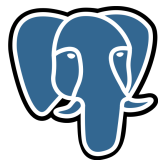
# Does PostgreSQL respond
## to the challenge of analytical queries?

Lepikhov Andrey

PostgreSQL Thailand Development Group

2024

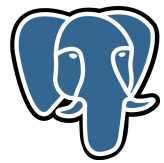


# Self Introduction

- 2007 - First touch to PostgreSQL (distributed query execution)
- 2010 - designer and user of databases based on PostgreSQL (and SQLite)
- 2017 - now - PostgreSQL Enthusiast, sporadic contributor and patch reviewer

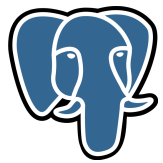
My projects:

- Multimaster, Shardman, Joinsel
- AQO, sr_plan, SwitchJoin, re-optimisation ...
- Patches: GROUP-BY, Self-Join Removal, OR->ANY Optimisation ...



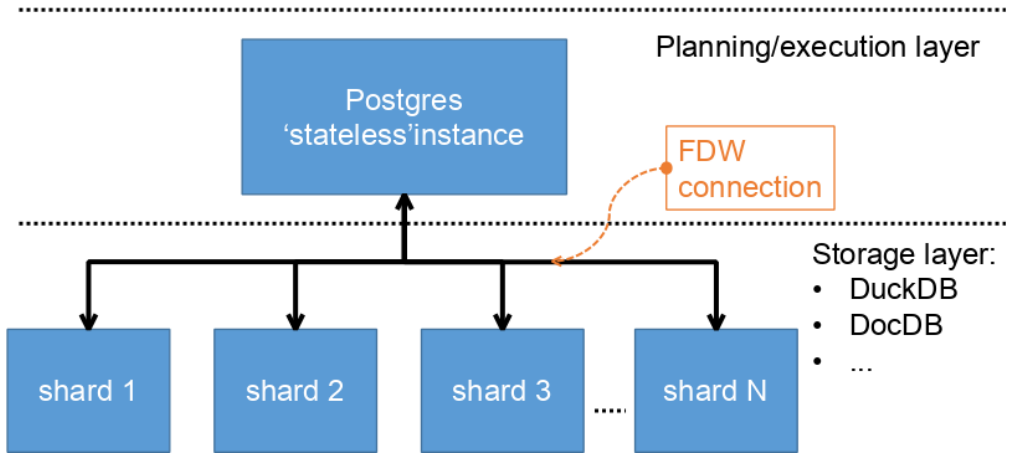
# Purpose

- The scope of the analytic queries problem
- What is the PostgreSQL current progress?
- What is needed to be done (compared to over DBMSes)?



# The risky tendency

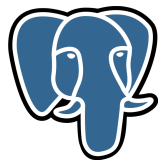
- YugaByte
- Shardman
- Crunchy Data DuckDB integration




Greenplum, Citus, and Postgres-XL altered the Postgres optimiser code. However, the new approach uses Postgres almost 'as is'.

# What is analytic query?

- It touches a massive part of the tuples in a relation
- Uses a mix of aggregate functions over the same data
- Have a complex query structure (join tree, groupings, limits, sortings, etc)
- Actively uses subqueries and CTEs
- Relations are burdened with many indexes



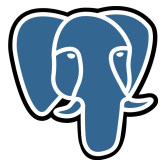
# What is the real progress?

| Date | Description |
|---|---|
| 26/03/2024 | Propagate pathkeys from CTEs up to the outer query. |
| 19/03/2024 | Postpone reparameterization of paths until create_plan() |
| 15/02/2024 | pull-up correlated subqueries |
| 21/01/2024 | Explore alternative orderings of group-by pathkeys during optimization |
| 17/11/2023 | Extract column statistics from CTE references, if possible. |
| 30/01/2023 | Make Vars be outer-join-aware |
| 27/01/2023 | Teach planner about more monotonic window functions |
| 18/01/2023 | Remove redundant grouping and DISTINCT columns |
| 02/08/2022 | Improve performance of ORDER BY / DISTINCT aggregates |
| 08/04/2022 | Teach planner and executor about monotonic window funcs |
| 02/04/2021 | Add Memoize executor node |
| 31/03/2021 | Add support for asynchronous execution |
| 06/04/2020 | Implement Incremental Sort |
| 27/03/2019 | Add support for multivariate MCV lists |
| 09/02/2019 | Create the infrastructure for planner support functions |
| 05/12/2017 | Support Parallel Append plan nodes |
| 06/10/2017 | Basic partition-wise join functionality |
| 05/04/2017 | Collect and use multi-column dependency stats |
| 27/03/2017 | Support hashed aggregation with grouping sets |
| 24/03/2017 | Implement multivariate n-distinct coefficients |
| 09/03/2017 | Add a Gather Merge executor node |
| 07/12/2016 | Implement table partitioning |
| 12/05/2015 | Add support for doing late row locking in FDWs |
| 01/05/2015 | Allow FDWs and custom scan providers to replace joins with scans |
| 30/04/2015 | Create an infrastructure for parallel computation in PostgreSQL |
| 21/02/2013 | Add postgres_fdw contrib module |
| 20/02/2011 | Implement an API to let foreign-data wrappers actually be functional |
| 14/10/2010 | Support MergeAppend plans, to allow sorted output from append relations |
| 04/01/2010 | Fetch the actual column min or max value using an index scan |

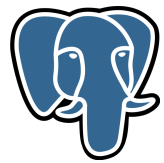
- Big storage
- Aggregates
- Query structure
- Subqueries & CTEs
- Indexes

# Answer to fast-growing data storage

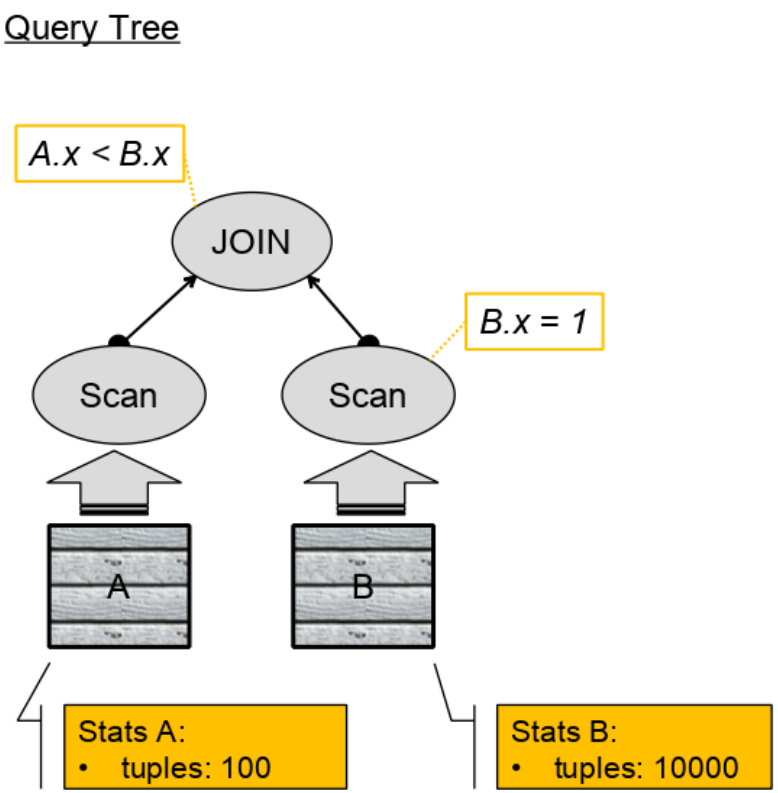
- Split data into partitions
- Distribute data (foreign data wrappers)
- Parallel execution techniques
- Smart caching (Memoize, Materialize)



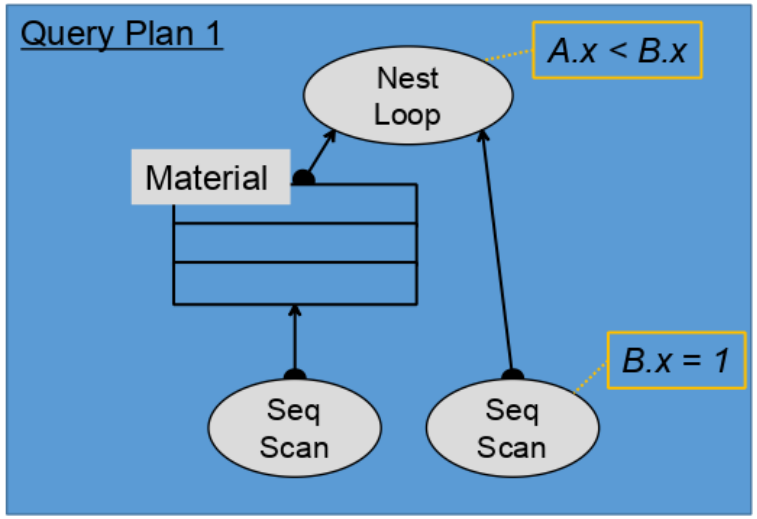
# Smart caching

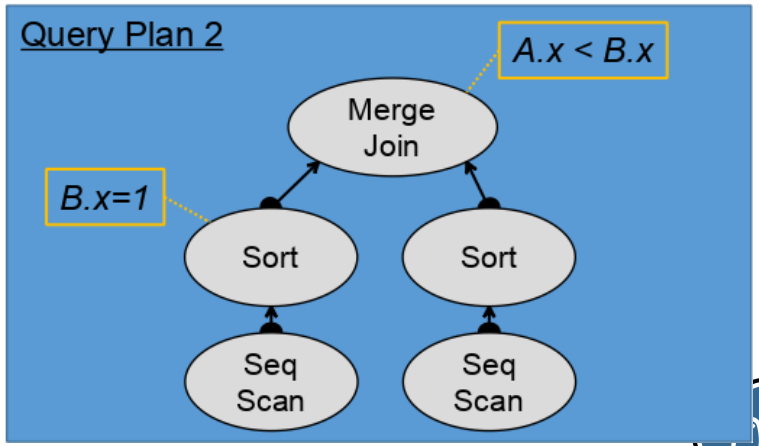


# Materialize



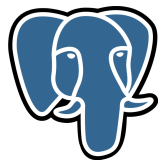

?



