18 - PostgreSQL 17 Performance Tuning: Hash Index

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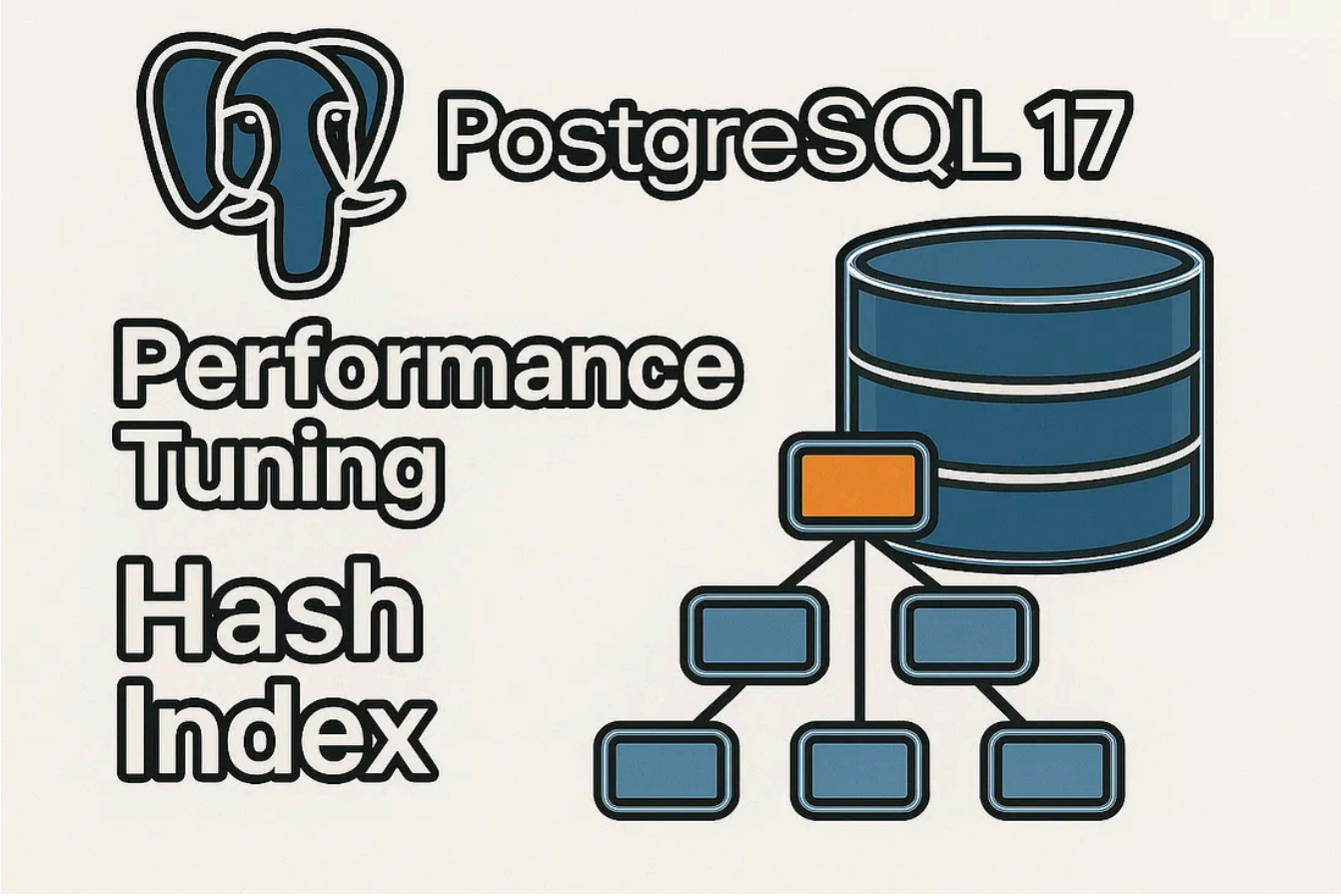
Jeyaram Ayyalusamy Following



Indexes are the backbone of database performance tuning. In PostgreSQL, the default index type is **B-Tree**, which handles a wide variety of queries very efficiently. But sometimes, a different type of index is a better fit.

What is a Hash Index in PostgreSQL?

A **Hash Index** is a special type of index in PostgreSQL that is optimized for **equality lookups** — queries where you check if a column equals a specific value (e.g., `WHERE email = 'user123@example.com'`).

Instead of storing values in a sorted order like a **B-Tree index**, a hash index uses a **hashing function**. The value you search for is hashed, and PostgreSQL jumps directly to the matching location in the index.

