OPTIMIZATION OF RELATIONAL QUERIES

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BME–TMIT

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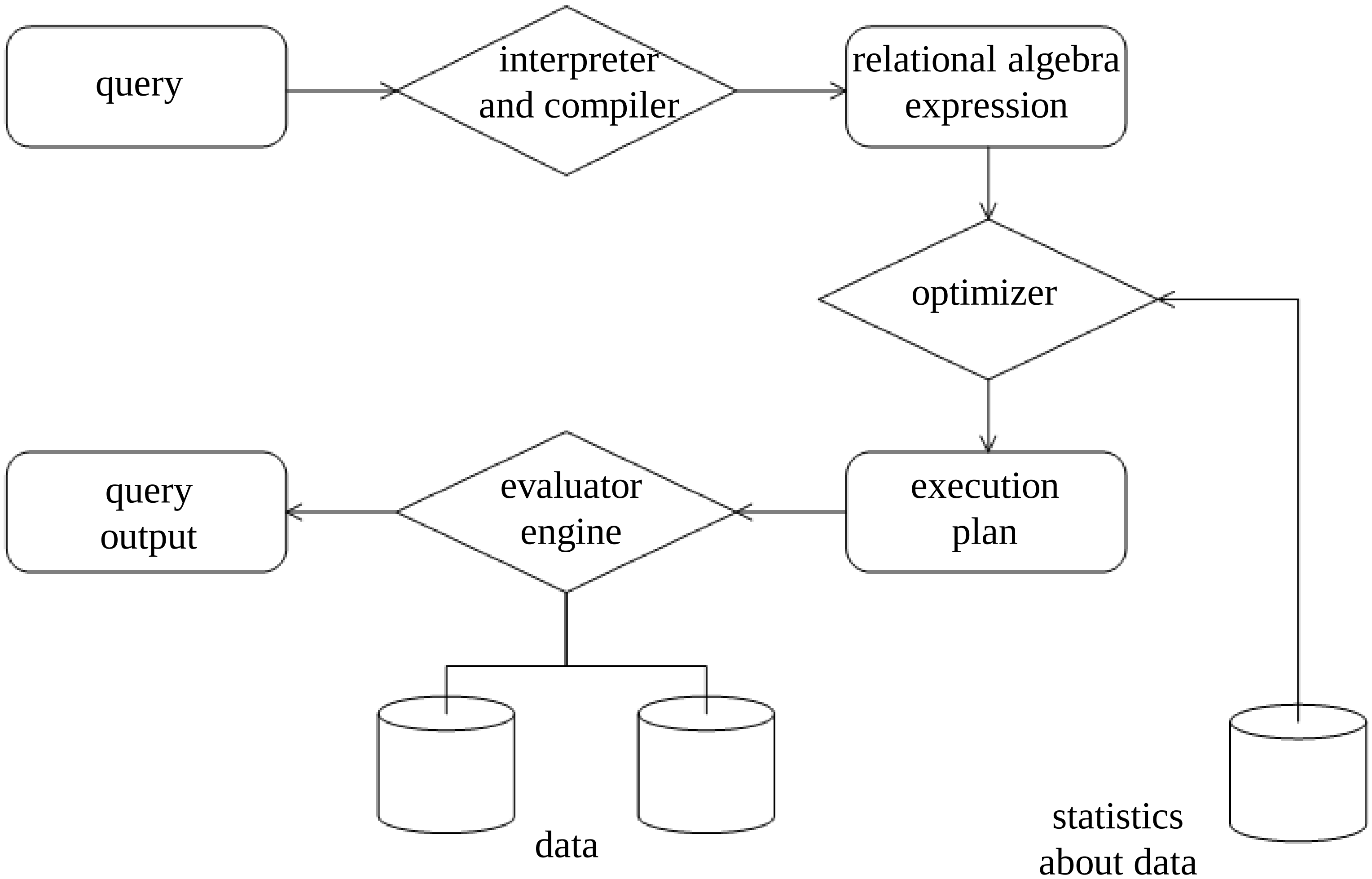
OVERVIEW



query
interpreter
and compiler
relational algebra
expression
optimizer
execution
plan
evaluator
engine
query
output
data
statistics
about data

STEPS

1. (Syntactical) analysis, compilation

   Does it make sense?

   Input: SQL statement

   Result: relational algebra expression

2. Cost optimization

3. Evaluation

CATALOG BASED COST ESTIMATION

- The following statistical data is stored in the so-called catalog
  - Catalog data about relations
  - Catalog data about indexes
  - Query cost
- Cost is estimated based on catalog data.

