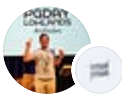
Statistics: How PostgreSQL Counts Without Counting

Part 1: A bird’s-eye view into PostgreSQL statistics



Sadeq Dousti · Follow

Published in Trade Republic Design and Engineering

10 min read · Jan 15, 2025

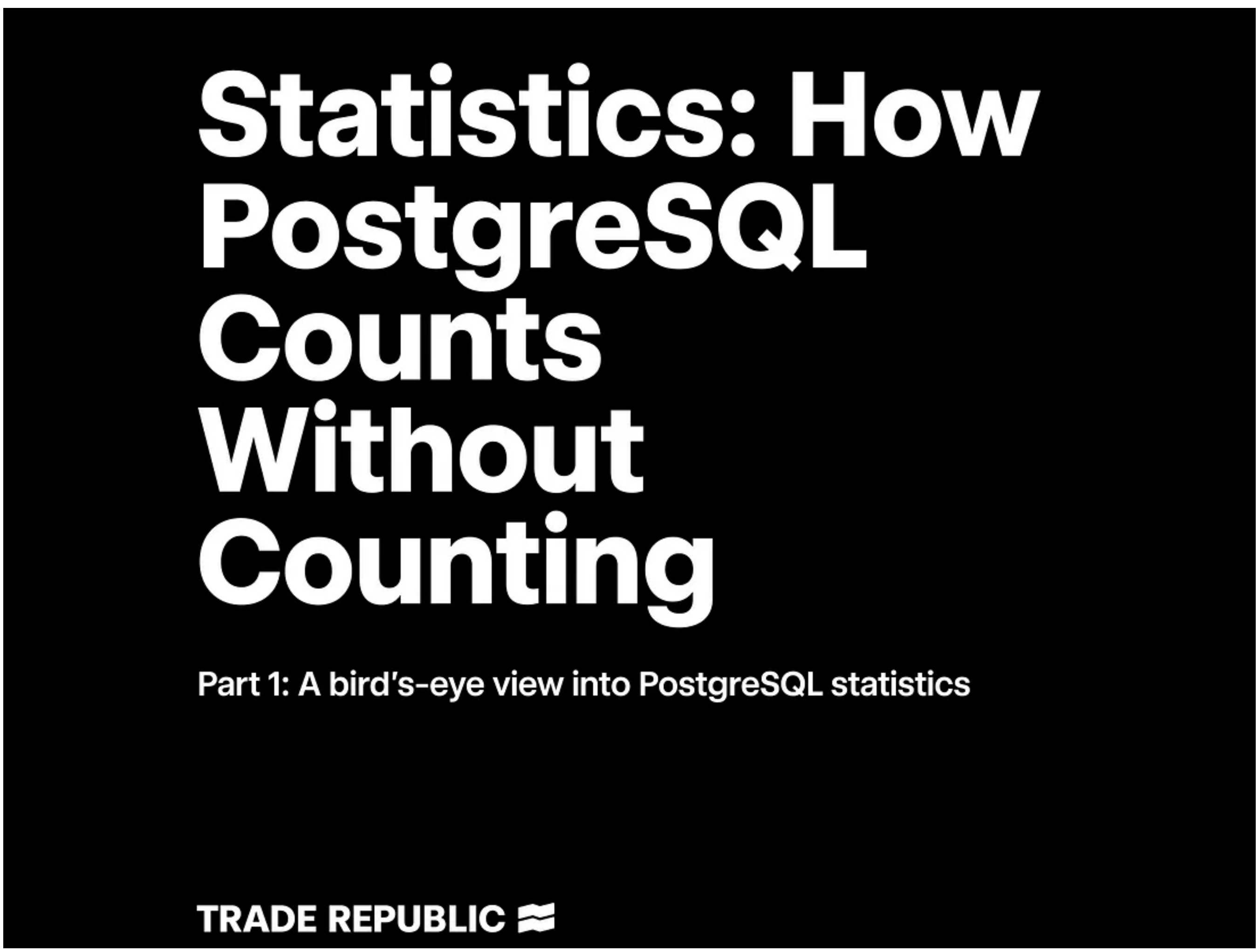


Table of Contents

Series Introduction

In this two-part article series, we'll explore how important data insights help PostgreSQL make smart decisions to keep everything running smoothly. Through easy-to-follow examples, we'll show you the benefits of regular database maintenance and how it prevents issues before they arise. We'll also discuss what happens when these data statistics become outdated and share simple ways to keep your database performing its best automatically. By the end of this series, you'll have a clear and enjoyable understanding of how PostgreSQL uses statistics to optimize performance and how you can fine-tune your own databases for maximum efficiency. Join us on this journey to make the most out of your PostgreSQL databases and ensure they run smoothly and effectively!

