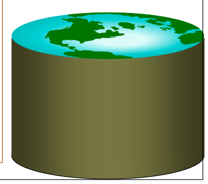
Physical Database Design and Tuning

R&G - Chapter 20

Although the whole of this life were said to be nothing but a dream and the physical world nothing but a phantasm, I should call this dream or phantasm real enough, if, using reason well, we were never deceived by it.

Baron Gottfried Wilhelm von Leibniz



Introduction

- **We will be talking at length about "database design"**
  - Conceptual Schema: info to capture, tables, columns, views, etc.
  - Physical Schema: indexes, clustering, etc.
- **Physical design linked tightly to query optimization**
  - So we'll study this "bottom up"
  - But note: DB design is usually "top-down"
    - conceptual *then* physical. Then iterate.
- **We must begin by understanding the *workload*:**
  - The most important queries and how often they arise.
  - The most important updates and how often they arise.
  - The desired performance for these queries and updates.

Understanding the Workload

- **For each query in the workload:**
  - Which relations does it access?
  - Which attributes are retrieved?
  - Which attributes are involved in selection/join conditions? How selective are these conditions likely to be?
- **For each update in the workload:**
  - Which attributes are involved in selection/join conditions? How selective are these conditions likely to be?
  - The type of update (INSERT/DELETE/UPDATE), and the attributes that are affected.

Creating an ISUD Chart

Insert, Select, Update, Delete Frequencies

			Employee Table		
Transaction	***Frequency***	***% table***	**Name**	**Salary**	**Address**
Payroll Run	monthly	100	S	S	S
Add Emps	daily	0.1	I	I	I
Delete Emps	daily	0.1	D	D	D
Give Raises	monthly	10	S	U	

Decisions to Make

- **What indexes should we create?**
  - Which relations should have indexes? What field(s) should be the search key? Should we build several indexes?
- **For each index, what kind of an index should it be?**
  - Clustered? Dynamic/static?
- **Should we make changes to the conceptual schema?**
  - More on this later…
- **Horizontal partitioning, replication, views ...**

Index Selection

- **One approach:**
  - Consider most important queries in turn.
  - Consider best plan using the current indexes, and see if better plan is possible with an additional index.
  - If so, create it.
- **Before creating an index, must also consider the impact on updates in the workload!**
  - Trade-off: indexes can make queries go faster, updates slower. Require disk space, too.

Issues to Consider in Index Selection

- **Attributes mentioned in a WHERE clause are candidates for index search keys.**
  - Range conditions are sensitive to clustering
  - Exact match conditions don't require clustering
    - Or do they???? :-)
- **Try to choose indexes that benefit as many queries as possible.**
- **NOTE: only one index can be clustered per relation!**
  - So choose it based on important queries that benefit the most from clustering!!

Issues in Index Selection (Contd.)

- **Multi-attribute search keys should be considered when a WHERE clause contains several conditions.**
  - If range selections are involved, order of attributes should be carefully chosen to match the range ordering.
  - Such indexes can sometimes enable index-only strategies for important queries.
    - For index-only strategies, clustering is not important!
- **When considering a join condition:**
  - B+-tree on inner is very good for Index Nested Loops.
    - Should be clustered if join column is not key for inner, and inner tuples need to be retrieved.
  - *Clustered* B+ tree on join column(s) good for Sort-Merge.

Example 1

```
SELECT E.ename, D.mgr
FROM Emp E, Dept D
WHERE E.dno=D.dno AND D.dname='Toy'
```

- **B+ tree index on *D.dname* supports 'Toy' selection.**
  - Given this, index on D.dno is not needed.
- **B+ tree index on *E.dno* allows us to get matching (inner) Emp tuples for each selected (outer) Dept tuple.**
- **What if WHERE included: `` ... AND E.age=25'' ?**
  - Could retrieve Emp tuples using index on *E.age*, then join with Dept tuples satisfying *dname* selection. Comparable to strategy that used *E.dno* index.
  - So, if *E.age* index is already created, this query provides much less motivation for adding an *E.dno* index.

