of relationships

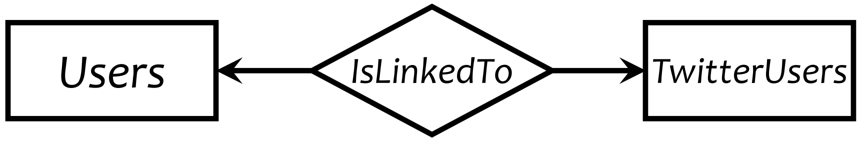
- E and F: entity sets
- Many-many: Each entity in E is related to 0 or more entities in F and vice versa
  - Example:

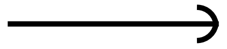


- Many-one: Each entity in E is related to 0 or 1 entity in F, but each entity in F is related to 0 or more in E
  - Example:



- One-one: Each entity in E is related to 0 or 1 entity in F and vice versa
  - Example:



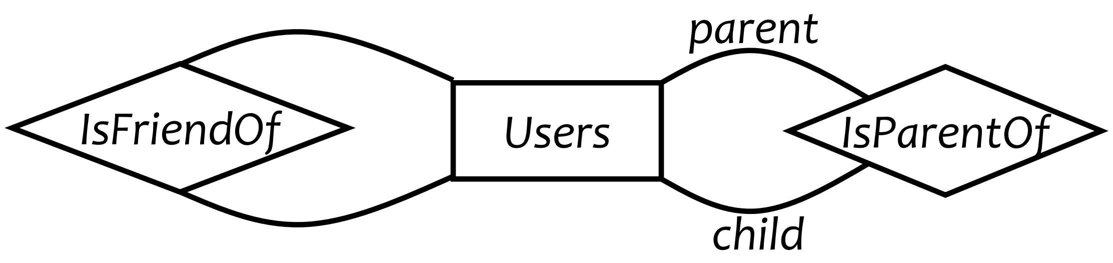
- "One" (0 or 1) is represented by an arrow $\longrightarrow$
- "Exactly one" is represented by a rounded arrow 

Roles in relationships

- How do we model "Friendship" among Users?
- An entity set may participate more than once in a relationship set

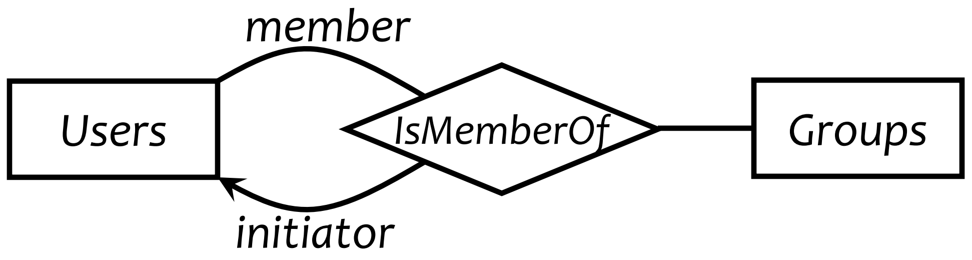
☞ May need to label edges to distinguish roles

- Examples
  - Users may be parents of others; label needed
  - Users may be friends of each other; label not needed



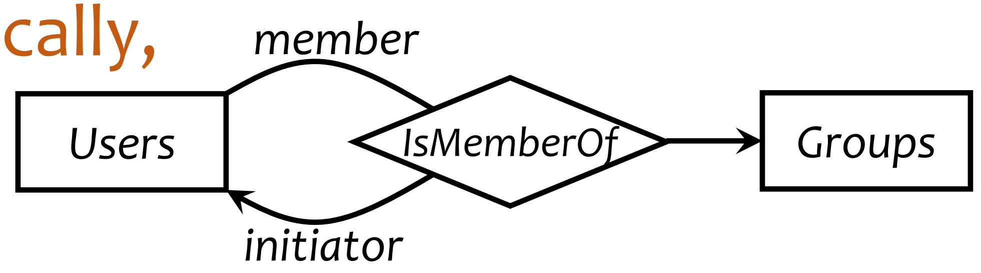
n-ary relationships

- Example: a user must have an initiator in order to join a group



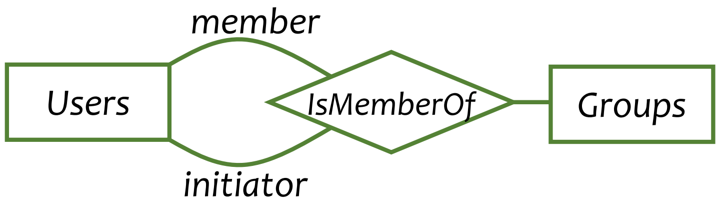
Rule for interpreting an arrow into entity set E in an n-ary relationship:

- Pick one entity from each of the other entity sets; together they can be related to at most one entity in E
- Exercise: hypothetically, what do these arrows imply?