Key Characteristics

- **Best for `=` operator**
  Works only for equality conditions. You cannot use it for range queries (`<`, `>`, `BETWEEN`) or sorting.
- **Fast lookups**
  For exact matches, hash indexes can be extremely fast, especially with large datasets.
- **Compact structure**
  They don't need to maintain order, so storage is usually smaller compared to B-Tree indexes.
- **Production-ready in PostgreSQL 17**
  Older PostgreSQL versions had limitations: hash indexes weren't WAL-logged (not crash safe). Starting from PostgreSQL 10 and now in **PostgreSQL 17**, they are fully durable and safe to use.

When to Use Hash Indexes

✅ Use when:

- You often query with equality checks (`=`).
- The column has many unique values (e.g., email, username, ID).

❌ Avoid when:

- You need range lookups (`>` , `<` , `BETWEEN`).
- You want the index to support sorting or ordering.
- You already benefit from a **B-Tree index**, which supports equality and ranges.

👉 In short:
A **Hash Index** in PostgreSQL is a **special-purpose index** that makes equality lookups **blazing fast**, but it's not a general replacement for the default **B-Tree index**.

Step 1: Creating the `employees` table

We'll start by creating a simple employees table. It contains employee details, including `email` , which will be the focus of our equality lookups.

```
CREATE TABLE employees (
    emp_id    BIGINT,
    emp_name  TEXT,
    email     TEXT,
    dept      TEXT,
    salary    NUMERIC
);
```

```
postgres=# CREATE TABLE employees (
    emp_id    BIGINT,
    emp_name  TEXT,
    email     TEXT,
    dept      TEXT,
    salary    NUMERIC
```

```
);
CREATE TABLE
postgres=#
```

📌 Here:

- `emp_id` is a unique identifier.
- `email` will be queried often, and we will later add a **hash index** on it.
- Other columns (`name` , `dept` , `salary`) are for realism and testing.

Step 2: Inserting 10 million rows

To test performance properly, we need a **large dataset.** We'll generate 10 million employee records with distinct email addresses.

```
-- Insert 10 million rows with random emails and departments
INSERT INTO employees (emp_name, email, dept, salary)
SELECT
  'Employee_' || g,
  'user' || g || '@example.com',
  'Dept_' || (g % 20),                -- 20 departments
  (random()*100000)::NUMERIC(10,2)    -- salary between 0 and 100k
FROM generate_series(1, 10000000) g;
```

```
postgres=# INSERT INTO employees (emp_name, email, dept, salary)
SELECT
  'Employee_' || g,
  'user' || g || '@example.com',
  'Dept_' || (g % 20),                -- 20 departments
  (random()*100000)::NUMERIC(10,2)    -- salary between 0 and 100k
FROM generate_series(1, 10000000) g;
```

```
INSERT 0 10000000
postgres=#
```

✅ After this step, the table has 10 million rows, each with a unique email (`user1@example.com`, `user2@example.com`, ..., `user10000000@example.com`).

Step 3: Analyzing the table

Whenever you bulk-load data, it's important to run **ANALYZE**. This updates the PostgreSQL query planner with accurate statistics.

```
ANALYZE employees;
```

```
postgres=# ANALYZE employees;
ANALYZE
postgres=#
```

Without this step, the planner might guess row counts incorrectly and choose suboptimal execution plans.

Step 4: Running a query without an index

Let's run a simple lookup: find the row where `email = 'user5000000@example.com'`.

```
EXPLAIN ANALYZE
```

```
SELECT * FROM employees WHERE email = 'user5000000@example.com';
```

```
postgres=# EXPLAIN ANALYZE
SELECT * FROM employees WHERE email = 'user5000000@example.com';
                                                          QUERY PLAN
------------------------------------------------------------------------------
 Gather  (cost=1000.00..164395.43 rows=1 width=62) (actual time=4931.459..4936.
   Workers Planned: 2
   Workers Launched: 2
   ->  Parallel Seq Scan on employees  (cost=0.00..163395.33 rows=1 width=62) (
         Filter: (email = 'user5000000@example.com'::text)
         Rows Removed by Filter: 3333333
 Planning Time: 0.469 ms
 Execution Time: 4936.386 ms
(8 rows)

postgres=#
```

```
Time: 4936.386 ms (00:04.936)
postgres=#
```

📊 What happened?

- PostgreSQL performed a **sequential scan**, reading all 10M rows.
- Only **one row** matched, but 3,333,333 rows had to be checked and discarded.
- The execution time was ~4.9 seconds — too slow for real-world workloads.

