Detailed Understanding of MVCC and Autovacuum Internals in PostgreSQL

MVCC and Autovacuum Internals

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PERCONA

Topics being discussed today …

- UNDO Management
- Transaction ID’s and PostgreSQL hidden columns
- MVCC and how different is it from other RDBMS’s
- Why Autovacuum ?
- Autovacuum settings
- Tuning Autovacuum

UNDO Management - Oracle and PostgreSQL

- Oracle and MySQL have separate storage for UNDO
  - May be limited space
  - ORA-01555 - Snapshot too Old
  - ORA-30036: unable to extend segment by 8 in undo tablespace
  - Requires no special care to cleanup bloat.
- PostgreSQL
  - Maintains UNDO within a table through versions - old and new row versions.
  - Transaction ID’s are used to identify a version a query can use.
  - A background process to delete old row versions explicitly.
  - No additional writes to a separate UNDO storage in the event of writes.
  - Row locks stored on tuple itself and no separate lock table.

MVCC

- MVCC : Multi-Version Concurrency Control
- Data Consistency
- Prevents viewing Inconsistent data
- Readers and Writers do not block each other
- No Rollback segments for UNDO
- UNDO management is within tables.
- A tuple contains the minimum and maximum transaction ids that are permitted to see it.
- Just like SELECT statements executing WHERE xmin <= txid_current() AND (xmax = 0 OR txid_current() < xmax)

Transaction ID's in PostgreSQL

- Each transaction is allocated a transaction ID (txid).
- txid is a 32-bit unsigned integer
- 4 Billion (4,294,967,296) ID's
  - 2 Billion in the past are visible and
  - 2 Billion in the future are not visible.
- ID's - 0, 1 and 2 are reserved.

  0 - INVALID txid
  1 - Used in initialization of Cluster
  2 - Frozen txid

- txid is circular.

Hidden Columns in PostgreSQL Tables

```
[avi@percona:]$psql -d percona -c "SELECT attname, format_type (atttypid, atttypmod) \
FROM pg_attribute WHERE attrelid::regclass::text='foo.bar' \
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)
```

Hidden Columns - xmin and xmax

- xmin : Transaction ID that inserted the tuple
- xmax : txid of the transaction that issued an update/delete on this tuple and not committed yet
  or
  when the delete/update has been rolled back.
  and 0 when nothing happened.

```
[avi@percona:]$psql -d percona -c "CREATE TABLE foo.bar (id int, name varchar (20) )"
CREATE TABLE
[avi@percona:]$psql -d percona -c "select txid_current()"
 txid_current
--------------
         1603
(1 row)

[avi@percona:]$psql -d percona -c "INSERT INTO foo.bar VALUES (generate_series(1,10), 'avi')"
INSERT 0 10
[avi@percona:]$psql -d percona -c "select xmin, xmax, id, name from foo.bar"
 xmin | xmax | id | name
------+------+----+------
 1604 |    0 |  1 | avi
 1604 |    0 |  2 | avi
 1604 |    0 |  3 | avi
 1604 |    0 |  4 | avi
 1604 |    0 |  5 | avi
 1604 |    0 |  6 | avi
 1604 |    0 |  7 | avi
 1604 |    0 |  8 | avi
 1604 |    0 |  9 | avi
 1604 |    0 | 10 | avi
(10 rows)
```

Extension : pg_freespacemap

- PostgreSQL uses **FSM** to choose the page where a tuple can be Inserted.
- **FSM** stores free space information of each page
- Using the extension **pg_freespacemap**, we can see the freespace available inside each page of a table.

```
percona=# CREATE EXTENSION pg_freespacemap;
CREATE EXTENSION
[avi@percona:]$ psql -d percona
psql (10.6)
Type "help" for help.

percona=# \x
Expanded display is on.
percona=# SELECT *, round(100 * avail/8192 ,2) as "freespace ratio"
FROM pg_freespace('foo.bar');
-[ RECORD 1 ]---+------
blkno           | 0
avail           | 7776
freespace ratio | 94.00
```

Delete a Record and see what happens ….