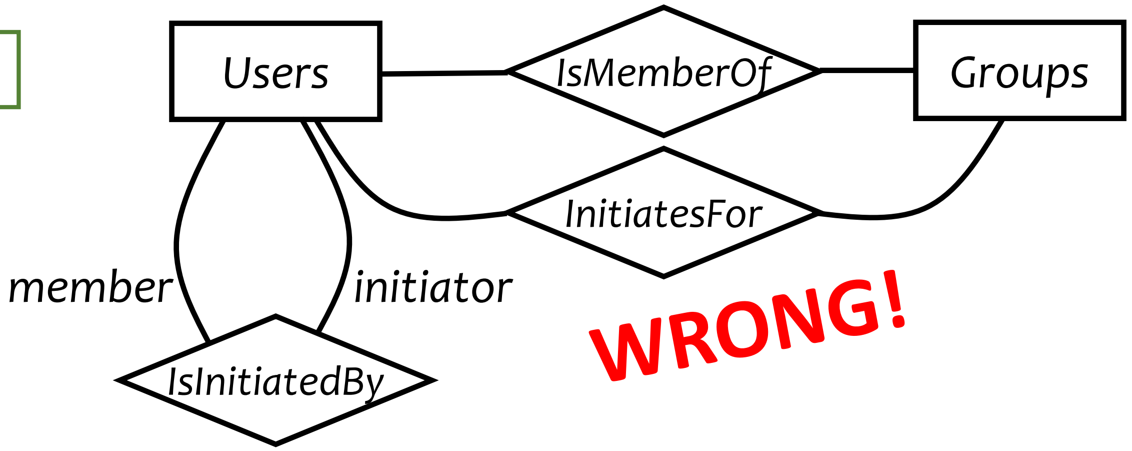


n-ary versus binary relationships

- Can we model n-ary relationships using just binary relationships?



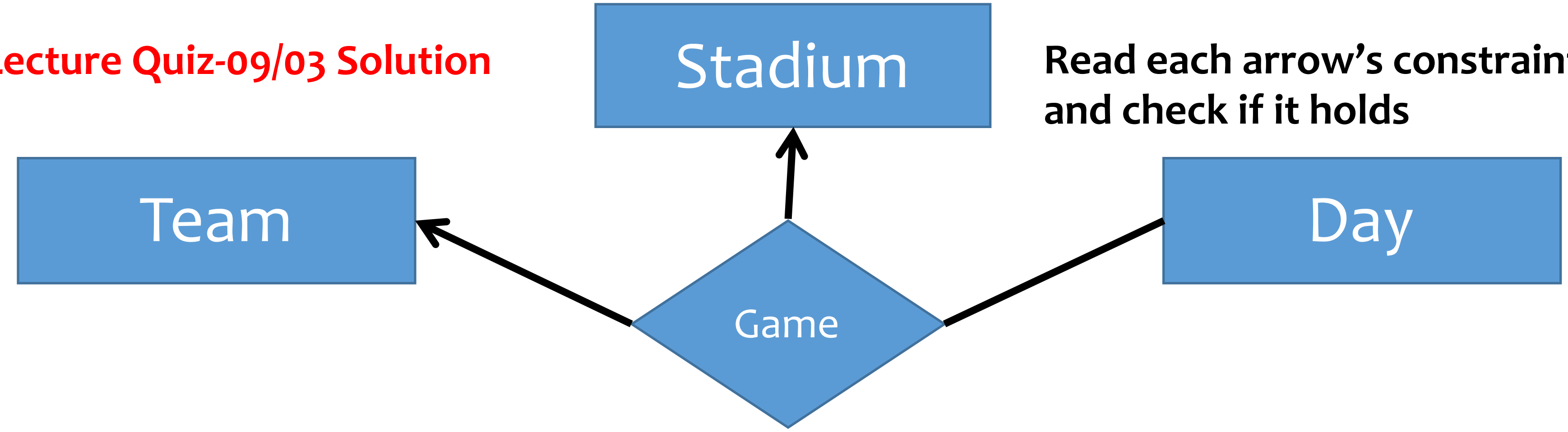
Are they equivalent?



- No; for example:
    - Ralph is in both abc and gov
    - Lisa has served as initiator in both abc and gov
    - Ralph was initiated by Lisa in abc, but not by her in gov

Lecture Quiz-09/03 Solution

Read each arrow's constraint and check if it holds



No (A)

Team	Stadium	Day
T1	S1	D1
T1	S2	D1
T2	S3	D2

(B) Yes

Team	Stadium	Day
T1	S1	D1
T2	S2	D2
T3	S3	D3

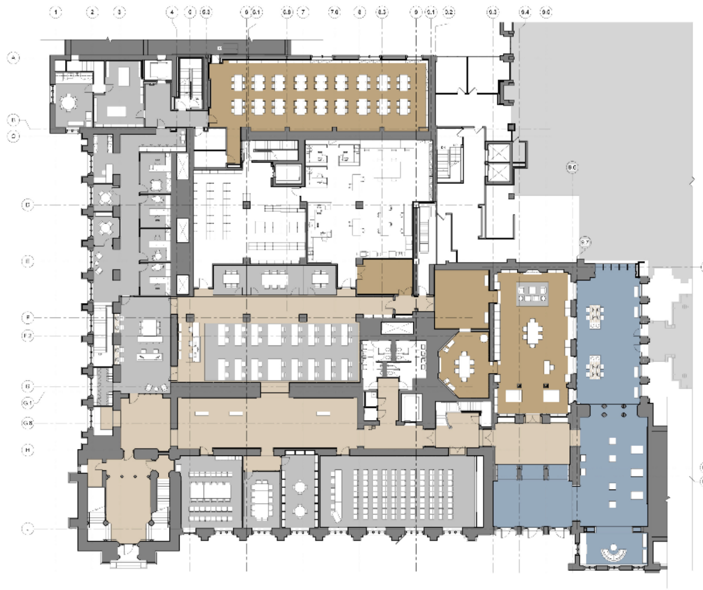
Team	Stadium	Day
T1	S1	D1
T1	S1	D2
T2	S1	D3

