The Volcano Optimizer Generator: Extensibility and Efficient Search

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Outline

Introduction

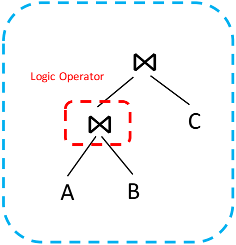
Method

Experiment

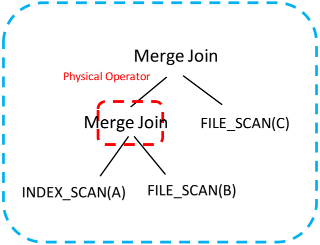
Conlusion

Query Execution

- **Logical Operator:** A function map the operator's inputs to its outputs. (e.g. join, selection, projection)
- **Physical Operator:** An algorithm that implements a logical operator. (e.g. hash join, merge join)
- **Operator Expression:** A hierarchy of operators.
- **Execution Plan:** An expression made up entirely of physical operators



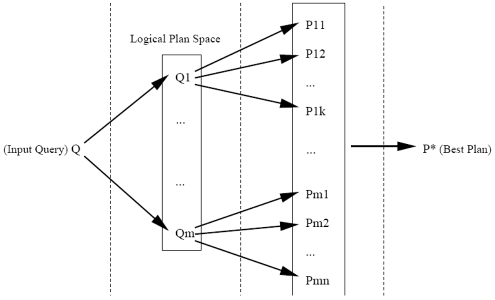
Logical Expression



Physical Expression

Query Optimization

- **Definition:** For a given query, find an execution plan for it that has the lowest cost
- **Challenges:** The number of candidate execution plans is huge
  - Equivalent expressions (e.g. $A \bowtie (B \bowtie C) = (A \bowtie B) \bowtie C$)
  - Different algorithms for each operation (e.g. Sort Merge Join, Hash Join, Nested Loop Join)



1. Logical plan space generation
2. Physical plan space generation
3. Search for best plan

Motivation

Cost difference between evaluation plans for a query can be enormous (e.g. seconds vs. days)

Existing Methods:

- Heuristic search: Use static rules to generate plan
- Stratified search: Planning is done in multiple stages
- Unified search: Perform query planning all at once

Problems:

- **Not effective:** Hard to generate good plans for complex queries
- **Not extensible:** Rules maintenance is a huge pain
- **Not efficient:** Waste a lot of effort in searching

Overview of Volcano

Objectives

- Usability as a stand-alone tool
- More efficient resource usage
- Extensible support for physical properties

Optimizer Components

Physical property: The properties of physical layout of data
Logical Rules: Logic-Logic transformation
Implementation Rules: Logic-Implementation transformation
Algorithm/Enforcer: Have required physical properties of their inputs, physical properties of its output, and cost function

Example

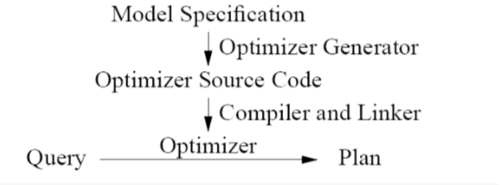
- Physical property: Select * FROM A ORDER BY id
- Logic Rules: $S \bowtie R = R \bowtie S$
- Implementation Rules: $\bowtie \rightarrow$ {Merge Join, Hash Join, Sort + Hash Join}
- Merge Join requires the inputs to be sorted on the join attributes and produces the output sorted

Optimizer Generator

Model Specification

- A set of logical operators and algebraic transformation rules
- A set of algorithms, enforcers and implementation rules
- An applicability function for each algorithm and enforcer
- A cost function for each algorithm and enforcer
- Property function for each operator, algorithm and enforcer

Generate Optimizer



Plan Search Engine

Basic Ideas

- The optimal execution plan of a query is composed of the optimal execution plan of its sub-queries.
- If the cost of a sub execution plan P is larger than cost threshold, any larger execution plan containing P can be pruned
- Recursively divide the query into sub-queries and find optimal execution plans of each sub-queries.

