

Through the Joining Glass

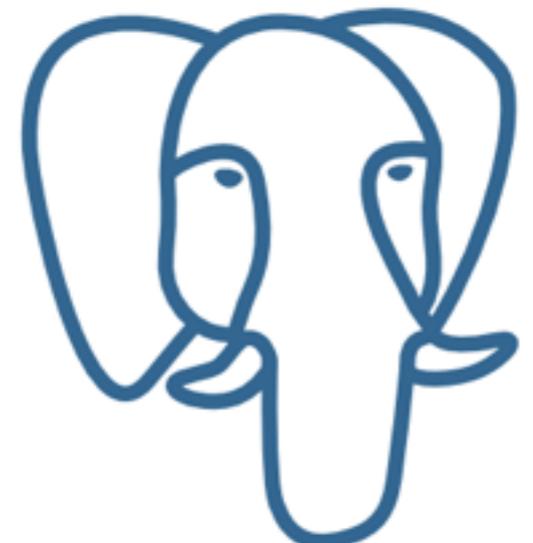
Daniel Gustafsson • Pivotal

Hello, I'm Daniel Gustafsson

Pivotal.



**GREENPLUM
DATABASE**





THE 9TH ANNUAL
**POSTGRESQL
CONFERENCE
EUROPE**

A photograph of the Warsaw cityscape, featuring traditional European buildings with red-tiled roofs under a clear blue sky.

W A R S A W
P O L A N D

O C T O B E R 2 4 - 2 7 2 0 1 7

```
CREATE TABLE t (
    a integer,
    b integer
);
```

```
CREATE TABLE tt (
    c integer,
    d integer
);
```

```
INSERT INTO t VALUES (1, 2);
INSERT INTO tt VALUES (2, 2);
```

```
=# SELECT t.a, tt.c FROM t, tt  
-# WHERE t.b = tt.d;
```

| a | c |
|---|---|
| 1 | 2 |

(1 row)

```
=# SELECT t.a, tt.c FROM t, tt  
-# WHERE t.b = tt.d;
```

| a | c |
|---|---|
| 1 | 2 |

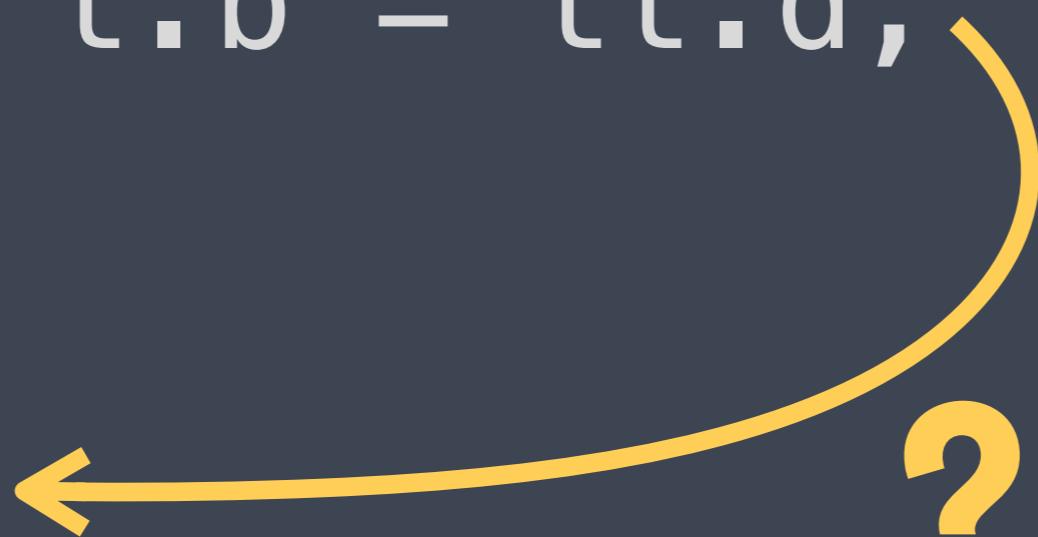
(1 row)



```
=# SELECT t.a, tt.c FROM t, tt  
-# WHERE t.b = tt.d;
```

| a | c |
|---|---|
| 1 | 2 |

(1 row)



Purpose

Introduce a few select
parts of the PostgreSQL
query planner and
hopefully demystify a little

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```
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SELECT a, c FROM t, tt WHERE b = d;
```



Parser

```
SELECT a, c FROM t, tt WHERE b = d;
```



Parser



Planner

```
SELECT a, c FROM t, tt WHERE b = d;
```



Parser



Planner



Executor

```
SELECT a, c FROM t, tt WHERE b = d;
```



Parser



Planner



Executor

\$

```
SELECT a, c FROM t, tt WHERE b = d;
```



Parser

Well defined



Planner



Executor

\$

```
SELECT a, c FROM t, tt WHERE b = d;
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Parser

Well defined



Planner



Executor

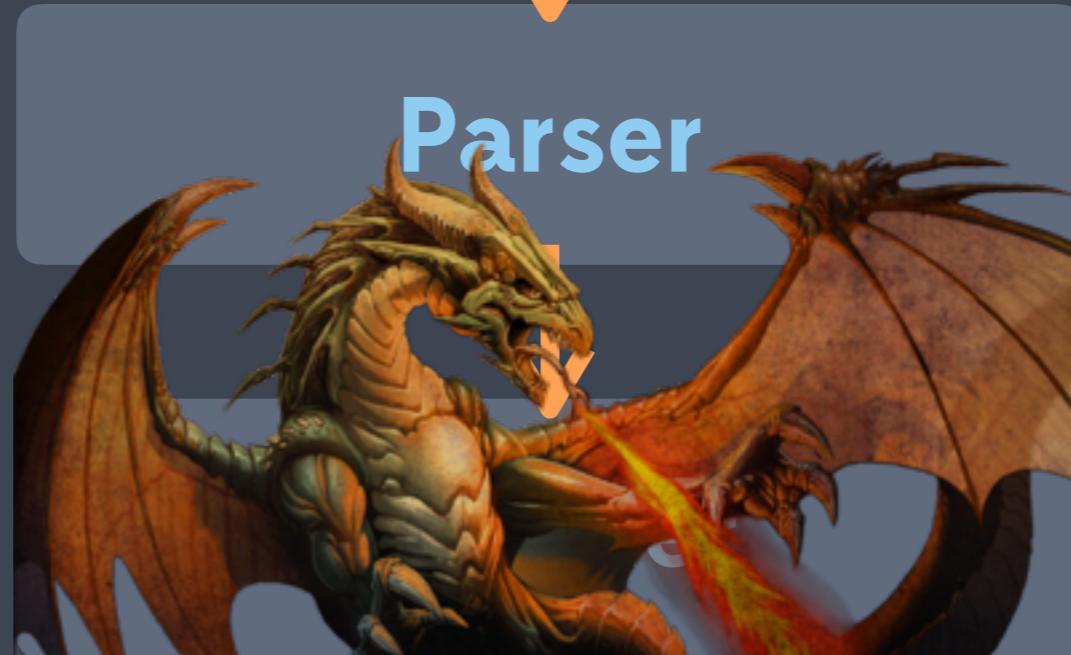
Well defined

\$

```
SELECT a, c FROM t, tt WHERE b = d;
```



Parser



Well defined

..bloody
complicated



Executor

Well defined



238 MAGIC TRICKS

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EVERY SINGLE TRICK IS PERFORMED WITH EVERYDAY THINGS YOU HAVE AROUND THE HOUSE... COINS, CARDS, BALLS, HANDKERCHIEFS, ROPES, etc.

ONLY
50¢
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- THE VANISHING BALL
- THE MIND READING TRICK
- THE SECRET OF NUMBER 9
- PHANTOM WRITING
- GROWING MONEY TRICK
- THE COIN LEAPING TRICK
- DISAPPEARING HANDKERCHIEF
- THE KNOT THAT UNTIES ITSELF
- THE DISAPPEARING COIN
- MAKING A BALL ROLL BY ITSELF
- MIRACLE CARD JUMPING TRICK
- THE PHANTOM MONEY TRICK, etc.