CATALOG DATA ABOUT RELATIONS

- n_r: number of records in relation r
- b_r: number of blocks storing the records of relation r
- s_r: size of a record
- f_r: how many records fit in a data block

CATALOG DATA ABOUT RELATIONS

- $V(A, r)$: how many different **v**alues attribute A has in relation r (cardinality).
  - $V(A, r) = |\pi_A(r)|$
  - If A is a key, then $V(A, r) = n_r$
- $SC(A, r)$: (**S**election **C**ardinality) average number of records that satisfy a selection condition.
  - If A is a key, then $SC(A, r) = 1$
  - In general $SC(A, r) = \frac{n_r}{V(A,r)}$
- If the records of a relation are physically stored together, then:

$$b_r = \left\lceil \frac{n_r}{f_r} \right\rceil$$

CATALOG DATA ABOUT INDEXES

- f_i: number of pointers going out of a node in case of a tree index, like B* tree
- HT_i: number of index levels (**H**eight of **T**ree)
  - $HT_i = \lceil \log_{f_i} b_r \rceil$ (B* tree)
  - $HT_i = 1$ (hash)
- LB_i: a number of leaf blocks (**L**owest level index **B**lock)

COST OF QUERY

Definition:

- **Number of block reading and writing operations from the disc** (without writing out the result).
- Takes the most time by far – good metric
  - By orders of magnitude more costly then performing operations in the RAM, etc.

COST OF OPERATIONS – OUTLINE

- Selection
  - Selection algorithms (basic, indexed, comparison based)
  - complex selection
- Join
  - Types
  - Size estimation
  - Join algorithms
- Other
  - Filtering repetitions
  - Union, intersection, subtraction

BASIC SELECTION ALGORITHMS (=)

A1: Linear search

- Cost:

$$E_{A1} = b_r$$

A2: Binary search

- Requirements:
  - Blocks are located continuously on the disk
  - The file is ordered by attribute A
  - The selection condition is equality on attribute A
- Cost:

$$E_{A2} = \lceil \log_2(b_r + 1) \rceil + \left\lceil \frac{SC(A,r)}{f_r} \right\rceil - 1$$

INDEXED SEARCH ALGORITHMS

Primary index – requires the data file to be physically ordered by the index attribute (search key). Everything else is a **secondary index**

A3: Using primary index, if the equality condition is defined on the key

$$\text{Cost: } E_{A3} = HT_i + 1$$

A4: Using primary index, if the equality condition is defined on a non-key attribute (the primary index is on the non-key attribute)

$$\text{Cost: } E_{A4} = HT_i + \left\lceil \frac{SC(A,r)}{f_r} \right\rceil$$

A5: Using secondary index.

$$\text{Cost: } E_{A5} = HT_i + SC(A,r)$$

$$\text{Cost: } E_{A5} = HT_i + 1, \text{ if } A \text{ is a key}$$

COMPARISON BASED SELECTION – $\sigma_{A \leq v}(R)$

Estimation of the **number of result records**:

- If v is unknown: $\frac{n_r}{2}$

- If v is known, and the distribution is uniform:

$$n_{\text{average}} = n_r \cdot \frac{v - \min(A, r)}{\max(A, r) - \min(A, r)}$$

COMPARISON BASED SELECTION – $\sigma_{A \leq v}(R)$

A6: With primary index.

- If v is unknown:

$$\text{Cost: } E_{A6} = HT_i + \frac{b_r}{2}$$

- If v is known:

$$\text{Cost: } E_{A6} = HT_i + \left\lceil \frac{c}{f_r} \right\rceil,$$

Where c is the number of records for which $A \leq v$

A7: With secondary index

$$\text{Cost: } E_{A7} = HT_i + \frac{LB_i}{2} + \frac{n_r}{2}$$

JOIN OPERATION

Definition:

$$r_1 \bowtie_\theta r_2 = \sigma_\theta(r_1 \times r_2)$$

Types:

- Natural join

$$r_1 \bowtie r_2 = \pi_{A \cup B}\left(\sigma_{R1.X=R2.X}\,(r_1 \times r_2)\right)$$

- Outer join
  - Left outer join: $r_1 * (+) r_2$
  - Right outer join: $r_1 (+) * r_2$
  - Full outer join: $r_1 (+) * (+) r_2$

- Theta join:

$$r_1 \bowtie_\theta r_2 = \sigma_\theta(r_1 \times r_2)$$

JOIN OPERATION: NESTED LOOP JOIN

Given are two relations, r and s:

FOR each record $t_r \in r$ DO BEGIN

  FOR each record $t_s \in s$ DO BEGIN

    test if pair (t_r, t_s), fulfills join condition θ

    IF yes, THEN add record $t_r . t_s$ to the result

  END

END

- „worst case” cost: $n_r \cdot b_s + b_r$
- If at least one relation fits in the memory, then its cost is: $b_r + b_s$

JOIN OPERATION: BLOCK NESTED LOOP JOIN

```
FOR each block b_r ∈ r DO BEGIN
    FOR each block b_s ∈ s DO BEGIN
        FOR each record t_r ∈ b_r DO BEGIN
            FOR each record t_s ∈ b_s DO BEGIN
                test pair (t_r, t_s)
            END
        END
    END
END
```

- „worst-case” cost: $b_r \cdot b_s + b_r$
- with a lot of memory: $b_r + b_s$

JOIN OPERATION: INDEXED NESTED LOOP JOIN

For one of the relations (s) we have an index

Let us put the indexed relation to the inner cycle of the first algorithm

$\Longrightarrow$ Using the index, the search can be performed at a lower cost

Cost:

$$b_r + n_r \cdot c,$$

where c is the cost of selection on s.

