Today’s topics
• Finish NULLs and Views in SQL from Lecture 3
• Relational Algebra (RA) and Relational Calculus (RC)
• Reading material
  – [RG] Chapter 4 (RA, RC)
  – [GUW] Chapters 2.4, 5.1, 5.2

Acknowledgement:
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Null Values
• Field values in a tuple are sometimes
  – unknown, e.g., a rating has not been assigned, or
  – inapplicable, e.g., no spouse’s name
  – SQL provides a special value null for such situations.

Standard Boolean 2-valued logic
• True = 1, False = 0
• Suppose X = 5
  – (X < 100) AND (X >= 1) is ...
  – (X > 100) OR (X >= 1) is ...
  – (X > 100) AND (X >= 1) is ...
  – NOT(X = 5) is ...
• Intuitively,
  – T = 1, F = 0
  – For V1, V2 ⊕ (1, 0)
  – V1 ⊙ V2 = MIN(V1, V2)
  – V1 ⊕ V2 = MAX(V1, V2)
  – ¬(V1) = 1 – V1

2-valued logic does not work for nulls
• Suppose rating = null, X = 5
• Is rating>8 true or false?
• What about AND, OR and NOT connectives?
  – (rating > 8) AND (X = 5)?
• What if we have such a condition in the WHERE clause?
3-Valued Logic For Null

- TRUE (= 1), FALSE (= 0), UNKNOWN (= 0.5)
  - unknown is treated as 0.5
- Now you can apply rules from 2-valued logic!
  - For V1, V2 ∈ {0, 0.5}
  - V1 = V2 = MAX(V1, V2)
  - ¬(V1) = 1
- Therefore,
  - NOT UNKNOWN = UNKNOWN
  - UNKNOWN OR TRUE = TRUE
  - UNKNOWN AND TRUE = UNKNOWN
  - UNKNOWN AND FALSE = FALSE
  - UNKNOWN OR FALSE = UNKNOWN

New issues for Null

- The presence of null complicates many issues. E.g.:
  - Special operators needed to check if value IS/IS NOT NULL
  - Be careful!
  - “WHERE X = NULL” does not work!
  - Need to write “WHERE X IS NULL”!
- Meaning of constructs must be defined carefully!
  - e.g., “WHERE” clause eliminates rows that don’t evaluate to true
  - So not only FALSE, but UNKNOWNS are eliminated too
  - Very important to remember!
- But NULL allows new operators (e.g. outer joins)
- Arithmetic with NULL
  - all of +, -, *, / return null if any argument is null
- Can force “no nulls” while creating a table
  - sname char(20) NOT NULL
  - primary key is always not null!

Aggregates with NULL

- What do you get for
  - SELECT count(*) from R1?
  - SELECT count(rating) from R1?

Aggregates with NULL

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  - SELECT count(*) from R1?
  - SELECT count(rating) from R1?

Overview: General Constraints

- Useful when more general ICs than keys are involved
- There are also Assertions to specify constraints that span across multiple tables
- There are Triggers too: procedure that starts automatically if specified changes occur to the DBMS
- See additional slides at the end
Views

• A view is just a relation, but we store a definition, rather than a set of tuples

```sql
CREATE VIEW YoungActiveStudents (name, grade)
AS SELECT S.name, E.grade
FROM Students S, Enrolled E
WHERE S.sid = E.sid and S.age < 21
```

• Views can be dropped using the DROP VIEW command

• Views and Security: Views can be used to present necessary information (or a summary), while hiding details in underlying relation(s)
  • the above view hides courses “cid” from E

Can create a new table from a query on other tables too

```sql
SELECT * INTO YoungActiveStudents
FROM Students S, Enrolled E
WHERE S.sid = E.sid and S.age < 21
```

“WITH” clause – very useful!