Step 5: Creating a hash index

Now, let's create a **Hash Index** on the `email` column.

```
CREATE INDEX idx_employee_email_hash ON employees USING hash (email);
```

```
postgres=# CREATE INDEX idx_employee_email_hash ON employees USING hash (email)
CREATE INDEX
postgres=#
```

📌 Explanation:

- `USING hash` tells PostgreSQL to build a **hash-based index** instead of the default B-Tree.
- Hash indexes are optimized for **equality checks**, not range scans.

Analyzing the table

Whenever you bulk-load data or creating new indexes, it's important to run **ANALYZE**. This updates the PostgreSQL query planner with accurate statistics.

```
ANALYZE employees;
```

```
postgres=# ANALYZE employees;
ANALYZE
```

```
postgres=#
```

Step 6: Query plan after using the hash index

Run the same query again:

```
postgres=# EXPLAIN ANALYZE
SELECT * FROM employees WHERE email = 'user5000000@example.com';
                                                        QUERY PLAN
-----------------------------------------------------------------------------
 Index Scan using idx_employee_email_hash on employees  (cost=0.00..8.02 rows=1
   Index Cond: (email = 'user5000000@example.com'::text)
 Planning Time: 0.130 ms
 Execution Time: 0.030 ms
(4 rows)

postgres=#
```

```
Time: 0.030 ms
postgres=#
```

🔥 Huge improvement:

- The sequential scan is replaced with an **Index Scan.**
- The database jumps directly to the matching row using the hash index.
- Execution time dropped from **~5.2 seconds to less than 1 millisecond.**

Step 7: Understanding when to use Hash Indexes

Hash indexes are **specialized.** They are not a replacement for B-Tree indexes, but they excel in certain cases:

✅ **When Hash Indexes Shine:**

- Queries with equality conditions (`=`).
- Lookups on columns with high cardinality (many unique values), like `email` , `username` , or `UUID` .

❌ **When Not to Use:**

- Range queries (`<` , `>` , `BETWEEN`) → Use B-Tree instead.
- Sorting or ordering → B-Tree indexes are required.

Step 8: Improvements in PostgreSQL 17

Historically, hash indexes had limitations (not WAL-logged, crash unsafe). But now:

- **WAL-logged:** Hash indexes survive crashes safely.
- **VACUUM/ANALYZE aware:** They integrate smoothly with normal maintenance.
- **Production-ready:** Fully safe and recommended for workloads needing equality lookups.

Step 9: Verifying index size

Sometimes indexes can be large. You can check how much space they take compared to the table:

```
SELECT
    pg_size_pretty(pg_relation_size('employees')) AS table_size,
    pg_size_pretty(pg_indexes_size('employees')) AS indexes_size,
    pg_size_pretty(pg_total_relation_size('employees')) AS total_size;
```

```
postgres=# SELECT
    pg_size_pretty(pg_relation_size('employees')) AS table_size,
    pg_size_pretty(pg_indexes_size('employees')) AS indexes_size,
    pg_size_pretty(pg_total_relation_size('employees')) AS total_size;
 table_size | indexes_size | total_size
------------+--------------+------------
 870 MB     | 256 MB       | 1126 MB
(1 row)

postgres=#
```

This helps you understand the **storage overhead** of adding hash indexes.

Final Thoughts

This experiment shows how **Hash Indexes in PostgreSQL 17** can make equality lookups **thousands of times faster**.

- Without indexes, queries degrade to slow sequential scans.
- With a hash index, lookups become nearly instant.
- The choice of index type matters — **match the index to the query pattern.**

👉 If your workload involves frequent equality lookups on columns like email, username, or unique IDs, hash indexes are a powerful option.

