Query Processing

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CS 640
Principles of Database Management and Use
Winter 2013

Some of these slides are based on
a slide set provided by Ulf Leser.

Notes

Outline

Notes

Query Processing Steps

Parsing
↓
Query Validation
↓
View Resolution
↓
Optimization
↓
Plan Compilation
↓
Execution

As given in:
Goetz Graefe: Query Evaluation Techniques for Large Databases. *ACM Comp. Surveys 25*(2): 73–170 (1993).

Notes

Query Processing Steps (Parsing)

Parsing
↓
Query Validation
↓
View Resolution
↓
Optimization
↓
Plan Compilation
↓
Execution

- Input: SQL query
- Output: internal representation (e.g. based on relational algebra)

As given in:
Goetz Graefe: Query Evaluation Techniques for Large Databases. *ACM Comp. Surveys 25*(2): 73–170 (1993).

Notes

Query Processing Steps (Query Validation)

Parsing
↓
Query Validation
↓
View Resolution
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Optimization
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Plan Compilation
↓
Execution

Check whether:

- mentioned tables, attributes, etc. exist,
- comparisons are feasible (e.g. comparability of attribute types),
- aggregation queries have a valid SELECT clause,
- etc.

As given in:
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Notes

Query Processing Steps (View Resolution)

Parsing
↓
Query Validation
↓
View Resolution
↓
Optimization
↓
Plan Compilation
↓
Execution

- Substitute references to views by the view definitions
- (More on views in a later lecture)

As given in:
Goetz Graefe: Query Evaluation Techniques for Large Databases. *ACM Comp. Surveys 25*(2): 73–170 (1993).

Notes

Query Processing Steps (Optimization)

Parsing
↓
Query Validation
↓
View Resolution
↓
Optimization
↓
Plan Compilation
↓
Execution

- Considers possible *query execution plans* (QEPs)
  - Different QEPs have different costs (that is, resources needed for their execution)
- Output: an *efficient* QEP
  (i.e. *estimated* cost is the lowest or comparatively low)
- This task is all but trivial...

As given in:
Goetz Graefe: Query Evaluation Techniques for Large Databases. *ACM Comp. Surveys 25*(2): 73–170 (1993).

Notes

Query Processing Steps (Optimization, cont'd)

Parsing
↓
Query Validation
↓
View Resolution
↓
Optimization
↓
Plan Compilation
↓
Execution

- The set of all possible QEPs is huge.
  - Optimizers enumerate only a restricted subset (*search space*)
- A desirable optimizer:
  - cost estimation is accurate
  - search space includes low cost QEPs
  - enumeration algorithm is efficient
- (Query optimization will be the main topic of our discussion next week.)

As given in:
Goetz Graefe: Query Evaluation Techniques for Large Databases. *ACM Comp. Surveys 25*(2): 73–170 (1993).

Notes

Query Processing Steps (Plan Compilation)

Parsing
↓
Query Validation
↓
View Resolution
↓
Optimization
↓
Plan Compilation
↓
Execution

- Translate the selected QEP into a representation ready for execution (e.g. compiled machine code, interpreted language)

As given in:
Goetz Graefe: Query Evaluation Techniques for Large Databases. *ACM Comp. Surveys 25*(2): 73–170 (1993).

Notes

Query Processing Steps (Execution)

Parsing
↓
Query Validation
↓
View Resolution
↓
Optimization
↓
Plan Compilation
↓
Execution

- Execute the compiled plan
- Return the query result via the respective interface

As given in:
Goetz Graefe: Query Evaluation Techniques for Large Databases. *ACM Comp. Surveys 25*(2): 73–170 (1993).

Notes

Query Representations

While it is processed by a DBMS, a query goes through multiple representations.

