Extended Operators in SQL and Relational Algebra

T. M. Murali

September 15, 2010
Bags or Sets?

- So far, we have said that relational algebra and SQL operate on relations that are *sets* of tuples.
- Real RDBMSs treat relations as *bags* of tuples.
  - A tuple *can* appear multiple times in a relation.
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Bags or Sets?

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- Real RDBMSs treat relations as \textit{bags} of tuples.
  - A tuple \textit{can} appear multiple times in a relation.
  - Performance is one of the main reasons; duplicate elimination is expensive since it requires sorting.
- If we use bag semantics, we may have to redefine the meaning of each relation algebra operator.
Bag Semantics: Projection and Selection

- Projection ($\pi()$): process each tuple independently; a tuple may appear in the resulting relation multiple times.
- Selection ($\sigma()$): process each tuple independently; a tuple may appear in the resulting relation multiple times.
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Bag Semantics: Union, Intersection, and Difference

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$R$ and $S$:

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- $R - S$: if tuple $t$ appears $k$ times in $R$ and $l$ times in $S$, $t$ appears in $R - S$ $\max\{0, k - l\}$ times.
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Bag Semantics: Products and Joins

- Product ($\times$): If a tuple $r$ appears $k$ times in a relation $R$ and tuple $s$ appears $l$ times in a relation $S$, then the tuple $rs$ appears $kl$ times in $R \times S$.

- Theta-join and Natural join ($\Join$): Since both can be expressed as applying a selection followed by a projection to a product, use the semantics of selection, projection, and the product.
Extended Operators

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- Extended projections: projection on steroids.
- Outerjoin: extension of joins that make sure every tuple is in the output.
Sorting

\[ \text{RA} \quad \tau_{A_1,A_2,...}(R). \]

\[ \text{SQL} \quad \text{SELECT} \ldots \text{FROM} \ldots \text{WHERE} \ldots \text{ORDER BY} \ A_1,A_2,\ldots. \]
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\[ \text{SQL } \text{SELECT } \ldots \text{ FROM } \ldots \text{WHERE } \ldots \text{ ORDER BY } A_1,A_2, \ldots. \]

- The result is a list of tuples in \( R \) but with the tuples sorted by their values in attributes \( A_1, A_2, \ldots \).
- In SQL, use `DESC` after an attribute to specify sorting in descending order; `ASC` is the default.
- If you use the result in another query, sorted order is lost.
Duplicate Elimination

**RA** \( \delta(R) \) is the relation containing exactly one copy of each tuple in \( R \).

**SQL** `SELECT DISTINCT ...`
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- Duplicate elimination is \textit{expensive}, since tuples must be sorted or partitioned.
- Set operations in SQL (UNION, INTERSECT, and EXCEPT) operate on \textit{sets} of tuples, i.e., they first eliminate duplicates.
- To make these operators treat relations as bags, follow the operation with the keyword ALL.
Aggregation

- Operators that summarise or aggregate the values in a single attribute of a relation.
- Operators are the same in relational algebra and SQL.
- All operators treat a relation as a bag of tuples.
- **SUM**: computes the sum of a column with numerical values.
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- **MIN and MAX**:
  - for a column with numerical values, computes the smallest or largest value, respectively.
  - for a column with string or character values, computes the lexicographically smallest or largest values, respectively.
- **COUNT**: computes the number of non-NULL tuples in a column.
  - In SQL, can use `COUNT(*)` to count the number of tuples in a relation.
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Use the grouping operator.
Example of Grouping in Relational Algebra

How do we answer the query “Count the number of classes and total enrollment of the classes each department teaches”?

1. Group Courses by DeptName.
2. For each group, create a new attribute that stores the number of classes taught by the department.
3. For each group, create a new attribute that stores the total enrollment of the classes taught by the department.

\[ \gamma L(\text{Courses}), \] where \( L \) is a list containing three elements:

1. DeptName: the grouping attribute,
2. \( \text{COUNT(Number)} \rightarrow \text{NumCourses} \): an aggregated attribute computing the count of the Number attribute in each group and naming the new attribute NumCourses,
3. \( \text{SUM(Enrollment)} \rightarrow \text{TotalEnrollment} \): an aggregated attribute computing the total of the Enrollment attribute and naming the new attribute TotalEnrollment.
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3. SUM(Enrollment) → TotalEnrollment: an aggregated attribute computing the total of the Enrollment attribute and naming the new attribute TotalEnrollment.
Example of Grouping Continued

How do we answer the query “Count the number of classes and total enrollment of the classes each department teaches”?

The complete operator is $\gamma_{\text{DeptName}}\text{, }\text{COUNT}(\text{Number})\rightarrow \text{NumCourses}, \text{SUM}(\text{Enrollment})\rightarrow \text{TotalEnrollment}(\text{Courses})$.

The schema of the new relation is $(\text{DeptName}, \text{NumCourses}, \text{TotalEnrollment})$.

We can group by multiple attributes.

We can create as many new attributes as necessary.