Example

SELECT * FROM A, B, C WHERE A.id $=$ B.id AND B.id $=$ C.id
Cost$(A \bowtie (B \bowtie C)) =$ Cost(A) $+$ Cost($\bowtie$) $+$ Cost$(B \bowtie C)$

Plan Search Engine

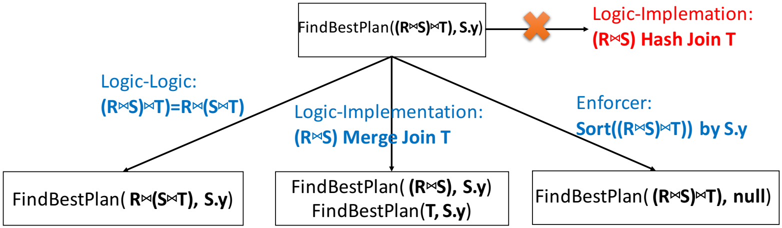
Enumerate Search Space

Three possible moves

- Logic-Logic Transform
- Logic-Implementation Transform
- Enforcers for required physical property

Example

SELECT * FROM R, S, T WHERE R.x=S.x AND S.y=T.y
ORDER BY S.y



FindBestPlan(**(R⋈S)⋈T), S.y**)

Logic-Implemation:
(R⋈S) Hash Join T

Logic-Logic:
(R⋈S)⋈T)=R⋈(S⋈T)

Logic-Implementation:
(R⋈S) Merge Join T

Enforcer:
Sort((R⋈S)⋈T)) by S.y

FindBestPlan(**R⋈(S⋈T), S.y**)

FindBestPlan(**(R⋈S), S.y**)
FindBestPlan(**T, S.y**)

FindBestPlan(**(R⋈S)⋈T), null**)

Algorithm Overview

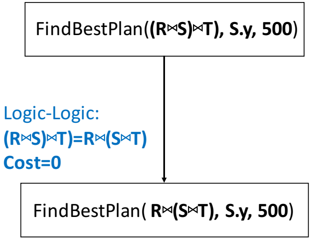
```
FindBestPlan (LogExpr, PhysProp, Limit)
    /*Check look-up table (LogExpr, PhysProp) -> (Execution Plan, Cost)*/
    If (LogExpr, PhysProp) in table
        /*Prune high cost plans*/
        If cost < Limit return (Execution Plan, Cost)
        else return Fail
    /* else: optimization required */
    Generate possible moves
    For move in moves
        Handle the move
    /* maintain the look-up table of explored facts */
    If LogExpr is not in the look-up table:
        Update loop-up table
    return best Plan and Cost
```

Handle Moves

Handle Logical Transformation

Recursively call the **FindBestPlan** function with the new logical expression

Examples



FindBestPlan(**(R⋈S)⋈T), S.y, 500**)

Logic-Logic:
(R⋈S)⋈T)=R⋈(S⋈T)
Cost=0

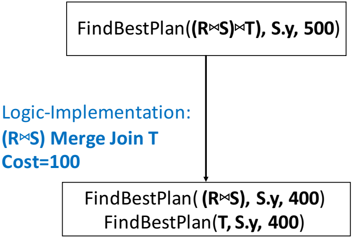
FindBestPlan(**R⋈(S⋈T), S.y, 500**)

Handle Moves

Handle Implementation Transformation

1. Update the total cost. TotalCost = Algorithm Cost
2. Recursively call FindBestPlan on each input of the algorithm

Examples



FindBestPlan(**(R⋈S)⋈T), S.y, 500**)