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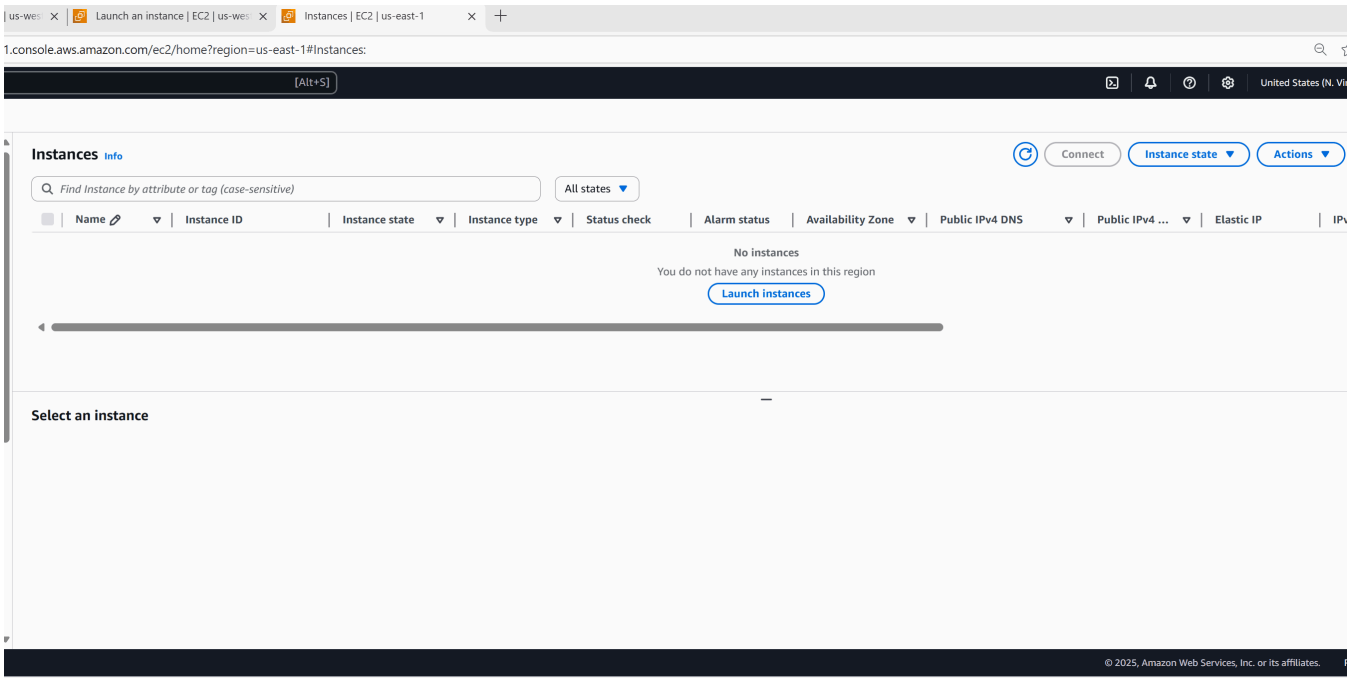

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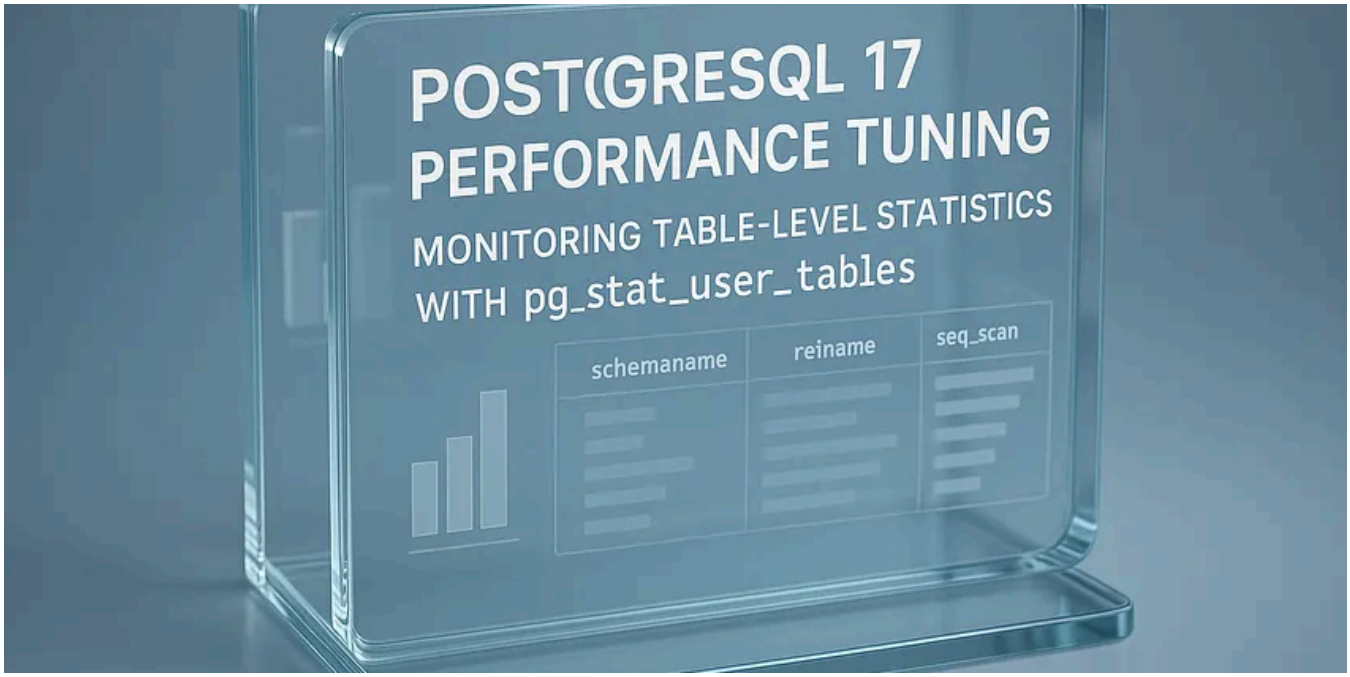