FURTHER JOIN IMPLEMENTATIONS

- sorted merge join
  - order relations by the attributes provided in the join condition
- hash join
  - one of the relations is accessed through a hash table when looking for its records matching the records of the other relation

FURTHER OPERATIONS

- *Filtering repetitions* (ordering, and then deleting)
- *Projection* (projection, then filtering repetitions)
- *Union* (ordering of both relations, and filtering duplications during merge)
- *Intersection* (ordering both relations, then leaving only the repetitions during merge)
- *Subtraction* (ordering both relations, and then during merge, we only leave those elements in the result set, which are only present in the first relation)

METHODS FOR EVALUATING EXPRESSIONS

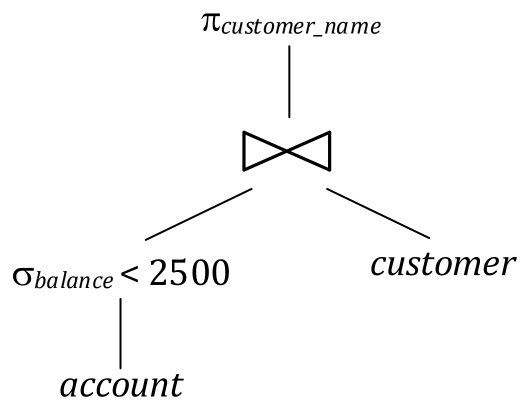
- Materialization
  - Evaluating a single operation of a complex expression at a time
- Pipelining
  - Multiple operations are evaluated in parallel
  - The result of an opeartion is immediately transferred to the input of the next operation

METHODS FOR EVALUATING EXPRESSIONS: MATERIALIZATION

- Canonical format:

$$\pi_{customer\_name}(\sigma_{balance<2500}(account) \bowtie customer)$$

- Query tree:



- Final cost: cost of operations + cost of storing sub-results
- Advantage: Easy implementation
- Drawback: Many storage operations (block operations)

METHODS FOR EVALUATING EXPRESSIONS: PIPELINING

- Parallel evaluation
- Operations create sub-results for the following operation, based on the sub-results of the preceding operation
- Does not calculate the whole relation (sub-result) at a time

Advantage:

- No temporary storage needed
- Low memory requirement

Drawback:

- Narrows down the algorithms that can be used

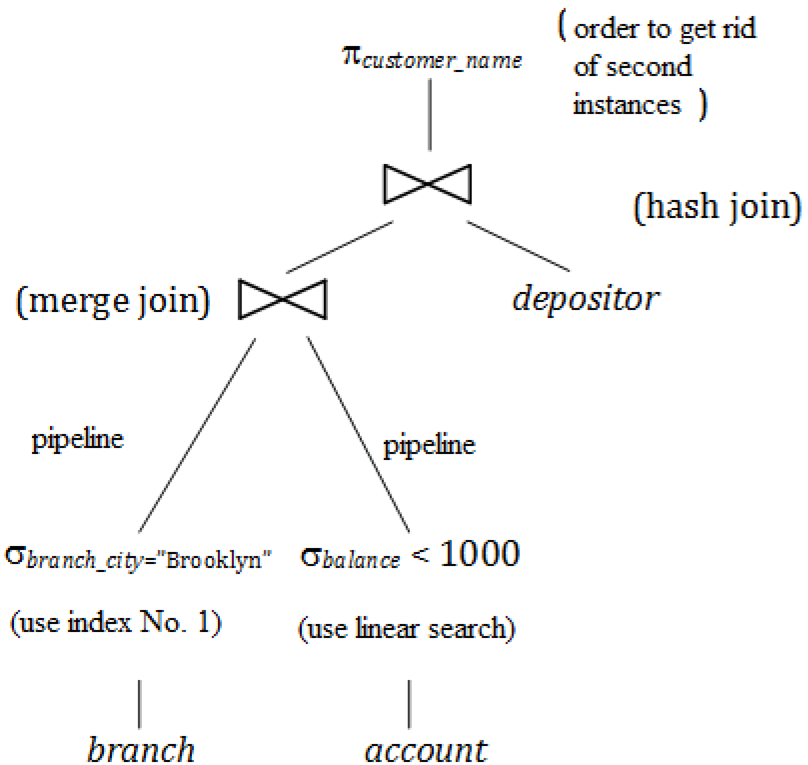
CHOOSING THE EXECUTION PLAN

Many execution plans are possible for the same result

Questions to be answered:

- Which operations?
- In what order?
- By which algorithm?
- By which workflow?

One exact execution plan:



CHOOSING THE EXECUTION PLAN: COST-BASED OPTIMIZATION

Greedy and wrong strategy:

- Listing all possible equivalent execution plans
- Evaluating each plan
- Choosing the optimal one

Example: In case of expression $r_1 \bowtie r_2 \bowtie r_3 \rightarrow 12$ equivalent expressions

In more general: to join n relations, $\frac{(2(n-1))!}{(n-1)!}$ equivalent expressions exist.

This would mean too much load for the system.

