PERCONA

PostgreSQL for MySQL DBAs

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PostgreSQL for MySQL DBAs

MySQL might be the most popular database on the internet but PostgreSQL is the only top database in the DB Engine Rankings gaining market share.

The good news is that if you know MySQL then you have a good base from which to explore PostgreSQL.

We will start with a simple installation, account creation, loading data, and some simple queries.

Then we will explore the very cool differences and how to exploit them.

Expand your skills in this talk!

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QUIZ TIME!!!!!!

QUIZ - Name the database!

Open Source Database

Over 25 years old (original implementation)

Sworn by or sworn at for standards compliance issues

Active user community

Growing in popularity - Db Engine Ranks

Invented by a man named Michael who has very definite views on many subjects

Who Am I

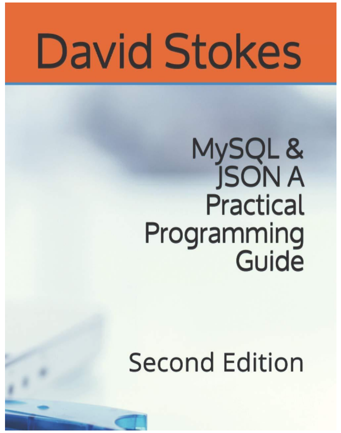
I am Dave Stokes

Technology Evangelist at Percona

Author of *MySQL & JSON - A Practical Programming Guide*

Over a decade on the Oracle MySQL Community Team

Started with MySQL 3.29



David Stokes

MySQL & JSON A Practical Programming Guide

Second Edition

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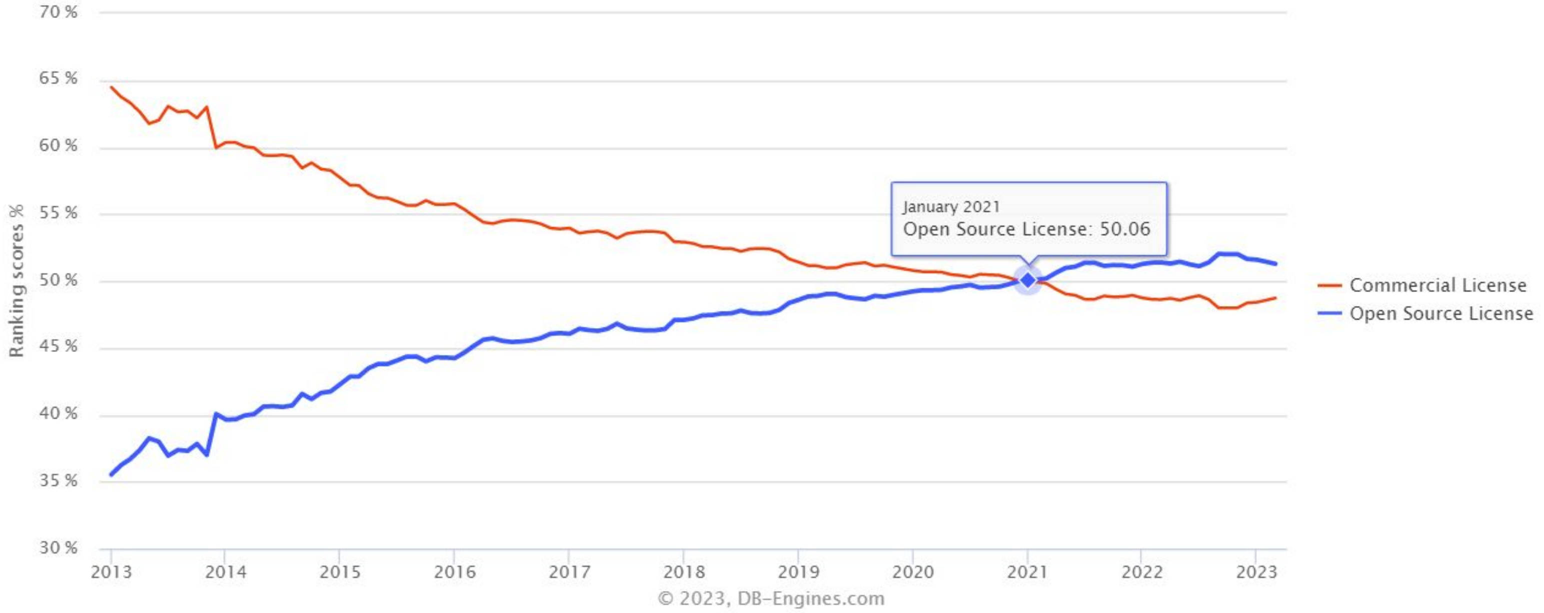
https://db-engines.com/en/ranking_osvsc

Popularity trend



The above chart shows the historical trend of the popularity of open source and commercial database management systems.

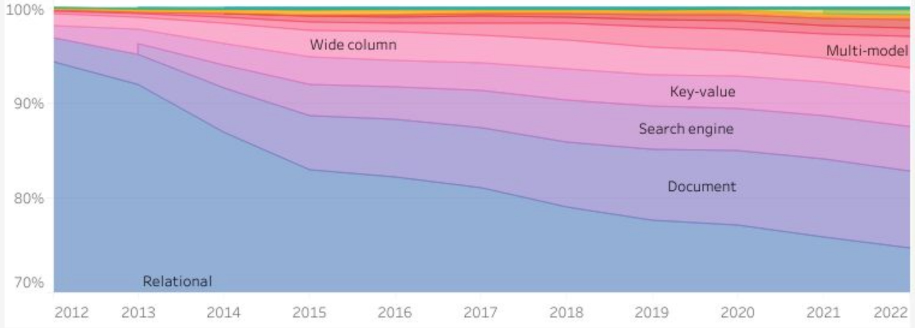
ARCHITECTURE & PERFORMANCE

DB-Engines Trends

DB-ENGINES

Relational	Document	Search engine	Key-value	Wide column	Multi-model	Graph	Time Series	Multivalue	Null	Object orient..	Spatial DBMS	Content	RDF	Navigational	Native XML	Search	Event
🟦	🟪	🟪	🟪	🟥	🟥	🟥	🟥	🟧	🟨	🟧	🟩	🟨	🟩	🟩	🟩	🟦	🟦