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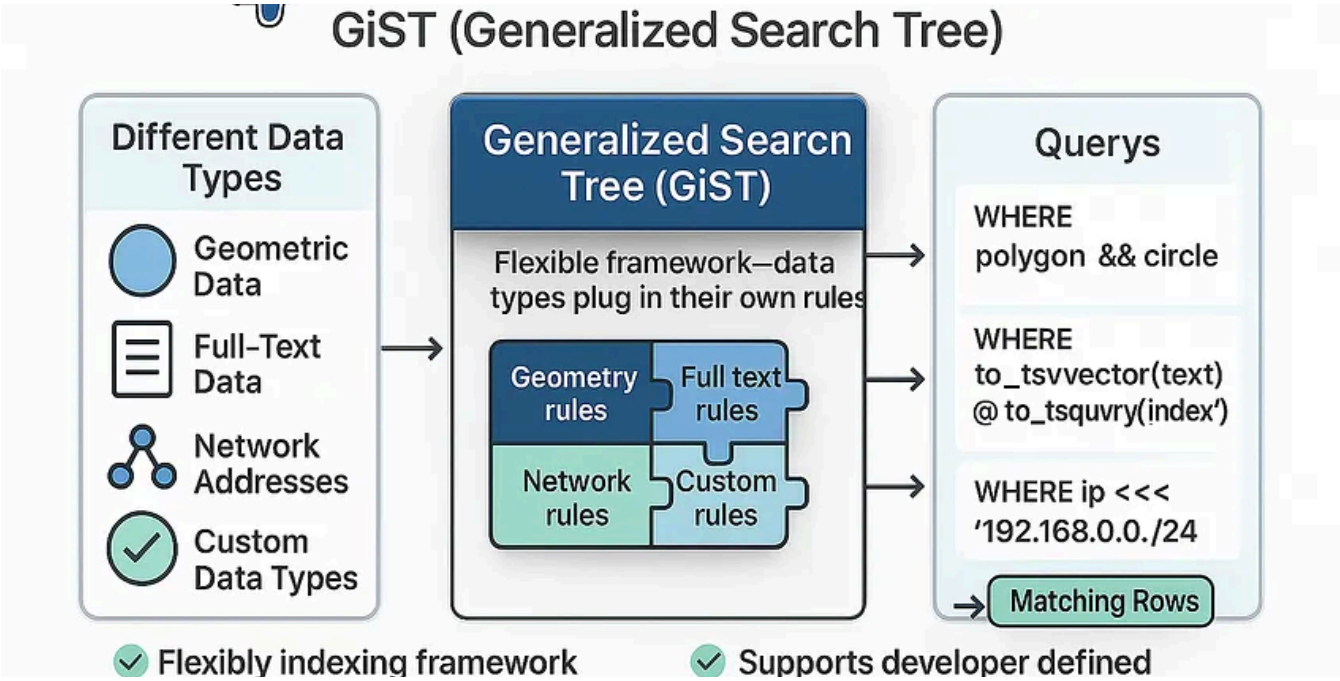

