21 - PostgreSQL 17 Performance Tuning: GiST (Generalized Search Tree)

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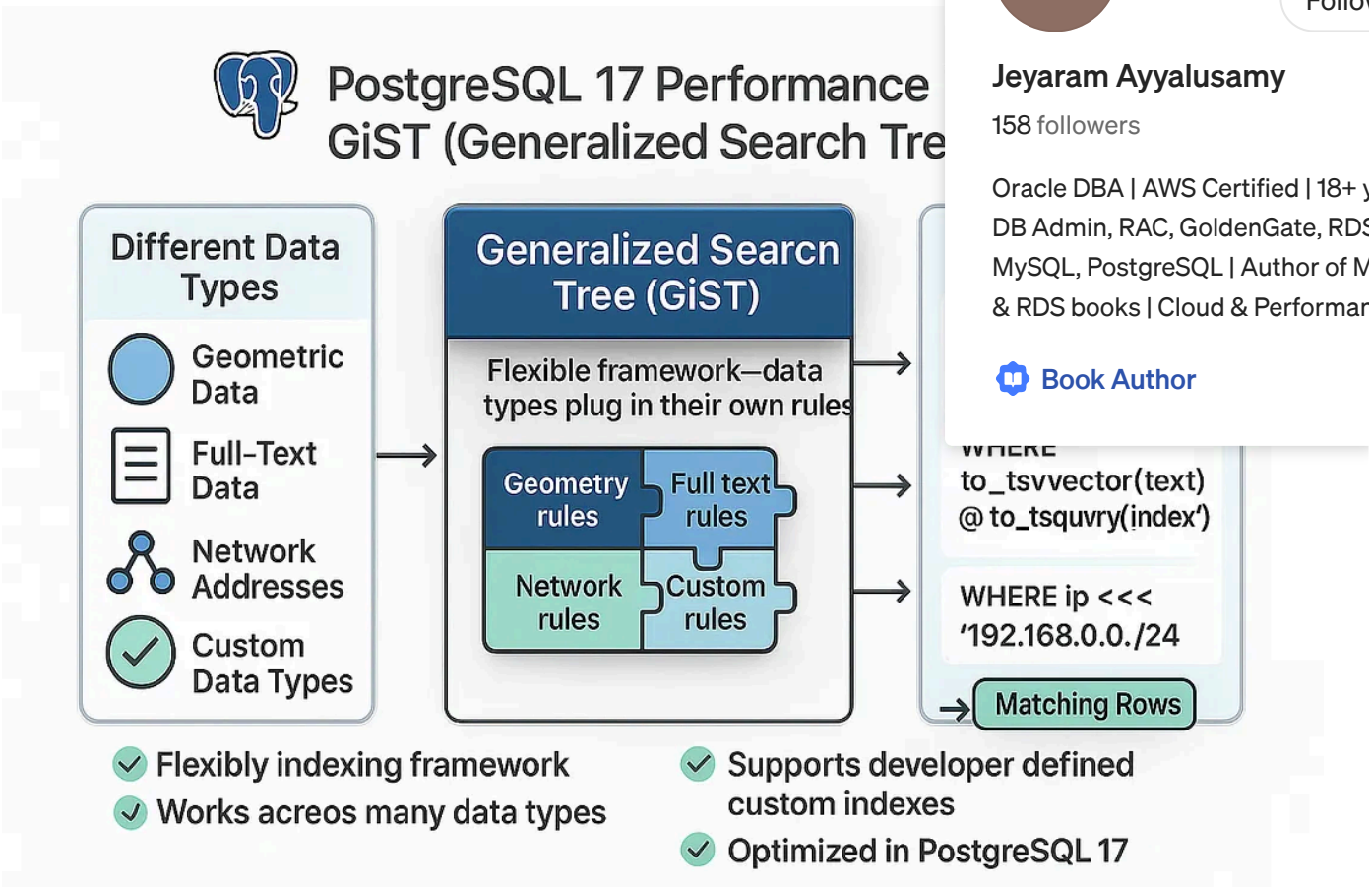
Jeyaram Ayyalusamy Following



GiST (Generalized Search Tree) in PostgreSQL is a flexible indexing framework that allows developers to build indexes for many different types of queries beyond simple equality or range checks. Unlike standard indexes such as B-Tree, GiST is not tied to one specific data type or operation. Instead, it provides a general structure

where different data types can "plug in" their own rules for how indexing and searching should work.