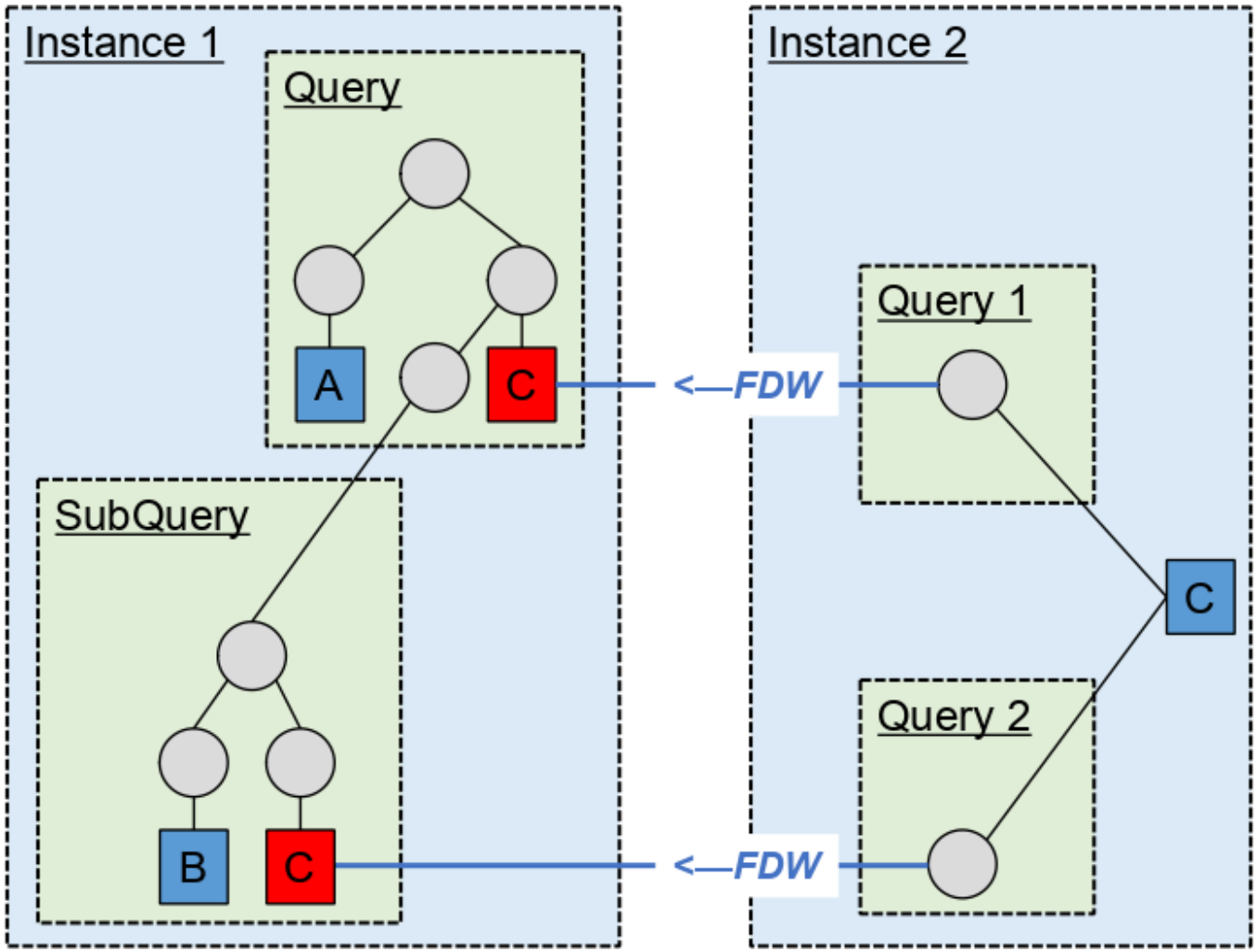



# What's more with materialization?

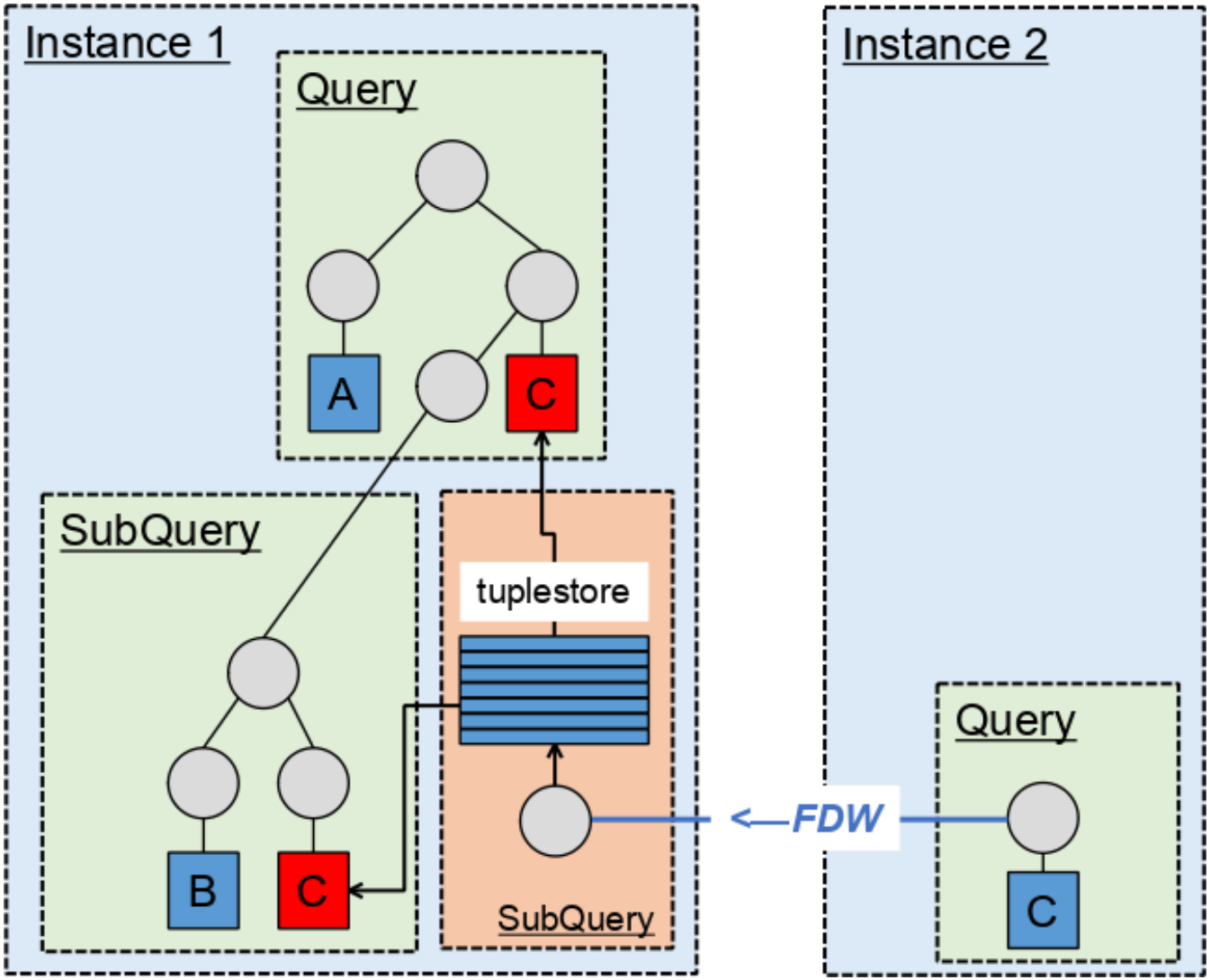
```
SELECT * FROM a LEFT JOIN foreign_table_b b1
ON b1.x IN (
  SELECT y FROM foreign_table_b b2
  WHERE b1.z=a.z
);
```



