PostgreSQL-Consulting

data egret

PostgreSQL Query Optimization

Step by step techniques

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Agenda

1. What is a slow query?
2. How to chose queries to optimize?
3. What is a query plan?
4. Optimization tools
5. Optimization examples

Is this query slow?


```
                                          QUERY PLAN
----------------------------------------------------------------------------------------------
Limit  (cost=12993.17..12993.17 rows=1 width=20) (actual time=606.385..606.385 rows=1 loops=1)
...
Planning time: 1.236 ms
Execution time: 607.057 ms
```

Does this query perform well enough for your system?

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- What is your baseline?
- 607.057 ms can be extremely fast for OLAP
- But 607.057 ms * 10000 parallel queries on OLTP?
- 607.057 ms on 10 y.o. SATA disks vs modern SSD

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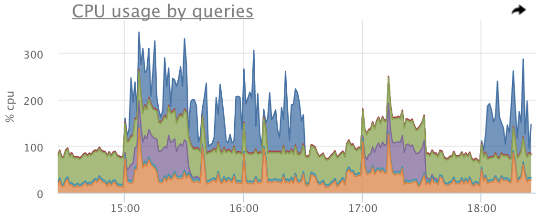
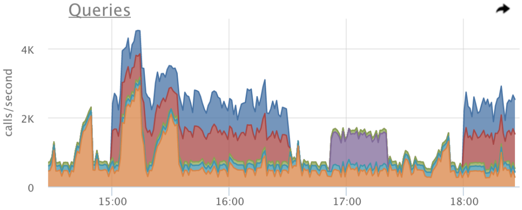
- Often it is useless to optimize all queries
- $log\_min\_duration\_statement = 100ms$
  Everything that's in the logs is due for review
- *pg_stat_statements*
  Lot's of useful stuff inside
- Monitoring system of choice
  Hopefully it has query info accumulated and ranged

How to find the queries to optimize?





Which queries to optimize first?


```
SELECT sum(total_time) AS total_time,
       sum(blk_read_time + blk_write_time) AS io_time,
       sum(total_time - blk_read_time - blk_write_time) AS cpu_time,
       sum(calls) AS ncalls,
       sum(rows) AS total_rows
  FROM pg_stat_statements
 WHERE dbid IN (SELECT oid FROM pg_database WHERE datname=current_database())
```

Which queries to optimize first?


```
WITH ttl AS (
  SELECT sum(total_time) AS total_time, sum(blk_read_time + blk_write_time) AS io_time,
         sum(total_time - blk_read_time - blk_write_time) AS cpu_time,
         sum(calls) AS ncalls, sum(rows) AS total_rows
    FROM pg_stat_statements WHERE dbid IN (
      SELECT oid FROM pg_database WHERE datname=current_database())
)
SELECT *,(pss.total_time-pss.blk_read_time-pss.blk_write_time)/ttl.cpu_time*100 cpu_pct
  FROM pg_stat_statements pss, ttl
 WHERE (pss.total_time-pss.blk_read_time-pss.blk_write_time)/ttl.cpu_time >= 0.05
 ORDER BY pss.total_time-pss.blk_read_time-pss.blk_write_time DESC LIMIT 1;
```

Which queries to optimize first?

- Lot's of metrics are possible to extract
- Requires time to come up with a good usable report
- DataEgret maintains it's report in the public domain[1]

[1] https://github.com/dataegret/pg-utils/blob/master/sql/global_reports/query_stat_total.sql

- Report operates with *total_time*, *io_time* and *cpu_time*, that is a difference of the first two
- Report also normalizes queries and calculates *md*5 hash for faster processing
- Main part of the report includes only those entries, that (any of the conditions qualifies):
  1. used more than 1% of total CPU or total IO time
  2. returned more than 2% of all rows
  3. had been called more than 2% of all query executions
- all other queries are combined into the *other* group
- report orders queries by total time spent, longest at the top

