Carnegie Mellon University

13 Query Planning – Part I

Intro to Database Systems
15-445/15-645
Fall 2021

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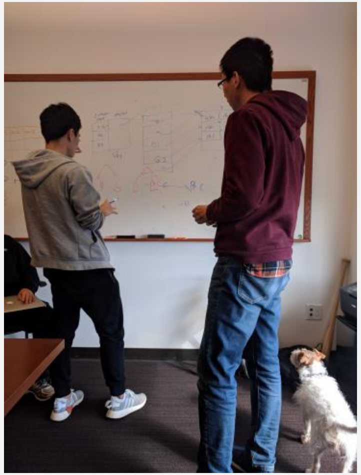


Databases!

ADMINISTRIVIA

Mid-Term Grade

→ Release today

→ Attend instructor's office hour to check your exam

Lin's office hour changed to Tue @ 2:30pm-4:00pm, GHC 9019

Project #2 is due on Sun Thu 21$^{\text{th}}$ @ 11:59pm

Project #3 will be released on Wed Oct 20$^{\text{th}}$

QUERY OPTIMIZATION

Remember that SQL is declarative.

→ User tells the DBMS what answer they want, not how to get the answer.

There can be a big difference in performance based on plan is used

IBM SYSTEM R

First implementation of a query optimizer from the 1970s.

→ People argued that the DBMS could never choose a query plan better than what a human could write.

Many concepts and design decisions from the **System R** optimizer are still used today.

QUERY OPTIMIZATION

Heuristics / Rules

→ Rewrite the query to remove stupid / inefficient things.

→ These techniques may need to examine catalog, but they do not need to examine data.

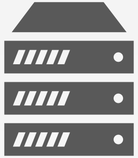
Cost-based Search

→ Use a model to estimate the cost of executing a plan.

→ Evaluate multiple equivalent plans for a query and pick the one with the lowest cost.

ARCHITECTURE OVERVIEW

Application



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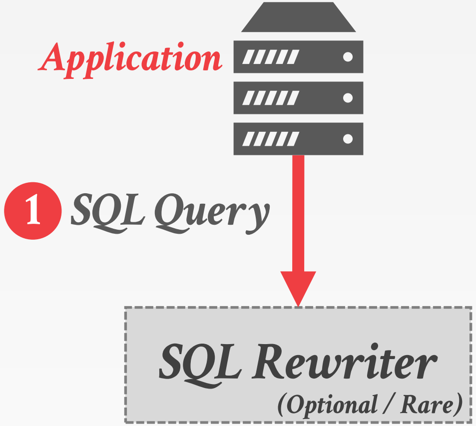

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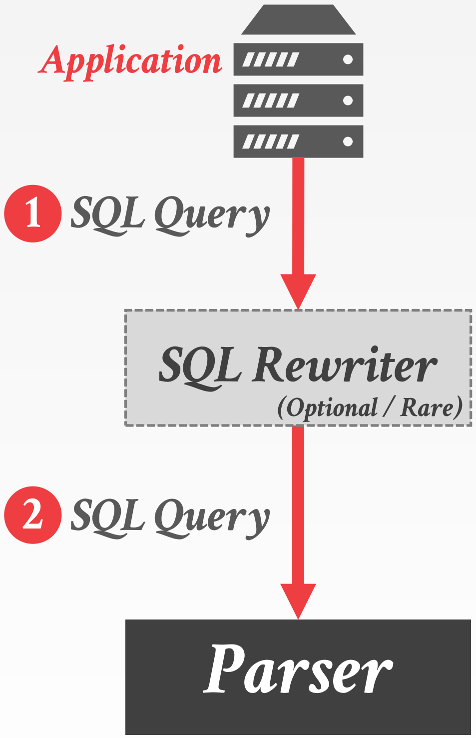

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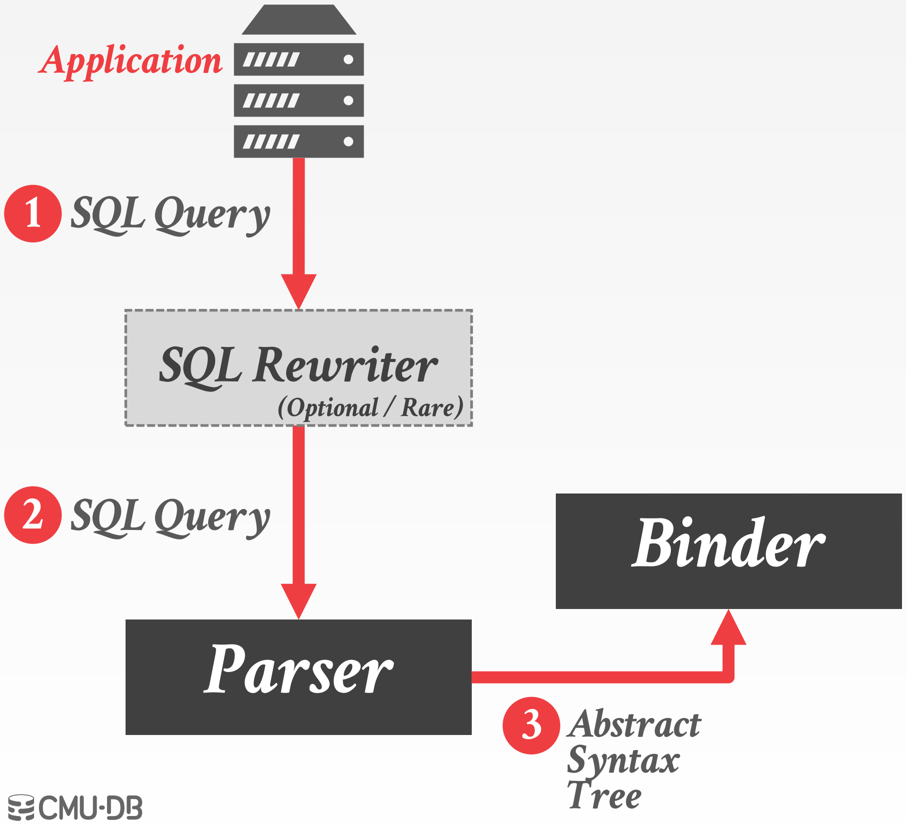

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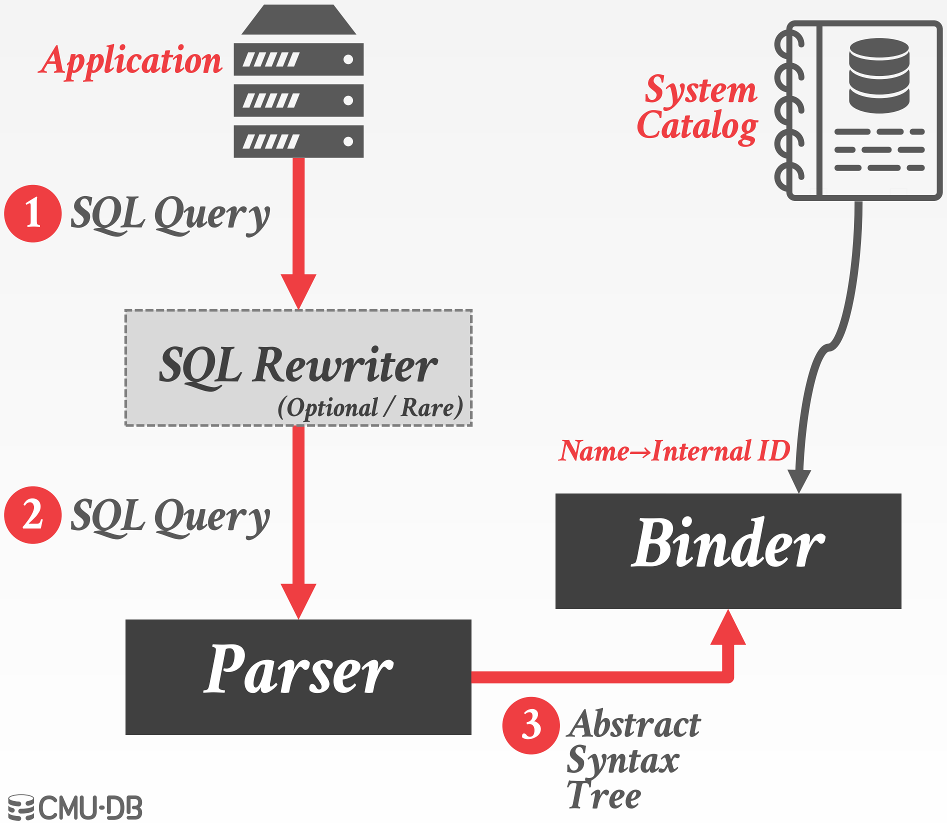

