Relational Database Design
Part I

CompSci 316
Introduction to Database Systems

Announcements (Thu. Sep. 5)
- Homework #1 due in < 2 weeks
  - Start early—as soon as any part is covered in class
- Sign up for Gradiance
- Set up Azure and our virtual machine ASAP!
  - We can’t help you on the due date if you are still waiting for your account to be activated or run into last-minute installation problems

Relational model: review
- A database is a collection of relations (or tables)
- Each relation has a list of attributes (or columns)
- Each attribute has 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, $K$ is a "tuple identifier"
  - No proper subset of $K$ satisfies the above condition
    - That is, $K$ is minimal
- Example: $Student (SID, name, age, GPA)$
  - $SID$ is a key of $Student$
  - $age$ is not a key (not an identifier)
  - $\{SID, name\}$ is not a key (not minimal)

Schema vs. instance

<table>
<thead>
<tr>
<th>Student</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
</tr>
<tr>
<td>142</td>
</tr>
<tr>
<td>123</td>
</tr>
<tr>
<td>857</td>
</tr>
<tr>
<td>456</td>
</tr>
</tbody>
</table>

- Is $name$ a key of $Student$?

Key declarations are part of the schema

More examples of keys

- $Enroll (SID, CID)$
  - 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, e.g., $Address (street\_address, city, state, zip)$
Usage of keys

- More constraints on data, fewer mistakes
- Look up a row by its key value
  - Many selection conditions are “key = value”
- “Pointers”
  - Example: Enroll (SID, CID)
    - SID is a key of Student
    - CID is a key of Course
    - An Enroll tuple “links” a Student tuple with a Course tuple
  - 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 recent prevalence of rapid Web development frameworks
  - For example, in Django:
    - You declare Python classes and their relationships
    - Django 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
  - The design model sometimes isn’t powerful enough
  - Designer discretion is still required in all but simple cases
  - Querying/modifying data in a general-purpose programming language isn’t necessarily easier than SQL
Entity-relationship (E/R) model

- Historically and still very popular
- 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 GMUW; 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

- Students enroll in courses
- 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: students take courses and receive grades

- Where do the grades go?
  - With Students?
  - With Courses?
  - With Enroll?

More on relationships

- There could be multiple relationship sets between the same entity sets
  - Example: Students Enroll Courses; Students TA Courses

- In a relationship set, each relationship is uniquely identified by the entities it connects
  - Example: Between Bart and CPS316, there can be at most one Enroll relationship and at most one TA relationship
  - What if Bart took CPS316 twice and got two different grades?

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
**N-ary relationships**

- Example: Each course has multiple TA's; in a course, each student is assigned to one TA.
- Meaning of an arrow into E: Pick one entity from each of the other entity sets; together they must be related to either 0 or 1 entity in E.
  - E.g., hypothetically, what would the multiplicities on the right mean?

**N-ary versus binary relationships**

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

**Roles in relationships**

- An entity set may participate more than once in a relationship set.
- May need to label edges to distinguish roles.
- Examples:
  - People mentor others; label needed.
  - People are roommates of each other; label not needed.
Weak entity sets

- Sometimes, the key of an entity set $E$ comes not completely from its own attributes, but from the keys of other (one or more) 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 buildings
  - Why must double diamonds be many-one/one-one?

Modeling $n$-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 Enroll 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: Graduate students are students, but they also have offices

```
<table>
<thead>
<tr>
<th>GradStudents</th>
<th>office</th>
</tr>
</thead>
</table>
```

```
Students  Enroll  Courses
SID name  
```

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

Cities

- name
- population
- county name
- county area

States

- name
- capital

Case study 1: second design

Cities

- name
- population
- county name
- county area

States

- name
- capital

- Cities IsCapitalOf

- Counties

- area

- In

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

- Technically, nothing in this design could prevent a city in state X from being the capital of another state Y, but oh well…
Case study 2: first design

```
<table>
<thead>
<tr>
<th>number</th>
<th>engine</th>
<th>E/L?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>name</th>
<th>address</th>
<th>number</th>
<th>E/L?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

Case study 2: second design

```
<table>
<thead>
<tr>
<th>number</th>
<th>name</th>
<th>address</th>
<th>number</th>
<th>E/L?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

```
<table>
<thead>
<tr>
<th>time</th>
<th>ExpressTrains</th>
<th>ExpressTrainStops</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LocalTrains</td>
<td>LocalTrainStops</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

Is the extra complexity worth it?