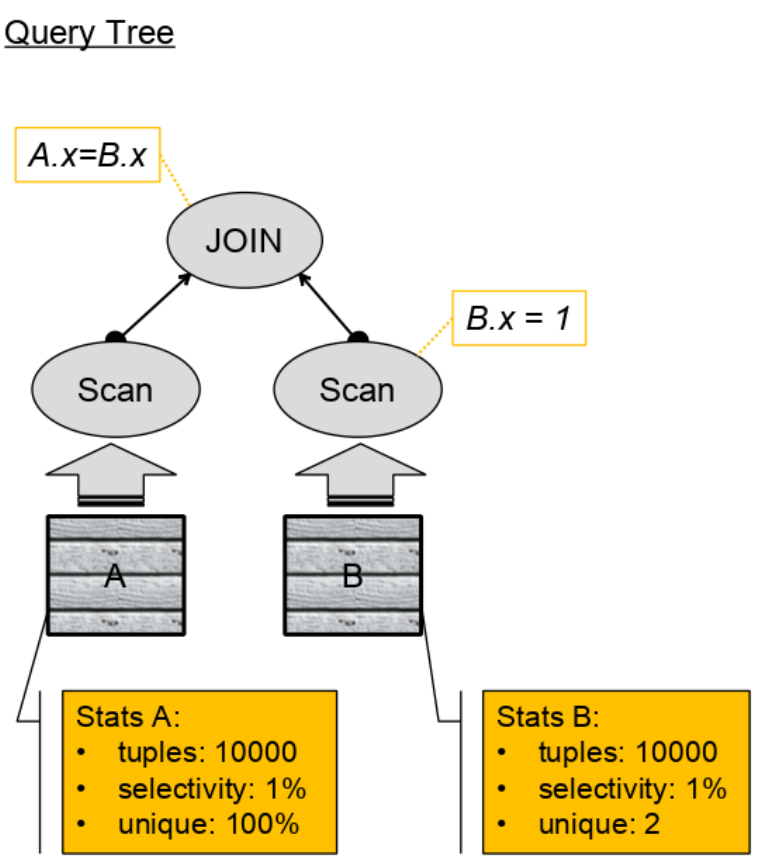
# What's more with materialization? - II



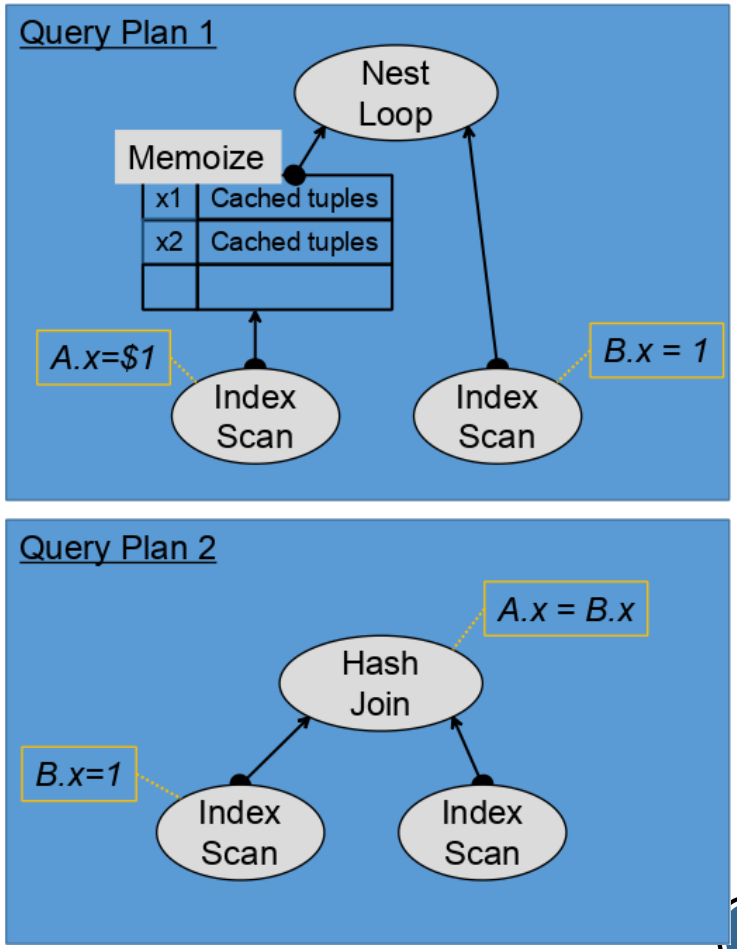
# Cross-query materialization



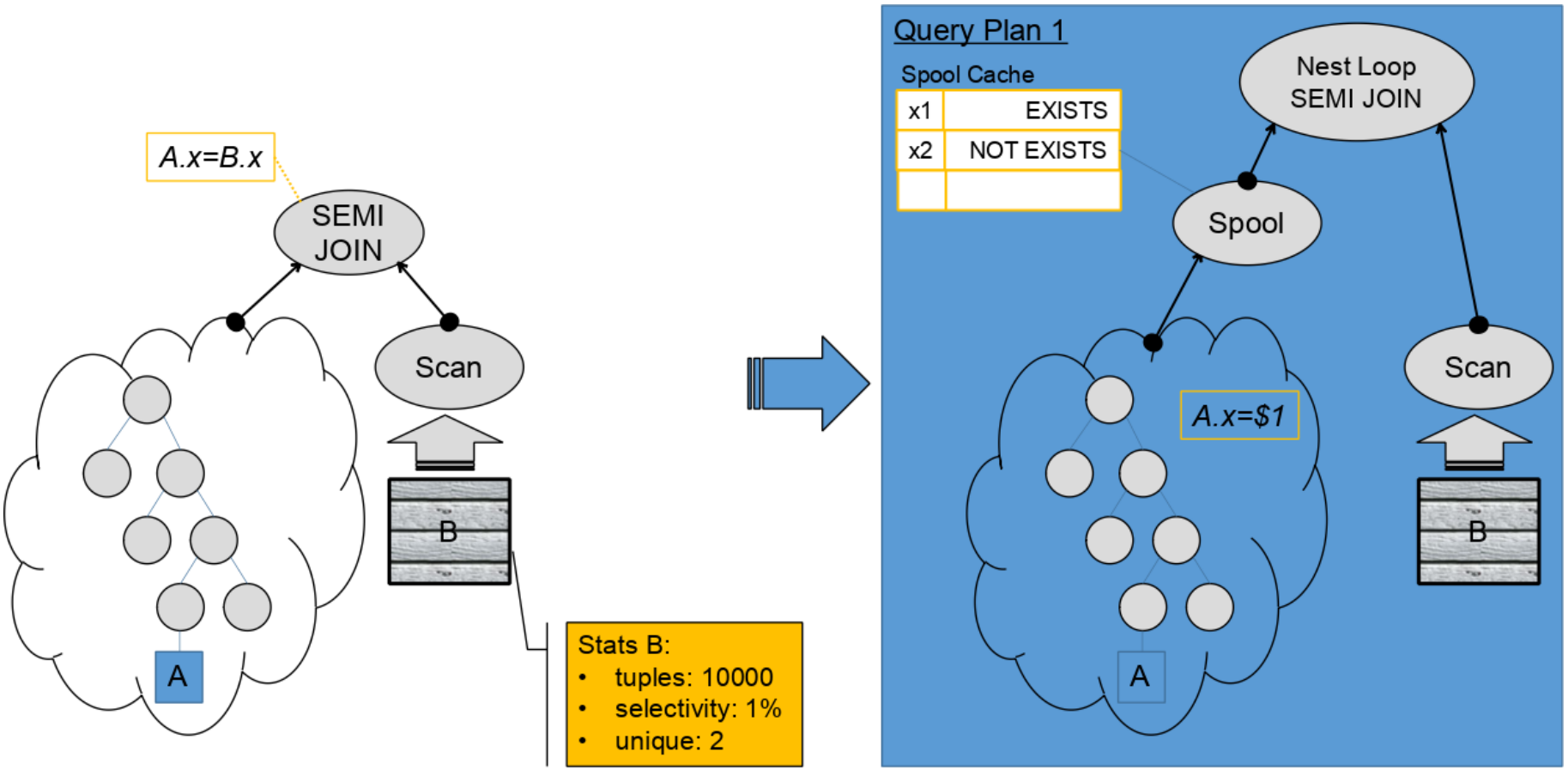
# Memoize


Query Tree
A.x=B.x
JOIN
B.x = 1
Scan
Scan
A
B
Stats A:
• tuples: 10000
• selectivity: 1%
• unique: 100%
Stats B:
• tuples: 10000
• selectivity: 1%
• unique: 2

