Relational Database Design using E/R

Introduction to Databases

CompSci 316 Spring 2019

DUKE
COMPUTER SCIENCE

Announcements (Thu. Jan. 17)

- Sign up for Piazza and Gradiance
- Set up your VM
- Homework 1 – Problems 1 and 2 posted (after class!)
  - Due in 2.5 weeks
  - Problem 1 is already posted on gradiance (attempt as many times as you need!)
- Office hours have been posted on website
  - First TA office hour tomorrow

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)

Keys

→ minimal & unique

- 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)

Superkey → (uid, name)

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*)

① key
② superkey
③ primary key
④ key = candidate key

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
    - A few popular ones:
        - Entity/Relationship (E/R) model
        - Object Definition Language (ODL)
        - UML (Unified Modeling Language)
- Translate specification to the data model of DBMS
    - Relational, XML, object-oriented, etc.
- Create DBMS schema

But what about ORM?

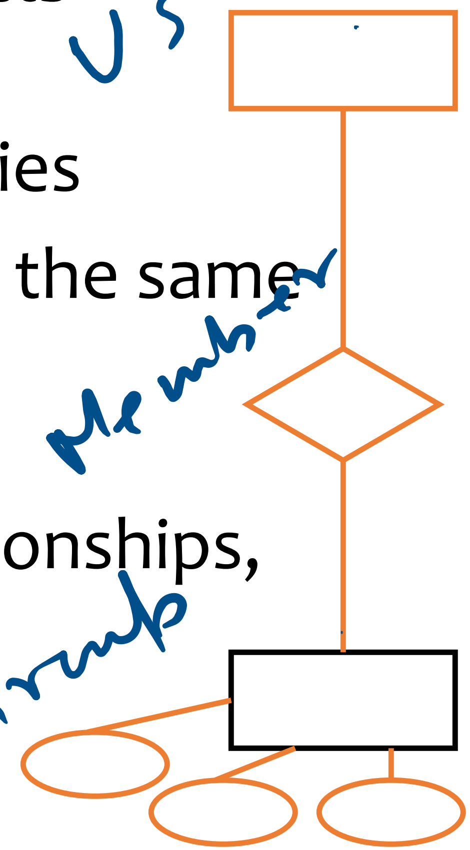
- Automatic object-relational mappers are made popular by rapid Web development frameworks
  - For example, with Python SQLAlchemy:
    - You declare Python classes and their relationships
    - It automatically converts them into database tables
    - If you want, you can just work with Python objects, and never need to be aware of the database schema or write SQL
- But you still need designer discretion in all but simple cases
- Each language/library has its own syntax for creating schema and for querying/modifying data
  - Quirks and limitations cause portability problems
  - They are not necessarily easier to learn than SQL

Entity-relationship (E/R) model

- Historically and still very popular
- Concepts applicable to other design models as well
- Can think of as a "watered-down" object-oriented design model
- Primarily a design model—not directly implemented by DBMS
- Designs represented by E/R diagrams
    - We use the style of E/R diagram covered by the GMUW book; there are other styles/extensions
    - Very similar to UML diagrams

