Universität Konstanz

Optimization of Nested Queries using the NF² Algebra

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Motivation

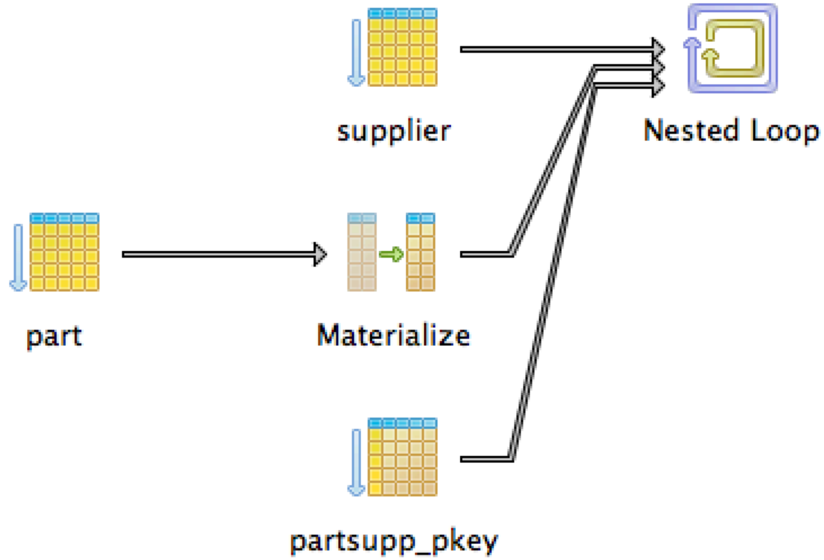
Example

"*All Parts offered by a supplier*"

```
SELECT p_name, s_name
FROM Part, Supplier
WHERE p_partkey IN (SELECT ps_partkey
                    FROM PartSupp
                    WHERE ps_suppkey = s_suppkey)
```

Motivation

- Execution plan in PostgreSQL 9.4.2:



- Execution time on a 10 GB TPC-H DB: $>$ 24 h

Motivation

Alternative formulation

```
SELECT p_name, s_name
FROM Part, Supplier, PartSupp
WHERE p_partkey = ps_partkey AND ps_suppkey = s_suppkey
```

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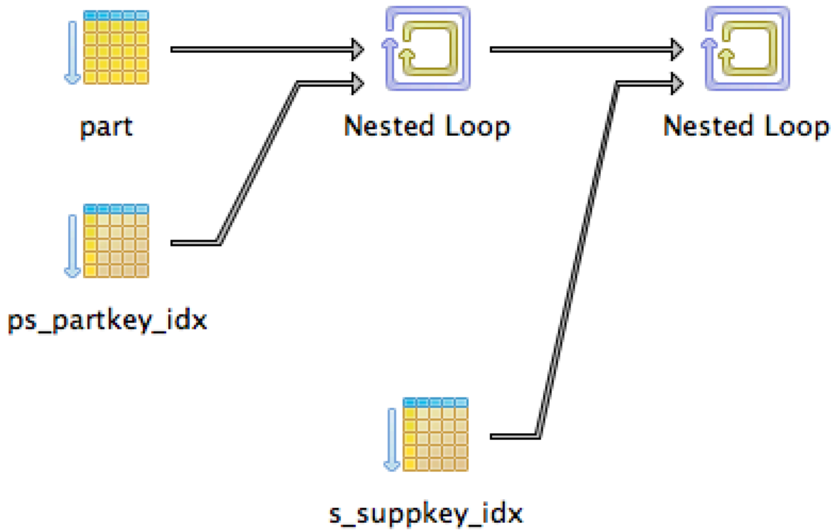

- Execution time on a 10 GB TPC-H DB: $\approx$ 32 s

Techniques for optimizing nested queries

- Transformations at the level of SQL
- Different formalisms (*e.g.* comprehension calculus)

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$\rightarrow$ Ideally, handle nested query optimization **algebraically**

How can we optimize this query algebraically?