Session 1

```
[avi@percona:]$psql -d percona
psql (10.6)
Type "help" for help.

percona=# BEGIN;
BEGIN
percona=# DELETE FROM foo.bar WHERE id = 9;
DELETE 1
percona=#
```

Session 2

```
percona=# BEGIN ;
BEGIN
percona=# select xmin, xmax, id, name from foo.bar;
 xmin | xmax | id | name
------+------+----+------
 1604 |    0 |  1 | avi
 1604 |    0 |  2 | avi
 1604 |    0 |  3 | avi
 1604 |    0 |  4 | avi
 1604 |    0 |  5 | avi
 1604 |    0 |  6 | avi
 1604 |    0 |  7 | avi
 1604 |    0 |  8 | avi
 1604 | 1605 |  9 | avi
 1604 |    0 | 10 | avi
(10 rows)
```

Now COMMIT the DELETE and see …

Session 1

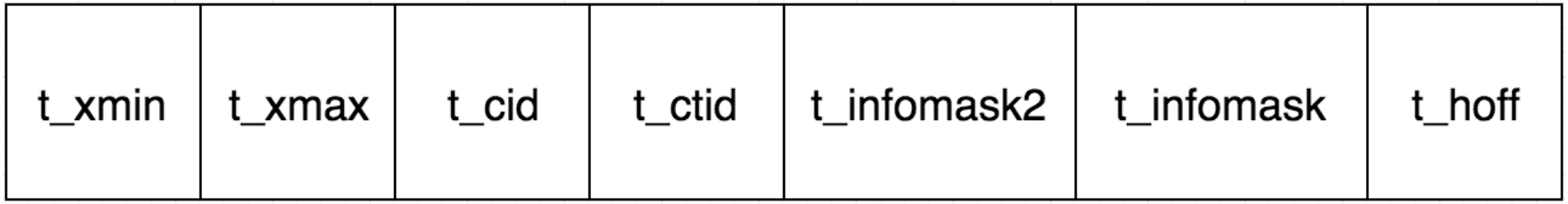
```
[avi@percona:]$psql -d percona
psql (10.6)
Type "help" for help.

percona=# BEGIN;
BEGIN
percona=# DELETE FROM foo.bar WHERE id = 9;
DELETE 1
percona=# COMMIT;
COMMIT
percona=#
```

Session 2

```
percona=# select xmin, xmax, id, name from foo.bar;
 xmin | xmax | id | name
------+------+----+------
 1604 |    0 |  1 | avi
 1604 |    0 |  2 | avi
 1604 |    0 |  3 | avi
 1604 |    0 |  4 | avi
 1604 |    0 |  5 | avi
 1604 |    0 |  6 | avi
 1604 |    0 |  7 | avi
 1604 |    0 |  8 | avi
 1604 |    0 | 10 | avi
(9 rows)
```

Heap Tuples

- Each Heap tuple in a table contains a HeapTupleHeaderData structure.



HeapTupleHeaderData Structure

t_xmin : txid of the transaction that inserted this tuple

t_xmax : txid of the transaction that issued an update/delete on this tuple and not committed yet
or
when the delete/update has been rolled back.
and 0 when nothing happened.

t_cid : The position of the SQL command within a transaction that has inserted this tuple, starting from 0. If 5th command of transaction inserted this tuple, cid is set to 4.

t_ctid : Contains the block number of the page and offset number of line pointer that points to the tuple.