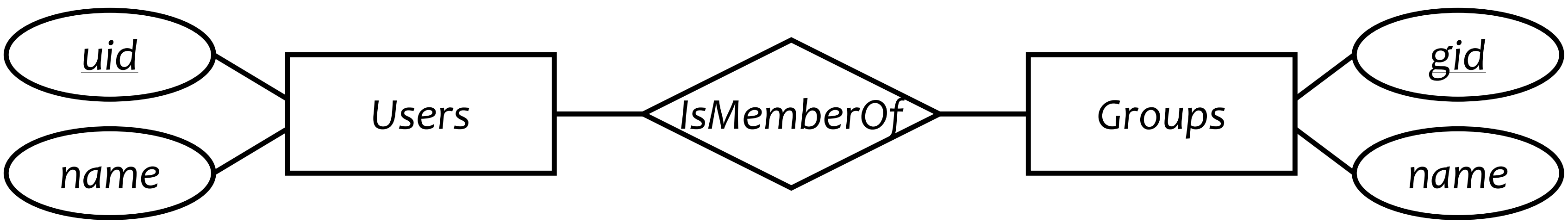
E/R basics

- 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

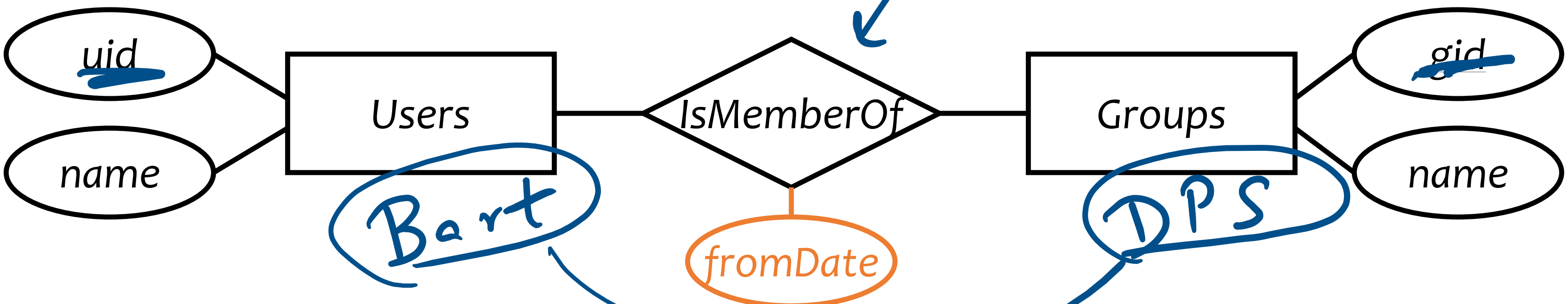
- Users are members of groups



- 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

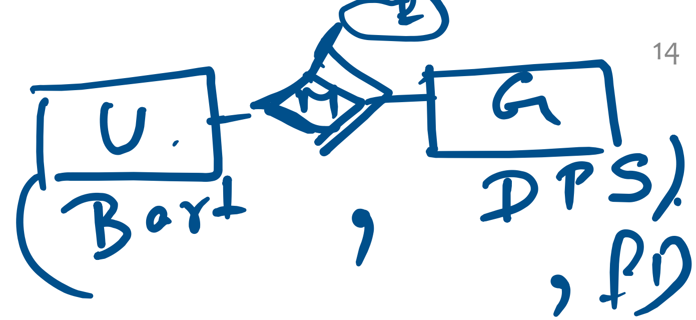
Attributes of relationships

- 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*!

More on relationships



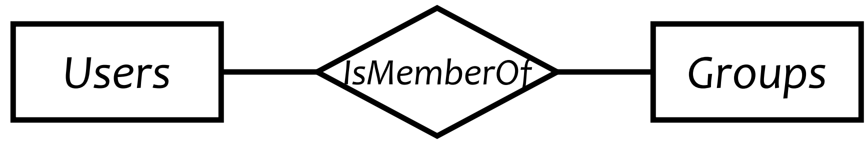
- There could be multiple relationship sets between the same entity sets
  - Example: *Users IsMemberOf Groups*; *Users Likes Groups*
- In a relationship set, each relationship is uniquely identified by the entities it connects
  - Example: Between Bart and "Dead Putting Society", there can be at most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

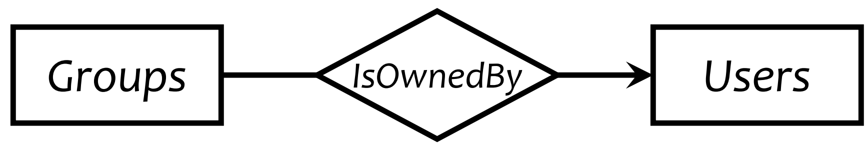
    ☞Make an entity set of *MembershipRecords*

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:

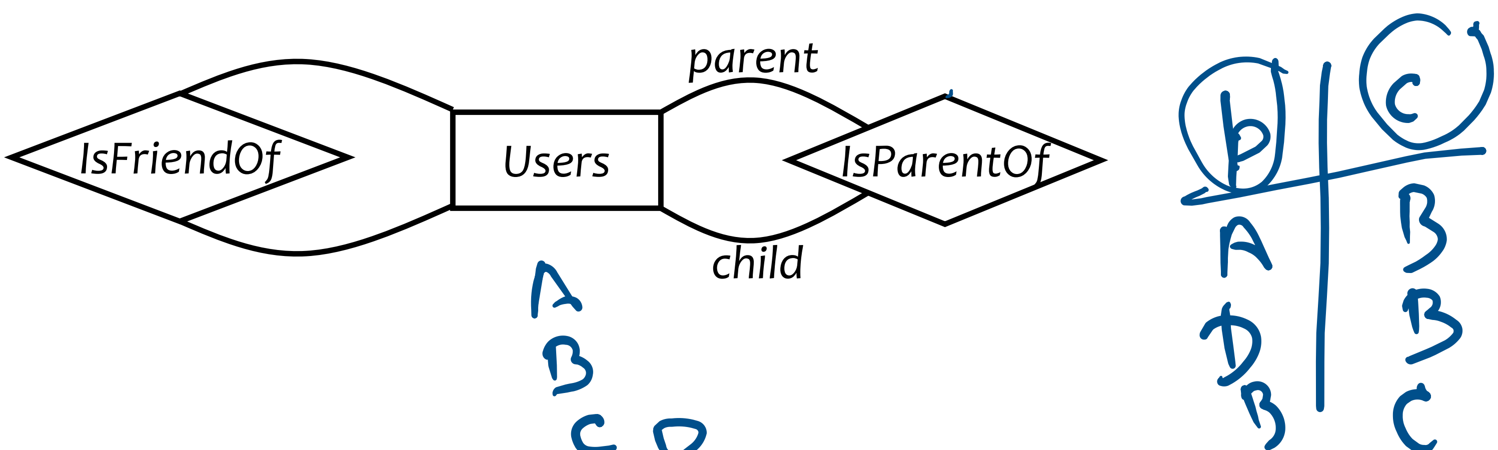
- "One" (0 or 1) is represented by an arrow 
- "Exactly one" is represented by a rounded arrow 