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$$\pi[\text{p\_name}, \text{s\_name}](\qquad\qquad\qquad\qquad)$$

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Let's try to use the relational algebra:

$$\pi[\text{p\_name, s\_name}](\quad \text{Part} \times \text{Supplier}\ )$$

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~~Let's try to use the relational algebra:~~

$$\cancel{\pi[\text{p\_name, s\_name}](\sigma[?](\text{Part} \times \text{Supplier}))}$$

Nestings cannot be represented by the relational algebra

How can we optimize this query algebraically?

$\Rightarrow$ Representation with NF^2 algebra

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NF^2 representation:

$$\pi[\text{p\_name, s\_name}](\sigma[\text{p\_partkey} \in \pi[\text{ps\_partkey}](\sigma[\text{ps\_suppkey} = \text{s\_suppkey}](\text{PartSupp}))](\text{Part} \times \text{Supplier}))$$

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No NF^2 backend is needed

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- We show how all types of nested queries are represented by NF^2 expressions
- We define NF^2 equivalences that formalize existing optimization techniques
- We introduce new optimization techniques, which are made possible by the NF^2 approach
- We discuss the neccessary changes to an optimizer based on Cascades framework
- We quantify the performance benefits of our approach

Equivalences for existing optimization techniques

Won Kim, *On Optimizing an SQL-like Nested Query*. ACM Transactions on Database Systems (TODS), 1982.

Unnesting of Type J and N queries

$$\sigma[A \in \pi[B](\sigma[F](Inner))](Outer) \equiv \pi[attr(Outer)](Inner \bowtie_{A=B \wedge F} Outer)$$

Unnesting of Type A queries

$$\sigma[A\ \theta\ f(\pi[B](Inner))](Outer)$$
$$\equiv \pi[attr(Outer)](\sigma[A\ \theta\ agg](Outer \times (agg := f(\pi[B](Inner))))$$

Unnesting of Type JA queries

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$$\equiv \pi[attr(Outer)](\sigma[A\ \theta\ agg](Outer \bowtie_F \gamma[G; agg := f(B)](Inner)))$$

If F has inequality predicates:

$$\sigma[A\ \theta\ f(\pi[B](\sigma[F](Inner)))](Outer)$$
$$\equiv \pi[attr(Outer)](\sigma[A\ \theta\ agg](Outer \bowtie \gamma[G; agg := f(B)](Outer \bowtie_F Inner)))$$

If f is COUNT:

$$\sigma[A\ \theta\ COUNT(\pi[B](\sigma[F](Inner)))](Outer)$$
$$\equiv \pi[attr(Outer)](\sigma[A\ \theta\ agg](Outer \bowtie \gamma[G; agg := COUNT(B)](Outer ⟕ Inner)))$$

Example: Type J and N unnesting rule

Type J and N unnesting rule

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$$\equiv \pi[attr(Outer)](Inner \bowtie_{A=B \wedge F} Outer)$$

Query from the introduction

$$\pi[\text{p\_name, s\_name}](\sigma[\text{p\_partkey} \in \pi[\text{ps\_partkey}]($$
$$\sigma[\text{ps\_suppkey} = \text{s\_suppkey}](\text{PartSupp}))](\text{Part} \times \text{Supplier}))$$

$$\equiv \pi[\text{p\_name, s\_name}]($$
$$\text{PartSupp} \ltimes_{\text{p\_partkey}=\text{ps\_partkey} \wedge \text{ps\_suppkey}=\text{s\_suppkey}} (\text{Part} \times \text{Supplier}))$$

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Existing relational algebra equivalences remain valid

Type J and N unnesting rule

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More equivalences for existing optimization techniques

Bellamkonda et al., *Enhanced Subquery Optimizations in Oracle*. In PVLDB, 2009.