Example 2

```
SELECT E.ename, D.mgr
FROM Emp E, Dept D
WHERE E.sal BETWEEN 10000 AND 20000
  AND E.hobby='Stamps' AND E.dno=D.dno
```

- **All selections are on Emp so it should be the outer relation in any Index NL join.**
  - Suggests that we build a B+ tree index on *D.dno.*
- **What index should we build on Emp?**
  - B+ tree on *E.sal* could be used, OR an index on *E.hobby* could be used. Only one of these is needed, and which is better depends upon the selectivity of the conditions.
    - As a rule of thumb, equality selections more selective than range selections.
- **As both examples indicate, our choice of indexes is guided by the plan(s) that we expect an optimizer to consider for a query. *Have to understand optimizers!***

Examples of Clustering

```
SELECT E.dno
FROM Emp E
WHERE E.age>40
```

```
SELECT E.dno, COUNT (*)
FROM Emp E
WHERE E.age>10
GROUP BY E.dno
```

```
SELECT E.dno
FROM Emp E
WHERE E.hobby=Stamps
```

- **B+ tree index on E.age can be used to get qualifying tuples.**
  - How selective is the condition?
  - Is the index clustered?
- **Consider the GROUP BY query.**
  - If many tuples have *E.age* > 10, using *E.age* index and sorting the retrieved tuples may be costly.
  - Clustered *E.dno* index may be better!
- **Equality queries and duplicates:**
  - Clustering on *E.hobby* helps!

Clustering and Joins

```
SELECT E.ename, D.mgr
FROM Emp E, Dept D
WHERE D.dname='Toy' AND E.dno=D.dno
```

- **Clustering is especially important when accessing inner tuples in INL.**
  - Should make index on *E.dno* clustered.
- **Suppose that the WHERE clause is instead:**

  WHERE E.hobby='Stamps' AND E.dno=D.dno
  - If many employees collect stamps, Sort-Merge join may be worth considering. A *clustered* index on D.dno would help.
- ***Summary*: Clustering is useful whenever many tuples are to be retrieved.**

Multi-Attribute Index Keys

- **To retrieve Emp records with *age*=30 AND *sal*=4000, an index on <*age,sal*> would be better than an index on *age* or an index on *sal*.**
  - Such indexes also called *composite* or *concatenated* indexes.
  - Choice of index key orthogonal to clustering etc.
- **If condition is: 20<*age*<30 AND 3000<*sal*<5000:**
  - Clustered tree index on <*age,sal*> or <*sal,age*> is best.
- **If condition is: *age*=30 AND 3000<*sal*<5000:**
  - Clustered <*age,sal*> index much better than <*sal,age*> index!
- **Composite indexes are larger, updated more often.**

Index-Only Plans

- **A number of queries can be answered without retrieving any tuples from one or more of the relations involved if a suitable index is available.**

<*E.dno*>

```
SELECT D.mgr
FROM Dept D, Emp E
WHERE D.dno=E.dno
```

<*E.dno,E.eid*>

```
SELECT D.mgr, E.eid
FROM Dept D, Emp E
WHERE D.dno=E.dno
```

<*E.dno*>

```
SELECT E.dno, COUNT(*)
FROM Emp E
GROUP BY E.dno
```

<*E.dno,E.sal*> *B-tree trick!*

```
SELECT E.dno, MIN(E.sal)
FROM Emp E
GROUP BY E.dno
```

<*E. age,E.sal*> or <*E.sal, E.age*>

```
SELECT AVG(E.sal)
FROM Emp E
WHERE E.age=25 AND
 E.sal BETWEEN 3000 AND 5000
```

Horizontal Decompositions

- **Usual Def. of decomposition: Relation is replaced by collection of relations that are *projections*. Most important case.**
  - We will talk about this at length as part of Conceptual DB Design
- **Sometimes, might want to replace relation by a collection of relations that are *selections.***
  - Each new relation has same schema as original, but subset of rows.
  - Collectively, new relations contain all rows of the original.
  - Typically, the new relations are disjoint.

Horizontal Decompositions (Contd.)

- Contracts (<u>Cid</u>, Sid, Jid, Did, Pid, Qty, Val)
- **Suppose that contracts with value > 10000 are subject to different rules.**
  - So queries on Contracts will often say *WHERE val>10000*.
- **One approach: clustered B+ tree index on the *val* field.**
- **Second approach: replace contracts by two new relations, LargeContracts and SmallContracts, with the same attributes (CSJDPQV).**
  - Performs like index on such queries, but no index overhead.
  - Can build clustered indexes on other attributes, in addition!

