Lecture #19

Carnegie Mellon University

ADVANCED DATABASE SYSTEMS

Optimizer Implementation (Part I)

@Andy_Pavlo // 15-721 // Spring 2020

QUERY OPTIMIZATION

For a given query, find a **correct** execution plan that has the lowest "cost".

This is the part of a DBMS that is the hardest to implement well (proven to be NP-Complete).

No optimizer truly produces the "optimal" plan

→ Use estimation techniques to guess real plan cost.

→ Use heuristics to limit the search space.

NEXT THREE WEEKS

Optimizer Implementations

Query Rewriting

Plan Enumerations

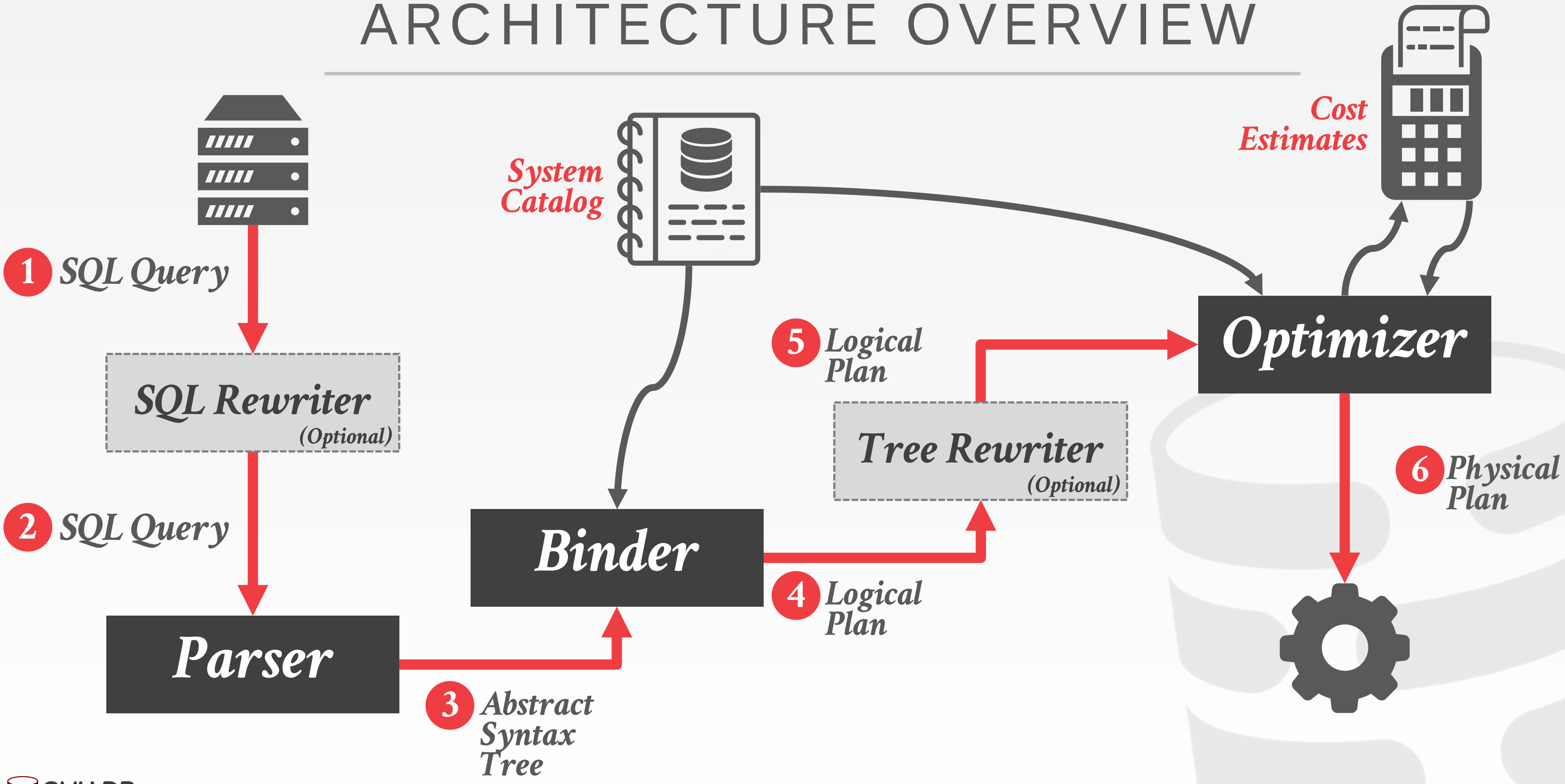
Adaptive Query Optimization

Cost Models

TODAY'S AGENDA

Background
Implementation Design Decisions
Optimizer Search Strategies

ARCHITECTURE OVERVIEW



LOGICAL VS. PHYSICAL PLANS

The optimizer generates a mapping of a logical algebra expression to the optimal equivalent physical algebra expression.

Physical operators define a specific execution strategy using an access path.

→ They can depend on the physical format of the data that they process (i.e., sorting, compression).
→ Not always a 1:1 mapping from logical to physical.

RELATIONAL ALGEBRA EQUIVALENCES

Two relational algebra expressions are said to be **equivalent** if on every legal database instance the two expressions generate the same set of tuples.

Example: $(A \bowtie (B \bowtie C)) = (B \bowtie (A \bowtie C))$

OBSERVATION

Search
Argument
Able

Query planning for OLTP queries is easy because they are **sargable**.

→ It is usually picking the best index with simple heuristics.

→ Joins are almost always on foreign key relationships with a small cardinality.

```
CREATE TABLE foo (
  id INT PRIMARY KEY,
  name VARCHAR(32),
  ⋮
);
```

```
SELECT name FROM foo
 WHERE id = 123;
```

COST ESTIMATION

Generate an estimate of the cost of executing a plan for the current state of the database.

→ Interactions with other work in DBMS
→ Size of intermediate results
→ Choices of algorithms, access methods
→ Resource utilization (CPU, I/O, network)
→ Data properties (skew, order, placement)

We will discuss this more next week…

DESIGN DECISIONS

Optimization Granularity

Optimization Timing

Prepared Statements

Plan Stability

Search Termination

OPTIMIZATION GRANULARITY

Choice #1: Single Query

→ Much smaller search space.
→ DBMS (usually) does not reuse results across queries.
→ To account for resource contention, the cost model must consider what is currently running.

Choice #2: Multiple Queries

→ More efficient if there are many similar queries.
→ Search space is much larger.
→ Useful for data / intermediate result sharing.

OPTIMIZATION TIMING

Choice #1: Static Optimization

→ Select the best plan prior to execution.
→ Plan quality is dependent on cost model accuracy.
→ Can amortize over executions with prepared statements.

Choice #2: Dynamic Optimization

→ Select operator plans on-the-fly as queries execute.
→ Will have re-optimize for multiple executions.
→ Difficult to implement/debug (non-deterministic)

Choice #3: Adaptive Optimization

→ Compile using a static algorithm.
→ If the estimate errors > threshold, change or re-optimize.

PREPARED STATEMENTS

```
SELECT A.id, B.val
  FROM A, B, C
 WHERE A.id = B.id
   AND B.id = C.id
   AND A.val > 100
   AND B.val > 99
   AND C.val > 5000
```

PREPARED STATEMENTS

```
PREPARE myQuery AS
  SELECT A.id, B.val
    FROM A, B, C
   WHERE A.id = B.id
     AND B.id = C.id
     AND A.val > 100
     AND B.val > 99
     AND C.val > 5000
```

```
EXECUTE myQuery;
```

PREPARED STATEMENTS

```
PREPARE myQuery AS
  SELECT A.id, B.val
    FROM A, B, C
   WHERE A.id = B.id
     AND B.id = C.id
     AND A.val > 100
     AND B.val > 99
     AND C.val > 5000
```

```
EXECUTE myQuery;
```

PREPARED STATEMENTS

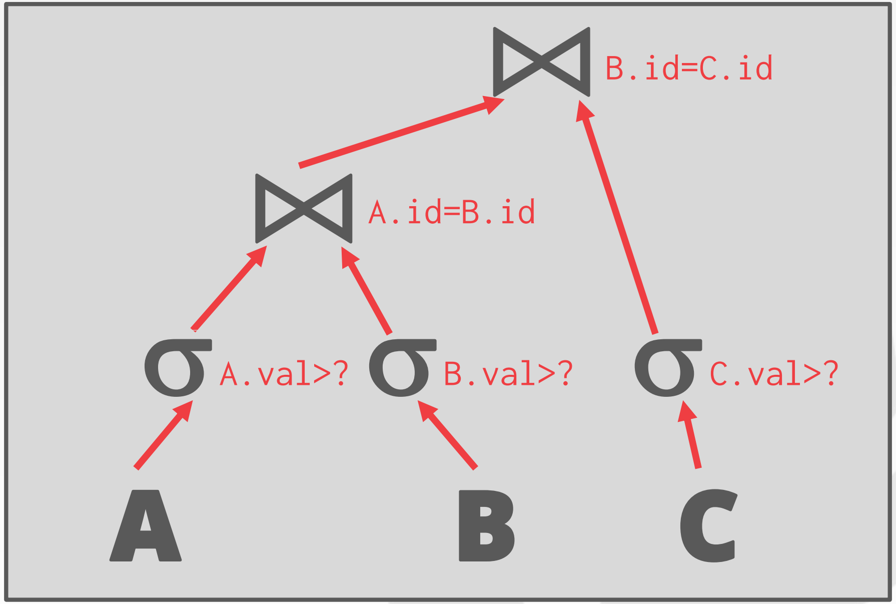
```
PREPARE myQuery(int, int, int) AS
  SELECT A.id, B.val
    FROM A, B, C
   WHERE A.id = B.id
     AND B.id = C.id
     AND A.val > ?
     AND B.val > ?
     AND C.val > ?
```

```
EXECUTE myQuery(100, 99, 5000);
```

PREPARED STATEMENTS

```
PREPARE myQuery(int, int, int) AS
  SELECT A.id, B.val
    FROM A, B, C
   WHERE A.id = B.id
     AND B.id = C.id
     AND A.val > ?
     AND B.val > ?
     AND C.val > ?
```

```
EXECUTE myQuery(100, 99, 5000);
```



What should be the join order for **A**, **B**, and **C?**

PREPARED STATEMENTS

Choice #1: Reuse Last Plan

→ Use the plan generated for the previous invocation.

Choice #2: Re-Optimize

→ Rerun optimizer each time the query is invoked.
→ Tricky to reuse existing plan as starting point.

Choice #3: Multiple Plans

→ Generate multiple plans for different values of the parameters (e.g., buckets).

Choice #4: Average Plan

→ Choose the average value for a parameter and use that for all invocations.

PLAN STABILITY

Choice #1: Hints

→ Allow the DBA to provide hints to the optimizer.

Choice #2: Fixed Optimizer Versions

→ Set the optimizer version number and migrate queries one-by-one to the new optimizer.