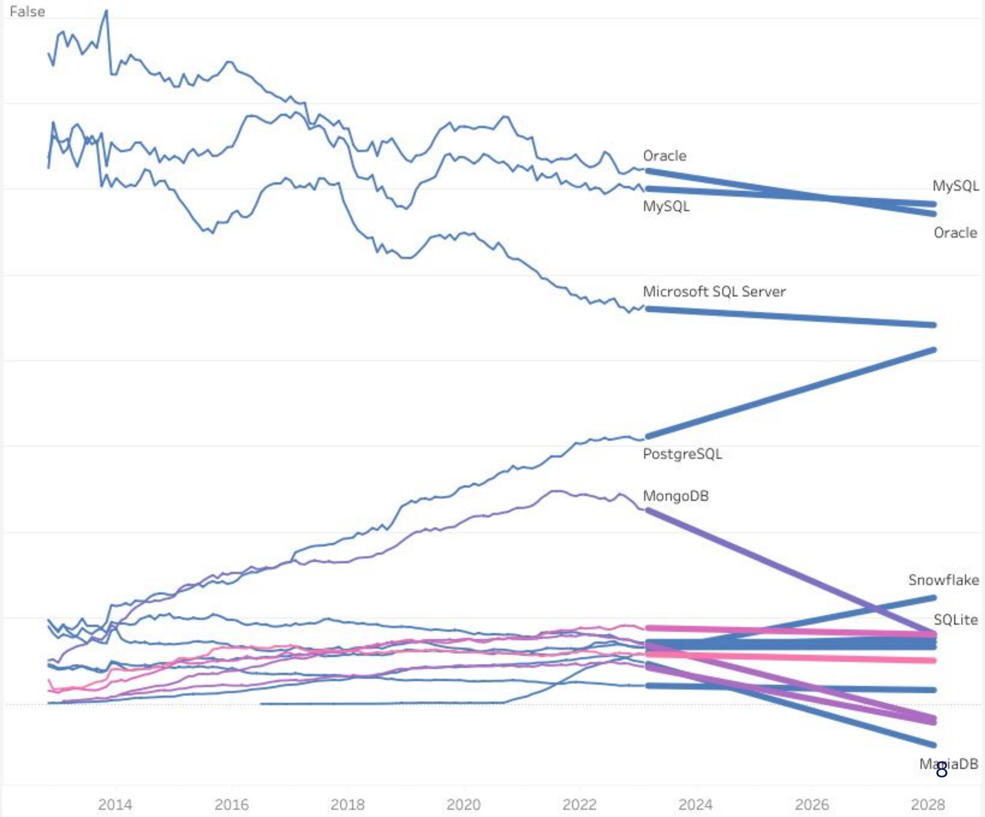
Score Evolution Per Type (warning : Y-Axis root at 70%)



Evolution Per Database and Forecast (Top 15 Db for All DBTypes)

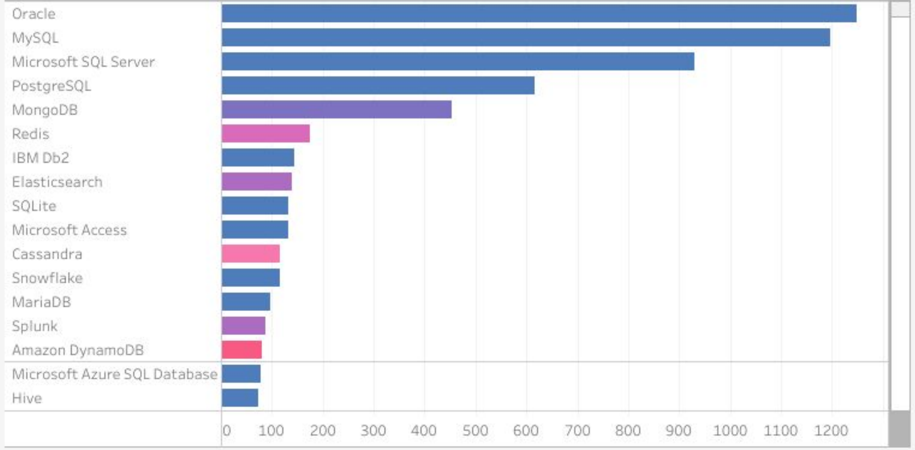
TopX
15

Log Scale
False



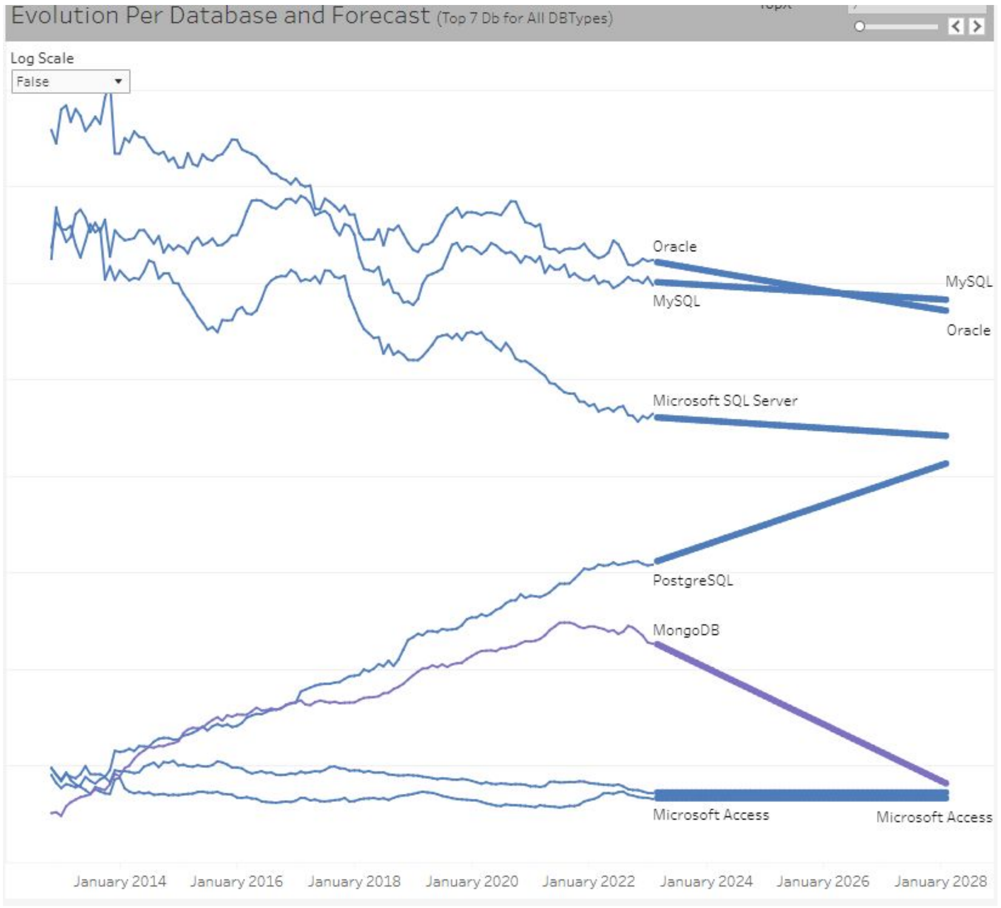
Database Engine Score for February 2023

February 2023



Projected Trends

Yikes!



