PostgreSQL-Consulting

data egret

PGDAY'17 RUSSIA

КОНФЕРЕНЦИЯ ПО БАЗАМ ДАННЫХ

PostgreSQL query planner's internals

How I Learned to Stop Worrying and Love the Planner

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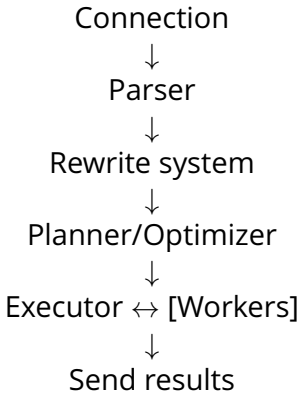
Why this talk?

- Why this query is so slow?
- Why planner is not using my index?
- What to do?

3 Where are we going?

- How planner works
- How we can affect it’s work
- When it can go wrong
- Known limitations

The Path of a Query



all in single process (backend) beside background workers (parallel seq scan, 9.6+)

EXPLAIN command

```
explain (ANALYZE,VERBOSE,COSTS,BUFFERS,TIMING[1]) select * from t1;
                                QUERY PLAN
-------------------------------------------------------------------------
Seq Scan on public.t1 (cost=0.00..104424.80 rows=10000000 width=8)
(actual time=0.218..2316.688 rows=10000000 loops=1)
  Output: f1, f2
  Buffers: shared read=44248
  I/O Timings: read=322.714[2]
Planning time: 0.024 ms
Execution time: 3852.588 ms
```

[1] COSTS and TIMING options are on by default

[2] I/O Timings shown when track_io_timing is enabled

Planner have to guess

```
Seq Scan on public.t1 (cost=0.00..104424.80 rows=10000000 width=8)
```

- startup cost
- total cost
- rows
- average row width

Cost stability principles

Quote from “Common issues with planner statistics by Tomas Vondra”: [3]

- **correlation to query duration**: The estimated cost is correlated with duration of the query, i.e. higher cost means longer execution.
- **estimation stability**: A small difference in estimation causes only small difference in costs, i.e. small error in estimation causes only small cost differences.
- **cost stability**: Small cost difference means small difference in duration.
- **cost comparability**: For a given query, two plans with (almost) the same costs should result in (almost) the same duration.

[3] `https://blog.pgaddict.com/posts/common-issues-with-planner-statistics`

Data retrieval methods

- seq scan – sequential scan of whole table
- index scan – random io (read index + read table)
- index only scan – read only index (9.2+)[4]
- bitmap index scan – something in between seq scan/index scan, possible to use several indexes at same time in OR/AND conditions

[4] `https://wiki.postgresql.org/wiki/Index-only_scans`

Join methods

- nested loop – optimal for small relations
- hash join – optimal for big relations
- merge join – optimal for big relations if they’re sorted

Aggregate methods

- aggregate
- hash aggregate
- group aggregate

Planner Cost Constants

```
#seq_page_cost = 1.0 # cost of a sequentially-fetched disk page
#random_page_cost = 4.0 # cost of a non-sequentially-fetched disk page
#cpu_tuple_cost = 0.01 # cost of processing each row during a query
#cpu_index_tuple_cost = 0.005 # cost of processing each index entry
#cpu_operator_cost = 0.0025 # cost of processing each operator or function
```