Solution: Heuristic cost-based optimization

CHOOSING THE EXECUTION PLAN: HEURISTIC, RULE BASED OPTIMIZATION

- Manipulating the query tree
- Example:

EMPLOYEE (EMPLOYEE_ID, LAST_NAME, FIRST_NAME, BIRTH_DATE, …)

PROJECT (PROJECT_ID, PNAME, …)

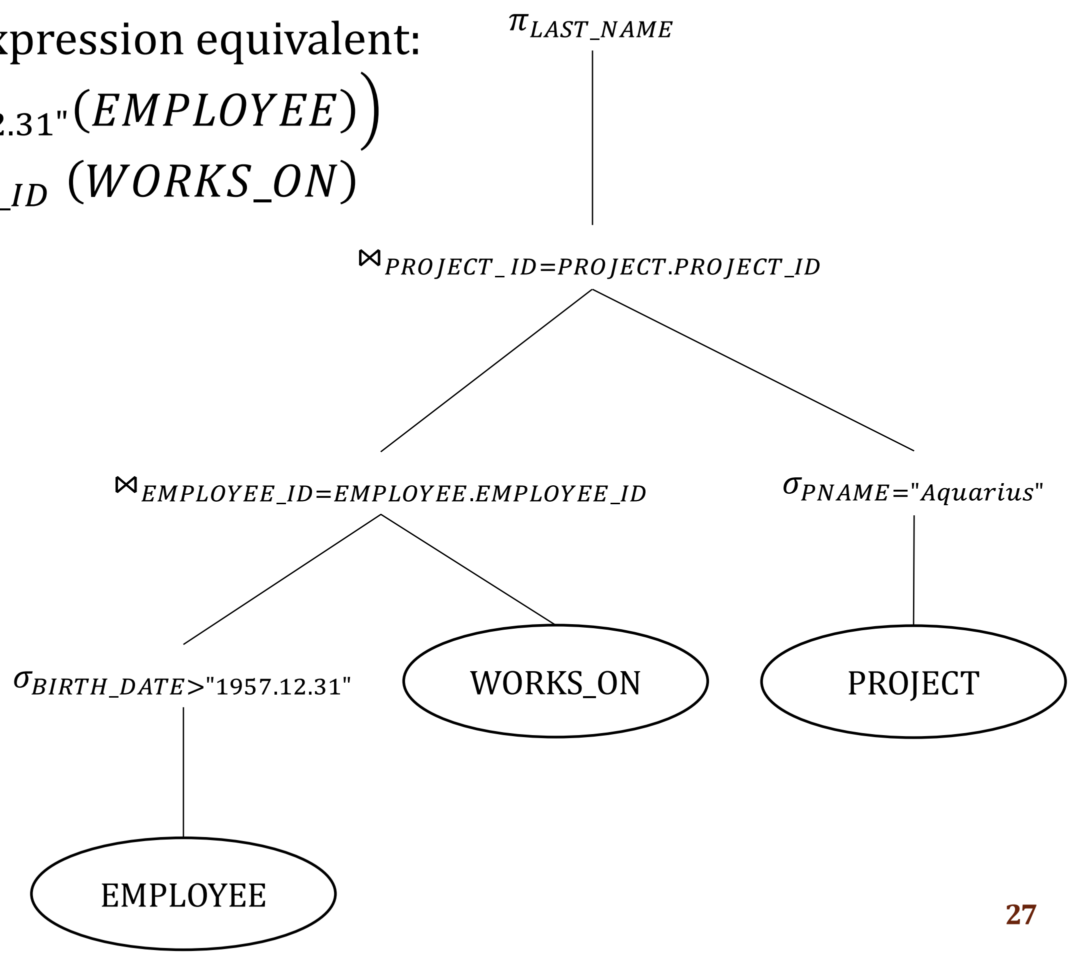
WORKS_ON (PROJECT_ID, EMPLOYEE_ID)

```
select last_name
  from employee, works_on, project
 where employee.birth_date > '1957.12.31'
   and works_on.project_id = project.project_id
   and works_on.employee_id = employee.employee_id
   and project.pname = 'Aquarius'
```

