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

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Database Tuning

Goal

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

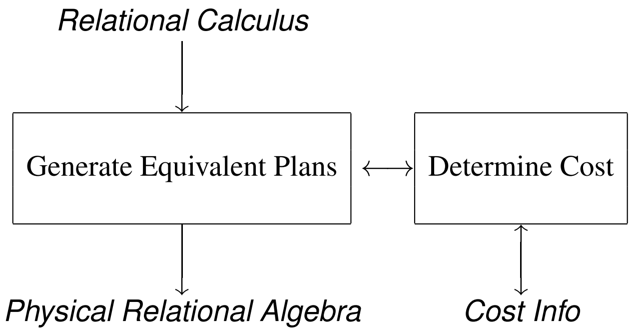
- optimize for response time?
- optimize for overall throughput?

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

Generate Equivalent Plans ⟷ Determine Cost

Physical Relational Algebra

Cost Info

Goal

Make the query compiler/optimizer pick a *GOOD* plan

How does it Search for Plans?

Query equivalence is undecidable!!

- always *good* transformations, e.g.,

$$\sigma_{A=:p}(R \bowtie S) \mapsto (\sigma_{A=:p}(R)) \bowtie S$$

- 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
- *distinct* (R, A): the number of distinct values of A

⇒ in practice much more complex *statistics* are kept

Based on these values we try to estimate the **cost** of query plans
⇒ 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:

- $|\mathrm{Mark}| = 10000$
- $b(\mathrm{Mark}) = 50$
- 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 $|\mathrm{Mark}|/100$ = 100 tuples with `Course = PHYS`.

Searching the CourseInd index has a cost of 2. Retrieval of the 100 matching tuples adds a cost of $100/b(\mathrm{Mark})$ 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 $|\mathrm{Mark}|/500$ = 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 $|R|/b(R)$.

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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
```

(without index)

```
Estimated Cost        = 50
Estimated Cardinality = 120

Optimizer Plan:

     RETURN
       |
     MSJOIN
    /      \
 TBSCAN  TBSCAN
   |       |
  SORT    SORT
   |       |
 TBSCAN  TBSCAN
   |       |
 Table:  Table:
 AUTHOR  WROTE
```

(index on `wrote(author)`)

```
Estimated Cost        = 25
Estimated Cardinality = 120

Optimizer Plan:

       RETURN
         |
       MSJOIN
      /      \
 TBSCAN      IXSCAN
   |        /      \
  SORT   Index:  Table:
   |     AW      WROTE
 TBSCAN
   |
 Table:
 AUTHOR
```

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

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
- …

Index Selection and Tools Example

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

Calculating initial cost (without recommmended indexes) [25.390385]
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

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

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