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RUSH ME MY MAGIC TRICK'S FOR WHICH I HAVE ENCLOSED 50¢.

Send me 3 for only \$1.25 (check here)

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Query Planning

Preprocessing

Simplification, constant folding

Scan/Join Planning

WHERE clause

Special Features

GROUP BY, window functions ..

Postprocessing

Convert plan to execution

Query Planning

Preprocessing

Simplification, constant folding

Scan/Join Planning

WHERE clause

Special Features

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Postprocessing

Convert plan to execution

Join Order Selection

Join Order Enumeration

Given the set of relations in a query, find the optimal order in which to access the relations in order to satisfy the query

A. a = B. b AND

A. d = D. d AND

B. c = C. c

A. a = B. b AND

A. d = D. d AND

B. C = C. C

N! join orderings:

ABCD, ABDC, ADBC, DABC ...

A.a = B.b AND

A.d = D.d AND

B.c = C.c

N! join orderings:

ABCD, ABDC, ADBC, DABC ...

{
}

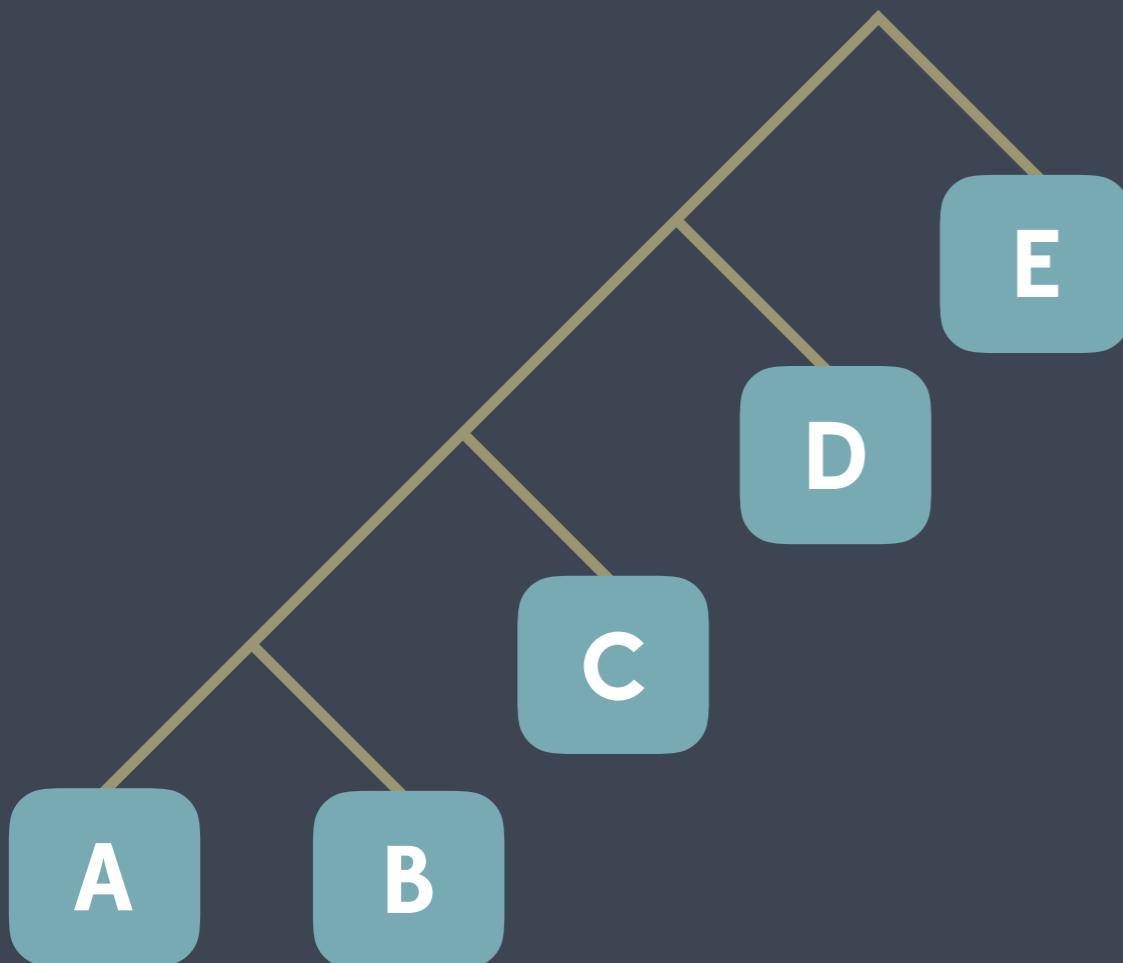
(N-1)! plans per join order:

((AB)C)D, ((AB)(CD)) ...

Join Trees

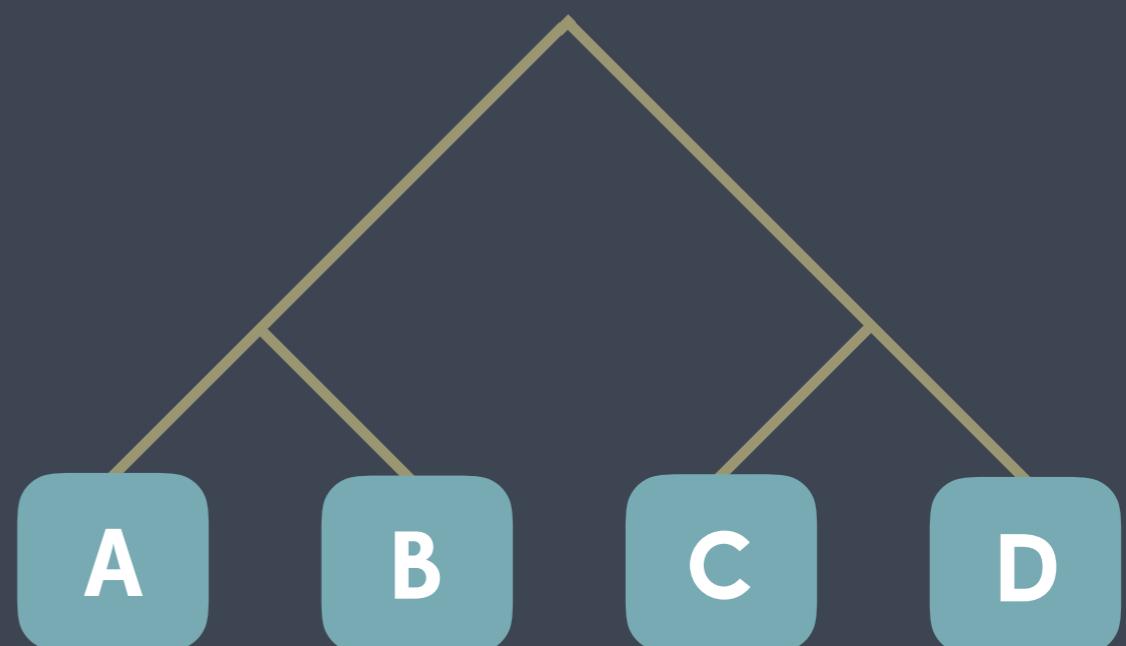


Left Sided



((((AB)C)D)E)