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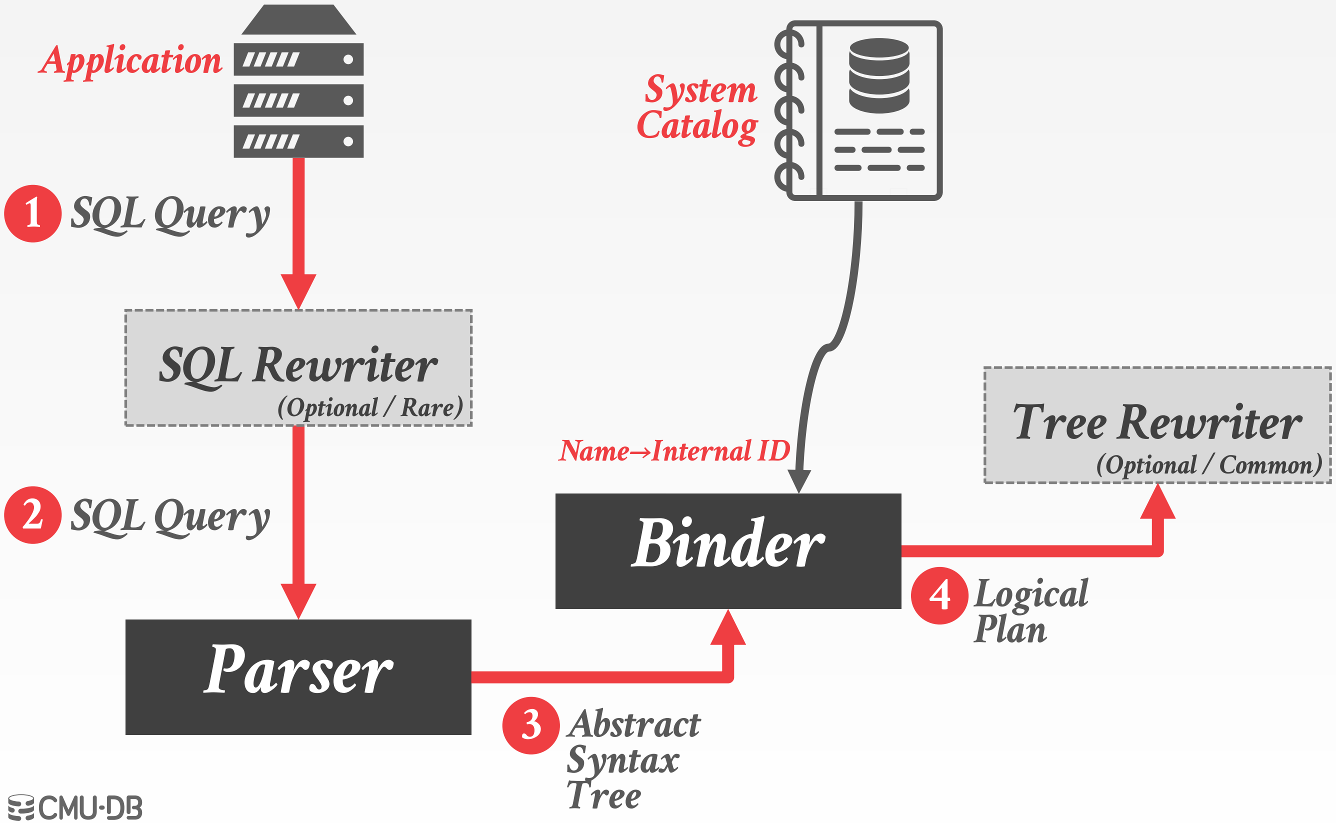

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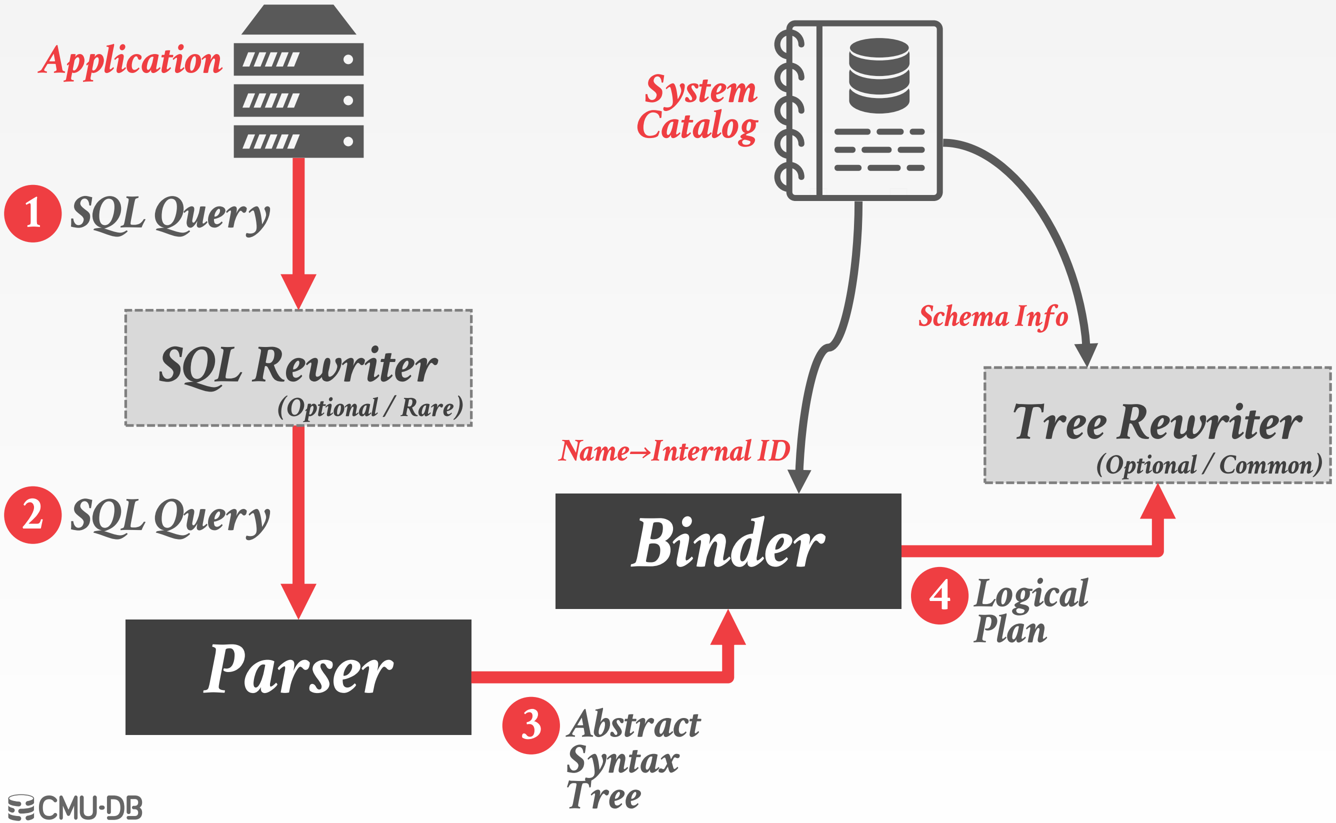

