Introduction to PostgreSQL for Oracle and MySQL DBAs

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History of PostgreSQL

Ingres

Year 1973 - INGRES (INteractive GRaphics Retrieval System), work on one of the world's first RDBMS was Started by Eugene Wong and Michael Stonebraker at University of California at Berkeley.

Year 1979 - Oracle Database first version was released.

Early 1980’s - INGRES used QUEL as its preferred Query Language. Whereas Oracle used SQL. Ingres lost its Market dominance to Oracle as it was too late for IngreS to adopt SQL as a Preferred Query Language as opposed to QUEL.

Year 1985 - UC Berkeley INGRES research project officially ended.

Postgres

Year 1986 - Postgres was introduced as a Post-Ingres evolution aimed to incorporate ORDBMS. Postgres used POSTQUEL as its query language until 1994

Year 1995 - Postgres95 replaced Postgres with its support for SQL as a query language. - Andrew Yu and Jolly Chen(PhD students from Stonebraker’s lab).

PostgreSQL

Year 1996 - Project renamed to PostgreSQL to reflect the original name Postgres and its SQL Compatibility.

Year 1997 - PostgreSQL first version - PostgreSQL 6.0 released.

PostgreSQL Features

- Portable
  - Written in C
  - Flexible across all the UNIX platforms, Windows, MacOS and others.
  - World’s most advanced open source database. Community driven.
  - ANSI/ISO Compliant SQL support.

- Reliable
  - ACID Compliant
  - Supports Transactions
  - Uses Write Ahead Logging

- Scalable
  - MVCC
  - Table Partitioning
  - Tablespaces
  - FDWs
  - Sharding

PostgreSQL Advanced Features

- Security
  - Host-Based Access Control
  - Object-Level and Row-Level Security
  - Logging and Auditing
  - Encryption using SSL
- High Availability
  - Synchronous/Asynchronous Replication and Delayed Standby
  - Cascading Replication
  - Online Consistent Physical Backups and Logical Backups
  - PITR
- Other Features
  - Triggers and Functions/Stored Procedures
  - Custom Stored Procedural Languages like PL/pgSQL, PL/perl, PL/TCL, PL/php, PL/python, PL/java.
  - PostgreSQL Major Version Upgrade using pg_upgrade
  - Unlogged Tables
  - Materialized Views
  - Hot Standby - Slaves accept Reads

PostgreSQL Cluster

- After Initializing your PostgreSQL using initdb (similar to mysqld --initialize) and starting it, you can create multiple databases in it.
- A group of databases running on one Server & One Port - Is called a Cluster in PostgreSQL.
- PostgreSQL Cluster may be referred to as a PostgreSQL Instance as well.
- A PostgreSQL Cluster or an Instance :
  - Serves only one TCP/IP Port
  - Has a Dedicated Data Directory
  - Contains 3 default databases : postgres, template0 and template1.
- When you add a Slave(aka Standby) to your PostgreSQL Cluster(Master), it may be referred to as a PostgreSQL High Availability Cluster or a PostgreSQL Replication Cluster.
- PostgreSQL Cluster that can accept Writes and ships WALs to Slave(Standby), is called a Master.

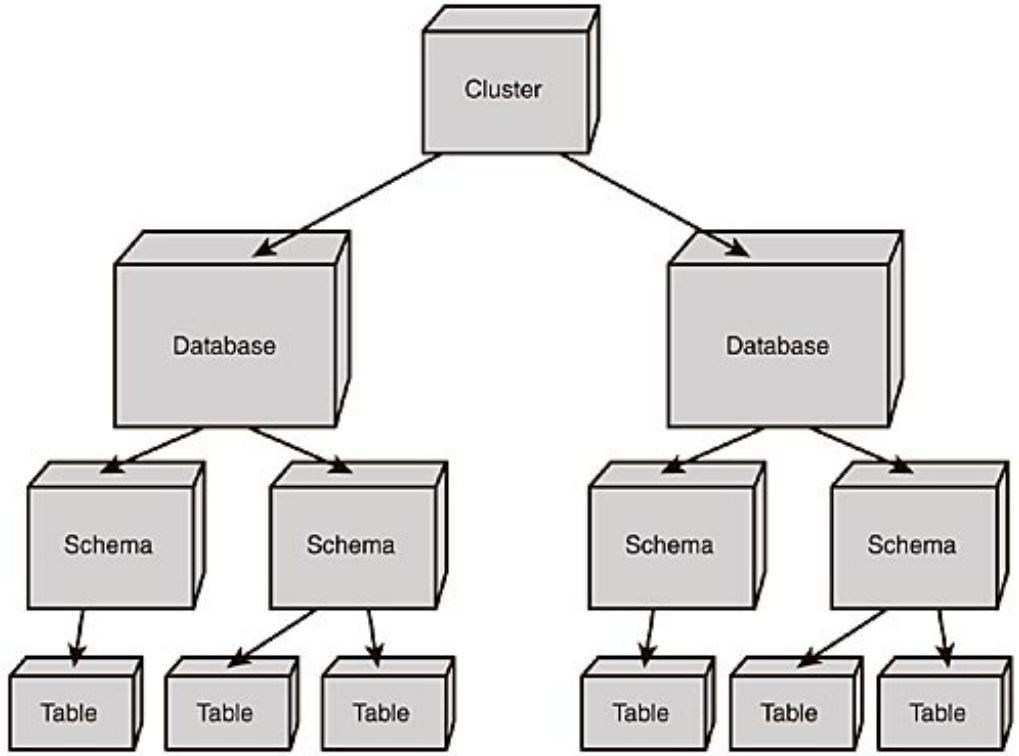
PostgreSQL Database & Schema

- A PostgreSQL Database can contain one or more Schemas. Default Schema is - public schema.
- A Schema is a logical entity used to group objects together. An example : A Folder/Directory that contains Tables, Index and other objects as files.
- A Database can be related to a Parent Folder/Directory that contains one or more Schemas.
- You can always have more than 1 Database with one or more Schemas in it.
- A Schema in PostgreSQL helps you group objects of a certain Application logic together. This helps you create multiple objects with the same name in one Database.

For example : In a Database named percona, A Table employee can exist in both full_time and contractor schemas.

Database : percona
Schema(s) : scott & tiger
Tables : 1. scott.employee
2. tiger.employee

- A Fully Qualified Table Name : schemaname.tablename must be used to query a particular Table in a Schema.
For example :
select * from scott.employee where salary > 10000;



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PostgreSQL ACID Compliance

- **Atomicity** : Transactions. Either All or Nothing.

  BEGIN …SQL1, SQL2, …SQLn…..COMMIT/ROLLBACK/END.

- **Consistency** : Give me a consistent picture of the data based on Isolation Levels.
  Let us see the following example when Isolation Level is READ_COMMITTED

  Query 1 : select count(*) from employees;

  9am : Records in employee table : 10000
  9:10 am : Query 1 Started by User 1
  9:11am : 2 employee records deleted by User 2.
  9:12am : Query 1 that was started by User 1 Completed.

  Result of Query 1 at 9:12am would still be 10000. A Consistent image as how it was at 9:00am.

- **Isolation** : Prevent Concurrent data access through Locking.