Choice #3: Backwards-Compatible Plans

→ Save query plan from old version and provide it to the new DBMS.

SEARCH TERMINATION

Approach #1: Wall-clock Time

→ Stop after the optimizer runs for some length of time.

Approach #2: Cost Threshold

→ Stop when the optimizer finds a plan that has a lower cost than some threshold.

Approach #3: Exhaustion

→ Stop when there are no more enumerations of the target plan. Usually done per group.

OPTIMIZATION SEARCH STRATEGIES

Heuristics

Heuristics + Cost-based Join Order Search

Randomized Algorithms

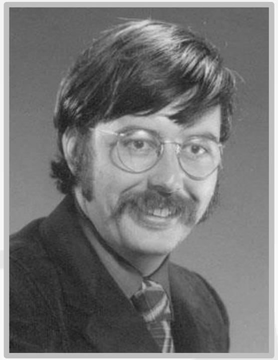
Stratified Search

Unified Search

HEURISTIC-BASED OPTIMIZATION

Define static rules that transform logical operators to a physical plan.

→ Perform most restrictive selection early
→ Perform all selections before joins
→ Predicate/Limit/Projection pushdowns
→ Join ordering based on cardinality



Stonebraker

Examples: INGRES and Oracle (until mid 1990s).

QUERY PROCESSING IN A RELATIONAL DATABASE MANAGEMENT SYSTEM
VLDB 1979

EXAMPLE DATABASE

```
CREATE TABLE ARTIST (
  ID INT PRIMARY KEY,
  NAME VARCHAR(32)
);
```

```
CREATE TABLE ALBUM (
  ID INT PRIMARY KEY,
  NAME VARCHAR(32) UNIQUE
);
```

```
CREATE TABLE APPEARS (
  ARTIST_ID INT
   ↳REFERENCES ARTIST(ID),
  ALBUM_ID INT
   ↳REFERENCES ALBUM(ID),
  PRIMARY KEY
   ↳(ARTIST_ID, ALBUM_ID)
);
```

INGRES OPTIMIZER

Retrieve the names of people that appear on Andy's mixtape

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, ALBUM
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=ALBUM.ID
   AND ALBUM.NAME="Andy's OG Remix"
```

Q1

```
SELECT ALBUM.ID AS ALBUM_ID INTO TEMP1
  FROM ALBUM
 WHERE ALBUM.NAME="Andy's OG Remix"
```

Q2

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, TEMP1
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=TEMP1.ALBUM_ID
```

Step #1: Decompose into single-value queries

INGRES OPTIMIZER

Retrieve the names of people that appear on Andy's mixtape

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, ALBUM
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=ALBUM.ID
   AND ALBUM.NAME="Andy's OG Remix"
```

Q1

```
SELECT ALBUM.ID AS ALBUM_ID INTO TEMP1
  FROM ALBUM
 WHERE ALBUM.NAME="Andy's OG Remix"
```

Q2

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, TEMP1
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=TEMP1.ALBUM_ID
```

Step #1: Decompose into single-value queries

INGRES OPTIMIZER

Retrieve the names of people that appear on Andy's mixtape

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, ALBUM
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=ALBUM.ID
   AND ALBUM.NAME="Andy's OG Remix"
```

Q1

```
SELECT ALBUM.ID AS ALBUM_ID INTO TEMP1
  FROM ALBUM
 WHERE ALBUM.NAME="Andy's OG Remix"
```

Q3

```
SELECT APPEARS.ARTIST_ID INTO TEMP2
  FROM APPEARS, TEMP1
 WHERE APPEARS.ALBUM_ID=TEMP1.ALBUM_ID
```

Q4

```
SELECT ARTIST.NAME
  FROM ARTIST, TEMP2
 WHERE ARTIST.ARTIST_ID=TEMP2.ARTIST_ID
```

Step #1: Decompose into single-value queries

INGRES OPTIMIZER

Retrieve the names of people that appear on Andy's mixtape

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, ALBUM
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=ALBUM.ID
   AND ALBUM.NAME="Andy's OG Remix"
```

Step #1: Decompose into single-value queries

Step #2: Substitute the values from Q1→Q3→Q4

Q1

```
SELECT ALBUM.ID AS ALBUM_ID INTO TEMP1
  FROM ALBUM
 WHERE ALBUM.NAME="Andy's OG Remix"
```

Q3

```
SELECT APPEARS.ARTIST_ID INTO TEMP2
  FROM APPEARS, TEMP1
 WHERE APPEARS.ALBUM_ID=TEMP1.ALBUM_ID
```

Q4

```
SELECT ARTIST.NAME
  FROM ARTIST, TEMP2
 WHERE ARTIST.ARTIST_ID=TEMP2.ARTIST_ID
```

INGRES OPTIMIZER

Retrieve the names of people that appear on Andy's mixtape

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, ALBUM
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=ALBUM.ID
   AND ALBUM.NAME="Andy's OG Remix"
```

ALBUM_ID
9999

Q3

```
SELECT APPEARS.ARTIST_ID INTO TEMP2
  FROM APPEARS, TEMP1
 WHERE APPEARS.ALBUM_ID=TEMP1.ALBUM_ID
```

Q4

```
SELECT ARTIST.NAME
  FROM ARTIST, TEMP2
 WHERE ARTIST.ARTIST_ID=TEMP2.ARTIST_ID
```

Step #1: Decompose into single-value queries

Step #2: Substitute the values from Q1→Q3→Q4

INGRES OPTIMIZER

Retrieve the names of people that appear on Andy's mixtape

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, ALBUM
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=ALBUM.ID
   AND ALBUM.NAME="Andy's OG Remix"
```

ALBUM_ID
9999

```
SELECT APPEARS.ARTIST_ID
  FROM APPEARS
 WHERE APPEARS.ALBUM_ID=9999
```

Step #1: Decompose into single-value queries

Step #2: Substitute the values from Q1→Q3→Q4

Q4

```
SELECT ARTIST.NAME
  FROM ARTIST, TEMP2
 WHERE ARTIST.ARTIST_ID=TEMP2.ARTIST_ID
```

INGRES OPTIMIZER

Retrieve the names of people that appear on Andy's mixtape

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, ALBUM
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=ALBUM.ID
   AND ALBUM.NAME="Andy's OG Remix"
```

ALBUM_ID
9999

ARTIST_ID
123
456

Step #1: Decompose into single-value queries

Step #2: Substitute the values from Q1→Q3→Q4

Q4

```
SELECT ARTIST.NAME
  FROM ARTIST, TEMP2
 WHERE ARTIST.ARTIST_ID=TEMP2.ARTIST_ID
```

INGRES OPTIMIZER

Retrieve the names of people that appear on Andy's mixtape

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, ALBUM
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=ALBUM.ID
   AND ALBUM.NAME="Andy's OG Remix"
```

ALBUM_ID
9999

ARTIST_ID
123
456

```
SELECT ARTIST.NAME
  FROM ARTIST
 WHERE ARTIST.ARTIST_ID=123
```

```
SELECT ARTIST.NAME
  FROM ARTIST
 WHERE ARTIST.ARTIST_ID=456
```

Step #1: Decompose into single-value queries

Step #2: Substitute the values from Q1→Q3→Q4

INGRES OPTIMIZER

Retrieve the names of people that appear on Andy's mixtape

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, ALBUM
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=ALBUM.ID
   AND ALBUM.NAME="Andy's OG Remix"
```

ALBUM_ID
9999

ARTIST_ID
123
456

NAME
O.D.B.

NAME
DJ Premier

Step #1: Decompose into single-value queries

Step #2: Substitute the values from Q1→Q3→Q4

HEURISTIC-BASED OPTIMIZATION

Advantages:

→ Easy to implement and debug.
→ Works reasonably well and is fast for simple queries.

Disadvantages:

→ Relies on magic constants that predict the efficacy of a planning decision.
→ Nearly impossible to generate good plans when operators have complex inter-dependencies.

HEURISTICS + COST-BASED JOIN SEARCH

Use static rules to perform initial optimization. Then use dynamic programming to determine the best join order for tables.

→ First cost-based query optimizer

→ **Bottom-up planning** (forward chaining) using a divide-and-conquer search method

Selinger

Examples: System R, early IBM DB2, most open-source DBMSs.

ACCESS PATH SELECTION IN A RELATIONAL DATABASE MANAGEMENT SYSTEM
SIGMOD 1979

SYSTEM R OPTIMIZER

Break query up into blocks and generate the logical operators for each block.

For each logical operator, generate a set of physical operators that implement it.

→ All combinations of join algorithms and access paths

Then iteratively construct a "left-deep" join tree that minimizes the estimated amount of work to execute the plan.

SYSTEM R OPTIMIZER

Retrieve the names of people that appear on Andy's mixtape ordered by their artist id.

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, ALBUM
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=ALBUM.ID
   AND ALBUM.NAME="Andy's OG Remix"
 ORDER BY ARTIST.ID
```

SYSTEM R OPTIMIZER

Retrieve the names of people that appear on Andy's mixtape ordered by their artist id.

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, ALBUM
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=ALBUM.ID
   AND ALBUM.NAME="Andy's OG Remix"
 ORDER BY ARTIST.ID
```

Step #1: Choose the best access paths to each table

ARTIST: Sequential Scan

APPEARS: Sequential Scan

ALBUM: Index Look-up on **NAME**

SYSTEM R OPTIMIZER

Retrieve the names of people that appear on Andy's mixtape ordered by their artist id.

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, ALBUM
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=ALBUM.ID
   AND ALBUM.NAME="Andy's OG Remix"
 ORDER BY ARTIST.ID
```

ARTIST: Sequential Scan
APPEARS: Sequential Scan
ALBUM: Index Look-up on **NAME**

Step #1: Choose the best access paths to each table

Step #2: Enumerate all possible join orderings for tables

ARTIST ⋈ APPEARS ⋈ ALBUM
APPEARS ⋈ ALBUM ⋈ ARTIST
ALBUM ⋈ APPEARS ⋈ ARTIST
APPEARS ⋈ ARTIST ⋈ ALBUM
ARTIST × ALBUM ⋈ APPEARS
ALBUM × ARTIST ⋈ APPEARS
⋮ ⋮ ⋮

SYSTEM R OPTIMIZER

Retrieve the names of people that appear on Andy's mixtape ordered by their artist id.

```
SELECT ARTIST.NAME
  FROM ARTIST, APPEARS, ALBUM
 WHERE ARTIST.ID=APPEARS.ARTIST_ID
   AND APPEARS.ALBUM_ID=ALBUM.ID
   AND ALBUM.NAME="Andy's OG Remix"
 ORDER BY ARTIST.ID
```

Step #1: Choose the best access paths to each table

Step #2: Enumerate all possible join orderings for tables

Step #3: Determine the join ordering with the lowest cost

ARTIST: Sequential Scan
APPEARS: Sequential Scan
ALBUM: Index Look-up on **NAME**