CHOOSING THE EXECUTION PLAN: HEURISTIC, RULE BASED OPTIMIZATION

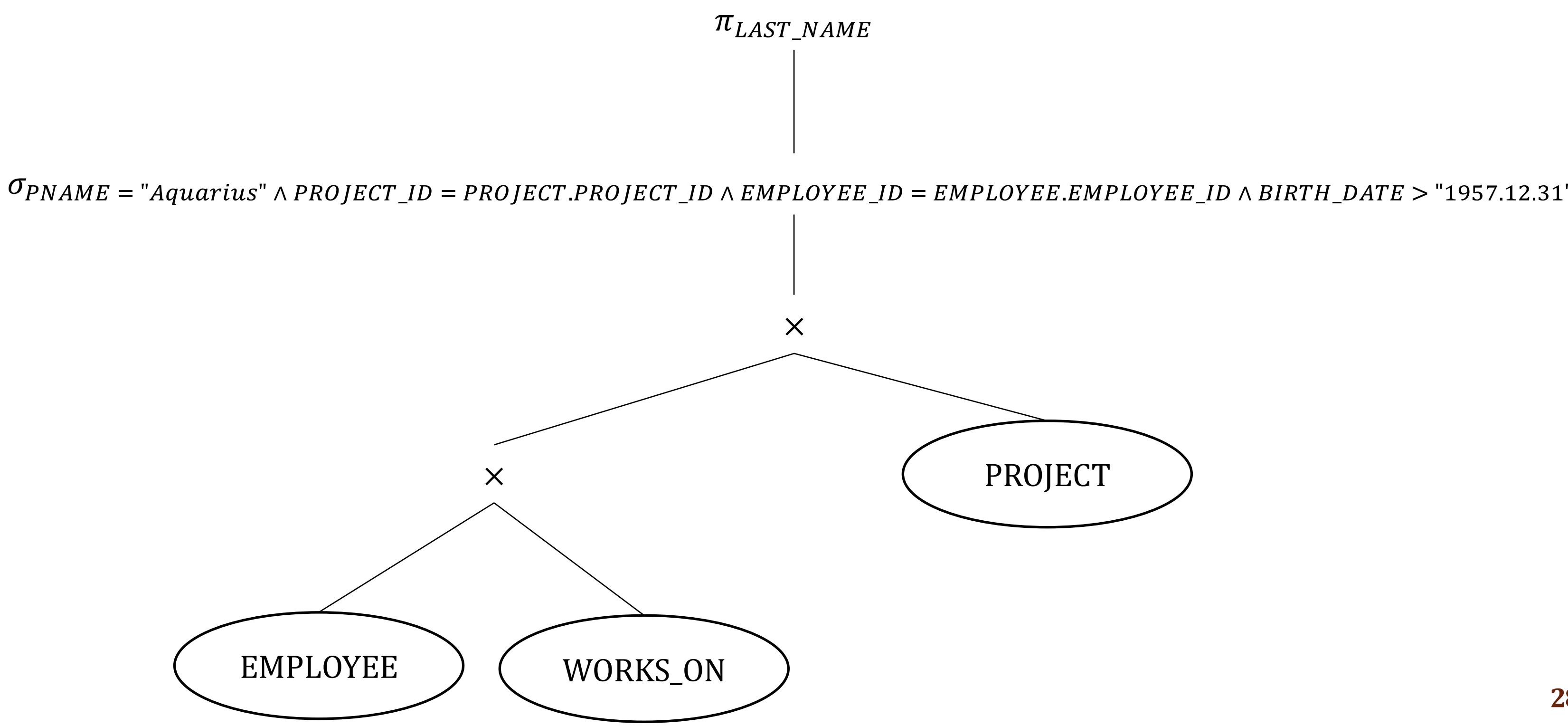
- A possible relational algebra expression equivalent:

$$\pi_{LAST\_NAME}\left(\left(\sigma_{BIRTH\_DATE>"1957.12.31"}(EMPLOYEE)\right) \bowtie_{EMPLOYEE\_ID=EMPLOYEE.EMPLOYEE\_ID} (WORKS\_ON) \bowtie_{PROJECT\_ID=PROJECT.PROJECT\_ID} \sigma_{PNAME="Aquarius"}(PROJECT)\right)$$



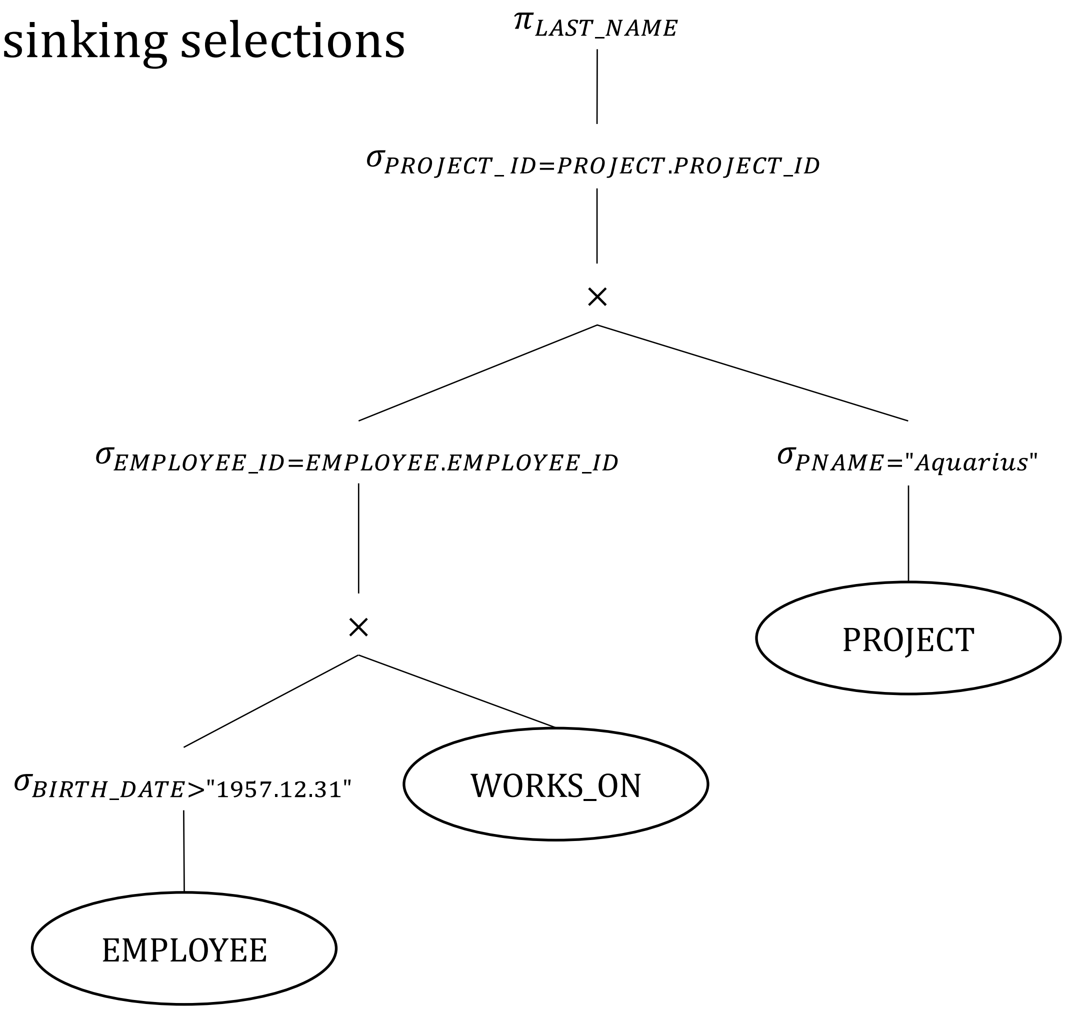
CHOOSING THE EXECUTION PLAN: HEURISTIC, RULE BASED OPTIMIZATION