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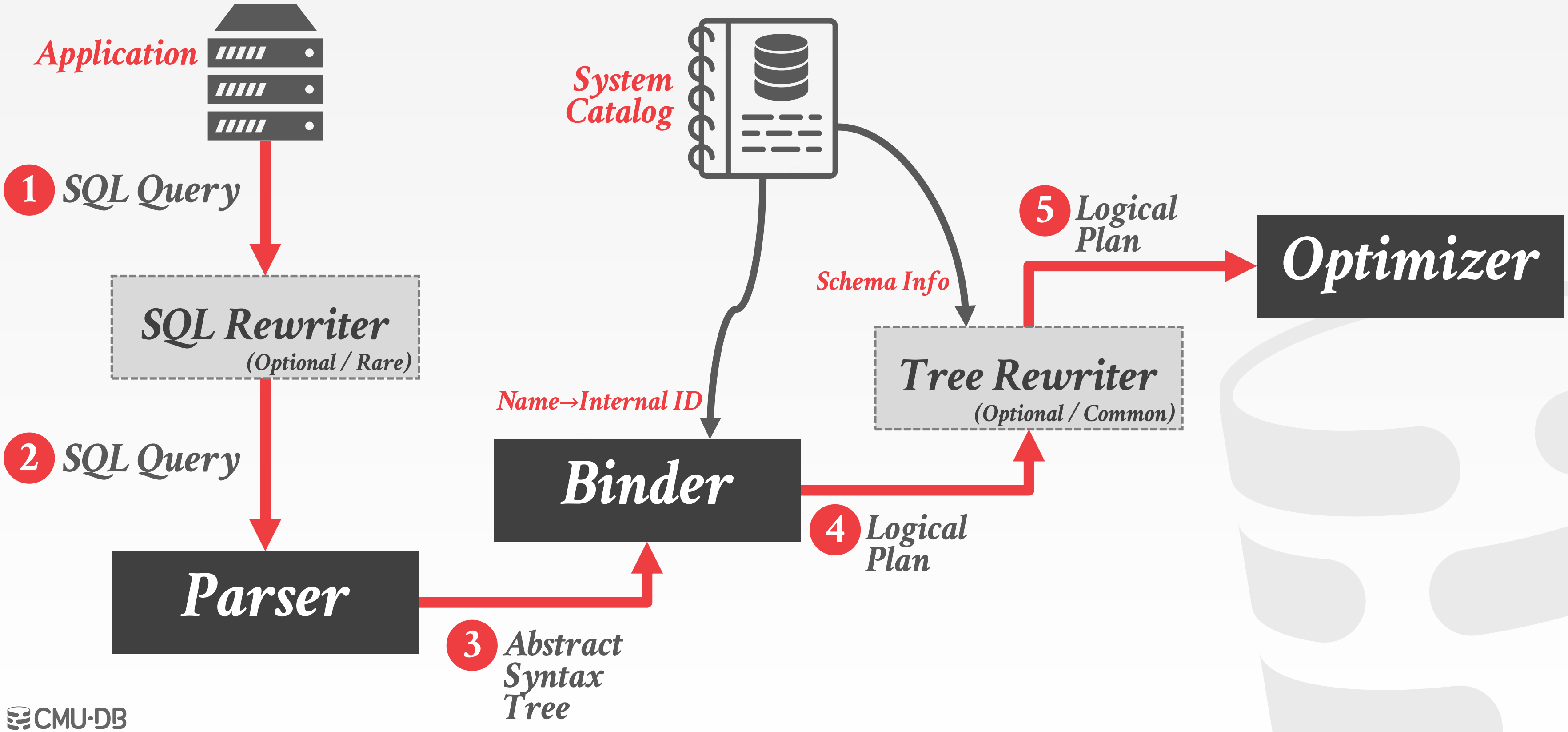

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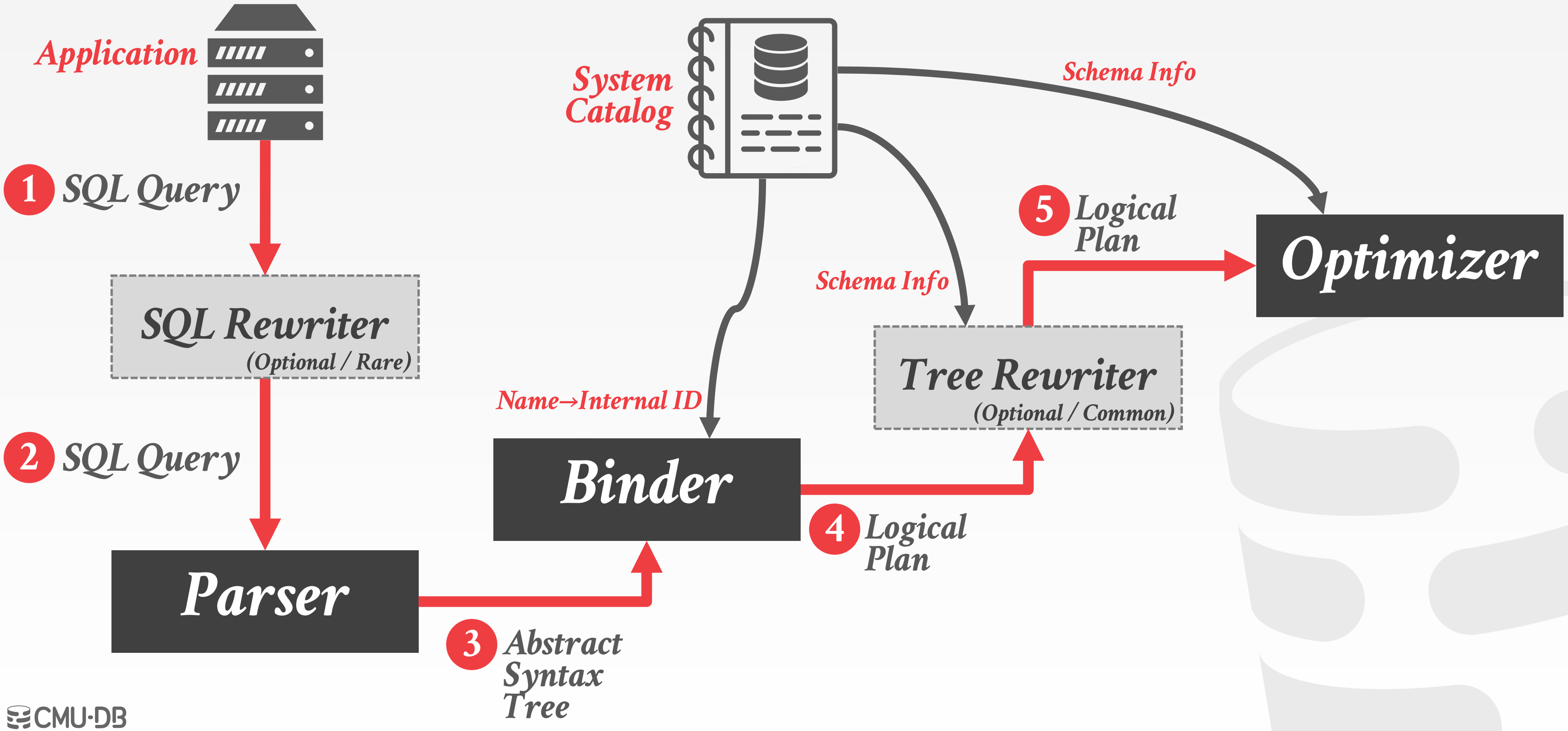

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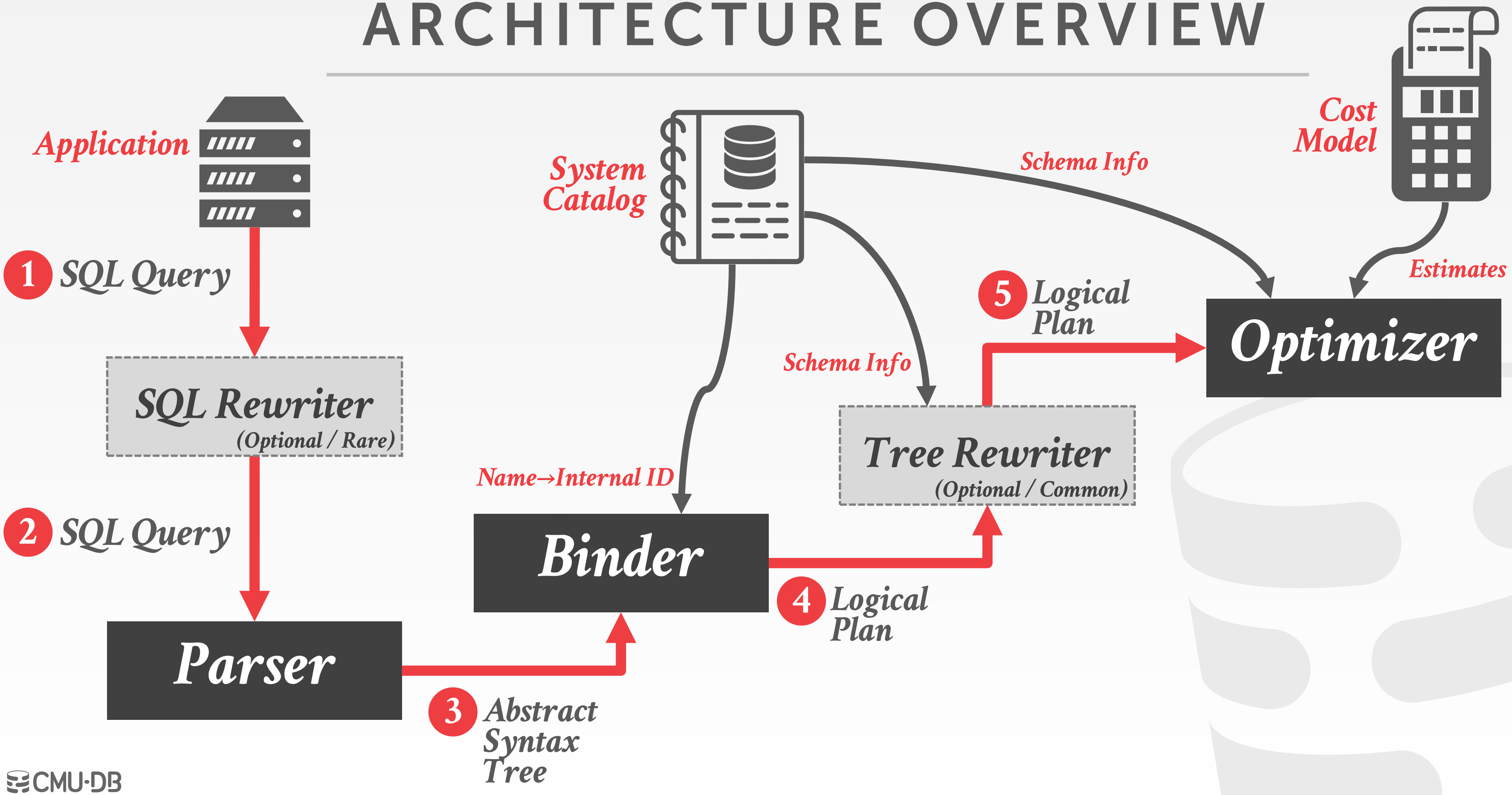