• You will find “WITH” clause very useful!

```sql
WITH Temp1 AS
(SELECT ….. .)
Temp2 AS
(SELECT ….. .)
SELECT X, Y
FROM Temp1, Temp2
WHERE …
```

• Can simplify complex nested queries

Summary

• SQL has a huge number of constructs and possibilities
  — You need to learn and practice it on your own
  — Given a problem, you should be able to write a SQL query and verify whether a given one is correct

• Pay attention to NULLs

• Can limit answers using “LIMIT” or “TOP” clauses
  — e.g. to output TOP 20 results according to an aggregate
  — also can sort using ASC or DESC keywords

Relational Query Languages

• Query languages: Allow manipulation and retrieval of data from a database
• Relational model supports simple, powerful QLS:
  — Strong formal foundation based on logic
  — Allows for much optimization
• Query Languages != programming languages
  — QLS not intended to be used for complex calculations
  — QLS support easy, efficient access to large data sets
Formal Relational Query Languages

- Two “mathematical” Query Languages form the basis for “real” languages (e.g. SQL), and for implementation:
  - Relational Algebra: More operational, very useful for representing execution plans
  - Relational Calculus: Lets users describe what they want, rather than how to compute it (Non-operational, declarative)
- Note: Declarative (RC, SQL) vs. Operational (RA)

Preliminaries

- A query is applied to relation instances, and the result of a query is also a relation instance.
  - Schemas of input relations for a query are fixed
    - query will run regardless of instance
  - The schema for the result of a given query is also fixed
    - Determined by definition of query language constructs
- Positional vs. named-field notation:
  - Positional notation easier for formal definitions, named-field notation more readable

Example Schema and Instances

```
Sailors(sid, sname, rating, age)
Boats(bid, bname, color)
Reserves(sid, bid, day)
```

<table>
<thead>
<tr>
<th>sid</th>
<th>name</th>
<th>rating</th>
<th>age</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>Dustin</td>
<td>7</td>
<td>45.0</td>
</tr>
<tr>
<td>31</td>
<td>Lubber</td>
<td>8</td>
<td>55.5</td>
</tr>
<tr>
<td>58</td>
<td>Rusty</td>
<td>10</td>
<td>35.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>sid</th>
<th>name</th>
<th>rating</th>
<th>age</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>Yuppy</td>
<td>9</td>
<td>35.0</td>
</tr>
<tr>
<td>31</td>
<td>Lubber</td>
<td>8</td>
<td>55.5</td>
</tr>
<tr>
<td>44</td>
<td>Guppy</td>
<td>5</td>
<td>35.0</td>
</tr>
<tr>
<td>58</td>
<td>Rusty</td>
<td>10</td>
<td>35.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>sid</th>
<th>bid</th>
<th>day</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>101</td>
<td>10/10/96</td>
</tr>
<tr>
<td>58</td>
<td>103</td>
<td>11/12/96</td>
</tr>
</tbody>
</table>

Logic Notations

- $\exists$ There exists
- $\forall$ For all
- $\land$ Logical AND
- $\lor$ Logical OR
- $\neg$ NOT

Relational Algebra

- Takes one or more relations as input, and produces a relation as output
  - operator
  - operand
  - semantic
  - so an algebra!
- Since each operation returns a relation, operations can be composed
  - Algebra is “closed”

Relational Algebra (RA)
Relational Algebra

- Basic operations:
  - Selection (σ) Selects a subset of rows from relation
  - Projection (π) Deletes unwanted columns from relation.
  - Cross-product (×) Allows us to combine two relations.
  - Set-difference (-) Tuples in reln. 1, but not in reln. 2.
  - Union (∪) Tuples in reln. 1 or in reln. 2.

- Additional operations:
  - Intersection (∩)
  - Join (⋈)
  - Division (/)
  - Renaming (ρ)

- Not essential, but (very) useful.

Selection

- Selects rows that satisfy selection condition
- No duplicates in result. Why?
- Schema of result identical to schema of (only) input relation

\[ \sigma_{\text{rating} > 8}(\mathcal{S}_2) \]

\[ \pi_{\text{name}, \text{rating}}(\sigma_{\text{rating} > 8}(\mathcal{S}_2)) \]

Projection

- Deletes attributes that are not in projection list.
- Schema of result contains exactly the fields in the projection list, with the same names that they had in the (only) input relation.
- Projection operator has to eliminate duplicates (Why)
  - Note: real systems typically don’t do duplicate elimination unless the user explicitly asks for it (performance)

\[ \pi_{\text{name}, \text{rating}}(\mathcal{S}_2) \]

Composition of Operators

- Result relation can be the input for another relational algebra operation
  - Operator composition

\[ \sigma_{\text{rating} > 8}(\mathcal{S}_2) \]

\[ \pi_{\text{name}, \text{rating}}(\sigma_{\text{rating} > 8}(\mathcal{S}_2)) \]