- Goal: choosing the quickest equivalent
- Step 1: canonical format (Cartesian, selection, projection)



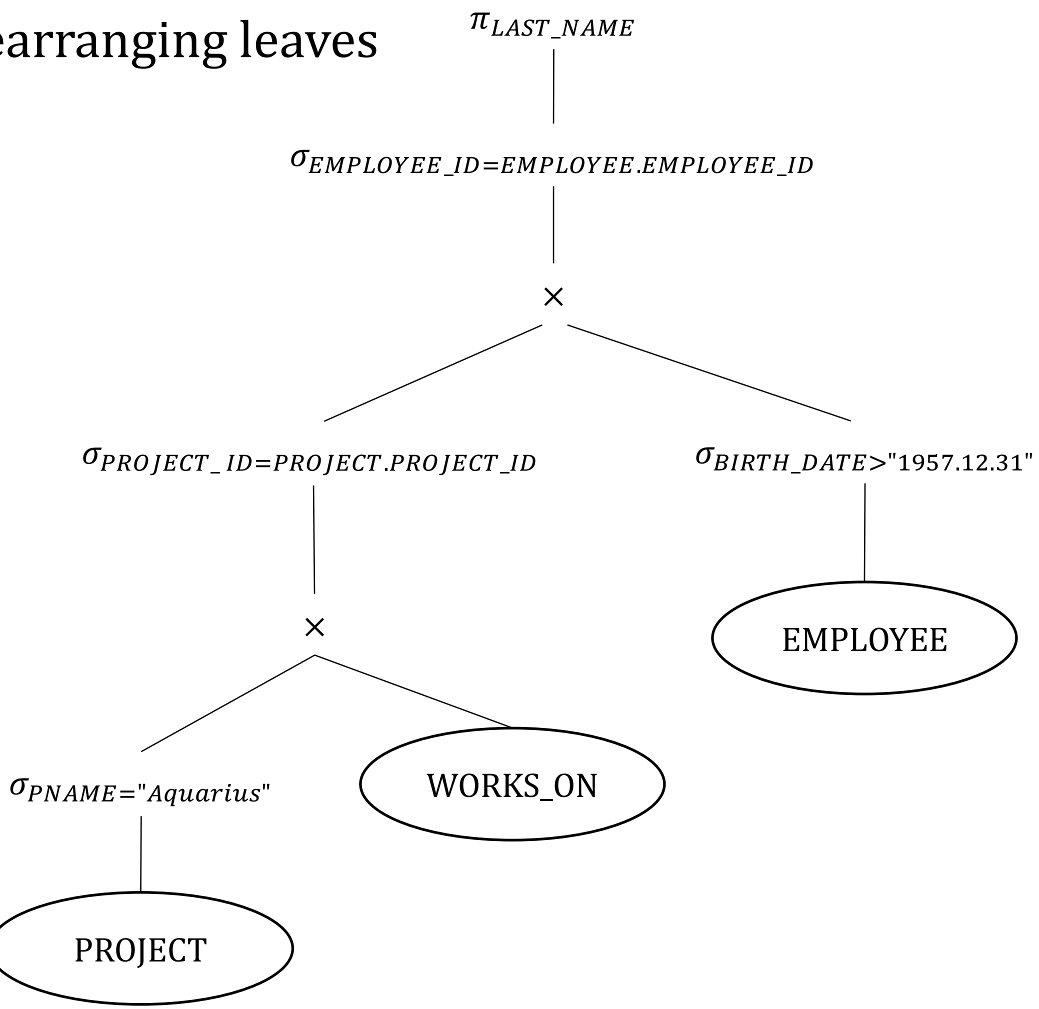
CHOOSING THE EXECUTION PLAN: HEURISTIC, RULE BASED OPTIMIZATION