With GiST, PostgreSQL supports advanced features such as:

- **Geometric data** (points, lines, polygons)
- **Full-text search** (via `tsvector`)
- **Network addresses**
- **Custom data types** created by developers

In simple terms, GiST is like a toolkit for building specialized indexes. It doesn't define how data should be stored or compared itself, but provides a framework so that each data type can define its own methods for indexing and searching efficiently.

👉 Example use cases: spatial queries (e.g., "find points with
text search queries.

GiST indexes speed up queries on data with **spatial/geometri**
`point`, `box`, `circle`, `polygon`) and also enable **nearest-neigh**
with the `<->` distance operator. GiST is also used for several
and certain full-text configurations.

Example (pattern):

```
CREATE INDEX idx_locations_gist ON locations USING gist (geolocation);
```

Step 1: Create the `locations` table (point geometry)

```
CREATE TABLE locations (
    location_id  BIGSERIAL PRIMARY KEY,
    name         TEXT,
```

```
    geolocation  POINT          -- (x, y) = (longitude, latitude) for this demc
);
```

```
postgres=# CREATE TABLE locations (
    location_id  BIGSERIAL PRIMARY KEY,
    name         TEXT,
    geolocation  POINT          -- (x, y) = (longitude, latitude) for this demc
);
CREATE TABLE
postgres=#
```

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Step 2: Insert 10,000,000 random points (global spre

```
-- 10M random points: longitude [-180,180], latitude [-
INSERT INTO locations (name, geolocation)
SELECT
  'Location_' || g,
  POINT( -180 + random()*360,     -- lon
         -90  + random()*180 )    -- lat
FROM generate_series(1, 10000000) AS g;
```

```
postgres=# INSERT INTO locations (name, geolocation)
SELECT
  'Location_' || g,
  POINT( -180 + random()*360,     -- lon
         -90  + random()*180 )    -- lat
```

```
FROM generate_series(1, 10000000) AS g;
INSERT 0 10000000
postgres=#
```

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

Step 3: ANALYZE after bulk load

```
ANALYZE locations;
```

```
postgres=# ANALYZE locations;
ANALYZE
postgres=#
```


Step 4: Baseline query without any index (bounding box)

Find all points inside a rough **NYC** bounding box (lon/lat rectangle).
Operator: `point <@ box` → "point is contained by box".

```
EXPLAIN ANALYZE
SELECT *
FROM locations
WHERE geolocation <@ box '((-74.1,40.6),(-73.7,40.9))';
```

```
postgres=# EXPLAIN ANALYZE
SELECT *
FROM locations
WHERE geolocation <@ box '((-74.1,40.6),(-73.7,40.9))';
                                                              QUERY PLAN
---------------------------------------------------------------------------------------
 Gather  (cost=1000.00..146529.33 rows=10000 width=40) (actual time=1781.469..5
   Workers Planned: 2
   Workers Launched: 2
   ->  Parallel Seq Scan on locations  (cost=0.00..144529.33 rows=4167 width=40
         Filter: (geolocation <@ '(-73.7,40.9),(-74.1,40.6)'::box)
         Rows Removed by Filter: 3333329
 Planning Time: 0.143 ms
 Execution Time: 5997.030 ms
(8 rows)

postgres=#
```

```
Time: 5997.030 ms (00:05.997)
postgres=#
```


Without an index, PostgreSQL scans the entire 10M-row table.

Step 5: Create a GiST index on `geolocation`

```
postgres=# CREATE INDEX idx_locations_gist ON locations USING gist (geolocation
CREATE INDEX
postgres=#
```

> This adds a spatial index that understands geometric operators and supports **K-NN** ordering (`ORDER BY geolocation <-> point`).