Union, Intersection, Set-Difference

- All of these operations take two input relations, which must be union-compatible:
  - Same number of fields.
  - ’Corresponding’ fields have the same type
  - Same schema as the inputs

Union, Intersection, Set-Difference

- Note: no duplicate
  - “Set semantic”
  - SQL: UNION
  - SQL allows “bag semantic” as well: UNION ALL
Union, Intersection, Set-Difference

<table>
<thead>
<tr>
<th>sid</th>
<th>sname</th>
<th>rating</th>
<th>age</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>dustin</td>
<td>7</td>
<td>45.0</td>
</tr>
<tr>
<td>31</td>
<td>lubber</td>
<td>8</td>
<td>55.5</td>
</tr>
<tr>
<td>58</td>
<td>rusty</td>
<td>10</td>
<td>35.0</td>
</tr>
</tbody>
</table>

\(S_1 = \{ \text{sid}, \text{sname}, \text{rating}, \text{age} \}\)

Cross-Product

- Each row of \(S_1\) is paired with each row of \(R_1\).
- Result schema has one field per field of \(S_1\) and \(R_1\), with field names "inherited" if possible.
  - Conflict: Both \(S_1\) and \(R_1\) have a field called sid.

\[
\begin{array}{cccc}
\text{sid} & \text{sname} & \text{rating} & \text{age} \\
22 & dustin & 7 & 45.0 \\
31 & lubber & 8 & 55.5 \\
58 & rusty & 10 & 35.0 \\
\end{array}
\]

Find names of sailors who've reserved boat #103

Sailors(sid, sname, rating, age)
Boats(bid, bname, color)
Reserves(sid, bid, day)
Expressing an RA expression as a Tree

Find sailors who’ve reserved a red or a green boat

What about aggregates?

Relational Calculus (RC)

Relational Calculus

TRC: example
A $\implies$ B

- A “implies” B
- Equivalently, if A is true, B must be true
- Equivalently, $\neg A \lor B$, i.e.
  - either A is false (then B can be anything)
  - otherwise (i.e. A is true) B must be true

Useful Logical Equivalences

- $\forall x P(x) = \neg \exists x \neg P(x)$
- $\neg (P \lor Q) = \neg P \land \neg Q$, de Morgan's laws
- $\neg (P \land Q) = \neg P \lor \neg Q$
- Similarly, $\neg (\neg P \lor Q) = P \land \neg Q$ etc.
- $A \implies B = \neg A \lor B$

TRC: example

Sailors(sid, sname, rating, age)
Boats(bid, bname, color)
Reserves(sid, bid, day)

- Find the names of sailors who have reserved at least two boats

TRC: example

Sailors(sid, sname, rating, age)
Boats(bid, bname, color)
Reserves(sid, bid, day)

- Find the names of sailors who have reserved at least two boats

{P | $\exists S \epsilon$ Sailors $\exists R1 \epsilon$ Reserves $\exists R2 \epsilon$ Reserves $\land S.sid = R1.sid \land S.sid = R2.sid \land R1.bid \neq R2.bid \land P.name = S.name$}

TRC: example

Sailors(sid, sname, rating, age)
Boats(bid, bname, color)
Reserves(sid, bid, day)

- Find the names of sailors who have reserved all boats
- Division operation

TRC: example

Sailors(sid, sname, rating, age)
Boats(bid, bname, color)
Reserves(sid, bid, day)

- Find the names of sailors who have reserved all boats
- Division operation in RA!
TRC: example

Sailors(sid, sname, rating, age)
Boats(bid, bname, color)
Reserves(sid, bid, day)

• Find the names of sailors who have reserved all red boats

How will you change the previous TRC expression?

Recall that $A \Rightarrow B$ is logically equivalent to $\sim A \lor B$
so $\Rightarrow$ can be avoided, but it is cleaner and more intuitive.

DRC: example

Sailors(sid, sname, rating, age)
Boats(bid, bname, color)
Reserves(sid, bid, day)

• Find the name and age of all sailors with a rating above 7

TRC:

$\{P | \exists S \in \text{Sailors} (S.\text{rating} > 7 \land P.\text{name} = S.\text{name} \land P.\text{age} = S.\text{age})\}$

DRC:

$\{<N, A> | \exists <I, N, T, A> \in \text{Sailors} \land T > 7\}$

• Variables are now domain variables
• We will use use TRC
  -- both are equivalent

More Examples: RC

• The famous “Drinker-Beer-Bar” example!