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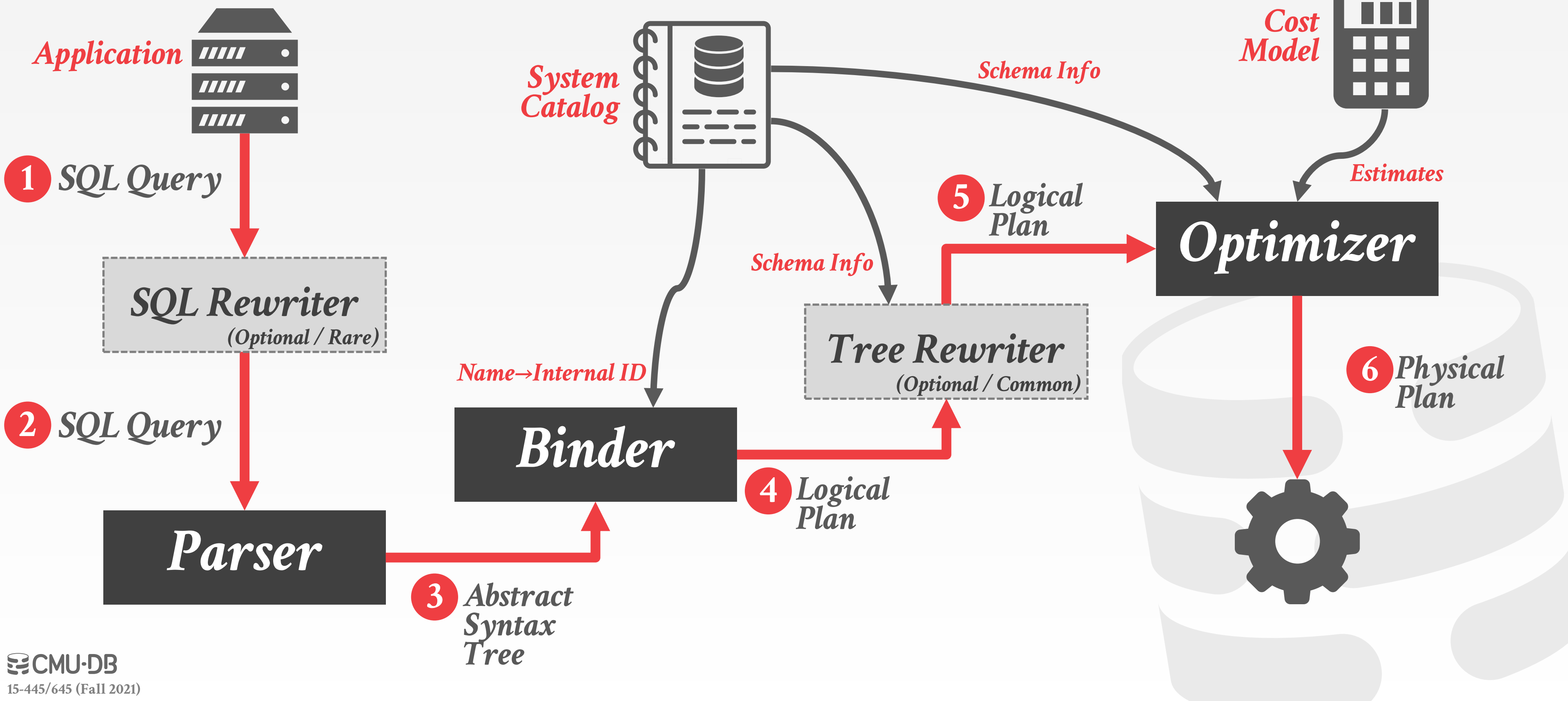

LOGICAL VS. PHYSICAL PLANS

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.

QUERY OPTIMIZATION IS NP-HARD

This is the hardest part of building a DBMS.

If you are good at this, you will get paid $$$.

People are starting to look at employing ML to improve the accuracy and efficacy of optimizers.

→ IBM DB2 tried this with LEO in the early 2000s…

TODAY'S AGENDA

Relational Algebra Equivalences

Logical Query Optimization

Nested Queries

Expression Rewriting

Cost Model

RELATIONAL ALGEBRA EQUIVALENCES

Two relational algebra expressions are equivalent if they generate the same set of tuples.

The DBMS can identify better query plans without a cost model.

This is often called query rewriting.

PREDICATE PUSHDOWN

```
SELECT s.name, e.cid
  FROM student AS s, enrolled AS e
 WHERE s.sid = e.sid
   AND e.grade = 'A'
```

$$\pi_{\text{name, cid}}(\sigma_{\text{grade='A'}}(\text{student} \bowtie \text{enrolled}))$$

PREDICATE PUSHDOWN

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SELECT s.name, e.cid
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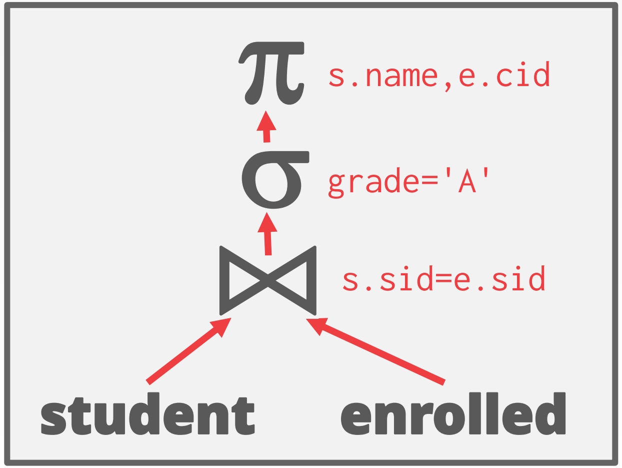

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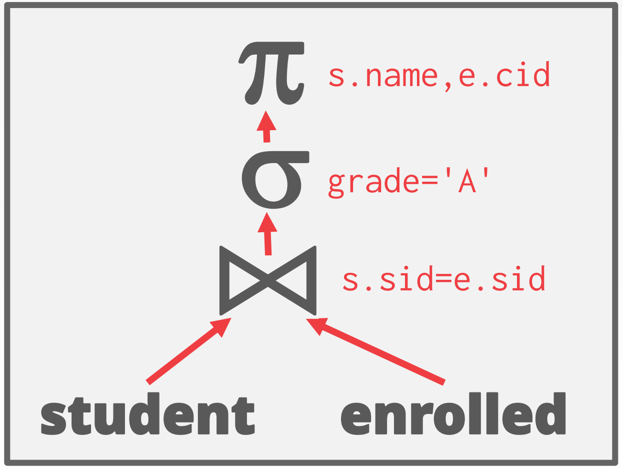

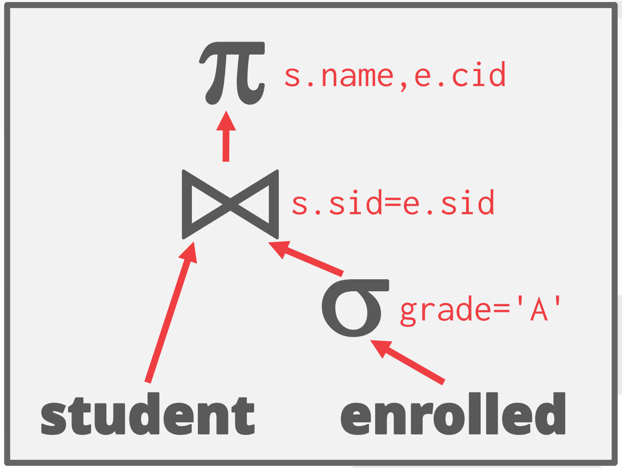

RELATIONAL ALGEBRA EQUIVALENCES

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$$=$$

$$\pi_{\text{name, cid}}(\text{student} \bowtie (\sigma_{\text{grade='A'}}(\text{enrolled})))$$

RELATIONAL ALGEBRA EQUIVALENCES

Selections:

→ Perform filters as early as possible.