- **Durability** : Once the Data is committed, it must be safe.
  Through WAL's, fsync, synchronous_commit, Replication.

PostgreSQL Terminology

- PostgreSQL was designed in academia
  - Objects are defined in academic terms
  - Terminology based on relational calculus/algebra

Industry Term	PostgreSQL Term
Table/Index	Relation
Row	Tuple
Column	Attribute
Data Block	Page (when block is on disk)
Page	Buffer (when block is in memory)

Client Architecture

Applications connect to Database and send SQL's to interact with the Database. Client-side APIs are needed

to send SQL's and receive the results.

- **libpq** :
  - C application programmer's interface to PostgreSQL.
  - libpq is is a set of library functions that allow client programs to pass queries to the PostgreSQL backend server and to receive the results of these queries.
  - Along with C, other PostgreSQL application interfaces such as C++, Perl, Python, Tcl and ECPG uses libpq.

- **JDBC** :
  - Java, Client side API

PostgreSQL Installation

PostgreSQL Installation using rpm's on RedHat/CentOS/OEL - we did this for you in your VM

PGDG Repository : PostgreSQL Global Development Group maintains YUM and APT repository of PostgreSQL for the linux platforms. One of the most easiest and the desired methods is to install PostgreSQL using rpm's from PGDG repo.

For YUM
https://yum.postgresql.org

For APT
https://apt.postgresql.org/pub/repos/apt/

Step 1 :

Choose the appropriate rpm that adds pgdg repo to your server. Please make sure to choose the desired PostgreSQL version and the OS version appropriately. Install the pgdg repo rpm using YUM.

yum install https://yum.postgresql.org/11/redhat/rhel-7.5-x86_64/pgdg-centos11-11-2.noarch.rpm

Step 2 :

Install PostgreSQL using the following step.

yum install postgresql11 postgresql11-contrib postgresql11-libs postgresql11-server

Clone the virtual machine shared with you

Initialize your first PostgreSQL Cluster

- We use **initdb** to Initialize a PostgreSQL cluster

```
$echo "PATH=/usr/pgsql-11/bin:$PATH">>~/.bash_profile
$source .bash_profile

$echo $PGDATA
/var/lib/pgsql/11/data

$initdb --version
initdb (PostgreSQL) 11.0

$initdb
```

```
avi@percona:~ $initdb
The files belonging to this database system will be owned by user "postgres".
This user must also own the server process.

The database cluster will be initialized with locale "en_CA.UTF-8".
The default database encoding has accordingly been set to "UTF8".
The default text search configuration will be set to "english".

Data page checksums are disabled.

fixing permissions on existing directory /var/lib/pgsql/11/data ... ok
creating subdirectories ... ok
selecting default max_connections ... 100
selecting default shared_buffers ... 128MB
selecting dynamic shared memory implementation ... posix
creating configuration files ... ok
running bootstrap script ... ok
performing post-bootstrap initialization ... ok
syncing data to disk ... ok

WARNING: enabling "trust" authentication for local connections
You can change this by editing pg_hba.conf or using the option -A, or
--auth-local and --auth-host, the next time you run initdb.

Success. You can now start the database server using:

    pg_ctl -D /var/lib/pgsql/11/data -l logfile start
```

Starting and Stopping PostgreSQL

- PostgreSQL can be stopped and started from command line using pg_ctl.
  - **Starting PostgreSQL**
    - *pg_ctl -D $PGDATA start*
  - **Stopping PostgreSQL**
    - *pg_ctl -D $PGDATA stop*

Shutdown Modes in PostgreSQL

- PostgreSQL Cluster supports various shutdown modes which has its own advantages and disadvantages and can be used according to the need that arises.

- **-ms (Smart Mode - Default mode)**
  - Waits for all connections to exist and does not allow new transactions.
  - Ensures that the committed transactions are applied to Disk through a CHECKPOINT before shutdown.
  - May take more time on busy systems

  $ pg_ctl -D $PGDATA stop -ms

- **-mf (Fast Mode - Recommended on Busy Systems)**
  - Closes/Kills all the open transactions and does not allow new transactions. SIGTERM is sent to server processes to exit promptly.
  - Ensures that the committed transactions are applied to Disk through a CHECKPOINT before shutdown.
  - Recommended on Busy Systems

  $ pg_ctl -D $PGDATA stop -mf

- **-mi (Immediate Mode - Forced and Abnormal Shutdown during Emergencies)**
  - SIGQUIT is sent to all the processes to exit immediately, without properly shutting down.
  - Requires Crash Recovery after Instance Start.
  - Recommended in Emergencies.

  $ pg_ctl -D $PGDATA stop -mi

Connecting to PostgreSQL and the shortcuts using backslash commands

- Connect to your PostgreSQL using psql
  - *$ psql*

    List the databases

    \l
    \l + (Observe the difference)

    To connect to your database

    \c dbname

    List Objects

    \dt -> List all the tables
    \dn -> List all the schemas

  - ***Show all backslash (shortcut) commands***

    \?

PostgreSQL Architecture

PostgreSQL Server

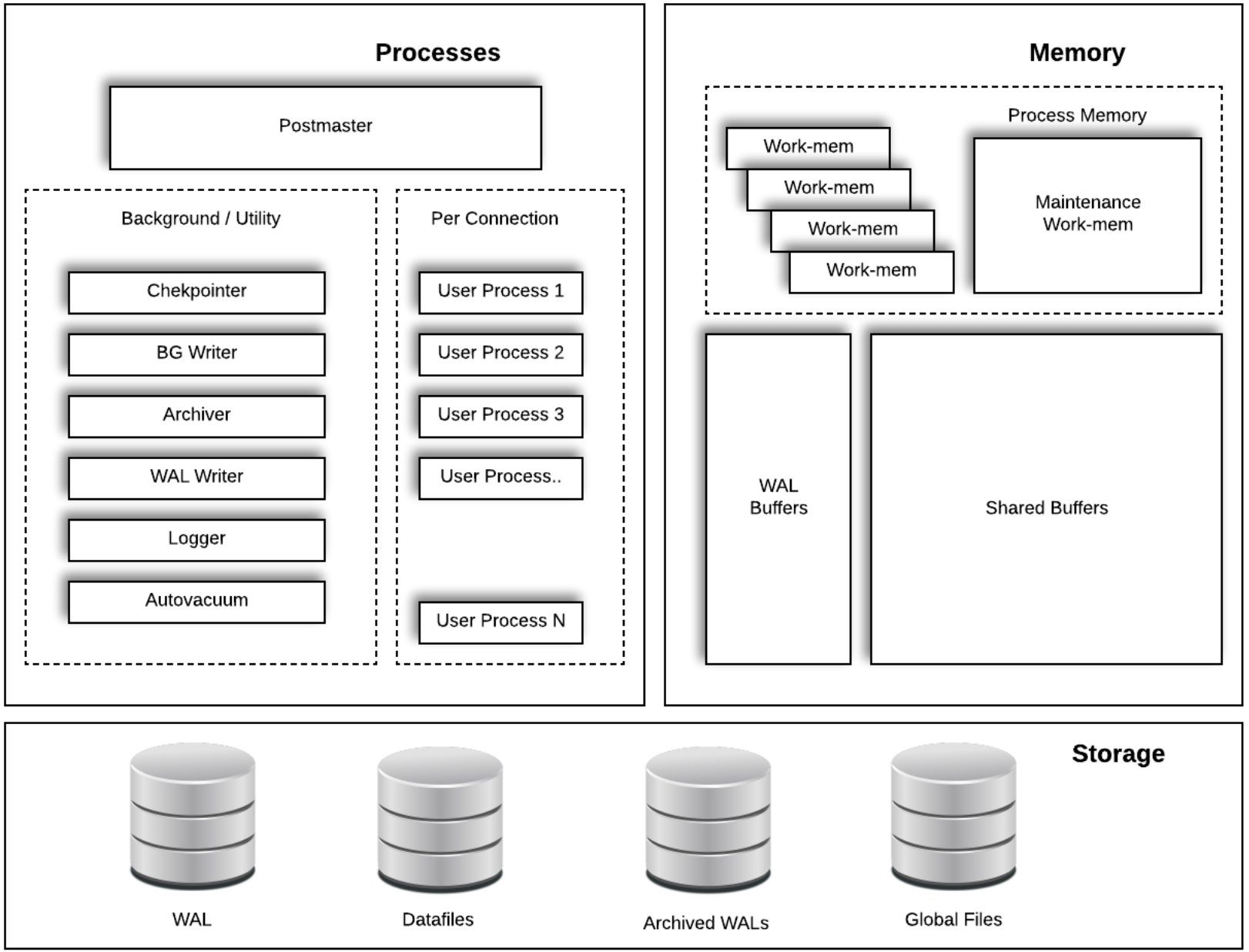
Multi-Process Architecture.