Subquery coalescing rule I

$\sigma[(A\ \theta_1\ \theta_3(\pi[B](\sigma[F_1](Inner)))\ \theta_2\ (A\ \theta_1\ \theta_3(\pi[B](\sigma[F_2](Inner)))](Outer)$
$\equiv \sigma[A\ \theta_1\ \theta_3(\pi[B](\sigma[F_1 \vee F_2](Inner))](Outer)$

Subquery coalescing rule II

$\sigma[(A\ \theta_1\ \theta_3(\pi[A](\sigma[F_1](Inner)))\ \theta_2\ (A\ \theta_1\ \theta_3(\pi[A](\sigma[F_2](Inner)))](Outer)$
$\equiv \sigma[A\ \theta_1\ \theta_3(\pi[A](\sigma[F_1](Inner))](Outer)$

Subquery coalescing rule III

$\sigma[(A\ \theta_1\ \theta_3(\pi[A](\sigma[F_1](Inner)))\ \theta_2\ (A\ \theta_1\ \theta_3(\pi[A](\sigma[F_2](Inner)))](Outer)$
$\equiv \sigma[A\ \theta_1\ \theta_3(\pi[A](\sigma[F_2](Inner))](Outer)$

Example: Subquery coalescing

Example

```
SELECT *
FROM Orders
WHERE o_totalprice >= (SELECT MAX(o_totalprice)
                       FROM Orders
                       WHERE o_orderpriority = '2-HIGH')
  AND o_totalprice >= (SELECT MAX(o_totalprice)
                       FROM Orders
                       WHERE o_orderpriority = '3-MEDIUM')
```

$$\Downarrow$$

```
SELECT *
FROM Orders
WHERE o_totalprice >= (SELECT MAX(o_totalprice)
                       FROM Orders
                       WHERE o_orderpriority = '2-HIGH'
                           OR o_orderpriority = '3-MEDIUM')
```

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- NF^2 representation:

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- NF^2 representation:

$$\sigma[\text{o\_totalprice} \geq \text{MAX}(\pi[\text{o\_totalprice'}](\sigma[\text{o\_orderpriority} = \text{'2-HIGH'}](\text{Orders'}))) \quad](\text{Orders})$$

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Example: Subquery coalescing

Equivalence rule

$$\begin{aligned}
&\sigma[A \geq \text{MAX}(\pi[B](\sigma[F_1](Inner))) \wedge \\
&\quad A \geq \text{MAX}(\pi[B](\sigma[F_2](Inner)))](Outer) \\
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\end{aligned}$$

Example

σ[o_totalprice $\geq$ MAX(π[o_totalprice'](
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Evaluation

SQL

$\downarrow$

NF^2

$\downarrow$

NF^2 optimizer

$\downarrow$

Execution plan

$\downarrow$

SQL

$\downarrow$

Execution in DB

Evaluation

SQL

↓

NF^2

↓

NF^2 optimizer

↓

Execution plan

↓

SQL

↓

Execution in DB

Set of 11 nested queries

- Subqueries in SELECT, FROM and WHERE clause
- Subqueries with multiple nestings
- Subqueries with redundancy