ANALYZE created index

```
ANALYZE locations;
```

```
postgres=# ANALYZE locations;
ANALYZE
postgres=#
```


Step 6: Re-run the bounding box query (now indexed)

```
EXPLAIN ANALYZE
SELECT *
FROM locations
WHERE geolocation <@ box '((-74.1,40.6),(-73.7,40.9))';
```

```
postgres=# EXPLAIN ANALYZE
SELECT *
FROM locations
WHERE geolocation <@ box '((-74.1,40.6),(-73.7,40.9))';
                                                        QUERY PLAN
-----------------------------------------------------------------------------------
 Bitmap Heap Scan on locations  (cost=405.93..29364.11 rows=10001 width=40) (ac
```

```
   Recheck Cond: (geolocation <@ '(-73.7,40.9),(-74.1,40.6)'::box)
   Heap Blocks: exact=13
   ->  Bitmap Index Scan on idx_locations_gist  (cost=0.00..403.43 rows=10001 w
         Index Cond: (geolocation <@ '(-73.7,40.9),(-74.1,40.6)'::box)
 Planning Time: 1.132 ms
 Execution Time: 10.241 ms
(7 rows)

postgres=#
```

```
Time: 10.241 ms
postgres=#
```

*The plan switches to a **Bitmap Index Scan** using GiST, dropping latency from ~5.997 s to ~10.241 ms.*

Step 7: Radius search with circles (point-in-circle)

Find all points within an approximate radius around Times S

Operator: `point <@ circle` → "point is inside circle".

> **Note:** Built-in geometric types treat lon/lat as planar; distanc
> meters. This is fine for demos; for accurate geodesic distanc

```
-- Times Square center ≈ (-73.9855, 40.7580)
-- Radius here is 0.02 degrees (~2.2 km in latitude for demo purposes)

postgres=# EXPLAIN ANALYZE
SELECT *
FROM locations
WHERE geolocation <@ circle '((-73.9855,40.7580), 0.02)';
```

```
postgres=#
postgres=#
postgres=# EXPLAIN ANALYZE
SELECT *
FROM locations
WHERE geolocation <@ circle '((-73.9855,40.7580), 0.02)';
                                                        QUERY PLAN
---------------------------------------------------------------------------------------------
 Bitmap Heap Scan on locations  (cost=405.93..29364.11 rows=10001 width=40) (ac
   Recheck Cond: (geolocation <@ '<(-73.9855,40.758),0.02>'::circle)
   ->  Bitmap Index Scan on idx_locations_gist  (cost=0.00..403.43 rows=10001 w
         Index Cond: (geolocation <@ '<(-73.9855,40.758),0.02>'::circle)
 Planning Time: 0.074 ms
 Execution Time: 0.041 ms
(6 rows)

postgres=
```

Step 8: K-NN nearest-neighbor with `<->` (fast top-K)

Return the **100 closest** points to Times Square:

```
EXPLAIN ANALYZE
SELECT location_id, name, geolocation
FROM locations
ORDER BY geolocation <-> POINT(-73.9855, 40.7580)
LIMIT 100;
```

```
ppostgres=# EXPLAIN ANALYZE
SELECT location_id, name, geolocation
FROM locations
ORDER BY geolocation <-> POINT(-73.9855, 40.7580)
```

```
LIMIT 100;
                                                                    QUERY PLAN
-------------------------------------------------------------------------------
 Limit  (cost=0.42..9.37 rows=100 width=48) (actual time=0.062..40.138 rows=100
   ->  Index Scan using idx_locations_gist on locations  (cost=0.42..895059.72
         Order By: (geolocation <-> '(-73.9855,40.758)'::point)
 Planning Time: 2.480 ms
 Execution Time: 40.240 ms
(5 rows)

postgres=
```

*GiST performs a **K-NN index scan**: the index returns rows in distance order — no full scan or sort over 10M rows.*