- Postmaster (Parent PostgreSQL Process)
- Backend Utility Processes
- Per-Connection backend processes
- Every Connection is a Process.

Background Utility Processes

Start your PostgreSQL Instance and see the postgres processes

```
avi@percona:~ $ps -eaf | grep postgres
postgres  1211     1  0 12:57 ?        00:00:00 /usr/pgsql-11/bin/postgres -D /var/lib/pgsql/11/data
postgres  1212  1211  0 12:57 ?        00:00:00 postgres: logger
postgres  1214  1211  0 12:57 ?        00:00:00 postgres: checkpointer
postgres  1215  1211  0 12:57 ?        00:00:00 postgres: background writer
postgres  1216  1211  0 12:57 ?        00:00:00 postgres: walwriter
postgres  1217  1211  0 12:57 ?        00:00:00 postgres: autovacuum launcher
postgres  1218  1211  0 12:57 ?        00:00:00 postgres: stats collector
postgres  1219  1211  0 12:57 ?        00:00:00 postgres: logical replication launcher
```



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Process Components

- **Postmaster :**
  - Master database control process.
  - Responsible for startup & shutdown
  - Spawning other necessary backend processes
- **Postgres backend :**
  - Dedicated, per-connection server process
  - Responsible for fetching data from disk and communicating with the client

Utility Processes

- **BGWriter :**
  - Background Writer
  - Writes/Flushes dirty data blocks to disk
- **WAL Writer :**
  - Writes WAL Buffers to Disk.
  - WAL Buffers are written to WALs(Write-Ahead Logs) on the Disk.
- **Autovacuum :**
  - Starts Autovacuum worker processes to start a vacuum and analyze
- **Checkpointer :**
  - Perform a CHECKPOINT that ensures that all the changes are flushed to Disk
  - Depends on configuration parameters.

Utility Processes (Cont.d)

- **Archiver :**
  - Archives Write-Ahead-Logs
  - Used for High Availability, Backups, PITR
- **Logger :**
  - Logs messages, events, error to syslog or log files.
  - Errors, slow running queries, warnings,..etc. are written to log files by this Process.
- **Stats Collector :**
  - Collects statistics of Relations.
  - Similar to ANALYZE in MySQL

Utility Processes (Cont.d)

- **WAL Sender :**
  - Sends WALs to Replica(s).
  - One WAL Sender for each Slave connected for Replication.
- **WAL Receiver :**
  - Started on a Slave(aka Standby or Replica) in Replication
  - Streams WALs from Master
- **bgworker :**
  - PostgreSQL is extensible to run user-supplied code in separate processes that are monitored by Postgres.
  - Such processes can access PostgreSQL's shared memory area
  - Connect as a Client using libpq
- **bgworker: logical replication launcher**
  - Logical Replication between a Publisher and a Subscriber

Memory Components

- **Shared Buffers**
  - PostgreSQL Database Memory Area
  - Shared by all the Databases in the Cluster
  - Pages are fetched from Disk to Shared Buffers during Reads/Writes
  - Modified Buffers are also called as Dirty Buffers
  - Parameter : *shared_buffers* sets the amount of RAM allocated to shared_buffers
  - Uses LRU Algorithm to flush less frequently used buffers.
  - Dirty Buffers written to disk after a CHECKPOINT.
- **WAL Buffers :**
  - Stores Write Ahead Log Records
  - Contains the change vector for a buffer being modified.
  - WAL Buffers written to WAL Segments(On Disk).
- **work_mem :**
  - Memory used by each Query for internal sort operations such as ORDER BY and DISTINCT.
  - Postgres writes to disk(temp files) if memory is not sufficient.

Memory Components (Cont.d)

- **maintenance_work_mem**
  - Amount of RAM used by VACUUM, CREATE INDEX, REINDEX like maintenance operations.
  - Setting this to a bigger value can help in faster database restore.

PostgreSQL is not Direct IO

- When it needs a Page(Data Block), it searches it’s own memory aka Shared Buffers.
- If not found in shared buffers, it will request the OS for the same block.
- The OS fetches the block from the Disk and gives it to Postgres, if the block is not found in OS Cache.
- More important to Caching when Database and Active Data set cannot fit in memory.

Disk Components

- **Data Directory**
  - In MySQL, Data Directory is created when you initialize your MySQL Instance.
  - Initialized using **initdb** in PostgreSQL. Similar to mysqld --initialize
  - Contains Write-Ahead-Logs, Log Files, Databases, Objects and other configuration files.
  - You can move WAL's and Logs to different directories using symlinks and parameters.
  - Environment Variable : $PGDATA
- **Configuration Files inside the Data Directory**
  - postgresql.conf (Similar to my.cnf file for MySQL).
  - Contains several configurable parameters.
  - pg_ident.conf
  - pg_hba.conf
  - postgresql.auto.conf