- Step 2: sinking selections



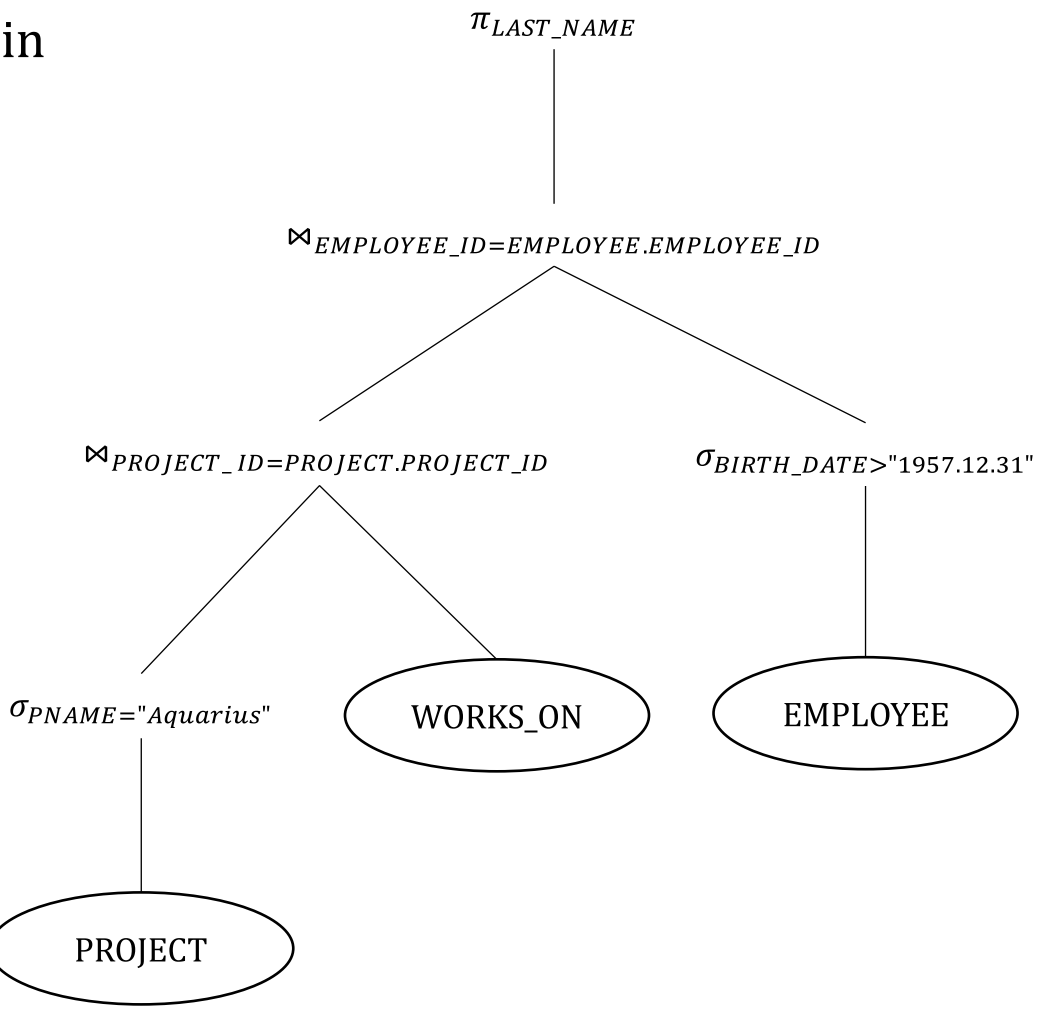
CHOOSING THE EXECUTION PLAN: HEURISTIC, RULE BASED OPTIMIZATION

- Step 3: rearranging leaves



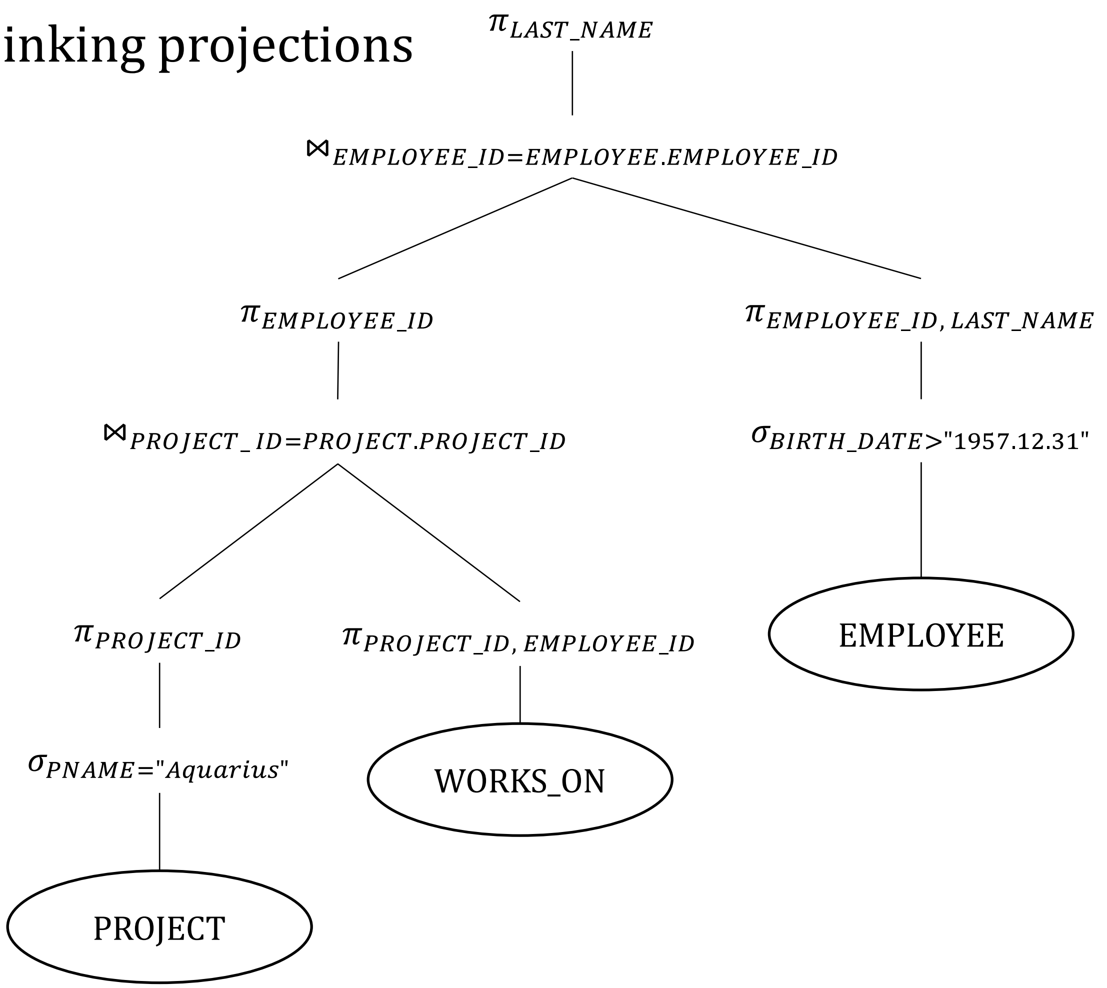
CHOOSING THE EXECUTION PLAN: HEURISTIC, RULE BASED OPTIMIZATION

- Step 4: join



CHOOSING THE EXECUTION PLAN: HEURISTIC, RULE BASED OPTIMIZATION

- Step 5: sinking projections



WHEN ARE TWO TREES EQUIVALENT?

RELATIONAL ALGEBRA TRANSFORMATIONS I.

- $\sigma_{c_1 \wedge c_2 \wedge \cdots \wedge c_n}(r) \equiv \sigma_{c_1}\left(\sigma_{c_2}\left(\ldots\left(\sigma_{c_n}(r)\right)\ldots\right)\right)$
- $\sigma_{c_1}\left(\sigma_{c_2}(r)\right) \equiv \sigma_{c_2}\left(\sigma_{c_1}(r)\right)$
- $\pi_{List_1}\left(\pi_{List_2}\left(\ldots\left(\pi_{List_n}(r)\right)\ldots\right)\right) \equiv \pi_{List_1}(r)$
- $\pi_{A_1, A_2, \ldots, A_n}(\sigma_c(r)) \equiv \sigma_c\left(\pi_{A_1, A_2, \ldots, A_n}(r)\right)$

WHEN ARE TWO TREES EQUIVALENT?

RELATIONAL ALGEBRA TRANSFORMATIONS II.

- $r \bowtie_c s \equiv s \bowtie_c r$
- $\sigma_c(r \bowtie s) \equiv \left(\sigma_c(r)\right) \bowtie s$
