ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
ΠΑΝΕΠΙΣΤΗΜΙΟ ΚΡΗΤΗΣ

Συστήματα Διαχείρισης Βάσεων Δεδομένων

Διάλεξη 4η: Physical and Logical Database Schema Tuning

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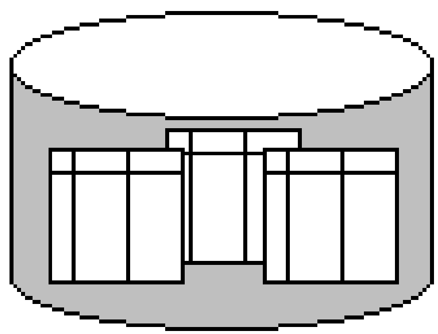
Τμήμα Επιστήμης Υπολογιστών

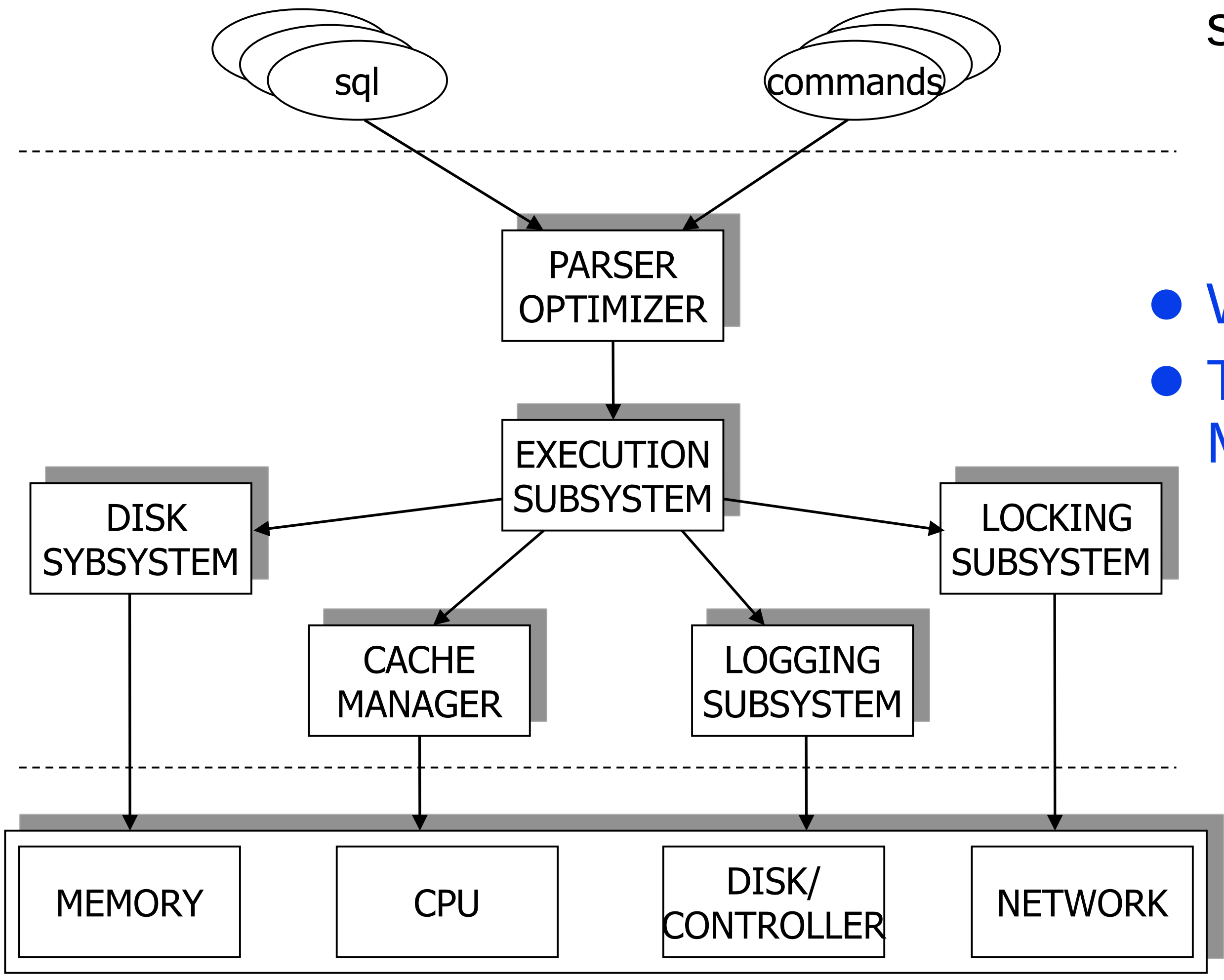
PHYSICAL AND LOGICAL DATABASE SCHEMA TUNING



