Relational Database Design
Part I

CPS 116
Introduction to Database Systems

Announcements (Thu. Sep. 8)

- Homework #1 is out
  - Due in 12 days, but start early—as soon as any portion has been covered
- Sign up for Gradiance
- Try our VM now
  - We can’t help you on the due date if you run into last-minute installation problems
- Duke CS account created
  - Email me immediately if you still need one
- Readings: see Tentative Syllabus on course website

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>SID</th>
<th>name</th>
<th>age</th>
<th>GPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>Bart</td>
<td>10</td>
<td>2.3</td>
</tr>
<tr>
<td>562</td>
<td>Ralph</td>
<td>8</td>
<td>2.5</td>
</tr>
<tr>
<td>142</td>
<td>Lisa</td>
<td>8</td>
<td>4.3</td>
</tr>
<tr>
<td>456</td>
<td>Lisa</td>
<td>8</td>
<td>2.3</td>
</tr>
</tbody>
</table>

- \( name \) is a key of Student?
  - Yes? Seems reasonable for this instance
  - No! Student names are not unique in general
- Key declarations are part of the schema

More examples of keys

- Enroll \((SID, CID)\)
  - \( \{SID, CID\} \)
  - 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 \((street_address, city, state, zip)\)
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

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?
    - But a student can have different grades for multiple courses
  - With Course?
    - But a course can assign different grades for multiple students
  - 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 CPS116, there can be at most one Enroll relationship and at most one TA relationship
  - What if Bart took CPS116 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: Students Enroll Courses
- Many-one: Each entity in $E$ is related to 0 or 1 entity in $F$ and vice versa
  - Example: Students TA Courses
- One-one: Each entity in $E$ is related to 0 or 1 entity in $F$ and vice versa
  - Example: Students Own AcpubAccounts

- “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; 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 $E$

N-ary versus binary relationships

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

  - No; for example:
    - Bart takes CPS116 and CPS114
    - Lisa TA’s CPS116 and CPS114
    - Bart is assigned to Lisa in CPS116, but not in CPS114

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
    - Denoted by double rectangle
    - The relationship sets through which $E$ obtains its key are drawn as double diamonds
Weak entity set examples

- Seats in rooms in buildings

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

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

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

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 could prevent 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 constraints

Case study 2: second design

- Is the extra complexity worth it?