Step 9: Polygon containment (point-in-polygon)

Operator: `point <@ polygon`.

```
-- Rough 4-vertex polygon around midtown Manhattan (ill
postgres=# EXPLAIN ANALYZE
SELECT count(*)
FROM locations
WHERE geolocation <@ polygon '((-74.02,40.70),(-73.94,4
```



```
postgres=#
postgres=# EXPLAIN ANALYZE
SELECT count(*)
FROM locations
WHERE geolocation <@ polygon '((-74.02,40.70),(-73.94,40.70),(-73.94,40.80),(-7
                                                                    QUERY PLAN
-------------------------------------------------------------------------------
 Aggregate  (cost=528.44..528.45 rows=1 width=8) (actual time=0.028..0.030 rows
   ->  Index Only Scan using idx_locations_gist on locations  (cost=0.42..503.4
```

```
          Index Cond: (geolocation <@ '((-74.02,40.7),(-73.94,40.7),(-73.94,40.8
          Heap Fetches: 0
 Planning Time: 1.248 ms
 Execution Time: 0.050 ms
(6 rows)

postgres=#
```

Step 10: Verify index usage & size (quick checks)

```
postgres=# -- Is the index being used?
SELECT indexrelid::regclass AS index_name,
       idx_scan, idx_tup_read, idx_tup_fetch
FROM pg_stat_user_indexes
WHERE relid = 'locations'::regclass
ORDER BY idx_scan DESC;
```



```
postgres=# SELECT indexrelid::regclass AS index_name,
       idx_scan, idx_tup_read, idx_tup_fetch
FROM pg_stat_user_indexes
WHERE relid = 'locations'::regclass
ORDER BY idx_scan DESC;
     index_name     | idx_scan | idx_tup_read | idx_tup_fetch
--------------------+----------+--------------+---------------
 idx_locations_gist |        4 |          113 |           100
 locations_pkey     |        0 |            0 |             0
(2 rows)

postgres=#
```

```
-- Table vs. indexes size
SELECT
  pg_size_pretty(pg_relation_size('locations'))        AS table_only,
  pg_size_pretty(pg_indexes_size('locations'))         AS indexes_only,
  pg_size_pretty(pg_total_relation_size('locations'))  AS total_with_indexes;
```

```
postgres=# SELECT
  pg_size_pretty(pg_relation_size('locations'))
  pg_size_pretty(pg_indexes_size('locations'))
  pg_size_pretty(pg_total_relation_size('locations'))
 table_only | indexes_only | total_with_indexes
------------+--------------+--------------------
 722 MB     | 850 MB       | 1572 MB
(1 row)

postgres=#
```



```
postgres=# -- Individual index size
SELECT
  indexrelid::regclass AS index_name,
  pg_size_pretty(pg_relation_size(indexrelid)) AS index_size
FROM pg_index
WHERE indrelid = 'locations'::regclass
ORDER BY pg_relation_size(indexrelid) DESC;
```

```
postgres=# SELECT
  indexrelid::regclass AS index_name,
  pg_size_pretty(pg_relation_size(indexrelid)) AS index_size
FROM pg_index
WHERE indrelid = 'locations'::regclass
ORDER BY pg_relation_size(indexrelid) DESC;
     index_name     | index_size
--------------------+------------
 idx_locations_gist | 635 MB
 locations_pkey     | 214 MB
(2 rows)

postgres=#
```

Step 11: Notes specific to GiST (kept focused)

- **CLUSTER is not supported on GiST.** GiST has no natural
  `... USING gist_index` is not allowed. (Use B-tree if you ne
- **K-NN requires** `<->` and a GiST operator class that suppor
  datatype (`point_ops` does).
- **ANALYZE** keeps selectivity estimates accurate. After larg
  `ANALYZE locations;`
- For **online index builds** on production:

```
CREATE INDEX CONCURRENTLY idx_locations_gist ON locations USING gist (geolocati
```

Summary

- **Workload:** 10M points in `locations(geolocation POINT)` .