Why Database Tuning?

- Troubleshooting (what is happening?):
  - Make managers and users happy given an application and a DBMS
- Capacity Sizing:
  - Buy the right DBMS given application requirements
- Application Programming:
  - Coding your application for performance

Why is Database Tuning hard?



The following query runs too slowly

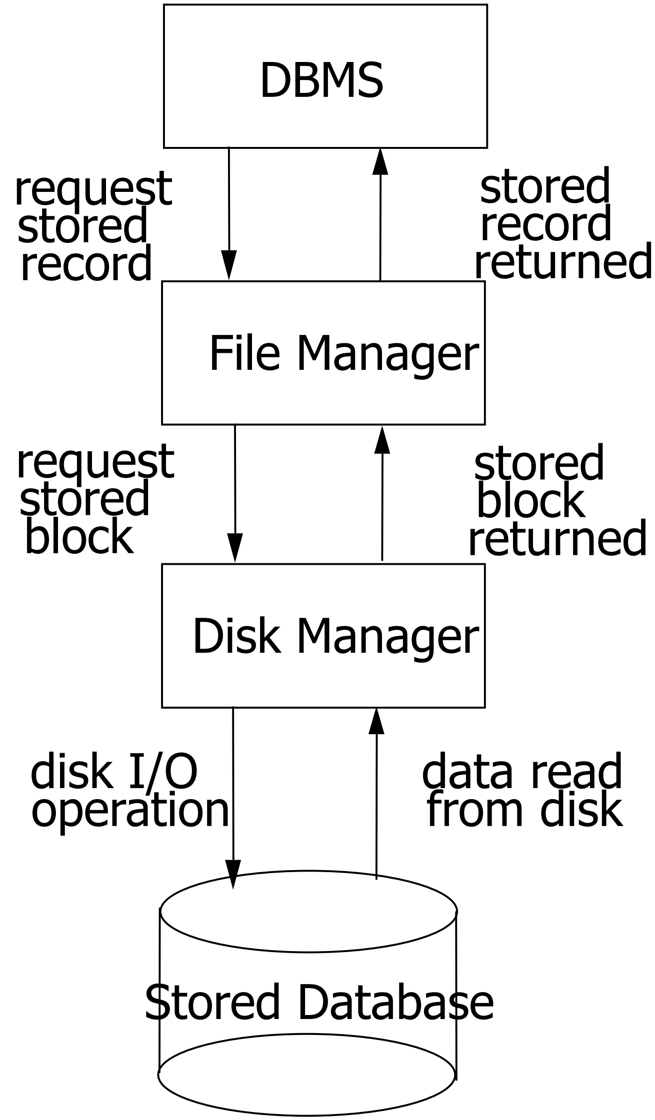
```
select *
from R
where R.a > 5;
```

- What do you do?
- Troubleshooting Methodology:
  - Hypothesis formulation
    - What is the cause of the problem?
  - Apply tuning principles to propose a fix
    - Hypothesis verification (experiments)

Tuning DB Design

- After designing schema
  - Make clustering decisions
  - Choose indexes
  - Refine the schemas (if necessary)