Logic-Implementation:
(R⋈S) Merge Join T
Cost=100

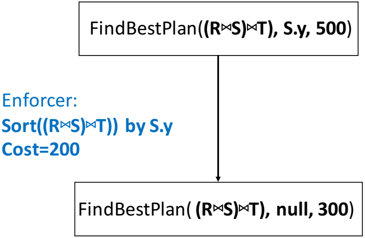
FindBestPlan(**(R⋈S), S.y, 400**)
FindBestPlan(**T, S.y, 400**)

Handle Moves

Handle Enforcer Transformation

1. Update physical property and cost
2. Recursively call the **FindBestPlan** function with the new physical property and cost

Examples



FindBestPlan(**(R$\bowtie$S)$\bowtie$T), S.y, 500**)

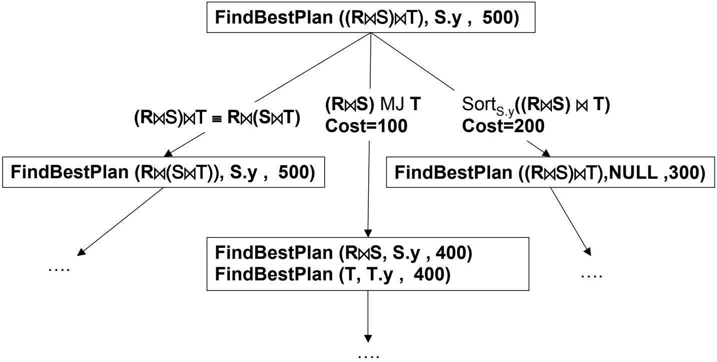
Enforcer:
Sort((R$\bowtie$S)$\bowtie$T)) by S.y
Cost=200

FindBestPlan(**(R$\bowtie$S)$\bowtie$T), null, 300**)

Depth-First Search Tree

Query

SELECT * FROM R, S, T WHERE R.x=S.x AND S.y=T.y
ORDER BY S.y



FindBestPlan ((R⋈S)⋈T), S.y , 500)

(R⋈S)⋈T ≡ R⋈(S⋈T)

(R⋈S) MJ T
Cost=100

Sort$_{S.y}$((R⋈S) ⋈ T)
Cost=200

FindBestPlan (R⋈(S⋈T)), S.y , 500)

FindBestPlan ((R⋈S)⋈T),NULL ,300)

FindBestPlan (R⋈S, S.y , 400)
FindBestPlan (T, T.y , 400)

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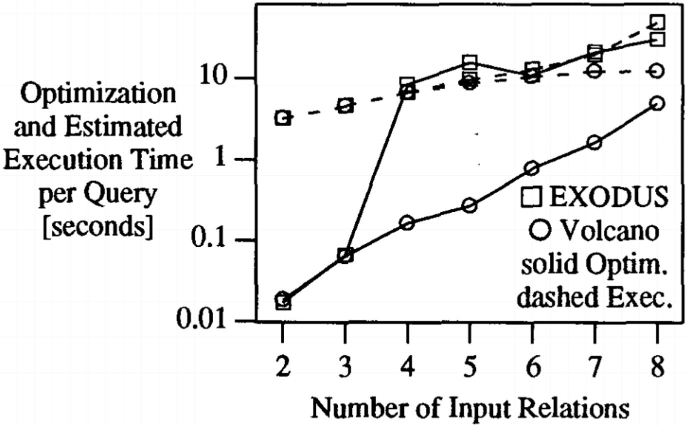
Experiment


Optimization and Estimated Execution Time per Query [seconds]
10
1
0.1
0.01
2
3
4
5
6
7
8
Number of Input Relations
□ EXODUS
○ Volcano
solid Optim.
dashed Exec.