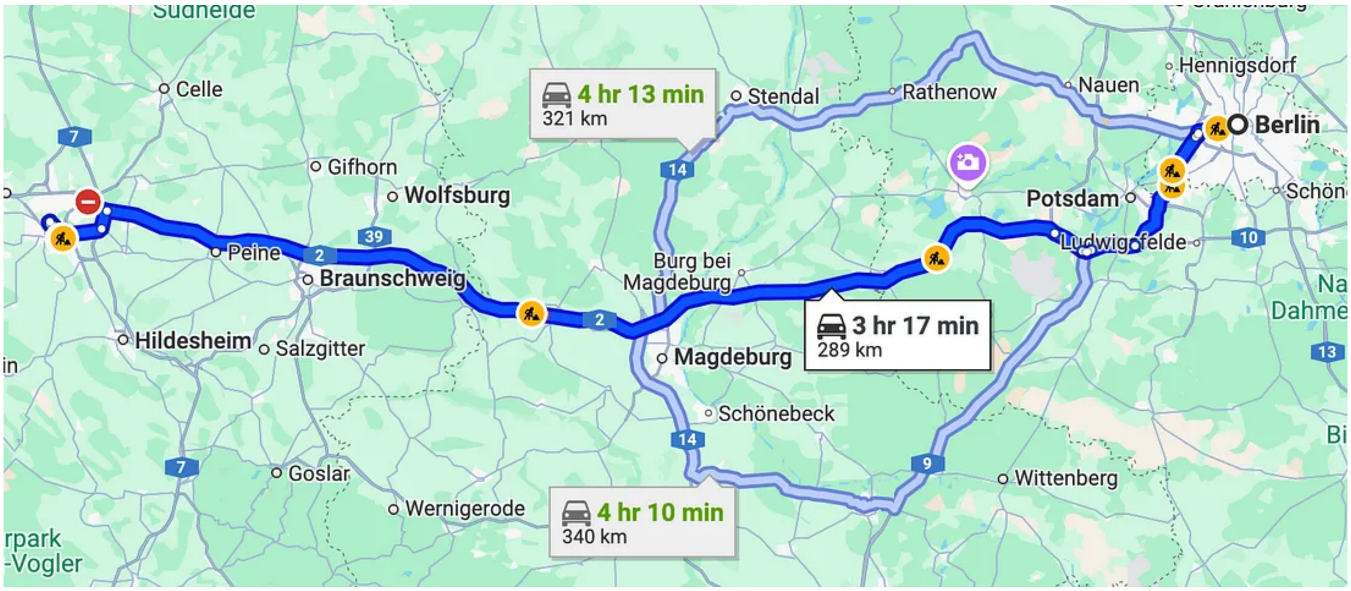
Part 2: https://traderepublic.substack.com/p/statistics-how-postgresql-counts-55d

The source code for queries in this article can be found in this GitHub repository: https://github.com/msdousti/pg-analyze-training.

Understanding the Query Planner

Let's plan for a trip: We'd like to travel from Berlin to Hanover. Which route should we take? Asking Google Maps, it shows us three routes:

- The suggested one would take **3 hr 17 min**.
- The other two routes are supposed to take **4 hr 13 min** and **4 hr 10 min**.



There are different routes for any trip. Google Maps gives us an estimated duration, based on the statistics it has previously gathered and analyzed.

How does Google Maps know these estimates? Well, it is based on past (driver) experiences and data it has collected and analyzed. In simple terms, it's based on **statistics**, that is regularly updated.

Now, would you trust Google Maps had I told you it hasn't updated its statistics in 10 years? Probably not. In the meantime, new roads may have been built, old roads may have been closed, traffic jams and construction sites could have been formed, etc.

Similarly, PostgreSQL's query planner must decide the most efficient way to execute a query. It evaluates different execution plans — like choosing between a sequential scan or using various indexes. When joining multiple tables, it considers different join algorithms and orders of joining tables. Once PostgreSQL selects a plan, it commits to it without the ability to backtrack, much like choosing a travel route and sticking with it despite unforeseen traffic.

The Role of Statistics

PostgreSQL relies heavily on **statistics** to make these decisions. Statistics are based on data that PostgreSQL has previously gathered about the table data. Without up-to-date statistics, PostgreSQL may make inaccurate estimations about row counts and data distribution, leading to inefficient query plans.

Setup

We'll use schema `analyze_training` for this whole series. The following snippet drops the schema (if exists) and then creates it, then sets the PostgreSQL search path to this schema. In this way, we have a clean slate to begin with:

```
drop schema if exists analyze_training cascade;

create schema analyze_training;

set search_path to analyze_training;
```

Demo: Without Statistics

To demonstrate this, I created a table `t` with a single integer column `n` and turned off `autovacuum`. Turning off `autovacuum` is a setting I **strongly advise against**, but it's necessary for this demonstration to show my point about the vitality of gathering statistics. I inserted 1,000 rows with values 0 to 999 modulo five, totaling ~200 of each integer value between 0 and 4.

```
create table t(n)
  with (autovacuum_enabled = off)
  as select mod(generate_series(0, 999), 5);
```

Next, we will use PostgreSQL `explain` keyword to see the query plans. We are specially interested in the `rows=N` part of the plan, where it estimates the number of returned rows.

```
explain select * from t;
                          QUERY PLAN
 Seq Scan on t  (cost=0.00..35.50 rows=2550 width=4)
(1 row)
```