- We must begin by understanding the query 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 relations are going to be updated?
  - 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

Analyzing Database Queries and Transactions

- Expected frequency of invocation of queries and updates
  - expected frequency of each field as a selection field or join field over all transactions
  - expected frequency of retrieving and /or updating each record
- Analyzing time constraints of queries and updates
  - stringent performance constraints
  - influence access paths on selection fields
- Analyzing expected frequency of updates
  - volatile files
  - reduce number of access paths

Decisions to Make

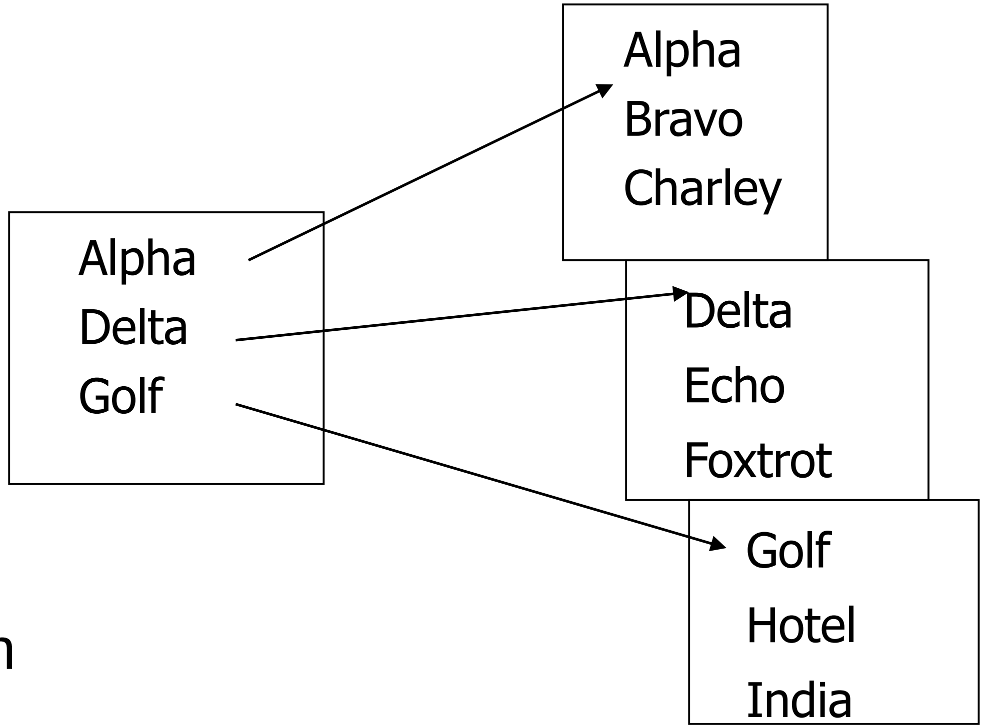
- What indexes should we create?
  - Which relations should have indexes? What field(s) should be the search key? Should we build several indexes?

- For each index, what kind of index should it be?
  - Clustered? Hash/tree? Dynamic/static? Dense/sparse?

- Should we make changes to the schema?
  - Consider alternative normalized schemas? (Remember, there are many choices in decomposing into BCNF, etc.)
  - Horizontal partitioning, replication, views, ...

Recall Index Classification

- Index is a structure which provides alternative access to the data
  - Primary - key in index same as key in file
  - Secondary - key in index different from original file
  - Clustered - key order in index is same as data file (only one per table)
  - Unclustered - index tree stores sorted keys, with leaf node pointer to look up data (multiple per table)
  - Dense - one index entry for each record
  - Sparse - one index entry for each block
  - Covered - contain all columns in Select, Where, or Join clauses



Choice of Indexes

- One approach:
  - Consider the most important queries to tune
  - Consider the best plan using the current indexes
  - See if a 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