so basically cost is just $\sum_i c_i n_i$. **How hard could it be?**

Well, kind of hard

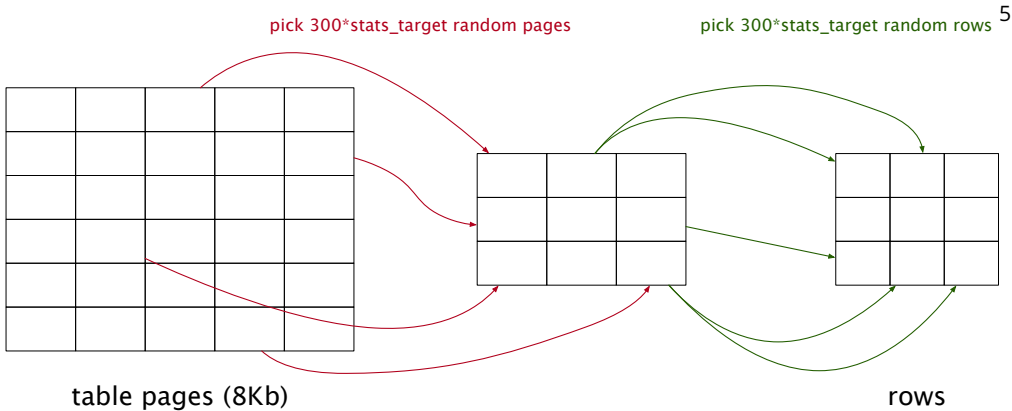
- How many rows we'll get when we'll filter table by this condition?
- How many pages is that? Will we read them sequentially or not?
- How many rows we'll get when we join 2 relations?

We have stats!

- pg_statistic – only readable by a superuser
- pg_stats view – the same but human-readable and available to all users (permissions apply)

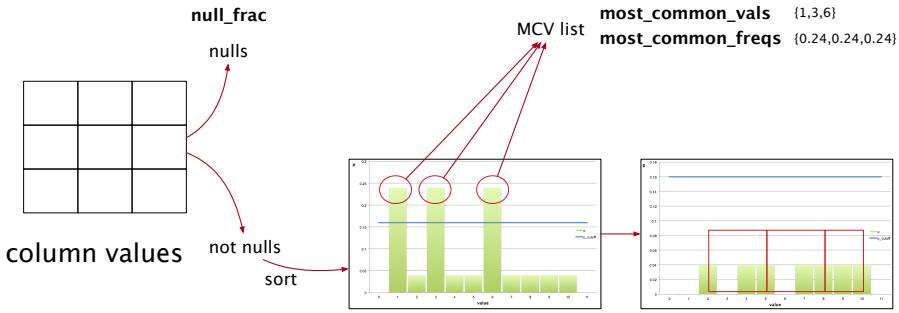
pg_stats

```
pgday=# \d pg_stats
         Column          |   Type   |
-------------------------+----------+-------------------------------------------------------------------
 tablename               | name     | name of the table or functional index
 attname                 | name     | name of the column or index column
 null_frac               | real     | fraction of column entries that are null
 avg_width               | integer  | average width in bytes of column's entries
 n_distinct              | real     | number (or fraction of number of rows) of distinct values
 most_common_vals        | anyarray | list of the most common values in the column
 most_common_freqs       | real[]   | list of the frequencies of the most common values
 histogram_bounds        | anyarray | list of intervals with approximately equal population
 correlation             | real     | correlation between physical row ordering and logical ordering
 most_common_elems       | anyarray |
 most_common_elem_freqs  | real[]   |
 elem_count_histogram    | real[]   |
```

[5] Algorithm Z from Vitter, Jeffrey S. (1 March 1985). “Random sampling with a reservoir”

Analyze



$$p_{cutoff} = MIN \left\{ \begin{array}{l} \frac{1}{stats\_target} \\ 1.25 p_{avg} \end{array} \right.$$

autoanalyze

- inserted + updated + deleted > threshold ⇒ run autoanalyze
- threshold = autovacuum_analyze_threshold + reltuples*autovacuum_analyze_scale_factor
- autovacuum_analyze_scale_factor (default = 0.1)
- autovacuum_analyze_threshold (default = 50)
- default_statistics_target (default = 100)
- rows in sample = 300 * stats_target

n_distinct underestimation example

```
select setseed(0.5);

create table test_ndistinct as
select
(case when random() < 0.1 then f1 end)::int f1
from normal_rand(10000000, 50000, 50000/3) as nr(f1);
```