Extension : pageinspect

- Included with the contrib module
- Show the contents of a page/block
- 2 functions we could use to get tuple level metadata and data
  - **get_raw_page** : reads the specified 8KB block
  - **heap_page_item_attrs** : shows metadata and data of each tuple

- Create the Extension pageinspect.

```
postgres=# CREATE EXTENSION pageinspect ;
CREATE EXTENSION
```

```
[avi@percona:]$ psql -d percona -c "\dt+ foo.bar"
                    List of relations
 Schema | Name | Type  |  Owner   |    Size    | Description
--------+------+-------+----------+------------+-------------
 foo    | bar  | table | postgres | 8192 bytes |
(1 row)

[avi@percona:]$psql -d percona -c "SELECT t_xmin, t_xmax, t_field3 as t_cid, t_ctid \
> FROM heap_page_items(get_raw_page('foo.bar', 0))"
 t_xmin | t_xmax | t_cid | t_ctid
--------+--------+-------+--------
   1604 |      0 |     0 | (0,1)
   1604 |      0 |     0 | (0,2)
   1604 |      0 |     0 | (0,3)
   1604 |      0 |     0 | (0,4)
   1604 |      0 |     0 | (0,5)
   1604 |      0 |     0 | (0,6)
   1604 |      0 |     0 | (0,7)
   1604 |      0 |     0 | (0,8)
   1604 |   1605 |     0 | (0,9)
   1604 |      0 |     0 | (0,10)
(10 rows)
```

```
percona=# SELECT lp,
       t_ctid AS ctid,
       t_xmin AS xmin,
       t_xmax AS xmax,
       (t_infomask & 128)::boolean AS xmax_is_lock,
       (t_infomask & 1024)::boolean AS xmax_committed,
       (t_infomask & 2048)::boolean AS xmax_rolled_back,
       (t_infomask & 4096)::boolean AS xmax_multixact,
       t_attrs[1] AS p_id,
       t_attrs[2] AS p_val
FROM heap_page_item_attrs(
        get_raw_page('foo.bar', 0),
        'foo.bar'
     ) where lp = 9;
-[ RECORD 1 ]----+-----------
lp               | 9
ctid             | (0,9)
xmin             | 1604
xmax             | 1605
xmax_is_lock     | f
xmax_committed   | t
xmax_rolled_back | f
xmax_multixact   | f
p_id             | \x09000000
p_val            | \x09617669
```

Delete a Record and Rollback ….

```
percona=# BEGIN;
BEGIN
percona=# DELETE FROM foo.bar WHERE id = 6;
DELETE 1
percona=# ROLLBACK;
ROLLBACK
```

Perform a select that sets the hint bits, after reading the commit log.
It is an IO in fact :(

```
percona=# select * from foo.bar where id = 6;
 id | name
----+------
  6 | avi
(1 row)
```

```
percona=# SELECT lp,
       t_ctid AS ctid,
       t_xmin AS xmin,
       t_xmax AS xmax,
       (t_infomask & 128)::boolean AS xmax_is_lock,
       (t_infomask & 1024)::boolean AS xmax_committed,
       (t_infomask & 2048)::boolean AS xmax_rolled_back,
       (t_infomask & 4096)::boolean AS xmax_multixact,
       t_attrs[1] AS p_id,
       t_attrs[2] AS p_val
FROM heap_page_item_attrs(
        get_raw_page('foo.bar', 0),
        'foo.bar'
     ) where lp = 6;
-[ RECORD 1 ]----+-----------
lp               | 6
ctid             | (0,6)
xmin             | 1604
xmax             | 1606
xmax_is_lock     | f
xmax_committed   | f
xmax_rolled_back | t
xmax_multixact   | f
p_id             | \x06000000
p_val            | \x09617669
```

- Just like SELECT statements executing
  WHERE xmin <= txid_current() AND (xmax = 0 OR txid_current() < xmax)

- The above statement must be understandable by now ….

Space occupied by the DELETED tuple ?

VACUUM / AUTOVACUUM

- **Live Tuples** : Tuples that are Inserted or up-to-date or can be read or modified.
- **Dead Tuples** : Tuples that are changed (Updated/Deleted) and unavailable to be used for any future transactions.
- Continuous transactions may lead to a number of dead rows. A lot of space can be rather re-used by future transactions.
- **VACUUM** in PostgreSQL would cleanup the dead tuples and mark it to free space map.
- transaction ID (**xmax**) of the deleting transaction must be older than the oldest transaction still active in PostgreSQL Server for vacuum to delete that tuple.
- **Autovacuum** in PostgreSQL automatically runs VACUUM on tables as a background process.
- Autovacuum is also responsible to run **ANALYZE** that updates the statistics of a Table.