Bushy

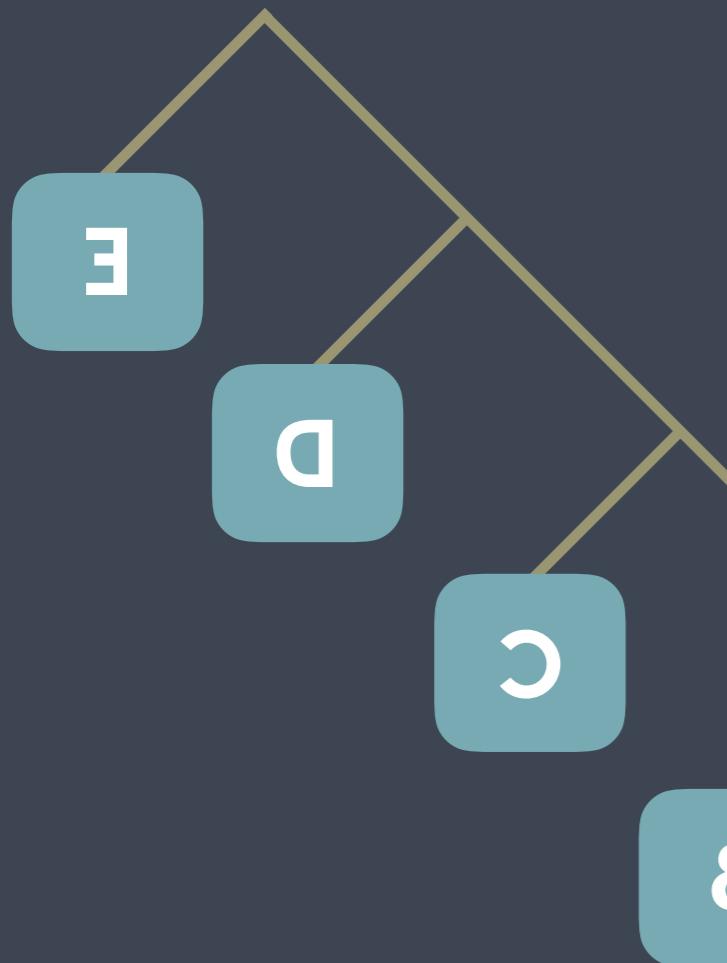


((AB)(CD))

Join Trees

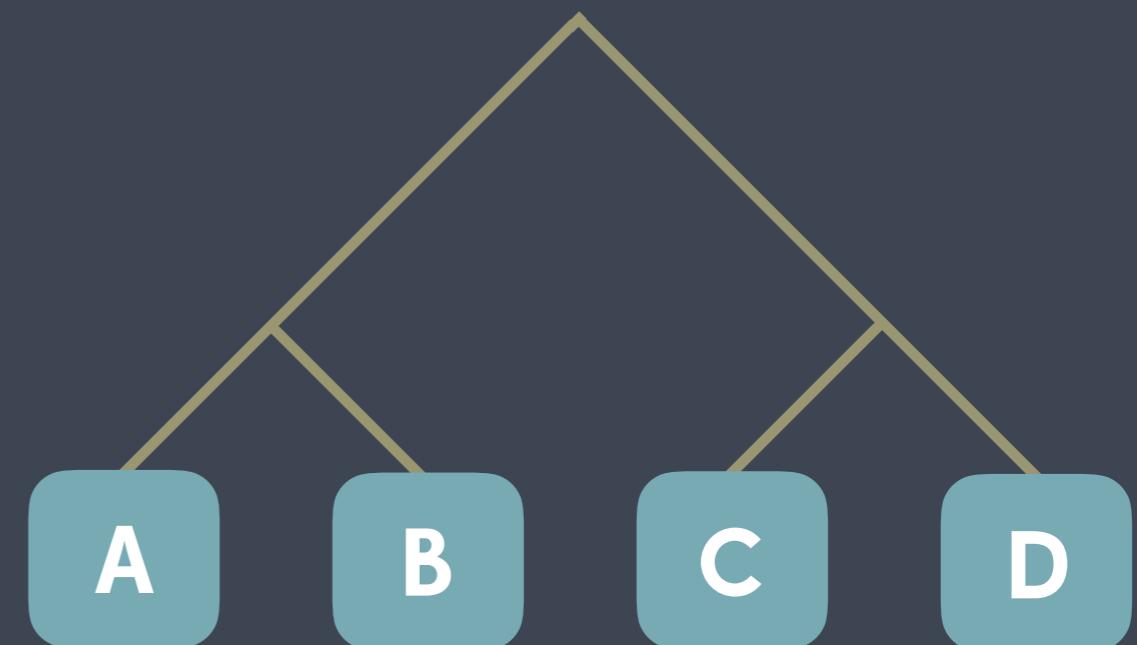


Right Sided



(E(D(C(BA))))

Bushy



((AB) (CD))

$N! \times (N-1)!$ possible plans

4 way join → 144 plans

10 way join → 1,316,818,944,000 plans

20 way .. 💀💣

Naive, and/or,
exhaustive
approaches
doesn't scale



9
7
6



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ATARI 400 (16 K) und ATARI 800 (bis 48 K) sind das Herz des kompletten Personal Computer Systems. Color-PAL-Signal für jeden Fernseher. 6502 Mikroprozessor. Grafik, Sound und über 160 Farben. Programmiersprachen BASIC, PASCAL, PILOT und ASSEMBLER-EDITOR. ROM-Programm-Module. Disk-Drives, Drucker, Programm-Recorder, Interface, Light Pen, Joysticks usw. als geprüftes ATARI-Zubehör.

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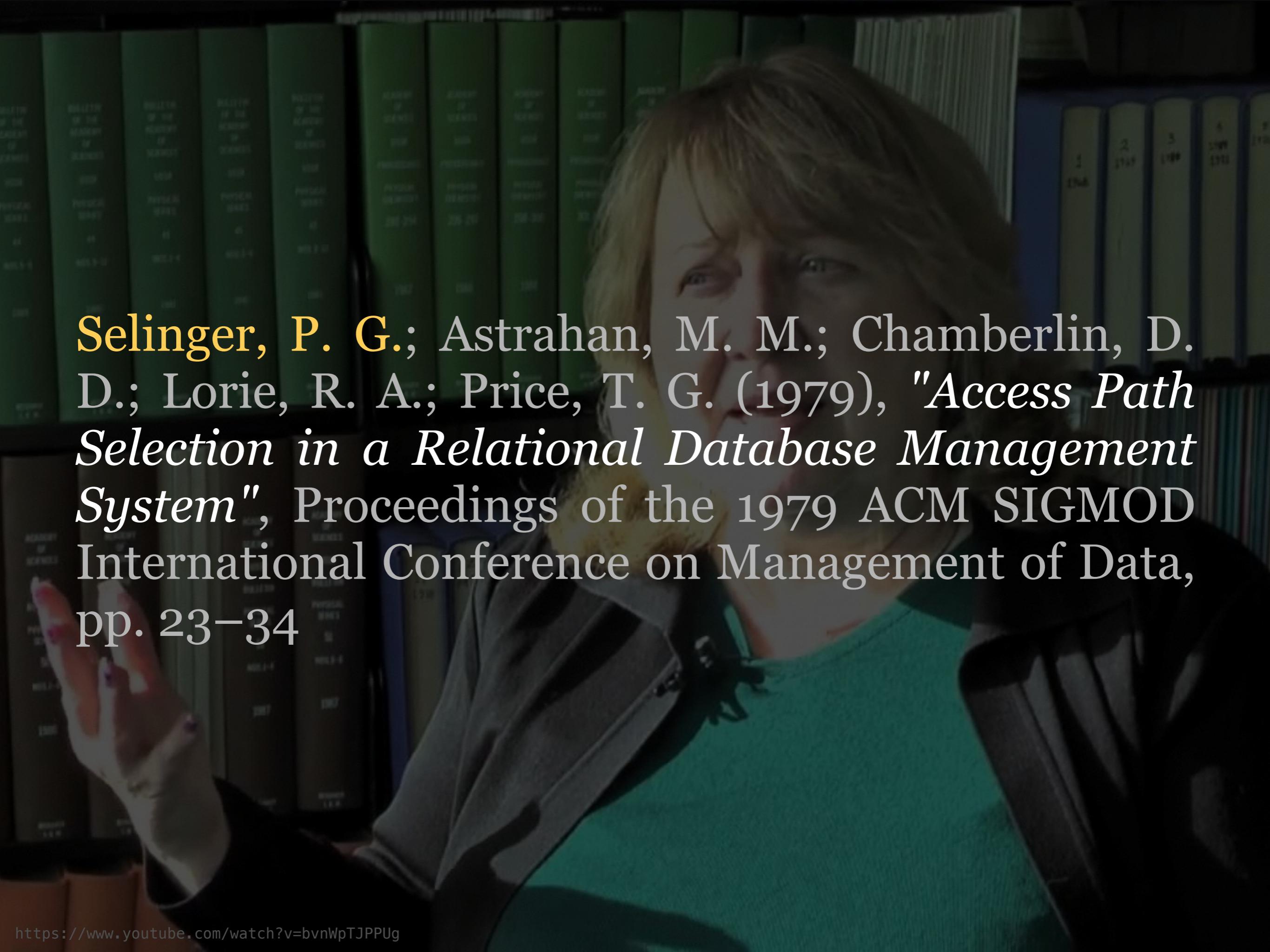
Für viele Bereiche.
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Herrn Ollmann.