Details of the report


```
total time:     19:59:57 (IO: 16.43%)
total queries:  200,609,344 (unique: 2,342)
report for all databases, version 0.9.5 @ PostgreSQL 9.6.3
tracking top 10000 queries, utilities off, logging 100ms+ queries
=======================================================================================================
pos:1    total time: 05:38:45 (28.2%, CPU: 30.9%, IO: 14.5%)     calls: 84,592,220 (42.17%)      avg_time: 0.24ms (IO: 8.3%)
user: all        db: all         rows: 198,391,036 (24.34%)      query:
other
=======================================================================================================
pos:2    total time: 04:59:15 (24.9%, CPU: 24.0%, IO: 29.9%)     calls: 5,610 (0.00%)    avg_time: 3200.60ms (IO: 19.7%)
user: postgres   db: ---------   rows: 5,608,185 (0.69%)         query:

WITH _deleted AS (DELETE FROM foos_2rm WHERE id IN (SELECT id FROM foos_2rm ORDER BY id LIMIT ?) RETURNING id)
DELETE FROM foos WHERE id IN (SELECT id FROM _deleted);
=======================================================================================================
pos:3    total time: 00:45:06 (3.8%, CPU: 2.3%, IO: 11.1%)       calls: 853,864 (0.43%)  avg_time: 3.17ms (IO: 48.6%)
user: ---------_background       db: ---------    rows: 164,706 (0.02%)    query:
SELECT  "foo_stats_master".* FROM "foo_stats_master" WHERE (foo_stats_master.created_at >= ?) AND (foo_stats_master.created_at < ?)
AND "foo_stats_master"."action" IN (?, ?, ?, ?) AND ("foo_stats_master"."foo_board_id" IS NOT NULL)
AND "foo_stats_master"."user_ip_inet" = ? AND "foo_stats_master"."employer_id" = ?
ORDER BY "foo_stats_master"."created_at" DESC LIMIT ?
```

So, we identified some queries to optimize

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What comes next?

- Any query can be prepended with *EXPLAIN* to see it's **execution plan**
- `EXPLAIN SELECT * FROM pg_database;`

```
                        QUERY PLAN
-----------------------------------------------------------
Seq Scan on pg_database  (cost=0.00..0.16 rows=6 width=271)
(1 row)
```

What is **execution plan**?

- Query goes through several stages in it's lifecycle
- 1. Connection
  2. Parser
  3. Rewrite system
  4. Planner / Optimizer
  5. Executor ↔ [Workers]
  6. Send results
- Planner prepares a **plan** for executor

What is **execution plan**?

- It is a tree
- Nodes and operations on them
- Planner uses statistics to chose the optimal plan

Details of *EXPLAIN*

```
EXPLAIN SELECT * FROM pg_database;
                        QUERY PLAN
-----------------------------------------------------------
Seq Scan on pg_database  (cost=0.00..0.16 rows=6 width=271)
(1 row)
```

Seq Scan	type of node operation
on pg_database	object of node operation
cost=0.00..0.16	cost of the node
rows=6	estimated rows
width=271	average width of a row

- **Seq Scan** — sequential scan of whole relation
- **Parallel Seq Scan** — parallel sequential scan of whole relation
- **Index Scan** — targeted random IO (read index + read table)
- **Index Only Scan** — read only from index[2]
- **Bitmap Index Scan** — prepare a map of rows to read from relation, possibly combining maps from several indexes
- **Bitmap Heap Scan** — use map from Bitmap Index Scan and read rows from relation, *always* follows Bitmap Index Scan
- **CTE Scan** - read from Common Table Expression (*WITH Block*)
- **Function Scan** - read results, returned by a function

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

Cost of the node. Startup and total cost.

- A cost of fetching 8K block sequentially
- Cost is a relative value: a cost of 10 is 10× greater than a cost of 1

```
explain select * from posts order by id limit 5;
                                     QUERY PLAN
---------------------------------------------------------------------------------------
 Limit  (cost=0.29..0.46 rows=5 width=28)
   ->  Index Scan using posts_pkey on posts  (cost=0.29..347.29 rows=10000 width=28)
(2 rows)
```

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```

- 0.29 + (347.29 - 0.29)*5/10000 = 0.4635

rows $\times$ width

- Rows $\times$ width of a root node gives a clue of a result size in bytes
- Even if the query is fast, lots of it's calls can cause a huge traffic between database and an application
- Thats why *SELECT* $*$ is not a good idea

- **join** – joins data from two nodes using appropriate join method
- **sort** – various methods of sorting
- **limit** – cuts the dataset off
- **aggregate** – performs aggregation
- **hash aggregate** – groups data
- **unique** – removes duplicates from sorted datasets
- **gather** – gather data from different workers

Options of *EXPLAIN* command


```
EXPLAIN [ ANALYZE ] [ VERBOSE ] statement
EXPLAIN [ ( option [, ...] ) ] statement
```

