CE246/IT257: Database Management System

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Formal Relational Query Languages

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Outline

- Relational Algebra
- Tuple Relational Calculus
- Domain Relational Calculus

Relational Algebra

- Procedural language
- Six basic operators
  - select: σ
  - project: $\prod$
  - union: $\cup$
  - set difference: –
  - Cartesian product: x
  - rename: ρ
- The operators take one or two relations as inputs and produce a new relation as a result.

Select Operation

- Notation: $\sigma_{p}(r)$
- *p* is called the **selection predicate**
- Defined as:

$$\sigma_p(\boldsymbol{r}) = \{t \mid t \in r \textbf{ and } p(t)\}$$

Where *p* is a formula in propositional calculus consisting of **terms** connected by : $\wedge$ (**and**), $\vee$ (**or**), $\neg$ (**not**)
Each **term** is one of:

<attribute> *op* <attribute> or <constant>

where *op* is one of: $=, \neq, >, \geq. <. \leq$

- Example of selection:

$$\sigma_{\,dept\_name=\text{“}Physics\text{”}}(instructor)$$

Project Operation

- Notation:

$$\Pi_{A_1, A_2, \ldots, A_k}(r)$$

  where A_1, A_2 are attribute names and r is a relation name.

- The result is defined as the relation of k columns obtained by erasing the columns that are not listed
- Duplicate rows removed from result, since relations are sets
- Example: To eliminate the *dept_name* attribute of *instructor*

$$\Pi_{ID,\ name,\ salary}\ (instructor)$$

Union Operation

- Notation: $r \cup s$
- Defined as:

  $r \cup s = \{t \mid t \in r \text{ or } t \in s\}$
- For $r \cup s$ to be valid.
  1. *r, s* must have the *same* **arity** (same number of attributes)
  2. The attribute domains must be **compatible** (example: 2nd column of *r* deals with the same type of values as does the 2nd column of *s*)
- Example: to find all courses taught in the Fall 2009 semester, or in the Spring 2010 semester, or in both

$$\Pi_{course\_id}(\sigma_{semester=\text{“Fall”}\ \land\ year=2009}(section))\ \cup$$

$$\Pi_{course\_id}(\sigma_{semester=\text{“Spring”}\ \land\ year=2010}(section))$$

Set Difference Operation

- Notation $r - s$
- Defined as:

  $r - s = \{t \mid t \in r \textbf{ and } t \notin s\}$

- Set differences must be taken between **compatible** relations.
  - r and s must have the same arity
  - attribute domains of r and s must be compatible
- Example: to find all courses taught in the Fall 2009 semester, but not in the Spring 2010 semester

$$\Pi_{course\_id}(\sigma_{semester=\text{“Fall”} \ \wedge \ year=2009}(section)) \ -$$
$$\Pi_{course\_id}(\sigma_{semester=\text{“Spring”} \ \wedge \ year=2010}(section))$$

Set-Intersection Operation

- Notation: $r \cap s$
- Defined as:
- $r \cap s = \{ t \mid t \in r$ **and** $t \in s \}$
- Assume:
  - *r*, *s* have the *same arity*
  - attributes of *r* and *s* are compatible
- Note: $r \cap s = r - (r - s)$

Cartesian-Product Operation

- Notation $r \times s$
- Defined as:

  $r \times s = \{t\, q \mid t \in r \textbf{ and } q \in s\}$

- Assume that attributes of r(R) and s(S) are disjoint. (That is, $R \cap S = \emptyset$).
- If attributes of *r(R)* and *s(S)* are not disjoint, then renaming must be used.

Rename Operation

- Allows us to name, and therefore to refer to, the results of relational-algebra expressions.
- Allows us to refer to a relation by more than one name.
- Example:

  $$\rho_{X}(E)$$

  returns the expression E under the name X
- If a relational-algebra expression E has arity n, then

  $$\rho_{x(A_1, A_2, \ldots, A_n)}(E)$$

  returns the result of expression E under the name X, and with the attributes renamed to $A_1, A_2, \ldots., A_n$.

Formal Definition

- A basic expression in the relational algebra consists of either one of the following:
  - A relation in the database
  - A constant relation
- Let E_1 and E_2 be relational-algebra expressions; the following are all relational-algebra expressions:
  - $E_1 \cup E_2$
  - $E_1 - E_2$
  - $E_1 \times E_2$
  - $\sigma_p (E_1)$, P is a predicate on attributes in E_1
  - $\prod_S(E_1)$, S is a list consisting of some of the attributes in E_1
  - $\rho_{x} (E_1)$, x is the new name for the result of E_1