10M rows, 90% nulls, ≈ 99.7% of values in between 0..100000

n_distinct underestimation example

```
# analyze verbose test_ndistinct;
INFO:  analyzing "public.test_ndistinct"
INFO:  "test_ndistinct": scanned 30000 of 35314 pages, containing 8495268 live rows and 0 dead rows;
30000 rows in sample, 10000067 estimated total rows

select * from pg_stats where tablename = 'test_ndistinct' and attname = 'f1';

...
null_frac              | 0.904067
avg_width              | 4
n_distinct             | 3080
most_common_vals       |
most_common_freqs      |
histogram_bounds       | {-8505,10072,15513,18933,21260,22574,24082,25695,26953,27898,28645...
correlation            | -0.00286606
```


n_distinct underestimation example

```
# explain analyze select distinct f1 from test_ndistinct ;
                                    QUERY PLAN
-------------------------------------------------------------------------------------------
 HashAggregate  (cost=160314.84..160345.64 rows=3080 width=4)
                (actual time=2558.751..2581.286 rows=90020 loops=1)
   Group Key: f1
   ->  Seq Scan on test_ndistinct  (cost=0.00..135314.67 rows=10000067 width=4)
                                   (actual time=0.045..931.687 rows=10000000 loops=1)
 Planning time: 0.048 ms
 Execution time: 2586.550 ms
```


n_distinct underestimation example

```
# set default_statistics_target = 50;
# analyze verbose test_ndistinct;
INFO:  analyzing "public.test_ndistinct"
INFO:  "test_ndistinct": scanned 15000 of 35314 pages, containing 4247361 live rows and 0 dead rows;
15000 rows in sample, 9999792 estimated total rows
# explain analyze select distinct f1 from test_ndistinct ;
                                    QUERY PLAN
-------------------------------------------------------------------------------------------
 HashAggregate  (cost=160311.40..160328.51 rows=1711 width=4)
                (actual time=2436.392..2455.851 rows=90020 loops=1)
   Group Key: f1
   ->  Seq Scan on test_ndistinct  (cost=0.00..135311.92 rows=9999792 width=4)
                                   (actual time=0.029..892.596 rows=10000000 loops=1)
 Planning time: 0.096 ms
 Execution time: 2461.160 ms
```


n_distinct underestimation example

```
# explain analyze select * from test_ndistinct where f1 < 5000;
                                    QUERY PLAN
-------------------------------------------------------------------------------------------
 Seq Scan on test_ndistinct  (cost=0.00..160316.36 rows=99 width=4)
                             (actual time=2.325..1436.792 rows=3480 loops=1)
   Filter: (f1 < 5000)
   Rows Removed by Filter: 9996520
 Planning time: 0.058 ms
 Execution time: 1437.424 ms
```


n_distinct underestimation example

```
alter table test_ndistinct alter column f1 set (n_distinct = 100000);
analyze verbose test_ndistinct;
INFO:  analyzing "public.test_ndistinct"
INFO:  "test_ndistinct": scanned 15000 of 35314 pages, containing 4247670 live rows and 0 dead rows;
15000 rows in sample, 10000012 estimated total rows
ANALYZE
```


n_distinct underestimation example

```
# explain analyze select distinct f1 from test_ndistinct ;
                                      QUERY PLAN
-------------------------------------------------------------------------------------------------
 Unique  (cost=1571431.43..1621431.49 rows=100000 width=4)
         (actual time=4791.872..7551.150 rows=90020 loops=1)
   ->  Sort  (cost=1571431.43..1596431.46 rows=10000012 width=4)
             (actual time=4791.870..6893.413 rows=10000000 loops=1)
         Sort Key: f1
         Sort Method: external merge  Disk: 101648kB
         ->  Seq Scan on test_ndistinct  (cost=0.00..135314.12 rows=10000012 width=4)
                                         (actual time=0.041..938.093 rows=10000000 loops=1)
 Planning time: 0.099 ms
 Execution time: 7714.701 ms
```


n_distinct underestimation example

```
set work_mem = '8MB';
SET
# explain analyze select distinct f1 from test_ndistinct ;
                                    QUERY PLAN
-------------------------------------------------------------------------------------------------
 HashAggregate  (cost=160314.15..161314.15 rows=100000 width=4)
                (actual time=2371.902..2391.415 rows=90020 loops=1)
   Group Key: f1
   ->  Seq Scan on test_ndistinct  (cost=0.00..135314.12 rows=10000012 width=4)
                                   (actual time=0.093..871.619 rows=10000000 loops=1)
 Planning time: 0.048 ms
 Execution time: 2396.186 ms
```