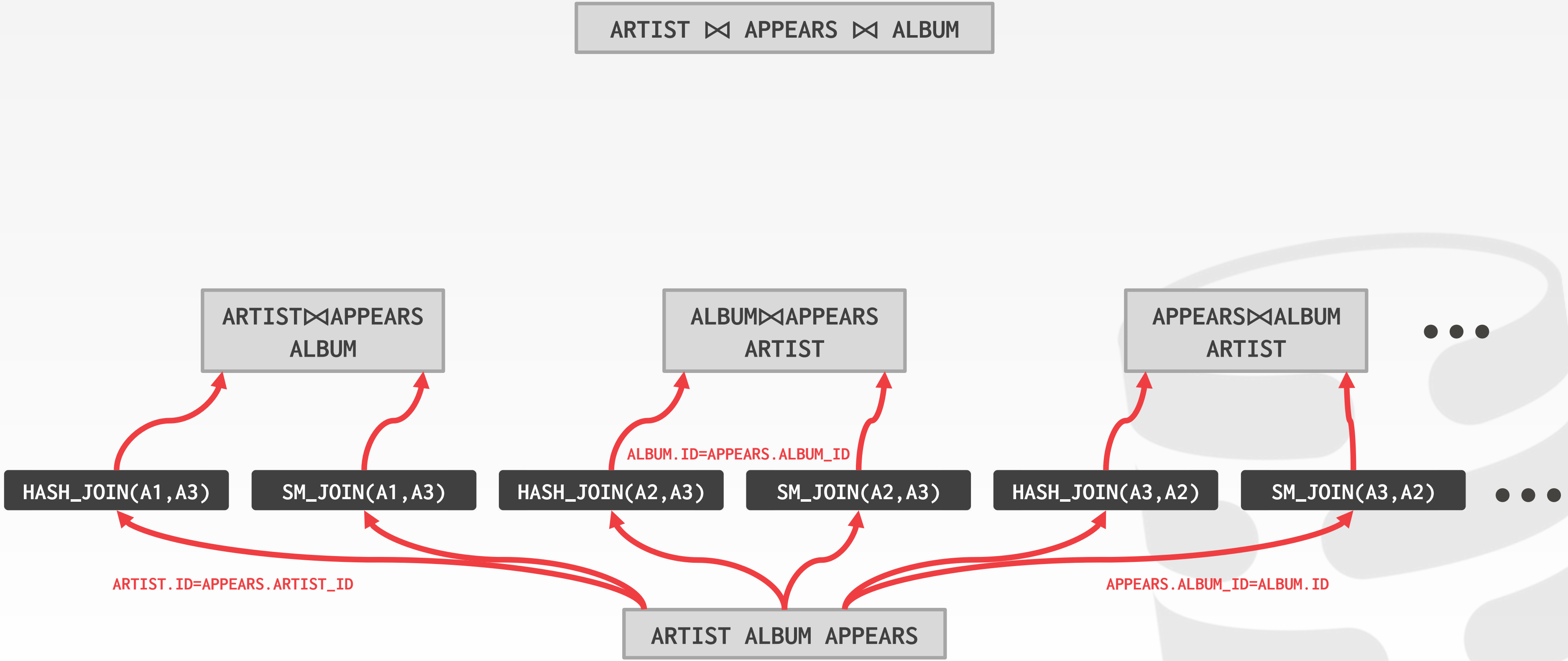
ARTIST ⋈ APPEARS ⋈ ALBUM
APPEARS ⋈ ALBUM ⋈ ARTIST
ALBUM ⋈ APPEARS ⋈ ARTIST
APPEARS ⋈ ARTIST ⋈ ALBUM
ARTIST × ALBUM ⋈ APPEARS
ALBUM × ARTIST ⋈ APPEARS
⋮ ⋮ ⋮