Roles in relationships

- An entity set may participate more than once in a relationship set

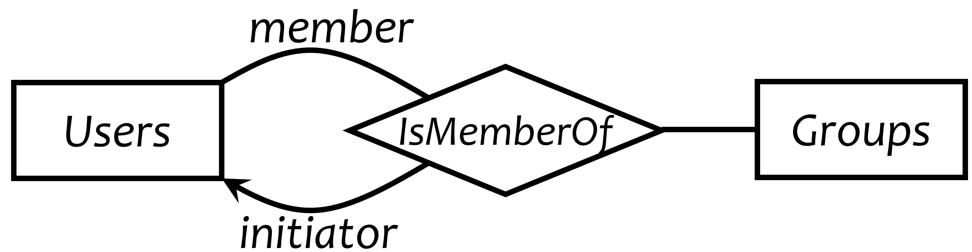
☞ May need to label edges to distinguish roles

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



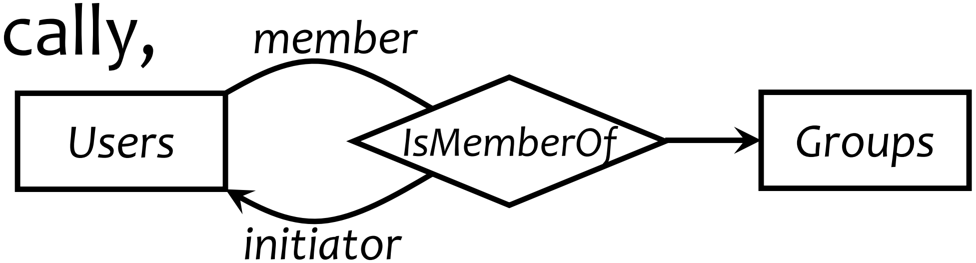
n-ary relationships

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



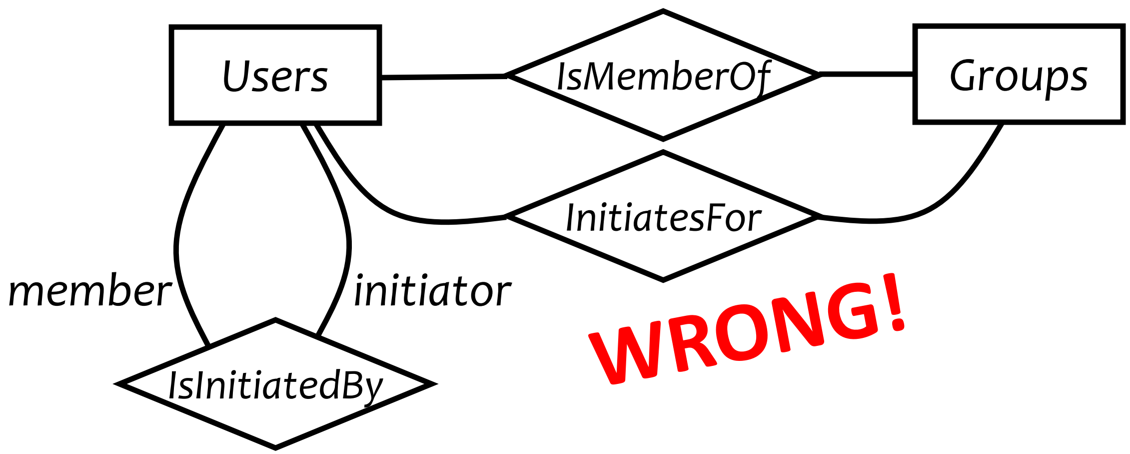
Rule for interpreting an arrow into entity set E in an n-ary relationship:

- 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?

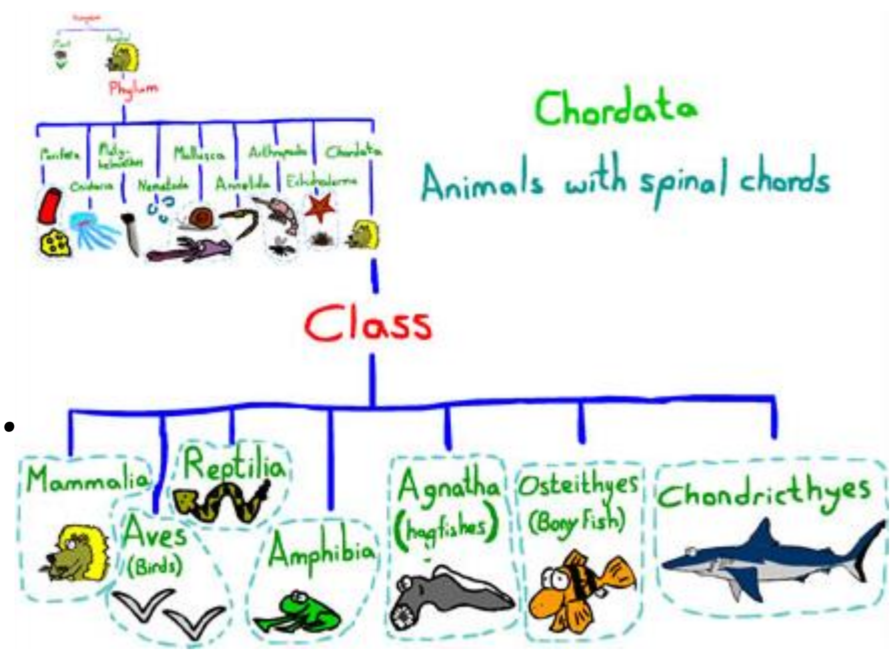


- No; for example:
  - Ralph is in both abc and gov
  - Lisa has served as initiator in both abc and gov
  - Ralph was initiated by Lisa in abc, but not by her in gov