We are specially interested in the `rows=N` part of the query plan

Running a query like `SELECT * FROM t;` resulted in PostgreSQL estimating 2,550 rows instead of the actual 1,000. Queries such as `SELECT COUNT(*) FROM t WHERE n = 0;` estimated 13 rows instead of the actual 200, and `SELECT COUNT(*) FROM t WHERE n = 10;` also incorrectly estimated 13 rows, despite knowing there are no such entries. This highlights how disabling statistics leads PostgreSQL to rely on flawed heuristics.

```
explain select * from t;
┌──────────────────────────────────────────────────────────┐
│                        QUERY PLAN                        │
├──────────────────────────────────────────────────────────┤
│ Seq Scan on t  (cost=0.00..35.50 rows=2550 width=4)      │
└──────────────────────────────────────────────────────────┘

explain select * from t where n = 0;
┌────────────────────────────────────────────────────────┐
│                       QUERY PLAN                       │
├────────────────────────────────────────────────────────┤
│ Seq Scan on t  (cost=0.00..41.88 rows=13 width=4)      │
│   Filter: (n = 0)                                      │
└────────────────────────────────────────────────────────┘

explain select * from t where n = 10;
┌────────────────────────────────────────────────────────┐
│                       QUERY PLAN                       │
├────────────────────────────────────────────────────────┤
│ Seq Scan on t  (cost=0.00..41.88 rows=13 width=4)      │
│   Filter: (n = 10)                                     │
└────────────────────────────────────────────────────────┘
```

Exploring `pg_class`

PostgreSQL stores metadata about tables in the `pg_class` system table. When `autovacuum` is disabled, querying `pg_class` for table `t` returned `-1` for the number of tuples, indicating PostgreSQL has no accurate information about the table's row count due to the lack of statistics.

```
select reltuples from pg_class
  where oid = 't'::regclass;
┌───────────┐
│ reltuples │
├───────────┤
│        -1 │
└───────────┘
```

Creating an Index

Creating an index on column `n` updated `pg_class` to reflect the accurate row count.

```
create index t_n_idx on t(n);


select reltuples from pg_class
  where oid = 't'::regclass;
┌───────────┐
│ reltuples │
├───────────┤
│      1000 │
└───────────┘
```

Queries like `SELECT * FROM t;` now correctly estimated 1,000 rows. However, specific queries like `SELECT COUNT(*) FROM t WHERE n = 0;` still provided inaccurate estimates (now 5 instead of 200). This demonstrates that while indexes improve some aspects, they don't always resolve issues related to missing or stale statistics.

```
explain select * from t;
┌─────────────────────────────────────────────────────┐
│                      QUERY PLAN                     │
├─────────────────────────────────────────────────────┤
│ Seq Scan on t  (cost=0.00..15.00 rows=1000 width=4) │
└─────────────────────────────────────────────────────┘


explain select * from t where n = 0;
┌──────────────────────────────────────────────────────────────────────┐
│                              QUERY PLAN                              │
├──────────────────────────────────────────────────────────────────────┤
│ Bitmap Heap Scan on t  (cost=4.19..9.52 rows=5 width=4)              │
│   Recheck Cond: (n = 0)                                              │
│   ->  Bitmap Index Scan on t_n_idx  (cost=0.00..4.19 rows=5 width=0) │
│         Index Cond: (n = 0)                                          │
└──────────────────────────────────────────────────────────────────────┘


explain select * from t where n = 10;
```

```
┌─────────────────────────────────────────────────────────────────────────┐
│                               QUERY PLAN                                │
├─────────────────────────────────────────────────────────────────────────┤
│ Bitmap Heap Scan on t  (cost=4.19..9.52 rows=5 width=4)                 │
│   Recheck Cond: (n = 10)                                                │
│   ->  Bitmap Index Scan on t_n_idx  (cost=0.00..4.19 rows=5 width=0)    │
│         Index Cond: (n = 10)                                            │
└─────────────────────────────────────────────────────────────────────────┘
```

Importance of Accurate Statistics

In real-world scenarios, inaccurate statistics can lead to significant performance issues. **I've witnessed my fair share of incidents where stale statistics caused queries that typically ran in milliseconds to take minutes or even hours.** More on this later!

Gathering Statistics

Analyzing the Table

Let's recreate the table as before, but without the index:

```
drop table t;

create table t(n)
  with (autovacuum_enabled = off)
  as select mod(generate_series(0, 999), 5);
```

Initially, `pg_class` has no knowledge of row counts. Also, there is no statistics about the table in `pg_stats` view (This is a very useful view that PostgreSQL provides on the underlying catalog table `pg_statistics`):

```
select reltuples from pg_class
  where oid = 't'::regclass;
```

```
┌───────────┐
│ reltuples │
├───────────┤
│        -1 │
└───────────┘


select * from pg_stats
  where schemaname = 'analyze_training' and tablename = 't';
(0 rows)
```

Running `ANALYZE` on the table allowed PostgreSQL to gather accurate statistics.

```
analyze t;


select reltuples from pg_class
  where oid = 't'::regclass;
┌───────────┐
│ reltuples │
├───────────┤
│      1000 │
└───────────┘


select * from pg_stats
  where schemaname = 'analyze_training' and tablename = 't';
┌─[ RECORD 1 ]───────────┬─────────────────────────┐
│ schemaname             │ public                  │
│ tablename              │ t                       │
│ attname                │ n                       │
│ inherited              │ f                       │
│ null_frac              │ 0                       │
│ avg_width              │ 4                       │
│ n_distinct             │ 5                       │
│ most_common_vals       │ {0,1,2,3,4}             │
│ most_common_freqs      │ {0.2,0.2,0.2,0.2,0.2}   │
│ histogram_bounds       │ ∅                       │
│ correlation            │ 0.20479521              │
│ most_common_elems      │ ∅                       │
│ most_common_elem_freqs │ ∅                       │
```

```
│ elem_count_histogram   │ ∅                             │
│ range_length_histogram │ ∅                             │
│ range_empty_frac       │ ∅                             │
│ range_bounds_histogram │ ∅                             │
└────────────────────────┴───────────────────────────────┘
```