We can apply other operators to the result, since the grouping operator produces a relation.
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Grouping in SQL

- Syntax is much simpler than relational algebra.
- Use the GROUP BY clause after the WHERE clause or after the FROM, if there is no WHERE clause.
- List grouping attributes after GROUP BY.
- Use SELECT clause to aggregate attributes.
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Grouping in SQL

```sql
SELECT DeptName, COUNT(Number) AS NumCourses,
       SUM(Enrollment) AS TotalEnrollment
FROM COURSES
GROUP BY DeptName;
```

- Aggregated attributes are evaluated on a per-group basis.
- Only attributes mentioned in the GROUP BY clause may appear unaggregated in the SELECT clause, e.g., Number must have an aggregation operator applied to it.
- There need not be any aggregated attribute in the SELECT clause.
- Read Chapter 6.4.6 of the textbook about affect of NULL values on grouping and aggregation.
Restricting Grouping in SQL

How do we answer the query “Count the number of classes each department teaches, restricted to departments that have total enrollment at least 500 in their classes (the classes taught by that department)”?

```sql
SELECT DeptName, COUNT(Number) AS NumCourses
FROM COURSES
GROUP BY DeptName
HAVING SUM(Enrollment) >= 500;
```
Restricting Grouping in SQL

- How do we answer the query “Count the number of classes each department teaches, restricted to departments that have total enrollment at least 500 in their classes (the classes taught by that department)”?
- Need to introduce the HAVING clause

```
SELECT DeptName, COUNT(Number) AS NumCourses
FROM COURSES
GROUP BY DeptName
HAVING SUM(Enrollment) >= 500;
```
Rules for HAVING Clauses

- An aggregation in a HAVING clause applies only to the group being tested.
- If an attribute appears unaggregated in a HAVING clause, it must appear in the GROUP BY line.
Complete SELECT Statement

```
SELECT Attribute list
FROM Relation list
WHERE Condition or Subquery
GROUP BY Attribute list
HAVING Condition or Subquery
ORDER BY Attribute list;
```
Complete SELECT Statement

SELECT Attribute list
FROM Relation list
WHERE Condition or Subquery
GROUP BY Attribute list
HAVING Condition or Subquery
ORDER BY Attribute list;

- WHERE is evaluated *before* GROUP BY and HAVING.
Joins in Relational Algebra and SQL

- Cross product:
  \[ R \times S \]
  SQL: \( R \text{ CROSS JOIN } S \);

- Theta join:
  RA: \( R \bowtie_C S \)
  SQL: \( R \text{ JOIN } S \text{ ON } C \);

- Natural join:
  RA: \( R \bowtie S \)
  SQL: \( R \text{ NATURAL JOIN } S \);
Outer Joins

- A *dangling tuple* is one that fails to pair with any tuple in the other relation in a join operation.
- Outer joins allow dangling tuples to be included in the result of join operations, by padding them with NULL values.
Outer Joins

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- Outer joins allow dangling tuples to be included in the result of join operations, by padding them with NULL values.

\[
\text{RA} \quad R \bowtie S
\]

\[
\text{SQL} \quad R \text{ NATURAL FULL OUTER JOIN } S;
\]
- Contains all tuples in \( R \bowtie S \).
- Also includes every tuple in \( R \) that is not joined with a tuple in \( S \), after padding a special null symbol \( \perp \) (NULL in case of SQL).
- Same condition applied to \( S \).
Outer Joins

- A *dangling tuple* is one that fails to pair with any tuple in the other relation in a join operation.
- Outer joins allow dangling tuples to be included in the result of join operations, by padding them with NULL values.

\[ RA \quad R \bowtie S \]

**SQL**  
\[ R \text{ NATURAL FULL OUTER JOIN } S; \]

- Contains all tuples in \( R \bowtie S \).
- Also includes every tuple in \( R \) that is not joined with a tuple in \( S \), after padding a special null symbol \( \bot \) (NULL in case of SQL).
- Same condition applied to \( S \).

- Left outer join:

\[ RA \quad R \bowtie_L S \]

**SQL**  
\[ R \text{ NATURAL LEFT OUTER JOIN } S; \]

- Like \( R \bowtie S \) but ignores dangling tuples in \( S \).
Outer Joins

- A dangling tuple is one that fails to pair with any tuple in the other relation in a join operation.
- Outer joins allow dangling tuples to be included in the result of join operations, by padding them with NULL values.

\[
\text{RA}\quad R \bowtie S \\
\text{SQL}\quad R \text{ NATURAL FULL OUTER JOIN } S; \\
\]
  - Contains all tuples in \( R \bowtie S \).
  - Also includes every tuple in \( R \) that is not joined with a tuple in \( S \), after padding a special null symbol \( \perp \) (NULL in case of SQL).
  - Same condition applied to \( S \).

- Left outer join:

\[
\text{RA}\quad R \bowtie_L S \\
\text{SQL}\quad R \text{ NATURAL LEFT OUTER JOIN } S; \\
\]
  - Like \( R \bowtie S \) but ignores dangling tuples in \( S \).

- Right outer join is analogous to left outer join.
- All outerjoin operators have theta-join analogues.