→ Break a complex predicate, and push down

$$\sigma_{p1 \wedge p2 \wedge \ldots pn}(\mathbf{R}) = \sigma_{p1}(\sigma_{p2}(\ldots \sigma_{pn}(\mathbf{R})))$$

Simplify a complex predicate

→ `(X=Y AND Y=3) → X=3 AND Y=3`

RELATIONAL ALGEBRA EQUIVALENCES

Joins:

→ Commutative, associative

$R \bowtie S = S \bowtie R$

$(R \bowtie S) \bowtie T = R \bowtie (S \bowtie T)$

The number of different join orderings for an n-way join is a **Catalan Number** (≈4^n)

→ Exhaustive enumeration will be too slow.

RELATIONAL ALGEBRA EQUIVALENCES

Projections:

→ Perform them early to create smaller tuples and reduce intermediate results (if duplicates are eliminated)
→ Project out all attributes except the ones requested or required (e.g., joining keys)

This is not important for a column store…

PROJECTION PUSHDOWN

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  FROM student AS s, enrolled AS e
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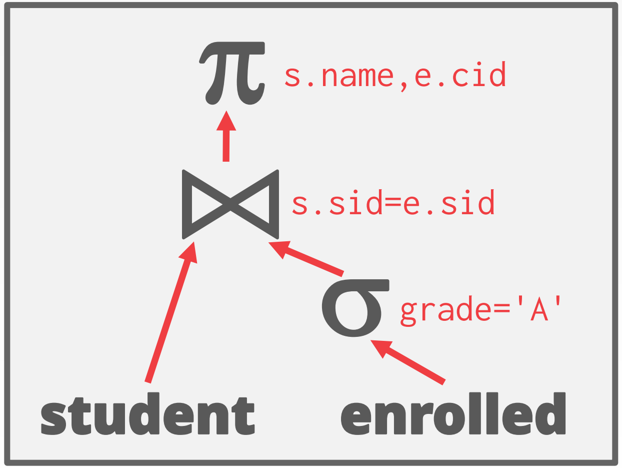

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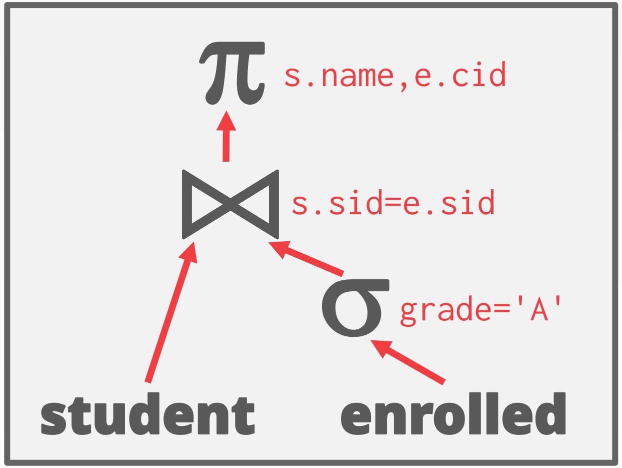
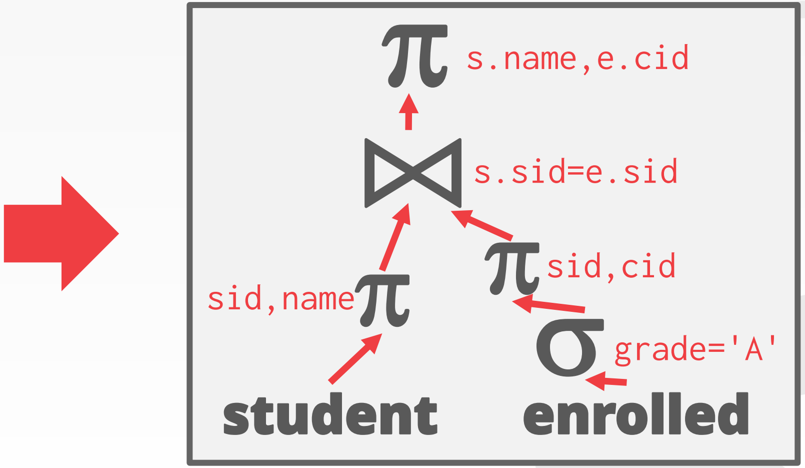




LOGICAL QUERY OPTIMIZATION

Transform a logical plan into an equivalent logical plan using pattern matching rules.

The goal is to increase the likelihood of enumerating the optimal plan in the search.

Cannot compare plans because there is no cost model but can "direct" a transformation to a preferred side.

LOGICAL QUERY OPTIMIZATION

Split Conjunctive Predicates

Predicate Pushdown

Replace Cartesian Products with Joins

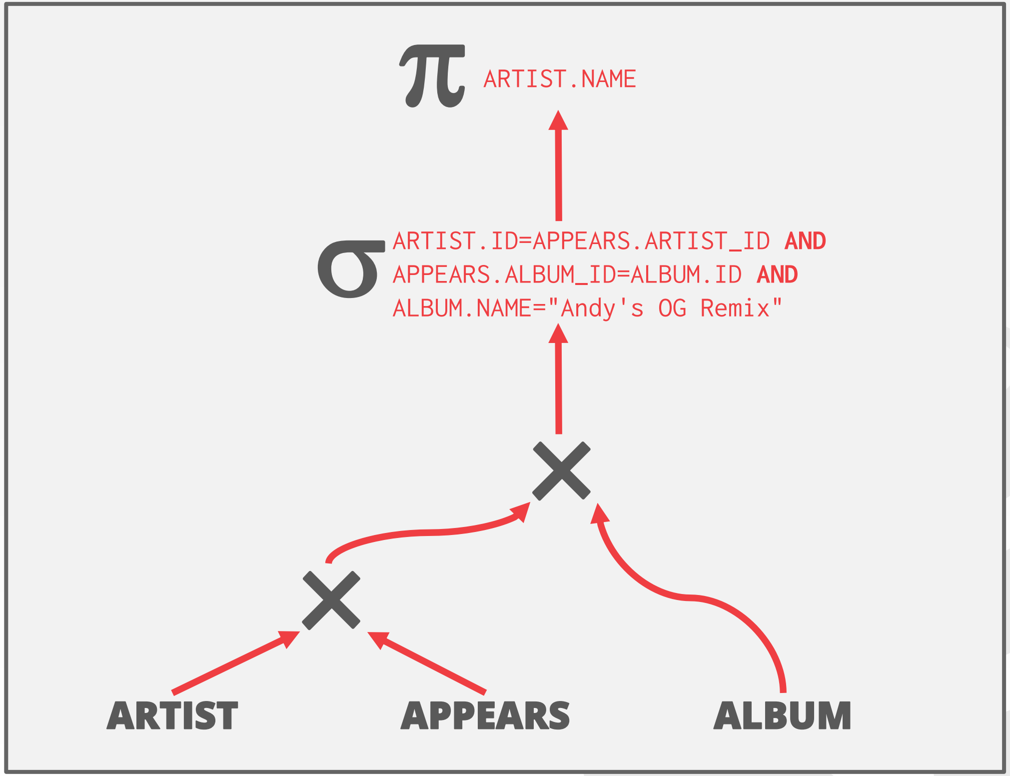
Projection Pushdown

Source: Thomas Neumann

SPLIT CONJUNCTIVE PREDICATES

```
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"
```

Decompose predicates into their simplest forms to make it easier for the optimizer to move them around.