- $\pi_L(r \bowtie_c s) \equiv \left(\pi_{A_1,\dots,A_n}(r)\right) \bowtie_c \left(\pi_{B_1,\dots,B_m}(s)\right)$
- $\pi_L(r \bowtie_c s) \equiv$ $\pi_L\left(\left(\pi_{A_1,\dots,A_n,A_{n+1},\dots,A_{n+k}}(r)\right) \bowtie_c \left(\pi_{B_1,\dots,B_m,B_{m+1},\dots,B_{m+p}}(s)\right)\right)$

Set operations (union, intersection) are commutative

Join, Cartesian product, union, and intersection are associative:

$$(r\theta s)\theta t \equiv r\theta(s\theta t)$$

WHEN ARE TWO TREES EQUIVALENT?

RELATIONAL ALGEBRA TRANSFORMATIONS III.

- $\sigma_C(r\ \theta\ s) \equiv \left(\sigma_C(r)\right)\ \theta\ \left(\sigma_C(s)\right)$
- $\pi_L(r\ \theta\ s) \equiv \left(\pi_L(r)\right)\ \theta\ (\pi_L(s))$

Further rules:

- $c \equiv \neg(c_1 \wedge c_2) \equiv (\neg c_1\ ) \vee (\neg c_2)$
- $c \equiv \neg(c_1 \vee c_2) \equiv (\neg c_1\ ) \wedge (\neg c_2)$

RULES, SUMMARY

- Conjuctions in selections are transformed to a series of selections.
- Selections are swapped with the other operations.
- Query tree leaves are re-arranged.
- Cartesian products and the selection (join) condition above them are transformed to a single operation (theta join)
- Projections are swapped with the other operations