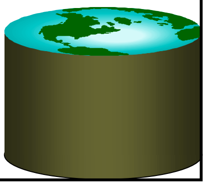
Physical Database Design and Tuning

15-415, Spring 2003, Lecture 19
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

- **After ER design, schema refinement, and the definition of views, we have the *conceptual* and *external* schemas for our database.**
- **The next step is to choose indexes, make clustering decisions, and to refine the conceptual and external schemas (if necessary) to meet performance goals.**
- **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.

Review - Normal Forms

- **Redundancy can cause problems**
  - Insert, Update, Delete anomalies
  - Functional Dependencies indicate possible redundancy
  - Decomposition can remove redunancy
- **Given FDs, can determine form of schema**
  - BCNF: no redundancy
  - 3NF: some redundancy possible

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.

Review: Normal Forms

- **Decomposition**
  - lossless-join mandatory
    - for each FD in relation R $X \rightarrow Y$, if $X \cap Y$ is empty, $\{(R - Y), XY\}$ is lossless
  - dependency preserving decomposition is nice
  - can always decompose to BCNF, but may not preserve dependencies
  - can always decompose to 3NF and preserve dependencies

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? Hash/tree? Dynamic/static? Dense/sparse?
- **Should we make changes to the conceptual schema?**
  - Consider alternative normalized schemas? (Remember, there are many choices in decomposing into BCNF, etc.)
  - Should we ``undo'' some decomposition steps and settle for a lower normal form? (*Denormalization.*)
  - Horizontal partitioning, replication, views ...

Settling for 3NF vs BCNF

- **CSJDPQV can be decomposed into SDP and CSJDQV, and both relations are in BCNF. (Which FD suggests that we do this?)**
  - Lossless decomposition, but not dependency-preserving.
  - Adding CJP makes it dependency-preserving as well.
- **Suppose that this query is very important:**
  - *Find the number of copies Q of part P ordered in contract C.*
  - Requires a join on the decomposed schema, but can be answered by a scan of the original relation CSJDPQV.
  - Could lead us to settle for the 3NF schema CSJDPQV.

Tuning the Conceptual Schema

- **Choice of conceptual schema should be guided by workload, in addition to redundancy issues:**
  - We may settle for a 3NF schema rather than BCNF.
  - Workload may influence choice we make in decomposing a relation into 3NF or BCNF.
  - We may further decompose a BCNF schema!
  - We might *denormalize* (i.e., undo a decomposition step), or we might add fields to a relation.
  - We might consider *horizontal decompositions.*
- **If such changes are made after a database in use, called *schema evolution*; might mask changes by defining *views*.**

Denormalization

- **Suppose that the following query is important:**
  - *Is the value of a contract less than the budget of the department?*
- **To speed up this query, we might add a field *budget* B to Contracts.**
  - This introduces the FD D $\rightarrow$ B wrt Contracts.
  - Thus, Contracts is no longer in 3NF.
- **Might choose to modify Contracts thus if the query is sufficiently important, and we cannot obtain adequate performance otherwise (i.e., by adding indexes or by choosing an alternative 3NF schema.)**

Example Schemas

Contracts (<u>Cid</u>, Sid, Jid, Did, Pid, Qty, Val)
Depts (<u>Did</u>, Budget, Report)
Suppliers (<u>Sid</u>, Address)
Parts (<u>Pid</u>, Cost)
Projects (<u>Jid</u>, Mgr)

- **We will concentrate on Contracts, denoted as CSJDPQV. The following ICs are given to hold: JP $\rightarrow$ C, SD $\rightarrow$ P, C is the primary key.**
  - What are the candidate keys for CSJDPQV?
  - What normal form is this relation schema in?

Horizontal Decompositions

- **Def. of decomposition: Relation is replaced by collection of relations that are *projections*. Most important case.**
- **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.)

- **Suppose that contracts with value > 10000 are subject to different rules. This means that queries on Contracts will often contain the condition *val>10000*.**
- **One way to deal with this is to build a clustered B+ tree index on the *val* field of Contracts.**
- **A second approach is to 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!

Issues to Consider in Index Selection

- **Attributes mentioned in a WHERE clause are candidates for index search keys.**
  - Exact match condition suggests hash index.
  - Range query suggests tree index.
    - Clustering is especially useful for range queries, although it can help on equality queries as well in the presence of duplicates.
- **Try to choose indexes that benefit as many queries as possible. Since only one index can be clustered per relation, choose it based on important queries that would benefit the most from clustering.**
- **How do Index Tuning Wizards work?**

Masking Conceptual Schema Changes

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

- **Suppose contracts w/ val > 10000 have different rules. Then queries on Contracts will often contain predicate *val>10000*.**
- **Can use Horizontal Decomposition into LargeContracts and SmallContracts**
- **This decomposition can be masked by a view.**
  - But, queries with condition *val>10000* must be asked wrt LargeContracts for efficiency: so some users may have to be aware of change.

Index Tuning Wizards

- **TARGET: Lower execution cost for final workload**
- **Indexable attributes: in WHERE, GROUP BY, ORDER BY clauses**
- **Steps:**
  1. Candidate Index Selection
     - Enumerate all *admissible indexes* (those that have indexable attributes as keys) with 1 attribute,
     - Then add all 2-attribute key combinations, …
     - Then add all k-attribute key combinations (user-defined k)
  2. Configuration Enumeration
     - Enumerate all configurations from above set
     - Simulate effect of indexes in candidate configuration using what-if queries to the optimizer
     - Suggest configuration that lowers workload cost the most
- **Greedy algorithms can be improved (see book)**

Now, About Indexes

- **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 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:**
  - Hash index 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  D.dname='Toy' AND E.dno=D.dno
```

- **Hash index on *D.dname* supports 'Toy' selection.**
  - Given this, index on D.dno is not needed.
- **Hash 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.

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.**

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.**
  - Suggests that we build a hash 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!***

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.**

Examples of Clustering

- **B+ tree index on E.age can be used to get qualifying tuples.**
  - How selective is the condition?
  - Is the index clustered?

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

- **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!

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

- **Equality queries and duplicates:**
  - Clustering on *E.hobby* helps!

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

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>
Tree index!

```
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>
Tree index!

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

<E. age,E.sal>
or
<E.sal, E.age>
Tree!

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

Points to Remember

- **Database design consists of several tasks: *requirements analysis, conceptual design, schema refinement, physical design* and *tuning.***
  - In general, have to go back and forth between these tasks to refine a database design, and decisions in one task can influence the choices in another task.
- **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?

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*!

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.**

Guidelines for Query Tuning (Contd.)

- **Avoid using intermediate relations:**

```
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
```

vs.

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

Tuning Queries and Views

- **If a query runs slower than expected, check if an index needs to be re-built, 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.
  - Selections involving arithmetic or string expressions.
  - Selections involving OR conditions.
  - 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.**

Summary of Database Tuning

- **The conceptual schema should be refined by considering performance criteria and workload:**
  - May choose 3NF or lower normal form over BCNF.
  - May choose among alternative decompositions into BCNF (or 3NF) based upon the workload.
  - May *denormalize*, or undo some decompositions.
  - May decompose a BCNF relation further!
  - May choose a *horizontal decomposition* of a relation.
  - Importance of dependency-preservation based upon the dependency to be preserved, and the cost of the IC check.
    - Can add a relation to ensure dep-preservation (for 3NF, not BCNF!); or else, can check dependency using a join.

Summary (Contd.)

- **Over time, indexes have to be fine-tuned (dropped, created, re-built, ...) 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 considered!
  - Null values, arithmetic conditions, string expressions, the use of ORs, 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.