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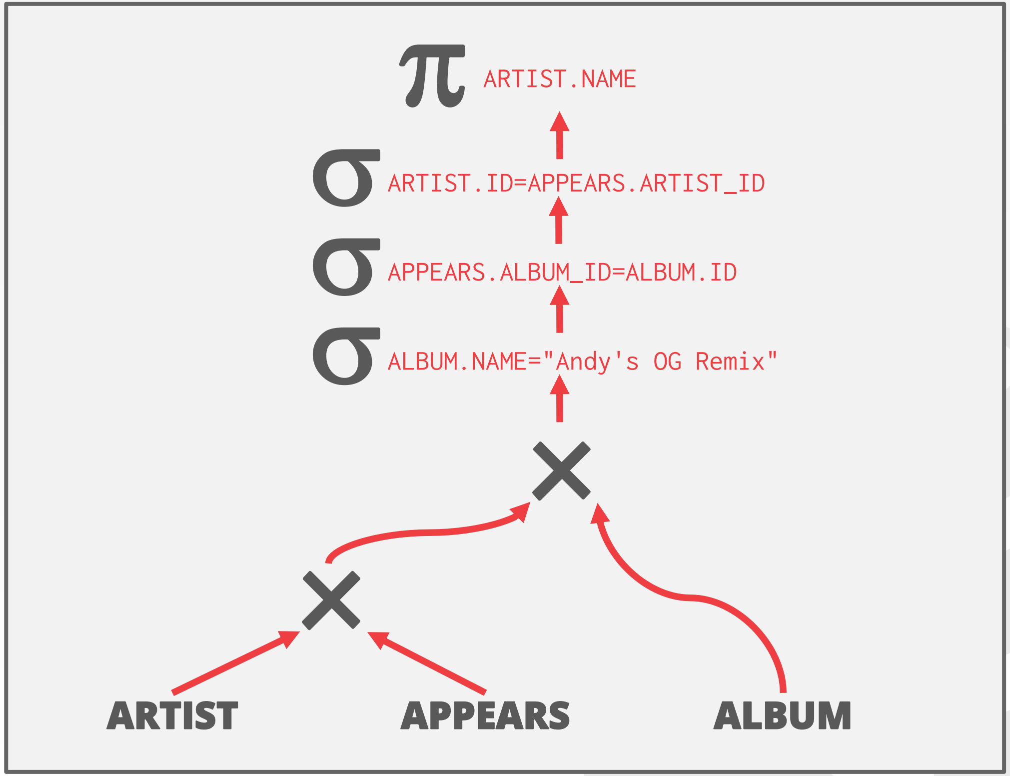

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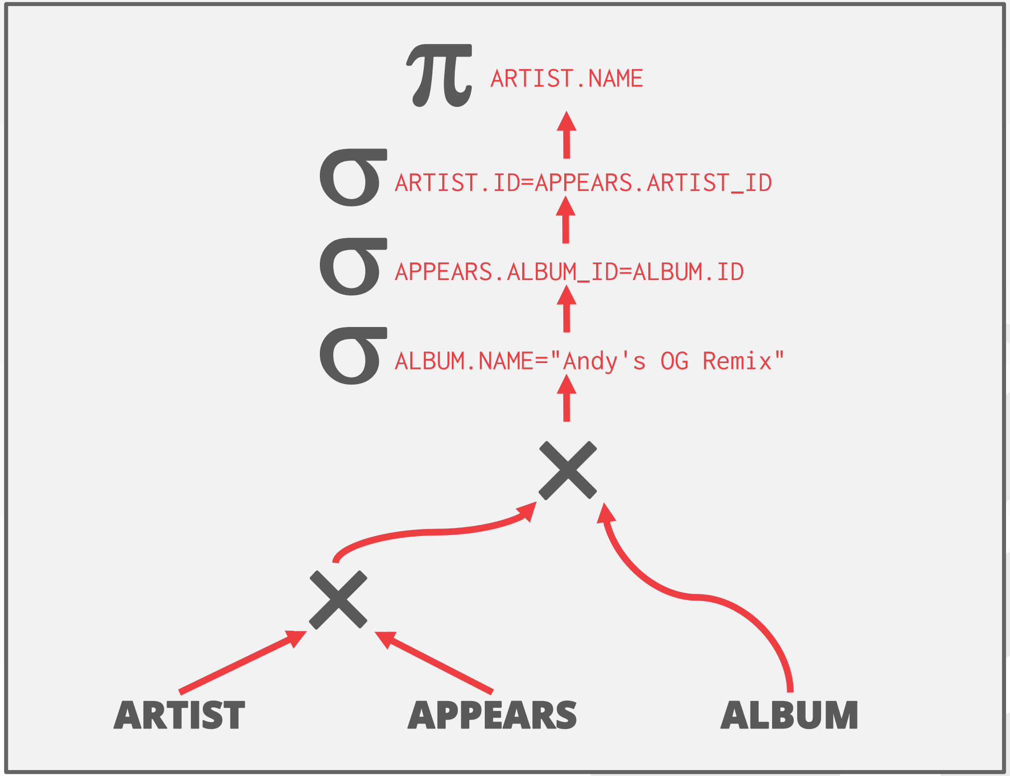
Move the predicate to the lowest applicable point in the plan.



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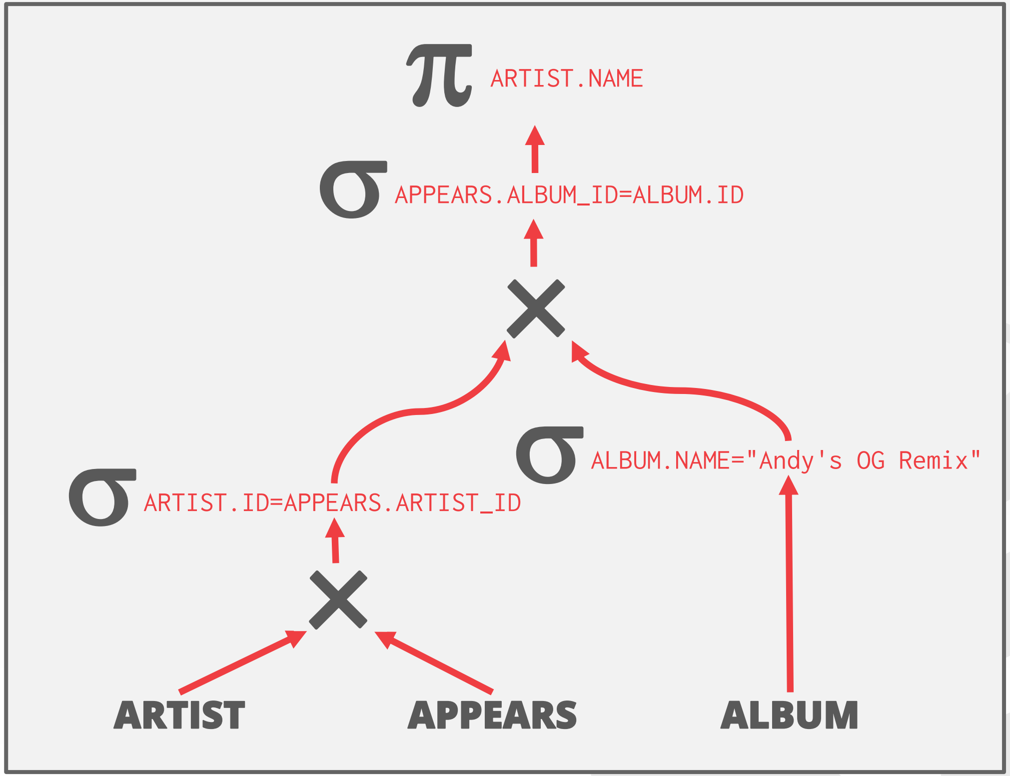