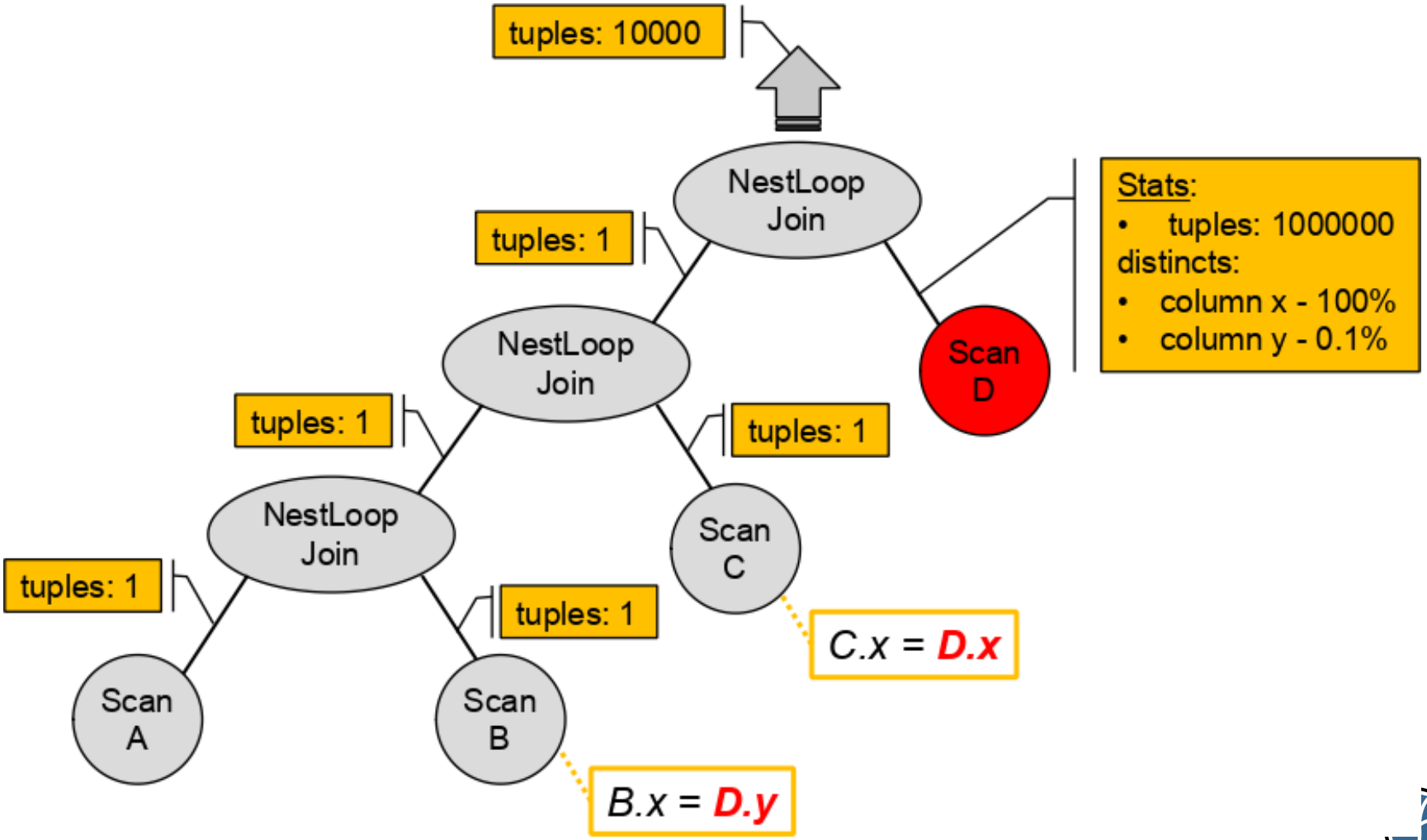
?


Query Plan 1
Nest Loop
Memoize
x1 Cached tuples
x2 Cached tuples
A.x=$1
B.x = 1
Index Scan
Index Scan
Query Plan 2
A.x = B.x
Hash Join
B.x=1
Index Scan
Index Scan

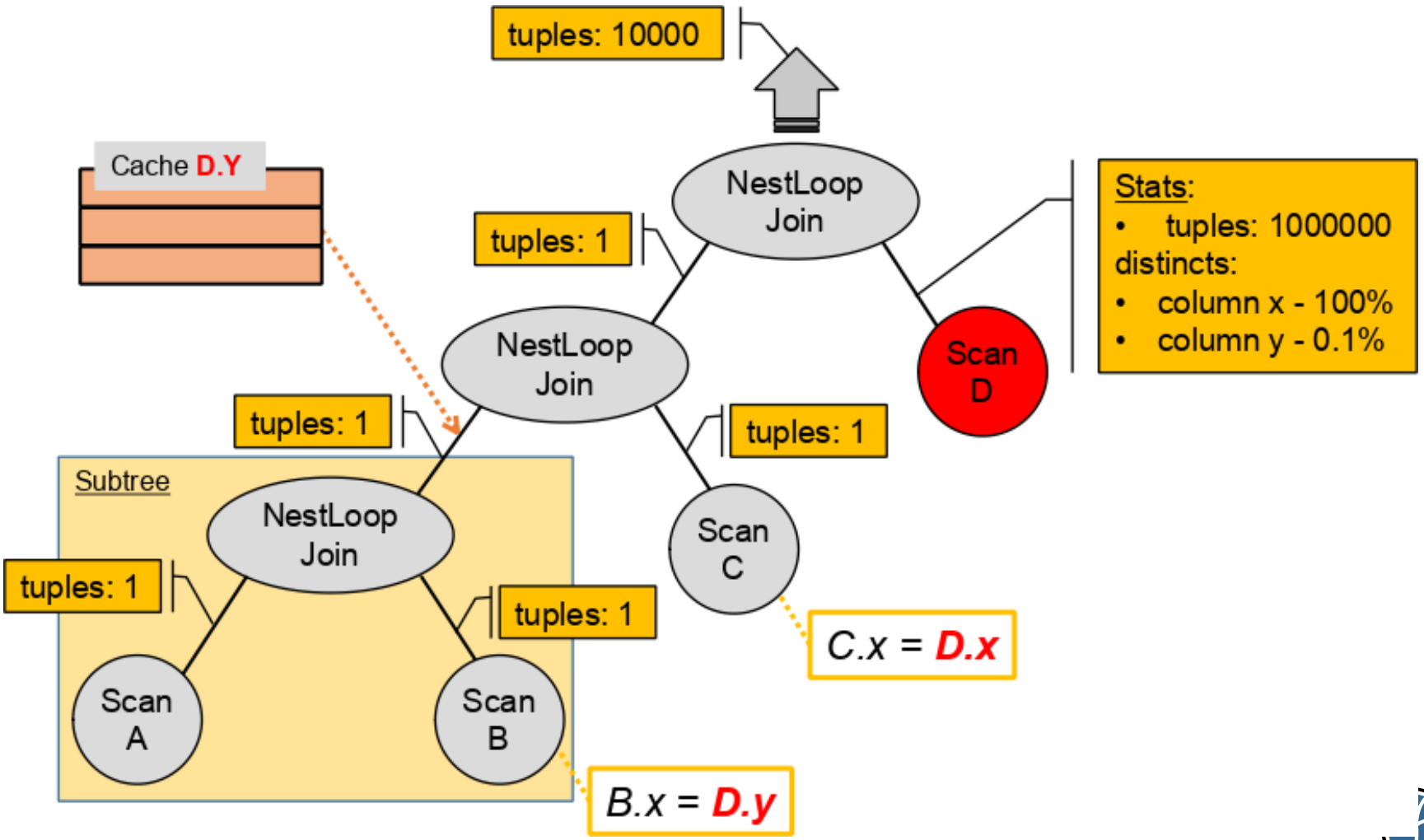
# Memoization: What's more?



# Parameters cache: example

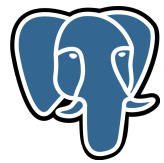


# Parameters cache: example

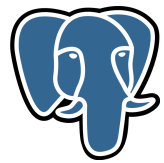


# Memoization: Top-bottom planning pass needed?

*Postgres optimisation passes from base relations to the top GROUP/ORDER-BY operation. We probably need a second, top-bottom optimisation pass to find out points of frequent rescanning and insert caching (Material, Memoize) nodes.*
*Such an approach could also let us find new paths for queries with limits.*

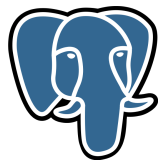


# Subqueries & CTE



# Subqueries & CTE

- Subquery -> JOIN transformation
- Precalculated Subquery and CTE result
- Use subquery stat (sort order, rows number, uniqueness) at the top-query planning
- Choose the best-fitting subquery plan



# Unnesting Correlated Subqueries (CSQ)

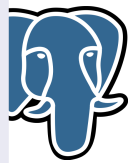
```
SELECT * FROM t1 WHERE y IN (
  SELECT y FROM t2 WHERE t1.x=t2.x);
```

**BEFORE Unnesting**

```
Seq Scan on t1
  Filter: (SubPlan 1)
  SubPlan 1
    -> Seq Scan on t2
          Filter: (t1.x = x)
```

**AFTER Unnesting**

```
Nested Loop Semi Join
  Join Filter: ((t1.x = t2.x) AND (t1.y = t2.y))
  -> Seq Scan on t1
  -> Seq Scan on t2
```



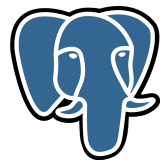
# CSQ - prospectives

Postgres can transform:

```
SELECT * FROM t1 WHERE y IN (
  SELECT y FROM t2 WHERE t1.x=t2.x);
```

The long list of possible transformations:

- Subquery in select list
- In disjunctive filter
- With GROUP-BY and inequality
- Must return single row (equality operator)
- Subquery references outer side (multilevel case)

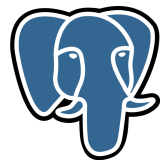


# CSQ - Just an example

```
CREATE UNIQUE INDEX ON t2(x);

SELECT * FROM t1 WHERE y = (
  SELECT y FROM t2 WHERE t1.x=t2.x);
```