System/R



A woman with blonde hair is looking down at a book she is holding. She is wearing a green t-shirt. In the background, there are many books on a shelf, suggesting a library or bookstore.

Selinger, P. G.; Astrahan, M. M.; Chamberlin, D. D.; Lorie, R. A.; Price, T. G. (1979), "*Access Path Selection in a Relational Database Management System*", Proceedings of the 1979 ACM SIGMOD International Conference on Management of Data, pp. 23–34

Selinger Algorithm

Step 1 • Enumerate all access paths to individual relations,
keep the cheapest around

Selinger Algorithm

- Step 1** • Enumerate all access paths to individual relations, keep the cheapest around
- Step 2** • Consider all ways to join two relations, using best access path as computed in step one

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- ...
- Step n** • Consider all ways to join n relations, reusing cached calculations from step n-1

Selinger Algorithm

- Step 1** • Enumerate all access paths to individual relations,
keep the **cheapest** around
- Cost based**
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calculations from step n-1

Dynamic Programming

A. a = B. b AND

A. d = D. d AND

B. c = C. c

Step 1 • Access Paths

```
A = OptimalAccess(Arelation);  
B = OptimalAccess(Brelation);
```



Step 2 • 2-way Join

$\{A, B\} = \text{Cheapest}(AB, BA);$
 $\{B, C\} = \text{Cheapest}(BC, CB);$



Step 3 • 3-way Join

$\{A, B, C\} = \text{Cheapest}(A\{B, C\}, \{B, C\}A, B\{A, C\}, \{A, C\}B, C\{A, B\}, \{A, B\}C);$

$\{A, B, D\} = \text{Cheapest}(A\{B, D\}, \{B, D\}A, B\{A, D\}, \{A, D\}B, D\{A, B\}, \{A, B\}D);$

...

Step 3 • 3-way Join

$$\{A, B, C\} = \text{Cheapest}(A\{B, C\}, \{B, C\}A, \\ B\{A, C\}, \{A, C\}B, \\ C\{A, B\}, \{A, B\}C);$$
$$\{A, B, D\} = \text{Cheapest}(A\{B, D\}, \{B, D\}A, \\ B\{A, D\}, \{A, D\}B, \\ D\{A, B\}, \{A, B\}D);$$

...

Precomputed
in step 2

Step n · n-way Join

$\{A, B, C, D\} = \dots$

Step n · n-way Join

$\{A, B, C, D\} = \dots$

Cheapest join order for query reached
or

Cheapest join order with the correct
ordering iff cheaper than cheapest
overall + final sort-step

PostgreSQL

GEQO - Genetic Query Optimizer



Relations
in query

geqo_threshold

Selinger Algorithm

PostgreSQL

GEQO - Genetic Query Optimizer

geqo_threshold

Default: 12

Selinger Algorithm

Relations
in query

GEQO

Heuristics required as the
search space increase

Travelling salesman algorithm
across the relations

..not terribly good, but currently
our best alternative

How Good Are Query Optimizers, Really?

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ABSTRACT

Finding a good join order is crucial for query performance. In this paper, we introduce the Join Order Benchmark (JOB) and experimentally revisit the main components in the classic query optimizer architecture using a complex, real-world data set and realistic multi-join queries. We investigate the quality of industrial-strength cardinality estimators and find that all estimators routinely produce large errors. We further show that while estimates are essential for finding a good join order, query performance is unsatisfactory if the query engine relies too heavily on these estimates. Using another set of experiments that measure the impact of the cost model, we find that it has much less influence on query performance than the cardinality estimates. Finally, we investigate plan enumeration techniques comparing exhaustive dynamic programming with heuristic algorithms and find that exhaustive enumeration improves performance despite the sub-optimal cardinality estimates.

1. INTRODUCTION

The problem of finding a good join order is one of the most studied problems in the database field. Figure 1 illustrates the classical, cost-based approach, which dates back to System R [36]. To obtain an efficient query plan, the query optimizer enumerates some subset

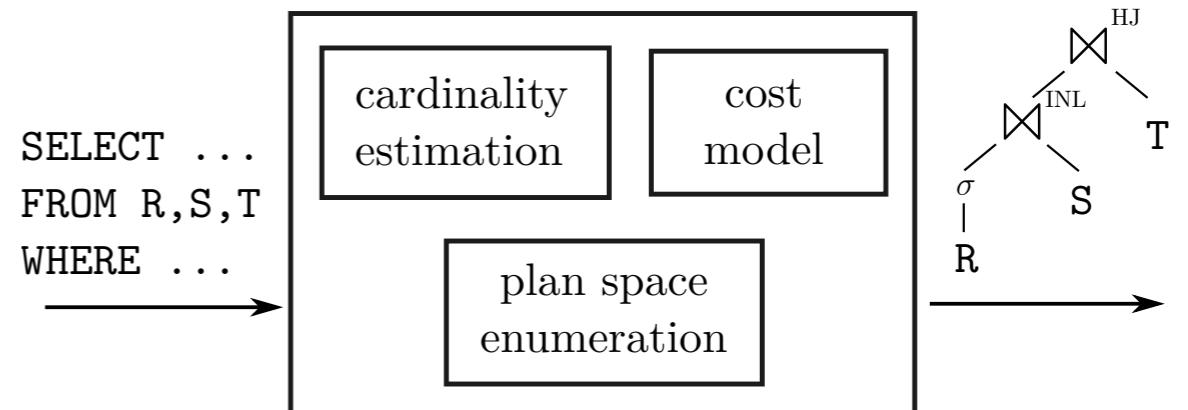


Figure 1: Traditional query optimizer architecture

- How important is an accurate cost model for the overall query optimization process?
- How large does the enumerated plan space need to be?

To answer these questions, we use a novel methodology that allows us to isolate the influence of the individual optimizer components on query performance. Our experiments are conducted using a real-world data set and 113 multi-join queries that provide a challenging, diverse, and realistic workload. Another novel aspect of this paper is that it focuses on the increasingly common main-memory

In this paper we have provided quantitative evidence for conventional wisdom that has been accumulated in three decades of practical experience with query optimizers. We have shown that query optimization is essential for efficient query processing and that exhaustive enumeration algorithms find better plans than heuristics.

Implementation



Data Structures

Plan Node

A plan is a tree of Plan nodes

How and What of query execution

Data Source (relation, join)

Targetlist (SELECT . . .)

Selection Conditions (WHERE . . .)