REPLACE CARTESIAN PRODUCTS

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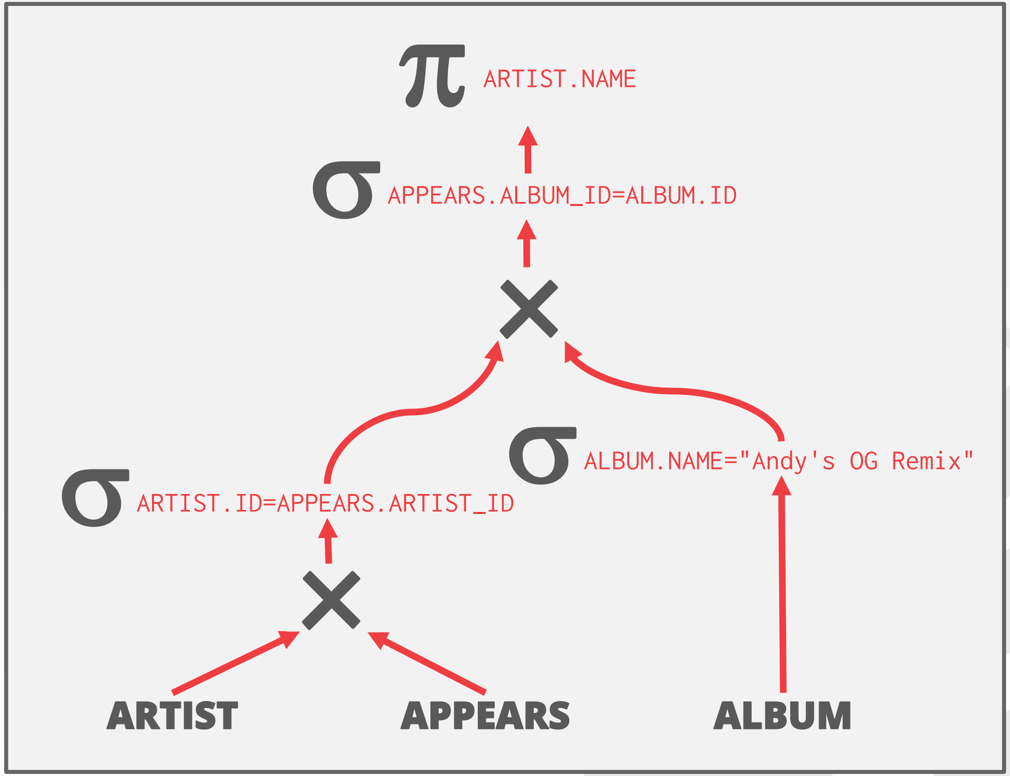
Replace all Cartesian Products with inner joins using the join predicates.



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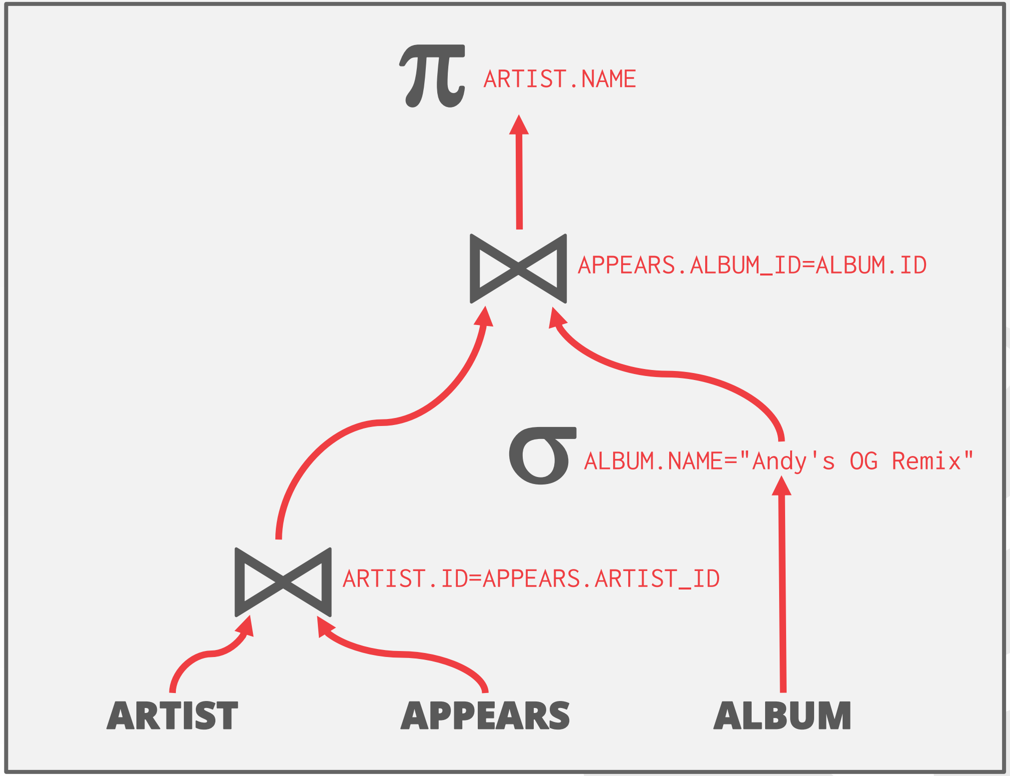

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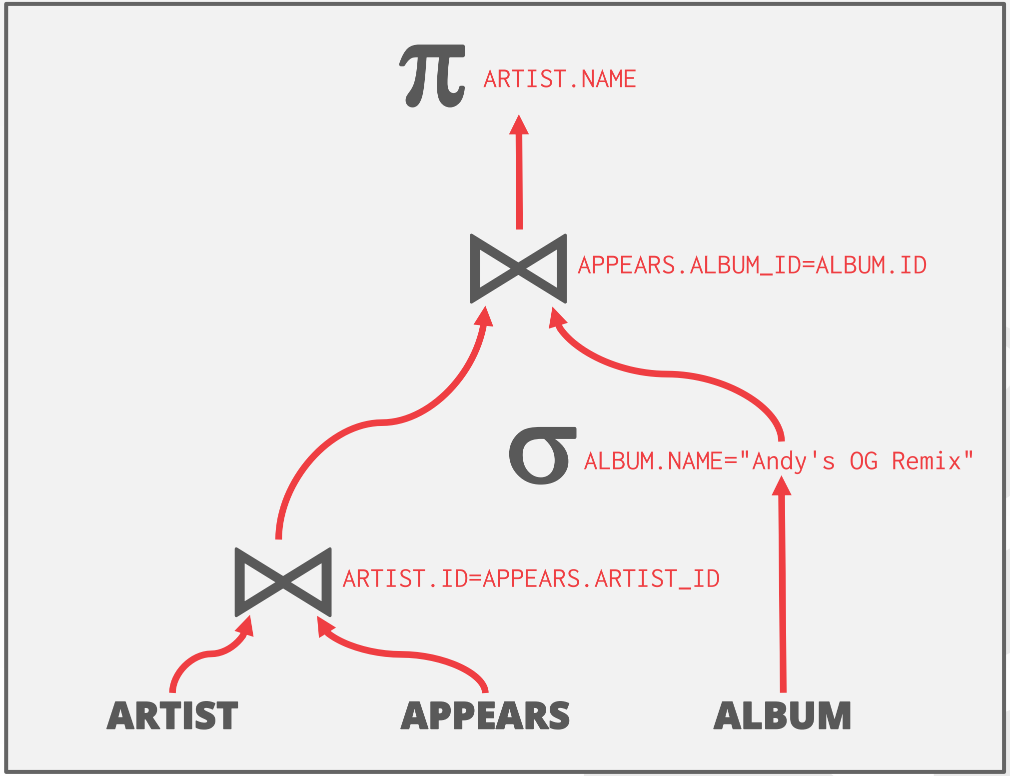
Eliminate redundant attributes before pipeline breakers to reduce materialization cost.