PG Features

Some cool stuff not found in MySQL

PostgreSQL has some interesting stuff not in MySQL

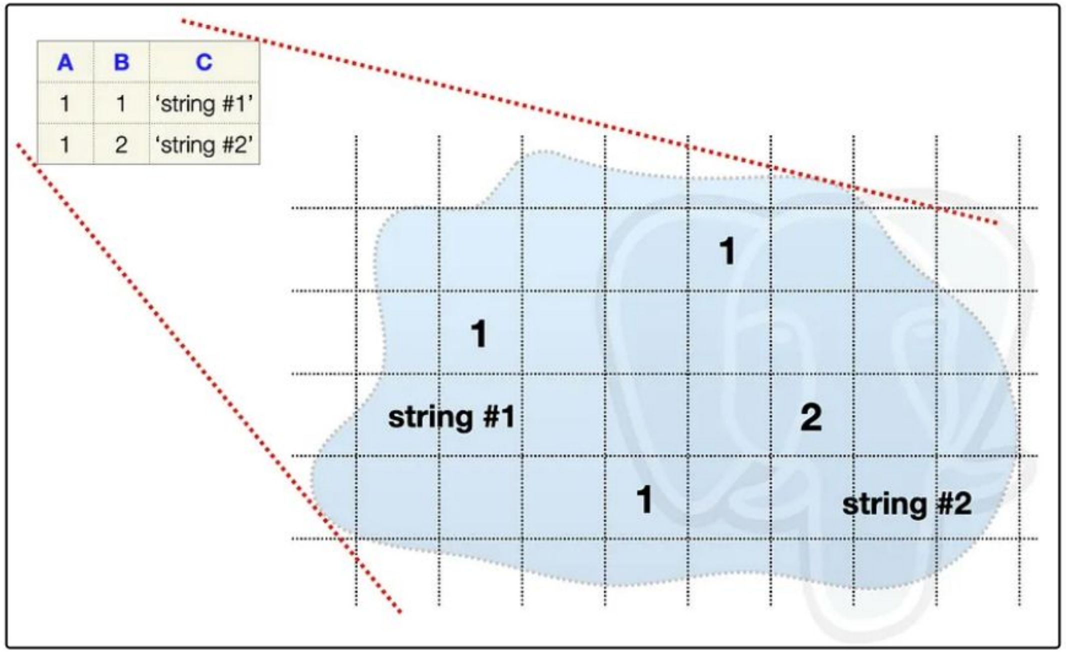
- Materialized Views
- MERGE() – process transactions logs, like from cash registers, as a batch rather than multiple round trips between application and database
- TWO JSON data types
- Many different types of indexes
  - Ability to index only parts of an index
  - Can 'roll your own'
- Better SQL standard compliance
  - More complete Window Functions
  - Sequences
    - Similar to MySQL AUTO_INCREMENT
    - Great for building test data
- Basis for many projects
  - FerretDB - MongoDB protocol
  - Pg_vector - You do not need a specialized vector database
- Harder to setup and run
  - Upgrades can be tricky

PostgreSQL’s Heap

Multiversion Concurrency Control

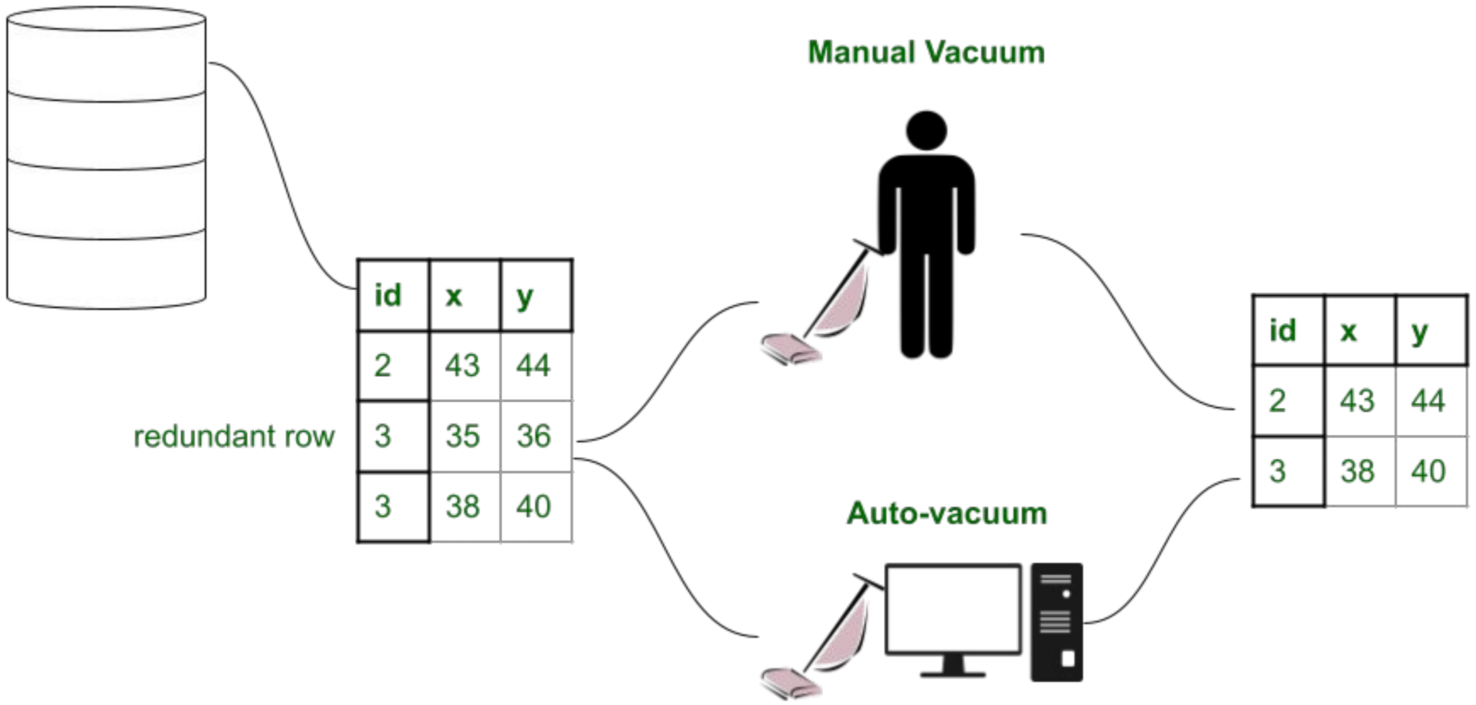
The Heap - https://medium.com/quadcode-life/structure-of-heap-table-in-postgresql-d44c94332052

- Tuples (rows) are stored in a heap by object identifier (OID)
- Data is unordered (use order by)
- Updated/replaced rows are kept in the heap until vacuumed (more later)
- The OID is a 32 bit INTEGER that can wrap around and make older data useless



A	B	C
1	1	'string #1'
1	2	'string #2'

Vacuum - https://www.geeksforgeeks.org/postgresql-autovacuum/



PostgreSQL

First Steps

First steps

Load whichever PG you want and get dvdrental.tar from https://www.postgresqltutorial.com/wp-content/uploads/2019/05/dvdrental.zip

```
$sudo su - postgres
$psql
postgresql=# CREATE DATABASE dvdrental;
postgresql=# exit;
#pgrestore -U postgres -d dvdrental dvdrental.tar
```

(still as user 'postgres')

```
$createuser –interactive -s <user>
```

The -s is for superuser

Yup this is dangerous as superuser bypasses some checks but remember you candidate is an experienced DBA (or should be)

Back in the <user> account

```
$psql -d dvdrental
dvdrental=#
```

\d commands

```
dvdrental=# \dt
             List of relations
 Schema |      Name       | Type  |  Owner
--------+-----------------+-------+----------
 public | actor           | table | postgres
 public | address         | table | postgres
 public | category        | table | postgres
 public | city            | table | postgres
 public | country         | table | postgres
 public | customer        | table | postgres
 public | film            | table | postgres
 public | film_actor      | table | postgres
 public | film_category   | table | postgres
 public | inventory       | table | postgres
 public | language        | table | postgres
 public | payment         | table | postgres
 public | rental          | table | postgres
 public | staff           | table | postgres
 public | store           | table | postgres
(15 rows)
```

The Sakila database has been used in the MySQL arena for a very long time in documentation, exams, blogs, and more.