- *ANALYZE* executes statement and shows execution details
- *VERBOSE* verbose output
- *COSTS* show plan costs
- *BUFFERS* show information about buffers operated by the query
- *TIMING* show time spent
- *SUMMARY* show totals at the end of output
- *FORMAT TEXT|XML|JSON|YAML* output in selected format

```
EXPLAIN (analyze) SELECT relname,relpages,reltuples FROM pg_class WHERE reltuples>10000;
                                              QUERY PLAN
----------------------------------------------------------------------------------------------------
 Seq Scan on pg_class  (cost=0.00..5.55 rows=6 width=72) (actual time=0.069..0.073 rows=6 loops=1)
   Filter: (reltuples > '10000'::double precision)
   Rows Removed by Filter: 334
 Planning time: 0.102 ms
 Execution time: 0.087 ms
(5 rows)
```

actual time=0.069..0.073	startup and total time of node execution
rows=6	actual rows
loops=1	number of times node had been executed
Rows Removed by Filter: 334	node processing details

A bit more complex query


```
EXPLAIN (analyze, buffers) SELECT r.relname, a.attname FROM pg_class r JOIN pg_attribute a ON a.attrelid=r.oid
 WHERE a.attnum>0 AND NOT attisdropped;
                                                      QUERY PLAN
-----------------------------------------------------------------------------------------------------------------------
 Hash Join  (cost=8.95..66.58 rows=1770 width=128) (actual time=0.215..2.246 rows=2039 loops=1)
   Hash Cond: (a.attrelid = r.oid)
   Buffers: shared hit=59 read=2
   I/O Timings: read=0.270
   ->  Seq Scan on pg_attribute a  (cost=0.00..33.29 rows=1770 width=68) (actual time=0.009..1.148 rows=2039 loops=1)
         Filter: ((NOT attisdropped) AND (attnum > 0))
         Rows Removed by Filter: 587
         Buffers: shared hit=46 read=2
         I/O Timings: read=0.270
   ->  Hash  (cost=4.70..4.70 rows=340 width=68) (actual time=0.198..0.198 rows=340 loops=1)
         Buckets: 1024  Batches: 1  Memory Usage: 42kB
         Buffers: shared hit=13
         ->  Seq Scan on pg_class r  (cost=0.00..4.70 rows=340 width=68) (actual time=0.002..0.095 rows=340 loops=1)
               Buffers: shared hit=13
 Planning time: 0.202 ms
 Execution time: 2.554 ms
(16 rows)
```

Now we have all we need to optimize

- We know what we want in terms of performance
- We know what query to optimize
- We have all the tools (*EXPLAIN ANALYZE*)

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- We know what we want in terms of performance
- We know what query to optimize
- We have all the tools (*EXPLAIN ANALYZE*)
- Now we only need to minimize the time executor spends on each node
- Or actually try to figure out what the query should do:
  Never optimize a SQL-query itself, try to optimize the operation it does

Simplest B-tree indexing


```
EXPLAIN ANALYZE SELECT * FROM test WHERE val=10;
                                          QUERY PLAN
------------------------------------------------------------------------------------------------
 Seq Scan on test  (cost=0.00..160.59 rows=37 width=16) (actual time=0.036..1.640 rows=18 loops=1)
   Filter: (val = 10)
   Rows Removed by Filter: 8900
 Planning time: 0.163 ms
 Execution time: 2.037 ms
(5 rows)
```

Simplest B-tree indexing


```
=> create index CONCURRENTLY test_val_idx on test using btree (val);
CREATE INDEX

=> EXPLAIN ANALYZE SELECT * FROM test WHERE val=10;
                                                      QUERY PLAN
-----------------------------------------------------------------------------------------------------------
 Bitmap Heap Scan on test  (cost=4.42..41.22 rows=18 width=16) (actual time=0.041..0.062 rows=18 loops=1)
   Recheck Cond: (val = 10)
   Heap Blocks: exact=12
   ->  Bitmap Index Scan on test_val_idx  (cost=0.00..4.42 rows=18 width=0)
                                                               (actual time=0.033..0.033 rows=18 loops=1)
         Index Cond: (val = 10)
 Planning time: 1.136 ms
 Execution time: 0.240 ms
(7 rows)
```

```
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
```

```
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
```

Optimizing long IN


```
1. SELECT * FROM test WHERE id<10000
1.2ms
2. SELECT * FROM test WHERE id<10000 AND val IN (a list from 1 to 10)
2.1ms
3. SELECT * FROM test WHERE id<10000 AND val IN (a list from 1 to 100)
6ms
4. SELECT * FROM test WHERE id<10000 AND val IN (a list from 1 to 1000)
38ms
5. SELECT * FROM test WHERE id<10000 AND val IN (a list from 1 to 10000)
380ms
```

```
explain analyze select * from test where id<10000 and val IN (1,...,100);
QUERY PLAN
-------------------------------------------------------------------------
Index Scan using test_pkey on test  (cost=0.43..1666.85 rows=10
width=140) (actual time=0.448..5.602 rows=16 loops=1)
Index Cond: (id < 10000)
Filter: (val = ANY ('1,...,100'::integer[]))
Rows Removed by Filter: 9984
```