What's inside the Data Directory ?

```
avi@percona:~ $ls -l $PGDATA
total 48
drwx------. 5 postgres postgres    41 Oct 30 13:54 base
drwx------. 2 postgres postgres  4096 Oct 30 13:54 global
drwx------. 2 postgres postgres     6 Oct 30 13:54 pg_commit_ts
drwx------. 2 postgres postgres     6 Oct 30 13:54 pg_dynshmem
-rw-------. 1 postgres postgres  4513 Oct 30 13:54 pg_hba.conf
-rw-------. 1 postgres postgres  1636 Oct 30 13:54 pg_ident.conf
drwx------. 4 postgres postgres    68 Oct 30 13:54 pg_logical
drwx------. 4 postgres postgres    36 Oct 30 13:54 pg_multixact
drwx------. 2 postgres postgres    18 Oct 30 13:54 pg_notify
drwx------. 2 postgres postgres     6 Oct 30 13:54 pg_replslot
drwx------. 2 postgres postgres     6 Oct 30 13:54 pg_serial
drwx------. 2 postgres postgres     6 Oct 30 13:54 pg_snapshots
drwx------. 2 postgres postgres     6 Oct 30 13:54 pg_stat
drwx------. 2 postgres postgres     6 Oct 30 13:54 pg_stat_tmp
drwx------. 2 postgres postgres    18 Oct 30 13:54 pg_subtrans
drwx------. 2 postgres postgres     6 Oct 30 13:54 pg_tblspc
drwx------. 2 postgres postgres     6 Oct 30 13:54 pg_twophase
-rw-------. 1 postgres postgres     3 Oct 30 13:54 PG_VERSION
drwx------. 3 postgres postgres    60 Oct 30 13:54 pg_wal
drwx------. 2 postgres postgres    18 Oct 30 13:54 pg_xact
-rw-------. 1 postgres postgres    88 Oct 30 13:54 postgresql.auto.conf
-rw-------. 1 postgres postgres 23796 Oct 30 13:54 postgresql.conf
avi@percona:~ $
```

Configuration Files inside the Data Directory

- PG_VERSION
  - Version String of the Database Cluster
- pg_hba.conf
  - Host-Based access control file (built-in firewall)
- pg_ident.conf
  - ident-based access file for OS User to DB User Mapping
- postgresql.conf
  - Primary Configuration File for the Database
- postmaster.opts
  - Contains the options used to start the PostgreSQL Instance
- postmaster.pid
  - The Parent Process ID or the Postmaster Process ID

postgresql.conf vs postgresql.auto.conf

- **postgresql.conf**
  - Configuration file for PostgreSQL similar to my.cnf for MySQL.
  - This file contains all the parameters and the values required to run your PostgreSQL Instance.
  - Parameters are set to their default values if no modification is done to this file manually.
  - Located in the data directory or /etc depending on the distribution you choose and the location can be modifiable.
- **postgresql.auto.conf**
  - PostgreSQL gives Oracle like compatibility to modify parameters using "ALTER SYSTEM".
  - Any parameter modified using ALTER SYSTEM is written to this file for persistence.
  - This is last configuration file read by PostgreSQL, when started. Empty by default.
  - Always located in the data directory.

View and modify parameters in PostgreSQL

- **Use show to view a value set to a parameter**

  ```
  $ psql -c "show work_mem"
  ```

- **To see all the settings, use show all**

  ```
  $ psql -c "show all"
  ```

- **Modifying a parameter value by manually editing the postgresql.conf file**

  ```
  $ vi $PGDATA/postgresql.conf
  ```

- **Use ALTER SYSTEM to modify a parameter**

  ```
  $ psql -c "ALTER SYSTEM SET archive_mode TO ON"
  ```

- **Use reload using the following syntax to get the changes into effect for parameters not needing RESTART**

  ```
  $ psql -c "select pg_reload_conf()"
   Or
  $ pg_ctl -D $PGDATA reload
  ```

Base Directory & Datafiles on Disk

- **Base Directory**
  - Contains Sub-Directories for every Database you create
  - Every Database Sub-Directory contains files for every Relation/Object created in the Database.

- **Datafiles**
  - Datafiles are the files for Relations in the base directory
  - Base Directory contains Relations.
  - Relations stored on Disk as 1GB segments.
  - Each 1GB Datafile is made up of several 8KB Pages that are allocated as needed.
  - Segments are automatically added unlike Oracle.

Base Directory (Database)

1. Create a database with name as : percona

$ psql —c "CREATE DATABASE percona"

2. Get the datid for the database and see if it exists in the base directory

$ psql —c "select datid, datname from pg_stat_database where datname = 'percona'"

```
postgres=# CREATE DATABASE percona;
CREATE DATABASE
postgres=# select datid, datname from pg_stat_database where datname = 'percona';
 datid | datname
-------+---------
 16384 | percona
(1 row)

postgres=# \q
avi@percona:~ $ls -ld $PGDATA/base/16384
drwx------. 2 postgres postgres 8192 Oct 30 18:53 /var/lib/pgsql/11/data/base/16384
avi@percona:~ $
```

Base Directory (Schema and Relations)

1. Create a schema named : scott

$ psql -d percona —c "CREATE SCHEMA scott"

2. Create a table named : employee in scott schema

$ psql -d percona —c "CREATE TABLE scott.employee(id int PRIMARY KEY, name varchar(20))"

3. Locate the file created for the table : scott.employee in the base directory

$ psql -d percona —c "select pg_relation_filepath('scott.employee')"

```
avi@percona:~ $psql -d percona -c "CREATE SCHEMA scott"
CREATE SCHEMA
avi@percona:~ $psql -d percona -c "CREATE TABLE scott.employee (id int PRIMARY KEY, name varchar(20))"
CREATE TABLE
avi@percona:~ $psql -d percona -c "select pg_relation_filepath('scott.employee')"
 pg_relation_filepath
----------------------
 base/16384/16386
(1 row)
```

Base Directory (Block Size)

1. Check the size of the table in the OS and value of parameter : block_size

psql -c "show block_size"

2. INSERT a record in the table and see the size difference

psql -d percona -c "INSERT INTO scott.employee VALUES (1, 'frankfurt')"

3. INSERT more records and check the size difference

psql -d percona -c "INSERT INTO scott.employee VALUES (generate_series(2,1000), 'junk')"

```
avi@percona:~ $psql -c "show block_size"
 block_size
------------
 8192
(1 row)

avi@percona:~ $ls -lh $PGDATA/base/16384/16386
-rw-------. 1 postgres postgres 0 Oct 30 18:59 /var/lib/pgsql/11/data/base/16384/16386
avi@percona:~ $psql -d percona -c "INSERT INTO scott.employee VALUES (1, 'frankfurt')"
INSERT 0 1
avi@percona:~ $ls -lh $PGDATA/base/16384/16386
-rw-------. 1 postgres postgres 8.0K Oct 30 20:47 /var/lib/pgsql/11/data/base/16384/16386
avi@percona:~ $psql -d percona -c "INSERT INTO scott.employee VALUES (generate_series(2,1000), 'junk')"
INSERT 0 999
avi@percona:~ $ls -lh $PGDATA/base/16384/16386
-rw-------. 1 postgres postgres 48K Oct 30 20:53 /var/lib/pgsql/11/data/base/16384/16386
avi@percona:~ $
```

Write Ahead Logs(WALs)

- **WALs**
  - When Client commits a transaction, it is written to WAL Segments (on Disk) before a success message is sent to Client.
  - Transaction Journal aka REDO Logs. Similar to InnoDB Buffers in MySQL.
  - Written by WAL Writer background process.
  - Ensures Durability with fsync and synchronous_commit set to ON and commit_delay set to 0.
  - Used during Crash Recovery.
  - Size of each WAL is 16MB. Modifiable during Initialization.
  - Created in **pg_xlog** directory until PostgreSQL 9.6.
  - Location of WALs is renamed to **pg_wal** from PostgreSQL 10.
  - WAL Directory exits in Data Directory by default. Can be modified using Symlinks.
  - WALs are deleted depending on the parameters : **wal_keep_segments and checkpoint_timeout**.

