Relational Database Design: Part I

Introduction to Databases
CompSci 316 Fall 2017
Announcements (Thu. Sep. 7)

• Homework #1 due in 12 days
  • Get started early!
  • Please set up VM now!

• Office hours have been posted

• More details on the course project available next week
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>uid</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?
  -
  -
- Key declarations are part of the schema
More examples of keys

• *Member* (*uid, gid*)
  
  A key can contain multiple attributes

• *Address* (*street_address, city, state, zip*)
  
  A relation can have multiple keys!
  
  • We typically pick one as the “primary” key, and *underline* all its attributes
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?
  • With Groups?
  • 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?
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?
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!)

```mermaid
graph LR
  Users[A] --> IsMemberOf[O]
  IsMemberOf[O] --> Groups[O]
  Users[A] --> PaidUsers[O]
  PaidUsers[O] --> avatar[O]
```

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
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
Case study 2: second design

Is the extra complexity worth it?

No double-diamonds here because train number + time uniquely determine a stop.