n_distinct underestimation example

```
# explain analyze select * from test_ndistinct where f1 < 5000;
                                    QUERY PLAN
-------------------------------------------------------------------------------------------
 Seq Scan on test_ndistinct  (cost=0.00..160316.61 rows=7550 width=4)
                             (actual time=0.723..839.347 rows=3480 loops=1)
   Filter: (f1 < 5000)
   Rows Removed by Filter: 9996520
 Planning time: 0.262 ms
 Execution time: 839.774 ms
```


n_distinct

- n_distinct plays important role in rows estimation when values are not in MCV list
- In very big tables it's possible to underestimate it in some cases
- It's possible to override n_distinct estimation via
  alter table xx alter column yy set (n_distinct = zz);

default_statistics_target

- Increasing default_statistics_target setting in config could help in this case but not recommended
- Default value 100 usually is good enough
- When it's not enough better increase it on selected columns only via **alter table xx alter column yy set statistics zz;**
- Otherwise it could lead to much longer planning time (autoanalyze will work longer too)

high default_statistics_target real example

```
# show default_statistics_target ;
 default_statistics_target
---------------------------
 6000
explain analyze SELECT "seven_charlie"."id" FROM "xray" JOIN "seven_charlie" ON
( "xray"."lima_seven" = "seven_charlie"."lima_seven" ) WHERE
( "xray"."alpha" = '139505' ) AND ( "seven_charlie"."seven_five" IS TRUE );

Nested Loop  (cost=0.850..798.110 rows=58 width=4) (actual time=0.081..3.314 rows=169 loops=1)
  ->  Index Scan using romeo on xray  (cost=0.420..205.390 rows=242 width=4) (actual time=0.023..0.79
        Index Cond: (alpha = 139505)
  ->  Index Scan using lima_two on seven_charlie  (cost=0.430..2.440 rows=1 width=8) (actual time=0.0
        Index Cond: ((lima_seven = papa3six.lima_seven) AND (seven_five = true))
 Planning time: 433.630 ms
 Execution time: 3.397 ms
```


high default_statistics_target real example

```
set default_statistics_target = 1000;
SET
# analyze verbose xray;
INFO:  analyzing "public.xray"
INFO:  "xray": scanned 6760 of 6760 pages, containing 851656 live rows and 2004 dead rows; 300000 row
ANALYZE

 Nested Loop  (cost=0.850..782.110 rows=57 width=4) (actual time=0.066..2.992 rows=169 loops=1)
  ->  Index Scan using romeo on xray  (cost=0.420..199.220 rows=238 width=4) (actual time=0.021..0.70
        Index Cond: (alpha = 139505)
  ->  Index Scan using lima_two on seven_charlie  (cost=0.430..2.440 rows=1 width=8) (actual time=0.0
        Index Cond: ((lima_seven = papa3six.lima_seven) AND (seven_five = true))
 Planning time: 75.196 ms
 Execution time: 3.071 ms
```


high default_statistics_target real example

```
# analyze verbose seven_charlie;
INFO:  "seven_charlie": scanned 300000 of 1548230 pages, containing 2184079 live rows and 8293 dead r

Nested Loop  (cost=0.850..782.110 rows=65 width=4) (actual time=0.197..26.517 rows=169 loops=1)
  ->  Index Scan using romeo on xray  (cost=0.420..199.220 rows=238 width=4) (actual time=0.064..3.15
        Index Cond: (alpha = 139505)
  ->  Index Scan using lima_two on seven_charlie  (cost=0.430..2.440 rows=1 width=8) (actual time=0.0
        Index Cond: ((lima_seven = papa3six.lima_seven) AND (seven_five = true))
 Planning time: 14.256 ms
 Execution time: 26.617 ms
```


Hacks

```
select name from pg_settings where name ~ 'enable_';
```

```
enable_bitmapscan
enable_indexscan
enable_indexonlyscan
enable_seqscan
enable_tidscan
```

```
enable_nestloop
enable_hashjoin
enable_mergejoin
enable_sort
enable_hashagg
enable_material
```

startup_cost += disable_cost

disable_cost = 10^{10}

Hacks

- Very good for testing
- Affects whole query
- Possible to use in functions in some bad cases via **alter function xxx() set enable_? = false**
- pg_hint_plan[6] extension (not in contrib) which provide hints