- **Before GiST:** Parallel Seq Scan for spatial filters (seconds).
- **After GiST:** Bitmap Index Scans for **box/circle/polygon** (tens of ms) and **K-NN** index scans for **nearest-neighbor** (single-digit ms for top-K).
- **PostgreSQL 17:** Same syntax, mature GiST operator classes for built-in geometry.

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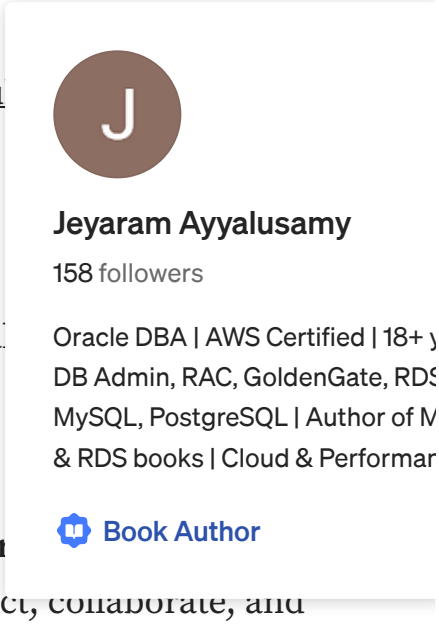

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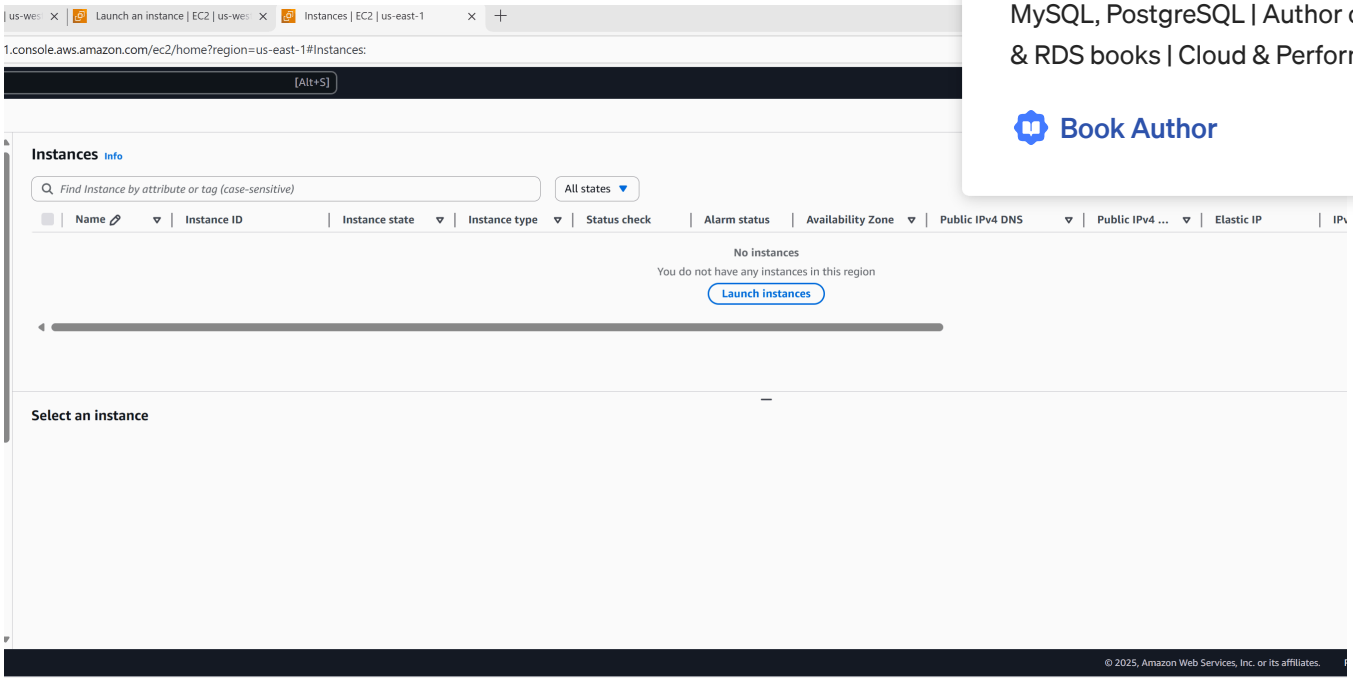