This database is very similar.

There is no `SHOW CREATE TABLE`

```
dvdrental=# show create table actor;

ERROR:  syntax error at or near "create"

LINE 1: show create table actor;

             ^

dvdrental=# \d actor;
                                                         Table "public.actor"
   Column    |            Type             | Collation | Nullable |                 Default
-------------+-----------------------------+-----------+----------+------------------------------------------
 actor_id    | integer                     |           | not null | nextval('actor_actor_id_seq'::regclass)
 first_name  | character varying(45)       |           | not null |
 last_name   | character varying(45)       |           | not null |
 last_update | timestamp without time zone |           | not null | now()
Indexes:
    "actor_pkey" PRIMARY KEY, btree (actor_id)
    "idx_actor_last_name" btree (last_name)
Referenced by:
    TABLE "film_actor" CONSTRAINT "film_actor_actor_id_fkey" FOREIGN KEY (actor_id) REFERENCES actor(actor_id) ON
UPDATE CASCADE ON DELETE RESTRICT
Triggers:
    last_updated BEFORE UPDATE ON actor FOR EACH ROW EXECUTE FUNCTION last_updated()
```

Simple queries work as expected

```
dvdrental=# SELECT *
            FROM actor
            ORDER BY last_name, first_name
            LIMIT 10;
 actor_id | first_name | last_name |      last_update
----------+------------+-----------+-----------------------
       58 | Christian  | Akroyd    | 2013-05-26 14:47:57.62
      182 | Debbie     | Akroyd    | 2013-05-26 14:47:57.62
       92 | Kirsten    | Akroyd    | 2013-05-26 14:47:57.62
      118 | Cuba       | Allen     | 2013-05-26 14:47:57.62
      145 | Kim        | Allen     | 2013-05-26 14:47:57.62
      194 | Meryl      | Allen     | 2013-05-26 14:47:57.62
       76 | Angelina   | Astaire   | 2013-05-26 14:47:57.62
      112 | Russell    | Bacall    | 2013-05-26 14:47:57.62
      190 | Audrey     | Bailey    | 2013-05-26 14:47:57.62
       67 | Jessica    | Bailey    | 2013-05-26 14:47:57.62
(10 rows)
```

Simple backup

```
$ pg_dump dvdrental > backup.sql
```

- pg_dump is the name of the 'backup' program
- dvdrental is name of the database to be backed up
- Dumping the output to file backup.sql

Equivalent to mysqldump

Simple restore

```
$ sudo su - postgres
$ psql
(psql 14.3 (Ubuntu 2:14.3-3-focal))
Type "help" for help.
dvdrental=# CREATE DATABASE newdvd;
dvdrental=# \q
$ ^d
```

```
$ psql -d newdvd -f backup.sql
```

Cheat Sheet

\c dbname	Switch connection to a new database
\l	List available databases
\dt	List available tables
\d table_name	Describe a table such as a column, type, modifiers of columns, etc.
\dn	List all schemes of the currently connected database
\df	List available functions in the current database
\dv	List available views in the current database
\du	List all users and their assign roles
SELECT version();	Retrieve the current version of PostgreSQL server
\g	Execute the last command again
\s	Display command history
\s filename	Save the command history to a file
\i filename	Execute psql commands from a file
\?	Know all available psql commands
\h	Get help Eg:to get detailed information on ALTER TABLE statement use the \h ALTER TABLE
\e	Edit command in your own editor
\a	Switch from aligned to non-aligned column output
\H	Switch the output to HTML format
\q	Exit psql shell

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Goodbye AUTO_INCREMENT, Hello SERIAL data type

Small Serial	2 bytes	1 to 32,767
Serial	4 bytes	1 to 2,147,483,647
Big Serial	8 bytes	1 to 9,223,372,036,854,775,807

Yup, MySQL has a SERIAL (`BIGINT UNSIGNED NOT NULL AUTO_INCREMENT UNIQUE)` but it is a) not widely used, b) will end up creating two indexes if also declared as the PRIMARY KEY.

Sneaking in sequences!

```
dvdrental=# CREATE SCHEMA test;
CREATE SCHEMA
dvdrental=# \c test
You are now connected to database "test" as user "percona".
test=# CREATE TABLE x (x SERIAL, y CHAR(20), z CHAR(20));
CREATE TABLE
test=# \d x
                                   Table "public.x"
 Column |      Type      | Collation | Nullable |           Default
--------+----------------+-----------+----------+------------------------------
 x      | integer        |           | not null | nextval('x_x_seq'::regclass)
 y      | character(20)  |           |          |
 z      | character(20)  |           |          |
```

Demo

```
test=# INSERT INTO X (y,z) VALUES (100,200),(300,450);
INSERT 0 2
test=# SELECT * FROM x;
 x |          y            |          z
---+-----------------------+-----------------------
 1 | 100                   | 200
 2 | 300                   | 450
(2 rows)
```

INSERT replies with the ***oid*** and the ***count***.
The ***`count`*** is the number of rows inserted or updated. ***`oid`*** is always 0

Values of ‘x’ generated by server

Table & Sequence created by create table

```
test=# \d
           List of relations
 Schema |  Name    |   Type    |  Owner
--------+----------+-----------+----------
 public | x        | table     | percona
 public | x_x_seq  | sequence  | percona
```

Basic Sequences

```
test=# CREATE SEQUENCE order_id START 1001;
CREATE SEQUENCE
test=# SELECT NEXTVAL('order_id');
 nextval
---------
    1001
(1 row)
```

Using nextval()

```
INSERT INTO
   order_details(order_id, item_id, product_name, price)
VALUES
   (100, nextval('order_item_id'), 'DVD Player', 100),
   (100, nextval('order_item_id'), 'Android TV', 550),
   (100, nextval('order_item_id'), 'Speaker', 250);
```

Versus a series

```
test=# create table test1 as (select generate_series(1,100) as id);
SELECT 100
test=# \d test1
               Table "public.test1"
 Column |  Type   | Collation | Nullable | Default
--------+---------+-----------+----------+---------
 id     | integer |           |          |


test=# select * from test1 limit 5;
 id
----
  1
  2
  3
  4
  5
(5 rows)
```

Fun with *wrapping* sequences

```
test=# create sequence wrap_seq as int minvalue 1 maxvalue 2 CYCLE;
CREATE SEQUENCE
test=# select NEXTVAL('wrap_seq');
 nextval
---------
       1
(1 row)

test=# select NEXTVAL('wrap_seq');
 nextval
---------
       2
(1 row)

test=# select NEXTVAL('wrap_seq');
 nextval
---------
       1
(1 row)

test=# select NEXTVAL('wrap_seq');
 nextval
---------
       2
(1 row)
```