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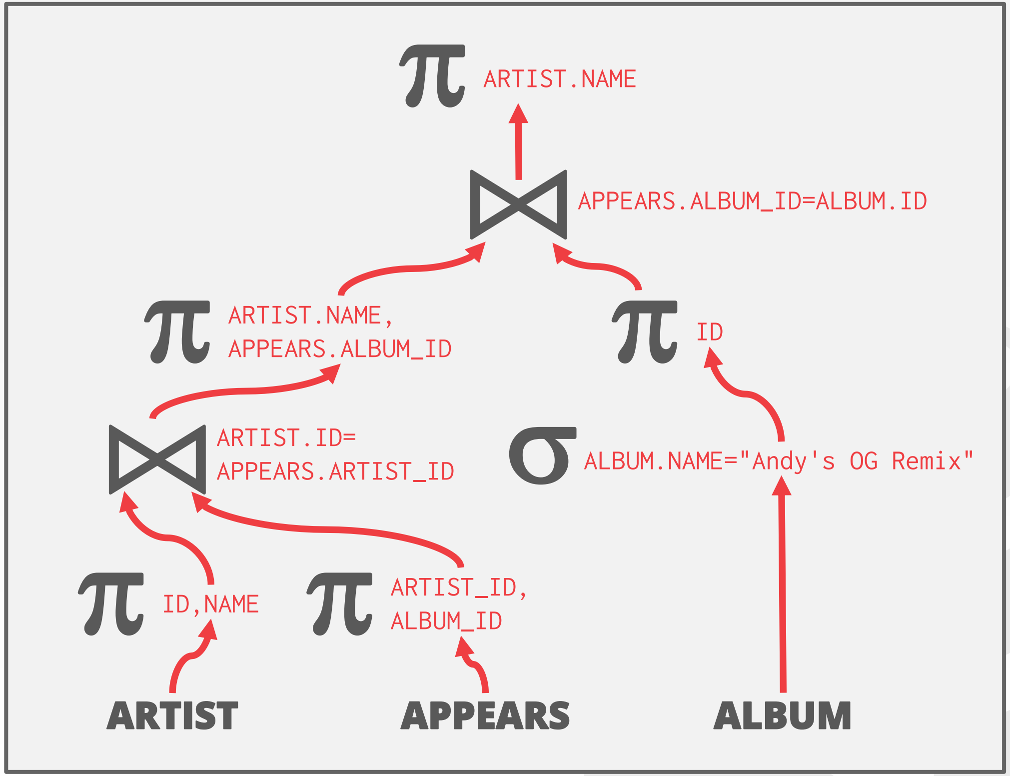

NESTED SUB-QUERIES

The DBMS treats nested sub-queries in the where clause as functions that take parameters and return a single value or set of values.

Two Approaches:

→ Rewrite to de-correlate and/or flatten them

→ Decompose nested query and store result to temporary table

NESTED SUB-QUERIES: REWRITE

```
SELECT name FROM sailors AS S
 WHERE EXISTS (
    SELECT * FROM reserves AS R
     WHERE S.sid = R.sid
       AND R.day = '2018-10-15'
 )
```

NESTED SUB-QUERIES: REWRITE

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```

```
SELECT name
  FROM sailors AS S, reserves AS R
 WHERE S.sid = R.sid
   AND R.day = '2018-10-15'
```

NESTED SUB-QUERIES: DECOMPOSE

```
SELECT S.sid, MIN(R.day)
  FROM sailors S, reserves R, boats B
 WHERE S.sid = R.sid
   AND R.bid = B.bid
   AND B.color = 'red'
   AND S.rating = (SELECT MAX(S2.rating)
                     FROM sailors S2)
 GROUP BY S.sid
HAVING COUNT(*) > 1
```

For each sailor with the highest rating (over all sailors) and at least two reservations for red boats, find the sailor id and the earliest date on which the sailor has a reservation for a red boat.

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DECOMPOSING QUERIES

For harder queries, the optimizer breaks up queries into blocks and then concentrates on one block at a time.

Sub-queries are written to a temporary table that are discarded after the query finishes.

DECOMPOSING QUERIES

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Nested Block

DECOMPOSING QUERIES

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SELECT MAX(rating) FROM sailors
```

```
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Nested Block

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   AND S.rating = ###

 GROUP BY S.sid
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Nested Block

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 GROUP BY S.sid
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```

Outer Block

EXPRESSION REWRITING

An optimizer transforms a query's expressions (e.g., **WHERE** clause predicates) into the optimal/minimal set of expressions.

Implemented using if/then/else clauses or a pattern-matching rule engine.

→ Search for expressions that match a pattern.
→ When a match is found, rewrite the expression.
→ Halt if there are no more rules that match.

```sql
CREATE TABLE A (
  id INT PRIMARY KEY,
  val INT NOT NULL );
```

MORE EXAMPLES

Impossible / Unnecessary Predicates

```sql
SELECT * FROM A WHERE 1 = 0;
```

Source: Lukas Eder

```
CREATE TABLE A (
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MORE EXAMPLES

Impossible / Unnecessary Predicates

```
SELECT * FROM A WHERE 1 = 0; ✗
```

```
SELECT * FROM A;
```

Join Election

```
SELECT A1.*
  FROM A AS A1 JOIN A AS A2
    ON A1.id = A2.id;
```

Source: Lukas Eder

```
CREATE TABLE A (
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MORE EXAMPLES

Impossible / Unnecessary Predicates

```
SELECT * FROM A WHERE 1 = 0; ❌
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Join Elimination

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MORE EXAMPLES

Join Elimination with Sub-Query

```
SELECT * FROM A AS A1
 WHERE EXISTS(SELECT val FROM A AS A2
               WHERE A1.id = A2.id);
```

Source: Lukas Eder

```sql
CREATE TABLE A (
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MORE EXAMPLES

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SELECT * FROM A;
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```

MORE EXAMPLES

Join Elimination with Sub-Query

```
SELECT * FROM A;
```

Merging Predicates

```
SELECT * FROM A
 WHERE val BETWEEN 1 AND 100
    OR val BETWEEN 50 AND 150;
```

Source: Lukas Eder

```
CREATE TABLE A (
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```

MORE EXAMPLES

Join Elimination with Sub-Query

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SELECT * FROM A;
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SELECT * FROM A
 WHERE val BETWEEN 1 AND 100
    OR val BETWEEN 50 AND 150;
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Source: Lukas Eder

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MORE EXAMPLES

Join Elimination with Sub-Query

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Merging Predicates

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→ Use a model to estimate the cost of executing a plan.

→ Enumerate multiple equivalent plans for a query and pick the one with the lowest cost.

QUERY OPTIMIZATION

Heuristics / Rules

→ Rewrite the query to remove stupid / inefficient things.
→ These techniques may need to examine catalog, but they do not need to examine data.

Cost-based Search

→ Use a model to estimate the cost of executing a plan.
→ Enumerate multiple equivalent plans for a query and pick the one with the lowest cost.

COST-BASED QUERY PLANNING

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

→ Estimates are only meaningful internally.

This is independent of the plan enumeration step that we will talk about next class.

COST MODEL COMPONENTS

Choice #1: Physical Costs

→ Predict CPU cycles, I/O, cache misses, RAM consumption, pre-fetching, etc…

→ Depends heavily on hardware.

Choice #2: Logical Costs

→ Estimate result sizes per operator.

→ Independent of the operator algorithm.

→ Need estimations for operator result sizes.

Choice #3: Algorithmic Costs

→ Complexity of the operator algorithm implementation.

DISK-BASED DBMS COST MODEL

The number of disk accesses will always dominate the execution time of a query.

→ CPU costs are negligible.
→ Must consider sequential vs. random I/O.

This is easier to model if the DBMS has full control over buffer management.

→ We will know the replacement strategy, pinning, and assume exclusive access to disk.

POSTGRES COST MODEL

Uses a combination of CPU and I/O costs that are weighted by "magic" constant factors.

Default settings are obviously for a disk-resident database without a lot of memory:

→ Processing a tuple in memory is **400x** faster than reading a tuple from disk.
→ Sequential I/O is **4x** faster than random I/O.

19.7.2. Planner Cost Constants

The *cost* variables described in this section are measured on an arbitrary scale. Only their relative values matter, hence scaling them all up or down by the same factor will result in no change in the planner's choices. By default, these cost variables are based on the cost of sequential page fetches; that is, `seq_page_cost` is conventionally set to `1.0` and the other cost variables are set with reference to that. But you can use a different scale if you prefer, such as actual execution times in milliseconds on a particular machine.

> **Note:** Unfortunately, there is no well-defined method for determining ideal values for the cost variables. They are best treated as averages over the entire mix of queries that a particular installation will receive. This means that changing them on the basis of just a few experiments is very risky.

`seq_page_cost (floating point)`

Sets the planner's estimate of the cost of a disk page fetch that is part of a series of sequential fetches. The default is 1.0. This value can be overridden for tables and indexes in a particular tablespace by setting the tablespace parameter of the same name (see ALTER TABLESPACE).

`random_page_cost (floating point)`

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IBM DB2 COST MODEL

Database characteristics in system catalogs

Hardware environment (microbenchmarks)

Storage device characteristics (microbenchmarks)

Communications bandwidth (distributed only)

Memory resources (buffer pools, sort heaps)

Concurrency Environment

→ Average number of users
→ Isolation level / blocking
→ Number of available locks

Source: Guy Lohman

CONCLUSION

We can use static rules and heuristics to optimize a query plan without needing to understand the contents of the database.

We use cost model to help perform more advanced query optimizations

NEXT CLASS

Statistics and plan enumeration