The `pg_stats` view showed detailed statistics per column, including schema name, table name, attribute name, percentage of nulls, average width, most common values, their frequencies, and histogram bounds. Correlation between data values and their physical storage was also assessed. In particular:

- `most_common_vals` are `{0,1,2,3,4}`, which are exactly the values we inserted.
- `most_common_freqs` are `{0.2,0.2,0.2,0.2,0.2}`, meaning each common value is present at roughly 20% of the rows.
- `histogram_bounds`: We'll discuss it in Part 2 of this article.

(Other stats — such as `most_common_elems` — are for non-scalar columns like arrays. We don't discuss them here.)

It's important to know that statistics are gathered per **single table column**. In other words, each column of a table has its own separate statistics, independent of other columns.

Showing query plans after statistics are gathered:

```
explain select * from t;
┌──────────────────────────────────────────────────────────┐
│                        QUERY PLAN                        │
├──────────────────────────────────────────────────────────┤
│ Seq Scan on t  (cost=0.00..15.00 rows=1000 width=4)      │
└──────────────────────────────────────────────────────────┘


explain select * from t where n = 0;
┌────────────────────────────────────────────────────────┐
```

```
|                       QUERY PLAN                        |
├─────────────────────────────────────────────────────────┤
| Seq Scan on t  (cost=0.00..17.50 rows=200 width=4)      |
|   Filter: (n = 0)                                       |
└─────────────────────────────────────────────────────────┘


explain select * from t where n = 10;
┌───────────────────────────────────────────────────┐
|                    QUERY PLAN                     |
├───────────────────────────────────────────────────┤
| Seq Scan on t  (cost=0.00..17.50 rows=1 width=4)  |
|   Filter: (n = 10)                                |
└───────────────────────────────────────────────────┘
```

PostgreSQL now accurately recognized the number of tuples in the table and provided correct estimates for queries:

- There are 1,000 rows in the table;
- Exactly 200 of them are 0;
- Exactly 0 of them are 10. PostgreSQL estimates 1, as estimating 0 would cause the query not to be executed at all. Since statistics are just estimate, the planner never estimates 0 rows, unless it can mathematically prove that there are no rows to be returned:

```
explain select * from t where 1=0;
┌───────────────────────────────────────────┐
|                QUERY PLAN                 |
├───────────────────────────────────────────┤
| Result  (cost=0.00..0.00 rows=0 width=0)  |
|   One-Time Filter: false                  |
└───────────────────────────────────────────┘
```

Utilizing EXPLAIN ANALYZE

Using `EXPLAIN ANALYZE` actually runs the query, allowing you to see the estimated versus actual row counts for queries. (Look at the `rows=N` in the first parenthesis and the second one in the query plan).

For instance:

```
explain analyze select * from t;
┌──────────────────────────────────────────────────────────────────────────────
│                                                QUERY PLAN
├──────────────────────────────────────────────────────────────────────────────
│ Seq Scan on t  (cost=0.00..15.00 rows=1000 width=4) (actual time=0.025..0.095
│ Planning Time: 0.069 ms
│ Execution Time: 0.136 ms
└──────────────────────────────────────────────────────────────────────────────


explain analyze select * from t where n = 0;
┌──────────────────────────────────────────────────────────────────────────────
│                                               QUERY PLAN
├──────────────────────────────────────────────────────────────────────────────
│ Seq Scan on t  (cost=0.00..17.50 rows=200 width=4) (actual time=0.013..0.123
│   Filter: (n = 0)
│   Rows Removed by Filter: 800
│ Planning Time: 0.042 ms
│ Execution Time: 0.141 ms
└──────────────────────────────────────────────────────────────────────────────


explain analyze select * from t where n = 10;
┌──────────────────────────────────────────────────────────────────────────────
│                                             QUERY PLAN
├──────────────────────────────────────────────────────────────────────────────
│ Seq Scan on t  (cost=0.00..17.50 rows=1 width=4) (actual time=0.100..0.100 ro
│   Filter: (n = 10)
│   Rows Removed by Filter: 1000
│ Planning Time: 0.063 ms
│ Execution Time: 0.110 ms
└──────────────────────────────────────────────────────────────────────────────
```

This command provides both the query plan and the actual execution details, helping you understand the accuracy of PostgreSQL's estimations based on the gathered statistics.

```
explain analyze select * from t;
                                         QUERY PLAN
 Seq Scan on t  (cost=0.00..18.00 rows=1000 width=4) (actual time=0.022..0.177 rows=1000 loops=1)
 Planning Time: 0.051 ms
 Execution Time: 13.404 ms
```

Using EXPLAIN ANALYZE, we can compare the query plan vs. the actual execution. We are especially interested in the number of rows estimated (left) vs. the actual number of rows returned (right).