SYSTEM R OPTIMIZER

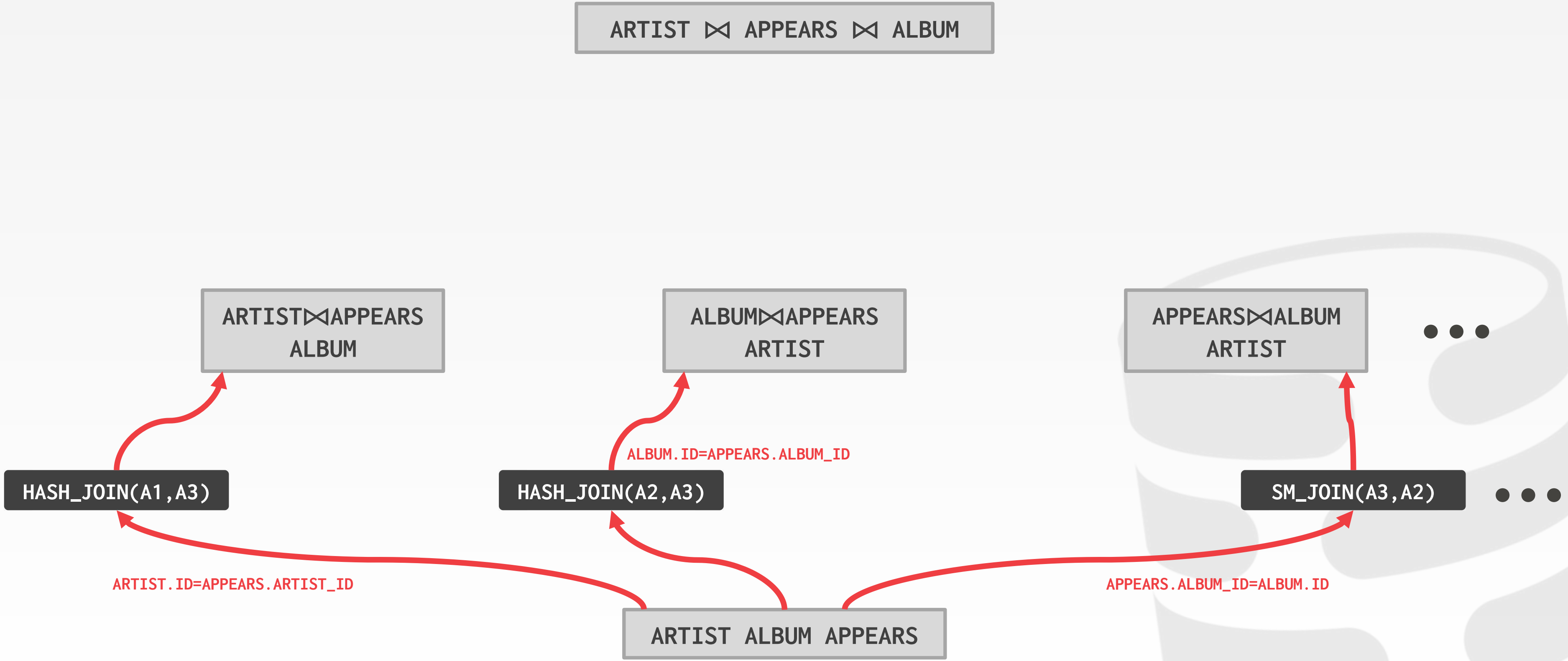
ARTIST ⋈ APPEARS ⋈ ALBUM

ARTIST ALBUM APPEARS

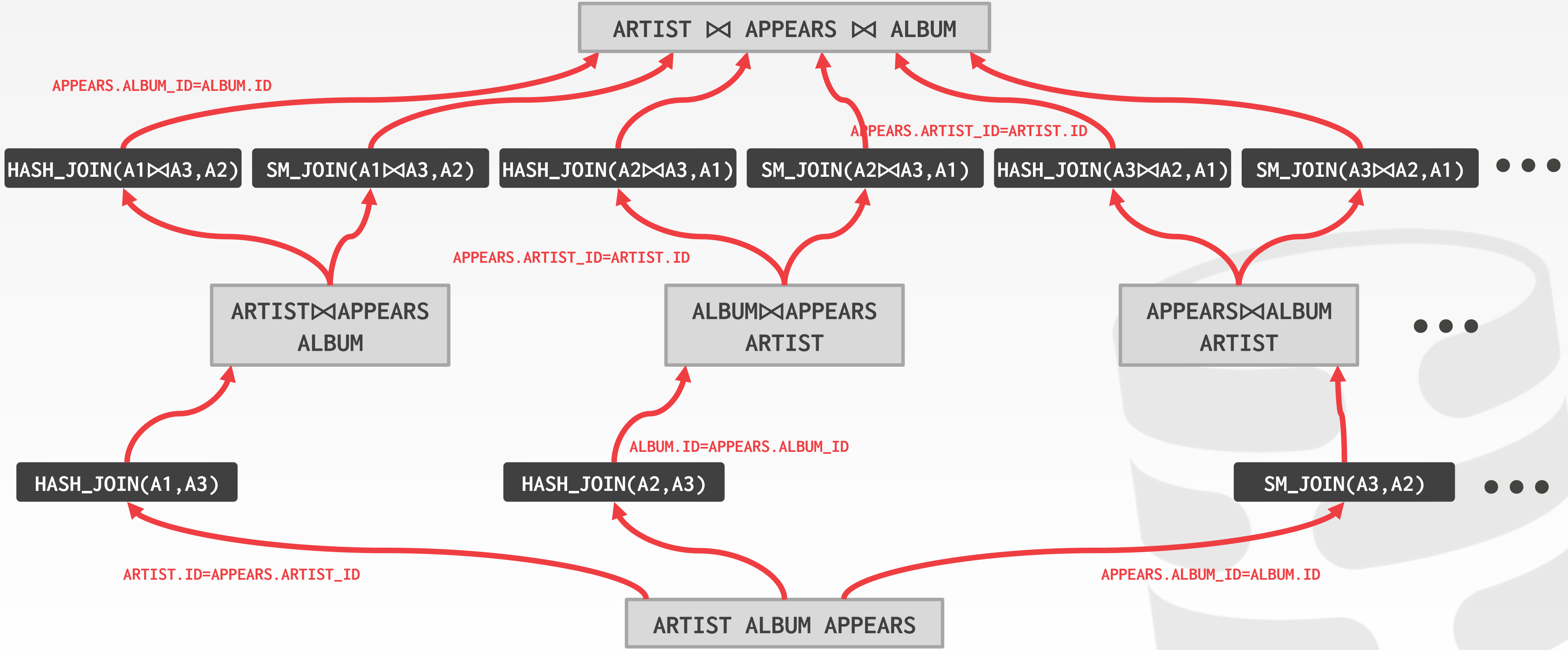
SYSTEM R OPTIMIZER



SYSTEM R OPTIMIZER



SYSTEM R OPTIMIZER



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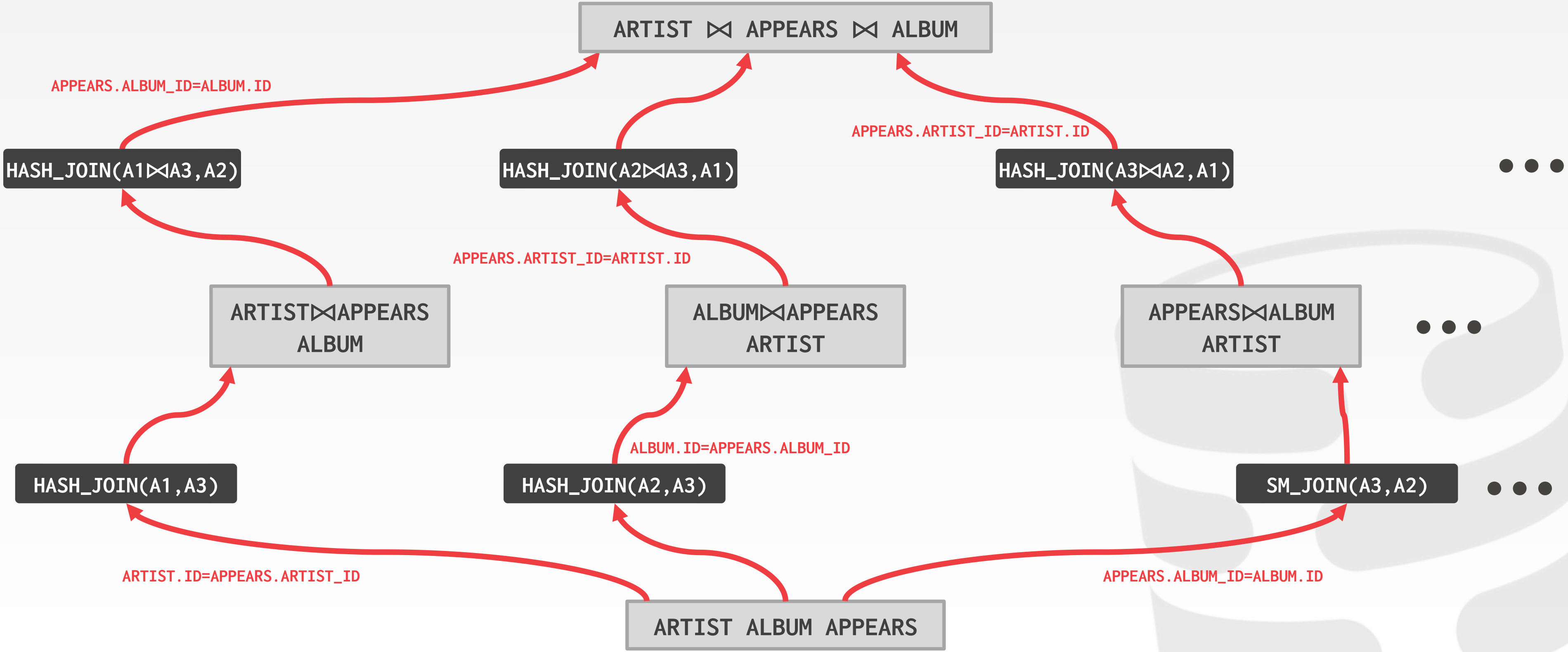

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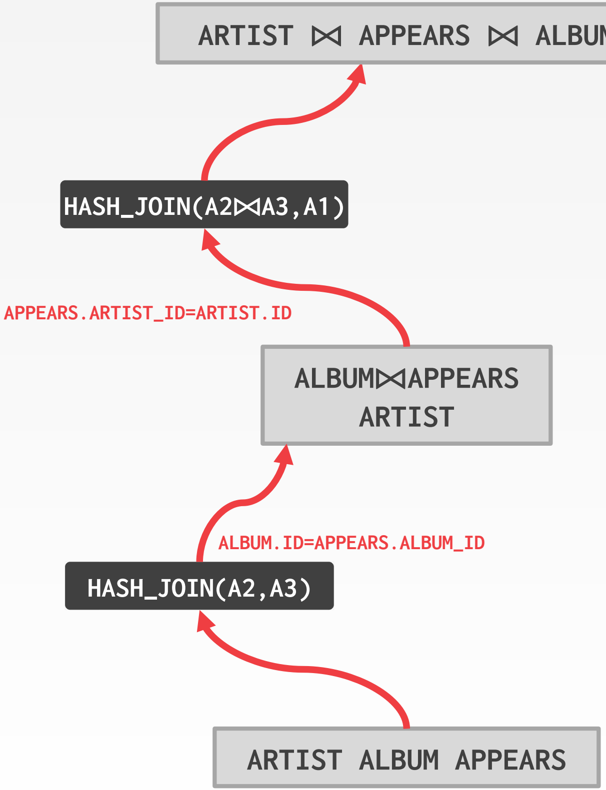
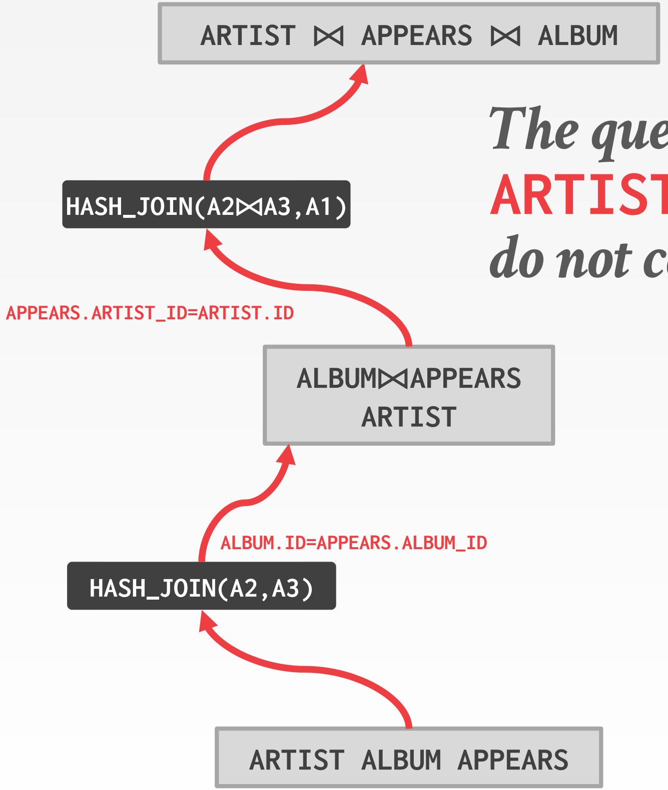


SYSTEM R OPTIMIZER



The query has **ORDER BY** *on* **ARTIST.ID** *but the logical plans do not contain sorting properties.*

TOP-DOWN VS. BOTTOM-UP

Top-down Optimization

→ Start with the outcome that you want, and then work down the tree to find the optimal plan that gets you to that goal.

→ **Examples**: Volcano, Cascades

Bottom-up Optimization

→ Start with nothing and then build up the plan to get to the outcome that you want.

→ **Examples**: System R, Starburst

POSTGRES OPTIMIZER

Imposes a rigid workflow for query optimization:

→ First stage performs initial rewriting with heuristics
→ It then executes a cost-based search to find optimal join ordering.
→ Everything else is treated as an "add-on".
→ Then recursively descends into sub-queries.

Difficult to modify or extend because the ordering must be preserved.

HEURISTICS + COST-BASED JOIN SEARCH

Advantages:

→ Usually finds a reasonable plan without having to perform an exhaustive search.

Disadvantages:

→ All the same problems as the heuristic-only approach.
→ Left-deep join trees are not always optimal.
→ Must take in consideration the physical properties of data in the cost model (e.g., sort order).

RANDOMIZED ALGORITHMS

Perform a random walk over a solution space of all possible (valid) plans for a query.

Continue searching until a cost threshold is reached or the optimizer runs for a length of time.

Examples: Postgres' genetic algorithm.

SIMULATED ANNEALING

Start with a query plan that is generated using the heuristic-only approach.

Compute random permutations of operators (e.g., swap the join order of two tables)

→ Always accept a change that reduces cost
→ Only accept a change that increases cost with some probability.
→ Reject any change that violates correctness (e.g., sort ordering)

QUERY OPTIMIZATION BY SIMULATED ANNEALING
SIGMOD 1987

POSTGRES GENETIC OPTIMIZER

More complicated queries use a **genetic algorithm** that selects join orderings (GEQO).

At the beginning of each round, generate different variants of the query plan.

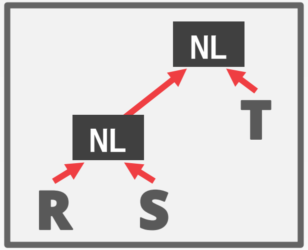
Select the plans that have the lowest cost and permute them with other plans. Repeat.

→ The mutator function only generates valid plans.

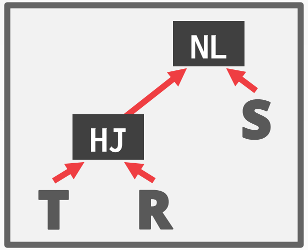
Source: Postgres Documentation

POSTGRES GENETIC OPTIMIZER

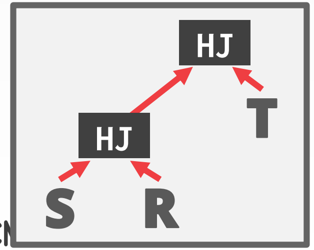
1st Generation



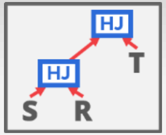
Cost: 300



Cost: 200



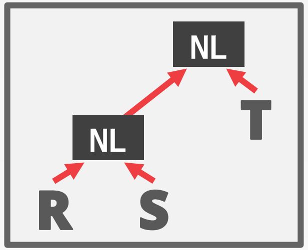
Cost: 100



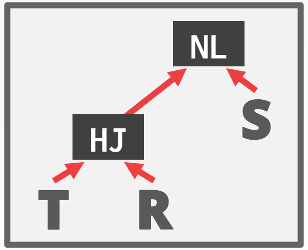
POSTGRES GENETIC OPTIMIZER

Best:100

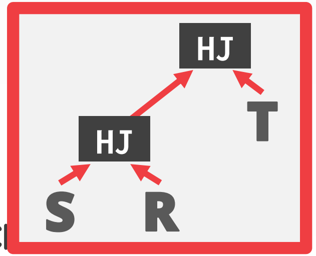
1st Generation



Cost: 300

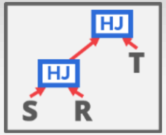


Cost: 200



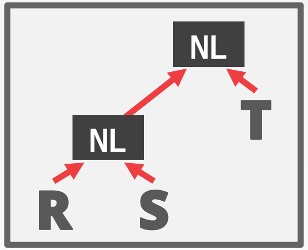
Cost: 100

POSTGRES GENETIC OPTIMIZER



Best:100

1st Generation



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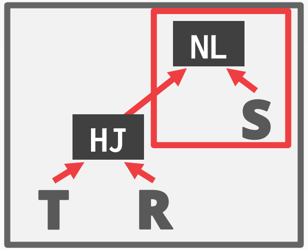