Background Processes in PostgreSQL

```
[avi@percona:]$ps -eaf | grep postgres
postgres 13532     1  0 Feb12 ?        00:00:00 /usr/pgsql-10/bin/postgres -D /var/lib/pgsql/10/data
postgres 13533 13532  0 Feb12 ?        00:00:00 postgres: logger process
postgres 13535 13532  0 Feb12 ?        00:00:00 postgres: checkpointer process
postgres 13536 13532  0 Feb12 ?        00:00:00 postgres: writer process
postgres 13537 13532  0 Feb12 ?        00:00:00 postgres: wal writer process
postgres 13538 13532  0 Feb12 ?        00:00:00 postgres: autovacuum launcher process
postgres 13539 13532  0 Feb12 ?        00:00:00 postgres: archiver process
postgres 13540 13532  0 Feb12 ?        00:00:01 postgres: stats collector process
postgres 13541 13532  0 Feb12 ?        00:00:00 postgres: bgworker: logical replication launcher
```

Let us run a VACUUM and see now …

```
[avi@percona:]$psql -d percona -c "VACUUM foo.bar"
VACUUM

[avi@percona:]$psql -d percona -c "SELECT t_xmin, t_xmax, t_field3 as t_cid, t_ctid \
FROM heap_page_items(get_raw_page('foo.bar', 0))"
 t_xmin | t_xmax | t_cid | t_ctid
--------+--------+-------+--------
   1604 |      0 |     0 | (0,1)
   1604 |      0 |     0 | (0,2)
   1604 |      0 |     0 | (0,3)
   1604 |      0 |     0 | (0,4)
   1604 |      0 |     0 | (0,5)
   1604 |   1606 |     0 | (0,6)
   1604 |      0 |     0 | (0,7)
   1604 |      0 |     0 | (0,8)
        |        |       |
   1604 |      0 |     0 | (0,10)
(10 rows)
```

Does it show some extra free space in the page now ???

Use pg_freespacemap again …

```
percona=# \x
Expanded display is on.
percona=#
percona=# SELECT *, round(100 * avail/8192 ,2) as "freespace ratio"
FROM pg_freespace('foo.bar');
-[ RECORD 1 ]---+------
blkno           | 0
avail           | 7808
freespace ratio | 95.00
```

When does Autovacuum run ??

- To start **autovacuum**, you must have the parameter **autovacuum** set to ON.
- Background Process : **Stats Collector** tracks the usage and activity information.
- PostgreSQL identifies the tables needing vacuum or analyze depending on certain parameters.
- Parameters needed to enable autovacuum in PostgreSQL are :
  autovacuum = on # (ON by default)
  track_counts = on # (ON by default)
- An automatic vacuum or analyze runs on a table depending on a certain mathematic equations.

- **Autovacuum VACUUM**
  - Autovacuum VACUUM threshold for a table = **autovacuum_vacuum_scale_factor** * number of tuples + **autovacuum_vacuum_threshold**
  - If the actual number of dead tuples in a table exceeds this effective threshold, due to updates and deletes, that table becomes a candidate for autovacuum vacuum.
- **Autovacuum ANALYZE**
  - Autovacuum ANALYZE threshold for a table = **autovacuum_analyze_scale_factor** * number of tuples + **autovacuum_analyze_threshold**
  - Any table with a total number of inserts/deletes/updates exceeding this threshold since last analyze is eligible for an autovacuum analyze.

- **autovacuum_vacuum_scale_factor** or **autovacuum_analyze_scale_factor** : Fraction of the table records that will be added to the formula. For example, a value of 0.2 equals to 20% of the table records.