Archived Logs and Why ?

- **Archived WALs**
  - WALs in pg_wal or pg_xlog are gone after a certain threshold. Archiving ensures recoverability and helps a Slave catch-up during replication lag.
  - Archiving in PostgreSQL can be enabled through parameters : archive_mode and archive_command.
  - Ships WALs to safe locations like a Backup Server or Cloud Storage like S3 or Object Store.
  - WALs are archived by archiver background process.
  - archive_command can be set with the appropriate shell command to archive WALs.

- **Lets enable Archiving now ...**

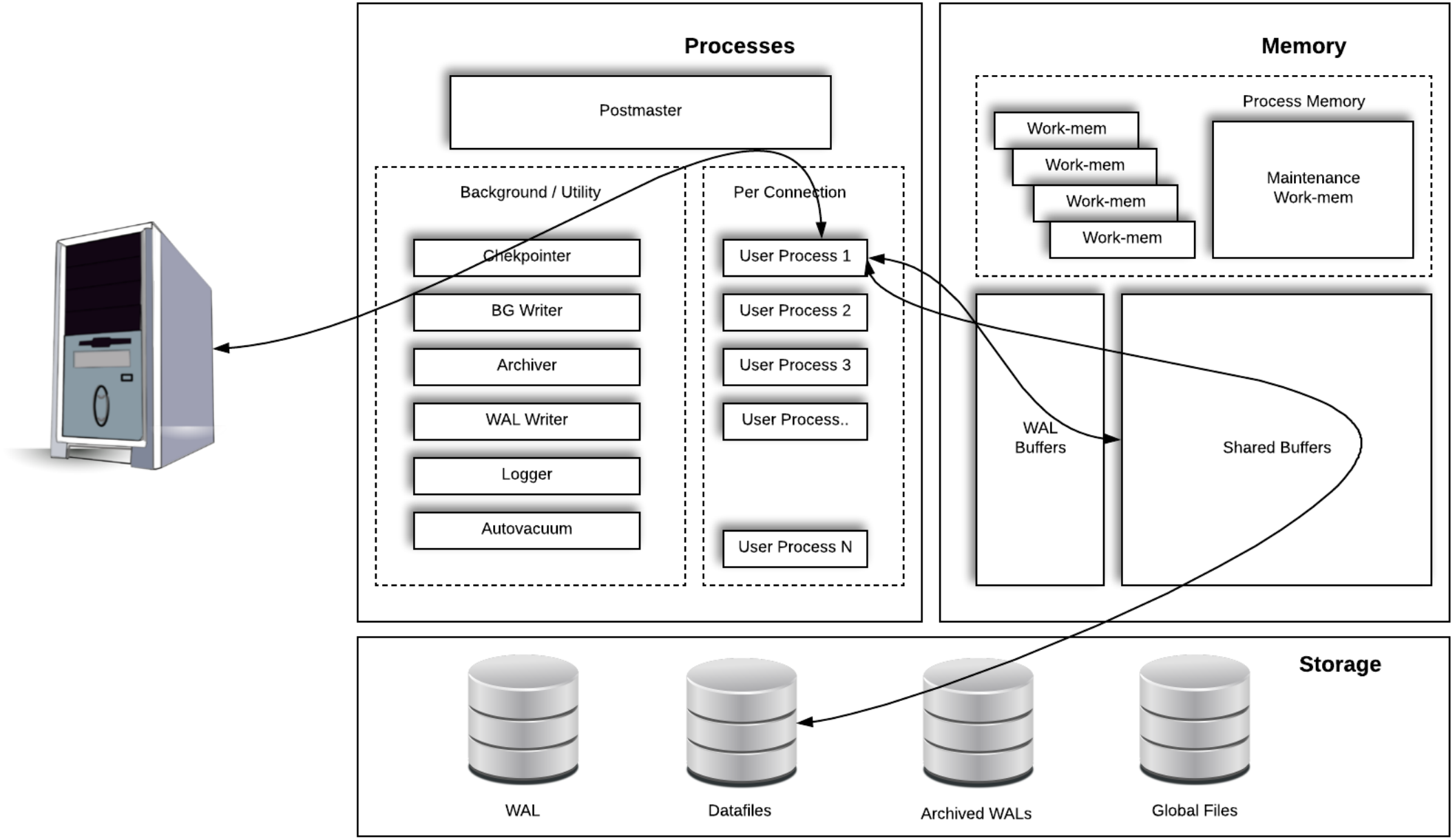
```
ALTER SYSTEM SET listen_addresses TO '*';

ALTER SYSTEM SET archive_mode TO 'ON';

ALTER SYSTEM SET archive_command TO 'cp %p /archive/%f';

$ pg_ctl –D $PGDATA restart –mf
```

Switch a WAL and see if an Archive is generated

- **Switch a WAL and see if the WAL is safely archived …**

```
$ psql -c "select pg_switch_wal()"
```

```
avi@percona:~ $ls -l $PGDATA/pg_wal
total 32768
-rw-------. 1 postgres postgres 16777216 Oct 30 21:09 000000010000000000000001
-rw-------. 1 postgres postgres 16777216 Oct 30 21:09 000000010000000000000002
drwx------. 2 postgres postgres       43 Oct 30 21:09 archive_status
avi@percona:~ $ls -l /archive/
total 16384
-rw-------. 1 postgres postgres 16777216 Oct 30 21:09 000000010000000000000001
avi@percona:~ $
```



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Users and Roles in PostgreSQL

- Database users are different from Operating System users.
- Users can be created in SQL using CREATE USER command or using the createuser utility.
- Database users are common for all the databases that exists in a cluster.
- Roles are created to segregate privileges for access control.

Users and Roles in PostgreSQL - Demo

- Let us consider creating a read_only and a read_write role in database - percona.
- **A read_only Role that only has SELECT, USAGE privileges on Schema : percona**
  - CREATE ROLE scott_read_only;
    GRANT SELECT ON ALL TABLES IN SCHEMA scott TO scott_read_only;
    GRANT USAGE ON SCHEMA scott TO scott_read_only;
- **A read_write Role that only has SELECT, INSERT, UPDATE, DELETE privileges on Schema : percona**
  - CREATE ROLE scott_read_write;
    GRANT SELECT, INSERT, UPDATE, DELETE ON ALL TABLES IN SCHEMA scott TO scott_read_write;
- **Create a User and assign either read_only or read_write role**
  - CREATE USER pguser WITH LOGIN ENCRYPTED PASSWORD 'pg123pass';
    GRANT scott_read_only to pguser;

    ALTER USER pguser WITH CONNECTION LIMIT 20;

Backups in PostgreSQL

- PostgreSQL provides native backup tools for both Logical and Physical backups.
- Backups similar to mysqldump and Xtrabackup are automatically included with Community PostgreSQL.
- Backups like RMAN in Oracle may be achieved using Open Source tools like pgBackRest and pgBarman.

  - **Logical Backups**
    - pg_dump (Both Custom(Compressed and non human-readable) and Plain Backups)
    - pg_restore (To restore the custom backups taken using pg_dump)
    - Logical Backups cannot be used to setup Replication and perform a PITR.
    - You cannot apply WAL's after restoring a Backup taken using pg_dump.