Usually, these are:

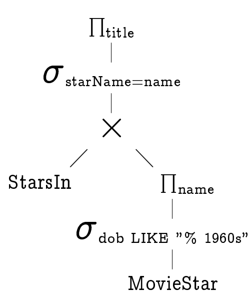
1. an expression in the query language (e.g. SQL query)
2. parse tree
3. logical plan
4. physical plan
5. compiled program

Notes

Logical Plans

- represented as an expression in a logical algebra (such as the relational algebra)
- closely related to the logical data model
- can be visualized as a tree of logical operators

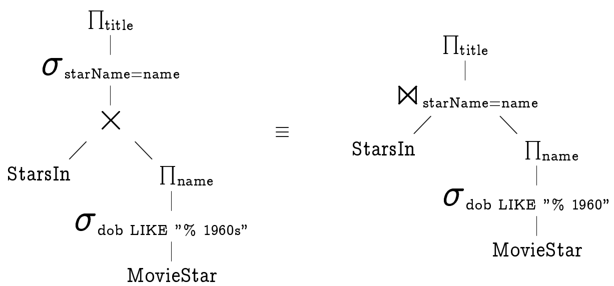
```
SELECT title
FROM StarsIn
WHERE starName IN (
      SELECT name
      FROM MovieStar
      WHERE dob LIKE "% 1960" )
```



Notes

Logical Plans (cont'd)

Remember, algebra expressions may be rewritten into *semantically equivalent* expressions.



Notes

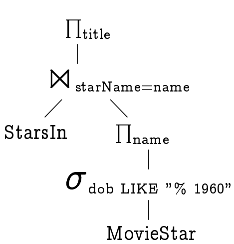
Physical Plans

- Also often called *query execution plan* (QEP)
- Represented as an expression in a *physical* algebra

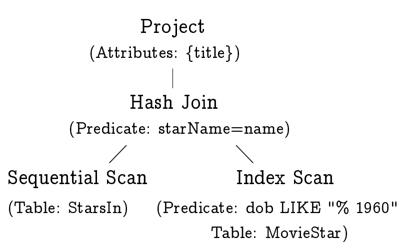
- Physical operators come with a specific algorithm.
  - e.g. a nested loop join

Notes

Physical Plans (Example)



A possible physical plan for the given logical plan:



Notes

Logical Operators vs. Physical Operators

- Logical operators and physical operators do not necessarily map directly into one another.
  - e.g. most join algorithms can project out attributes (without duplicate elimination)
  - e.g. a (physical) duplicate removal operator implements only a part of the (logical) projection operator
  - e.g. a (physical) sort operator has no counterpart in a (set based) logical algebra
- Physical operators can be associated with a cost function (to compute the amount of resources needed for their execution).

Notes

Examples for Physical Operators

- Table scan
- Sorting
- Duplicate elimination
- Selection
- Projection

Notes

Table Scan

- The leaves of each physical operator tree are (physical) tables.
- Accessing them completely implies a *sequential scan*.
  - Load each page of the table.
  - Sequentially scanning a table that occupies n pages has n I/O cost.

Combining the scan with the next operation in the plan is often better.

Example: `SELECT A, B FROM t WHERE A = 5`

Selection: If index on `A` available, perform an index scan instead (i.e. obtain relevant tuples by accessing the index)
- Especially effective if `A` is a key

Projection: Integrate into the table scan (i.e. read all tuples but only pass on attributes that are needed)
- Can also be combined with an index scan.

Notes

Sorting

- Many physical operators require input to be sorted.
- However, the (unsorted) input may not fit into main memory.
- We need an *external sorting* algorithm.
  - Intermediate results are temporarily stored on secondary memory.

Notes

(Simple) External Merge Sort

- First, sort each page internally.
- Group these sorted pages into pairs and for each pair merge its two pages.
- Each of these groups is then merged with another group, resulting in groups of four pages.
- And so on.
- The final group is the completely sorted file.

- This strategy makes use of 3 page buffers in main memory.
- If more buffers are available, we should exploit them ...

Notes

External Merge Sort

- Suppose:
  - $m+1$ page buffers are available in main memory;
  - the input occupies p pages.
- Stage 1:
  - Group the pages into $\frac{p}{m}$ groups.
  - Sort each group (using an m-way merge after sorting each of its pages internally).
- Each additional stage n ($n > 1$):
  - Group the sorted groups from stage n-1 into larger groups such that each larger group consists of m of the previous groups (and m^n pages).
  - For each of these new groups perform an m-way merge.
  - If $m^{n+1} \geq p$ we are done.
- Maximum number of stages: $\lceil \log_m(p) \rceil$
- Maximum number of pages read and written: $2 \times p \times \lceil \log_m(p) \rceil$

Notes

Duplicate Elimination (Option 1)

Two steps:

1. Sort input table (or intermediate result) on DISTINCT column(s)
   - Can be skipped if input is sorted already.
2. Scan sorted table and output unique tuples.