Next: two special relationships

… is part of/belongs to …

… is a kind of …

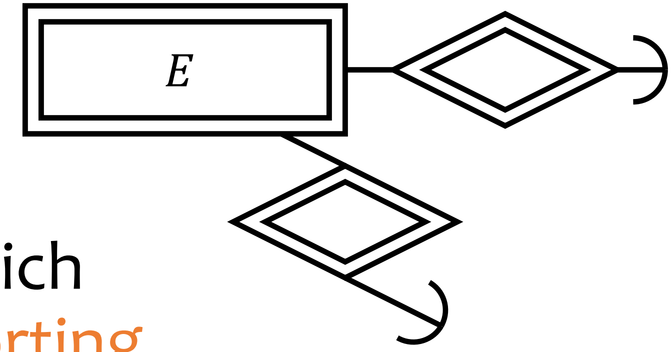


http://blogs.library.duke.edu/renovation/files/2012/08/Rubenstein-Library-First-Floor-Floorplan.jpg
http://www.sharky-jones.com/Sharkyjones/Artwork/taxonomy%20artwork/Class1.jpg

Weak entity sets

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

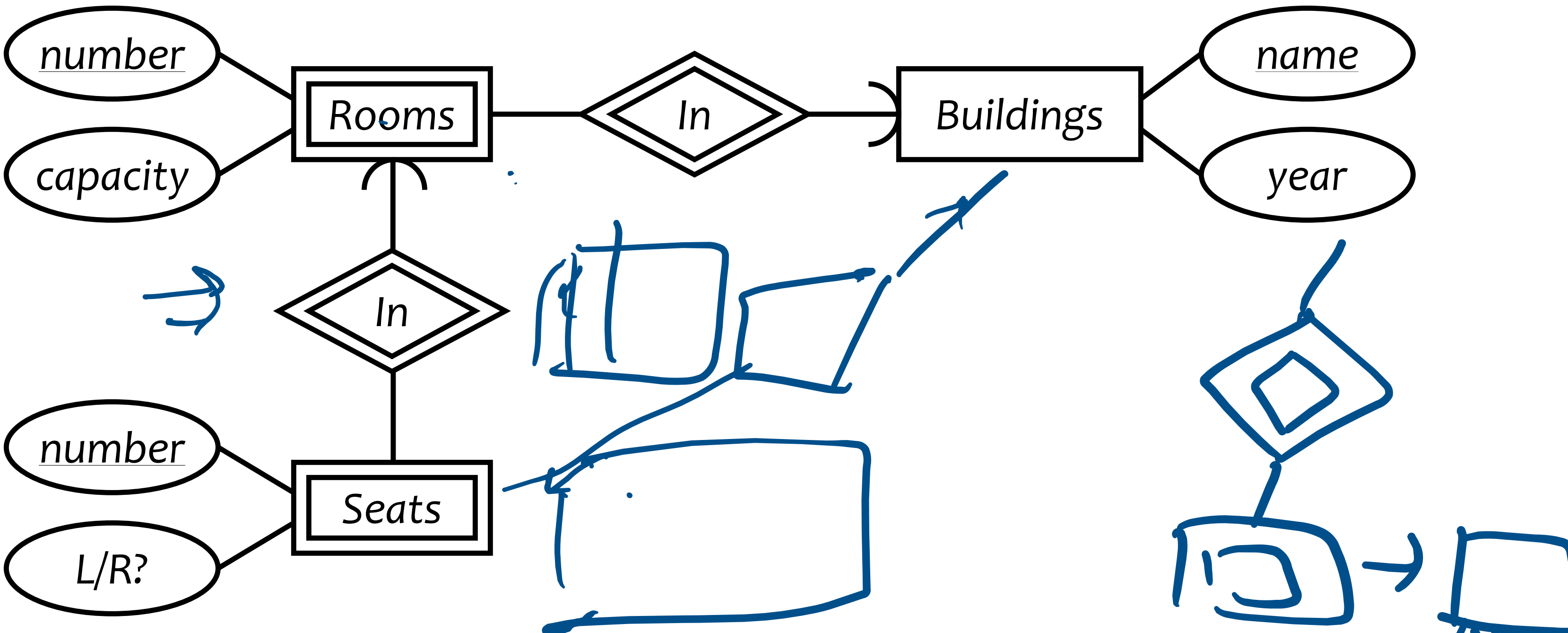
- The key of a weak entity set E comes not completely from its own attributes, but from the keys of one or more other entity sets
  - E must link to them via many-one or one-one relationship sets
- Example: *Rooms* inside *Buildings* are partly identified by *Buildings*' name
- A weak entity set is drawn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

