Introduction to Data Management
CSE 344

Lectures 18: Design Theory
Database Design Process

Conceptual Model:

Relational Model:
- Tables + constraints
- And also functional dep.

Normalization:
- Eliminates anomalies

Conceptual Schema

Physical storage details

Physical Schema

Before Midterm

Sec 7 + Lec 17

Lec 16

Lec 17
Lec 18
From E/R Diagrams to Relational Schema

- Entity set $\rightarrow$ relation
- Relationship $\rightarrow$ relation
Product(prod-ID, category, price)

<table>
<thead>
<tr>
<th>prod-ID</th>
<th>category</th>
<th>price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo55</td>
<td>Camera</td>
<td>99.99</td>
</tr>
<tr>
<td>Pokemn19</td>
<td>Toy</td>
<td>29.99</td>
</tr>
</tbody>
</table>
N-N Relationships to Relations

Represent this in relations
N-N Relationships to Relations

Orders\((\text{prod-ID}, \text{cust-ID}, \text{date})\)
Shipment\((\text{prod-ID}, \text{cust-ID}, \text{name}, \text{date})\)
Shipping-Co\((\text{name}, \text{address})\)

<table>
<thead>
<tr>
<th>prod-ID</th>
<th>cust-ID</th>
<th>name</th>
<th>date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo55</td>
<td>Joe12</td>
<td>UPS</td>
<td>4/10/2011</td>
</tr>
<tr>
<td>Gizmo55</td>
<td>Joe12</td>
<td>FEDEX</td>
<td>4/9/2011</td>
</tr>
</tbody>
</table>
N-1 Relationships to Relations

Represent this in relations

Orders

Shipment

Shipping-Co

prod-ID

cust-ID

date

name

address
Orders

Shipping-Co

Remember: no separate relations for many-one relationship
Multi-way Relationships to Relations

Purchase (prod-ID, ssn, name)

Try this at home!
Modeling Subclasses

Some objects in a class may be special
- define a new class
- better: define a subclass

So --- we define subclasses in E/R
Subclasses

Product

<table>
<thead>
<tr>
<th>name</th>
<th>category</th>
</tr>
</thead>
<tbody>
<tr>
<td>price</td>
<td></td>
</tr>
<tr>
<td>isa</td>
<td></td>
</tr>
</tbody>
</table>

Software Product

- platforms

Educational Product

- Age Group

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Subclasses to Relations

**Product**
- **isa**
  - **Software Product**
  - **Educational Product**

**Product**
- **name**
- **category**
- **price**

**Product**
- **isa**

**Sw.Product**
- **isa**

**Ed.Product**
- **Age Group**

<table>
<thead>
<tr>
<th>Name</th>
<th>Price</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo</td>
<td>99</td>
<td>gadget</td>
</tr>
<tr>
<td>Camera</td>
<td>49</td>
<td>photo</td>
</tr>
<tr>
<td>Toy</td>
<td>39</td>
<td>gadget</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>platforms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo</td>
<td>unix</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Age Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo</td>
<td>toddler</td>
</tr>
<tr>
<td>Toy</td>
<td>retired</td>
</tr>
</tbody>
</table>

Other ways to convert are possible

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Modeling Union Types with Subclasses

Say: each piece of furniture is owned either by a person or by a company
Modeling Union Types with Subclasses

Say: each piece of furniture is owned either by a person or by a company

Solution 1. Acceptable but imperfect (What’s wrong ?)
Modeling Union Types with Subclasses

Solution 2: better, more laborious
Weak Entity Sets

Entity sets are weak when their key comes from other classes to which they are related.

Team (sport, number, universityName)
University (name)
Database Design Process

Conceptual Model:

Relational Model:
Tables + constraints
And also functional dep.

Normalization:
Eliminates anomalies

Conceptual Schema

Physical storage details
Physical Schema
What makes good schemas?

- Why so many database tables???
- I updated a schema once
  it sucked
Relational Schema Design

<table>
<thead>
<tr>
<th>Name</th>
<th>SSN</th>
<th>PhoneNumber</th>
<th>City</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fred</td>
<td>123-45-6789</td>
<td>206-555-1234</td>
<td>Seattle</td>
</tr>
<tr>
<td>Fred</td>
<td>123-45-6789</td>
<td>206-555-6543</td>
<td>Seattle</td>
</tr>
<tr>
<td>Joe</td>
<td>987-65-4321</td>
<td>908-555-2121</td>
<td>Westfield</td>
</tr>
</tbody>
</table>

One person may have multiple phones, but lives in only one city

Primary key is thus (SSN, PhoneNumber)

What is the problem with this schema?
Relational Schema Design

Anomalies:
• Redundancy = repeat data
• Update anomalies = what if Fred moves to “Bellevue”?
• Deletion anomalies = what if Joe deletes his phone number?

<table>
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</tr>
</tbody>
</table>
Relation Decomposition

Break the relation into two:

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</tr>
</tbody>
</table>

Anomalies have gone:
- No more repeated data
- Easy to move Fred to “Bellevue” (how ?)
- Easy to delete all Joe’s phone numbers (how ?)
Relational Schema Design (or Logical Design)

How do we do this systematically?