- Create indexes on Primary Key columns (default clustered)
- Avoid indexes that are too wide
- Don't create indexes with less than 75% selectivity
  - Example: index on Yes/No column
- 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

Issues to Consider in Index Selection

- 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

- When considering a join condition (indexes on foreign keys):
  - 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

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
```

- Clearly, Emp 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

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>
dense unclusterred

```
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>
dense

```
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
```

Some Schemas are Better than Others

- A relation schema is a relation name and a set of attributes

  R(a int, b varchar[20]);

- A relation instance for R is a set of records over the attributes in the schema for R

- Schema1:

  ```
  OnOrder1(supplier_id,
    part_id, quantity,
    supplier_address)
  ```

- Schema 2:

  ```
  OnOrder2(supplier_id,
    part_id, quantity)
  Supplier(supplier_id,
    supplier_address)
  ```

- Space
  - Schema 2 saves space
- Information preservation
  - Some supplier addresses might get lost with schema 1
- Performance trade-off
  - Frequent access to address of supplier given an ordered part, then schema 1 is good
  - Many new orders, schema 1 is not good

Recall Functional Dependencies

- X is a set of attributes of relation R, and A is a single attribute of R: X determines A (the functional dependency X → A holds for R) iff:
  - For any relation instance I of R, whenever there are two records r and r' in I with the same X values, they have the same A value as well
    - `OnOrder1(supplier_id, part_id, quantity, supplier_address)`
      - `supplier_id → supplier_address` is an interesting FD
  - Attributes X from R constitute a key of R if X determines every attribute in R and no proper subset of X determines an attribute in R
    - `OnOrder1(supplier_id, part_id, quantity, supplier_address)`
      - `supplier_id, part_id` is not a key
    - `Supplier(supplier_id, supplier_address)`
      - `supplier_id` is a key

Recall Functional Dependencies

- A relation is normalized if every interesting functional dependency X → A involving attributes in R has the property that X is a key of R
  - `OnOrder1` is not normalized
  - `OnOrder2` and `Supplier` are normalized
- Relation R is in BCNF if: for any nontrivial FD X→Y of R, X must be a superkey
  - X→Y is nontrivial if Y is not a subset of X
  - X is a superkey if X→(all attributes of R)
  - Motivation: removing redundancy
- Relation R is in 3NF if: for each nontrivial FD X→Y, either X is a superkey, or Y is a member of some candidate key
  - Motivation: preserve FDs
- A BCNF relation is also a 3NF relation, but not vice versa

Tuning a Relational Schema

- The choice of relational schema should be guided by the workload, in addition to redundancy issues:
  - We may settle for a 3NF schema rather than BCNF
  - Workload may influence the choice we make in decomposing a relation into 3NF or BCNF
  - We may further decompose a BCNF schema, or add an attribute!
  - We might denormalize (i.e., undo a decomposition step)
  - We might consider horizontal decompositions

- If such changes are made after a database is in use, called schema evolution; might want to mask some of these changes from applications by defining views

Tuning Normalization

- A single normalized relation XYZ is better than two normalized relations XY and XZ
  - if the single relation design allows queries to access X, Y and Z together without requiring a join
- The two-relation design is better iff:
  - Users access tend to partition between the two sets Y and Z most of the time
  - Attributes Y or Z have large values

Schema Tuning

- Rule of Thumb:
  - If ABC is normalized, and AB and AC are also normalized, then use ABC, unless:
    - Queries very rarely access ABC, but AB or AC (80% of the time)
    - Attribute B or C values are large
- Example
  - Schema 1:
    - `R1(bond_ID, issue_date, maturity, …)`
    - `R2(bond_ID, date, price)`
  - Schema 2:
    - `R1(bond_ID, issue_date, maturity, today_price, yesterday_price,…,10dayago_price)`

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 dependencies hold: JP → C, SD → P
  - C is the primary key
  - What are the candidate keys for CSJDPQV? C, JSD, JP
  - What normal form is this relation schema in? 3NF