UNDERSTAND THE DIFFERENCE IN ANSWERS FOR ALL FOUR DRINKERS


Drinker Category 1

Find drinkers that frequent some bar that serves some beer they like.

$q(x) = \exists y. (z. \text{Frequents}(x, y) \land \text{Serves}(y, z) \land \text{Likes}(x, z))$
a shortcut for

$\exists y. (z. \text{Frequents} (x, y) \land \text{Serves} (y, z) \land \text{Likes} (x, z))$

The difference is that in the first one, one variable = one attribute
in the second one, one variable = one tuple (Tuple RC)
Both are equivalent and feel free to use the one that is convenient to you
Find drinkers that frequent some bar that serves some beer they like.

\[ Q(x) = \exists y. \exists z. \text{Frequents}(x, y) \land \text{Serves}(y, z) \land \text{Likes}(x, z) \]

Find drinkers that frequent only bars that serve some beer they like.

\[ Q(x) = \exists y. \exists z. \text{Frequents}(x, y) \land \text{Serves}(y, z) \land \text{Likes}(x, z) \]

Find drinkers that frequent some bar that serves only beers they like.

\[ Q(x) = \exists y. \exists z. \text{Frequents}(x, y) \land \text{Serves}(y, z) \land \text{Likes}(x, z) \]

Find drinkers that frequent only bars that serve only beer they like.

\[ Q(x) = \exists y. \exists z. \text{Frequents}(x, y) \land \text{Serves}(y, z) \land \text{Likes}(x, z) \]

Why should we care about RC

- RC is declarative, like SQL, and unlike RA (which is operational)
- Gives foundation of database queries in first-order logic
  - you cannot express all aggregates in RC, e.g. cardinality of a relation or sum (possible in extended RA and SQL)
  - still can express conditions like "at least two tuples" (or any constant)
- RC expression may be much simpler than SQL queries
  - and easier to check for correctness than SQL
  - power to use \( \land \) and \( \Rightarrow \)
  - then you can systematically go to a "correct" SQL query

From RC to SQL

Query: Find drinkers that like some beer (so much) that they frequent all bars that serve it

\[ Q(x) = \exists y. \text{Likes}(x, y) \land \forall z. (\text{Serves}(z, y) \Rightarrow \text{Frequents}(x, z)) \]

Step 1: Replace \( \forall \) with \( \exists \) using de Morgan's Laws

\[ Q(x) = \exists y. \text{Likes}(x, y) \land \forall z. \text{Serves}(z, y) \land \text{Frequents}(x, z) \]

Step 2: Translate into SQL

\[
\text{SELECT DISTINCT } L\text{.drinker}
\text{ FROM Likes L}
\text{ WHERE not exists (SELECT S.bar}
\text{ FROM Serves S}
\text{ WHERE L.beer=S.beer}
\text{ AND not exists (SELECT *}
\text{ FROM Frequents F}
\text{ WHERE F.drinker=L.drinker}
\text{ AND F.bar=S.bar))}
\]

The “correct” intermediate steps

- Write the query in RC
- If you have a variable under “negation”, also add the “domain”, i.e. where the variable appears without a negation
  - e.g. if you have \( H(x, y) \) for a subquery,
  - where \( x \) and \( y \) can only come from a relation \( R(x, y) \)
  - make it \( R(x, y) \land \neg H(x, y) \)
- This is to make the query "safe" and "domain independent" – we will discuss this when we do Datalog
- Intuitively, if you are trying to find “sailors that do not satisfy some criteria” you have to specify the domain of sailors, say from the sailor table, otherwise you are looking at an infinite space
The “correct” intermediate step

Make all subqueries with negation domain independent i.e. say where x is coming from

Q(x) = ∃y Likes(x, y) \land \neg \exists z. (Likes(x, z) \land Serves(z, y) \land \neg Frequents(x, z))

which can be simplified to the previous query

Summary

- You learnt three query languages for the Relational DB model
  - SQL
  - RA
  - RC

- All have their own purposes

- You should be able to write a query in all three languages and convert from one to another
  - However, you have to be careful, not all “valid” expressions in one may be expressed in another
  - (S | ¬ (S c Sailors)) – infinitely many tuples – an “unsafe” query
  - More when we do “Datalog”, also see Ch. 4.4 in [RG]

- Next topic: DBMS internals
  - storage/indexing, query execution, algorithms, optimization