Evaluation

SQL

$\downarrow$

NF^2

$\downarrow$

NF^2 optimizer

$\downarrow$

Execution plan

$\downarrow$

SQL

$\downarrow$

Execution in DB

- 1:1 translation from SQL

Evaluation

SQL

$\downarrow$

NF^2

$\downarrow$

NF^2 optimizer

$\downarrow$

Execution plan

$\downarrow$

SQL

$\downarrow$

Execution in DB

- Optimize each query **with** and **without** NF^2 rules

Evaluation

SQL

$\downarrow$

NF^2

$\downarrow$

NF^2 optimizer

$\downarrow$

Execution plan

$\downarrow$

SQL

$\downarrow$

Execution in DB

- Generated by the NF^2 optimizer

Evaluation

SQL

$\downarrow$

NF^2

$\downarrow$

NF^2 optimizer

$\downarrow$

Execution plan

$\downarrow$

SQL

$\downarrow$

Execution in DB

- Derived from execution plan

Evaluation

SQL

$\downarrow$

NF^2

$\downarrow$

NF^2 optimizer

$\downarrow$

Execution plan

$\downarrow$

SQL

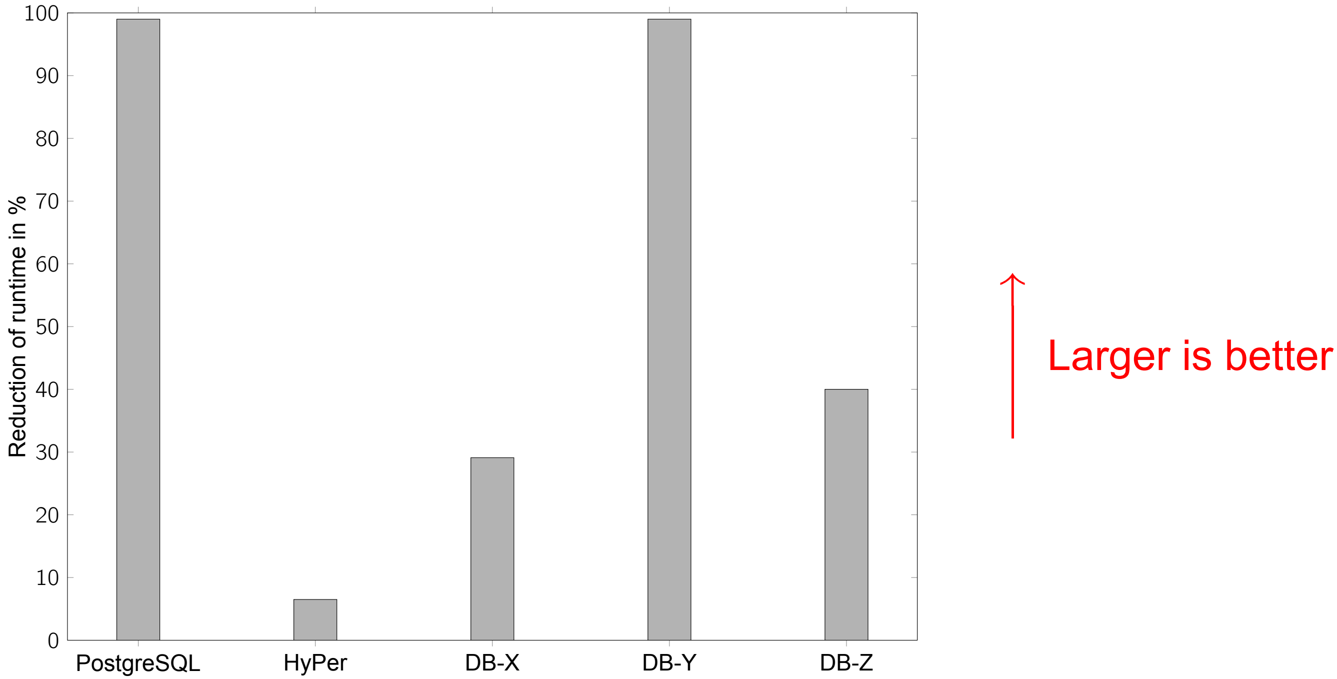
$\downarrow$

Execution in DB

Systems:

- Postgres 9.4.2
- HyPer
- Three commercial database systems

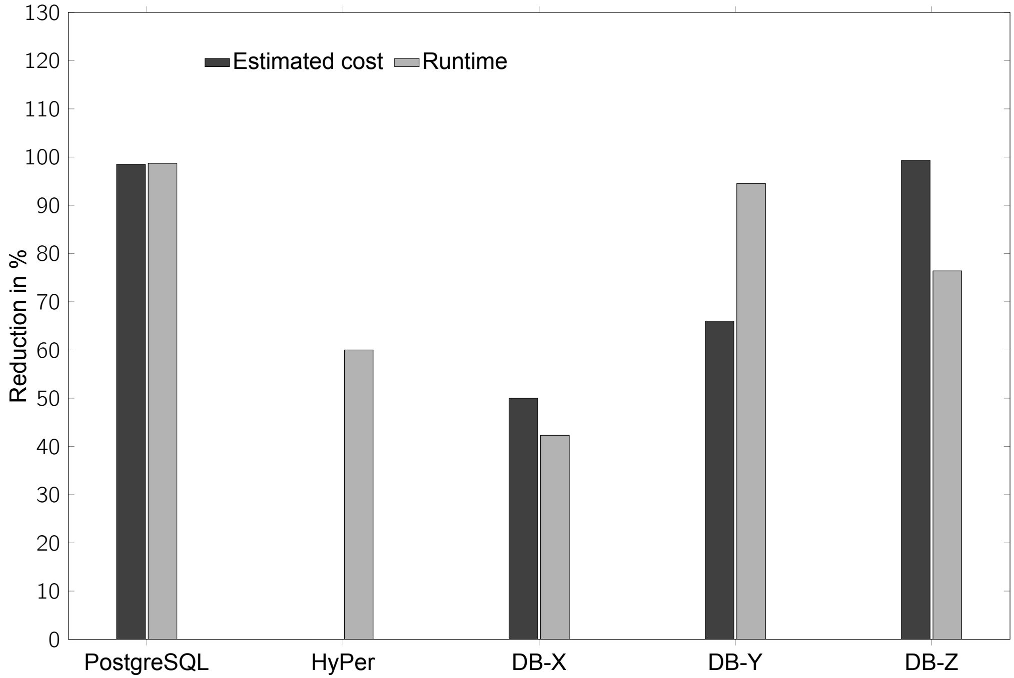
Evaluation: Runtime reduction over all queries



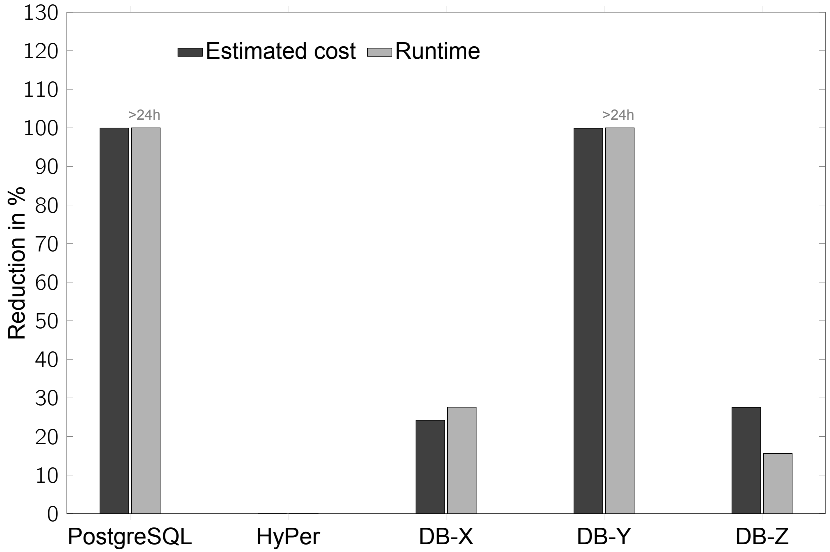
Formula to compute the runtime reduction:

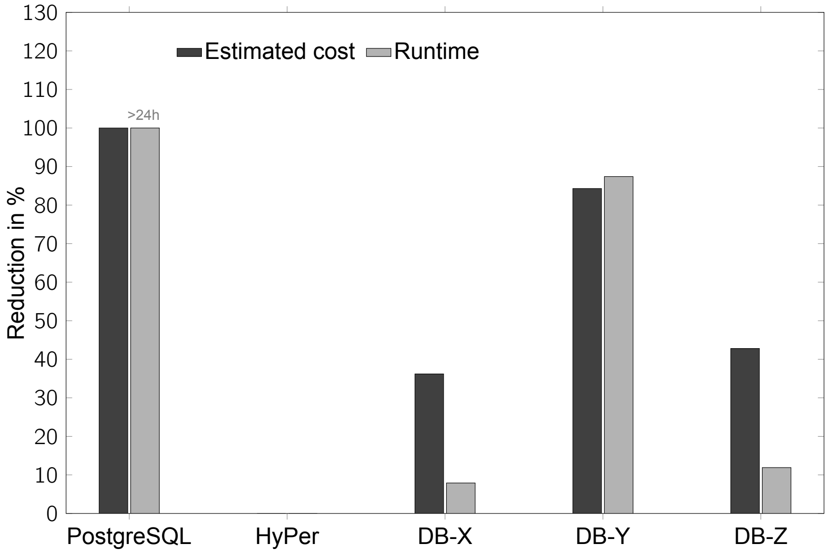
$$\frac{(\text{runtime original query} - \text{runtime transformed query})}{\text{runtime original query}} * 100$$