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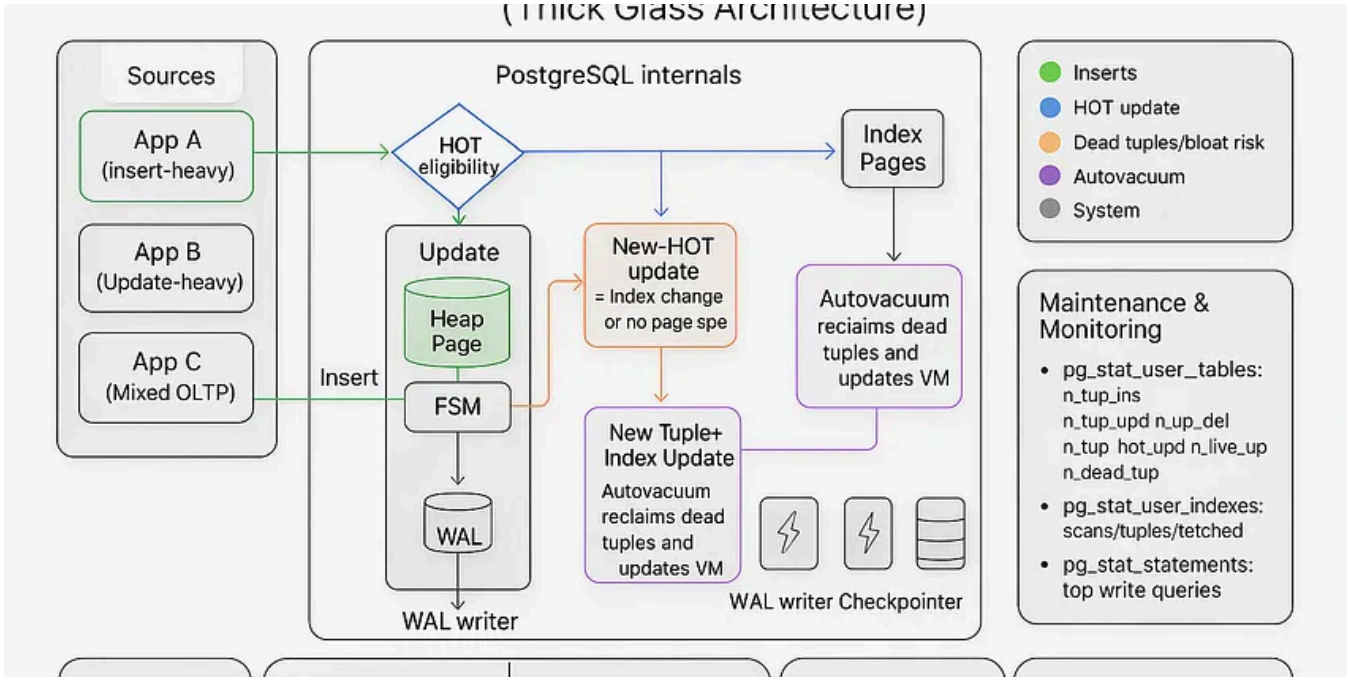