- Generated output is sorted
- Cannot be pipelined

Notes

Duplicate Elimination (Option 2)

- Idea: Scan the input and gradually populate an internal data structure that holds each unique input tuple once.
- For each input tuple check whether it has already been seen
  - No: insert tuple into the data structure and output the tuple
  - Yes: skip to the next input tuple
- Possible data structures:
  - Hash table – might be faster, needs good hash function
  - Binary tree – some cost for balancing, robust
- Does not sort output (but existing sorting would remain)
- Can be pipelined

Notes

Nested Loop Join

(We focus on equi joins and natural joins.)

- General idea:

```
FOR EACH tuple r in relation R DO
    FOR EACH tuple s in relation S DO
        IF r.A = s.A THEN output tuple r ∪ s.
```

- Of course, we do this for relations that are distributed over multiple pages:

```
FOR EACH page p of R DO
    FOR EACH page q of S DO
        FOR EACH tuple r on page p DO
            FOR EACH tuple s on page q DO
                IF r.A = s.A THEN output tuple r ∪ s.
```

- I/O cost: $\text{pages}(R) + \text{pages}(R) \times \text{pages}(S)$

Notes

Nested Loop Join (Possible Improvements)

- Block nested loop join
- Zig-zag join
- Index nested loop join

Notes

Sort-Merge Join

- Sort phase:
  - Sort *both* inputs on the join attributes
  - May need to use an external sorting algorithm
  - Sorting may be skipped for inputs that are already sorted
- Merge phase:
  - Synchronously iterate over both (sorted) inputs
  - Merge and output tuples that can be joined
  - Caution if join values may appear multiple times

Notes

Sort-Merge Join (Example)

R

A	**B**
a2	1
a4	0
a3	2
a4	1

⟶ sort(B)

A	**B**
a4	0
a2	1
a4	1
a3	2

⇐ ⇒

B	**C**
0	c2
2	c3
2	c1
3	c4

⟵ sort(B)

S

B	**C**
3	c4
2	c1
0	c2
2	c3

R $\bowtie$ **S**

A	**B**	**C**
a4	0	c2
a3	2	c3
a3	2	c1

Notes

Sort-Merge Join (Cost Estimation)

- I/O costs for sort phase are approximately:

$$\underbrace{2 \times \text{pages}(R) \times \left\lceil \log(\text{pages}(R)) \right\rceil}_{\text{sorting } R} + \underbrace{2 \times \text{pages}(S) \times \left\lceil \log(\text{pages}(S)) \right\rceil}_{\text{sorting } S}$$

- I/O costs for merge phase are:

$$\text{pages}(R) + \text{pages}(S)$$

Notes

Hash Join

- Idea: use join attributes as hash keys in both input relations
- Choose hash function for building hash tables with m buckets (where m is the number of page buffers available in main memory)
- **Partitioning phase:**
  - Scan relation R and populate its hash table.
  - Whenever the page buffer for a hash bucket is full, write it to disc and start a new page for that buffer.
  - Finally, write the remaining page buffers to disc.
  - Do the same for relation S (using the same hash function!).
  - Result: hash-partitioned versions of both relations on disc
  - Now, we only need to compare tuples in corresponding partitions.
- **Probing phase:**
  - Read in a complete partition from R (assuming $|R| < |S|$).
  - Scan over the corresponding partition of S and produce join tuples.
- I/O costs: $\underbrace{2\Big(\text{pages}(R) + \text{pages}(S)\Big)}_{\text{partitioning}} + \underbrace{\Big(\text{pages}(R) + \text{pages}(S)\Big)}_{\text{probing}}$

Notes

Summary

- For each query different physical operators can be combined into different, semantically equivalent QEPs (query execution plans).
- Each physical operator comes with an algorithm.
- Commonly used techniques for many of these algorithms:
  - Combining: Multiple tasks may be combined once some input data has been read in.
  - Partitioning: Either by sorting or by hashing, we can partition the input(s) and do less work by ignoring many irrelevant combinations.
  - Indexing: Existing indexes may be exploited for reducing work to relevant parts of the input.
- Each of these algorithms has a certain cost.
- Thus, different QEPs have different costs.
- The actual cost can only be estimated (as long as we do not execute the QEP).

Notes