Database Tuning and Physical Design: Query Optimization, Index Selection, and Schema, Query, and Transaction Tuning

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School of Computer Science
University of Waterloo

Databases CS348

Database Tuning

Goal
Make a set of applications execute “as fast as possible”.

- optimize for response time?
- optimize for overall throughput?

How can we affect performance (as DBAs)?
- make queries run faster (data structures, clustering, replication)
- make updates run faster (locality of data items)
- minimize congestion due to concurrency

How to Speed up Queries?
- generate all physical plans equivalent to the query
- pick the one with the lowest cost

Relational Calculus

<table>
<thead>
<tr>
<th>Generate Equivalent Plans</th>
<th>Determine Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Relational Algebra</td>
<td>Cost Info</td>
</tr>
</tbody>
</table>

How does it Search for Plans?

Query equivalence is undecidable!!

- always good transformations, e.g.,
  \[ \sigma_{A=p}(R \bowtie S) \rightarrow (\sigma_{A=p}(R)) \bowtie S \]
- rewrites using integrity constraints
- cost-based access path selection and join ordering

...the query optimizer may not find the right plan (query tuning)
Cost Models for Query Optimization

How do we figure out how fast a particular plan is??

For every stored relation \( R \) with an attribute \( A \) we keep:
- \( |R| \): the cardinality of \( R \) (the number of tuples in \( R \))
- \( b(R) \): the blocking factor for \( R \)
- \( \min(R, A) \): the minimum value for \( A \) in \( R \)
- \( \max(R, A) \): the maximum value for \( A \) in \( R \)
- \( \text{distinct}(R, A) \): the number of distinct values of \( A \)

\( \Rightarrow \) in practice much more complex statistics are kept

Based on these values we try to estimate the cost of query plans
\( \Rightarrow \) costs estimated in number of disk I/O operations

Example: Cost of Retrieval

**Schema:**
Mark(Studnum, Course, Assignnum, Mark)

**Query:**
SELECT Studnum, Mark
FROM Mark
WHERE Course = 'PHYS'
AND Studnum = 100 AND Mark > 90

**Indices:**
- clustering index CourseInd on Course
- non-clustering index StudnumInd on Studnum

**Stats:**
- \( |\text{Mark}| = 10000 \)
- \( b(\text{Mark}) = 50 \)
- 500 different students
- 100 different courses
- 100 different marks

Strategy 1: Use CourseInd

Assuming uniform distribution of tuples over the courses, there will be about \( |\text{Mark}| / 100 = 100 \) tuples with \( \text{Course} = \text{PHYS} \).

Searching the CourseInd index has a cost of 2. Retrieval of the 100 matching tuples adds a cost of \( 100 / b(\text{Mark}) \) data blocks.

The total cost of 4.

Selection of \( N \) tuples from relation \( R \) using a clustered index has a cost of \( 2 + N / b(R) \).

Strategy 2: Use StudnumInd

Assuming uniform distribution of tuples over student numbers, there will be about \( |\text{Mark}| / 500 = 20 \) tuples for each student.

Searching the StudnumInd has a cost of 2. Since this is not a clustered index, we will make the pessimistic assumption that each matching record is on a separate data block, i.e., 20 blocks will need to be read.

The total cost is 22.

Selection of \( N \) tuples from relation \( R \) using a non-clustered index has a cost of \( 2 + N \).
Strategy 3: Scan the Relation

The relation occupies $10,000/50 = 200$ blocks, so 200 block I/O operations will be required.

Selection of $N$ tuples from relation $R$ by scanning the entire relation has a cost of $|R|/b(R)$.

in practice: more complex designs available (= more choices)  
... and the estimation is extended to all relational operators

Query Plan Tools (EXPLAIN)

How do we know what plan is used (and what the estimated cost is)?

⇒ db2expln and dynexpln tools

select name from author, wrote where aid=author

<table>
<thead>
<tr>
<th>(without index)</th>
<th>(index on wrote(author))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated Cost</td>
<td>50</td>
</tr>
<tr>
<td>Estimated Cardinality</td>
<td>120</td>
</tr>
<tr>
<td>Optimizer Plan:</td>
<td>RETURN</td>
</tr>
<tr>
<td></td>
<td>MSJOIN</td>
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<td></td>
<td>TBSCAN TBSCAN</td>
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<td></td>
<td>SORT SORT</td>
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<tr>
<td></td>
<td>TBSCAN TBSCAN</td>
</tr>
<tr>
<td>Table:</td>
<td>Table:</td>
</tr>
<tr>
<td>AUTHOR WROTE</td>
<td>AUTHOR</td>
</tr>
</tbody>
</table>

Estimated Cost 25  
Estimated Cardinality 120

Optimizer Plan:

RETURN

MSJOIN

TBSCAN IXSCAN

SORT Index: Table: AW WROTE

Table: AUTHOR

Index Selection and Tools

Idea

Convert physical design into another optimization problem

- generate the space of all possible physical designs
- pick the best one based on a given WORKLOAD

Workload

An abstraction of applications executed against a database:

- list of queries
- list of updates
- frequencies/probabilities of the above
- sequencing constraints
- ...

More complex Designs

Multi-attribute Indices

complex search/join conditions (in lexicographical order!)
index-only plans (several clustered indices)

Join Indices

allow replacing joins by index lookups

Materialized Views

allow replacing subqueries by index lookups

Problem 1

how does the query optimizer know if/where to use such indices/views?

Problem 2

balance between cost of rematerialization and savings for queries.
Index Selection and Tools Example

```
rees$ db2advis -d cs338 -s "select name from author,wrote where aid=author"
```

Calculating initial cost (without recommended indexes) [25.390385] timerons
Initial set of proposed indexes is ready.
Found maximum set of [2] recommended indexes
Cost of workload with all indexes included [0.364030] timerons
  total disk space needed for initial set [ 0.014] MB
  total disk space constrained to [ -1.000] MB
2 indexes in current solution
  [25.3904] timerons (without indexes)
  [ 0.3640] timerons (with current solution)
(%98.57) improvement

Trying variations of the solution set.
```
-- execution finished at timestamp 2006-11-23-12.25.24.205770
--
-- LIST OF RECOMMENDED INDEXES
--
-- index[1], 0.009MB
CREATE INDEX WIZ8 ON "DAVID "."AUTHOR" ("AID" ASC, "NAME" ASC) ;
-- index[2], 0.005MB
CREATE INDEX AW ON "DAVID "."WROTE" ("AUTHOR" ASC) ;
--
Index Advisor tool is finished.
```

⇒ can be fed a workload instead of a single query

Summary

Physical design has enormous impact on performance

- decisions based on understanding what the DBMS is doing
  ⇒ query execution, transaction processing, and query optimization
- modern systems provide tools for DBAs (EXPLAIN)
- VERY active area of research

Schema Tuning and Normal Forms

So far we only added data structures to improve performance. what to do if this isn’t enough?

Changes to the conceptual design

Goals:
- avoid expensive operations in query execution (joins)
- retrieve related data in fewer operations

Techniques:
- alternative normalization/weaker normal form
- co-clustering of relations (if available)/denormalization
- vertical/horizontal partitioning of data (and views)
- avoiding concurrency hot-spots