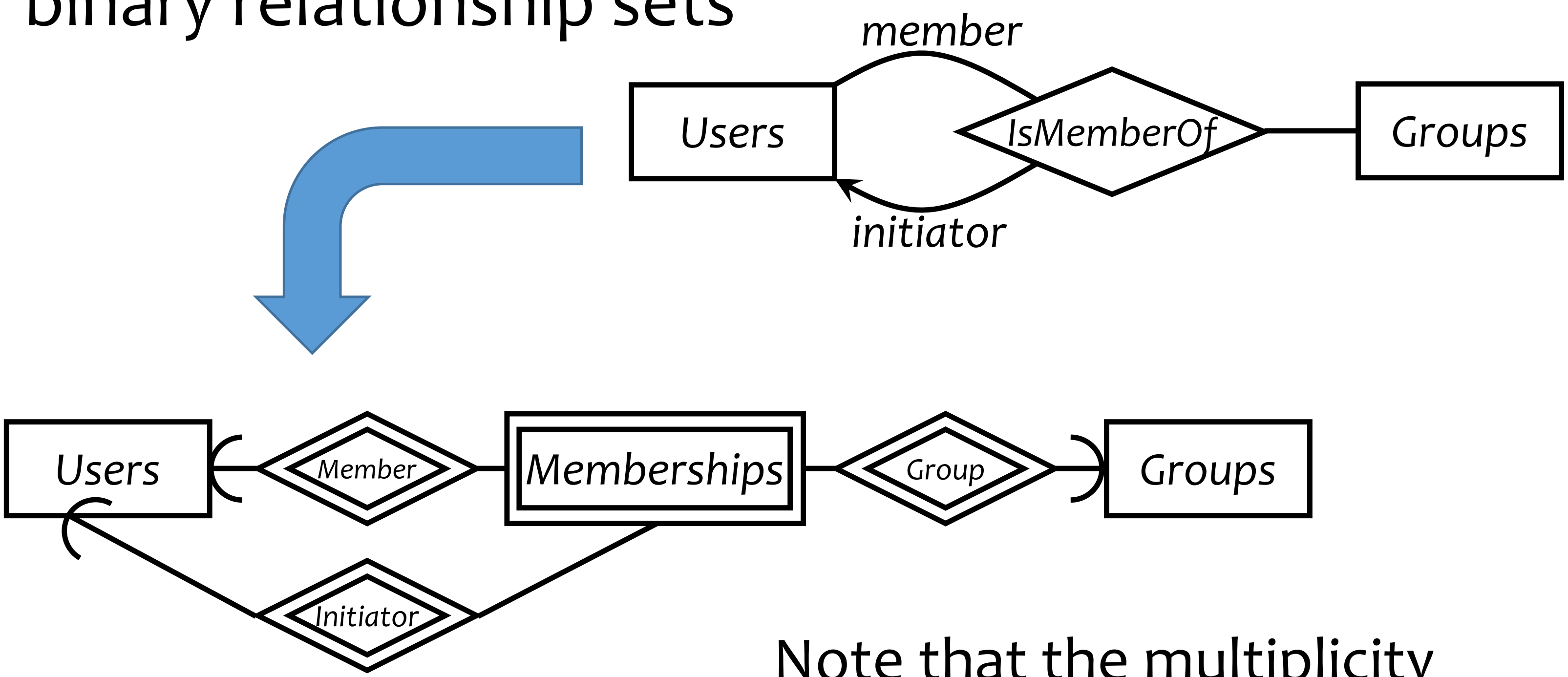
- Seats in rooms in building



- 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

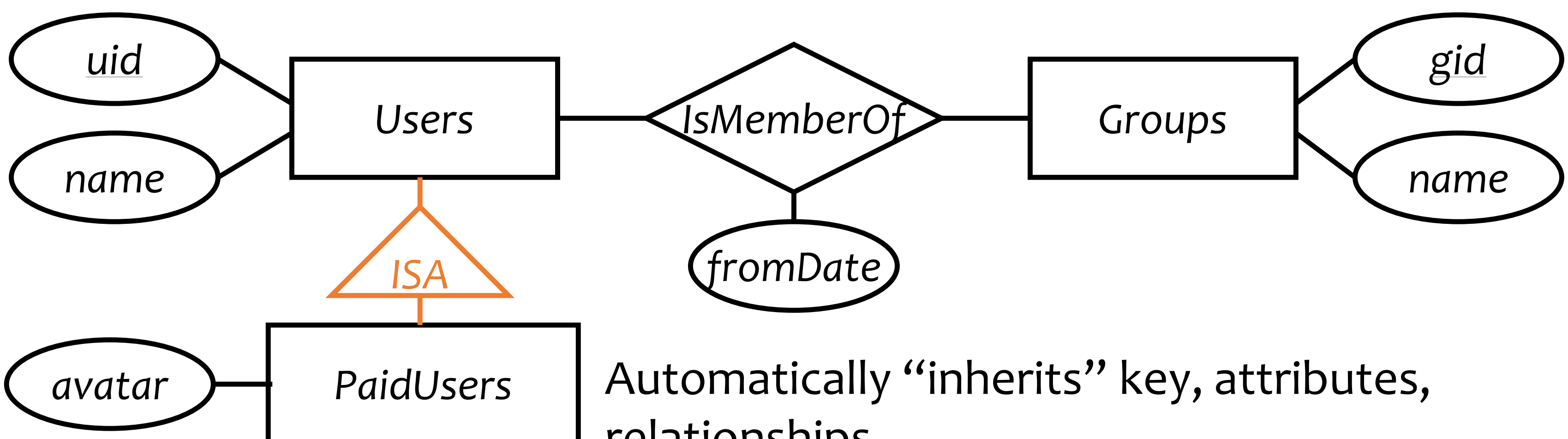
- An n-ary relationship set can be replaced by a weak entity set (called a connecting entity set) and n binary relationship sets