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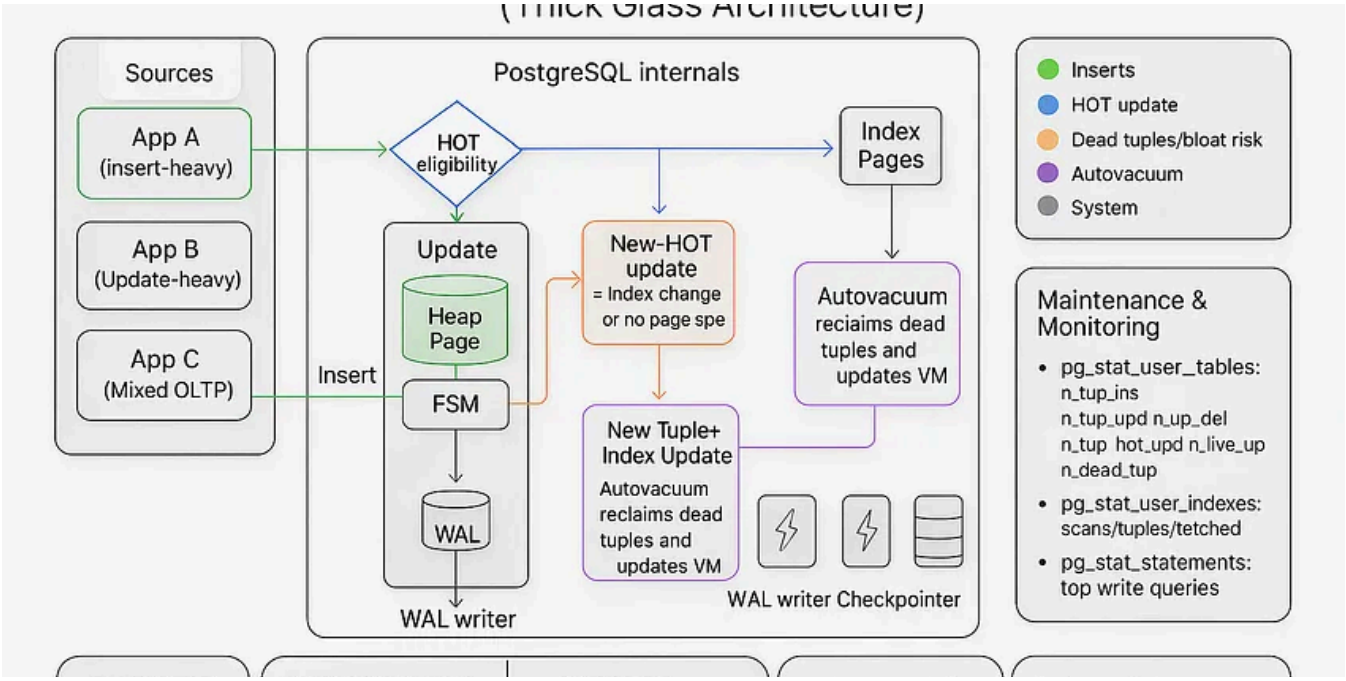

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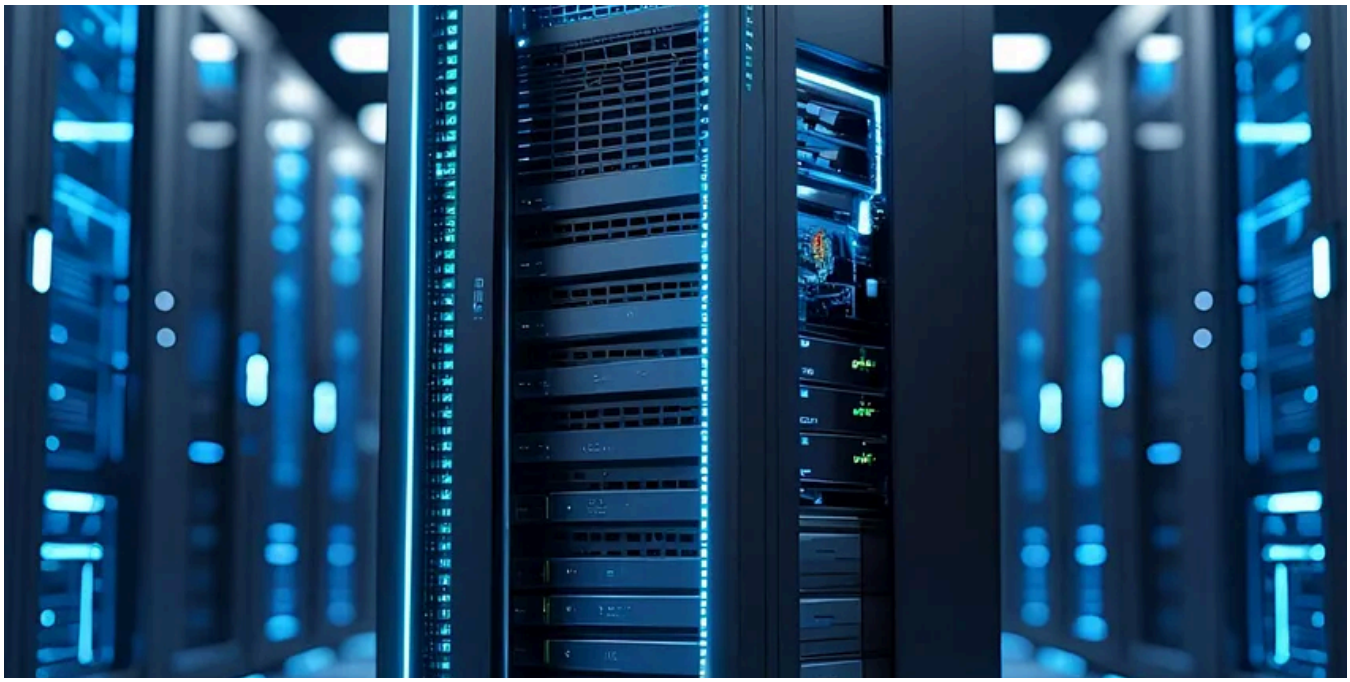