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Checking the details on sequences

```
test=# \d order_id;
                          Sequence "public.order_id"
  Type   | Start | Minimum |       Maximum        | Increment | Cycles? | Cache
--------+-------+---------+----------------------+-----------+---------+-------
 bigint |  1001 |       1 | 9223372036854775807 |         1 | no      |     1


test=# \d wrap_seq;
                    Sequence "public.wrap_seq"
  Type    | Start | Minimum | Maximum | Increment | Cycles? | Cache
---------+-------+---------+---------+-----------+---------+-------
 integer |     1 |       1 |       2 |         1 | yes     |     1
```

\ds - list sequences

```
dvdrental=#  \ds
                     List of relations
 Schema |               Name            |   Type    |  Owner
--------+-------------------------------+-----------+----------
 public | actor_actor_id_seq            | sequence | postgres
 public | address_address_id_seq        | sequence | postgres
 public | category_category_id_seq      | sequence | postgres
 public | city_city_id_seq              | sequence | postgres
 public | country_country_id_seq        | sequence | postgres
 public | customer_customer_id_seq      | sequence | postgres
 public | film_film_id_seq              | sequence | postgres
 public | inventory_inventory_id_seq | sequence | postgres
 public | language_language_id_seq      | sequence | postgres
 public | payment_payment_id_seq        | sequence | postgres
 public | rental_rental_id_seq          | sequence | postgres
 public | staff_staff_id_seq            | sequence | postgres
 public | store_store_id_seq            | sequence | postgres
(13 rows)
```

Using Explain

Query tuning can be tough to learn

Explaining EXPLAIN - MySQL edition

```
SQL > EXPLAIN SELECT Name FROM City WHERE District='Texas' ORDER BY Name\G
*************************** 1. row ***************************
           id: 1
  select_type: SIMPLE
        table: City
   partitions: NULL
         type: ALL
possible_keys: NULL
          key: NULL
      key_len: NULL
          ref: NULL
         rows: 4188
     filtered: 10
        Extra: Using where; Using filesort
1 row in set, 1 warning (0.0011 sec)
Note (code 1003): /* select#1 */ select `world`.`city`.`Name` AS `Name` from
`world`.`city` where (`world`.`city`.`District` = 'Texas') order by
`world`.`city`.`Name`
```

Test data

```
test=# CREATE TABLE t1 (id SERIAL PRIMARY KEY);
CREATE TABLE
test=# INSERT INTO t1 SELECT GENERATE_SERIES(1,100000);
INSERT 0 100000
test=# CREATE TABLE t2 (id INT NOT NULL);
CREATE TABLE
test=# INSERT INTO t2 SELECT GENERATE_SERIES(1,100000);
INSERT 0 100000
test=#
```

With and without index - Ignore the ANALYZE for now

```
test=# EXPLAIN (ANALYZE) SELECT 1 FROM t2 WHERE ID=101;    #NO Index
                                          QUERY PLAN
-----------------------------------------------------------------------------------------------
 Seq Scan on t2  (cost=0.00..1693.00 rows=1 width=4) (actual time=0.019..5.641 rows=1 loops=1)
   Filter: (id = 101)
   Rows Removed by Filter: 99999
 Planning Time: 0.054 ms
 Execution Time: 5.658 ms
(5 rows)
test=# EXPLAIN (ANALYZE) SELECT 1 FROM t1 WHERE ID=101;    #YES Index
                                                   QUERY PLAN
----------------------------------------------------------------------------------------------------
-------------
 Index Only Scan using t1_pkey on t1  (cost=0.29..4.31 rows=1 width=4) (actual time=0.090..0.091
rows=1 loops=1)
   Index Cond: (id = 101)
   Heap Fetches: 0
 Planning Time: 0.469 ms
 Execution Time: 0.110 ms
```

This is a good comparison of timings

Options in parens new to a MySQL DBA

And no YAML or XML output

Learning to read the output of EXPLAIN

```
dvdrental=# explain SELECT title, first_name, last_name
dvdrental-# FROM film f
dvdrental-# INNER JOIN film_actor fa ON f.film_id=fa.film_id
dvdrental-# INNER JOIN actor a ON fa.actor_id=a.actor_id;
                    QUERY PLAN
------------------------------------------------------------------------
 Hash Join  (cost=83.00..196.65 rows=5462 width=28)
   Hash Cond: (fa.actor_id = a.actor_id)
   ->  Hash Join  (cost=76.50..175.51 rows=5462 width=17)
         Hash Cond: (fa.film_id = f.film_id)
         ->  Seq Scan on film_actor fa  (cost=0.00..84.62 rows=5462 width=4)
         ->  Hash  (cost=64.00..64.00 rows=1000 width=19)
               ->  Seq Scan on film f  (cost=0.00..64.00 rows=1000 width=19)
   ->  Hash  (cost=4.00..4.00 rows=200 width=17)
         ->  Seq Scan on actor a  (cost=0.00..4.00 rows=200 width=17)
(9 rows)
```

Connections

MySQL has a series of threads

PostgreSQL needs to fork a new process

There are connection poolers available

Vacuum

`VACUUM` reclaims storage occupied by dead tuples*.

In normal PostgreSQL operation, tuples that are deleted or obsoleted by an update are not physically removed from their table; they remain present until a `VACUUM` is done.

Therefore it's necessary to do `VACUUM` periodically, especially on frequently-updated tables.
-PG Documentation

MySQL uses as difference MVCC approach that automatically takes care of dead tuples and vacuuming will seem very odd to a MySQL DBA

A **tuple** is **PostgreSQL's internal representation of a row in a table**.

VACUUM and AUTOVACUUM

PostgreSQL's VACUUM command has to process each table on a regular basis for several reasons:

- To recover or reuse disk space occupied by updated or deleted rows.
- To update data statistics used by the PostgreSQL query planner.
- To update the visibility map, which speeds up index-only scans.
- To protect against loss of very old data due to transaction ID wraparound or multixact ID wraparound.

```
test=# create table foo (id int, value int);
CREATE TABLE

test=# insert into foo values (1,1);
INSERT 0 1

test=# update foo set value=2 where id =1;
UPDATE 1
test=# update foo set value=3 where id =1;
UPDATE 1
test=# update foo set value=4 where id =1;
UPDATE 1

test=# select relname, n_dead_tup from pg_stat_all_tables where relname = 'foo';
 relname | n_dead_tup
---------+------------
 foo     |          3
(1 row)
```

Using VACUUM

```
test=# VACUUM foo;
VACUUM
test=# select relname, n_dead_tup from pg_stat_all_tables where relname = 'foo';
 relname | n_dead_tup
---------+------------
 foo     |          0
(1 row)
```

Visibility Map

Vacuum maintains a visibility map for each table to keep track of **which pages** contain only tuples that **are known to be visible to all active transactions** (and all future transactions, until the page is again modified).

This has two purposes.

- vacuum itself can skip such pages on the next run, since there is nothing to clean up.
- Second, it allows PostgreSQL to answer some queries using only the index, without reference to the underlying table.