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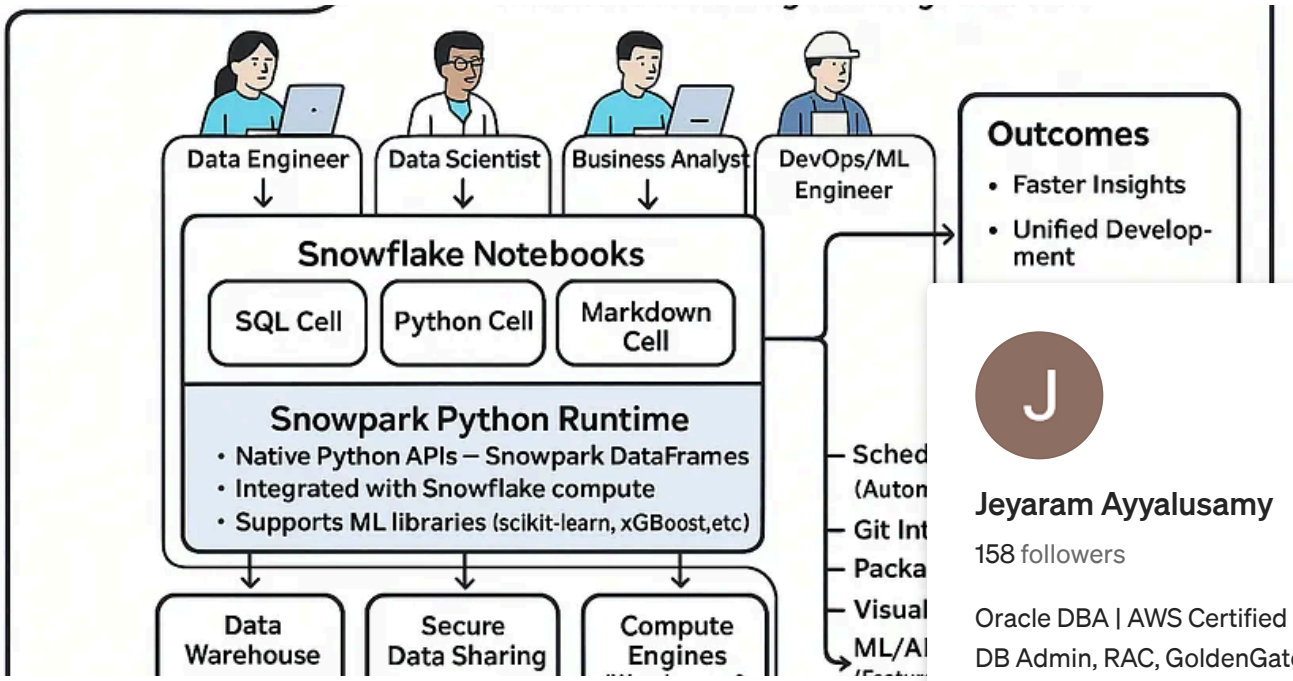

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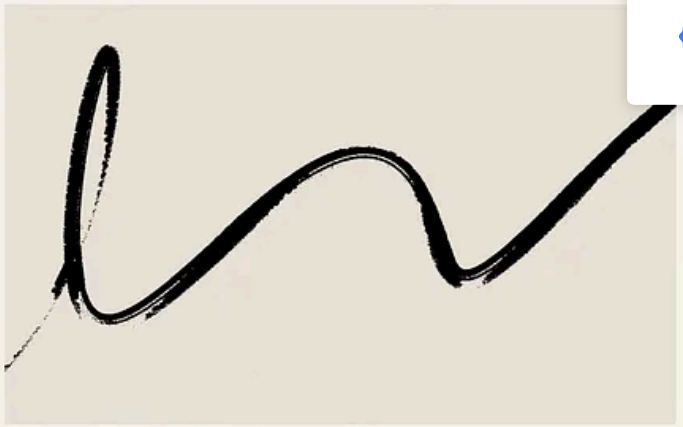