Yes (C)

Team	Stadium	Day
T1	S1	D1
T2	S1	D2
T3	S1	D1

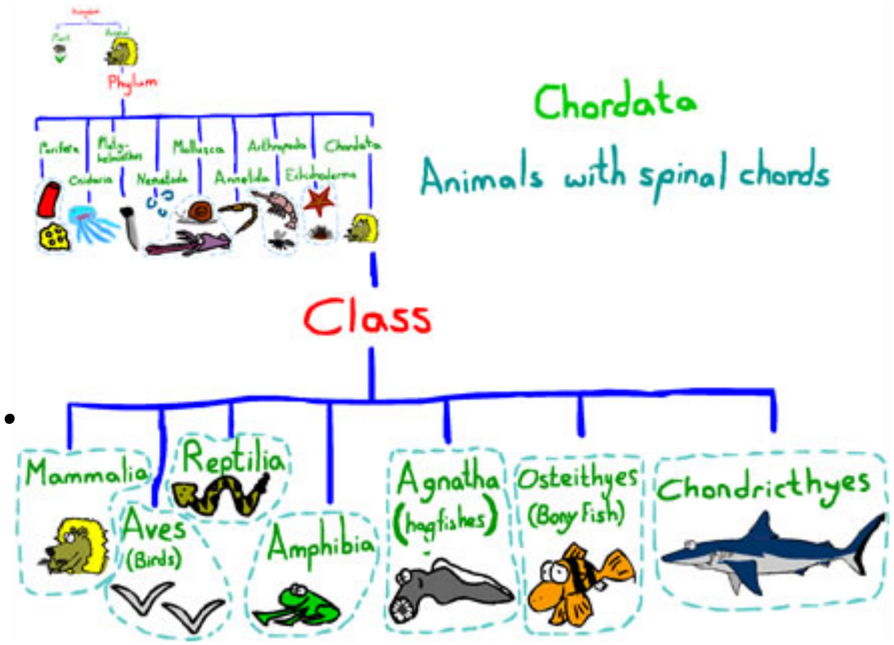
(D) No

Next: two special relationships



… is part of/belongs to …

… is a kind of …



http://blogs.library.duke.edu/renovation/files/2012/08/Rubenstein-Library-First-Floor-Floorplan.jpg
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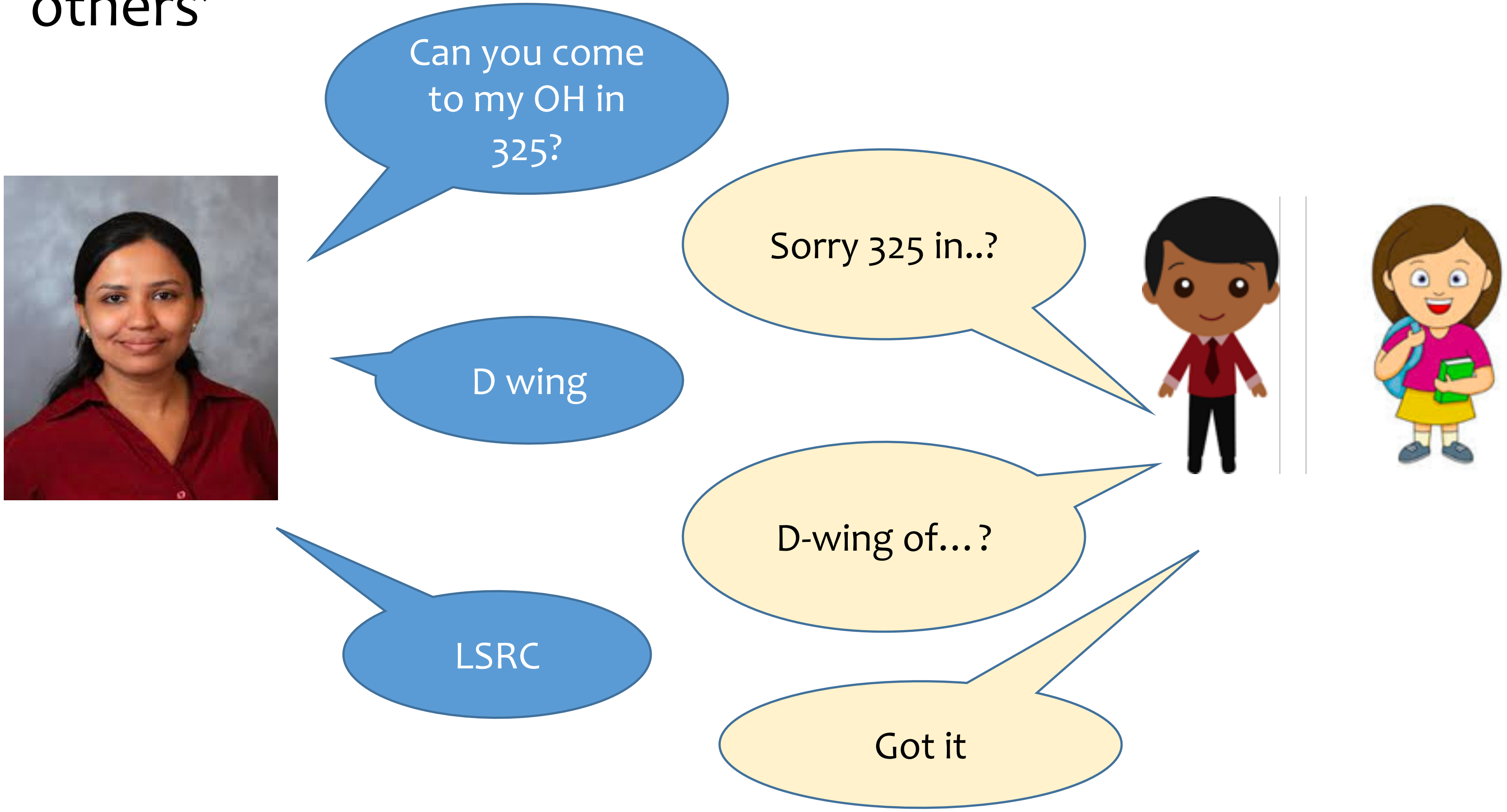
Weak entity sets