  Since PostgreSQL indexes don't contain tuple visibility information, a normal index scan fetches the heap tuple for each matching index entry, to check whether it should be seen by the current transaction. **An index-only scan, on the other hand, checks the visibility map first.** If it's known that all tuples on the page are visible, the heap fetch can be skipped. This is most useful on large data sets where the visibility map can prevent disk accesses.

  The visibility map is vastly smaller than the heap, so it can easily be cached even when the heap is very large.

Transaction ID Wraparound

32-bit transaction ID - Much Too Small

XIDs can be viewed as lying on a circle or circular buffer. As long as the end of that buffer does not jump past the front, the system will function correctly.

To prevent running out of XIDs and avoid wraparound, the vacuum process is also responsible for “freezing” row versions that are over a certain age (tens of millions of transactions old by default).

However, there are failure modes which prevent it from freezing extremely old tuples and the oldest unfrozen tuple limits the number of past IDs that are visible to a transaction (only two billion past IDs are visible).

If the remaining XID count reaches one million, the database will stop accepting commands and must be restarted in single-user mode to recover. Therefore, it is extremely important to monitor the remaining XIDs so that your database never gets into this state.

Wrap Around XIDs

PostgreSQL's MVCC transaction semantics depend on being able to compare transaction ID (XID) numbers: a row version with an insertion XID greater than the current transaction XID is “in the future” and should not be visible to the current transaction.

XIDs have limited size of 32 bits so a cluster that runs for a long time (more than 4 billion transactions) would suffer transaction ID wraparound

- XID counter wraps around to zero
- transactions that were in the past appear to be in the future — which means their output become invisible. In short, catastrophic data loss.

To avoid this, it is **necessary to vacuum every table in every database at least *once every two billion transactions***.

Caveats

Plain **VACUUM** (without FULL) simply reclaims space and makes it available for re-use.

- This form of the command can operate in parallel with normal reading and writing of the table, as an exclusive lock is not obtained.
- However, extra space is not returned to the operating system (in most cases); it's just kept available for re-use within the same table.

It also allows us to leverage multiple CPUs in order to process indexes.

- This feature is known as parallel vacuum.

VACUUM FULL rewrites the entire contents of the table into a new disk file with no extra space, allowing unused space to be returned to the operating system.

- This form is much slower and requires an ACCESS EXCLUSIVE lock on each table while it is being processed.

Autovacuum

PostgreSQL has an optional but highly recommended feature called **autovacuum**, whose purpose is to automate the execution of VACUUM and ANALYZE commands.

```
test=# SHOW autovacuum;
 autovacuum
------------
 on
(1 row)
```

Write-heavy applications can exceed autovacuum's ability to clean up, so you need to pay attention!

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Don’t forget these tools too!

REINDEX

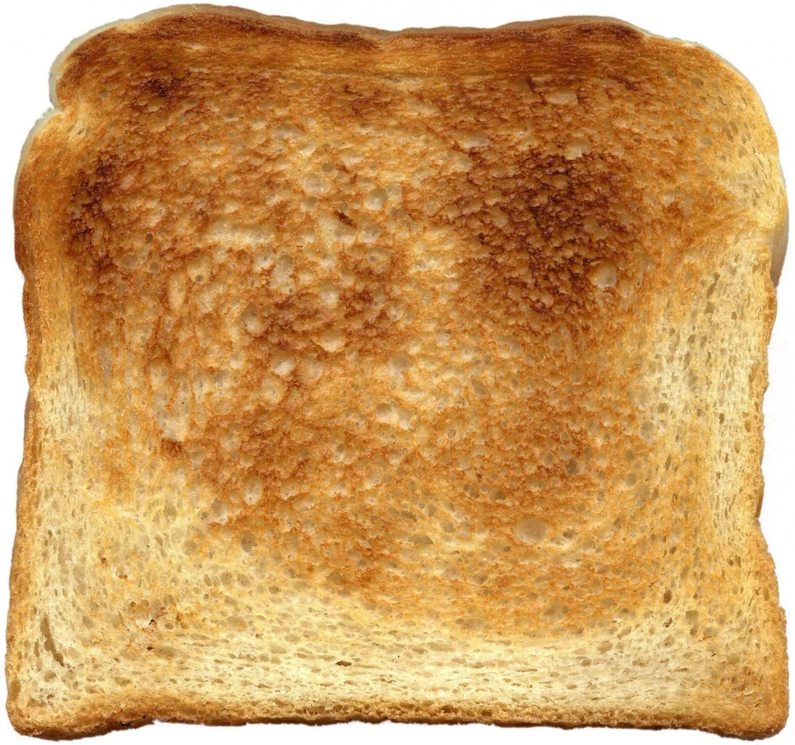
CLUSTER

VACUUM FULL

pg_repack

TOAST

The Oversized-Attribute Storage Technique – similar to what InnoDB does when data is too long for a row.



Use Roles

Yes, MySQL has roles but they are not that popular.

PostgreSQL Basics: Roles and Privileges

https://www.red-gate.com/simple-talk/databases/postgresql/postgresql-basics-roles-and-privileges/

PostgreSQL Basics: Object Ownership and Default Privileges

https://www.red-gate.com/simple-talk/uncategorized/postgresql-basics-object-ownership-and-default-privileges/

Wow Factor

The Things a MySQL DBA will be impressed by

FILTER

```
SELECT
  fa.actor_id,
  SUM(length) FILTER (WHERE rating = 'R'),
  SUM(length) FILTER (WHERE rating = 'PG')
FROM film_actor AS fa
LEFT JOIN film AS f
  ON f.film_id = fa.film_id
GROUP BY fa.actor_id
```

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Materialized Views

```
test=# create materialized view v2 as SELECT a, b, c*4 from base;
SELECT 3
test=# select * from v2 where a > 6;
a | b | ?column?
---+---+----------
7 | 8 | 36
(1 row)
```

```
test=# refresh materialized view v2;
REFRESH MATERIALIZED VIEW
```

Index Types

B-tree
Hash
GiST
SP-GiST
GIN
BRIN

Each index type uses a different algorithm that is best suited to different types of queries.

By default, the `CREATE INDEX` command creates B-tree indexes.

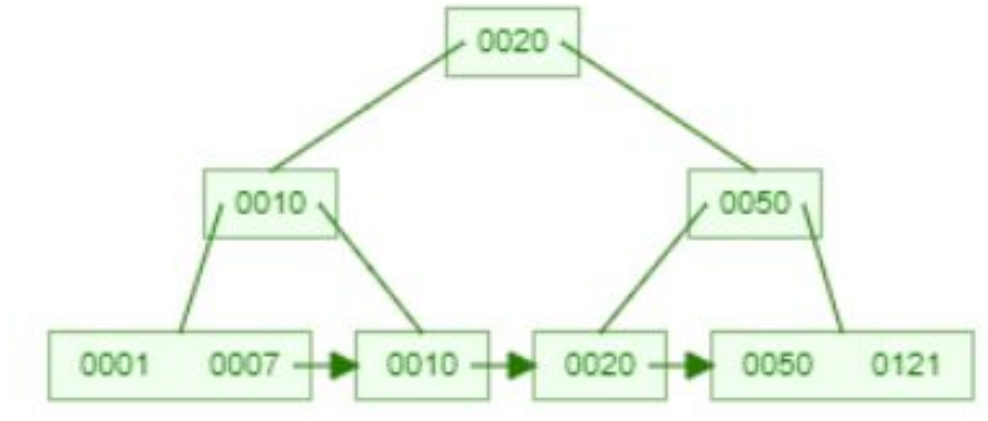
https://www.cs.usfca.edu/~galles/visualization/BPlusTree.html

B+ Trees are great for binary and range searches.