Optimizing long IN


```
explain select count(*) from test JOIN (VALUES (1),...,(10)) AS
v(val) USING (val) where id<10000;
QUERY PLAN
------------------------------------------------------------------------
Aggregate  (cost=497.65..497.66 rows=1 width=0)
->
Hash Join
  (cost=0.69..497.65 rows=1 width=0)
Hash Cond: (test.val = "*VALUES*".column1)
->  Index Scan using test_pkey on test  (cost=0.43..461.22
rows=9645 width=4)
Index Cond: (id < 10000)
->  Hash  (cost=0.12..0.12 rows=10 width=4)
->  Values Scan on "*VALUES*"  (cost=0.00..0.12 rows=10
width=4)
```

Optimizing long IN


```
1. SELECT * FROM test WHERE id<10000
1.2ms
2. JOIN (VALUES (1),...,(10))
1.6ms (was 2.1ms)
3. JOIN (VALUES (1),...,(100))
2ms (was 6ms)
4. JOIN (VALUES (1),...,(1000))
3.9ms (was 38ms)
5. JOIN (VALUES (1),...,(10000))
10ms (was 380ms)
```

DISTINCT authors


```
EXPLAIN (analyze) SELECT DISTINCT author_id FROM blog_post;
                                                           QUERY PLAN
----------------------------------------------------------------------------------------------------------------------------
 Unique  (cost=0.42..32912.78 rows=1001 width=4) (actual time=0.019..347.327 rows=1001 loops=1)
   ->  Index Only Scan using u_bp_author_ctime on blog_post  (cost=0.42..30412.72 rows=1000020 width=4)
                                                             (actual time=0.018..268.112 rows=1000000 loops=1)
         Heap Fetches: 0
 Planning time: 0.068 ms
 Execution time: 347.495 ms
(5 rows)
```

Alternative: Loose index scan


```
EXPLAIN (analyze) WITH RECURSIVE t AS (
  -- start from least author_id                    -- anchor
  (SELECT author_id AS _author_id FROM blog_post ORDER BY author_id LIMIT 1)
  UNION ALL
  -- find the next author_id > "current" author_id  -- iterator
  SELECT author_id AS _author_id
    FROM t, LATERAL (SELECT author_id FROM blog_post WHERE author_id>t._author_id
   ORDER BY author_id LIMIT 1) AS a_id
)
-- return found values
SELECT _author_id FROM t;
```

Alternative: Loose index scan


```
                                   QUERY PLAN
-----------------------------------------------------------------------------------------------------------------------
 CTE Scan on t  (cost=52.27..54.29 rows=101 width=4) (actual time=0.017..11.176 rows=1001 loops=1)
   CTE t
     -> Recursive Union  (cost=0.42..52.27 rows=101 width=4) (actual time=0.016..10.154 rows=1001 loops=1)
         ->  Limit  (cost=0.42..0.46 rows=1 width=4) (actual time=0.015..0.015 rows=1 loops=1)
             ->  Index Only Scan using u_bp_author_ctime on blog_post  (cost=0.42..30412.72 rows=1000020 width=4)
                                                                        (actual time=0.014..0.014 rows=1 loops=1)
                   Heap Fetches: 0
         ->  Nested Loop  (cost=0.42..4.98 rows=10 width=4) (actual time=0.009..0.010 rows=1 loops=1001)
             ->  WorkTable Scan on t t_1  (cost=0.00..0.20 rows=10 width=4) (actual time=0.000..0.000 rows=1 loops=1001)
             ->  Limit  (cost=0.42..0.46 rows=1 width=4) (actual time=0.009..0.009 rows=1 loops=1001)
                 ->  Index Only Scan using u_bp_author_ctime on blog_post blog_post_1  (cost=0.42..10973.87 rows=333340 width=4)
                                                                                    (actual time=0.009..0.009 rows=1 loops=1001)
                       Index Cond: (author_id > t_1._author_id)
                       Heap Fetches: 0
 Planning time: 0.143 ms
 Execution time: 11.301 ms
(14 rows)
```

Queries which cannot be optimized

- NOT IN (query) instead of EXISTS
- JOIN instead IN/EXISTS
- unordered LIMIT
- ORDER BY random()

Queries which cannot be optimized

- NOT IN (query) instead of EXISTS
- JOIN instead IN/EXISTS
- unordered LIMIT
- ORDER BY random()
- **Avoid them!**

Takeaways

- Do not optimize all the queries - start with most critical for your **production** system
- Find your baseline
- Do not tune the query, try to figure out how to do what it does more effectively!

Questions?

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