Path

A Path is a Plan node omitting the details irrelevant to the planner

RelOptInfo

Created for each base relation and
join relation

List of Paths representing how to
scan/join the relation
(`RelOptInfo.pathlist`)

List of all join clauses involving the
relation (`RelOptInfo.joininfo`)

RANGE TABLE lists the relations in the query

```
SELECT a, c FROM t, tt AS t2 WHERE b = d;
```



range table entries



```
SELECT a, c FROM t JOIN tt ON (b = d);
```

```
:rtable (
  {RTE
  :alias <>
  :eref
    {ALIAS
    :aliasname t
    :colnames ("a" "b")
    }
  :rtekind 0
  :relid 16385
  :relkind r
  ...
}
{RTE
:alias
  {ALIAS
  :aliasname t2
  :colnames <>
  }
:eref
  {ALIAS
  :aliasname t2
  :colnames ("c" "d")
  }
  :rtekind 0
  :relid 16388
  :relkind r
  ...
}
)
```

SELECT a, c
FROM t, tt **AS** t2
WHERE b = d;

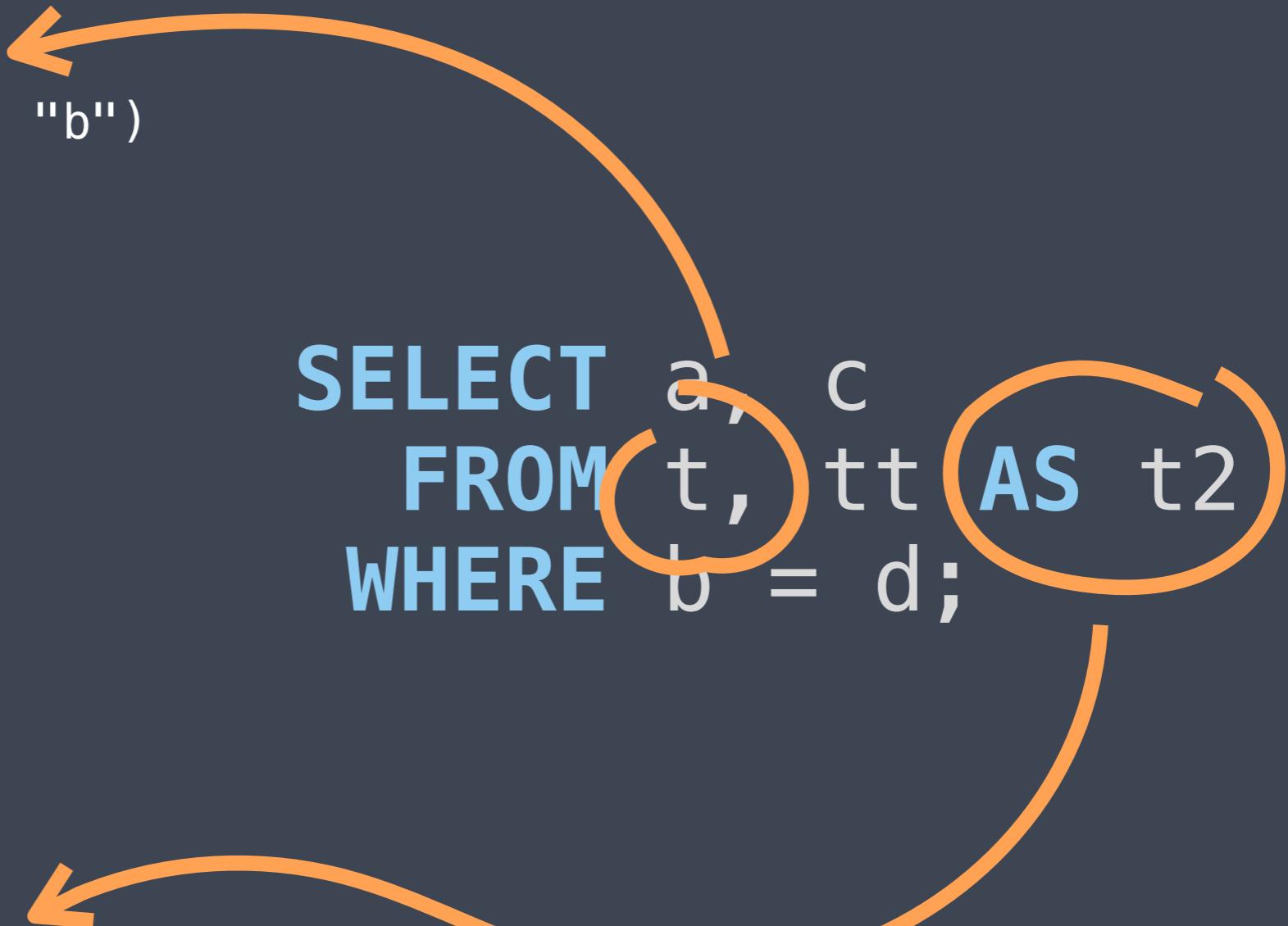


Controlled by logging GUCS:

debug_print_parse
debug_print_rewritten
debug_print_plan

```
:rtable (
  {RTE
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  ...
}
)
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SELECT a, c
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  :aliasname t2
  :colnames ("c" "d")
  }
:rtekind 0
:relid 16388
:relkind r
...
)
}
```

=# **SELECT** relname **FROM** pg_class
-# **WHERE** oid **IN** (16385, 16388);
relname

t
tt
(2 rows)



□□□□□

```

RelOptInfo *
standard_join_search(PlannerInfo *root, int levels_needed, List *initial_rels)
{
    int             lev;
    RelOptInfo *rel;

    /*
     * This function cannot be invoked recursively within any one planning
     * problem, so join_rel_level[] can't be in use already.
     */
    Assert(root->join_rel_level == NULL);

    /*
     * We employ a simple "dynamic programming" algorithm: we first find all
     * ways to build joins of two jointree items, then all ways to build joins
     * of three items (from two-item joins and single items), then four-item
     * joins, and so on until we have considered all ways to join all the
     * items into one rel.
     *
     * root->join_rel_level[j] is a list of all the j-item rels. Initially we
     * set root->join_rel_level[1] to represent all the single-jointree-item
     * relations.
     */
    root->join_rel_level = (List **) palloc0((levels_needed + 1) * sizeof(List *));
    root->join_rel_level[1] = initial_rels;

    for (lev = 2; lev <= levels_needed; lev++)
    {
        ListCell   *lc;

        /*
         * Determine all possible pairs of relations to be joined at this
         * level, and build paths for making each one from every available
         * pair of lower-level relations.
         */
        join_search_one_level(root, lev);

        /*
         * Run generate_gather_paths() for each just-processed joinrel. We
         * could not do this earlier because both regular and partial paths
         * can get added to a particular joinrel at multiple times within
         * join_search_one_level. After that, we're done creating paths for
         * the joinrel, so run set_cheapest().
         */
        foreach(lc, root->join_rel_level[lev])
        {
            rel = (RelOptInfo *) lfirst(lc);

            /* Create GatherPaths for any useful partial paths for rel */
            generate_gather_paths(root, rel);

            /* Find and save the cheapest paths for this rel */
            set_cheapest(rel);
        }

        #ifdef OPTIMIZER_DEBUG
            debug_print_rel(root, rel);
        #endif
    }

    /*
     * We should have a single rel at the final level.
     */
    if (root->join_rel_level[levels_needed] == NIL)
        elog(ERROR, "failed to build any %d-way joins", levels_needed);
    Assert(list_length(root->join_rel_level[levels_needed]) == 1);

    rel = (RelOptInfo *) linitial(root->join_rel_level[levels_needed]);
    root->join_rel_level = NULL;

    return rel;
}

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         * join_rel_level[lev]. Note that we're done generating paths for
         * the joinrel, so run set_cheapest().
         */
        for (lc = root->join_rel_level[lev - 1]; lc != NIL; lc = lnext(lc))
        {
            RelOptInfo *rel = (RelOptInfo *) lfirst(lc);
            /* Create GatherPaths for all useful partial paths for rel */
            generate_gather_paths(root, rel);
            /* Find and save the cheapest paths for rel */
            set_cheapest(rel);
        }
        /* If OPTIMIZER_DEBUG
         * debug_print_rel(root, rel);
         */
    }
    /* We should have a single rel at the final level.
     */
    if (root->join_rel_level[levels_needed] == NIL)
        elog(ERROR, "failed to build any %d-way joins", levels_needed);
    Assert(list_length(root->join_rel_level[levels_needed]) == 1);

    rel = (RelOptInfo *) linitial(root->join_rel_level[levels_needed]);
    root->join_rel_level = NULL;

    return rel;
}

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RelOptInfo *
standard_join_search(
    PlannerInfo *root,
    int levels_needed,
    List *initial_rels);