Masking Conceptual Schema Changes

```
CREATE VIEW Contracts(cid, sid, jid, did, pid, qty, val)
        AS SELECT *
        FROM LargeContracts
        UNION
        SELECT *
        FROM SmallContracts
```

- Horizonal Decomposition **from above**
- **Masked by a view.**
  - NOTE: queries with condition *val>10000* must be asked wrt LargeContracts for efficiency: so some users may have to be aware of change.
    - I.e. the users who were having performance problems
    - Arguably that's OK -- they wanted a solution!

Index Tuning "Wizards"

- **Both IBM's DB2 and MS SQL Server have automated index advisors**
  - Some info in Section 20.6 of the book
- **Basic idea:**
  - They take a workload of queries
    - Possibly based on logging what's been going on
  - They use the optimizer cost metrics to estimate the cost of the workload over different choices of sets of indexes
  - Enormous # of different choices of sets of indexes:
    - Heuristics to help this go faster

Tuning Queries and Views

- **If a query runs slower than expected, check if an index needs to be re-clustered, or if statistics are too old.**
- **Sometimes, the DBMS may not be executing the plan you had in mind. Common areas of weakness:**
  - Selections involving null values (bad selectivity estimates)
  - Selections involving arithmetic or string expressions (ditto)
  - Selections involving OR conditions (ditto)
  - Complex subqueries (more on this later)
  - Lack of evaluation features like index-only strategies or certain join methods or poor size estimation.
- **Check the plan that is being used! Then adjust the choice of indexes or rewrite the query/view.**
  - E.g. check via POSTGRES "Explain" command
  - Some systems rewrite for you under the covers (e.g. DB2)
    - Can be confusing and/or helpful!

More Guidelines for Query Tuning

- **Minimize the use of DISTINCT: don't need it if duplicates are acceptable, or if answer contains a key.**
- **Minimize the use of GROUP BY and HAVING:**

```
SELECT MIN (E.age)
FROM Employee E
GROUP BY E.dno
HAVING E.dno=102
```

```
SELECT MIN (E.age)
FROM Employee E
WHERE E.dno=102
```

- Consider DBMS use of index when writing arithmetic expressions: *E.age=2*D.age* will benefit from index on *E.age*, but might not benefit from index on *D.age*!

Guidelines for Query Tuning (Contd.)

- **Avoid using intermediate relations:**

```
SELECT E.dno, AVG(E.sal)
FROM Emp E, Dept D
WHERE E.dno=D.dno
      AND D.mgrname='Joe'
GROUP BY E.dno
```

vs.

```
SELECT * INTO Temp
FROM Emp E, Dept D
WHERE E.dno=D.dno
      AND D.mgrname='Joe'
```

and

```
SELECT T.dno, AVG(T.sal)
FROM Temp T
GROUP BY T.dno
```

- Does not materialize the intermediate reln Temp.
- If there is a dense B+ tree index on <*dno, sal*>, an index-only plan can be used to avoid retrieving Emp tuples in the second query!

Points to Remember

- **Understanding the nature of the *workload* for the application, and the performance goals, is essential to developing a good design.**
  - What are the important queries and updates? What attributes/relations are involved?

Points to Remember

- **Indexes must be chosen to speed up important queries (and perhaps some updates!).**
  - Index maintenance overhead on updates to key fields.
  - Choose indexes that can help many queries, if possible.
  - Build indexes to support index-only strategies.
  - Clustering is an important decision; only one index on a given relation can be clustered!
  - Order of fields in composite index key can be important.
- **Static indexes may have to be periodically re-built.**
- **Statistics have to be periodically updated.**

Points to remember (Contd.)

- **Over time, indexes have to be fine-tuned (dropped, created, re-clustered, ...) for performance.**
  - Should determine the plan used by the system, and adjust the choice of indexes appropriately.
- **System may still not find a good plan:**
  - Only left-deep plans?
  - Null values, arithmetic conditions, string expressions, the use of ORs, nested queries, etc. can confuse an optimizer.
- **So, may have to rewrite the query/view:**
  - Avoid nested queries, temporary relations, complex conditions, and operations like DISTINCT and GROUP BY.