  - **Physical Backups**
    - pg_basebackup : File System Level & Online Backup, similar to Xtrabackup for MySQL.
    - Useful to build Replication and perform PITR.
    - This Backup can only use one process and cannot run in parallel.
    - Explore Open Source Backup tools like : pgBackRest, pgBarman and WAL-e for more features like Xtrabackup.

Try Logical Backup - pg_dump and pg_restore

- **Let's use pgbench to create some sample tables**

```
$ pgbench –i percona  (Initialize)
$ pgbench –T 10 –c 10 –j 2 percona (load some data)
```

Use pg_dump to backup the DDL (schema-only) of database : percona

```
$ pg_dump –s percona –f /tmp/percona_ddl.sql
```

Use pg_dump to backup a table (with data) using custom and plain text format

```
$ pg_dump –Fc –t public.pgbench_history –d percona –f /tmp/pgbench_history
$ pg_dump –t public.pgbench_branches –d percona –f /tmp/pgbench_branches
```

Create an another database and restore both the tables using pg_restore and psql

```
$ psql –c “CREATE DATABASE testdb”
$ pg_restore –t pgbench_history –d testdb /tmp/pgbench_history
$ psql –d testdb –f /tmp/pgbench_branches
```

pg_dumpall to backup GLOBALS or all Databases

- **pg_dumpall**
  - Can dump all the databases of a cluster into a script file.
  - Use psql to restore the backup taken using pg_dumpall.
  - Can be used to dump global objects such as ROLES and TABLESPACES.

  - To dump only Globals using pg_dumpall, use the following syntax.
    - **$ pg_dumpall -g > /tmp/globals.sql**

  - To dump all databases (or entire Cluster), use the following syntax.
    - **$ pg_dumpall > /tmp/globals.sql**

Try Physical/Binary/File System Level Backup - pg_basebackup

- **Command line options for pg_basebackup**

```
$ pg_basebackup --help

  -D     --> Target Location of Backup.

  -cfast --> Issues a fast checkpoint to start the backup earlier

  -Ft    --> Tar format. Use -Fp for plain

  -v     --> Print the Backup statistics/progress.

  -U     --> A User who has Replication Privilege.

  -W     --> forcefully ask for password of replication User above. (Not mandatory).

  -z     --> Compresses the Backup

  -R     --> Creates a recovery.conf file that can be used to setup replication

  -P     --> Shows the progress of the backup

  -l     --> Creates a backup_label file
```

Use pg_basebackup to perform your first Full Backup

- **Run pg_basebackup now ….**

```
$ pg_basebackup -U postgres -p 5432 -h 127.0.0.1 -D /tmp/backup_11052018 -Ft -z -Xs -P -R
-l backup_label
```

```
avi@percona:~ $pg_basebackup -U postgres -p 5432 -h 127.0.0.1 -D /tmp/backup_11052018 -Ft -z -Xs -P -R -l backup_label
58549/58549 kB (100%), 1/1 tablespace
avi@percona:~ $
avi@percona:~ $ls -l /tmp/backup_11052018
total 6428
-rw-------. 1 postgres postgres 6560306 Oct 31 02:35 base.tar.gz
-rw-------. 1 postgres postgres   17667 Oct 31 02:35 pg_wal.tar.gz
avi@percona:~ $
avi@percona:~ $tar -xzf /tmp/backup_11052018/base.tar.gz
avi@percona:~ $
avi@percona:~ $cat backup_label
START WAL LOCATION: 0/6000028 (file 000000010000000000000006)
CHECKPOINT LOCATION: 0/6000060
BACKUP METHOD: streamed
BACKUP FROM: master
START TIME: 2018-10-31 02:35:24 EDT
LABEL: backup_label
START TIMELINE: 1
avi@percona:~ $_
```

MVCC in PostgreSQL

- MVCC : Multi-Version Concurrency Control.
- Maintains Data Consistency Internally.
- Prevents transactions from viewing inconsistent data.
- Readers do not block Writers and Writers do not block Readers.
- MVCC controls which tuples can be visible to transactions via Versions.
- Hidden Column xmin that has the transaction ID for every row.
- UNDO is not maintained in a Separate UNDO Segment. UNDO is stored as Older Versions within the same Table.
- Every Tuple has hidden columns => xmin and xmax that records the minimum and maximum transaction ids that are permitted to see the row.
- xmin can be interpreted as the lowest transaction ID that can see this column.
  Just like SELECT statements executing WHERE xmin <= txid_current() AND (xmax = 0 OR txid_current() < xmax)
- Dead rows are the rows that no active or future transaction would see.
- Rows that got deleted would get their xmax with the txid that deleted them.

Hidden columns of a Table

- Describe the table : scott.employee using \d

  percona=# \d scott.employee

- Look for hidden columns using pg_attribute

```
SELECT attname, format_type (atttypid, atttypmod)
  FROM pg_attribute
WHERE attrelid::regclass::text='scott.employee'
ORDER BY attnum;
```

```
percona=# \d scott.employee
                    Table "scott.employee"
 Column |         Type          | Collation | Nullable | Default
--------+-----------------------+-----------+----------+---------
 id     | integer               |           | not null |
 name   | character varying(20) |           |          |
Indexes:
    "employee_pkey" PRIMARY KEY, btree (id)

percona=# SELECT attname, format_type (atttypid, atttypmod)
percona-# FROM pg_attribute
percona-# WHERE attrelid::regclass::text='scott.employee'
percona-# ORDER BY attnum;
 attname  |      format_type
----------+-----------------------
 tableoid | oid
 cmax     | cid
 xmax     | xid
 cmin     | cid
 xmin     | xid
 ctid     | tid
 id       | integer
 name     | character varying(20)
(8 rows)
```

Understanding xmin

- **xmin** :
  - The transaction ID(xid) of the inserting transaction for this row version. Upon update, a new row version is inserted.

```
percona=# select txid_current();
 txid_current
--------------
          646
(1 row)

percona=# INSERT into scott.employee VALUES (3000,'avi');
INSERT 0 1

percona=# select xmin,xmax,cmin,cmax,* from scott.employee where id = 3000;
 xmin | xmax | cmin | cmax | id   | emp_name
------+------+------+------+------+----------
```

  - ```
 647 | 0 | 0 | 0 | 3000 | avi
(1 row)
```

  - This means that, already running transactions with txid less than 647 cannot see the row inserted by txid 647.
```

Understanding xmax

- **xmax :**
  - This values is 0 if it was not a deleted row version.
  - Before the DELETE is committed, the xmax of the row version changes to the ID of the transaction that has issued the DELETE.

  - **Open 2 Terminals**

    On Terminal 1 :

    $ psql –d percona

    ```
    percona=# BEGIN;
    percona=# select txid_current();
    percona=# DELETE from scott.employee where id = 9;
    ```

    On Terminal 2 :

    $ psql -d percona

    Issue the following SQL before and after the delete on Terminal 1 and observe the difference

    ```
    percona=# select xmin,xmax,cmin,cmax,* from scott.employee where id = 10;
    ```

Understanding xmax

```
avi@percona:~ $psql -d percona
psql (11.0)
Type "help" for help.