**Proved single row return**

```
Seq Scan on t1
   Filter: (y = (SubPlan 1))
   SubPlan 1
      -> Index Scan using t2_x_idx on t2
            Index Cond: (x = t1.x)
```

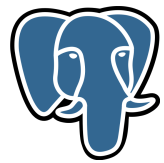


# New CTE features

Before 2024, the general idea was to isolate the planning of the query and its subplans to simplify the process. In 2024, there is a big leap ahead: propagation of sorting.
Example:

EXPLAIN (COSTS OFF)

```
WITH x AS MATERIALIZED (
  SELECT unique1 FROM tenk1 b
  ORDER BY unique1
) SELECT count(*) FROM tenk1 a
WHERE unique1 IN (SELECT * FROM x);
```



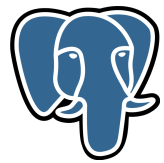
# Sort info propagation - example

## Before:

```
Aggregate
  CTE x
    -> Index Only Scan using tenk1_unique1 on tenk1 b
  -> Nested Loop
        -> HashAggregate
              Group Key: x.unique1
              -> CTE Scan on x
        -> Index Only Scan using tenk1_unique1 on tenk1 a
              Index Cond: (unique1 = x.unique1)
```

## After:

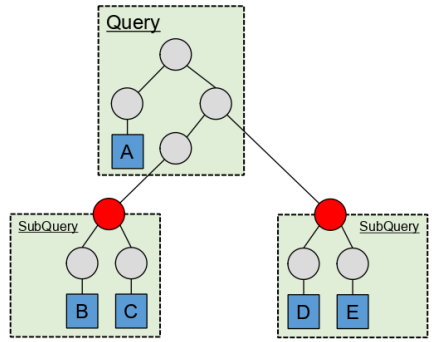
```
Aggregate
  CTE x
    -> Index Only Scan using tenk1_unique1 on tenk1 b
  -> Merge Semi Join
        Merge Cond: (a.unique1 = x.unique1)
        -> Index Only Scan using tenk1_unique1 on tenk1 a
        -> CTE Scan on x
```



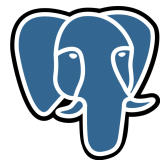
# CTE - what's more?

Break membrane between query and subquery planning (maybe on demand):

- Expose alternative paths to the upper query
- Push parameters into a subquery
- Replan subquery if the upper query has additional info



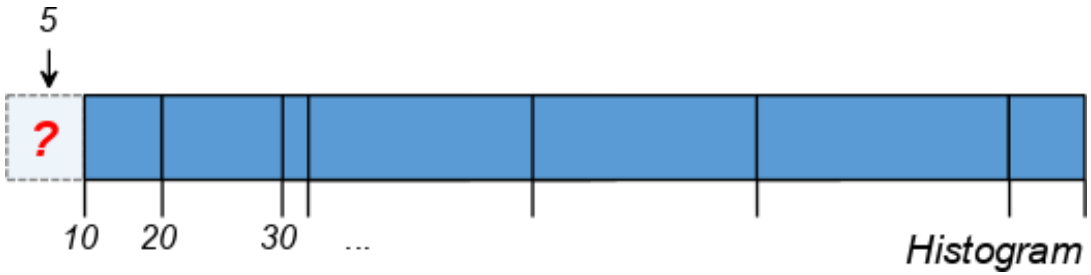
Indexes ?



# Indexes as an optimisation tool

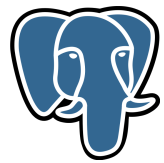
2010 - inequality estimations with indexes:

**SELECT** $*$ **FROM table WHERE** x $<$ 5;




Optimiser fetches index tuples to estimate cardinality in cases:

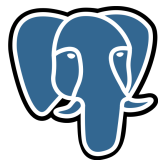
- Histogram too simple
- The value hits the first (last) histogram bin
- The value out of the histogram



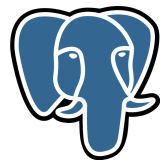
# What's more with indexes

Index estimation is a promising way to tackle optimistic '1-tuple' estimations.

- Direct index fetch is too heavy
- Change Access Method interface to allow index estimations based on the number of pages/average width data.
- Implement Index Estimation for equalities
- Multi-clause filters estimations covered by an index