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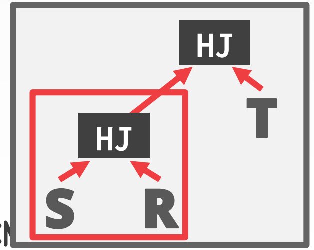
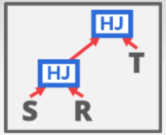


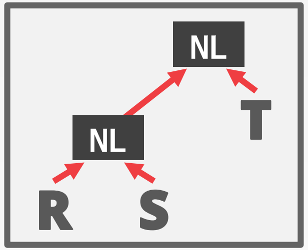
Cost: 100

POSTGRES GENETIC OPTIMIZER

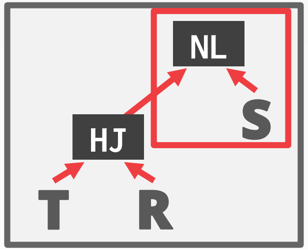


Best:100

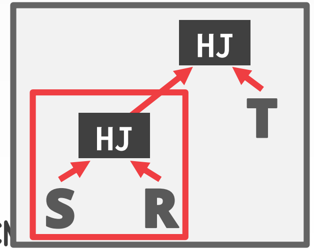
1st Generation



Cost: 300

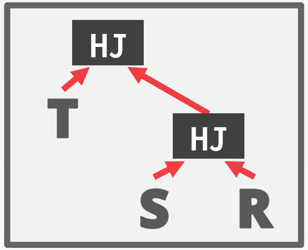


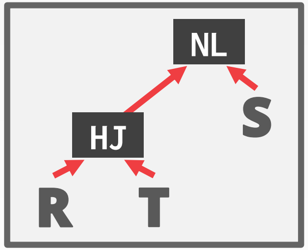
Cost: 200

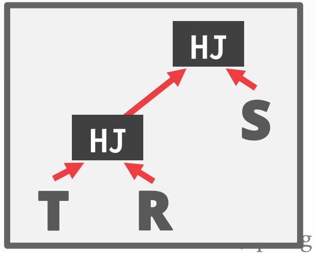


Cost: 100

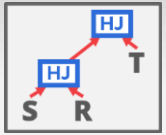
2nd Generation







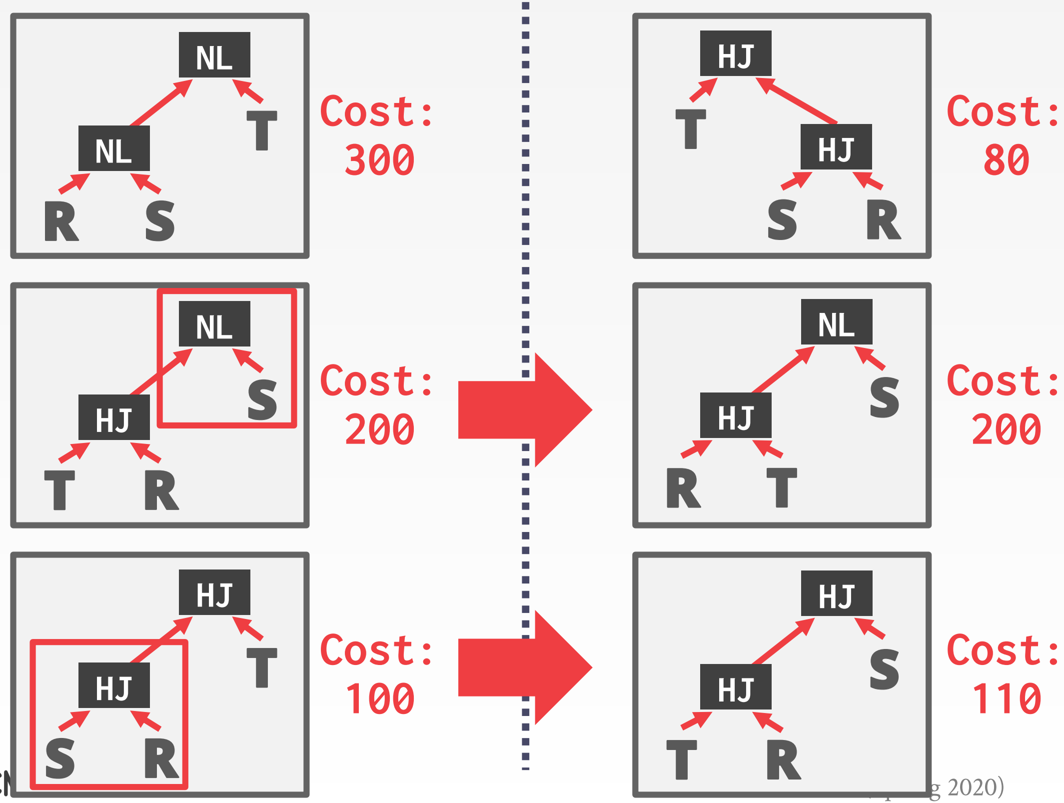
POSTGRES GENETIC OPTIMIZER



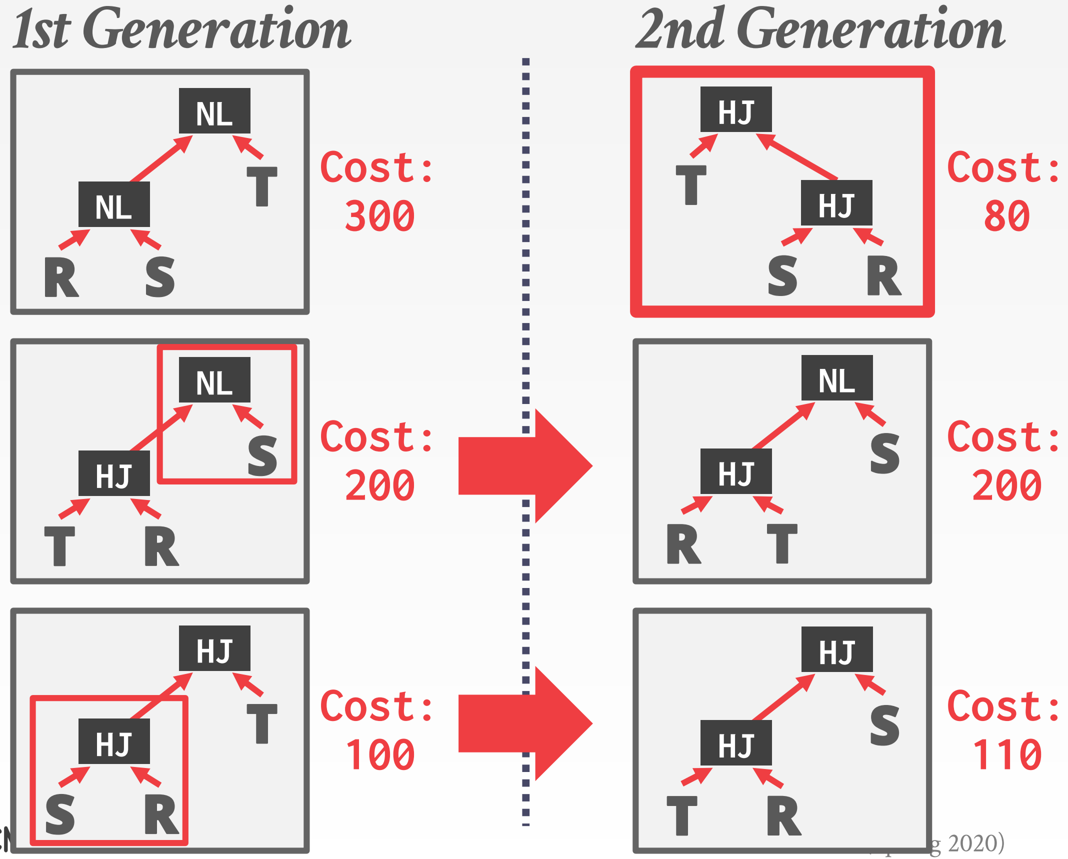
Best:100

1st Generation

2nd Generation

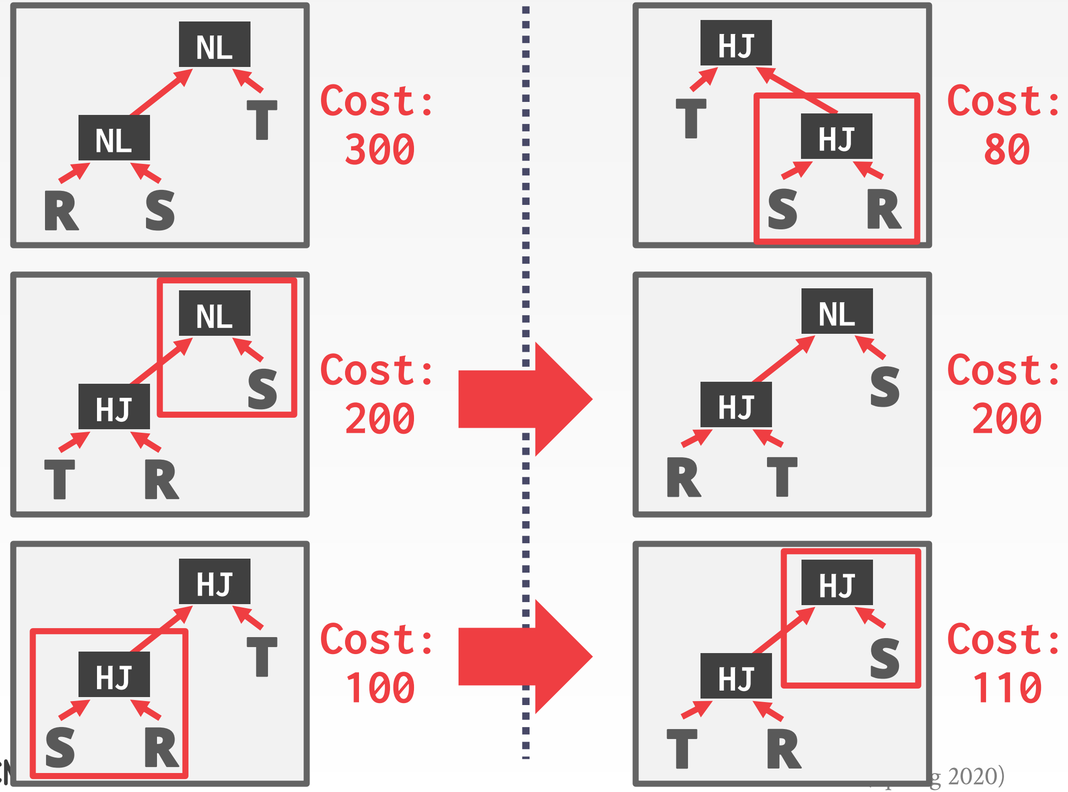


POSTGRES GENETIC OPTIMIZER

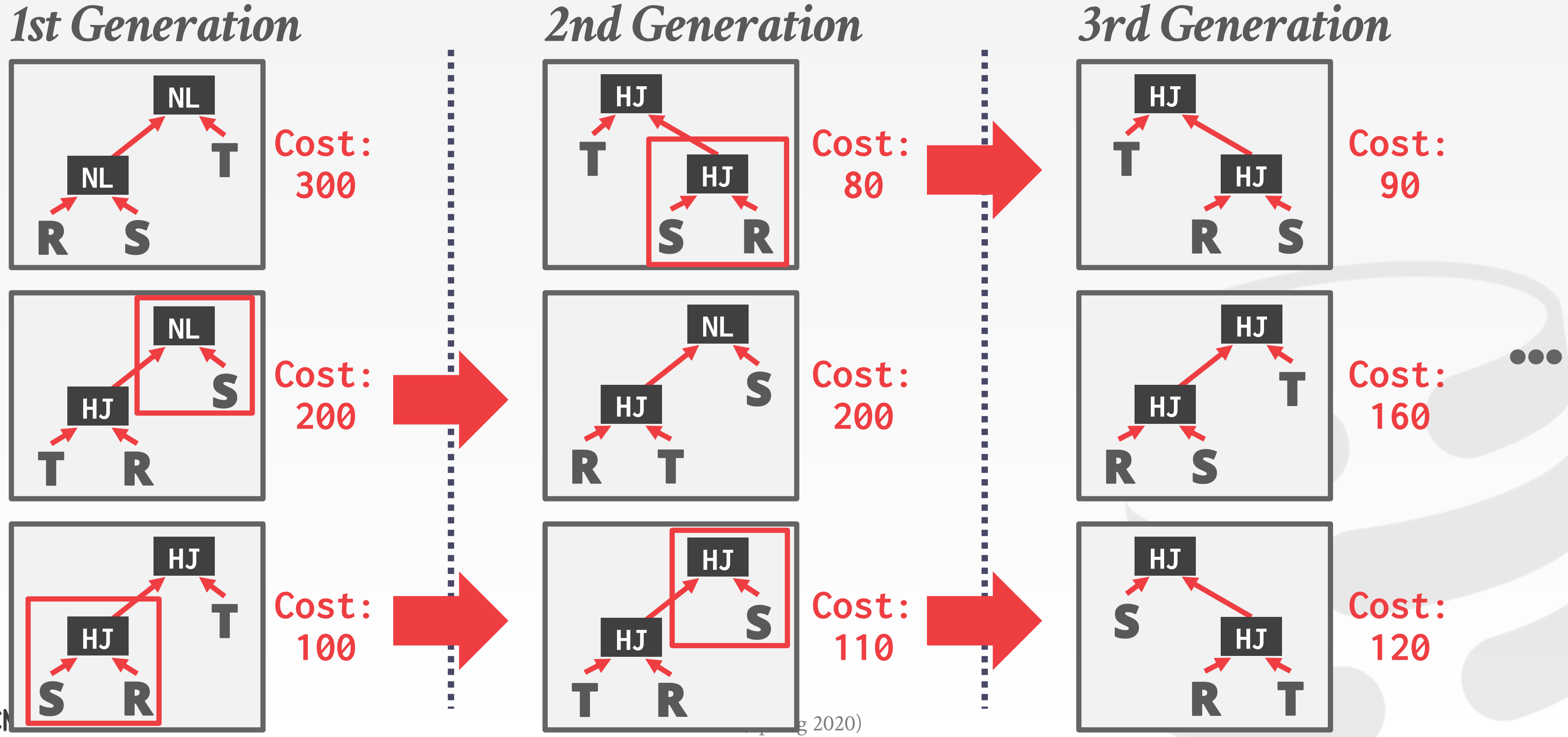


POSTGRES GENETIC OPTIMIZER

1st Generation | *2nd Generation*



POSTGRES GENETIC OPTIMIZER



RANDOMIZED ALGORITHMS

Advantages:

→ Jumping around the search space randomly allows the optimizer to get out of local minimums.

→ Low memory overhead (if no history is kept).

Disadvantages:

→ Difficult to determine why the DBMS may have chosen a plan.

→ Must do extra work to ensure that query plans are deterministic.

→ Still must implement correctness rules.

OBSERVATION

Writing query transformation rules in a procedural language is hard and error-prone.

→ No easy way to verify that the rules are correct without running a lot of fuzz tests.

→ Generation of physical operators per logical operator is decoupled from deeper semantics about query.

A better approach is to use a declarative DSL to write the transformation rules and then have the optimizer enforce them during planning.

OPTIMIZER GENERATORS

Framework to allow a DBMS implementer to write the declarative rules for optimizing queries.

→ Separate the search strategy from the data model.

→ Separate the transformation rules and logical operators from physical rules and physical operators.

Implementation can be independent of the optimizer's search strategy.

Examples: Starburst, Exodus, Volcano, Cascades, OPT++

OPTIMIZER GENERATORS

Use a rule engine that allows transformations to modify the query plan operators.

The physical properties of data is embedded with the operators themselves.

Choice #1: Stratified Search

→ Planning is done in multiple stages

