# Database Tuning

## Query Tuning

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Adapted from "Database Tuning" by Dennis Shasha and Philippe Bonnet.





## Outline







## About Query Tuning

- Query tuning: rewrite a query to run faster!
- Other tuning approaches may have harmful side effects:
  - adding index
  - changing the schema
  - modify transaction length
- Query tuning: only beneficial side effects
  - first thing to do if query is slow!





## Outline

## Steps in Query Processing

1. Parser
   - input: SQL query
   - output: relational algebra expression
2. Optimizer
   - input: relational algebra expression
   - output: query plan
3. Execution engine
   - input: query plan
   - output: query result





## 1. Parser

Parser:

- Input: SQL query from user
  Example:
  ```
  SELECT balanace
  FROM account
  WHERE balance < 2500
  ```
- Output: relational algebra expression
  Example: $\sigma_{balance<2500}(\Pi_{balance}(account))$
- Algebra expression for a given query not unique!
  Example: The following relational algebra expressions are equivalent.
  - $\sigma_{balance<2500}(\Pi_{balance}(account))$
  - $\Pi_{balance}(\sigma_{balance<2500}(account))$





## 2. Optimizer

Optimizer:

- Input: relational algebra expression
  Example: $\Pi_{balance}(\sigma_{balance<2500}(account))$
- Output: query plan
  Example:

  $\Pi_{balance}$
  |
  $\sigma_{balance<2500}$
  *use index 1*
  |
  *account*
- query plan is selected in three steps:
  A) equivalence transformation
  B) annotation of the relational algebra expression
  C) cost estimation for different query plans





## A) Equivalence Transformation

- Equivalence of relational algebra expressions:
  - equivalent if they generate the same set of tuples on every legal database instance
  - legal: database satisfies all integrity constraints specified in the database schema
- Equivalence rules:
  - transform one relational algebra expression into equivalent one
  - similar to numeric algebra: $a + b = b + a$, $a(b + c) = ab + ac$, etc.
- Why producing equivalent expressions?
  - equivalent algebraic expressions give the same result
  - but usually the execution time varies significantly

# Equivalence Rules – Examples

- Selection operations are commutative: $\sigma_{\theta_1}(\sigma_{\theta_2}(E)) = \sigma_{\theta_2}(\sigma_{\theta_1}(E))$
  - $E$ is a relation (table)
  - $\theta_1$ and $\theta_2$ are conditions on attributes, e.g. $E.sallary < 2500$
  - $\sigma_\theta$ selects all tuples that satisfy $\theta$
- Selection distributes over the theta-join operation if $\theta_1$ involves only attributes of $E_1$ and $\theta_2$ only attributes of $E_2$:

$$\sigma_{\theta_1 \wedge \theta_2}(E_1 \bowtie_\theta E_2) = (\sigma_{\theta_1}(E_1)) \bowtie_\theta (\sigma_{\theta_2}(E_2))$$

  - $\bowtie_\theta$ is the theta-join; it pairs tuples from the input relations (e.g., $E_1$ and $E_2$) that satisfy condition $\theta$, e.g. $E_1.accountID = E_2.ID$
- Natural join is associative: $(E_1 \bowtie E_2) \bowtie E_3 = E_1 \bowtie (E_2 \bowtie E_3)$
  - the join condition in the natural join is equality on all attributes of the two input relations that have the same name
- Many other rules can be found in Silberschatz et al.,"Database System Concepts"





# Equivalence Rules – Example Query

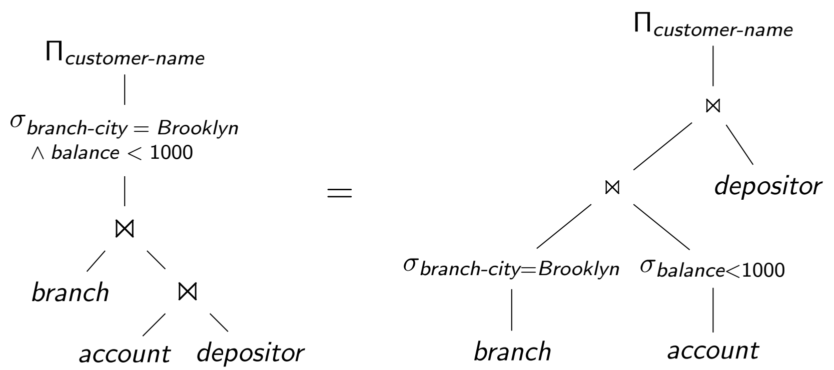
- Schema:
  branch(branch-name, branch-city, assets)
  account(account-number, branch-name, balance)
  depositor(customer-name,account-number)
- Query:
  SELECT customer-name
  FROM branch, account, depositor
  WHERE branch-city=Brooklyn AND
  balance < 1000 AND
  branch.branch-name = account.branch-name AND
  account.account-number = depositor.account-number