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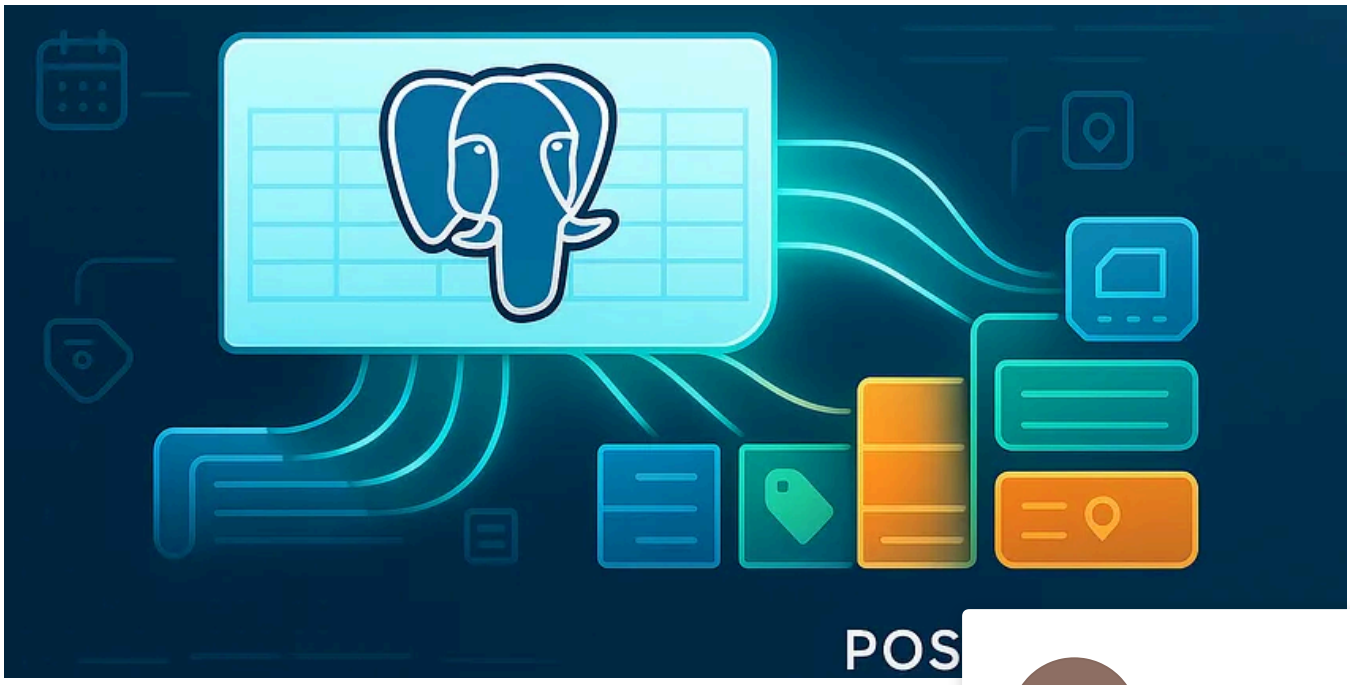

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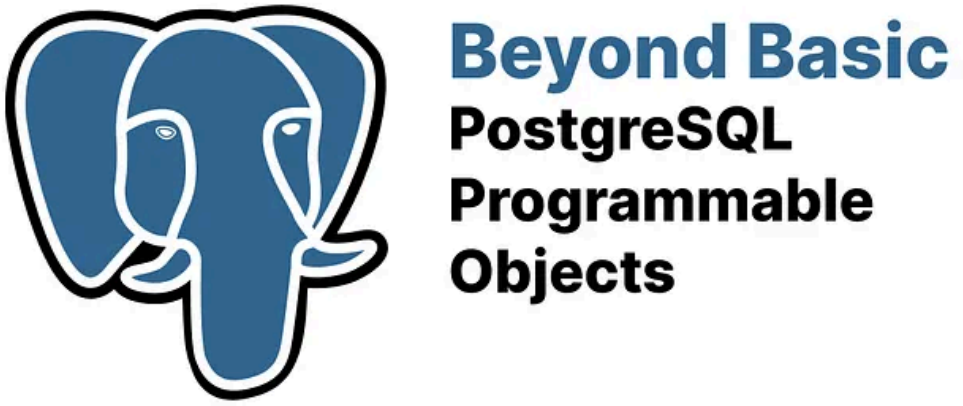

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