Tuple Relational Calculus

Tuple Relational Calculus

- A nonprocedural query language, where each query is of the form
  $\{t \mid P(t)\}$
- It is the set of all tuples *t* such that predicate *P* is true for *t*
- *t* is a *tuple variable*, *t* [*A*] denotes the value of tuple *t* on attribute *A*
- $t \in r$ denotes that tuple *t* is in relation *r*
- *P* is a *formula* similar to that of the predicate calculus

Predicate Calculus Formula

1. Set of attributes and constants
2. Set of comparison operators: (e.g., $<$, $\leq$, $=$, $\neq$, $>$, $\geq$)
3. Set of connectives: and ($\wedge$), or (v), not ($\neg$)
4. Implication ($\Rightarrow$): x $\Rightarrow$ y, if x if true, then y is true

   $$x \Rightarrow y \equiv \neg x \vee y$$

5. Set of quantifiers:
   - $\exists\ t \in r\ (Q\ (t\ ))$ ≡ ”there exists” a tuple in *t* in relation *r* such that predicate *Q* (*t*) is true
   - $\forall t \in r\ (Q\ (t\ ))$ ≡ *Q* is true “for all” tuples *t* in relation *r*

Example Queries

- Find the *ID, name, dept_name, salary* for instructors whose salary is greater than $80,000

$$\{t \mid t \in instructor \land t\,[salary\,] > 80000\}$$

Notice that a relation on schema (*ID, name, dept_name, salary*) is implicitly defined by the query

- As in the previous query, but output only the *ID* attribute value

$$\{t \mid \exists\ s \in \text{instructor}\ (t\,[ID\,] = s\,[ID\,] \land s\,[salary\,] > 80000)\}$$

Notice that a relation on schema (*ID*) is implicitly defined by the query

Example Queries

- Find the names of all instructors whose department is in the Watson building

$$
\begin{aligned}
\{t \mid \exists s \in \mathit{instructor}\ (&t[\mathit{name}] = s[\mathit{name}] \\
&\land \exists u \in \mathit{department}\ (u[\mathit{dept\_name}] = s[\mathit{dept\_name}] \text{“} \\
&\qquad \land u[\mathit{building}] = \text{“Watson”}))\}
\end{aligned}
$$

- Find the set of all courses taught in the Fall 2009 semester, or in the Spring 2010 semester, or both

$$
\begin{aligned}
\{t \mid\ &\exists s \in \mathit{section}\ (t[\mathit{course\_id}] = s[\mathit{course\_id}] \land \\
&\qquad s[\mathit{semester}] = \text{“Fall”} \land s[\text{year}] = 2009 \\
&\lor \exists u \in \mathit{section}\ (t[\mathit{course\_id}] = u[\mathit{course\_id}] \land \\
&\qquad u[\mathit{semester}] = \text{“Spring”} \land u[\text{year}] = 2010)\}
\end{aligned}
$$

Example Queries

- Find the set of all courses taught in the Fall 2009 semester, and in the Spring 2010 semester

$$\begin{aligned}\{t \mid \exists s \in section\ (&t\,[course\_id] = s\,[course\_id] \land \\ &s\,[semester] = \text{"Fall"} \land s\,[\text{year}] = 2009 \\ \land\ \exists u \in section\ (&t\,[course\_id] = u\,[course\_id] \land \\ &u\,[semester] = \text{"Spring"} \land u\,[\text{year}] = 2010\ )\}\end{aligned}$$

- Find the set of all courses taught in the Fall 2009 semester, but not in the Spring 2010 semester

$$\begin{aligned}\{t \mid \exists s \in section\ (&t\,[course\_id] = s\,[course\_id] \land \\ &s\,[semester] = \text{"Fall"} \land s\,[\text{year}] = 2009 \\ \land\ \neg\ \exists u \in section\ (&t\,[course\_id] = u\,[course\_id] \land \\ &u\,[semester] = \text{"Spring"} \land u\,[\text{year}] = 2010\ )\}\end{aligned}$$

Universal Quantification

- Find all students who have taken all courses offered in the Biology department
  - $\{t \mid \exists\ r \in student\ (t\,[ID] = r\,[ID]) \land$
    $(\forall\ u \in course\ (u\,[dept\_name]=\text{“Biology”} \Rightarrow$
    $\exists\ s \in takes\ (t\,[ID] = s\,[ID\,] \land$
    $s\,[course\_id] = u\,[course\_id]))\}$

Safety of Expressions

- It is possible to write tuple calculus expressions that generate infinite relations.
- For example, $\{ t \mid \neg\, t \in r \}$ results in an infinite relation if the domain of any attribute of relation *r* is infinite
- To guard against the problem, we restrict the set of allowable expressions to safe expressions.
- An expression $\{t \mid P(t)\}$ in the tuple relational calculus is *safe* if every component of *t* appears in one of the relations, tuples, or constants that appear in *P*
  - NOTE: this is more than just a syntax condition.
    - E.g. $\{ t \mid t[A] = 5 \lor \textbf{true} \}$ is not safe --- it defines an infinite set with attribute values that do not appear in any relation or tuples or constants in *P*.