```

```

RelOptInfo *
standard_join_search(PlannerInfo *root, int levels_needed, List *initial_rels)
{
    int lev;
    RelOptInfo *rel;

    /*
     * This function cannot be invoked recursively within any one planning
     * problem, so join_rel_level[] can't be in use already.
     */
    Assert(root->join_rel_level == NULL);

    /*
     * We employ a simple "dynamic programming" algorithm: we first find all
     * ways to build joins of two jointree items, then all ways to build joins
     * of three items (from two-item joins and single items), then four-item
     * joins, and so on until we have considered all ways to join all the
     * items into one rel.
     *
     * root->join_rel_level[j] is a list of all the j-item rels. Initially we
     * set root->join_rel_level[1] to represent all the single-jointree-item
     * relations.
     */
    root->join_rel_level = (List **) palloc0((levels_needed + 1) * sizeof(List *));
    root->join_rel_level[1] = linitial(initial_rels);
    for (lev = 2; lev <= levels_needed; lev++)
    {
        /* Find and save the cheapest paths for this rel */
        set_cheapest(rel);

        /*
         * Determine all possible pairs of relations to be joined at this
         * level, and build paths for making each one from every available
         * pair of lower-level relations.
         */
        join_search_one_level(root, lev);

        /*
         * Run generate_gather_paths() for each just-processed joinrel. We
         * could not do this earlier because both regular and partial paths
         * can get added to a particular joinrel at multiple times within
         * join_search_one_level. After that, we're done creating paths for
         * the joinrel, so run set_cheapest().
         */
        foreach(lc, root->join_rel_level[lev])
        {
            rel = (RelOptInfo *) lfist(lc);

            /* Create GatherPaths for any useful partial paths for rel */
            generate_gather_paths(root, rel);

            /* Find and save the cheapest paths for this rel */
            set_cheapest(rel);
        }

        #ifdef OPTIMIZER_DEBUG
        debug_print_rel(root, rel);
        #endif
    }

    /*
     * We should have a single rel at the final level.
     */
    if (root->join_rel_level[levels_needed] == NIL)
        elog(ERROR, "failed to build any %d-way joins", levels_needed);
    Assert(list_length(root->join_rel_level[levels_needed]) == 1);

    rel = (RelOptInfo *) linitial(root->join_rel_level[levels_needed]);
    root->join_rel_level = NULL;
    return rel;
}

```

```

RelOptInfo *
standard_join_search(
    PlannerInfo *root,
    int levels_needed,
    List *initial_rels);

```

void join_search_one_level(PlannerInfo *root, int level)

```
void  
join_search_one_level(PlannerInfo *root, int level)  
{  
    List **joinrels = root->join_rel_level;  
    ListCell *r;  
    int k;  
  
    Assert(joinrels[level] == NIL);  
  
    /* Set join_cur_level so that new joinrels are added to proper list */  
    root->join_cur_level = level;  
  
    foreach(r, joinrels[level - 1])  
    {  
        RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);  
  
        if (old_rel->joininfo != NIL || old_rel->has_eclass_joins ||  
            has_join_restriction(root, old_rel))  
        {  
            ListCell *other_rels;  
  
            if (level == 2) /* consider remaining initial rels */  
                other_rels = lnext(r);  
            else /* consider all initial rels */  
                other_rels = list_head(joinrels[1]);  
  
            make_rels_by_clause_joins(root,  
                old_rel,  
                other_rels);  
        }  
        else  
        {  
            make_rels_by_clauseless_joins(root,  
                old_rel,  
                list_head(joinrels[1]));  
        }  
    }  
  
    for (k = 2;; k++)  
    {  
        int other_level = level - k;  
  
        if (k > other_level)  
            break;  
  
        foreach(r, joinrels[k])  
        {  
            RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);  
            ListCell *other_rels;  
            ListCell *r2;  
  
            if (old_rel->joininfo == NIL && !old_rel->has_eclass_joins &&  
                !has_join_restriction(root, old_rel))  
                continue;  
  
            if (k == other_level)  
                other_rels = lnext(r); /* only consider remaining rels */  
            else  
                other_rels = list_head(joinrels[other_level]);  
  
            for_each_cell(r2, other_rels)  
            {  
                RelOptInfo *new_rel = (RelOptInfo *) lfirst(r2);  
  
                if (!bms_overlap(old_rel->relids, new_rel->relids))  
                {  
                    if (have_relevant_joinclause(root, old_rel, new_rel) ||  
                        have_join_order_restriction(root, old_rel, new_rel))  
                    {  
                        (void) make_join_rel(root, old_rel, new_rel);  
                    }  
                }  
            }  
        }  
        if (joinrels[level] == NIL)  
        {  
            foreach(r, joinrels[level - 1])  
            {  
                RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);  
  
                make_rels_by_clauseless_joins(root,  
                    old_rel,  
                    list_head(joinrels[1]));  
            }  
  
            if (joinrels[level] == NIL &&  
                root->join_info_list == NIL &&  
                !root->has_lateralRTEs)  
                elog(ERROR, "failed to build any %d-way joins", level);  
        }  
    }  
}
```

```

void
join_search_one_level(PlannerInfo *root, int level)
{
    List **joinrels = root->join_rel_level;
    ListCell *r;
    int k;

    Assert(joinrels[level] == NIL);

    /* Set join_cur_level so that new joinrels are added to proper list */
    root->join_cur_level = level;

    foreach(r, joinrels[level - 1])
    {
        RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);

        if (old_rel->joininfo != NIL || old_rel->has_eclass_joins ||
            has_join_restriction(root, old_rel))
        {
            listcell *other_level;
            if (level == 2) /* consider remaining initial rels */
                other_level = lnext(r);
            else
                other_level = list_head(joinrels[1]);
            make_rels_by_clauseless_joins(root,
                                           old_rel,
                                           list_head(joinrels[1]));
        }
        else
        {
            make_rels_by_clauseless_joins(root,
                                           old_rel,
                                           list_head(joinrels[1]));
        }
    }

    for (k = 2; ; k++)
    {
        int other_level = level - k;
        if (k > other_level)
            break;
        foreach(r, joinrels[k])
        {
            RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);
            RelOptInfo *listcell *r2;
            if (old_rel->joininfo == NIL && !old_rel->has_eclass_joins &&
                !has_join_restriction(root, old_rel))
                continue;
            if (k == other_level)
                other_rel = r;
            else
                other_rel = list_head(joinrels[other_level]);
            foreach(r2, other_rel)
            {
                RelOptInfo *new_rel = (RelOptInfo *) lfirst(r2);
                if (!new_rel->valid || !new_rel->relids)
                {
                    if (have_relevant_joinclause(root, old_rel, new_rel) ||
                        have_join_order_restriction(root, old_rel, new_rel))
                    {
                        (void) make_join_rel(root, old_rel, new_rel);
                    }
                }
            }
        }
        if (joinrels[level] == NIL)
    }
    foreach(r, joinrels[level - 1])
    {
        RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);
        make_rels_by_clauseless_joins(root,
                                       old_rel,
                                       list_head(joinrels[1]));
    }

    if (joinrels[level] == NIL &&
        root->join_info_list == NIL &&
        !root->has_lateralRTEs)
        elog(ERROR, "failed to build any %d-way joins", level);
}