Note that the multiplicity constraint for *IsMemberOf* is lost

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

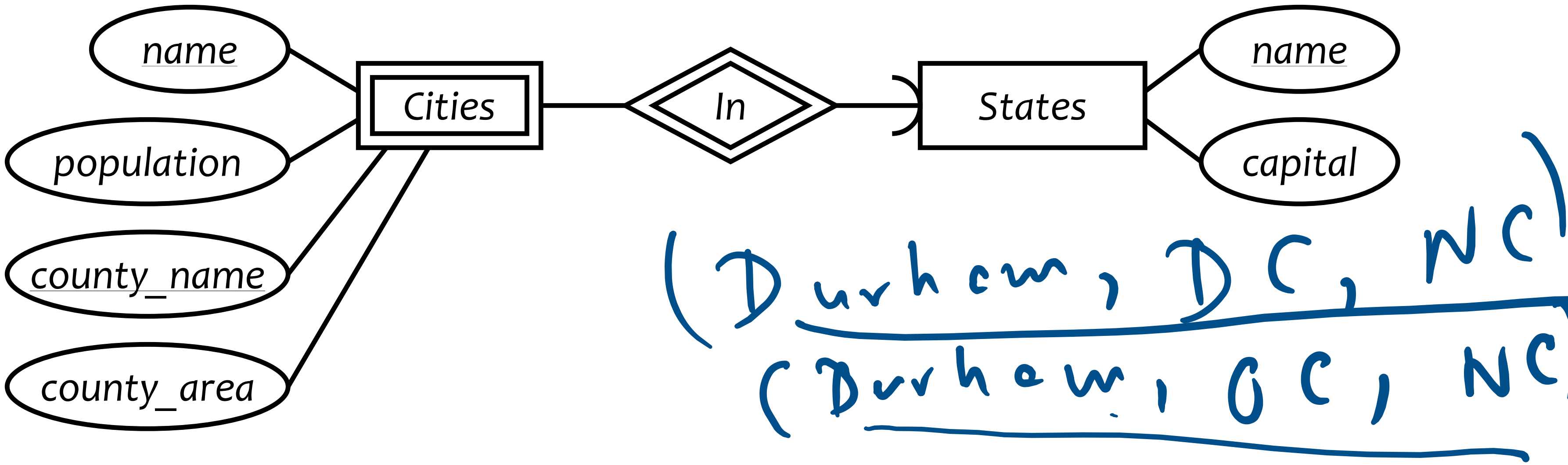
Summary of E/R concepts

- 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: first design



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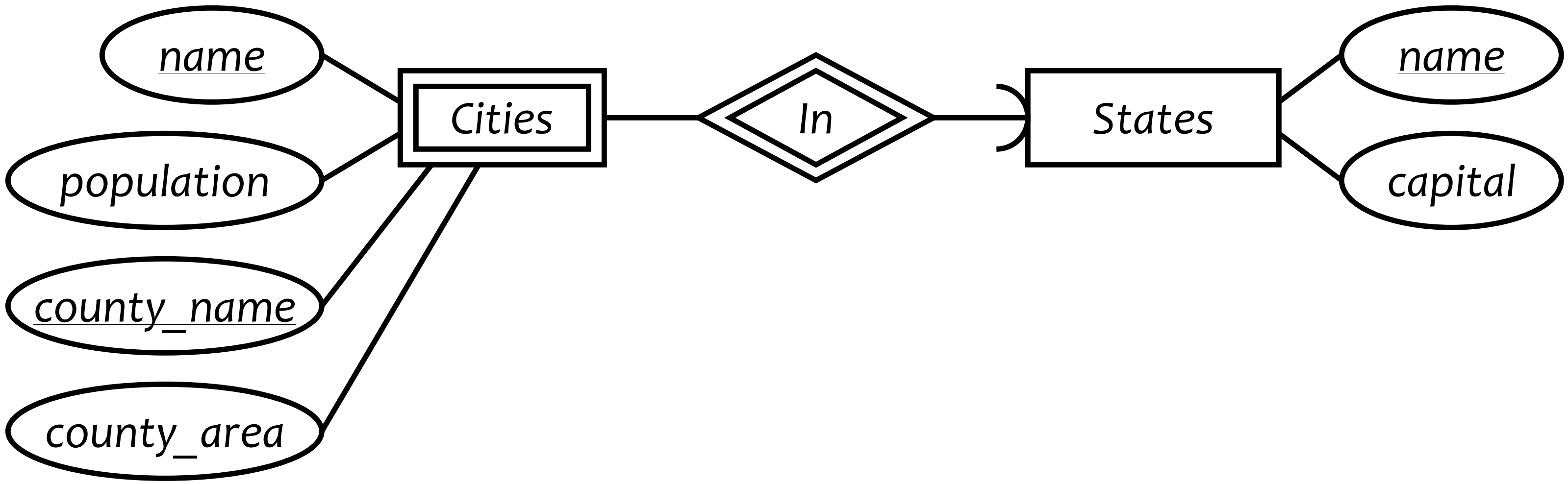
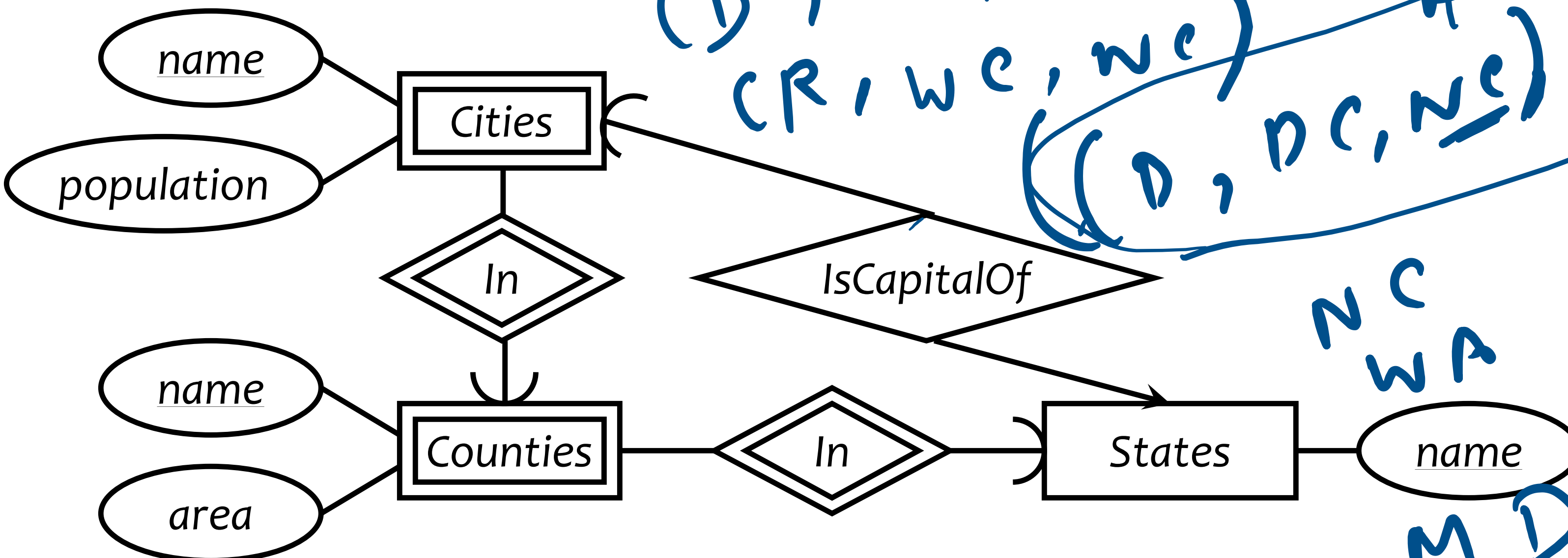