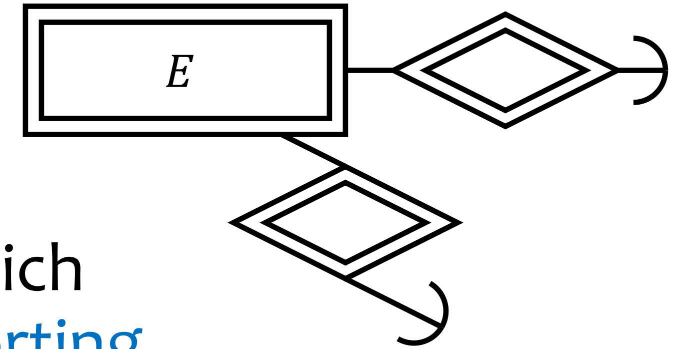
Sometimes, an entity's identity depends on some others'



Weak entity sets

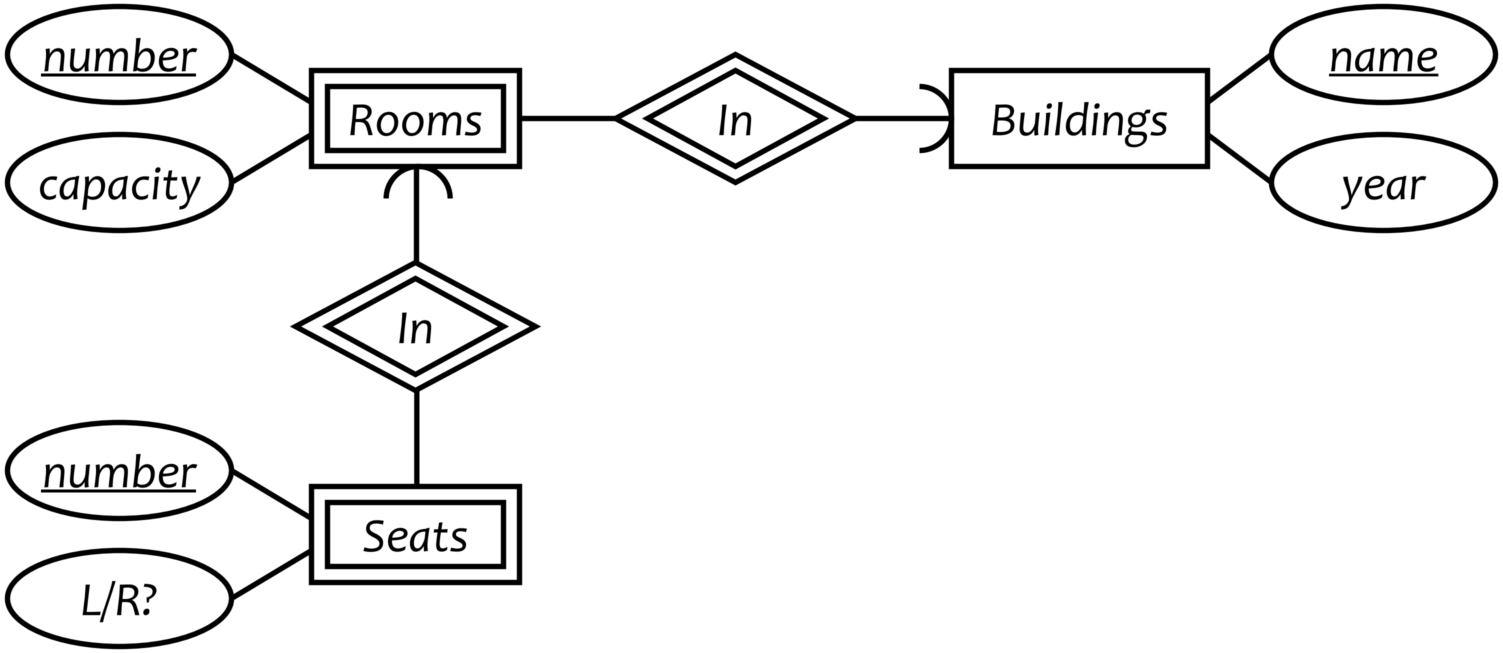
Sometimes, an entity's identity depends on some others'