Yup, same as MySQL

(more or less)

The DEFAULT type of index



An Example

```
test=# CREATE TABLE staff (id) as SELECT 'Employee' || x FROM generate_series(1,500) as g(x);
SELECT 500
test=# CREATE INDEX staff_id ON staff(id);
CREATE INDEX
test=# EXPLAIN (verbose) SELECT * FROM staff WHERE id='Employee101';
                              QUERY PLAN
---------------------------------------------------------------------------------
 Index Only Scan using staff_id on public.staff  (cost=0.27..8.29 rows=1 width=11)
   Output: id
   Index Cond: (staff.id = 'Employee101'::text)
(3 rows)
```

A Bad Example

```
test=# EXPLAIN (verbose) SELECT * FROM staff WHERE lower(id)='emp101';
                     QUERY PLAN
----------------------------------------------------------
 Seq Scan on public.staff  (cost=0.00..10.50 rows=2 width=6)
   Output: id
   Filter: (lower(staff.id) = 'emp101'::text)
(3 rows)
```

The optimizer does not recognize lower(id) as matching an existing index!

A Bad Example Fixed

```
test=# CREATE INDEX staff_id_lc ON staff(lower(id));
CREATE INDEX
test=# EXPLAIN (verbose) SELECT * FROM staff WHERE lower(id)='emp101';
                        QUERY PLAN
--------------------------------------------------------------------
 Bitmap Heap Scan on public.staff  (cost=4.29..7.42 rows=2 width=6)
   Output: id
   Recheck Cond: (lower(staff.id) = 'emp101'::text)
   ->  Bitmap Index Scan on staff_id_lc  (cost=0.00..4.29 rows=2 width=0)
         Index Cond: (lower(staff.id) = 'emp101'::text)
(5 rows)
```

Now it recognizes it!

Bitmapped Index Scans are used when:

Used when:

- an index lookup might generate multiple hits on the same heap (data) page
- using multiple indexes for a single query is useful

Creates a bitmap of matching entries in memory

Row or block-level granularity

Bitmap allows heap pages to be visited only once for multiple matches

Bitmap can merge the results from several indexes with AND/OR filtering

Automatically enabled by the optimizer

YEA!

Hash

Hash indexes store a 32-bit hash code derived from the value of the indexed column.

Hashes can only handle simple equality comparisons.

The query planner will consider using a hash index whenever an indexed column is involved in a comparison using the **equal operator**

GiST or Generalized Search Tree

GiST is an infrastructure within which many different tree based indexing strategies can be implemented.

GIST Indexes are not a single kind of index

Some of the contributed models:

- **rtree_gist, btree_gist** - GiST implementation of R-tree and B-tree
- **intarray** - index support for one-dimensional array of int4's
- **tsearch2** - a searchable (full text) data type with indexed access
- **ltree** - data types, indexed access methods and queries for data organized as a tree-like structures
- **hstore** - a storage for (key,value) data
- **cube** - data type, representing multidimensional cubes

GiST

GiST indexes are also capable of optimizing “nearest-neighbor” searches, such as

```
SELECT * FROM places
       ORDER BY location <-> point '(101,456)'
       LIMIT 10;
```

This will find the ten places closest to a given target point.

GiST

Supports data types with loosely-coupled values, like tsvector, JSONB

Uniquely supports data types with tightly-coupled values •
- multi-dimensional types (geographic)
- range types
- IP network data type

SP-GiST

SP-GiST indexes, like GiST indexes, offer an infrastructure that supports various kinds of searches. SP-GiST permits implementation of a wide range of different non-balanced disk-based data structures, such as quadtrees, k-d trees, and radix trees (tries).

As an example, the standard distribution of PostgreSQL includes SP-GiST operator classes for two-dimensional points, which support indexed queries using these operators:

What SP-GiST are supported on your system?

```
test=# SELECT opfname
         FROM pg_opfamily, pg_am
         WHERE opfmethod = pg_am.oid
         AND amname = ’spgist’
         ORDER BY opfname;
   opfname
----------------
 box_ops
 kd_point_ops
 network_ops
 poly_ops
 quad_point_ops
 range_ops
 text_ops
(7 rows)
```

GIN

GIN indexes are “inverted indexes” which are appropriate for data values that contain multiple component values, such as arrays.

Think text or JSON

SImilar to MySQL’s multi-valued indexes. Key stored once w/ many row pointers

BRIN or Block Range INdexes

BRIN indexes store summaries about the values stored in consecutive physical block ranges of a table.

Thus, they are most effective for columns whose values are well-correlated with the physical order of the table rows. If the data is truly random, or if there is much churn of the key values in a 'hot' database, the assumptions underlying BRIN may break down

Like GiST, SP-GiST and GIN, BRIN can support many different indexing strategies, and the particular operators with which a BRIN index can be used vary depending on the indexing strategy.

For data types that have a linear sort order, the indexed data corresponds to the minimum and maximum values of the values in the column for each block range.

This supports indexed queries using these operators: < <= = >= >

BRIN Features

- Tiny indexes designed for large tables
- Minimum/maximum values stored for a range of blocks (default 1MB, 128 8k pages)
- Allows skipping large sections of the table that cannot contain matching values
- Ideally for naturally-ordered tables, e.g., insert-only tables are chronologically ordered
- Index is 0.003% the size of the heap
- Indexes are inexpensive to update
- Index every column at little cost
- Slower lookups than B-tree

Note that BRIN index size is in kb not MB

```
test=# create table demo as SELECT generate_series(1,1000000) as x;
SELECT 1000000
test=# create index btree_idx on demo(x);
CREATE INDEX
test=# create index brin_idx on demo using brin(x);
CREATE INDEX
test=# SELECT relname, pg_size_pretty(pg_relation_size(oid))
       FROM pg_class WHERE relname LIKE 'brin_%' OR relname = 'btree_idx'
       ORDER BY relname;
      relname       | pg_size_pretty
--------------------+-----------------
 brin_idx           | 24 kB
 brin_random_x      | 24 kB
 btree_idx          | 21 MB
```

Remember

B-tree is ideal for unique values

BRIN is ideal for the indexing of many columns

GIN is ideal for indexes with many duplicates

SP-GIST is ideal for indexes whose keys have many duplicate prefixes

GIST for everything else

Index part of column & Function Indexes

```
CREATE INDEX title_idx ON articles (title) WHERE published = true;

CREATE INDEX title_idx ON articles (lower(title));
```