- County area information is repeated for every city in the county
  - ☞Redundancy is bad (why?)
- State capital should really be a city
  - ☞Should "reference" entities through explicit relationships

Case study 1: second design

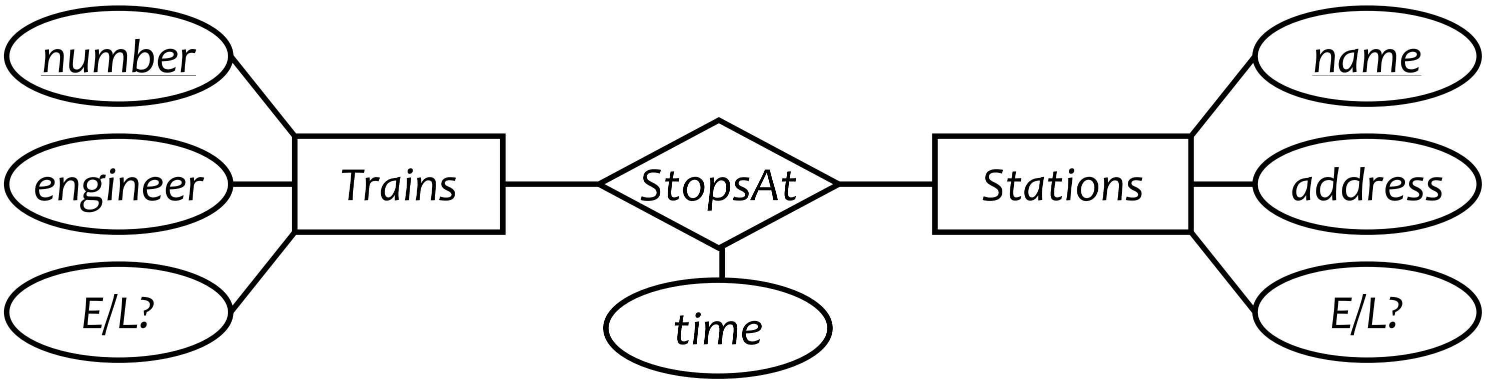


- Technically, nothing in this design prevents a city in state X from being the capital of another state Y, but…