```

**void
join_search_one_level(PlannerInfo *root,
int level)**
join_search_one_level
Consider ways to produce join relations containing
exactly 'level' jointree items. (This is one step of
the dynamic-programming method embodied in
standard_join_search.) Join rel nodes for each
feasible combination of lower-level rels are created
and returned in a list. Implementation paths are
created for each such joinrel, too.
level: level of rels we want to make this time
root->join_rel_level[j], 1 <= j < level, is a list of
rels containing j items
The result is returned in root->join_rel_level[level].

```

void
join_search_one_level(PlannerInfo *root, int level)
{
    List **joinrels = root->join_rel_level;
    ListCell *r;
    int k;

    Assert(joinrels[level] == NIL);
    /* Set join_cur_level so that new joinrels are added to proper list */
    root->join_cur_level = level;

    foreach(r, joinrels[level - 1])
    {
        RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);

        if (old_rel->joininfo != NIL || old_rel->has_eclass_joins ||
            has_join_restriction(root, old_rel))
        {
            ListCell *other_rels;
            if (level == 2) /* consider remaining initial rels */
                other_rels = lnext(r);
            else /* consider initial rels */
                other_rels = list_head(joinrels[1]);
            make_rels_by_clause_joins(root,
                                       old_rel,
                                       other_rels);
        }
        else /* make_rels_by_clauseless_joins */
            make_rels_by_clauseless_joins(root,
                                           old_rel,
                                           list_head(joinrels[1]));
    }

    for (k = 2; k++)
    {
        int other_level = level - k;
        if (k > other_level)
            break;
        foreach(r, joinrels[k])
        {
            RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);
            if (!old_rel->joininfo)
                continue;
            if (old_rel->joininfo == NIL && !old_rel->has_eclass_joins &&
                !has_join_restriction(root, old_rel))
                continue;
            if (k == other_level)
                other_rels = lnext(r); /* only consider remaining rels */
            else
                other_rels = list_head(joinrels[other_level]);

            for_each_cell(r2, other_rels)
            {
                RelOptInfo *new_rel = (RelOptInfo *) lfirst(r2);
                if (!bms_overlap(old_rel->relids, new_rel->relids))
                {
                    if (have_relevant_joinclause(root, old_rel, new_rel) ||
                        have_join_order_restriction(root, old_rel, new_rel))
                    {
                        (void) make_join_rel(root, old_rel, new_rel);
                    }
                }
            }
        }
    }

    if (joinrels[level] == NIL)
    {
        foreach(r, joinrels[level - 1])
        {
            RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);
            make_rels_by_clauseless_joins(root,
                                           old_rel,
                                           list_head(joinrels[1]));
        }
    }

    if (joinrels[level] == NIL &&
        root->join_info_list == NIL &&
        !root->has_lateralRTEs)
        elog(ERROR, "failed to build any %d-way joins", level);
}

```

void
join_search_one_level(PlannerInfo *root,
int level)

*** First, consider left-sided and right-sided plans,**
*** in which rels of exactly level-1 member relations**
*** are joined against initial relations. We prefer to**
*** join using join clauses, but if we find a rel of**
*** level-1 members that has no join clauses, we will**
*** generate Cartesian-product joins against all initial**
*** rels not already contained in it.**

***/**
foreach(r, joinrels[level - 1])

```

        for_each_cell(r2, other_rels)
        {
            RelOptInfo *new_rel = (RelOptInfo *) lfirst(r2);
            if (!bms_overlap(old_rel->relids, new_rel->relids))
            {
                if (have_relevant_joinclause(root, old_rel, new_rel) ||
                    have_join_order_restriction(root, old_rel, new_rel))
                {
                    (void) make_join_rel(root, old_rel, new_rel);
                }
            }
        }
    }

    if (joinrels[level] == NIL)
    {
        foreach(r, joinrels[level - 1])
        {
            RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);
            make_rels_by_clauseless_joins(root,
                                           old_rel,
                                           list_head(joinrels[1]));
        }
    }

    if (joinrels[level] == NIL &&
        root->join_info_list == NIL &&
        !root->has_lateralRTEs)
        elog(ERROR, "failed to build any %d-way joins", level);
}

```

```

void
join_search_one_level(PlannerInfo *root, int level)
{
    List **joinrels = root->join_rel_level;
    ListCell *r;
    int k;

    Assert(joinrels[level] == NIL);
    /* Set join_cur_level so that new joinrels are added to proper list */
    root->join_cur_level = level;

    foreach(r, joinrels[level - 1])
    {
        RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);

        if (old_rel->joininfo != NIL || old_rel->has_eclass_joins ||
            has_join_restriction(root, old_rel))
        {
            ListCell *other_rels;
            if (level == 2) /* consider remaining initial rels */
                other_rels = lnext(r);
            else /* consider initial rels */
                other_rels = list_head(joinrels[1]);
            make_rels_by_clause_joins(root,
                                       old_rel,
                                       other_rels);
        }
        else /* make_rels_by_clauseless_joins */
            make_rels_by_clauseless_joins(root,
                                           old_rel,
                                           list_head(joinrels[1]));
    }
    for (k = 2; k++)
    {
        int other_level = level - k;
        if (k > other_level)
            break;
        foreach(r, joinrels[k])
        {
            RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);
            if (!old_rel->joininfo)
                continue;
            if (old_rel->joininfo == NIL && !old_rel->has_eclass_joins &&
                !has_join_restriction(root, old_rel))
                continue;
            if (k == other_level)
                other_rels = lnext(r); /* only consider remaining rels */
            else
                other_rels = list_head(joinrels[other_level]);
            for_each_cell(r2, other_rels)
            {
                RelOptInfo *new_rel = (RelOptInfo *) lfirst(r2);
                if (!bms_overlap(old_rel->relids, new_rel->relids))
                {
                    if (have_relevant_joinclause(root, old_rel, new_rel) ||
                        have_join_order_restriction(root, old_rel, new_rel))
                    {
                        (void) make_join_rel(root, old_rel, new_rel);
                    }
                }
            }
        }
        if (joinrels[level] == NIL)
            foreach(r, joinrels[level - 1])
            {
                RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);
                make_rels_by_clauseless_joins(root,
                                              old_rel,
                                              list_head(joinrels[1]));
            }
        if (joinrels[level] == NIL &&
            root->join_info_list == NIL &&
            !root->has_lateralRTEs)
            elog(ERROR, "failed to build any %d-way joins", level);
    }
}

```

**void
join_search_one_level(PlannerInfo *root,
int level)**

* First, consider left-sided and right-sided plans,
* in which rels of exactly level-1 member relations
* are joined against initial relations. We prefer to
* join using join clauses, but if we find a rel of
* level-1 members that has no join clauses, we will
* generate Cartesian-product joins against all initial
* rels not already contained in it.

*/
foreach(r, joinrels[level - 1])

A{B,C}, {B,C}A, B{A,C}, {A,C}B ..

```

void
join_search_one_level(PlannerInfo *root, int level)
{
    List **joinrels = root->join_rel_level;
    ListCell *r;
    int k;

    Assert(joinrels[level] == NIL);

    /* Set join_cur_level so that new joinrels are added to proper list */
    root->join_cur_level = level;

    foreach(r, joinrels[level - 1])
    {
        RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);

        if (old_rel->joininfo != NIL || old_rel->has_eclass_joins ||
            has_join_restriction(root, old_rel))
        {
            ListCell *other_rels;
            if (level == 2) /* consider remaining initial rels */
                other_rels = lnext(r);
            else /* consider all initial rels */
                other_rels = list_head(joinrels[1]);

            make_rels_by_clause_joins(root,
                                       old_rel,
                                       other_rels);
        }
        else
        {
            make_rels_by_clauseless_joins(root,
                                           old_rel,
                                           list_head(joinrels[1]));
        }
    }

    for (k = 2;; k++)
    {
        int other_level = level - k;

        if (k > other_level)
            break;
    }

    /* foreach(r, joinrels[k]) {
        RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);
        ListCell *other_rels;
        ListCell *r2;
        if (old_rel->joininfo == NIL & !old_rel->has_eclass_joins &&
            !has_join_restriction(root, old_rel))
            continue;
        if (k == other_level)
            other_rels = lnext(r); /* only consider remaining rels */
        else
            other_rels = list_head(joinrels[other_level]);
        for_each_cell(r2, other_rels)
        {
            RelOptInfo *new_rel = (RelOptInfo *) lfirst(r2);
            if (!bms_overlap(old_rel->relids, new_rel->relids))
            {
                if (old_rel->has_eclass_joins || old_rel->joininfo != NIL)
                {
                    if (old_rel->joininfo != NIL)
                        make_join_rel(root, old_rel, new_rel);
                    else
                        (void) make_join_rel(root, old_rel, new_rel);
                }
            }
        }
    }

    if (joinrels[level] == NIL)
    {
        foreach(r, joinrels[level - 1])
        {
            RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);
            make_rels_by_clauseless_joins(root,
                                           old_rel,
                                           list_head(joinrels[1]));
        }
    }

    if (joinrels[level] == NIL & root->join_rel_list == NIL &&
        !root->has_lateralizes)
        elog(ERROR, "failed to build any %d-way joins", level);
}