Choice #2: Unified Search

→ Perform query planning all at once.

STRATIFIED SEARCH

First rewrite the logical query plan using transformation rules.

→ The engine checks whether the transformation is allowed before it can be applied.
→ Cost is never considered in this step.

Then perform a cost-based search to map the logical plan to a physical plan.

STARBURST OPTIMIZER

Lohman

Better implementation of the System R optimizer that uses declarative rules.

Stage #1: Query Rewrite

→ Compute a SQL-block-level, relational calculus-like representation of queries.

Stage #2: Plan Optimization

→ Execute a System R-style dynamic programming phase once query rewrite has completed.

Example: Latest version of IBM DB2

GRAMMAR-LIKE FUNCTIONAL RULES FOR REPRESENTING QUERY OPTIMIZATION ALTERNATIVES
SIGMOD 1988

STARBURST OPTIMIZER

Advantages:

→ Works well in practice with fast performance.

Disadvantages:

→ Difficult to assign priorities to transformations

→ Some transformations are difficult to assess without computing multiple cost estimations.

→ Rules maintenance is a huge pain.

UNIFIED SEARCH

Unify the notion of both logical→logical and logical→physical transformations.

→ No need for separate stages because everything is transformations.

This approach generates many transformations, so it makes heavy use of memoization to reduce redundant work.

VOLCANO OPTIMIZER

General purpose cost-based query optimizer, based on equivalence rules on algebras.

→ Easily add new operations and equivalence rules.

→ Treats physical properties of data as first-class entities during planning.

→ **Top-down approach** (backward chaining) using branch-and-bound search.

Graefe

Example: Academic prototypes

THE VOLCANO OPTIMIZER GENERATOR: EXTENSIBILITY AND EFFICIENT SEARCH
ICDE 1993

VOLCANO OPTIMIZER

Start with a logical plan of what we want the query to be.

```
ARTIST ⋈ APPEARS ⋈ ALBUM
ORDER-BY(ARTIST.ID)
```

VOLCANO OPTIMIZER

Start with a logical plan of what we want the query to be.

Invoke rules to create new nodes and traverse tree.

→ **Logical→Logical:**
  JOIN(A,B) to JOIN(B,A)

→ **Logical→Physical:**
  JOIN(A,B) to HASH_JOIN(A,B)

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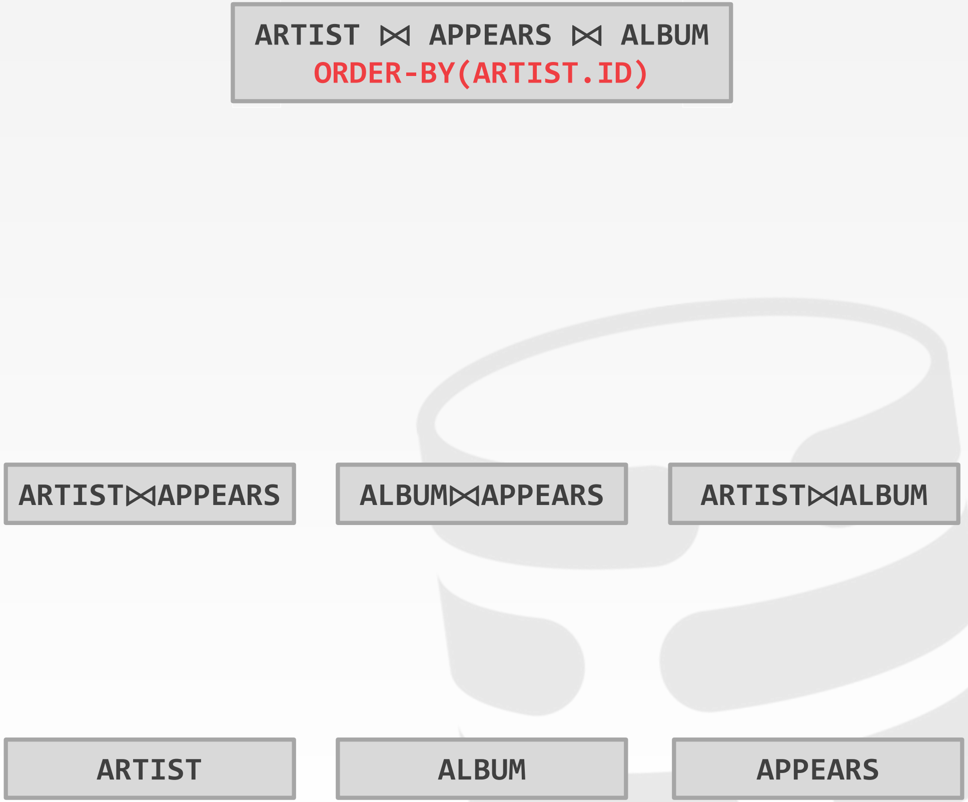

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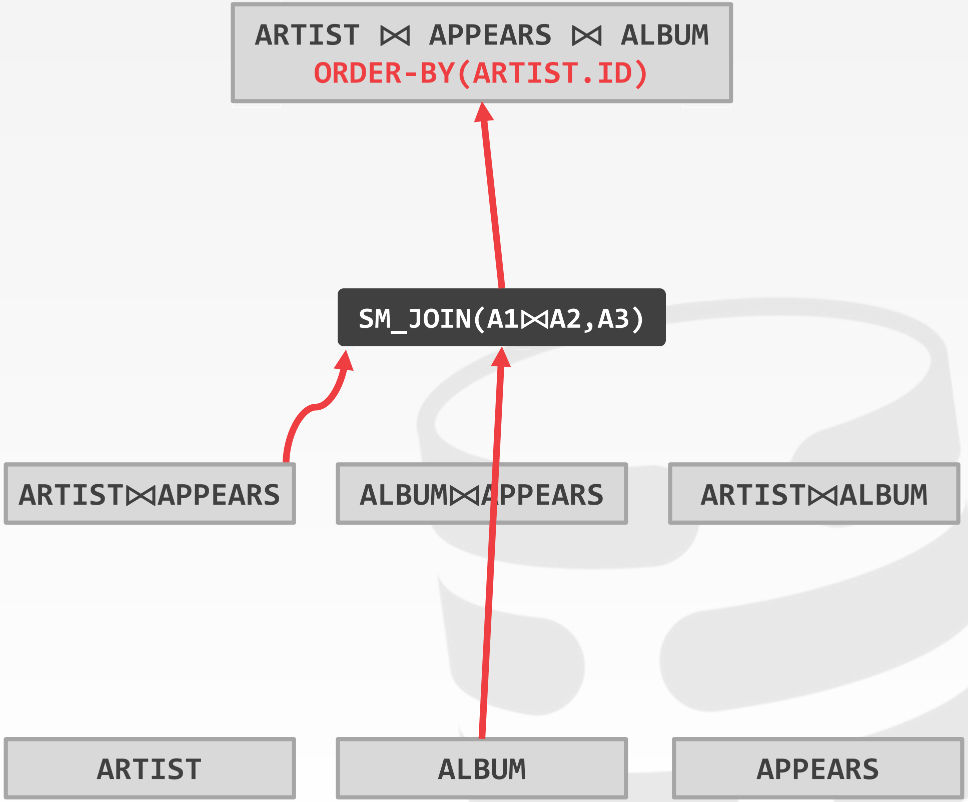