> *Using* `EXPLAIN ANALYZE` *on data modification queries like* `INSERT` *or* `UPDATE` *can be dangerous, because the query is actually executed against your data. If you only intend to know the query plan and its actual running time, without modifying the data, wrap* `EXPLAIN ANALYZE` in a `BEGIN;...ROLLBACK;` block, and note that `ROLLBACK` can create dead rows (more on dead rows later!)

Defining A Utility Function

To streamline the process of comparing estimates with actual execution, I defined a utility function that executes `EXPLAIN ANALYZE` in JSON format:

```
explain (analyze, format json)
  select * from t;
┌─────────────────────────────────────┐
│              QUERY PLAN             │
├─────────────────────────────────────┤
│ [                                   │
│   {                                 │
│     "Plan": {                       │
│       "Node Type": "Seq Scan",      │
│       "Parallel Aware": false,      │
│       "Async Capable": false,       │
│       "Relation Name": "t",         │
│       "Alias": "t",                 │
│       "Startup Cost": 0.00,         │
│       "Total Cost": 15.00,          │
│       "Plan Rows": 1000,            │
│       "Plan Width": 4,              │
```

```
│        "Actual Startup Time": 0.020, │
│        "Actual Total Time": 0.158,   │
│        "Actual Rows": 1000,          │
│        "Actual Loops": 1             │
│      },                              │
│      "Planning Time": 0.072,         │
│      "Triggers": [                   │
│      ],                              │
│      "Execution Time": 0.240         │
│    }                                 │
│ ]                                    │
└──────────────────────────────────────┘
```

The function extracts relevant information like node type, planned rows, and actual rows. This function simplifies the analysis and makes it easier to assess the accuracy of PostgreSQL's statistics.

```
create type pln as (scan text, estimate text, actual text);


create or replace function c(query text)
returns pln language plpgsql as $$
declare
  jsn jsonb;
  plan jsonb;
begin
  execute format('explain (analyze, format json) %s', query)
    into jsn;
  select jsn->0->'Plan' into plan;
  return row(plan->>'Node Type', plan->>'Plan Rows', plan->>'Actual Rows');
end;
$$;
```

Example usage:

```
select * from c('select * from t');
┌──────────┬──────────┬────────┐
│   scan   │ estimate │ actual │
├──────────┼──────────┼────────┤
```

```
│ Seq Scan │ 1000     │ 1000   │
└──────────┴──────────┴────────┘


select * from c('select * from t where n=0');
┌──────────┬──────────┬────────┐
│   scan   │ estimate │ actual │
├──────────┼──────────┼────────┤
│ Seq Scan │ 200      │ 200    │
└──────────┴──────────┴────────┘


select * from c('select * from t where n=10');
┌──────────┬──────────┬────────┐
│   scan   │ estimate │ actual │
├──────────┼──────────┼────────┤
│ Seq Scan │ 1        │ 0      │
└──────────┴──────────┴────────┘
```

> *Credit: The function is inspired by the* `count_estimate` *function from PostgresSQL Count Estimate wiki page.*

We will use this utility function in Part 2!

Conclusions

Mastering the query planner is essential for optimizing database performance and ensuring efficient data retrieval. This article highlighted the pivotal role that accurate statistics play in helping the query planner decide on the cost of the chosen plan.

In part 2, we will build on the concepts discussed here. We'll look at histograms, vacuum, dangers of stale statistics, and multi-column statistics. Stay tuned!

Postgresql · Statistics · Query Optimization · Planner · Database

Follow

Published in Trade Republic Design and Engineering

115 Followers · Last published 1 day ago

Design and Engineering @ Trade Republic

Follow

Written by Sadeq Dousti

5 Followers · 2 Following

No responses yet

Write a response

What are your thoughts?

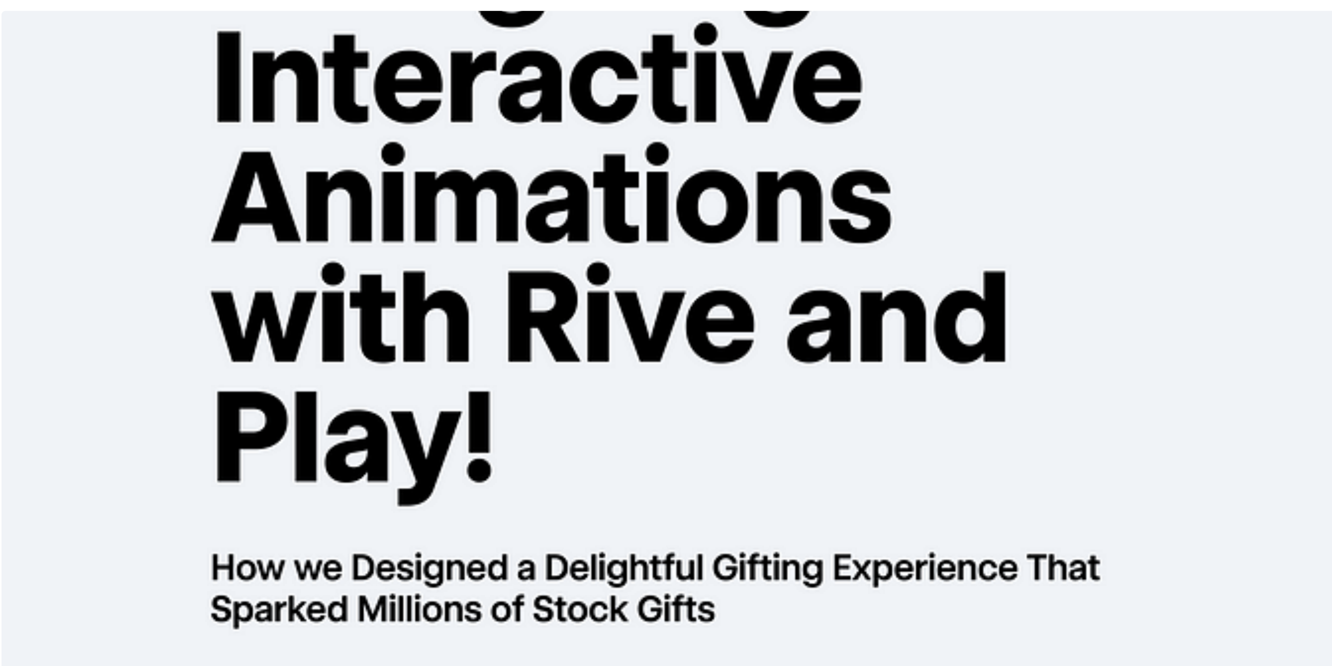
More from Sadeq Dousti and Trade Republic Design and Engineering