# Equivalence Rules – Example Query

- Equivalent relational algebra expressions:





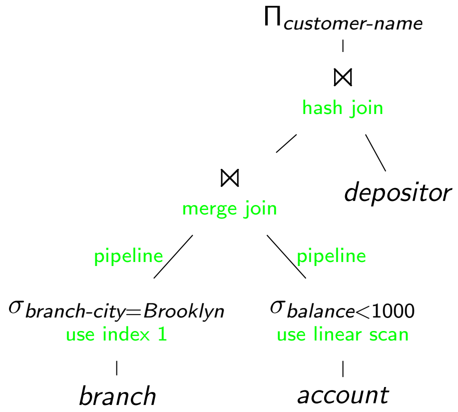



# B) Annotation: Creating Query Plans

- Algebra expression is not a query plan.
- Additional decisions required:
  - which indexes to use, for example, for joins and selects?
  - which algorithms to use, for example, sort-merge vs. hash join?
  - materialize intermediate results or pipeline them?
  - etc.
- Each relational algebra expression can result in many query plans.
- Some query plans may be better than others!

## Query Plan – Example

- query plan of our example query:
  (account physically sorted by branch-name; index 1 on branch-city sorts records with same value of branch-city by branch-name)








## C) Cost Estimation

- Which query plan is the fastest one?
- This is a very hard problem:
  - cost for each query plan can only be estimated
  - huge number of query plans may exist





## Statistics for Cost Estimation

- Catalog information: database maintains statistics about relations
- Example statistics:
  - number of tuples per relation
  - number of blocks on disk per relation
  - number of distinct values per attribute
  - histogram of values per attribute
- Statistics used to estimate cost of operations, for example
  - selection size estimation
  - join size estimation
  - projection size estimation
- Problems:
  - cost can only be estimated
  - updating statistics is expensive, thus they are often out of date





## Choosing the Cheapest Query Plan

- Problem: Estimating cost for all possible plans too expensive.
- Solutions:
  - pruning: stop early to evaluate a plan
  - heuristics: do not evaluate all plans
- Real databases use a combination:
  - Apply heuristics to choose promising query plans.
  - Choose cheapest plan among the promising plans using pruning.
- Examples of heuristics:
  - perform selections as early as possible
  - perform projections early
  - avoid Cartesian products

## 3. Execution Engine

The execution engine

- receives query plan from optimizer
- executes plan and returns query result to user





## Query Tuning and Query Optimization

- Optimizers are not perfect:
  - transformations produce only a subset of all possible query plans
  - only a subset of possible annotations might be considered
  - cost of query plans can only be estimated
- Query Tuning: Make life easier for your query optimizer!





## Outline







## Which Queries Should Be Rewritten?

- Rewrite queries that run “too slow”
- How to find these queries?
  - query issues far too many disc accesses,
    for example, point query scans an entire table
  - you look at the query plan and see that relevant indexes are not used

## Running Example

- Employee(ssnum,name,manager,dept,salary,numfriends)
  - clustering index on ssnum
  - non-clustering index on name
  - non-clustering index on dept
  - keys: ssnum, name
- Students(ssnum,name,course,grade)
  - clustering index on ssnum
  - non-clustering index on name
  - keys: ssnum, name
- Techdept(dept,manager,location)
  - clustering index on dept
  - key: dept
  - manager may manage many departments
  - a location may contain many departments





## DISTINCT

- How can DISTINCT hurt?
  - DISTINCT forces sort or other overhead.
  - If not necessary, it should be avoided.
- Query: Find employees who work in the information systems department.

```
SELECT DISTINCT ssnum
FROM Employee
WHERE dept = 'information systems'
```

- DISTINCT not necessary:
  - ssnum is a key of Employee, so it is also a key of a subset of Employee.
  - Note: Since an index is defined on ssnum, there is likely to be no overhead in this particular examples.





## Non-Correlated Subqueries

- Many systems handle subqueries inefficiently.
- Non-correlated: attributes of outer query not used in inner query.
- Query:

```
SELECT ssnum
FROM Employee
WHERE dept IN (SELECT dept FROM Techdept)
```

- May lead to inefficient evaluation:
  - check for each employee whether they are in Techdept
  - index on Employee.dept not used!
- Equivalent query:

```
SELECT ssnum
FROM Employee, Techdept
WHERE Employee.dept = Techdept.dept
```

- Efficient evaluation:
  - look up employees for each dept in Techdept
  - use index on Employee.dept





## Temporary Tables

- Temporary tables can hurt in the following ways:
  - force operations to be performed in suboptimal order (optimizer often does a very good job!)
  - creating temporary tables i.s.s.[1] causes catalog update – possible concurrency control bottleneck
  - system may miss opportunity to use index
- Temporary tables are good:
  - to rewrite complicated correlated subqueries
  - to avoid ORDER BYs and scans in specific cases (see example)