Denormalization

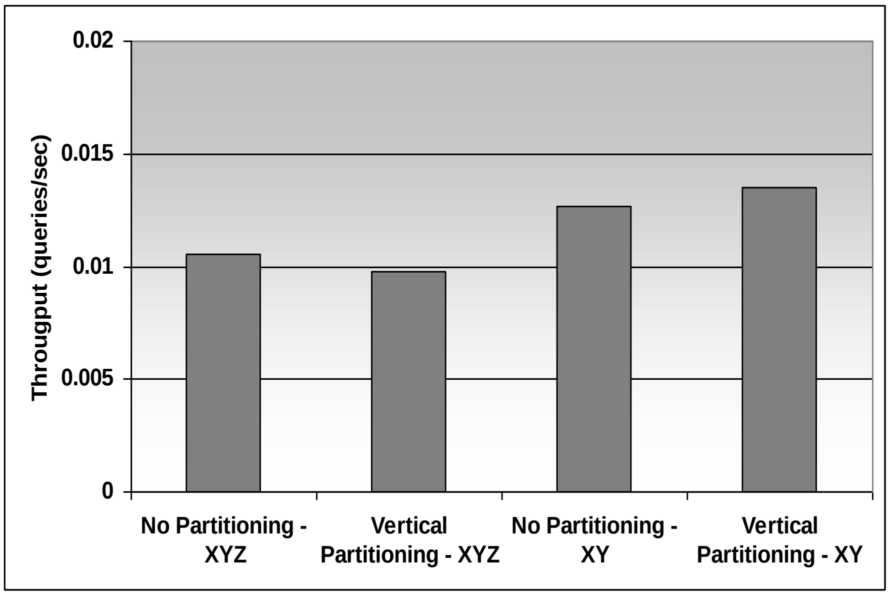
- Denormalizing means violating normalization for the sake of performance:
  - speeds up performance when attributes from different normalized relations are often accessed together
  - hurts performance for relations that are often updated
- Suppose that the following query Q is important:
  - Is the value of a contract less than the budget of the department?
  - Need a join between Contracts and Depts
- To speed up Q, we might add a field budget B to Contracts
  - This introduces the FD: D → B wrt Contracts
  - Thus, Contracts is no longer in 3NF
- We might choose to modify Contracts
  - 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)

(Vertical) Decomposition of a BCNF Relation

FD's: JP → C, SD → P Keys: C, JSD, JP

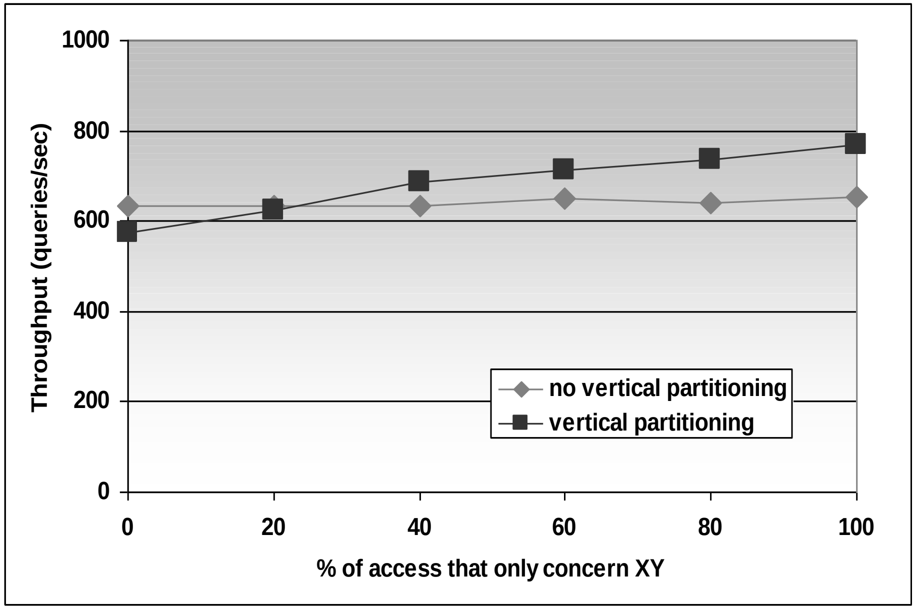
- Suppose we choose {SDP, CSJDQV}
  - Both are in BCNF
  - No reason to decompose further
- However, suppose that these queries are important:
  - Find the contracts held by supplier S
  - Find the contracts that department D is involved in
- Decomposing CSJDQV further into CS, CD and CJQV could speed up these queries (Why?)
- On the other hand, the following query is slower:
  - Find the total value of all contracts held by supplier S
  - Reason: need a join operation