In Trade Republic Design and Engineering by Sadeq Dousti

Postgres partitioning performance: Hash vs. List

In our design, we came up with a would-be large PostgreSQL table that just stores IDs of incoming (Kafka) events, for the purpose of...

Sep 23, 2024 87 3



In Trade Republic Design and Engineering by Chethan KVS

Designing Interactive Animations for Trade Republic's Stock Gifting with Rive and Play!

How we Designed a Delightful Gifting Experience That Sparked Millions of Stock Gifts

Feb 24 461 3

In Trade Republic Design and Engineering by Leonardo Cardoso

Get Ready for Swift Macros

A Comprehensive Guide

Oct 23, 2023 93 1

In Trade Republic Design and Engineering by Sadeq Dousti

Statistics: How PostgreSQL Counts Without Counting

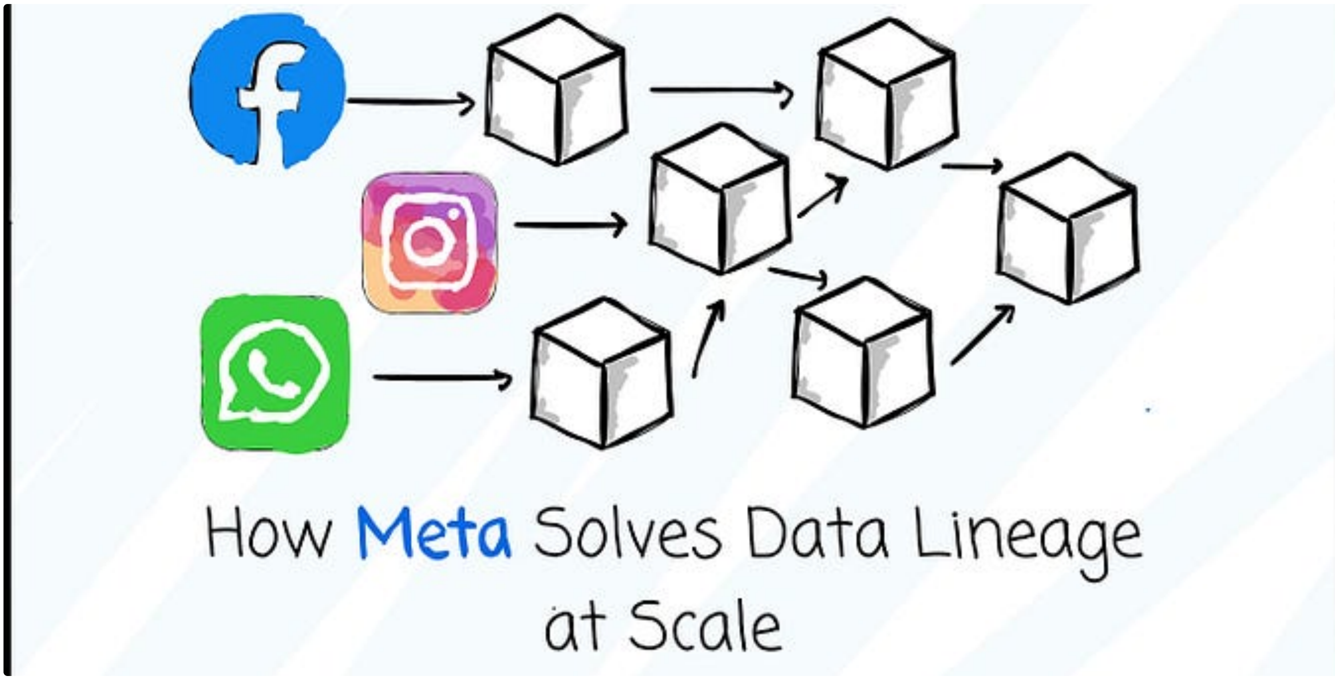
Part 2: Into the trenches of PostgreSQL statistics