percona=# BEGIN;
BEGIN
percona=# select txid_current();
 txid_current
--------------
        12831
(1 row)

percona=# DELETE FROM scott.employee WHERE id = 1;
DELETE 1
```

```
avi@percona:~ $psql -d percona
psql (11.0)
Type "help" for help.

percona=# select xmin,xmax,cmin,cmax,* from scott.employee where id = 1;
 xmin | xmax | cmin | cmax | id |   name
------+------+------+------+----+-----------
  571 |    0 |    0 |    0 |  1 | frankfurt
(1 row)

percona=# select xmin,xmax,cmin,cmax,* from scott.employee where id = 1;
 xmin | xmax  | cmin | cmax | id |   name
------+-------+------+------+----+-----------
  571 | 12831 |    0 |    0 |  1 | frankfurt
(1 row)

percona=# select xmin,xmax,cmin,cmax,* from scott.employee where id = 1;
 xmin | xmax | cmin | cmax | id | name
------+------+------+------+----+------
(0 rows)
```


PERCONA

Vacuum in PostgreSQL

- Due to continuous transactions in the databases and the number of dead rows, there exists a lot of space that can be re-used by future transactions.

- Tuples that are deleted or updated generate dead tuples that are not physically deleted.
  See view => **pg_stat_user_tables**

- VACUUM in PostgreSQL would clear off the dead tuples and mark it to free space map so that the future transactions can re-use the space.

```
VACUUM percona.employee;
```

- VACUUM FULL in PostgreSQL would rebuild the entire Table with explicit Locks, releasing the space to File System. Similar to ALTER TABLE in MySQL.

```
VACUUM FULL percona.employee;
```

- Autovacuum in PostgreSQL automatically runs VACUUM on tables depending on the following parameters. ***autovacuum_vacuum_scale_factor*** *and* ***autovacuum_vacuum_threshold***

ANALYZE in PostgreSQL

- ANALYZE collects statistics about the contents of tables in the database, and stores the results in the system catalogs.
- The autovacuum daemon, takes care of automatic analyzing of tables when they are first loaded with data.
- Accurate statistics will help the planner to choose the most appropriate query plan, and thereby improve the speed of query processing.

```
ANALYZE percona.employee;
```

- Autovacuum Launcher Process runs an Analyze on a Table depending on the following parameters : ***autovacuum_analyze_scale_factor*** *and* ***autovacuum_analyze_threshold****.*

Vacuum and Analyze in ACTION ..

- Check the size of table : scott.employee

```
\dt+ scott.employee
```

- Check the number of live and dead tuples

```
SELECT relname, n_live_tup, n_dead_tup
  FROM pg_stat_user_tables
  WHERE relname = 'employee';
```

- Delete some records and now check the dead tuples

```
DELETE FROM scott.employee WHERE id < 1000 ;
```

- Check the number of live and dead tuples again ..
- Run VACUUM ANALYZE and check the dead tuples

```
VACUUM ANALYZE scott.employee ;
```

- Run VACUUM FULL and check the table size now

```
VACUUM FULL scott.employee ;
\dt+ scott.employee
```

```
percona=# \dt+ scott.employee
                    List of relations
 Schema |   Name   | Type  |  Owner   | Size  | Description
--------+----------+-------+----------+-------+-------------
 scott  | employee | table | postgres | 72 kB |
(1 row)

percona=# ANALYZE scott.employee ;
ANALYZE
percona=# SELECT relname, n_live_tup, n_dead_tup
percona-# FROM pg_stat_user_tables
percona-# WHERE relname = 'employee';
 relname  | n_live_tup | n_dead_tup
----------+------------+------------
 employee |        999 |          2
(1 row)
```

```
percona=# DELETE FROM scott.employee WHERE id < 1000 ;
DELETE 998
percona=# ANALYZE scott.employee ;
ANALYZE
percona=# SELECT relname, n_live_tup, n_dead_tup
FROM pg_stat_user_tables
WHERE relname = 'employee';
 relname  | n_live_tup | n_dead_tup
----------+------------+------------
 employee |          1 |       1000
(1 row)

percona=# VACUUM ANALYZE scott.employee ;
VACUUM
percona=# SELECT relname, n_live_tup, n_dead_tup
FROM pg_stat_user_tables
WHERE relname = 'employee';
 relname  | n_live_tup | n_dead_tup
----------+------------+------------
 employee |          1 |          0
(1 row)

percona=# VACUUM FULL scott.employee ;
VACUUM
percona=# \dt+ scott.employee
                        List of relations
 Schema |   Name   | Type  |  Owner   |    Size    | Description
--------+----------+-------+----------+------------+-------------
 scott  | employee | table | postgres | 8192 bytes |
(1 row)
```


PERCONA

Tablespaces in PostgreSQL

- Tablespaces
  - Can be used to move Table & Indexes to different disks/locations
  - Helps distributing IO.

- **Steps to create tablespace in PostgreSQL**

- Step 1 : Create a directory for the tablespace
  - ```
    $ mkdir -p /tmp/tblspc_1
    $ chown postgres:postgres /tmp/tblspc_1
    $ chmod 700 /tmp/tblspc_1
    ```

- Step 2 : Create tablespace using the new directory
  - ```
    $ psql -c "CREATE TABLESPACE tblspc_1 LOCATION '/tmp/tblspc_1'"
    ```

- Step 3 : Create a table in the new table-space
  - ```
    $ psql -d percona -c "CREATE TABLE scott.foo (id int) TABLESPACE tblspc_1"
    ```
    ```

PostgreSQL Indexes

- **PostgreSQL supports several Index types such as :**
  - B-tree Indexes
  - Hash Indexes
  - BRIN Indexes
  - GiST Indexes
  - GIN Indexes
  - Partial indexes or Functional Indexes

PostgreSQL Partitioning

- **Partitioning until PostgreSQL 9.6**
  - PostgreSQL supported Partitioning via Table Inheritance.
  - CHECK Constraints and Trigger Functions to re-direct Data to appropriate CHILD Tables.
  - Supports both RANGE and LIST Partitioning.

- **Declarative Partitioning since PostgreSQL 10 (Oracle and MySQL like Syntax)**
  - Avoid the trigger based Partitioning and makes it easy and faster.
  - Uses internal C Functions instead of PostgreSQL Triggers.
  - Supports both RANGE and LIST Partitioning.

- **Advanced Partitioning from PostgreSQL 11**
  - Supports default partitions
  - Hash Partitions
  - Parallel Partition scans
  - Foreign Keys
  - Optimizer Partition elimination

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  - Supports both RANGE and LIST Partitioning.

