Introduction to Data Management
CSE 344

Lectures 18: Design Theory
Announcements

• HW6 and WQ6 are out
  – Due on Monday, 11/21
• Back to Tues/Wed cycle for HW7-8 and WQ7
• Today and next lecture:
  – Design theory (3.1-3.4)
Where are we?

• First half of 344:
  – Data models: instance, schema, languages
    • Relational and NoSQL
  – Query processing

• Second half of 344: Using DBMSs effectively
  – Conceptual design
  – Transactions
  – Parallel databases
What is this class about?

- **Focus: Using DBMSs**
- Relational Data Model
  - SQL, Relational Algebra, Relational Calculus, datalog
- Semistructured Data Model
  - JSON, CouchDB (NoSQL)
- Conceptual design
  - E/R diagrams, Views, and Database normalization
- Transactions
- Parallel databases, MapReduce, and Spark
- Data integration and data cleaning
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 18

Lec 17

Lec 18
Lec 19

name
price
makes
company
name
address
What makes good schemas?
Relational Schema Design

<table>
<thead>
<tr>
<th>Name</th>
<th>SSN</th>
<th>PhoneNumber</th>
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<tbody>
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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

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

Break the relation into two:

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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**

For a relation $R$ with attributes $A_1, \ldots, A_m$ and $B_1, \ldots, B_n$, $A_1, \ldots, A_m \rightarrow B_1, \ldots, B_n$ holds in $R$ if:

$$\forall t, t' \in R,$$

$$t.A_1 = t'.A_1 \land \ldots \land t.A_m = t'.A_m \implies t.B_1 = t'.B_1 \land \ldots \land t.B_n = t'.B_n$$

<table>
<thead>
<tr>
<th>$R$</th>
<th>$A_1$</th>
<th>$\ldots$</th>
<th>$A_m$</th>
<th>$B_1$</th>
<th>$\ldots$</th>
<th>$B_n$</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$t$</td>
<td></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>
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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>
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<td>Salesrep</td>
</tr>
<tr>
<td>E9999</td>
<td>Mary</td>
<td>1234</td>
<td>Lawyer</td>
</tr>
</tbody>
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\[\text{EmpID} \rightarrow \text{Name, Phone, Position}\]
\[\text{Position} \rightarrow \text{Phone}\]
\[\text{but not} \quad \text{Phone} \rightarrow \text{Position}\]
# Example

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- Position  ➔  Phone
### Example

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But not Phone ➔ Position
Example

<table>
<thead>
<tr>
<th>name</th>
<th>category</th>
<th>color</th>
<th>department</th>
<th>price</th>
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<tbody>
<tr>
<td>Gizmo</td>
<td>Gadget</td>
<td>Green</td>
<td>Toys</td>
<td>49</td>
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<tr>
<td>Tweaker</td>
<td>Gadget</td>
<td>Green</td>
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Do all the FDs hold on this instance?

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

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</tr>
<tr>
<td>Gizmo</td>
<td>Stationary</td>
<td>Green</td>
<td>Office-supp.</td>
<td>59</td>
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What about this one?
Terminology

• 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 lec 17 and sec 7
Why bother with FDs?

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- **Redundancy** = repeat data
- **Update anomalies** = what if Fred moves to “Bellevue”?
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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:

$name^+ = \{\text{name, color}\}$

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

$\text{color}^+ = \{\text{color}\}$
Closure Algorithm

$X = \{A_1, \ldots, A_n\}$.

Repeat until $X$ doesn’t change do:

if $B_1, \ldots, B_n \rightarrow C$ is a FD and $B_1, \ldots, B_n$ are all in $X$
then add $C$ to $X$.

Example:

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

Hence:

$\{\text{name, category}\}^+ =$

$\{ \text{name, category, color, department, price} \}$

Hence: name, category $\rightarrow$ color, department, price
Example

In class:

\[ R(A,B,C,D,E,F) \]

\[
\begin{align*}
A, B & \rightarrow C \\
A, D & \rightarrow E \\
B & \rightarrow D \\
A, F & \rightarrow B
\end{align*}
\]

Compute \( \{A,B\}^+ \) \( X = \{A, B, \} \)

Compute \( \{A, F\}^+ \) \( X = \{A, F, \} \)
Example

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Example

In class:

\[ R(A, B, C, D, E, F) \]

\[
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A, B & \rightarrow C \\
A, D & \rightarrow E \\
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\]

Compute \( \{A, B\}^+ \) \( X = \{A, B, C, D, E\} \)

Compute \( \{A, F\}^+ \) \( X = \{A, F, B, C, D, E\} \)

What is the key of \( R \)?
Practice at Home

Find all FD’s implied by:

- \( A, B \rightarrow C \)
- \( A, D \rightarrow B \)
- \( B \rightarrow D \)
Practice at Home

Find all FD’s implied by:

\[
\begin{align*}
A, B & \rightarrow C \\
A, D & \rightarrow B \\
B & \rightarrow D
\end{align*}
\]

Step 1: Compute \(X^+\), for every \(X\):

\[
\begin{align*}
A^+ &= A, \quad B^+ = BD, \quad C^+ = C, \quad D^+ = D \\
AB^+ &= ABCD, \quad AC^+ = AC, \quad AD^+ = ABCD, \\
&\quad\quad\quad BC^+ = BCD, \quad BD^+ = BD, \quad CD^+ = CD \\
ABC^+ &= ABD^+ = ACD^+ = ABCD \text{ (no need to compute— why ?)} \\
BCD^+ &= BCD, \quad ABCD^+ = ABCD
\end{align*}
\]

Step 2: Enumerate all FD’s \(X \rightarrow Y\), s.t. \(Y \subseteq X^+\) and \(X \cap Y = \emptyset\):

\[
\begin{align*}
AB \rightarrow CD, \quad AD \rightarrow BC, \quad ABC \rightarrow D, \quad ABD \rightarrow C, \quad ACD \rightarrow B
\end{align*}
\]
Keys

• A **superkey** is a set of attributes $A_1, \ldots, A_n$ s.t. for any other attribute $B$, we have $A_1, \ldots, A_n \rightarrow B$

• A **key** is a minimal superkey
  – A superkey and for which no subset is a superkey
Computing (Super)Keys

• For all sets $X$, compute $X^+$

• If $X^+ = [\text{all attributes}]$, then $X$ is a superkey

• Try reducing to the minimal $X$’s to get the key
Example

Product(name, price, category, color)

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

What is the key?
Example

Product(name, price, category, color)

\[
\begin{align*}
\text{name, category} & \rightarrow \text{price} \\
\text{category} & \rightarrow \text{color}
\end{align*}
\]

What is the key?

\[(\text{name, category}) + = \{ \text{name, category, price, color} \}\]

Hence (name, category) is a key
Key or Keys?

Can we have more than one key?

Given R(A,B,C) define FD’s s.t. there are two or more distinct keys
Key or Keys?

Can we have more than one key?

Given R(A,B,C) define FD’s s.t. there are two or more distinct keys:

- $A \rightarrow B$
- $B \rightarrow C$
- $C \rightarrow A$

or

- $AB \rightarrow C$
- $BC \rightarrow A$

or

- $A \rightarrow BC$
- $B \rightarrow AC$

what are the keys here?
Eliminating Anomalies

Main idea:

• $X \rightarrow A$ is OK if $X$ is a (super)key

• $X \rightarrow A$ is not OK otherwise
  – Need to decompose the table, but how?

Boyce-Codd Normal Form