Feb 17 7

See all from Sadeq Dousti

See all from Trade Republic Design and Engineering

Recommended from Medium

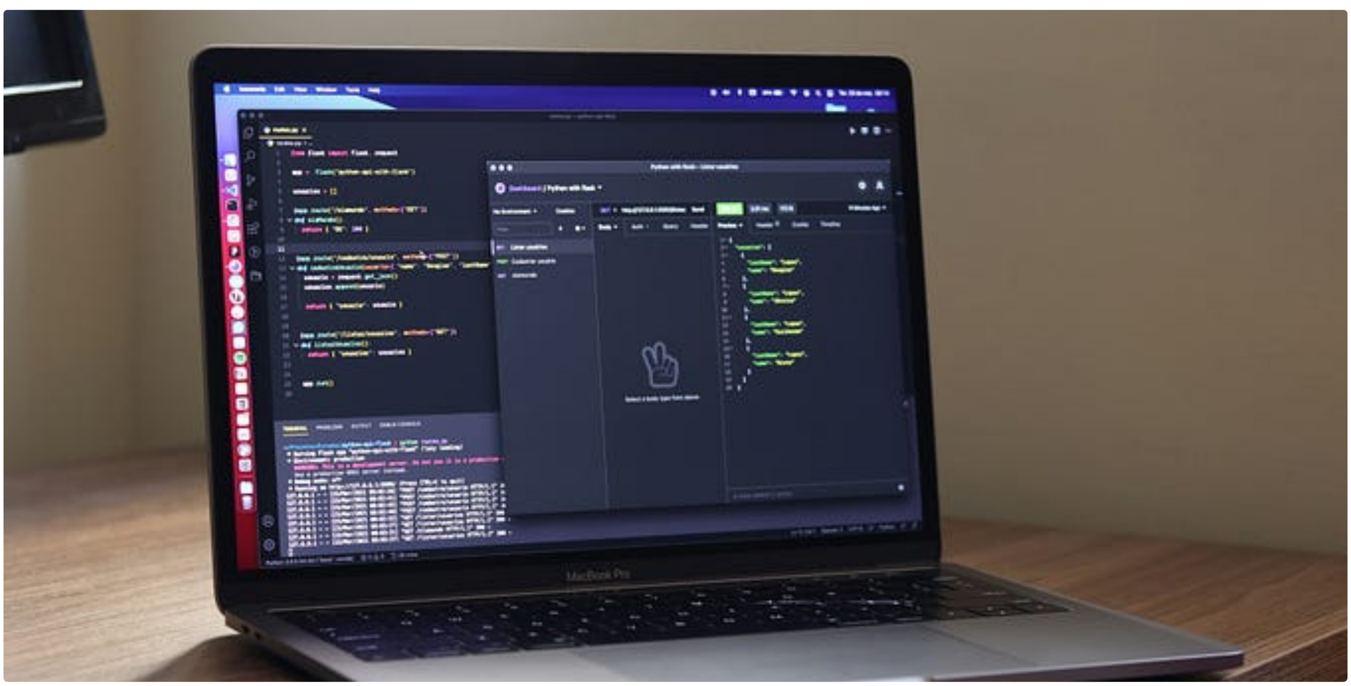


In Data Engineer Things by Vu Trinh

How Meta Solves Data Lineage At Scale

Meta's Approach to Data Lineage: How They Did It and What We Can Learn

5d ago 65 1



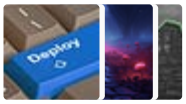
In The Pythoneers by Abhay Parashar

10 MindBlowing Free APIs to Supercharge Your Next Project

Make your projects 10x better!