```

**void
join_search_one_level(PlannerInfo *root,
int level)**

- * Now, consider "bushy plans" in which relations of k
- * initial rels are joined to relations of level-k
- * initial rels, for $2 \leq k \leq \text{level}-2$.
- * We only consider bushy-plan joins for pairs of rels
- * where there is a suitable join clause (or join order
- * restriction), in order to avoid unreasonable growth
- * of planning time.

for (k=2;; k++)

```

void
join_search_one_level(PlannerInfo *root, int level)
{
    List **joinrels = root->join_rel_level;
    ListCell *r;
    int k;

    Assert(joinrels[level] == NIL);

    /* Set join_cur_level so that new joinrels are added to proper list */
    root->join_cur_level = level;

    foreach(r, joinrels[level - 1])
    {
        RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);

        if (old_rel->joininfo != NIL || old_rel->has_eclass_joins
            & has_join_restriction(root, old_rel))
        {
            ListCell *other_rels;
            if (level == 2) /* consider remaining initial rels */
                other_rels = lnext(r);
            else /* consider all initial rels */
                other_rels = list_head(joinrels[1]);

            make_rels_by_clause_joins(root,
                                       old_rel,
                                       other_rels);
        }
        else
        {
            make_rels_by_clauseless_joins(root,
                                           old_rel,
                                           list_head(joinrels[1]));
        }
    }

    for (k = 2;; k++)
    {
        int other_level = level - k;

        if (k > other_level)
            break;

        /* foreach(r, joinrels[k])
        {
            RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);
            ListCell *other_rels;
            ListCell *r2;
            if (old_rel->joininfo == NIL && !old_rel->has_eclass_joins &&
                !has_join_restriction(root, old_rel))
                continue;
            if (k == other_level)
                other_rels = lnext(r); /* only consider remaining rels */
            else
                other_rels = list_head(joinrels[other_level]);
            for_each_cell(r2, other_rels)
            {
                RelOptInfo *new_rel = (RelOptInfo *) lfirst(r2);

                if (!bms_overlap(old_rel->relids, new_rel->relids))
                {
                    if (old_rel->has_eclass_joins && !new_rel->has_eclass_joins)
                        make_join_rel(root, old_rel, new_rel);
                    (void) make_join_rel(root, old_rel, new_rel);
                }
            }
        }
        if (joinrels[level] == NIL)
        {
            foreach(r, joinrels[level - 1])
            RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);
            make_rels_by_clauseless_joins(root,
                                           old_rel,
                                           list_head(joinrels[1]));
        }
    }

    if (joinrels[level] == NIL && joinrels[0] == NIL &&
        !root->has_lateralizes)
        elog(ERROR, "failed to build any %d-way joins", level);
}

```

void
join_search_one_level(PlannerInfo *root,
int level)

{A,B}{B,C}, {A,C}{B,C}

- * Now, consider "bushy plans" in which relations of k
- * initial rels are joined to relations of level-k
- * initial rels, for $2 \leq k \leq \text{level}-2$.
- *
- * We only consider bushy-plan joins for pairs of rels
- * where there is a suitable join clause (or join order
- * restriction), in order to avoid unreasonable growth
- * of planning time.
- */

for (k=2;; k++)

```

void
join_search_one_level(PlannerInfo *root, int level)
{
    List **joinrels = root->join_rel_level;
    ListCell *r;
    int k;

    Assert(joinrels[level] == NIL);

    /* Set join_cur_level so that new joinrels are added to proper list */
    root->join_cur_level = level;
    /* */
    /* Each(r, joinrels[level - 1]) */
    {
        RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);
        if (old_rel->joininfo != NIL && !old_rel->has_eclass_joins &&
            !has_join_restriction(root, old_rel))
        {
            ListCell *other_rels;
            if (k == 1) /* consider remaining initial rels */
                other_rels = lnext(r);
            else /* consider all initial rels */
                other_rels = list_head(joinrels[1]);
            make_rels_by_clause_joins(root,
                                      old_rel,
                                      other_rels);
        }
        else
            make_rels_by_clauseless_joins(root,
                                           old_rel,
                                           list_head(joinrels[1]));
    }
}

if (k > other_level)
    break;
}

for (k = 2;; k++)
{
    int other_level = level - k;
    if (k > other_level)
        break;

    foreach(r, joinrels[k])
    {
        RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);
        ListCell *other_rels;
        ListCell *r2;

        if (old_rel->joininfo == NIL && !old_rel->has_eclass_joins &&
            !has_join_restriction(root, old_rel))
            continue;

        if (k == other_level)
            other_rels = lnext(r); /* only consider remaining rels */
        else
            other_rels = list_head(joinrels[other_level]);

        for_each_cell(r2, other_rels)
        {
            RelOptInfo *new_rel = (RelOptInfo *) lfirst(r2);

            if (!bms_overlap(old_rel->relids, new_rel->relids))
            {
                if (have_relevant_joinclause(root, old_rel, new_rel) ||
                    have_join_order_restriction(root, old_rel, new_rel))
                {
                    (void) make_join_rel(root, old_rel, new_rel);
                }
            }
        }
    }
}

if (joinrels[level] == NIL)
{
    foreach(r, joinrels[level - 1])
    {
        RelOptInfo *old_rel = (RelOptInfo *) lfirst(r);
        make_rels_by_clauseless_joins(root,
                                       old_rel,
                                       list_head(joinrels[1]));
    }
}

if (joinrels[level] == NIL &&
    root->join_info_list == NIL &&
    !root->has_lateralRTEs)
    elog(ERROR, "failed to build any %d-way joins", level);
}

```

* Since `make_join_rel(x, y)` handles both x,y and y,x cases, we only need to go as far as the halfway point.

*/

if (`k > other_level`)

break;

}

for (`k = 2;; k++`)

{
 int other_level = `level - k`;

if (`k > other_level`)
 break;

foreach(`r, joinrels[k]`)

{
 RelOptInfo *old_rel = (RelOptInfo *) lfirst(`r`);
 ListCell *other_rels;
 ListCell *r2;

if (`old_rel->joininfo == NIL && !old_rel->has_eclass_joins &&`
 `!has_join_restriction(root, old_rel))`
 continue;

if (`k == other_level`)
 other_rels = `lnext(r)`; /* only consider remaining rels */
 else
 other_rels = `list_head(joinrels[other_level])`;

for_each_cell(`r2, other_rels`)

{
 RelOptInfo *new_rel = (RelOptInfo *) lfirst(`r2`);
 if (!`bms_overlap`(`old_rel->relids`, `new_rel->relids`))
 {
 if (`have_relevant_joinclause`(`root, old_rel, new_rel`) ||
 `have_join_order_restriction`(`root, old_rel, new_rel`))
 {
 (void) `make_join_rel`(`root, old_rel, new_rel`);
 }
 }
 }
 }
}

if (`joinrels[level] == NIL`)

{
 foreach(`r, joinrels[level - 1]`)

{
 RelOptInfo *old_rel = (RelOptInfo *) lfirst(`r`);
 make_rels_by_clauseless_joins(`root`,

`old_rel`,
 `list_head(joinrels[1]))`;

}
}

if (`joinrels[level] == NIL &&`
 `root->join_info_list == NIL &&`
 `!root->has_lateralRTEs)`
 `elog(ERROR, "failed to build any %d-way joins", level);`

}

ti ;jca

Summary

The Selinger Algorithm has stood the test of time pretty well

Future work is needed to keep up with increased complexity and **BIG DATA**

The PostgreSQL codebase is of unrivalled quality

Join us at PGConf EU '17

Thanks

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<https://github.com/danielgustafsson/presentations/tree/master/joins>