- The key of a weak entity set E comes not completely from its own attributes, but from the keys of one or more other entity sets
    - E must link to them via many-one or one-one relationship sets
- Example: *Rooms* inside *Buildings* are partly identified by *Buildings*' name
- A weak entity set is drawn as a double rectangle
- The relationship sets through which it obtains its key are called supporting relationship sets, drawn as double diamonds



Weak entity set examples

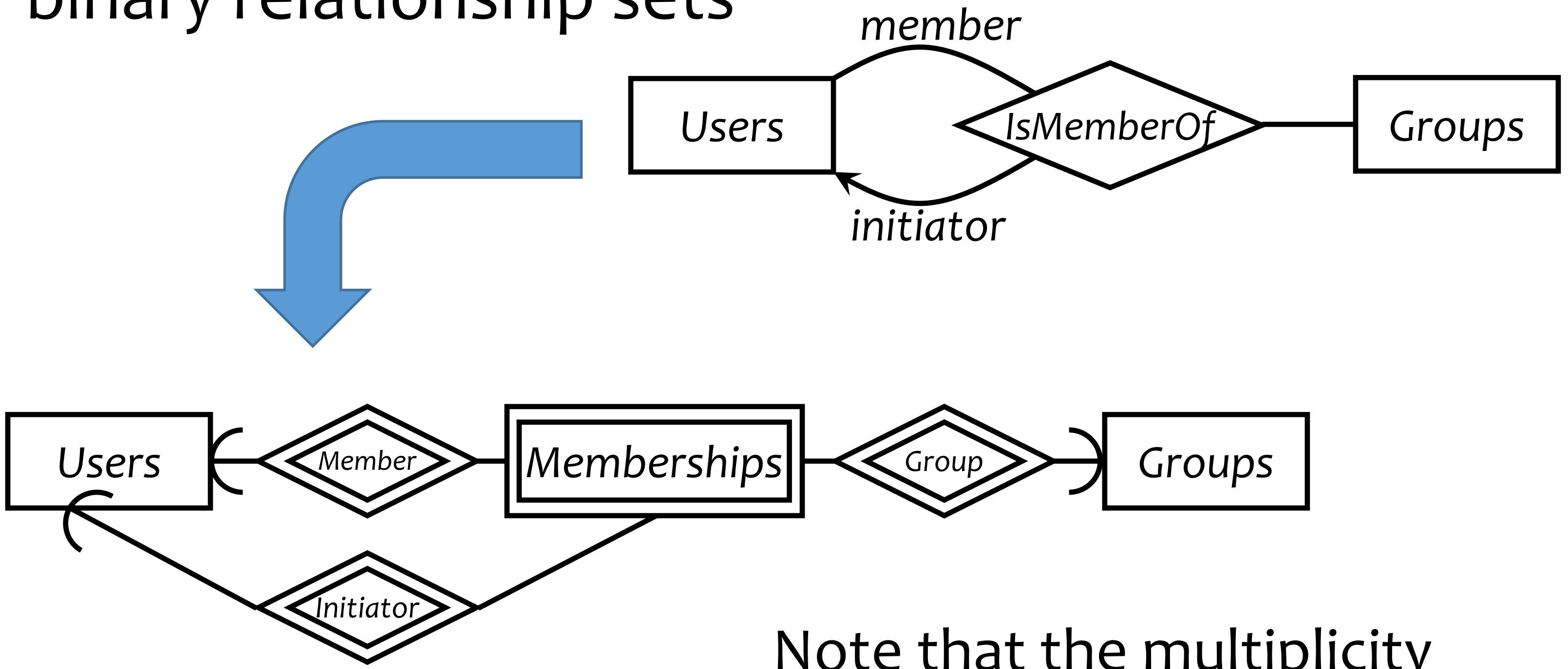
- Seats in rooms in building



- Why must double diamonds be many-one/one-one?
  - With many-many, we would not know which entity provides the key value!

Remodeling n-ary relationships

- An n-ary relationship set can be replaced by a weak entity set (called a connecting entity set) and n binary relationship sets

