Relational Database Design: Part I
Introduction to Databases
CompSci 316 Fall 2014

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

- 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

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Age</th>
<th>Pop</th>
</tr>
</thead>
<tbody>
<tr>
<td>142</td>
<td>Bart</td>
<td>10</td>
<td>0.9</td>
</tr>
<tr>
<td>123</td>
<td>Milhouse</td>
<td>10</td>
<td>0.2</td>
</tr>
<tr>
<td>857</td>
<td>Lisa</td>
<td>8</td>
<td>0.7</td>
</tr>
<tr>
<td>456</td>
<td>Ralph</td>
<td>8</td>
<td>0.3</td>
</tr>
</tbody>
</table>

* 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]

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? Can we capture historical membership information as well?

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:
      ![Diagram showing Many-many relationship]

  • 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:
      ![Diagram showing Many-one relationship]

  • One-one: Each entity in \( E \) is related to 0 or 1 entity in \( F \) and vice versa
    • Example:
      ![Diagram showing One-one relationship]

• “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 must be related to at most one entity
- 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 ...
Weak entity sets

Sometimes, an entity's identity depends on some others’
• The key of 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
  • $E$ is called a weak entity set, drawn as a double rectangle
  • The relationship sets through which $E$ obtains its key are called supporting relationship sets, drawn as double diamonds

Weak entity set examples

• Seats in rooms in building

  ![Diagram](image)

  • 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

  ![Diagram](image)

  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!)

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

- 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 oh well...

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

• 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?