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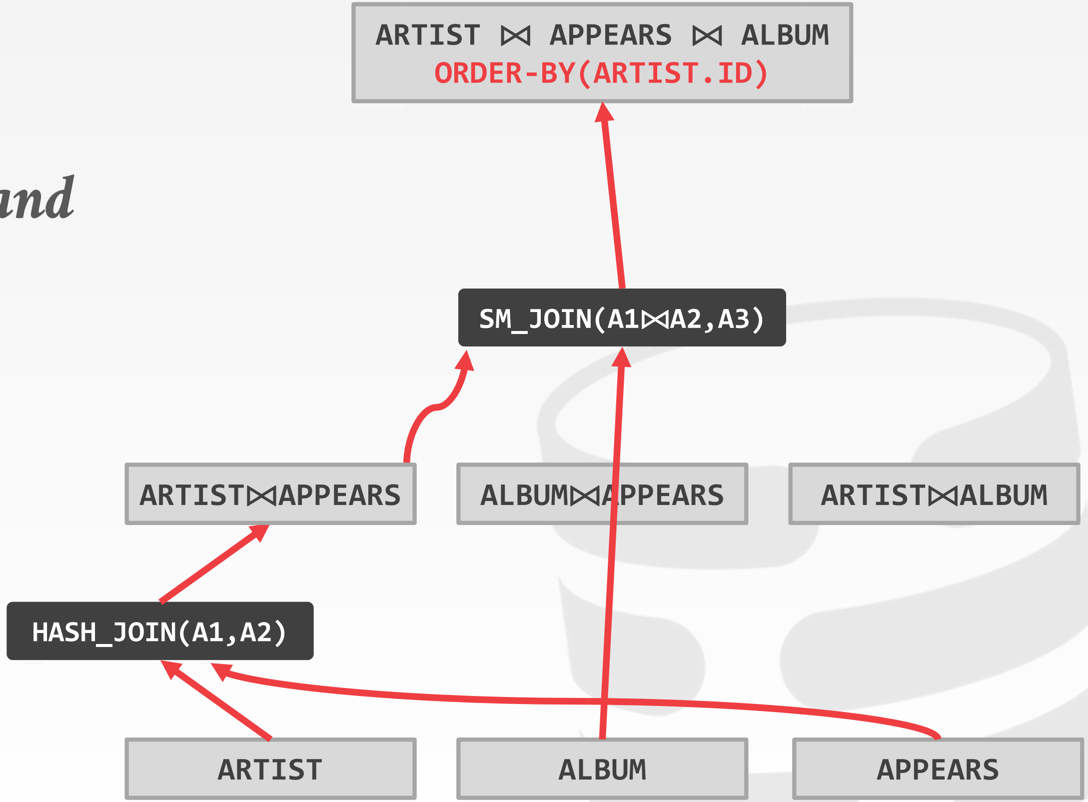

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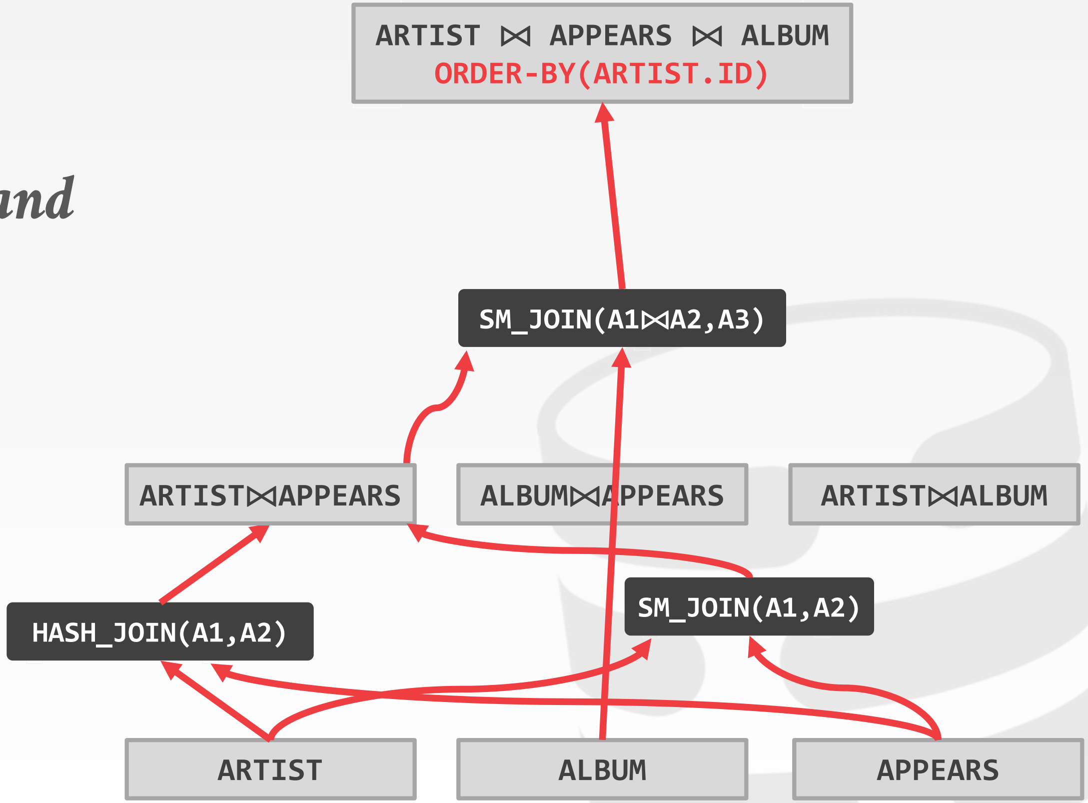

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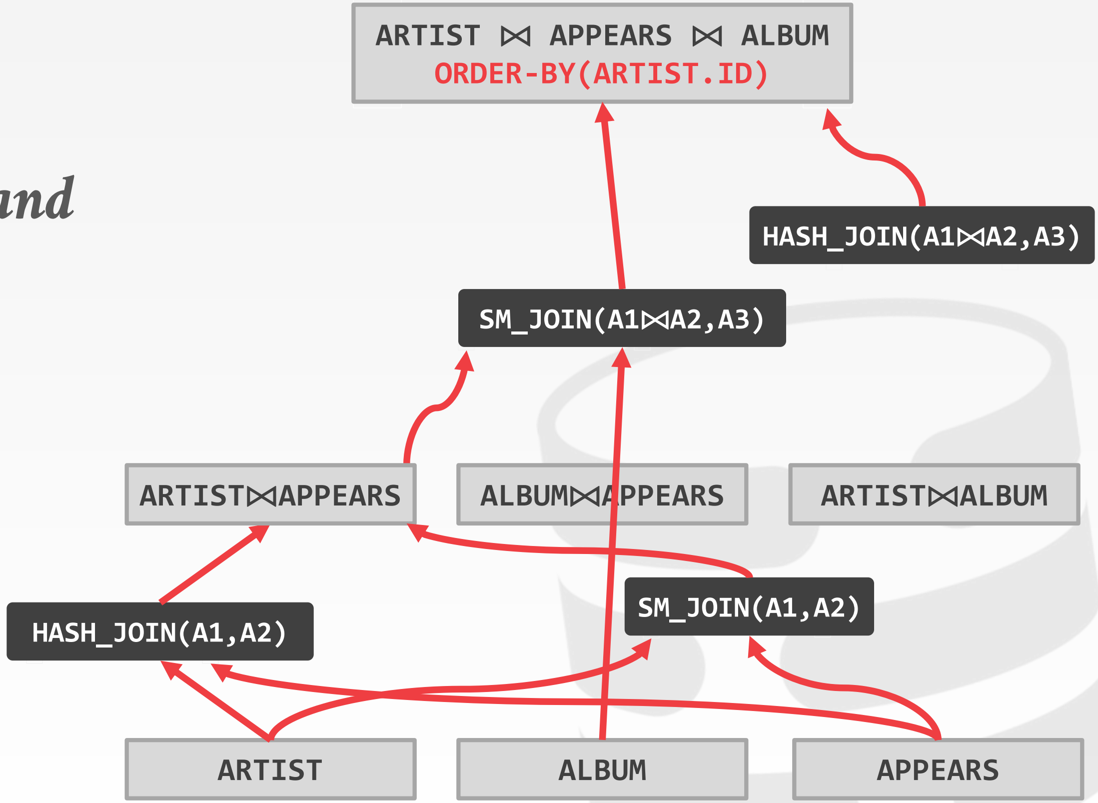
Can create "enforcer" rules that require input to have certain properties.