- **Advanced Partitioning from PostgreSQL 11**
  - Supports default partitions
  - Hash Partitions
  - Parallel Partition scans
  - Foreign Keys
  - Optimizer Partition elimination, etc

PostgreSQL Declarative Partitioning

- **Create a table and partition by RANGE**

```
CREATE TABLE scott.orders (id INT, order_time TIMESTAMP WITH TIME ZONE, description TEXT) PARTITION
BY RANGE (order_time);

ALTER TABLE scott.orders ADD PRIMARY KEY (id, order_time);

CREATE TABLE scott.order_2018_01_04 PARTITION OF scott.orders
    FOR VALUES FROM ('2018-01-01') TO ('2018-05-01');

CREATE TABLE scott.order_2018_05_08 PARTITION OF scott.orders
    FOR VALUES FROM ('2018-05-01') TO ('2018-09-01');

CREATE TABLE scott.order_2018_09_12 PARTITION OF scott.orders
    FOR VALUES FROM ('2018-09-01') TO ('2019-01-01');
```

- **Insert values to the table**

```
INSERT INTO scott.orders (id, order_time, description)
SELECT random() * 6, order_time, md5(order_time::text)
FROM generate_series('2018-01-01'::date, CURRENT_TIMESTAMP, '1 hour') as order_time;
```

```
percona=# \d+ scott.orders
                                        Table "scott.orders"
   Column    |           Type           | Collation | Nullable | Default | Storage  | Stats target | Description
-------------+--------------------------+-----------+----------+---------+----------+--------------+-------------
 id          | integer                  |           | not null |         | plain    |              |
 order_time  | timestamp with time zone |           | not null |         | plain    |              |
 description | text                     |           |          |         | extended |              |
Partition key: RANGE (order_time)
Indexes:
    "orders_pkey" PRIMARY KEY, btree (id, order_time)
Partitions: scott.order_2018_01_04 FOR VALUES FROM ('2018-01-01 00:00:00-05') TO ('2018-05-01 00:00:00-04'),
            scott.order_2018_05_08 FOR VALUES FROM ('2018-05-01 00:00:00-04') TO ('2018-09-01 00:00:00-04'),
            scott.order_2018_09_12 FOR VALUES FROM ('2018-09-01 00:00:00-04') TO ('2019-01-01 00:00:00-05')

percona=# INSERT INTO scott.orders (id, order_time, description)
percona-# SELECT random() * 6, order_time, md5(order_time::text)
percona-# FROM generate_series('2018-01-01'::date, CURRENT_TIMESTAMP, '1 hour') as order_time;
INSERT 0 7283
percona=# _
```

PostgreSQL Declarative Partitioning - EXPLAIN

- **Use EXPLAIN to see the Execution Plan of the following SELECT statement**

```
EXPLAIN SELECT id, order_time, description
        FROM scott.orders
        WHERE order_time between '2018-05-22 02:00:00' and '2018-05-28 02:00:00';
```

- **Create Indexes on Partition Keys to ensure optimal performance**

```
CREATE INDEX order_idx_2018_01_04 ON scott.order_2018_01_04 (order_time);
CREATE INDEX order_idx_2018_05_08 ON scott.order_2018_05_08 (order_time);
CREATE INDEX order_idx_2018_09_12 ON scott.order_2018_09_12 (order_time);
```

EXPLAIN - Before and After creating indexes on partition key

- **Before**

```
percona=# EXPLAIN SELECT id, order_time, description
FROM scott.orders
WHERE order_time between '2018-05-22 02:00:00' and '2018-05-28 02:00:00';
                                                                         QUERY PLAN
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------
 Append  (cost=0.00..76.00 rows=145 width=45)
   ->  Seq Scan on order_2018_05_08  (cost=0.00..75.28 rows=145 width=45)
         Filter: ((order_time >= '2018-05-22 02:00:00-04'::timestamp with time zone) AND (order_time <= '2018-05-28 02:00:00-04'::timestamp with time zone))
(3 rows)
```

- **After**

```
percona=# EXPLAIN SELECT id, order_time, description
FROM scott.orders
WHERE order_time between '2018-05-22 02:00:00' and '2018-05-28 02:00:00';
                                                                         QUERY PLAN

----------------------------------------------------------------------------------------------------------------------------------------------------------------------------
---
 Append  (cost=0.28..6.91 rows=145 width=45)
   ->  Index Scan using order_idx_2018_05_08 on order_2018_05_08  (cost=0.28..6.18 rows=145 width=45)
         Index Cond: ((order_time >= '2018-05-22 02:00:00-04'::timestamp with time zone) AND (order_time <= '2018-05-28 02:00:00-04'::timestamp with time zone
))
(3 rows)
```

PostgreSQL High Availability

- **Streaming Replication for PostgreSQL 9.x and above**
  - WAL Segments are streamed to Standby/Slave and replayed on Slave.
  - Not a Statement/Row/Mixed Replication like MySQL.
  - This can be referred to as a byte-by-byte or Storage Level Replication
  - Slaves are always Open for Read-Only SQLs but not Writes
  - You cannot have different Schema or Data in a Master and a Slave in Streaming Replication.
  - Allows Cascading Replication
  - Supports both Synchronous and Asynchronous Replication
  - Supports a Delayed Standby for faster PITR

- **Logical Replication and Logical Decoding for PostgreSQL 10 and above**
  - Allows for Replication of selected Tables using Publisher and Subscriber Model.
  - Similar to binlog_do_db in MySQL, but no DDL Changes are replicated.
  - Subscribers are also open for Writes automatically
  - Used in Data Warehouse environments that stores Data fetched from multiple OLTP Databases for Reporting, etc.

PostgreSQL Streaming Replication (SR)

- **Step 1 : Create a user in Master with REPLICATION ROLE.**

```
CREATE USER replicator
WITH REPLICATION
ENCRYPTED PASSWORD 'replicator';
```

- **Step 2 : Parameters you should know while setting up SR**

archive_mode : Must be set to ON to enable Archiving of WALs

wal_level : Must be set to "hot_standy" until 9.5 and "replica" in the later versions.

max_wal_senders : Must be set to 3 if you are starting with 1 Slave. For every Slave, you may add 2 wal senders.

wal_keep_segments : Number of WALs always retained in pg_xlog (Until PostgreSQL 9.6) or pg_wal (From PostgreSQL 10)

archive_command : This parameter takes a shell command. It can be a simple copy command to copy the WAL segments to another location or a Script that has the logic to archive the WALs to S3 or a remote Backup Server.

hot_standby : Must be set to ON on Standby/Replica and has no effect on the Master. However, when you setup your Replication, parameters set on Master are automatically copied. This parameter is important to enable READS on Slave. Else, you cannot run your SELECTS on Slave.

- **Step 3 : Set the parameters that are not set already**

```
ALTER SYSTEM SET wal_keep_segments TO '50';
select pg_reload_conf();
```

- **Step 4 : Add an entry to pg_hba.conf of Master to allow Replication connections from Slave.**
  Default location of pg_hba.conf is the Data Directory.

```
$ vi pg_hba.conf

  Add the following line between >>>>> and <<<<<< to the end of the pg_hba.conf file.
  >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
  host replication replicator 192.168.0.28/32 md5
  <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<

  Replace the IP address(192.168.0.28) with your Slave IP address
```

- **Step 5 : Give a SIGHUP or RELOAD**

```
$ pg_ctl -D $PGDATA reload
```

- **Step 6 : Use pg_basebackup to backup of your Master data directory to the Slave data directory**

```
$ pg_basebackup -U replicator -p 5432 -D /slave -Fp -Xs -P -R
```

- **Step 7 : Change the port number of your slave if you are creating the replication in the same server for demo**

```
$ echo "port = 5433" >> /slave/postgresql.auto.conf
```

- **Step 8 : Start your Slave**

```
$ pg_ctl –D /slave start
```

- **Step 9 : Check the replication status from Master using the view : pg_stat_replication**

```
select * from pg_stat_replication ;
```

Questions ??