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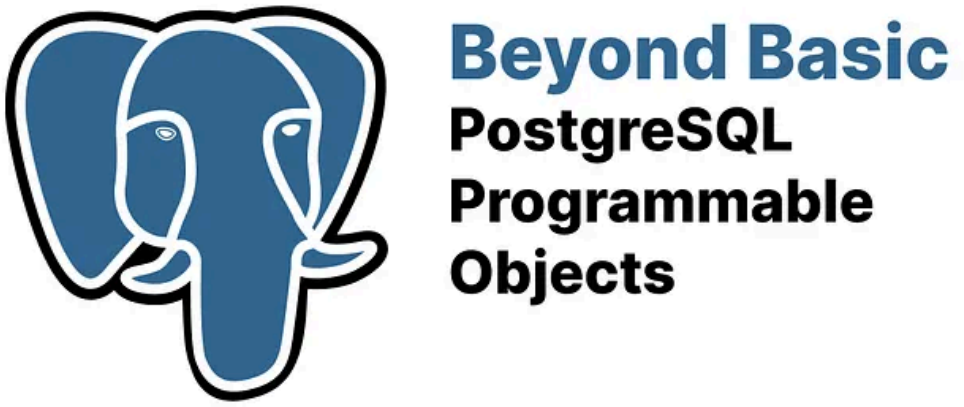

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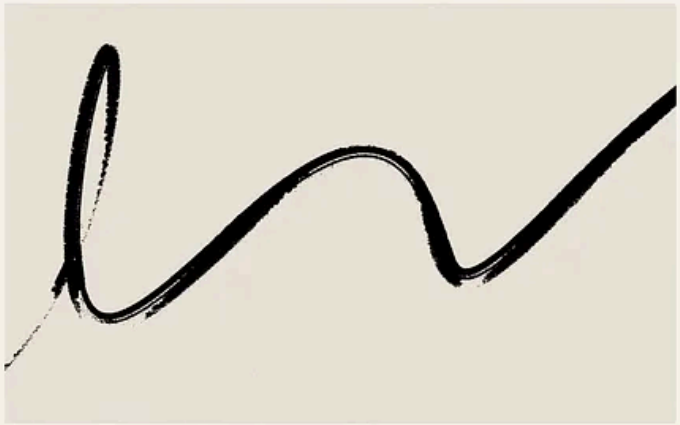

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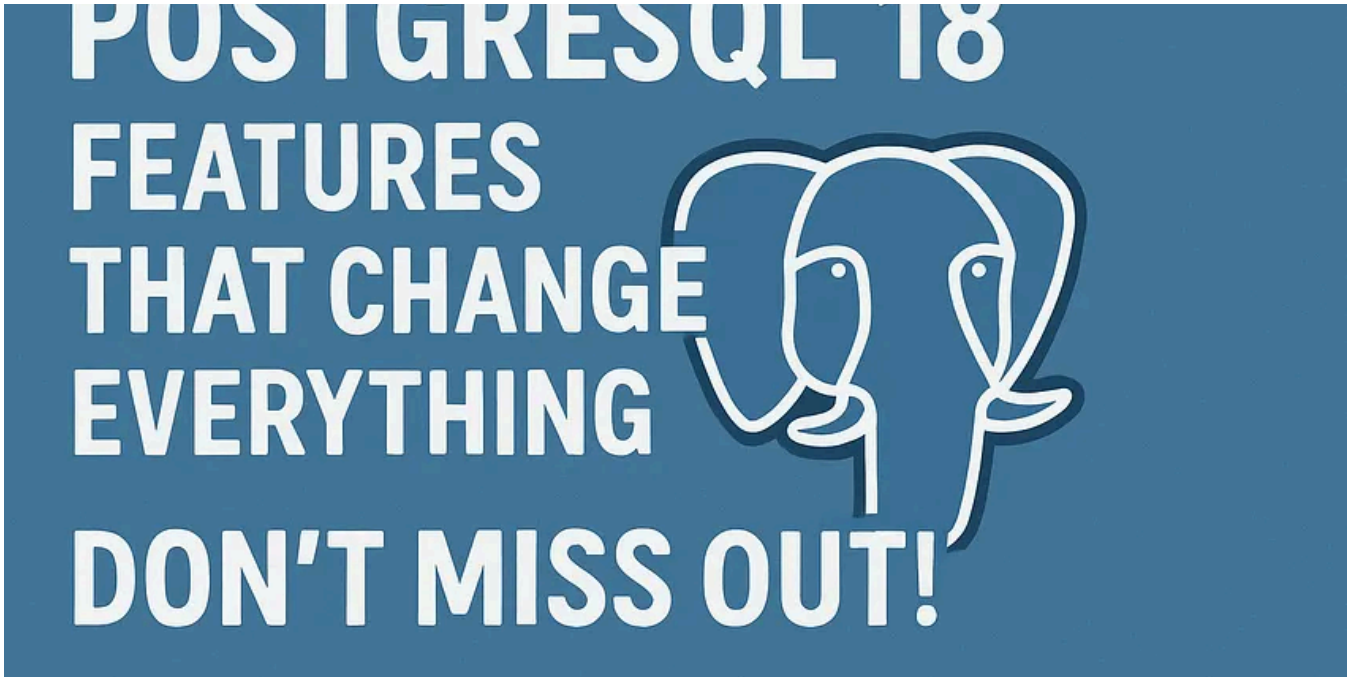