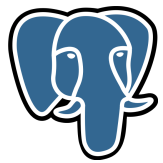


# Aggregates & Window Functions

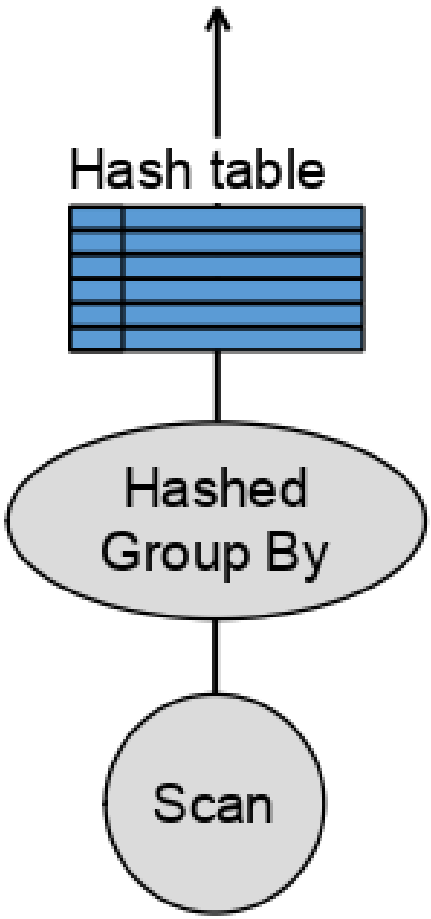


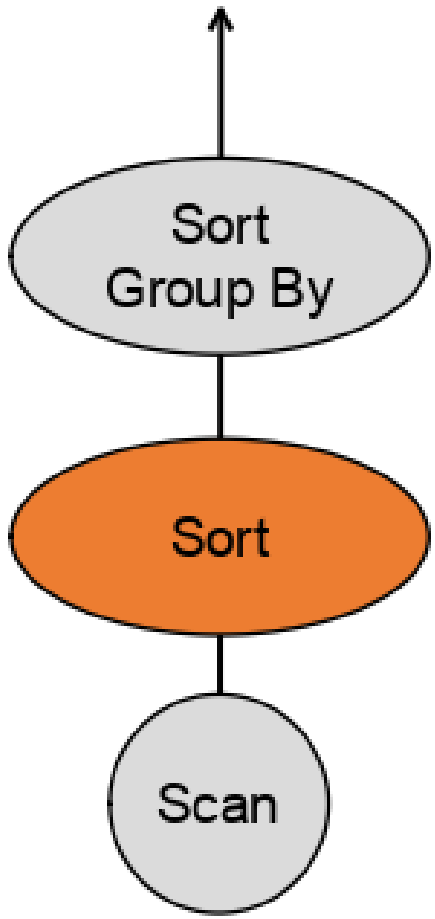
# Aggregates & Window Functions

- Hashed Aggregates
- Combine aggregate's sort orders
- Prosupport machinery



# Hashed Aggregates



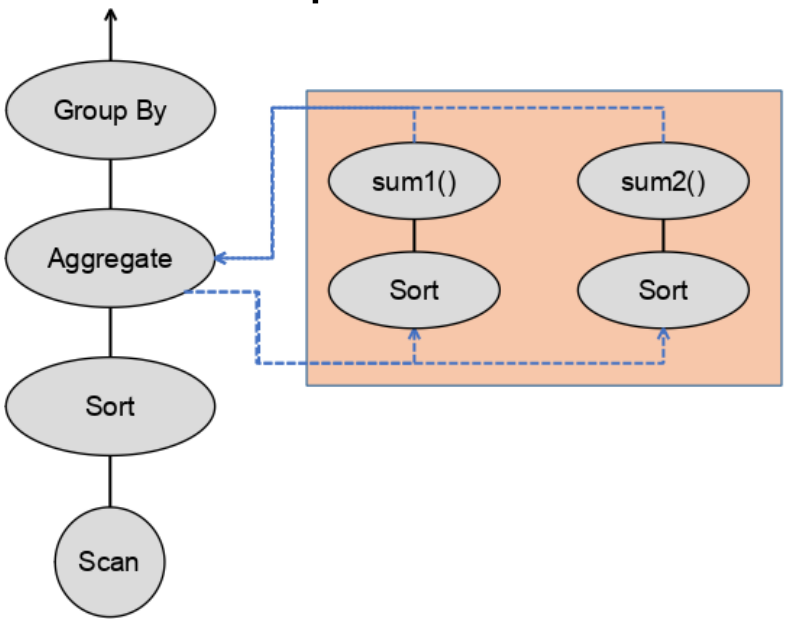



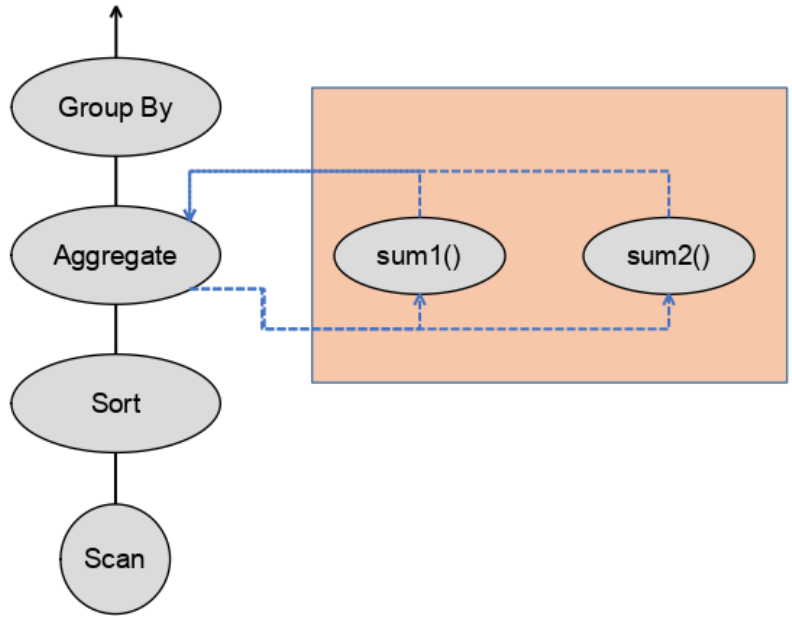
# Combine sortings

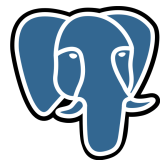


**SELECT sum**(unique1 **ORDER BY** ten), **sum**(unique1 **ORDER BY** ten,two)
**FROM** tenk1 **GROUP BY** ten;

## Execution plans:

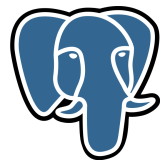


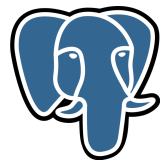
# Combine sorting

```
EXPLAIN (ANALYZE, TIMING OFF, COSTS ON)
SELECT sum(unique1 ORDER BY ten), sum(unique1 ORDER BY ten,two)
FROM tenk1 GROUP BY ten;

-- PG13:

GroupAggregate (cost=1108.97..1209.02) (actual rows=10 loops=1)
  Output: sum(unique1 ORDER BY ten), sum(unique1 ORDER BY ten, two), ten
  Group Key: tenk1.ten
  -> Sort (cost=1108.97..1133.95) (actual rows=10000 loops=1)
        Output: ten, unique1, two
        Sort Key: tenk1.ten
        -> Seq Scan on public.tenk1 (cost=0.00..444.95)
              Output: ten, unique1, two
Execution Time: 116.375 ms

-- PG17:

GroupAggregate (cost=1109.39..1209.49) (actual rows=10 loops=1)
  Output: sum(unique1 ORDER BY ten), sum(unique1 ORDER BY ten, two), ten
  Group Key: tenk1.ten
  -> Sort (cost=1109.39..1134.39) (actual rows=10000 loops=1)
        Output: ten, unique1, two
        Sort Key: tenk1.ten, tenk1.two
        -> Seq Scan on public.tenk1 (cost=0.00..445.00)
              Output: ten, unique1, two
Execution Time: 12.650 ms
```



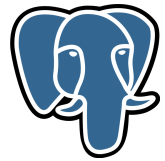
# Prosupport machinery

- A function has been a black box for the planner: rows? cost? selectivity? ...
- Postgres community respond to the challenge - prosupport
- Prosupport - routine which can be attached to any stored procedure
- At the planning stage, Prosupport can provide cost, rows, selectivity recommendations
- full function replacement, index condition
- Window function optimisations



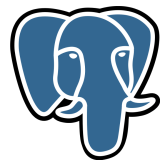
# Prosupport machinery - an example

```
PREPARE stmt(int) AS SELECT x FROM test WHERE int4mul(x, $1) < 100;

EXECUTE stmt(0);
                                    QUERY PLAN
-------------------------------------------------------------------------------
 Seq Scan on test (cost=0.00..20.00 rows=333 width=4) (actual rows=1000 loops=1)
   Filter: (int4mul(x, 0) < 100)

EXECUTE stmt(1);
                                    QUERY PLAN
-------------------------------------------------------------------------------
 Seq Scan on test (cost=0.00..20.00 rows=333 width=4) (actual rows=99 loops=1)
   Filter: (int4mul(x, 1) < 100)

EXECUTE stmt(2);
                                    QUERY PLAN
-------------------------------------------------------------------------------
 Seq Scan on test (cost=0.00..20.00 rows=333 width=4) (actual rows=49 loops=1)
   Filter: (int4mul(x, 2) < 100)
```



# Prosupport machinery - use help routine

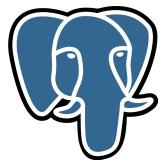
```
UPDATE pg_proc SET prosupport = 'int4mul_support' WHERE proname = 'int4mul';
PREPARE stmt(int) AS SELECT x FROM test WHERE int4mul(x, $1) < 100;

EXECUTE stmt(0);
                                        QUERY PLAN
-------------------------------------------------------------------------------------------
 Seq Scan on test (cost=0.00..15.00 rows=1000 width=4) (actual rows=1000 loops=1)

EXECUTE stmt(1);
                                      QUERY PLAN
-------------------------------------------------------------------------------------------
 Seq Scan on test (cost=0.00..17.50 rows=99 width=4) (actual rows=99 loops=1)
   Filter: (x < 100)

EXECUTE stmt(2);
                                      QUERY PLAN
-------------------------------------------------------------------------------------------
 Seq Scan on test (cost=0.00..20.00 rows=333 width=4) (actual rows=49 loops=1)
   Filter: (int4mul(x, 2) < 100)
```



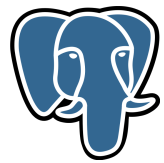
# Prosupport - usage

# Prosupport - what's more?

- Prosupport for aggregates
- Same technique for Query tree nodes?
- Sublink, Coalesce, BoolExpr - can we register prosupport routines to transform them on-demand?

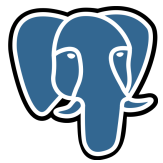


# Query structure



# Manage complex Query

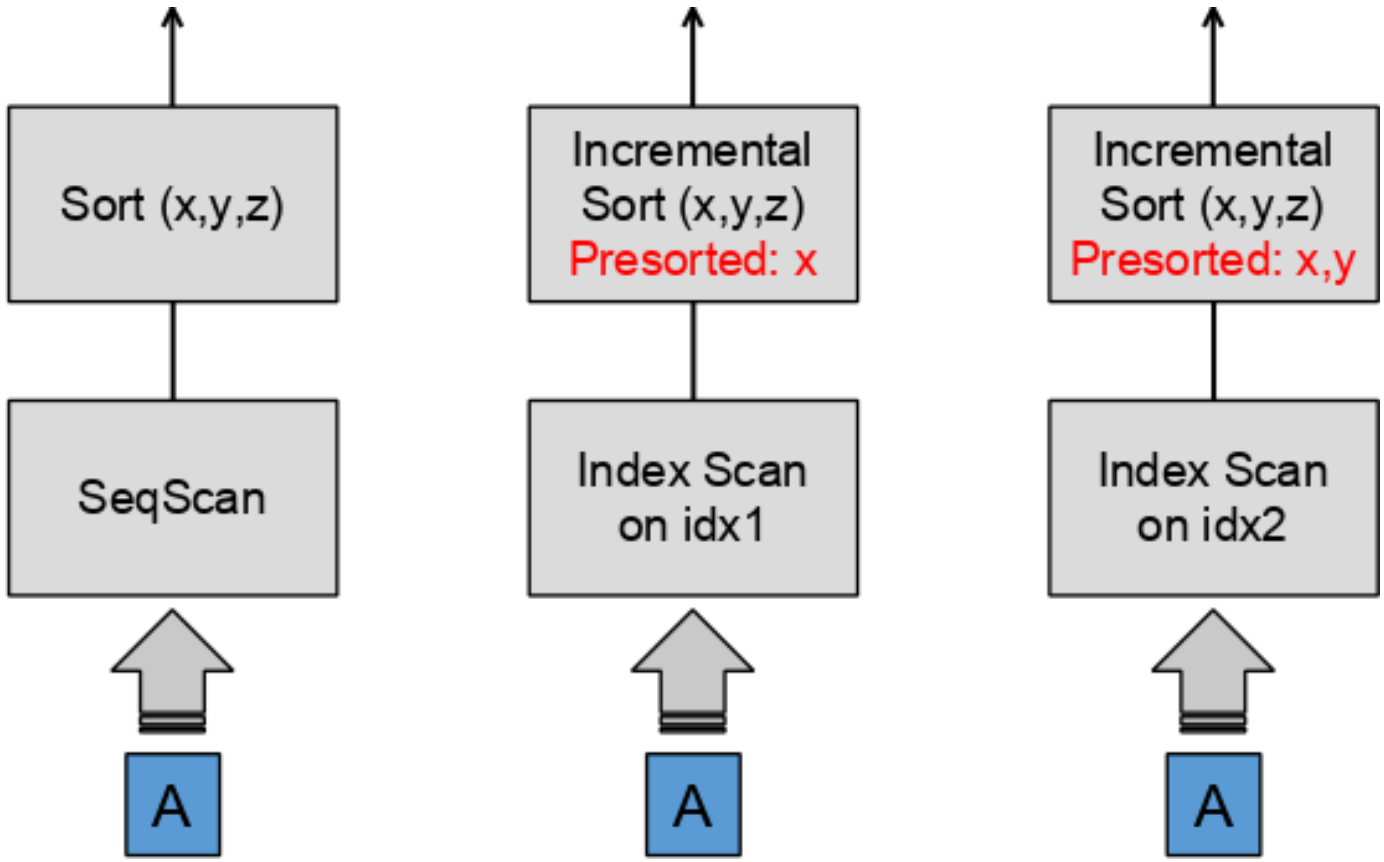
- Multiple joins
- Minimize of sort operations
- Left Joins and inner-generated NULLS
- Multicolumn statistics