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



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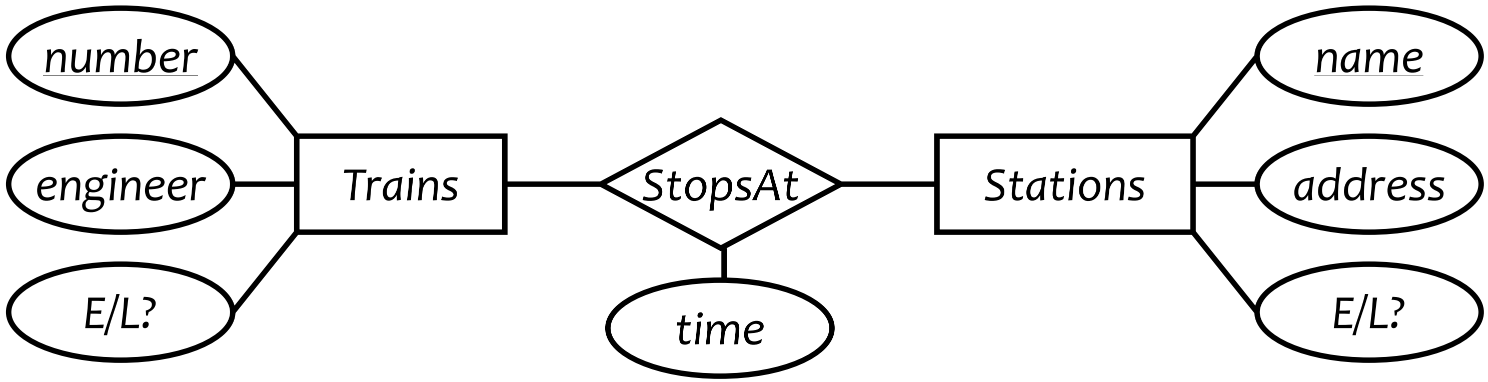
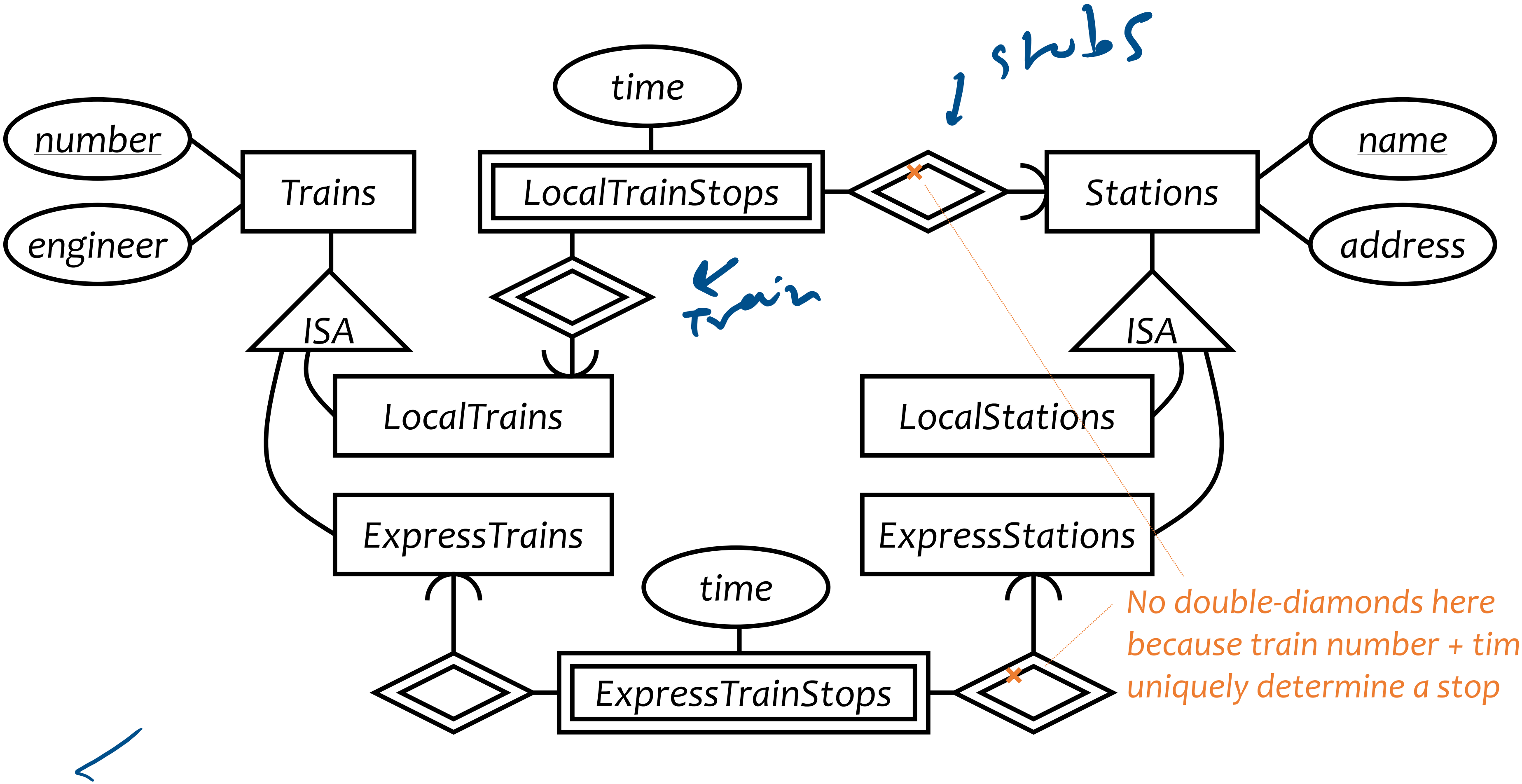


- Nothing in this design prevents express trains from stopping at local stations
  - ☞We should capture as many constraints as possible
- A train can stop at a station only once during a day
  - ☞We should not introduce unintended constraints

Case study 2: second design



Is the extra complexity worth it?