CS 4604: Introduction to Database Management Systems

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Lecture #5: Entity/Relational Models---Part 1
E/R: NOT IN BOOK!

- IMPORTANT:
  - Follow only lecture slides for this topic!
  - Differences from the book:
    - More details
    - Slightly different notation
- Also, Handout 2 is out (practice for E/R).
- Will discuss questions in class next week.
Database Design

- Requirements Analysis: user’s needs
- Conceptual Design: high level (E/R)
- Logical Design: tables (schema)
- Schema Refinement: normalization
- Physical Design: indices etc.
- Security Design: access controls
Database Design

- Requirements Analysis
  - user’s needs

- Conceptual Design
  - high level (E/R)

- Logical Design
  - tables (schema)

- Schema Refinement
  - normalization

- Physical Design
  - indices etc.

- Security Design
  - access controls
Basic Database Terminology

- **Data model**: describes high-level conceptual structuring of data
  - Example: Data is set of student records, each with ID, name, address, and courses
  - Example: Data is a graph where nodes represent people and edges represent friendship relations

- **Schema** describes how data is to be structured and stored in a database
  - Defined during creation of the database
  - Schemas rarely change

- **Data** is actual “instance” of database
  - Updated continuously
  - Changes rapidly
Why Learn About Database Modeling?

- The way in which data is stored is very important for subsequent access and manipulation by SQL.

- Properties of a good data model:
  - It is easy to write correct and easy to understand queries.
  - Minor changes in the problem domain do not change the schema.
  - Major changes in the problem domain can be handled without too much difficulty.
  - Can support efficient database access.
Purpose of E/R Model

- The E/R model allows us to sketch the design of a database informally.
  - Represent different types of data and how they relate to each other
- Designs are drawings called *entity-relationship diagrams*.
- Fairly mechanical ways to convert E/R diagrams to real implementations like relational databases exist.
Purpose of E/R Model

- When designing E/R diagrams,
  - forget about relations/tables!
  - only consider how to model the information you need to represent in your database.
Example

- Professors advising students, Students taking courses, Students taught by professors
Tools

- Entities (‘entity sets’)
- Relationships (‘rel. sets’) and mapping constraints
- Attributes
Example

- Professors advising students, Students taking courses, Students taught by professors

Nouns $\rightarrow$ entity sets

Verbs $\rightarrow$ relationship sets
Entity Sets

- **Entity** = “thing” or objects
- **Entity set** = collection of similar entities.
  - Similar to a class in object-oriented languages.
- **Attribute** = property of an entity set.
  - Generally, all entities in a set have the same properties.
  - Our convention is to use ‘atomic attributes’ e.g. integers, character strings etc.
  - FYI: there exist
    - **multivalued** or set-valued attributes (eg., ‘dependents’ for EMPLOYEE)
    - **derived** attributes (eg., 15% tip)
E/R Diagrams

- In an entity-relationship diagram, each entity set is represented by a rectangle.
- Each attribute of an entity set is represented by an oval, with a line to the rectangle representing its entity set.
Example: Entity Sets

- Students
  - PID
  - Name
  - Number
  - Address

- Courses
  - Name
  - DeptName
  - Classroom
Relationships

- A relationship connects two or more entity sets.
- It is represented by a diamond, with lines to each of the entity sets involved.

- Don’t confuse ‘Relationships’ with ‘Relations’!
Example: Relationships

- Students Take Courses
- Professors Teach Courses
- Professors Advise Students
Instance of an E/R Diagram

- An E/R is NOT an implementation of the DB
  – Just a notation for specifying structure

- Still useful to think of instance of an E/R Diagram === the particular data stored in a database
Instance of an Entity Set

- For each entity set, the instance stores a specific set of entities
- Each entity is a tuple containing specific values for each attribute
- Example: Instance of Entity set Students

<table>
<thead>
<tr>
<th>Name</th>
<th>PID</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hermione Grainger</td>
<td>HG</td>
<td>Gryffindor Tower</td>
</tr>
<tr>
<td>Draco Malfoy</td>
<td>DM</td>
<td>Slytherin Tower</td>
</tr>
<tr>
<td>Harry Potter</td>
<td>HP</td>
<td>Gryffindor Tower</td>
</tr>
<tr>
<td>Ron Weasley</td>
<td>RW</td>
<td>Gryffindor Tower</td>
</tr>
</tbody>
</table>
Instance of a Relationship

- Example: Instance of relationship Takes (no DeptName)

<table>
<thead>
<tr>
<th>Student</th>
<th>PID</th>
<th>Address</th>
<th>CourseName</th>
<th>Enrollment</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hermione Grainger</td>
<td>HG</td>
<td>Gryffindor</td>
<td>Potions</td>
<td>∞</td>
<td>A-</td>
</tr>
<tr>
<td>Draco Malfoy</td>
<td>DM</td>
<td>Slytherin</td>
<td>Potions</td>
<td>∞</td>
<td>B</td>
</tr>
<tr>
<td>Harry Potter</td>
<td>HP</td>
<td>Gryffindor</td>
<td>Potions</td>
<td>∞</td>
<td>A</td>
</tr>
<tr>
<td>Ron Weasley</td>
<td>RW</td>
<td>Gryffindor</td>
<td>Potions</td>
<td>∞</td>
<td>C</td>
</tr>
</tbody>
</table>