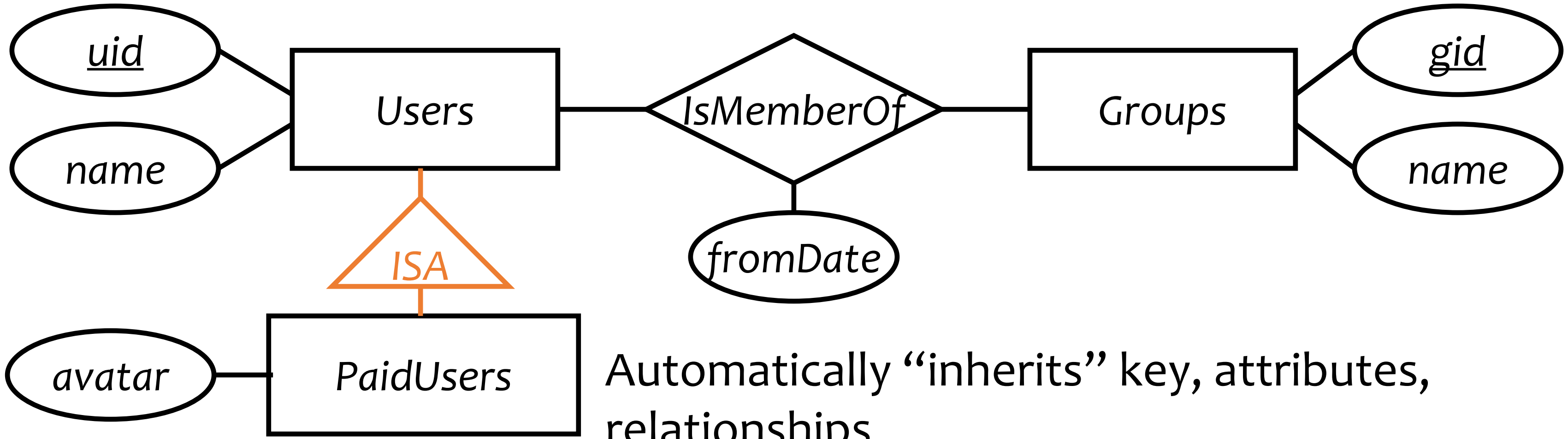


Note that the multiplicity constraint for *IsMemberOf* is lost

Are they equivalent now?

ISA relationships

- Similar to the idea of subclasses in object-oriented programming: subclass = special case, fewer entities, and possibly more properties
  - Represented as a triangle (direction is important)
- Example: paid users are users, but they also get avatars (yay!)



Automatically “inherits” key, attributes, relationships

Summary of E/R concepts

- Entity sets
  - Keys
  - Weak entity sets
- Relationship sets
  - Attributes of relationships
  - Multiplicity
  - Roles
  - Binary versus n-ary relationships
    - Modeling n-ary relationships with weak entity sets and binary relationships
  - ISA relationships

Case study 1

- Design a database representing cities, counties, and states
  - For states, record name and capital (city)
  - For counties, record name, area, and location (state)
  - For cities, record name, population, and location (county and state)
- Assume the following:
  - Names of states are unique
  - Names of counties are only unique within a state
  - Names of cities are only unique within a county
  - A city is always located in a single county
  - A county is always located in a single state

Case study 1

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    - For states, record name and capital (city)
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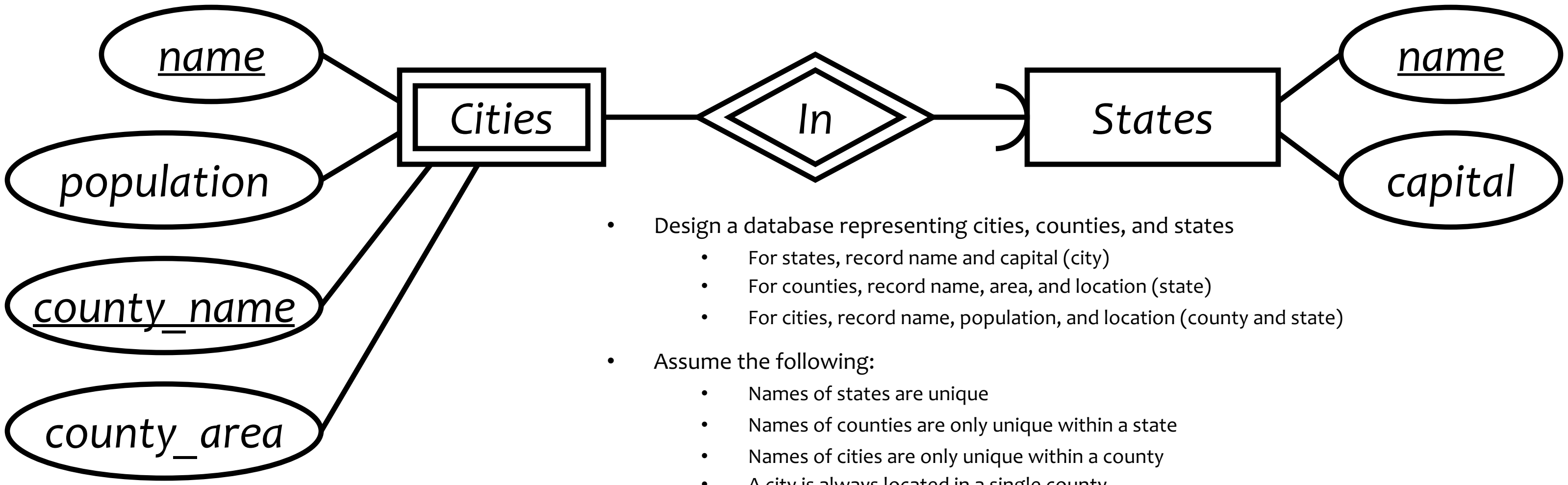
Case study 1: first design



