

## 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



## Review - Normal Forms

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



## Review: Normal Forms

- **Decomposition**
  - lossless-join mandatory
    - for each FD in relation R  $X \twoheadrightarrow Y$ , if  $X \twoheadrightarrow Y$  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



## 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.



## 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*

Transaction	Frequency	% table	Employee 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 ...



## 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*.**



## Example Schemas

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

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



## 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.



## 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  $D \square B$  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.)**



## 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.**
  - 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
```

- **Horizontal 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!



## 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 to Consider in Index Selection

- **Attributes mentioned in a WHERE clause are candidates for index search keys.**
  - Exact match condition suggests hash index.
    - Note: rather inflexible, supported by few systems in practice.
    - Hence B+-trees might still be a good choice.
  - 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.**
- **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:**
  - 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 E.dno=D.dno AND D.dname='Toy'
```

- **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.



### 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 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!**



### Examples of Clustering

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

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

- **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:**

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

- 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>*

*<E.dno,E.eid>*  
Tree index!

*<E.dno>*

*<E.dno,E.sal>*  
Tree index!

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

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

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

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

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

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

```
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?



## 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.**



## 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-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** (bad selectivity estimates)
  - Selections involving **arithmetic or string expressions** (ditto)
  - Selections involving **OR conditions** (ditto)
  - Complex, correlated subqueries
  - **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:**

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
```

```
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  $\langle dno, sal \rangle$ , an index-only plan can be used to avoid retrieving Emp tuples in the second query!



## 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.