- Relationship R between (entity sets) E and F
  - Relates some *entities* in E to some *entities* in F
Instance of a Relationship

- Instance is a set of pairs of tuples \((e; f)\) where \(e\) is in \(E\) and \(f\) is in \(F\)
  - Instance need not relate every tuple in \(E\) with every tuple in \(F\)
  - Relationship set for \(R\): the pairs of tuples \((e; f)\) related by \(R\)

- (Conceptually) An instance of \(R\) is simply the ‘concatentation’ of the attribute lists for all pairs of tuples \((e; f)\) in the relationship set for \(R\)

- ‘Tuples’ in \(R\) have two components, one from \(E\) and one from \(F\)
Attributes for a Relationship

- Question: What is Grade an attribute of?
- Such an attribute is a property of the entity-pairs in the relationship

![Database Diagram: Students, Courses, Professors, and their attributes]
Many-Many Relationships

- In a *many-many* relationship, an entity of either set can be connected to many entities of the other set.
Many-One Relationships

- Some binary relationships are *many-one* from one entity set to another.
- Each entity of the first set is connected to at most one entity of the second set.
- But an entity of the second set can be connected to zero, one, or many entities of the first set.
One-One Relationships

- In a one-one relationship, each entity of either entity set is related to at most one entity of the other set.

- The schema defines the multiplicity of relationships. Don't use the instances of the schema to determine multiplicity.
Representing “Multiplicity”

- Show a many-one relationship by an arrow entering the “one” side.
- Show a one-one relationship by arrows entering both entity sets.
Different kinds of relationships

- **Many-many**
  - Students ↔ Courses

- **Many-one**
  - Prof. ↔ Office

- **One-one**
  - Prof. ↔ Rooms
Exactly one

- In some situations, we can also assert “exactly one,” i.e., each entity of one set must be related to exactly one entity of the other set. To do so, we use a rounded arrow.
Example: Exactly One

- Consider *Best-course* between *Profs* and *Courses*.
- Some courses are not the best-course of any professor, so a rounded arrow to *Profs* would be inappropriate.
- But a professor has to have a best-course
Roles in Relationships

- Can the same entity set appear more than once in the same relationship?
- Prerequisite relationship between two Courses

- But which course is the pre-req?
Roles in Relationships

- Label the connecting lines with the *role* of the entity
Parallel Relationships

- Can there be more than one relationship between the same pair of entities?
- TA and Take relationship between Students and Classes
Are Attributes on Relationships Needed

- Attribute on relationship $\rightarrow$ Attribute to an entity and make relationship multi-way
Entity vs. attribute

- Entity EMPLOYEE (w/ emp#, name, job_code, ...)
- Q: How about ‘spouse’ - entity or attribute?
- Q: How about ‘dependents’?
Entity vs. attribute

- Entity EMPLOYEE (w/ emp#, name, job_code, ...)
- Q: How about ‘spouse’ - entity or attribute?
- A: probably, ‘attribute’ is enough
- Q: How about ‘dependents’?
- A: Entity - we may have many dependents
Multi-way Relationships

- Relationships may connect more than 2 entity sets
- \( \geq 1 \) professor can teach a course but each student evaluates each professor separately
- Three-way Evaluation relationship between Students, Professors, and Classes
Multi-way Relationships

- >= 1 professor can teach a course but each student taught by at most one professor, and each student only evaluates that professor
- Add arrow directed towards Professors
Multiplicity in Multiway Relationships

- An arrow pointing to an entity set E => if we select an entity from each of the other entity sets, the selected entities are related to at most one entity in E.

<table>
<thead>
<tr>
<th>Student</th>
<th>Course</th>
<th>Professor</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hermione Grainger</td>
<td>Potions</td>
<td>Snape</td>
<td>F-</td>
</tr>
<tr>
<td>Draco Malfoy</td>
<td>Potions</td>
<td>Snape</td>
<td>A*</td>
</tr>
<tr>
<td>Harry Potter</td>
<td>Potions</td>
<td>Lupin</td>
<td>A+</td>
</tr>
<tr>
<td>Ron Weasley</td>
<td>Potions</td>
<td>Lupin</td>
<td>B+</td>
</tr>
</tbody>
</table>

- E/R diagram forbids connections between “Hermione Grainger”, “Potions" and two different professors.
Binary vs Ternary Rel.