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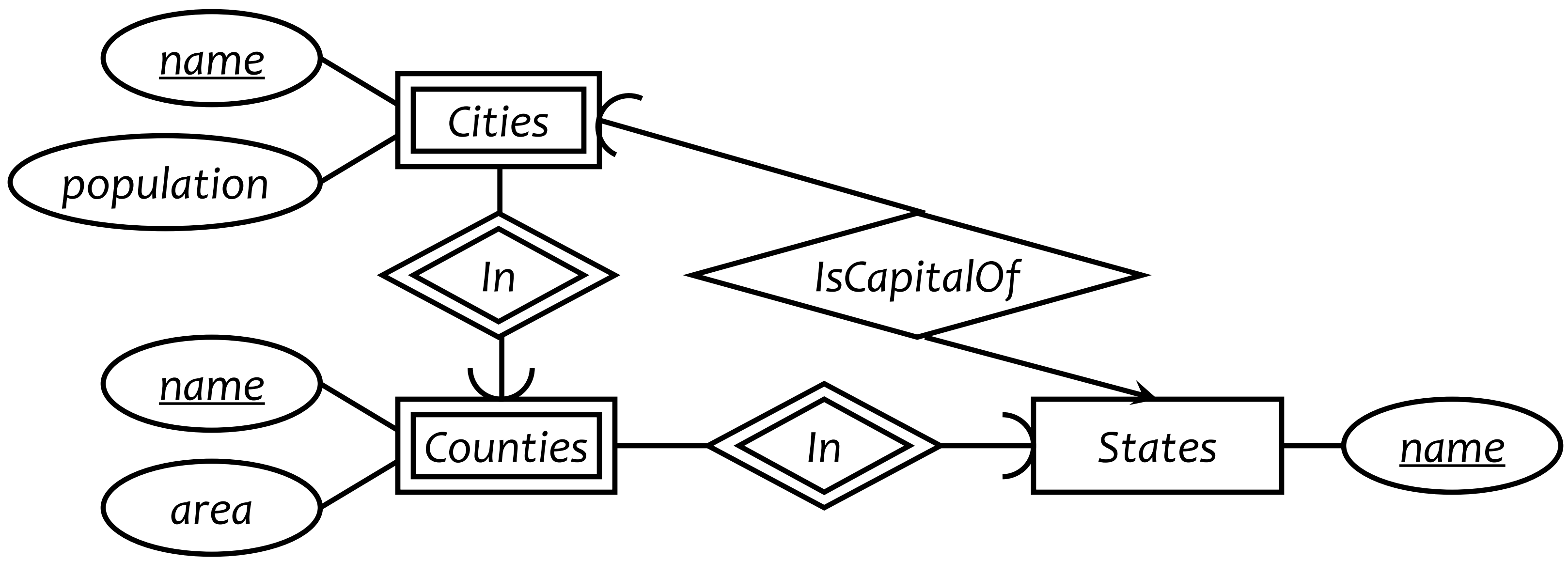
  - A city is always located in a single county
  - A county is always located in a single state

- County area information is repeated for every city in the county
  - ☞Redundancy is bad (why?)
- State capital should really be a city
  - ☞Should "reference" entities through explicit relationships

Case study 1: second design



- Technically, nothing in this design prevents a city in state X from being the capital of another state Y …

Case study 2

- Design a database consistent with the following:
  - A station has a unique name and an address, and is either an express station or a local station
  - A train has a unique number and an engineer, and is either an express train or a local train
  - A local train can stop at any station
  - An express train only stops at express stations
  - A train can stop at a station for any number of times during a day
  - Train schedules are the same everyday