[6] https://osdn.net/projects/pghintplan/

Join ordering problem

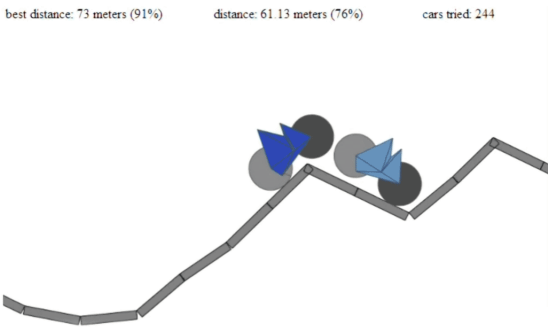
- There are O(n!) ways to join n relations which grows very fast (10! ≈ 3.6M)
- ORMs like to join everything
- It's possible to break this number down by using CTEs but be careful
- join_collapse_limit, from_collapse_limit (default 8 relations)

Genetic Query Optimizer (geqo)

- geqo_threshold (default 12 relations)
- Chose suboptimal plan in reasonable time
- “Mutation” and selection phases

Genetic algorithm fun demo

7



[7] http://boxcar2d.com/

What planner can't do properly

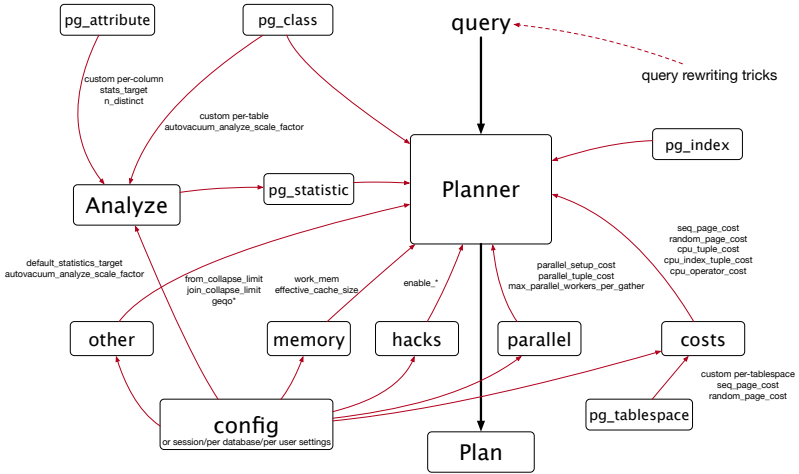
- Estimate number of rows correctly for conditions like "a=x and b=y" where a and b statistically dependent
- Use indexes for conditions like created_at + interval '1 day' >= NOW()
- Use index to count distinct values[8]
- Cope with lots of partitions
- Estimate correctly how many rows need to be read when using index scan on a for "where condition order by a limit n"

[8] `https://wiki.postgresql.org/wiki/Loose_indexscan`

Query rewriting tricks

- Disable index usage in where clause: a = x => a+0 = x
- Disable index usage in order by clause: order by a => order by a+0
- Restrict push up/pull downs from subquery with offset 0
- Replace left join with exists/not exists to force nested loop
- Move non-limiting join after limit

What have we learned?



Troubleshooting

- Don’t panic!
- Check if planner’s estimates are wrong (off by orders of magnitude)
- Check for missing indexes when a lot of filtering is done
- For complex plans `https://explain.depesz.com/` could help
- Extract problem part
- Check for outdated/incomplete stats
- Play with hacks and query rewriting tricks

Would you like to know more?

- Robert Haas – The PostgreSQL Query Planner, PostgreSQL East 2010
- Tom Lane – Hacking the Query Planner, PGCon 2011
- Bruce Momjian – Explaining the Postgres Query Optimizer
- PostgreSQL Manual 67.1. Row Estimation Examples
- PostgreSQL Manual 14.1. Using EXPLAIN
- depesz: Implement multivariate n-distinct coefficients
- depesz: Explaining the unexplainable
- www.slideshare.net/alexius2/

Questions?

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