- Start with some relational schema
- Find out its functional dependencies (FDs)
- Use FDs to normalize the relational schema
Functional Dependencies (FDs)

**Definition**

If two tuples agree on the attributes

\[ A_1, A_2, \ldots, A_n \]

then they must also agree on the attributes

\[ B_1, B_2, \ldots, B_m \]

Formally:

\[ A_1, A_2, \ldots, A_n \rightarrow B_1, B_2, \ldots, B_m \]
Functional Dependencies (FDs)

**Definition** \( A_1, \ldots, A_m \rightarrow B_1, \ldots, B_n \) holds in \( R \) if:

\[
\forall t, t' \in R, \\
(t.A_1 = t'.A_1 \land \ldots \land t.A_m = t'.A_m \rightarrow t.B_1 = t'.B_1 \land \ldots \land t.B_n = t'.B_n)
\]

<table>
<thead>
<tr>
<th>R</th>
<th>A_1</th>
<th>...</th>
<th>A_m</th>
<th>B_1</th>
<th>...</th>
<th>B_n</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

if \( t, t' \) agree here then \( t, t' \) agree here
Example

An FD holds, or does not hold on an instance:

<table>
<thead>
<tr>
<th>EmpID</th>
<th>Name</th>
<th>Phone</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>E0045</td>
<td>Smith</td>
<td>1234</td>
<td>Clerk</td>
</tr>
<tr>
<td>E3542</td>
<td>Mike</td>
<td>9876</td>
<td>Salesrep</td>
</tr>
<tr>
<td>E1111</td>
<td>Smith</td>
<td>9876</td>
<td>Salesrep</td>
</tr>
<tr>
<td>E9999</td>
<td>Mary</td>
<td>1234</td>
<td>Lawyer</td>
</tr>
</tbody>
</table>

EmpID → Name, Phone, Position
Position → Phone
but not Phone → Position
## Example

<table>
<thead>
<tr>
<th>EmpID</th>
<th>Name</th>
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</table>

Position → Phone
### Example

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</tr>
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<tr>
<td>E9999</td>
<td>Mary</td>
<td>1234</td>
<td>Lawyer</td>
</tr>
</tbody>
</table>

But not Phone $\rightarrow$ Position
Example

<table>
<thead>
<tr>
<th>name</th>
<th>category</th>
<th>color</th>
<th>department</th>
<th>price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo</td>
<td>Gadget</td>
<td>Green</td>
<td>Toys</td>
<td>49</td>
</tr>
<tr>
<td>Tweaker</td>
<td>Gadget</td>
<td>Green</td>
<td>Toys</td>
<td>99</td>
</tr>
</tbody>
</table>

Do all the FDs hold on this instance?

- name \(\rightarrow\) color
- category \(\rightarrow\) department
- color, category \(\rightarrow\) price
<table>
<thead>
<tr>
<th>name</th>
<th>category</th>
<th>color</th>
<th>department</th>
<th>price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo</td>
<td>Gadget</td>
<td>Green</td>
<td>Toys</td>
<td>49</td>
</tr>
<tr>
<td>Tweaker</td>
<td>Gadget</td>
<td>Green</td>
<td>Toys</td>
<td>49</td>
</tr>
<tr>
<td>Gizmo</td>
<td>Stationary</td>
<td>Green</td>
<td>Office-supp.</td>
<td>59</td>
</tr>
</tbody>
</table>
Buzzwords

• FD holds or does not hold on an instance

• If we can be sure that every instance of $R$ will be one in which a given FD is true, then we say that $R$ satisfies the FD

• If we say that $R$ satisfies an FD $F$, we are stating a constraint on $R$
  – Recall constraints from this morning’s sec 7
Why bother with FDs?

Anomalies:
- **Redundancy** = repeat data
- **Update anomalies** = what if Fred moves to “Bellevue”?
- **Deletion anomalies** = what if Joe deletes his phone number?
An Interesting Observation

If all these FDs are true:

- name $\rightarrow$ color
- category $\rightarrow$ department
- color, category $\rightarrow$ price

Then this FD also holds:

- name, category $\rightarrow$ price

If we find out from application domain that a relation satisfies some FDs, it doesn’t mean that we found all the FDs that it satisfies! There could be more FDs implied by the ones we have.
Closure of a set of Attributes

**Given** a set of attributes $A_1, \ldots, A_n$

The **closure** is the set of attributes $B$, notated $\{A_1, \ldots, A_n\}^+$, s.t. $A_1, \ldots, A_n \rightarrow B$

**Example:**

1. name $\rightarrow$ color
2. category $\rightarrow$ department
3. color, category $\rightarrow$ price

**Closures:**

- $\text{name}^+ = \{\text{name, color}\}$
- $\{\text{name, category}\}^+ = \{\text{name, category, color, department, price}\}$
- $\text{color}^+ = \{\text{color}\}$
Closure Algorithm

\[ X = \{A_1, \ldots, A_n\}. \]

**Repeat until** \( X \) doesn’t change **do**:  

\[
\text{if } B_1, \ldots, B_n \rightarrow C \text{ is a FD and } \quad B_1, \ldots, B_n \text{ are all in } X \\
\text{then add } C \text{ to } X.
\]

**Example:**

1. name \( \rightarrow \) color  
2. category \( \rightarrow \) department  
3. color, category \( \rightarrow \) price

\[
\{\text{name, category}\}^+ = \{\text{name, category, color, department, price}\}
\]

Hence:  

\[
\text{name, category} \rightarrow \text{color, department, price}
\]