Case study 2 : first design

- Design a database consistent with the following:
  - A station has a unique name and an address, and is either an express station or a local station
  - A train has a unique number and an engineer, and is either an express train or a local train
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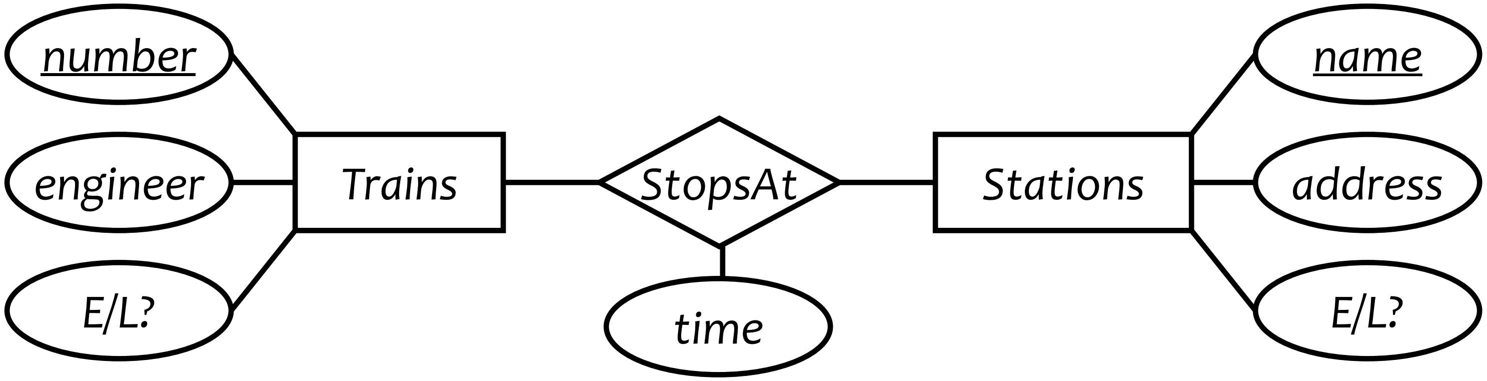
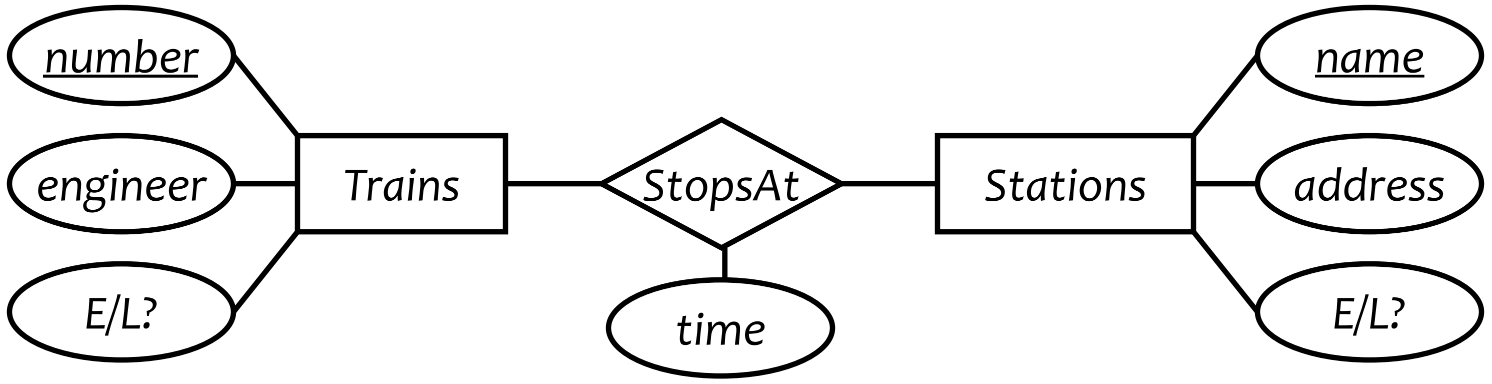
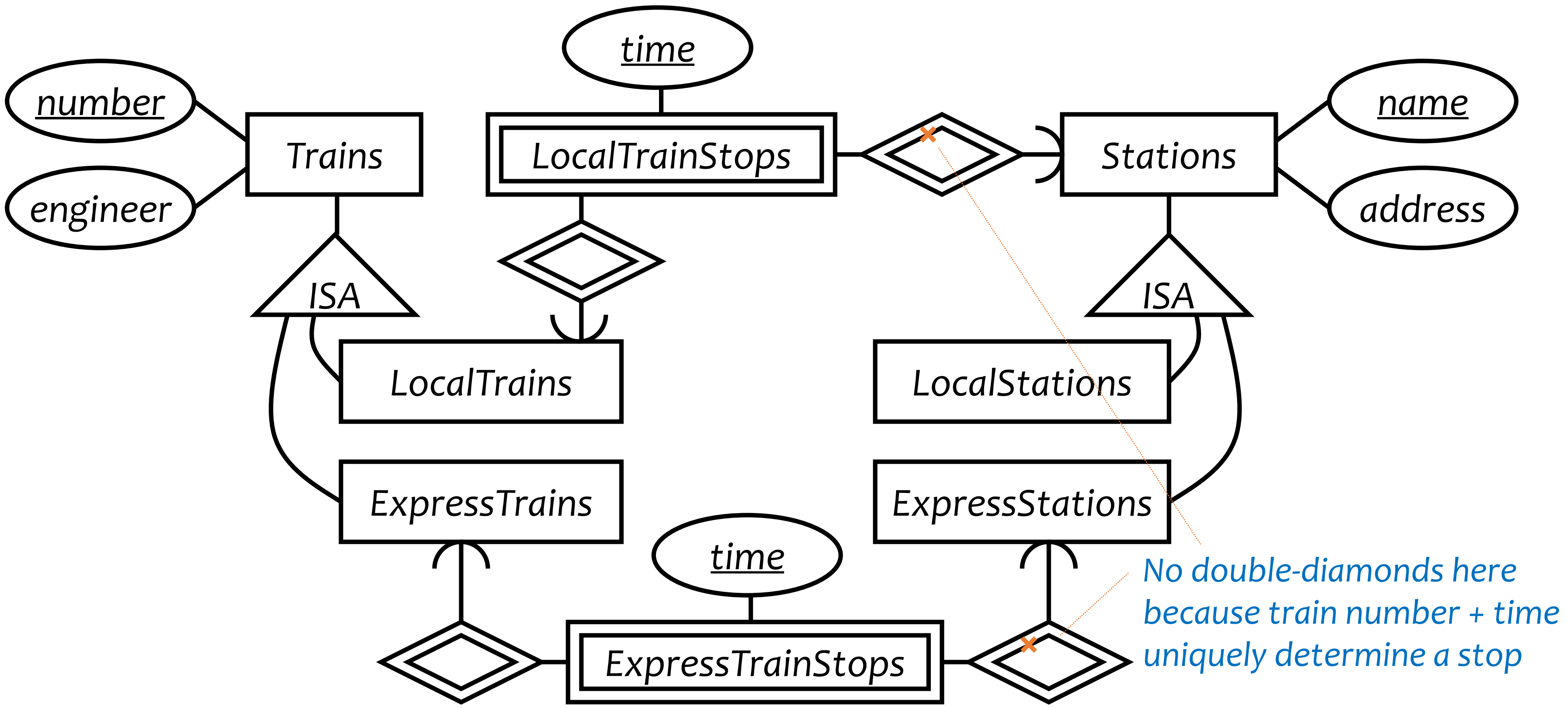


Case study 2: first design



- Nothing in this design prevents express trains from stopping at local stations
  - ☞We should capture as many constraints as possible
- A train can stop at a station only once during a day
  - ☞We should not introduce unintended constraints

Case study 2: second design



Is the extra complexity worth it?