Vertical Partitioning and Scan



- R (X,Y,Z)
  - X is an integer
  - YZ are large strings
- Scan Query
- Vertical partitioning exhibits poor performance when all attributes are accessed
- Vertical partitioning provides a sped up if only two of the attributes are accessed

Vertical Partitioning and Point Queries



- R (X,Y,Z)
  - X is an integer
  - YZ are large strings
- A mix of point queries access either XYZ or XY
- Vertical partitioning gives a performance advantage if the proportion of queries accessing only XY is greater than 20%
- The join is not expensive compared to a simple look-up

Horizontal Decompositions

- "Vertical" Decomposition: Relation is replaced by a collection of relations that are projections
- "Horizontal" decomposition
  - Sometimes, might want to replace relation by a collection of relations that are selections
  - Each new relation has same schema as the original, but a subset of the rows
  - Collectively, new relations contain all rows of the original. Typically, the new relations are disjoint
- Suppose contracts with value > 10000 are very often
  - Queries on Contracts will often contain the condition val > 10000
- One 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

Denormalizing -- data

Settings:

lineitem (<u>L_ORDERKEY, L_PARTKEY , L_SUPPKEY</u>, L_LINENUMBER, L_QUANTITY, L_EXTENDEDPRICE , L_DISCOUNT, L_TAX , L_RETURNFLAG, L_LINESTATUS , L_SHIPDATE, L_COMMITDATE, L_RECEIPTDATE, L_SHIPINSTRUCT , L_SHIPMODE , L_COMMENT);

region(<u>R_REGIONKEY</u>, R_NAME, R_COMMENT);

nation(<u>N_NATIONKEY</u>, N_NAME, *N_REGIONKEY*, N_COMMENT);

supplier(<u>S_SUPPKEY</u>, S_NAME, S_ADDRESS, *S_NATIONKEY*, S_PHONE, S_ACCTBAL, S_COMMENT);

- 600000 rows in lineitem, 25 nations, 5 regions, 500 suppliers

Denormalizing -- transactions

```
lineitemdenormalized (L_ORDERKEY, L_PARTKEY ,
    L_SUPPKEY, L_LINENUMBER, L_QUANTITY,
    L_EXTENDEDPRICE ,
    L_DISCOUNT, L_TAX , L_RETURNFLAG, L_LINESTATUS ,
    L_SHIPDATE, L_COMMITDATE,
    L_RECEIPTDATE, L_SHIPINSTRUCT ,
    L_SHIPMODE , L_COMMENT, L_REGIONNAME);
```

- 600000 rows in line item denormalized
- Cold Buffer
- Dual Pentium II (450MHz, 512Kb), 512 Mb RAM, 3x18Gb drives (10000RPM), Windows 2000