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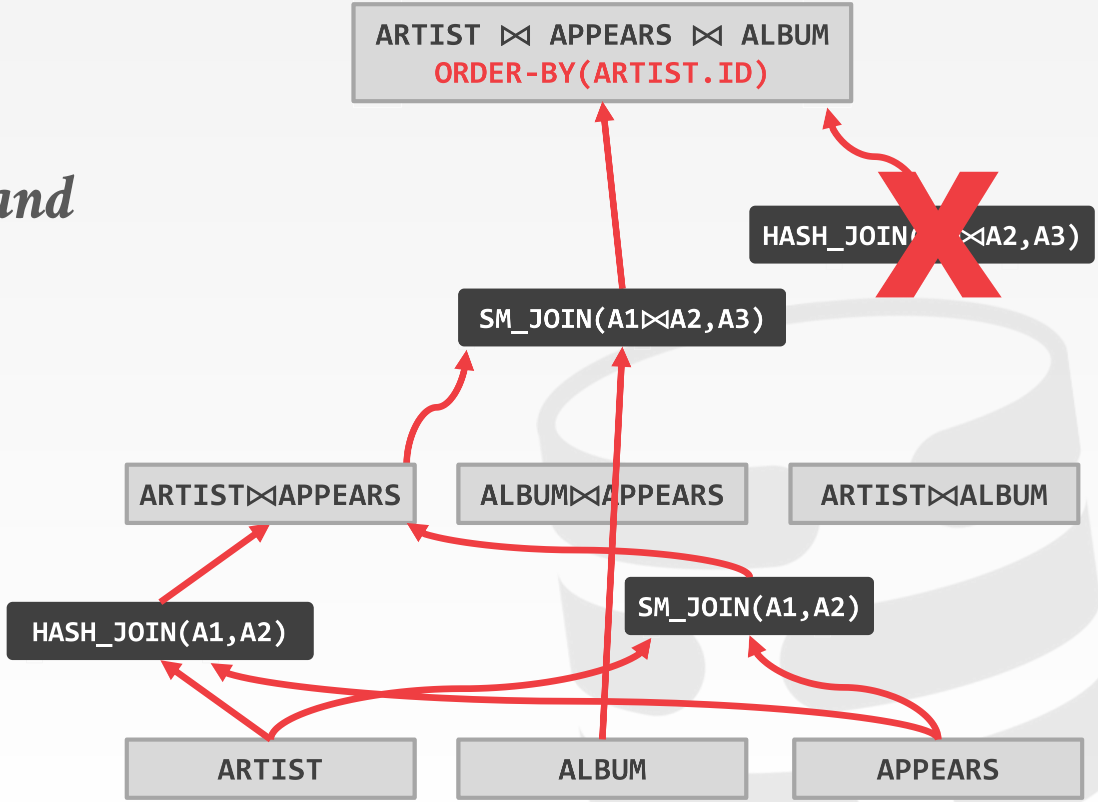

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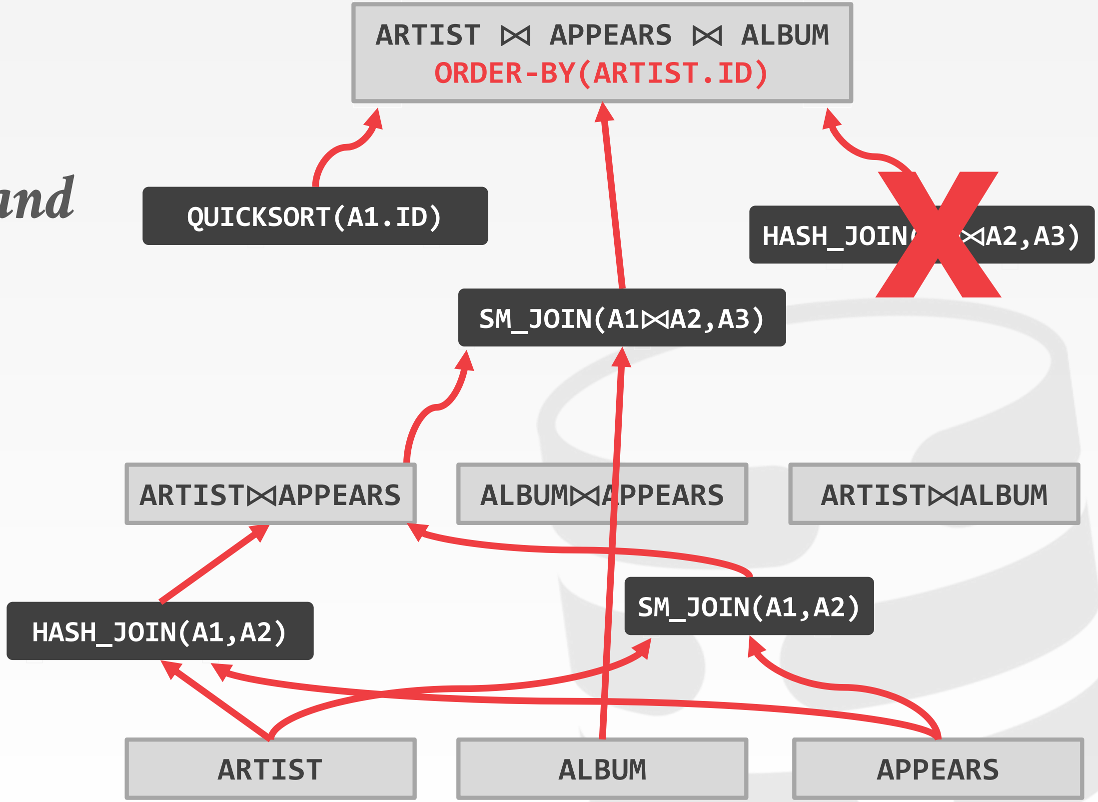

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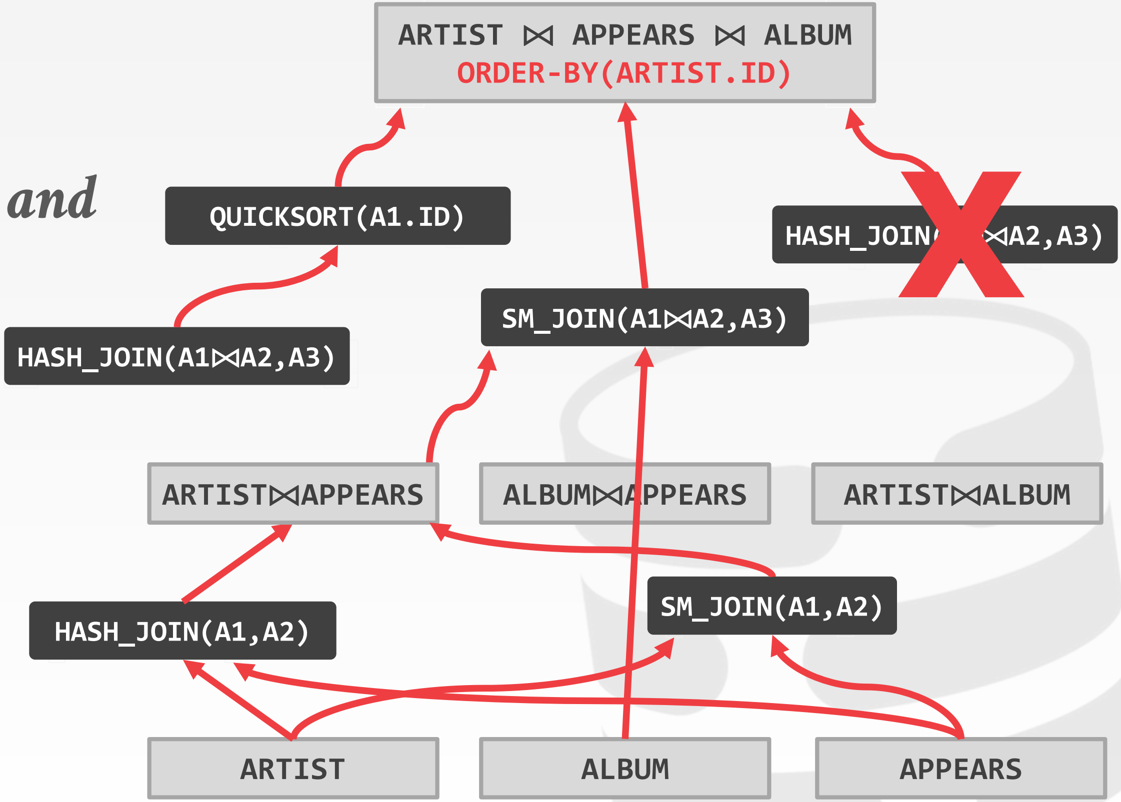

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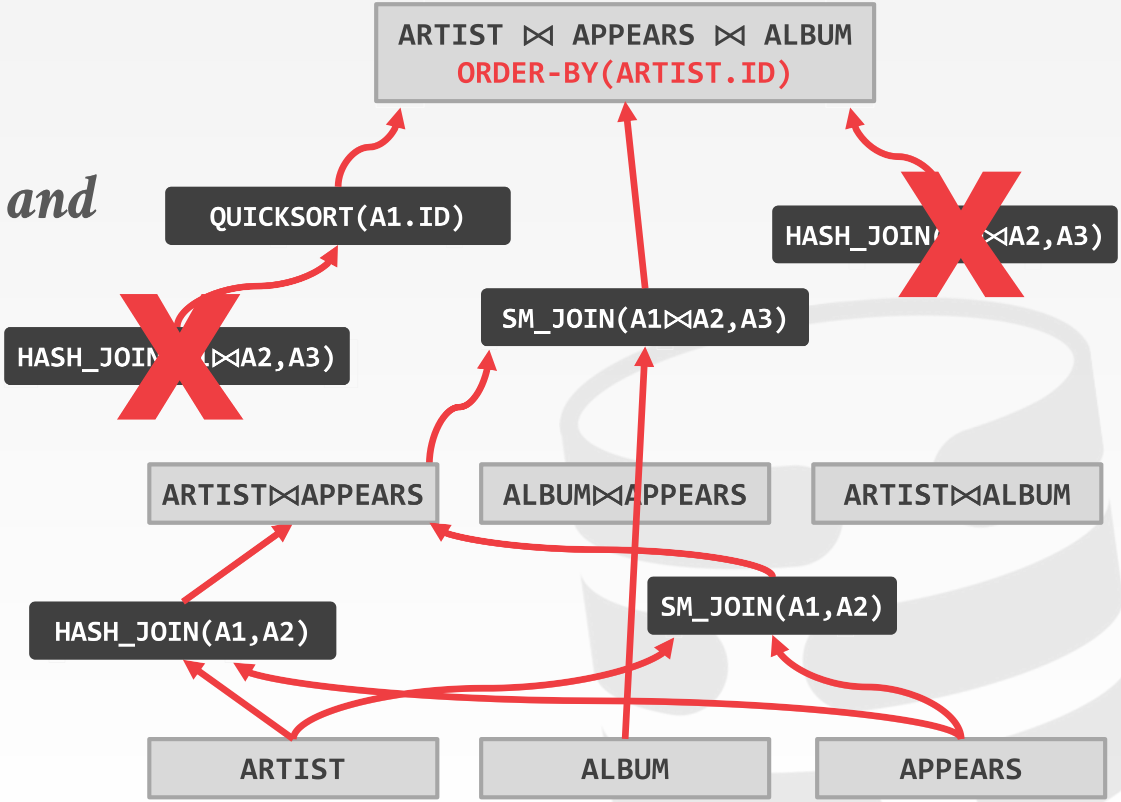

VOLCANO OPTIMIZER

Advantages:

→ Use declarative rules to generate transformations.
→ Better extensibility with an efficient search engine.
Reduce redundant estimations using memoization.

Disadvantages:

→ All equivalence classes are completely expanded to generate all possible logical operators before the optimization search.
→ Not easy to modify predicates.

PARTING THOUGHTS

Query optimization is **hard**.

This difficulty is why NoSQL systems didn't implement optimizers (at first).

NEXT CLASS

Optimizers! First Blood, Part II

Dynamic Programming vs. Cascades