Discussion

Pros

- Unified, fully cost-based model
- Easily add new operations and equivalence rules
- Pruning strategies can effectively reduce the searching space

Cons

- Only compare their method with one query optimization method
- Exhaustively generates all logically equivalent expressions

Conclusion

- Volcano improves the work of EXODUS
- Top-down optimizer, uses dynamic programming and memoisation
- Enumerates physical search space in depth-first order
- Uses branch and bound pruning to prune the search space
- Use physical properties to direct the search
- Volcano has gained widespread acceptance in the industry as a state-of-the-art optimizer; the optimizers of Microsoft SQL Server [21] and Tandem ServerWare SQL Product [6] are based on Volcano

Backup Slids

Logical / Implementation Rules

- **Logical Rules:** The algebraic rules of expression equivalence. They are used to get equivalent logical expressions.
- **Implementation Rules:** The possible mappings of operators to algorithms
- Algorithms have three properties
  - Required physical properties of its inputs
  - Physical properties of its output
  - Cost function

Example

- Commutative law: $R \bowtie S = S \bowtie R$
- Join can be implemented by merge-join, hash join or nested-loop join.
- merge-join requires the inputs to be sorted on the join attributes and produces the output sorted

Optimizer Generator

Model Specification

- A set of logical operators and algebraic transformation rules
- A set of algorithms, enforcers and implementation rules
- An applicability function for each algorithm and enforcer
- A cost function for each algorithm and enforcer
- Property function for each operator, algorithm and enforcer

- Given a model specification, Volcano generate a query optimizer.
- Optimizer source code is compiled and linked with the other DBMS software such as the query execution engine and with the search engine.
- When the DBMS is operational, the input query is passed to the optimizer, which generates an optimized plan for it.

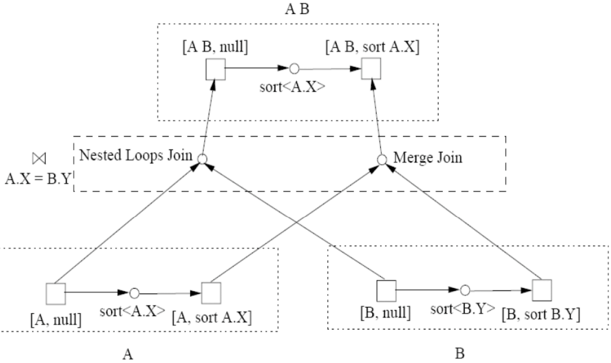
Difference between EXODUOS

- Volcano took less time to optimize
- EXODUS optimizer generator measurements were quite volatile and took a lot of memory
- EXODUSs generated optimizer and search engine do not explore and exploit physical properties

Difference between Starburst

- Volcano took less time to optimize
- New operators are integrated at the query rewrite level optimization in this level is heuristic
- Starburst has a hierarchy of intermediate levels

Physical Transformation



PQDAG for A ⋈ B on A.X=B.Y

dotted boxes - logical eqv. nodes; solid boxes – phys. eqv. nodes

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Algorithm

FindBestPlan (LogExpr, PhysProp, Limit)

- if the pair LogExpr and PhysProp is in the look-up table
    - if the cost in the look-up table < Limit
        - return Plan and Cost
    - else return failure
- /* else: optimization required */
- create the set of possible "moves" from
    - applicable transformations
    - algorithms that give the required PhysProp
    - enforcers for required PhysProp
- order the set of moves by promise

Algorithm

- for the most promising moves
  - if the move uses a transformation
    - apply the transformation creating NewLogExpr
    - call FindBestPlan (NewLogExpr, PhysProp, Limit)
  - else if the move uses an algorithm
    - TotalCost := cost of the algorithm
    - for each input I while TotalCost < Limit
      - determine required physical properties PP for I
        - Cost = FindBestPlan (I, PP, Limit − TotalCost)
        - add Cost to TotalCost
  - else /* move uses an enforcer */
    - TotalCost := cost of the enforcer
    - modify PhysProp for enforced property
    - call FindBestPlan for LogExpr with new PhysProp

Algorithm

- /* maintain the look-up table of explored facts */
- if LogExpr is not in the look-up table
  - insert LogExpr into the look-up table
  - insert PhysProp and best plan found into look-up table
- return best Plan and Cost