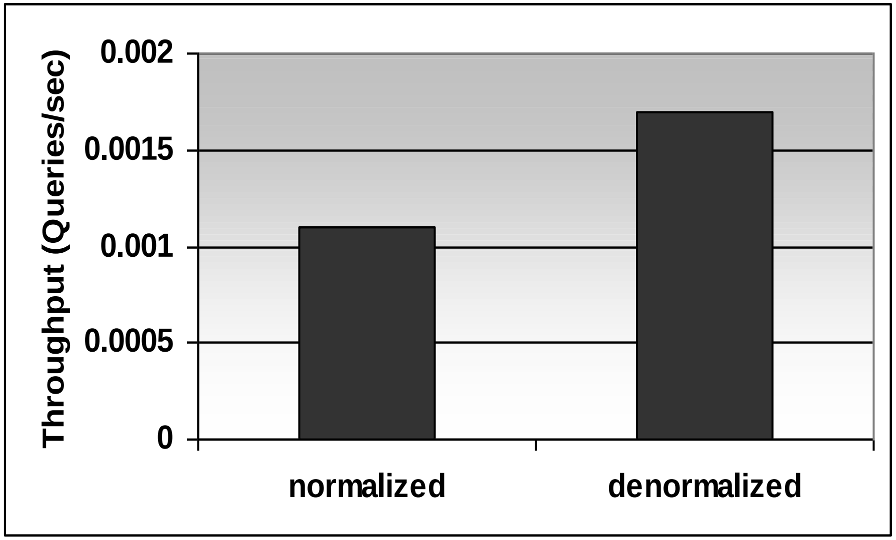
Queries on Normalized vs. Denormalized Schemas

Queries:

```
select L_ORDERKEY, L_PARTKEY, L_SUPPKEY, L_LINENUMBER,
  L_QUANTITY, L_EXTENDEDPRICE, L_DISCOUNT, L_TAX,
  L_RETURNFLAG, L_LINESTATUS, L_SHIPDATE, L_COMMITDATE,
  L_RECEIPTDATE, L_SHIPINSTRUCT, L_SHIPMODE, L_COMMENT, R_NAME
from LINEITEM, REGION, SUPPLIER, NATION
where L_SUPPKEY = S_SUPPKEY
      and S_NATIONKEY = N_NATIONKEY
      and N_REGIONKEY = R_REGIONKEY
      and R_NAME = 'EUROPE';

select L_ORDERKEY, L_PARTKEY, L_SUPPKEY, L_LINENUMBER,
  L_QUANTITY, L_EXTENDEDPRICE,  L_DISCOUNT, L_TAX,
  L_RETURNFLAG, L_LINESTATUS, L_SHIPDATE, L_COMMITDATE,
  L_RECEIPTDATE, L_SHIPINSTRUCT, L_SHIPMODE, L_COMMENT,
  L_REGIONNAME
from LINEITEMDENORMALIZED
where L_REGIONNAME = 'EUROPE';
```

Denormalization



- TPC-H schema
- Query: find all lineitems whose supplier is in Europe
- With a normalized schema this query is a 4-way join
- If we denormalize lineitem and add the name of the region for each lineitem (foreign key denormalization) throughput improves 30%

Masking Conceptual Schema Changes

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

- The replacement of Contracts by LargeContracts and SmallContracts can be masked by the view
- However, queries with the condition *val>10000* must be asked wrt LargeContracts for efficient execution: so users concerned with performance have to be aware of the change

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
  - More later in the this course…

Summary

- DB 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 DB 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
- 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

Summary

- Static indexes may have to be periodically re-built
- Statistics have to be periodically updated
- 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:
  - So, may have to rewrite the query/view
  - Avoid nested queries, temporary relations, complex conditions, and operations like DISTINCT and GROUP BY (more in following assisting lectures)

References

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- S, Chaudhuri, V. Narasayya An Efficient, Cost-Driven Index Selection Tool for Microsoft SQL Server VLDB, Athens, 1997

Τέλος Ενότητας

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ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
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- Το έργο «**Ανοικτά Ακαδημαϊκά Μαθήματα στο Πανεπιστήμιο Κρήτης**» έχει χρηματοδοτήσει μόνο τη αναδιαμόρφωση του εκπαιδευτικού υλικού.
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Σημειώματα

Σημείωμα αδειοδότησης

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