Find unused indexes

```
SELECT s.relname,
       s.indexrelname,
       pg_relation_size(s.indexrelid) AS index_size
FROM pg_stat_user_indexes s
JOIN pg_catalog.pg_index i ON s.indexrelid = i.indexrelid
WHERE s.idx_scan = 0 AND 0 <>ALL (i.indkey)
AND NOT i.indisunique AND NOT EXISTS (SELECT 1 FROM pg_catalog.pg_constraint c
WHERE c.conindid = s.indexrelid)
ORDER BY pg_relation_size(s.indexrelid) DESC;
```

Duplicate indexes

```
SELECT pg_size_pretty(sum(pg_relation_size(idx))::bigint) as size,
       (array_agg(idx))[1] as idx1,
       (array_agg(idx))[2] as idx2
FROM ( SELECT indexrelid::regclass as idx, (indrelid::text ||E'\n'|| indclass::text ||E'\n'||
indkey::text ||E'\n'|| coalesce(indexprs::text,'')||E'\n' || coalesce(indpred::text,'')) as key
FROM pg_index) sub
GROUP BY key HAVING count(*) > 1
ORDER BY sum(pg_relation_size(idx)) DESC;
```

Suggested Reading On PG Indexes

https://momjian.us/main/writings/pgsql/indexing.pdf

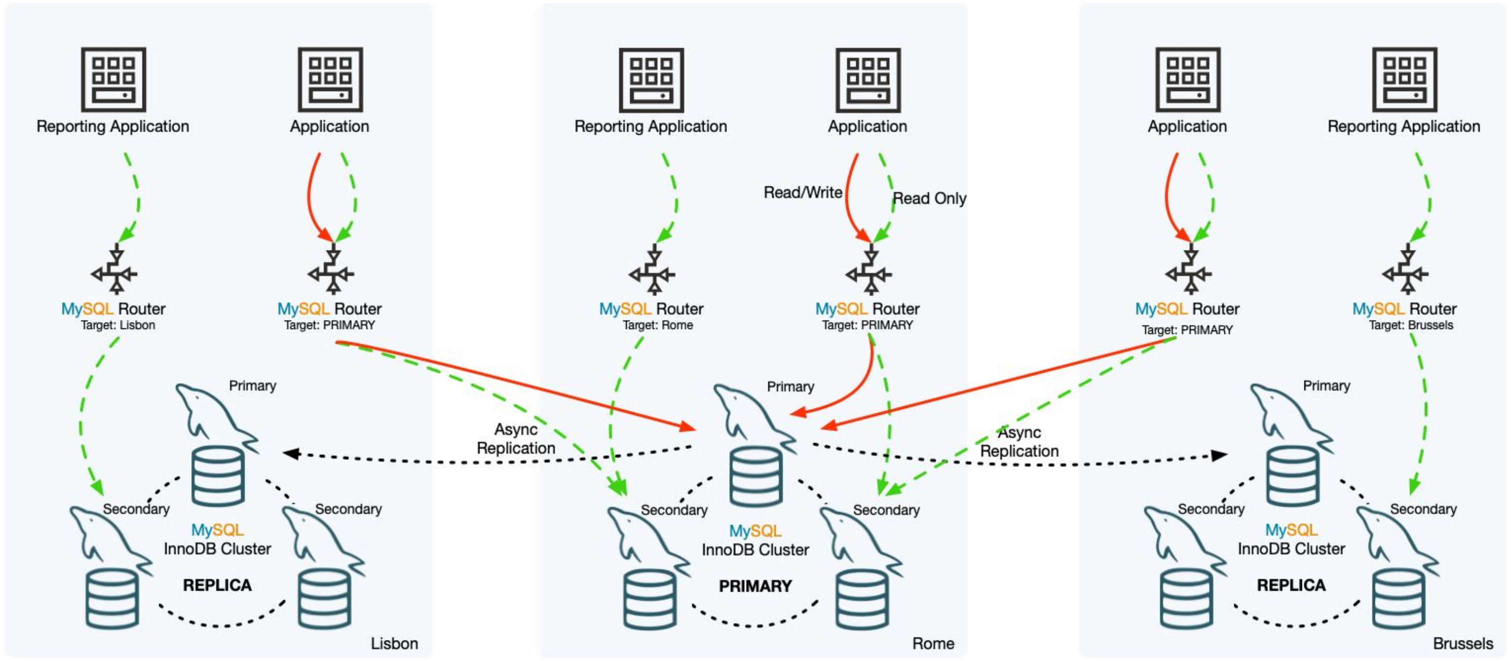
https://www.postgresql.org/docs/current/indexes-types.html

OMGHDWSHTPI2023*

Oh My Goodness How Do We Still Have This Problem In 2023?

Replication

No open source equivalent to InnoDB Cluster or even Galera



Need for connection pooling - multi-process versus multi-threading

For later learning …

https://www.youtube.com/watch?v=S7jEJ9o9o2o

https://www.highgo.ca/2021/03/20/how-to-check-and-resolve-bloat-in-postgresql/

https://onesignal.com/blog/lessons-learned-from-5-years-of-scaling-postgresql/

https://www.postgresql.org/docs/

https://www.scalingpostgres.com/

https://psql-tips.org/psql_tips_all.html

“It is different”

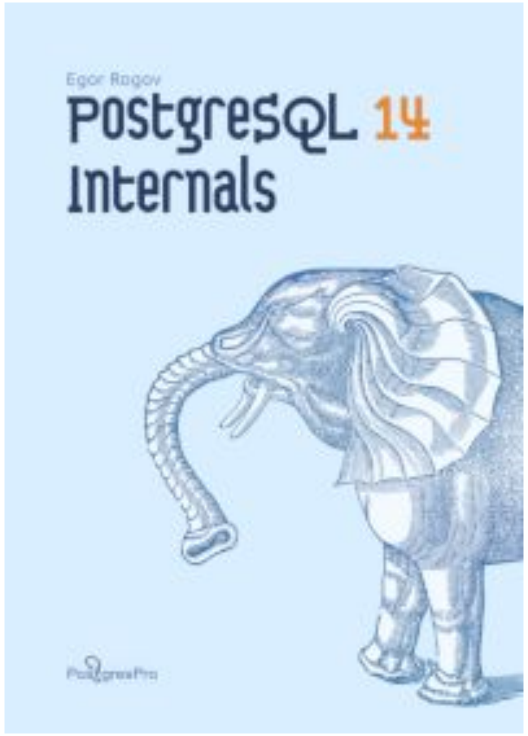
Different != Better

https://postgrespro.com/community/books/internals

This book is for those who will not settle for a black-box approach when working with a database.

Briefly touching upon the main concepts of PostgreSQL, the book then plunges into the depths of data consistency and isolation, explaining implementation details of multiversion concurrency control and snapshot isolation, buffer cache and write-ahead log, and the locking system.

The rest of the book covers the questions of planning and executing SQL queries, including the discussion of data access and join methods, statistics, and various index types.



Links

https://ottertune.com/blog/the-part-of-postgresql-we-hate-the-most/

https://philbooth.me/blog/nine-ways-to-shoot-yourself-in-the-foot-with-postgresql

https://neon.tech/blog/quicker-serverless-postgres

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Thank You!

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