2h ago 895 12

Lists

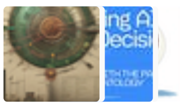


Predictive Modeling w/ Python

20 stories · 1854 saves

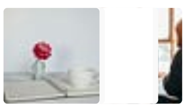
Practical Guides to Machine Learning

10 stories · 2223 saves



data science and AI

40 stories · 340 saves



Productivity

245 stories · 696 saves

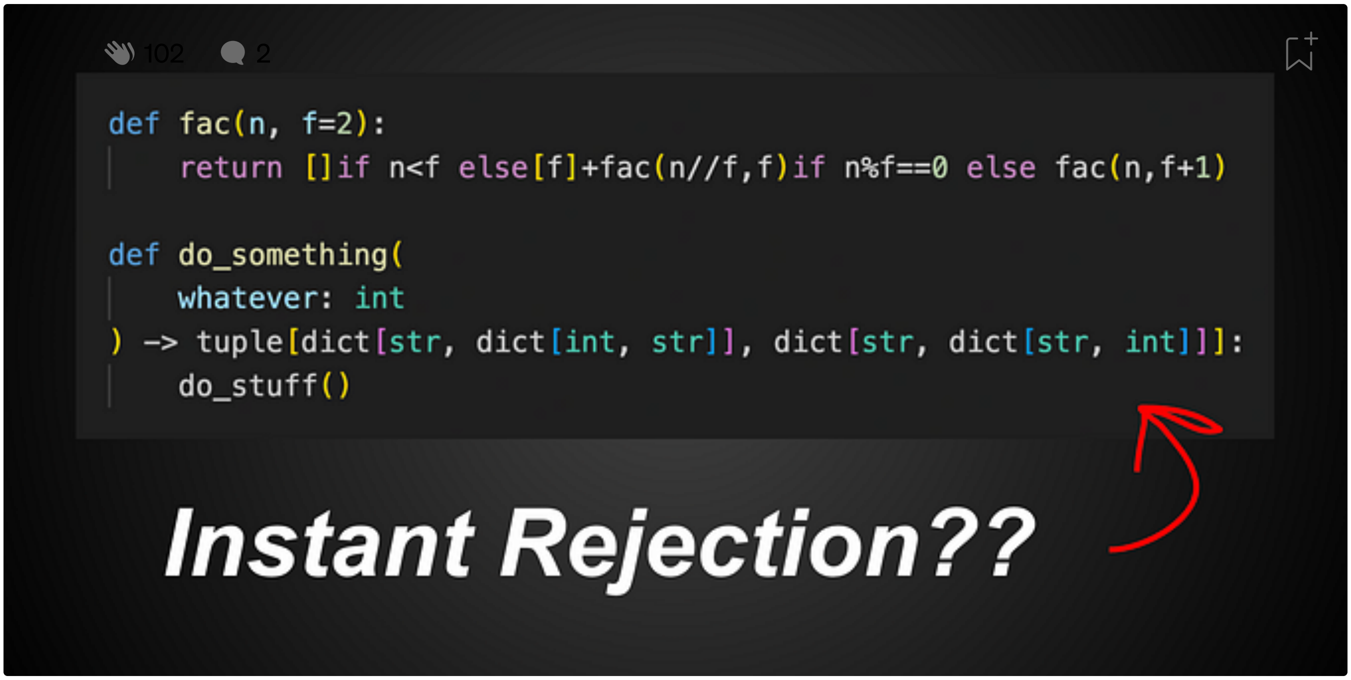
Query Optimization Method	Execution Time	Performance Improvement (vs. No Index)
No Index	42,049 ms (≈42 sec)	Baseline
With B-tree Index	9,684 ms (≈9.7 sec)	77% faster
With Chunk-Skipping Index + Columnstore	304 ms (0.3 sec)	99.28% faster

In Timescale by Team Timescale

Handling Billions of Rows in PostgreSQL

Here’s how to scale PostgreSQL to handle billions of rows using Timescale compression and chunk-skipping indexes.

102 2



In Level Up Coding by Liu Zuo Lin

15 Python Things That Lead To Instant PR Rejection

1) Zero type hints

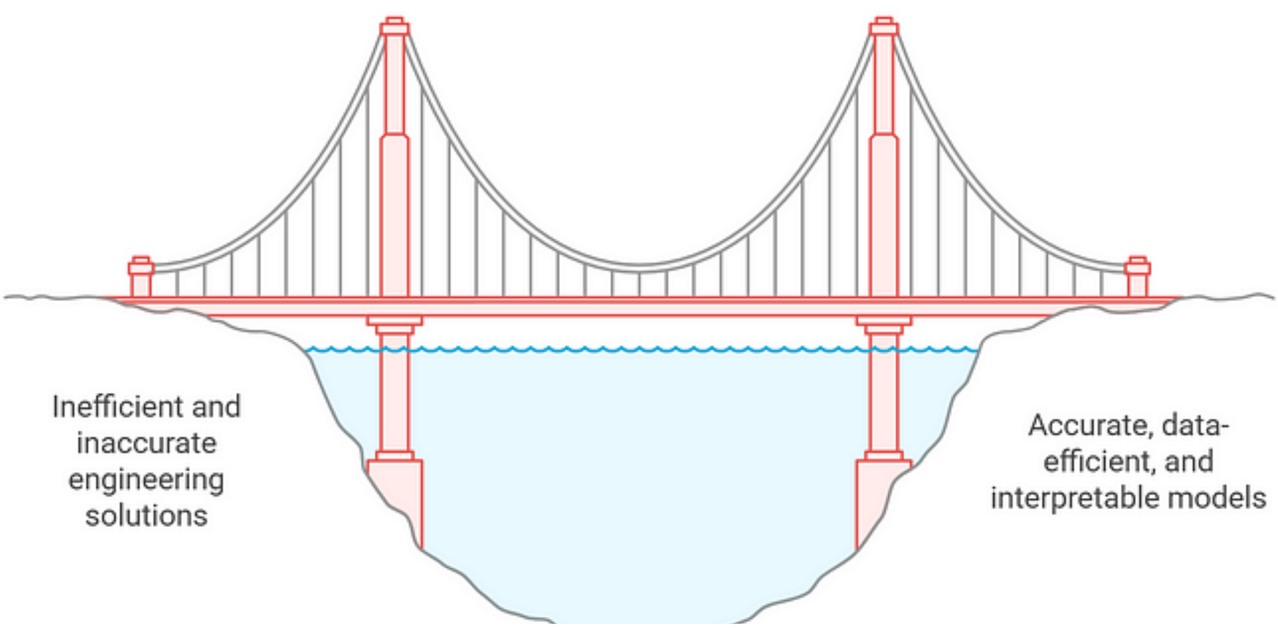
4d ago 301 4

In Data Science Collective by Paolo Perrone

Chart Smarter: How to Design Data Visualizations That Work

Our brains are built for visuals.

6d ago 945 8



In AI Advances by Shuai Guo, PhD

Surrogate Modeling: The Secret to Faster, Smarter Engineering

Its fundamentals, capabilities, and engineering applications

4d ago 350 3

See more recommendations