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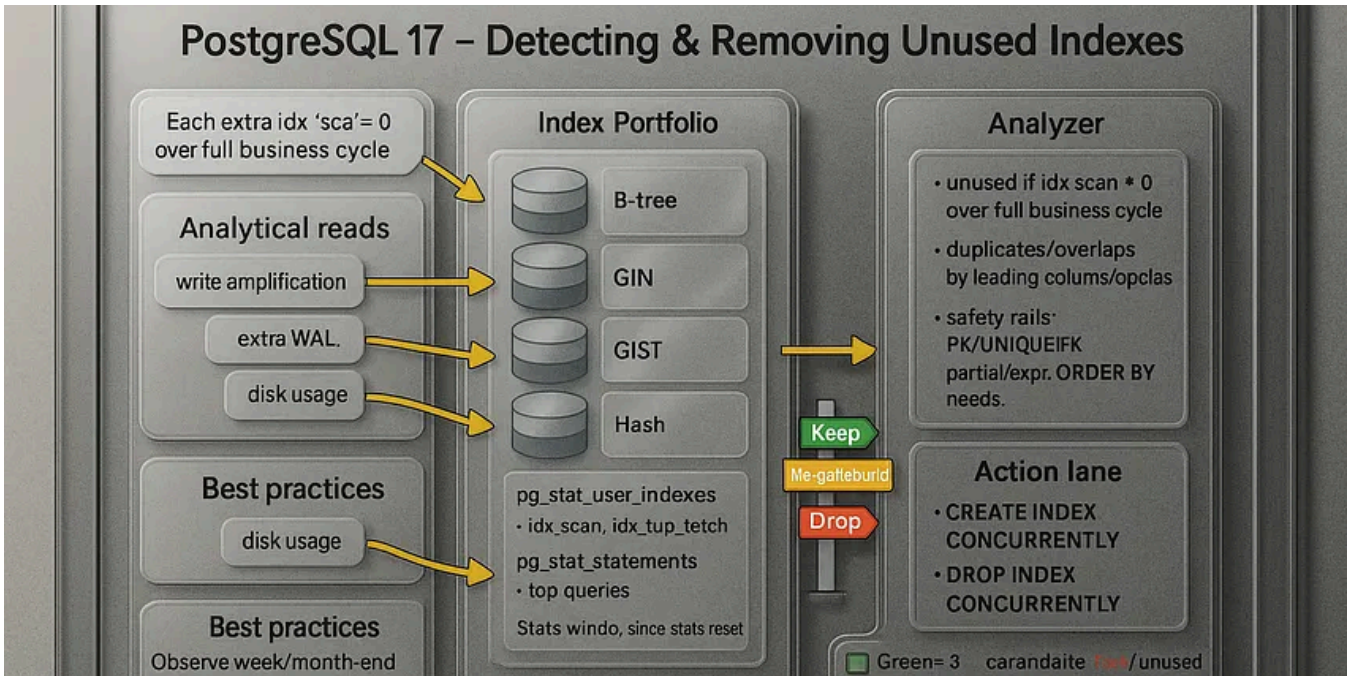

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