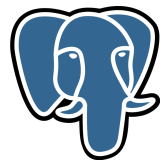


# Incremental Sort



```
CREATE INDEX idx1 ON test (x);
CREATE INDEX idx2 ON test (x,y);
SELECT x,y,z FROM test ORDER BY x,y,z;
```



# Minimize of sort operations

```
SELECT x,y,z FROM test ORDER BY x,y,z;
```

## Full sort plan

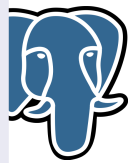
```
Sort (cost=9845.82..10095.82 rows=100000 width=12)
  Sort Key: x, y, z
  -> Seq Scan on test (cost=0.00..1541.00 rows=100000 width=12)
```

## Exploit presorted column x

```
Incremental Sort (cost=7.62..8599.52 rows=100000 width=12)
  Sort Key: x, y, z
  Presorted Key: x
  -> Index Scan using test_x_idx on test (cost=0.29..4007.59 rows=100000 width=12)
```

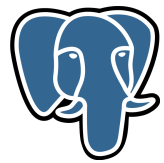
## Exploit presorted columns x and y

```
Incremental Sort (cost=0.86..7118.86 rows=100000 width=12)
  Sort Key: x, y, z
  Presorted Key: x, y
  -> Index Scan using test_x_y_idx on test (cost=0.29..4007.90 rows=100000 width=12)
```

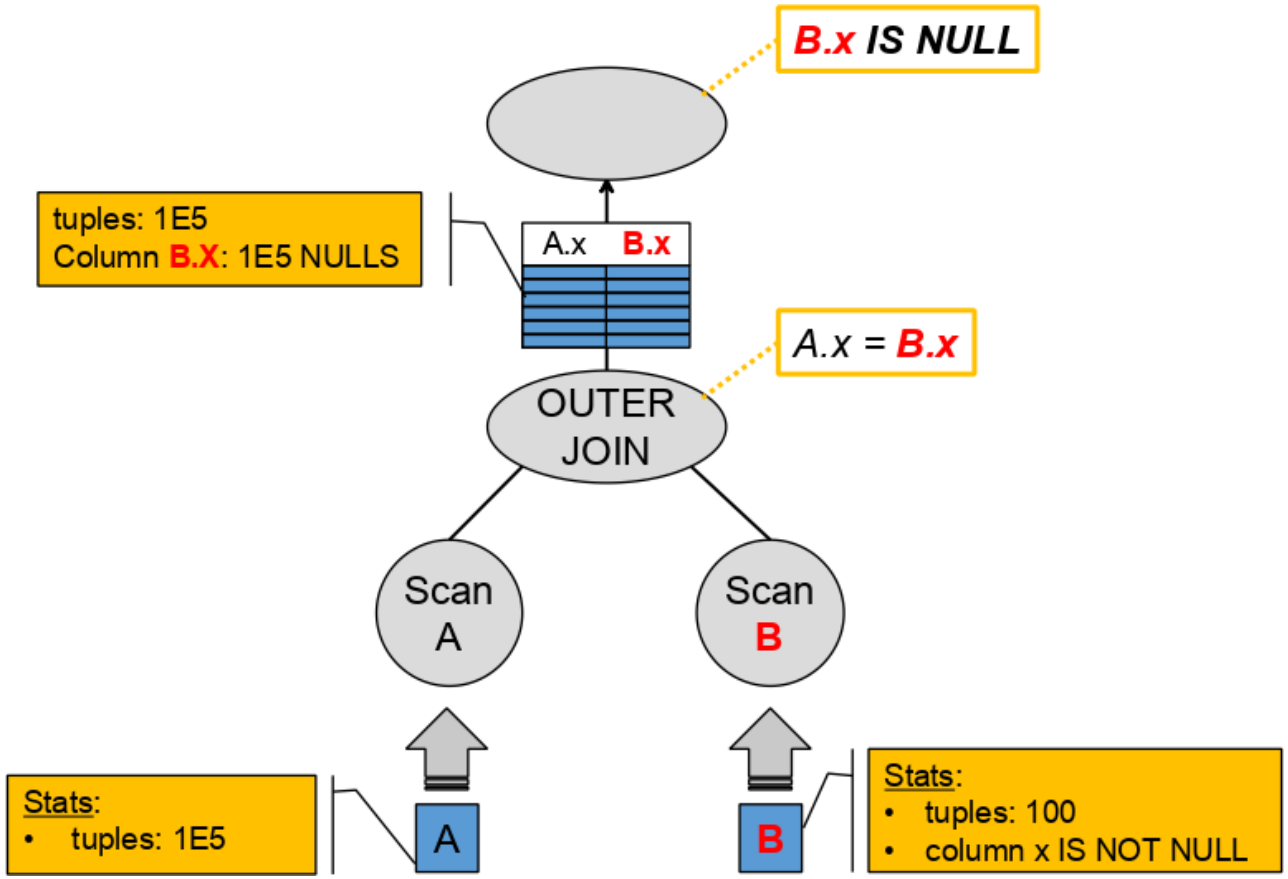


# Sort - what's more?

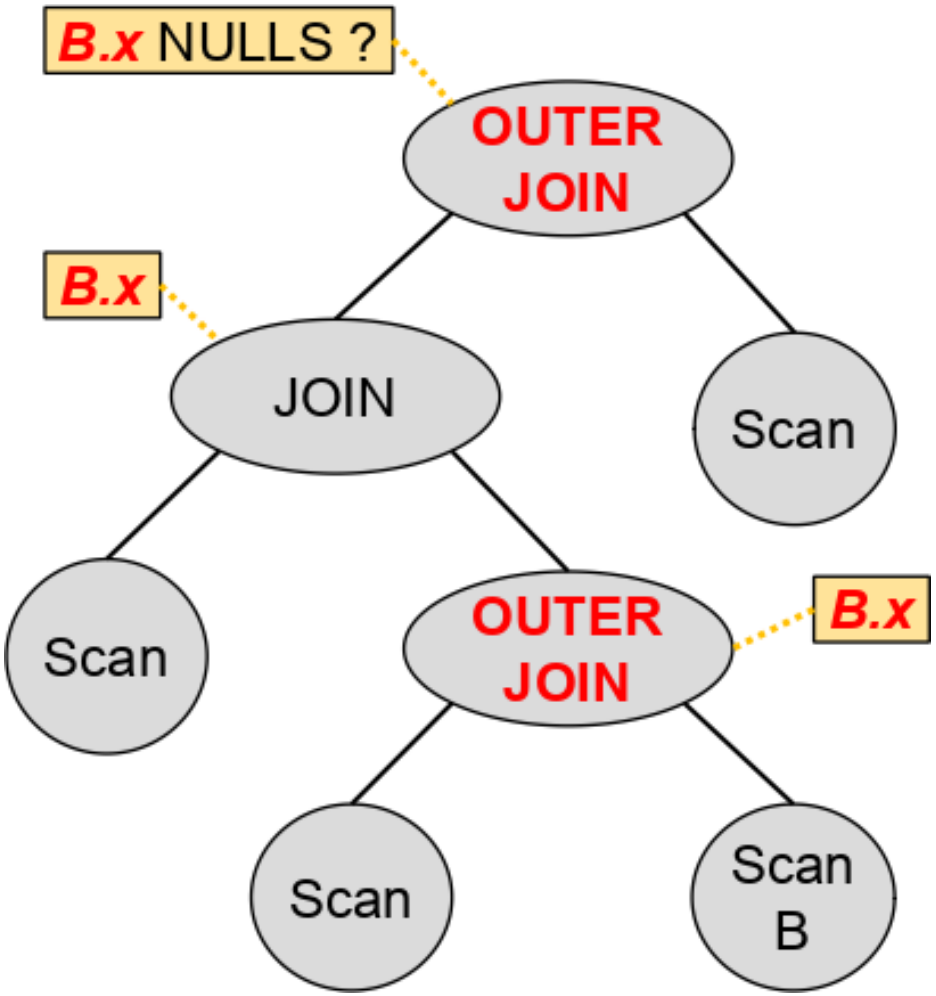
```
EXPLAIN SELECT x,y,z FROM test ORDER BY x,y;

                                 QUERY PLAN
-----------------------------------------------------------------------------
 Incremental Sort (cost=42.85..9765.17 rows=100000 width=12)
   Sort Key: x, y
   Presorted Key: x
   -> Index Scan using idx1 on test (cost=0.29..4028.28 rows=100000 width=12)

EXPLAIN SELECT x,y,z FROM test ORDER BY x,y,z;

                                 QUERY PLAN
-----------------------------------------------------------------------------
 Incremental Sort (cost=42.85..9765.17 rows=100000 width=12)
   Sort Key: x, y, z
   Presorted Key: x
   -> Index Scan using idx1 on test (cost=0.29..4028.28 rows=100000 width=12)
```