[1] in some systems

## Unnecessary Temporary Table

- Query: Find all IT department employees who earn more than 40000.

```
SELECT * INTO Temp
FROM Employee
WHERE salary > 40000

SELECT ssnum
FROM Temp
WHERE Temp.dept = 'IT'
```

- Inefficient SQL:
  - index on dept can not be used
  - overhead to create Temp table (materialization vs. pipelining)
- Efficient SQL:

```
SELECT ssnum
FROM Employee
WHERE Employee.dept = 'IT'
      AND salary > 40000
```





## Joins: Use Clustering Indexes and Numeric Values

- Query: Find all students who are also employees.
- Inefficient SQL:

```
SELECT Employee.ssnum
FROM Employee, Student
WHERE Employee.name = Student.name
```

- Efficient SQL:

```
SELECT Employee.ssnum
FROM Employee, Student
WHERE Employee.ssnum = Student.ssnum
```

- Benefits:
  - Join on two clustering indexes allows merge join (fast!).
  - Numerical equality is faster evaluated than string equality.





## Don't use HAVING where WHERE is enough

- Query: Find average salary of the IT department.
- Inefficient SQL:

```
SELECT AVG(salary) as avgsalary, dept
FROM Employee
GROUP BY dept
HAVING dept = 'IT'
```

- Problem: May first compute average for employees of all departments.
- Efficient SQL: Compute average only for relevant employees.

```
SELECT AVG(salary) as avgsalary, dept
FROM Employee
WHERE dept = 'IT'
GROUP BY dept
```





## Use Views with Care (I/II)

- Views: macros for queries
  - queries look simpler
  - but are never faster and sometimes slower
- Creating a view:

```
CREATE VIEW Techlocation
AS SELECT ssnum, Techdept.dept, location
FROM Employee, Techdept
WHERE Employee.dept = Techdept.dept
```

- Using the view:

```
SELECT location
FROM Techlocation
WHERE ssnum = 452354786
```

- System expands view and executes:

```
SELECT location
FROM Employee, Techdept
WHERE Employee.dept = Techdept.dept
      AND ssnum = 452354786
```

## Use Views with Care (II/II)

- Query: Get the department name for the employee with social security number 452354786 (who works in a technical department).
- Example of an inefficient SQL:

```
SELECT dept
FROM Techlocation
WHERE ssnum = 452354786
```

- This SQL expands to:

```
SELECT dept
FROM Employee, Techdept
WHERE Employee.dept = Techdept.dept
      AND ssnum = 452354786
```

- But there is a more efficient SQL (no join!) doing the same thing:

```
SELECT dept
FROM Employee
WHERE ssnum = 452354786
```





## System Peculiarity: Indexes and OR

- Some systems never use indexes when conditions are OR-connected.
- Query: Find employees with name Smith or who are in the acquisitions department.

```
SELECT Employee.ssnum
FROM Employee
WHERE Employee.name = 'Smith'
OR Employee.dept = 'acquisitions'
```

- Fix: use UNION instead of OR

```
SELECT Employee.ssnum
FROM Employee
WHERE Employee.name = 'Smith'
UNION
SELECT Employee.ssnum
FROM Employee
WHERE Employee.dept = 'acquisitions'
```





## System Peculiarity: Order in FROM clause

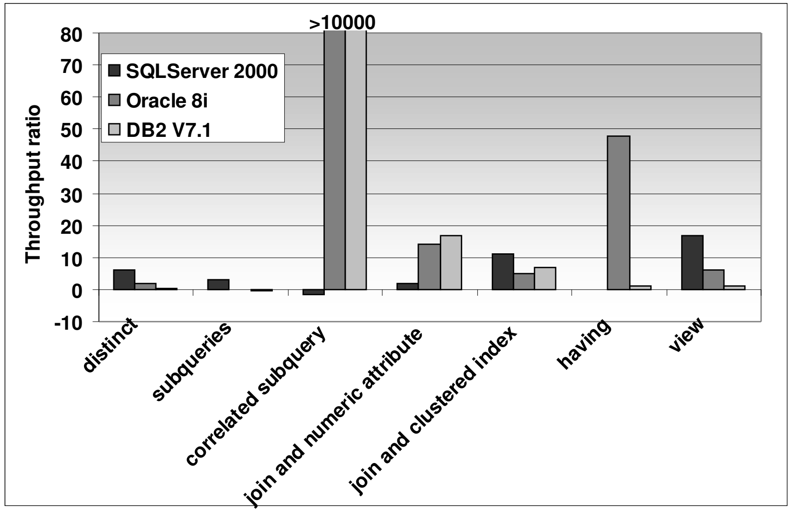
- Order in FROM clause should be irrelevant.
- However: For long joins (e.g., more than 8 tables) and in some systems the order matters.
- How to figure out? Check query plan!





## Experimental Evaluation

Throughput increase in percent.




Running Example: 100k employees, 100k students, 10 technical departments