Evaluation: Subquery in Select Clause

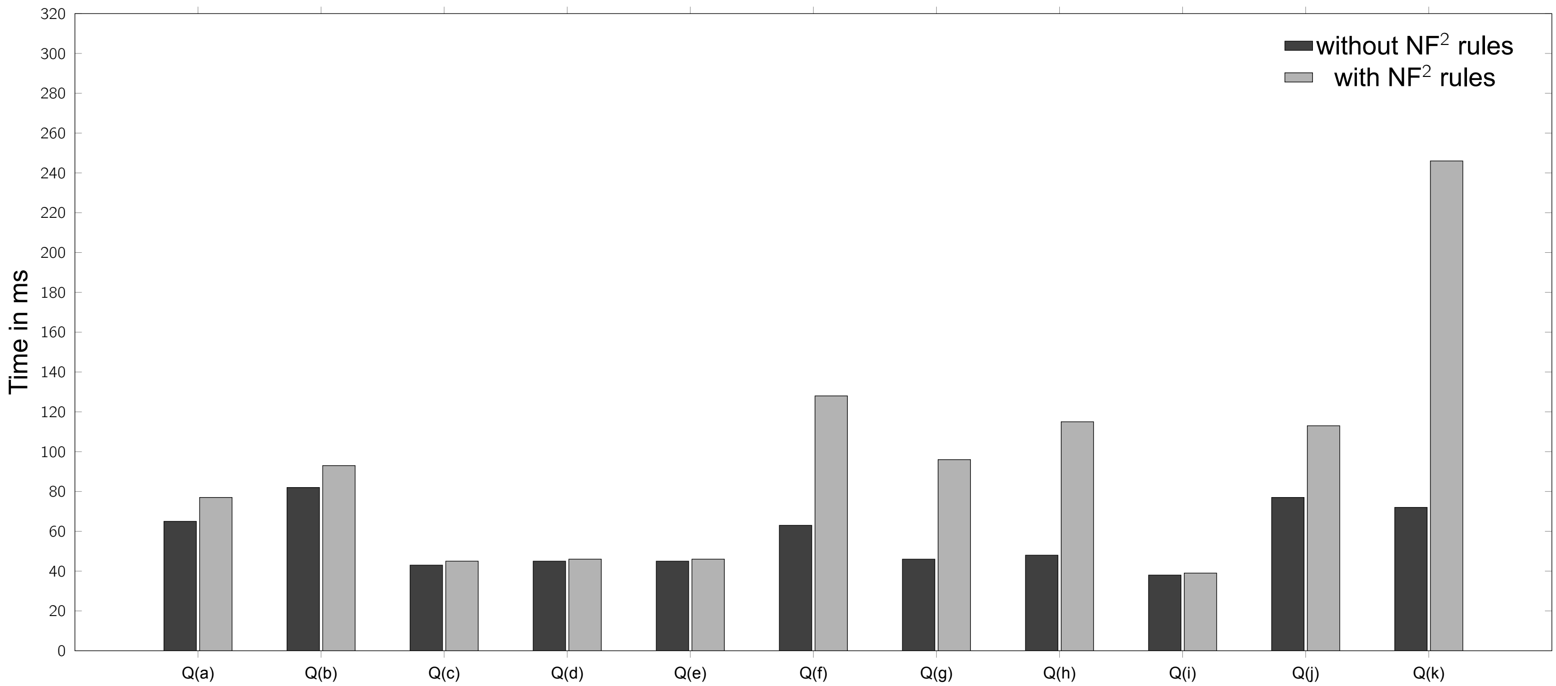


Evaluation: Subqueries with Multiple Nestings

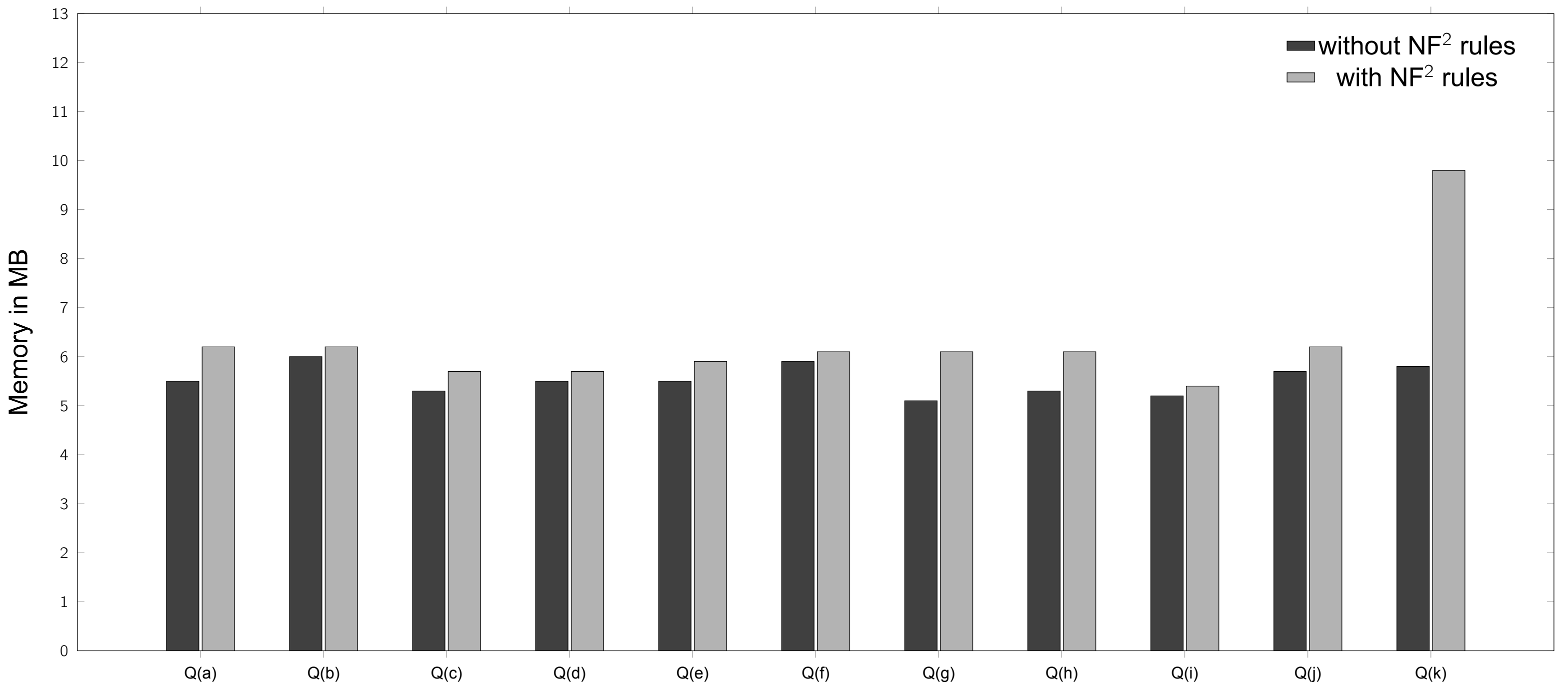




Evaluation: NF^2 Optimizer (Runtime)



Evaluation: NF^2 Optimizer (Memory)



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- Can represent all types of nested queries
- Extension of the relational algebra
  $\Rightarrow$ Existing equivalences remain valid
- Can be integrated into a transformation-based optimizer with little effort
- No NF^2 backend is needed