Safety of Expressions (Cont.)

- Consider again that query to find all students who have taken all courses offered in the Biology department
  - $$\{t \mid \exists\ r \in student\ (t[ID] = r[ID]) \land \\ (\forall\ u \in course\ (u[dept\_name] = \text{“Biology”} \Rightarrow \\ \exists\ s \in takes\ (t[ID] = s[ID] \land \\ s[course\_id] = u[course\_id]))\}$$
- Without the existential quantification on student, the above query would be unsafe if the Biology department has not offered any courses.

Domain Relational Calculus

Domain Relational Calculus

- A nonprocedural query language equivalent in power to the tuple relational calculus
- Each query is an expression of the form:

$$\{ < x_1, x_2, \ldots, x_n > \mid P(x_1, x_2, \ldots, x_n) \}$$

  - $x_1, x_2, \ldots, x_n$ represent domain variables
  - P represents a formula similar to that of the predicate calculus

Example Queries

- Find the *ID, name, dept_name, salary* for instructors whose salary is greater than $80,000
  - $\{< i, n, d, s> \mid < i, n, d, s> \in instructor \land s > 80000\}$
- As in the previous query, but output only the *ID* attribute value
  - $\{< i> \mid < i, n, d, s> \in instructor \land s > 80000\}$
- Find the names of all instructors whose department is in the Watson building

$$\{< n > \mid \exists\ i, d, s\ (< i, n, d, s > \in instructor \land \exists\ \text{b, a}\ (< d, b, a> \in department \land b = \text{“Watson”}\ ))\}$$

Example Queries

- Find the set of all courses taught in the Fall 2009 semester, or in the Spring 2010 semester, or both

$$\{<c> \mid \exists\, a, s, y, b, r, t \ (<c, a, s, y, b, r, t> \in section \ \land \\ s = \text{“Fall”} \land y = 2009\ ) \\ \lor\ \exists\, a, s, y, b, r, t\ (<c, a, s, y, b, r, t> \in section\ ] \land \\ s = \text{“Spring”} \land y = 2010)\}$$

This case can also be written as

$$\{<c> \mid \exists\, a, s, y, b, r, t \ (<c, a, s, y, b, r, t> \in section \ \land \\ (\ (s = \text{“Fall”} \land y = 2009\ )\ \lor (s = \text{“Spring”} \land y = 2010))\}$$

- Find the set of all courses taught in the Fall 2009 semester, and in the Spring 2010 semester

$$\{<c> \mid \exists\, a, s, y, b, r, t \ (<c, a, s, y, b, r, t> \in section \ \land \\ s = \text{“Fall”} \land y = 2009\ ) \\ \land\ \exists\, a, s, y, b, r, t\ (<c, a, s, y, b, r, t> \in section\ ] \land \\ s = \text{“Spring”} \land y = 2010)\}$$

Safety of Expressions

The expression:

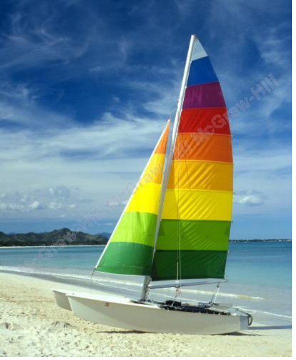
$$\{ < x_1, x_2, \ldots, x_n > \mid P\,(x_1, x_2, \ldots, x_n)\}$$

is safe if all of the following hold:

1. All values that appear in tuples of the expression are values from *dom* (*P*) (that is, the values appear either in *P* or in a tuple of a relation mentioned in *P*).
2. For every "there exists" subformula of the form $\exists\ x\ (P_1(x))$, the subformula is true if and only if there is a value of x in *dom* (P_1) such that $P_1(x)$ is true.
3. For every "for all" subformula of the form $\forall_x\ (P_1\ (x))$, the subformula is true if and only if $P_1(x)$ is true for all values x from *dom* (P_1).

Universal Quantification

- Find all students who have taken all courses offered in the Biology department
  - $\{< i > \mid \exists\ n, d, tc\ (< i, n, d, tc > \in \mathit{student}\ \wedge$
    $(\forall\ ci, ti, dn, cr\ (< ci, ti, dn, cr > \in \mathit{course}\ \wedge\ dn =\text{“Biology”}$
    $\Rightarrow\ \exists\ si, se, y, g\ (<i, ci, si, se, y, g> \in \mathit{takes}\ )))\}$
  - Note that without the existential quantification on student, the above query would be unsafe if the Biology department has not offered any courses.



End of Chapter 6

Database System Concepts, 6th Ed.