- Can a ternary rel. be replaced by binary rels?
Attempt 1

Is this OK?
− S “can-supply” P, D “needs” P, and D “deals-with” S does not imply that D has agreed to buy P from S.
− How do we record qty?
Attempt 2: contd

Diagram:
- Parts
- Contract
- Departments
- Suppliers

Relationships:
- Parts to Contract
- Contract to Departments
- Contract to Suppliers

Attributes:
- qty
- c-id
Converting Multiway to Binary

- It is easy to convert a multiway relationship to multiple binary relationships
  - Create a new connecting entity set. Think of its entities as the tuples in the relationship set for the multiway relationship
  - Introduce relationships from the connecting entity set to each of the entities in the original relationship
  - If an entity set plays > 1 role, create a relationship for each role
Converting Multiway to Binary

Equivalent:

[Diagram showing equivalent concept with entities and relationships]

Prakash 2018
Not exactly equivalent, but can be made so by additional FDs.
Example of the Conversion

- Instance of Evaluation (ternary) relationship before conversion:

<table>
<thead>
<tr>
<th>Student</th>
<th>Course</th>
<th>Professor</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hermione Grainger</td>
<td>Potions</td>
<td>Snape</td>
<td>F-</td>
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Example of the Conversion

- **Instance of Evaluation (ternary) relationship before conversion:**

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<td>Potions</td>
<td>Lupin</td>
<td>B+</td>
</tr>
</tbody>
</table>

- **After**

**Evaluation entity set**

<table>
<thead>
<tr>
<th>Eval_Id</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>e1</td>
<td>F-</td>
</tr>
<tr>
<td>e2</td>
<td>A*</td>
</tr>
<tr>
<td>e3</td>
<td>A+</td>
</tr>
<tr>
<td>e4</td>
<td>B+</td>
</tr>
</tbody>
</table>

**Student_of entity set**

<table>
<thead>
<tr>
<th>Eval_Id</th>
<th>Student</th>
</tr>
</thead>
<tbody>
<tr>
<td>e1</td>
<td>Hermione Grainger</td>
</tr>
<tr>
<td>e2</td>
<td>Draco Malfoy</td>
</tr>
<tr>
<td>e3</td>
<td>Harry Potter</td>
</tr>
<tr>
<td>e4</td>
<td>Ron Weasley</td>
</tr>
</tbody>
</table>
Details of the Conversion

- Create an entity in the new Evaluation entity set for each instance (row) in the ternary Evaluation relationship.

- In the Student_of relationship, relate each entity in the Evaluation entity set with the corresponding student entity.

- How many students can the Student_of relationship relate an Evaluation entity to?
  - Only one!

- Therefore, the multiplicity of Student_of is many-to-one from Evaluation to Student.
Conversion
Subclasses: Example

- University Employees, Handout 2 (will be released next week)

All employees have a unique ID. In addition to professors, universities also employ staff. The university pays all its employees a salary. Professors come in three flavors: 9-month appointees, calendar year appointees, and research professors. Each 9-month appointee and research professor has a grant that pays part of the employee’s salary. Calendar year and 9-month professors teach classes while research professors do not.
Subclasses: Example

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Someone from staff IS A employee
A Professor IS A employee
A Research Professor IS A Professor
A Teacher IS A Professor
A 9-month appointee IS A ??
All employees have a unique ID. In addition to professors, universities also employ staff. The university pays all its employees a salary. Professors come in three flavors: 9-month appointees, calendar year appointees, and research professors. Each 9-month appointee and research professor has a grant that pays part of the employee’s salary. Calendar year and 9-month professors teach classes while research professors do not.

Someone from staff IS A employee
A Professor IS A employee
A Research Professor IS A Professor
A Teacher IS A Professor
A 9-month appointee IS A Teacher!
Subclasses: Example

- University Employees, Handout 2
Subclasses in the E/R Model

- A subclass of an entity set E is an entity set F such that
  - each entity in F is an entity in E
  - the entity set F must have at least one attribute or participate in at least one relationship that E does not

- Connect E to F using an *isa* relationship denoted by a triangle

- Convention is to draw E above F

- Each *isa* relationship is one-one but we do not draw the arrows.

- The set of *isa* relationships must form a tree.
Students enrolled in a university can be either undergraduates or graduates. Graduate students can be enrolled either in a Masters or a Ph.D. program. Each graduate student must submit a thesis. The thesis can be uniquely identified by its title. Each student can be a TA for at most one course. Furthermore, a course can have at most one graduate student as a TA (it may have multiple undergraduate TAs).
Subclasses: Example

- University Students, Handout 2
E/R vs. OO Subclasses

- In object-oriented programming languages, each object is in only one class.
  - A subclass inherits variables and methods from the superclasses.

- In an E/R diagram, an entity has components in all the subclasses to which it belongs
  - If an entity $e$ has a component in an subclass, then $e$ has a component in the superclass
  - Does $e$ have a component in the root?
  - The attributes of $e$ are the union of the attributes of its components
  - $e$ participates in all the relationships its components participate in
Prof. Fingers InMany Pies has a 9-month appointment, teaches in one semester every year, and does not teach in the other semester.

In the other semesters, his research grant pays his salary.

Which entity sets does he have components in? (using a different isa hierarchy than before)
Components of an Entity

- How do we represent students enrolled in combined Bachelors-Masters programs?
- Such a student has components in multiple entity sets
Components of an Entity

- Such a student has components in multiple entity sets