# NULLs Counting Problem



# NULLs Counting Problem - levels



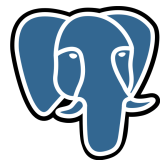
# NULLs Counting Problem - join types

```
EXPLAIN (COSTS OFF)
SELECT oid, relname
FROM pg_class c1
  LEFT JOIN pg_class c2
  ON c1.relname = c2.relname;
```

```
Hash Left Join
  Hash Cond: (c1.relname = c2.relname)
  -> Seq Scan on pg_class c1
  -> Hash
        -> Seq Scan on pg_class c2
```

```
EXPLAIN (COSTS OFF)
SELECT c1.oid, c1.relname
FROM pg_class c1
  LEFT JOIN pg_class c2 ON true
  WHERE c1.relname = c2.relname;
```

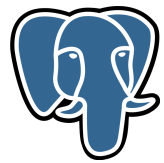
```
Hash Join
  Hash Cond: (c1.relname = c2.relname)
  -> Seq Scan on pg_class c1
  -> Hash
        -> Seq Scan on pg_class c2
```



# Extended Statistics

**SELECT** * **FROM table WHERE** id **IN** (1,2,3,4,5) **AND** enabled = **true AND**
status = 'ready';

Selectivity 'id IN (1,2,3,4,5)' -> 0.00001
Selectivity 'enabled = true' -> 0.5
Selectivity 'status = ready' -> 0.1
Selectivity of the whole clause — ?

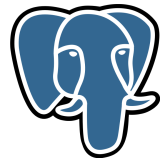


# Extended Statistics

CREATE STATISTICS ON id,enabled,status FROM tablename;

- **MCV** - **M**ost **C**ommon **V**alues on composite value of (x1,x2,x3).
- **ndistinct** - number of distinct values on all combinations of columns: (x1,x2),(x1,x3),(x1,x2,x3)...
- **dependencies** - functional dependencies between combinations of columns: x1->x2, (x1,x2)->x3,...

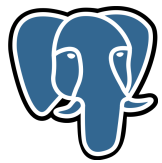
*Vondra. T. CREATE STATISTICS improvements, PGConf.DE 2022*



# Laboriousness of Extended Statistics

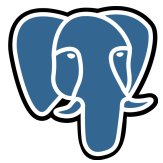
- **MCV** - two arrays: values[] and frequences[].
- **ndistinct** - 1 integer for each of $2^n - (n + 1)$ combinations
- **dependencies** - 1 float value for each of combinations

| columns: | 2 | 3 | 4 | ... | 8 |
|---|---|---|---|---|---|
| distinct combinations: | 1 | 4 | 11 | ... | 247 |
| dependency combinations: | 2 | 9 | 28 | ... | 1016 |



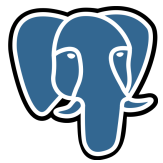
# Index to define statistics

**Table** ”Parcels”:
Indexes:
”parcel_pkey” **PRIMARY KEY**, btree (id)
”parcel_parcel_id” btree (parcel_id)
”parcel_id_prik” btree (parcel_id, prik)
”parcel_id_sn_pol” btree (parcel_id, sn_pol)
”parcel_par_begin” btree (parcel_id, prik_begin_period)
”parcel_par_patient” btree (parcel_id, patient_id)
”parcel_par_recid” btree (parcel_id, recid)
”parcel_per_prik” btree (period, prik)

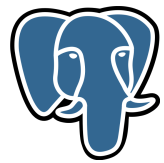


# Extended statistics - what's more?

- Extended statistics for JOINs
- Reduction of combinations inside Distinct and Dependencies based on index definition
- New methods - multidimensional histogram

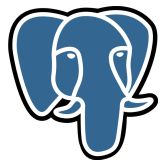


# Miscellaneous optimisations



# Miscellaneous optimisations - examples

- VALUES -> ANY transformation
- OR list -> ANY transformation
- GROUP-BY makes column 'unique'
- Static functions evaluation
- ...



# Miscellaneous optimisations - VALUES -> ANY

```
SELECT * FROM a
WHERE a.x IN (VALUES (1), (2), (3));
```

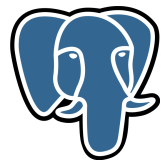
```
SELECT * FROM a
WHERE a.x = ANY ('{1,2,3}');
```

**BEFORE transformation**

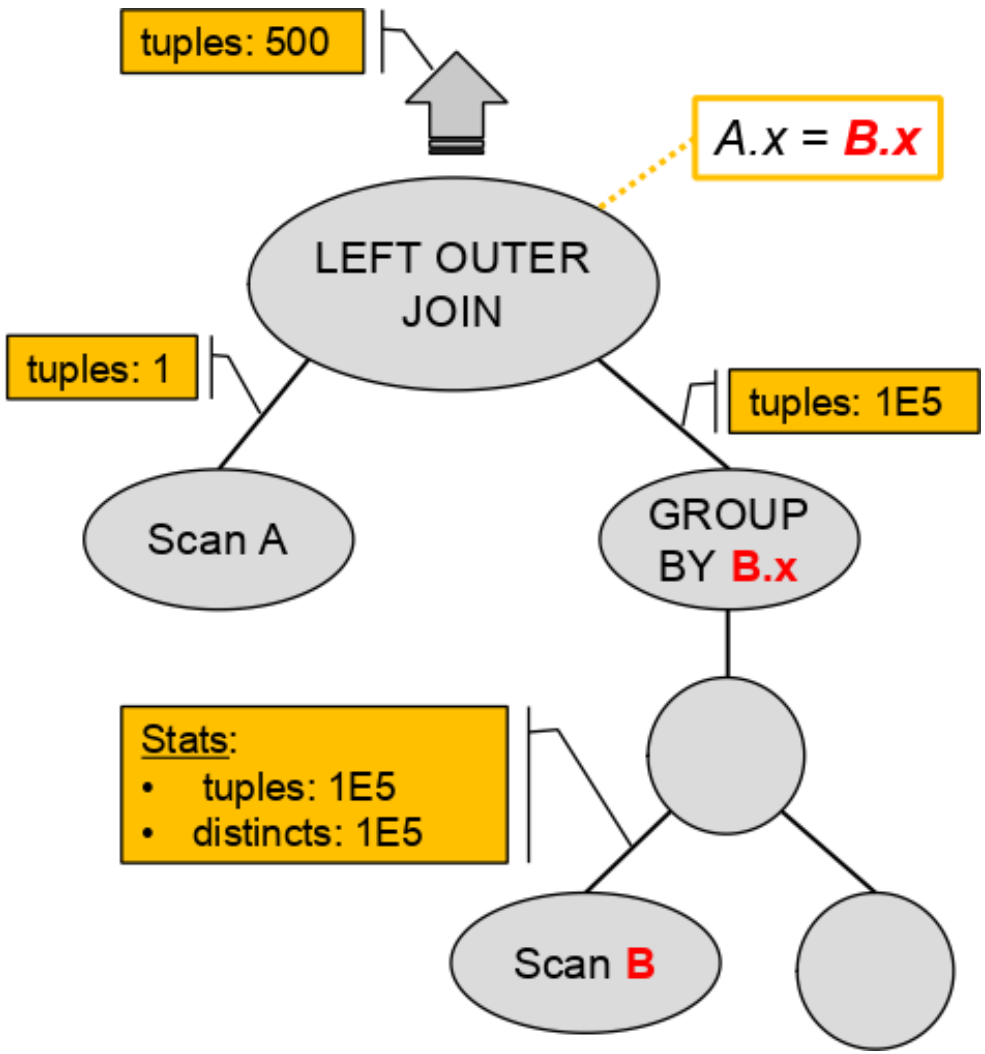
```
Hash Semi Join
  Hash Cond:
    (a.x = "*VALUES*".column1)
  -> Seq Scan on a
  -> Hash
        -> Values Scan on
                      "*VALUES*"
```

**AFTER transformation**

```
Seq Scan on a
  Filter:
    (x = ANY ('{1,2,3}'::integer[]))
```



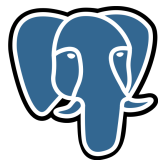
# Miscellaneous optimisations - GROUP-BY




GROUP-BY makes grouped column 'almost' unique. We can use at in cardinality estimations.

# Miscellaneous optimisations - pro & cons

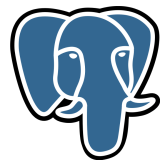
- It may be dozens of such optimisations
- Have quite a narrow application
- May add a lot of overhead in general case
- May hide better query plans
- Complicates the core code



# Miscellaneous optimisations - resume

Let extensions do it!

- Query transformation hooks
- Selectivity estimation/statistics hooks
- Optimisation stages hooks
- the add_path hooks
- EXPLAIN node hook
- Extensible parts in the planner structures: PlannerInfo, Query and PlanStatement nodes



# Questions ?