- **autovacuum_vacuum_threshold** or **autovacuum_analyze_threshold** : Minimum number of obsolete records or dml's needed to trigger an autovacuum.

- Let's consider a table: foo.bar with 1000 records and the following autovacuum parameters.

  autovacuum_vacuum_scale_factor = 0.2
  autovacuum_vacuum_threshold = 50
  autovacuum_analyze_scale_factor = 0.1
  autovacuum_analyze_threshold = 50

- Table : foo.bar becomes a candidate for autovacuum VACUUM when,
  Total number of Obsolete records = (0.2 * 1000) + 50 = 250

- Table : foo.bar becomes a candidate for autovacuum ANALYZE when,
  Total number of Inserts/Deletes/Updates = (0.1 * 1000) + 50 = 150

Tuning Autovacuum in PostgreSQL

- Setting global parameters alone may not be appropriate, all the time.
- Regardless of the table size, if the condition for autovacuum is reached, a table is eligible for autovacuum vacuum or analyze.
- Consider 2 tables with ten records and a million records.
- Frequency at which a vacuum or an analyze runs automatically could be greater for the table with just ten records.
- Use table level autovacuum settings instead.

```
ALTER TABLE foo.bar SET (autovacuum_vacuum_scale_factor = 0,
autovacuum_vacuum_threshold = 100);
```

- There cannot be more then **autovacuum_max_workers** number of auto vacuum processes running at a time. Default is 3.
- Each autovacuum runs with a gap of **autovacuum_naptime**, default is 1 min.

Can i increase autovacuum_max_workers ?
Is VACUUM IO Intensive ?????

- Autovacuum reads 8KB (default **block_size**) pages of a table from disk and modifies/writes to the pages containing dead tuples.
- Involves both read and write IO and may be heavy on big tables with huge amount of dead tuples.

- Autovacuum IO Parameters :

  autovacuum_vacuum_cost_limit : total cost limit autovacuum could reach (combined by all autovacuum jobs).

  autovacuum_vacuum_cost_delay : autovacuum will sleep for these many milliseconds when a cleanup reaching *autovacuum_vacuum_cost_limit* cost is done.

  vacuum_cost_page_hit : Cost of reading a page that is already in shared buffers and doesn't need a disk read.

  vacuum_cost_page_miss : Cost of fetching a page that is not in shared buffers.

  vacuum_cost_page_dirty : Cost of writing to each page when dead tuples are found in it.

- Default Values for the Autovacuum IO parameters
  ————————————————————————————————

  autovacuum_vacuum_cost_limit = -1 (Defaults to vacuum_cost_limit) = 200
  autovacuum_vacuum_cost_delay = 20ms
  vacuum_cost_page_hit = 1
  vacuum_cost_page_miss = 10
  vacuum_cost_page_dirty = 20

- Let’s imagine what can happen in 1 second. (1 second = 1000 milliseconds)

- In a best case scenario where read latency is 0 milliseconds, autovacuum can wake up and go for sleep 50 times (1000 milliseconds / 20 ms) because the delay between wake-ups needs to be 20 milliseconds.

  1 second = 1000 milliseconds = 50 * **autovacuum_vacuum_cost_delay**

- **Read IO limitations with default parameters**
  - If all the pages with dead tuples are found in shared buffers, in every wake up 200 pages can be read. Cost associated per reading a page in shared_buffers is 1.

    So, in 1 second, (50 * 200/vacuum_cost_page_hit * 8 KB) = **78.13 MB** can be read by autovacuum.

  - If the pages are not in shared buffers and need to fetched from disk, an autovacuum can read : 50 * ((200 / vacuum_cost_page_miss) * 8) KB = **7.81 MB** per second.
- **Write IO limitations with default parameters**
  - To delete dead tuples from a page/block, the cost of a write operation is : vacuum_cost_page_dirty, set to 20 by default.
  - At the most, an autovacuum can write/dirty : 50 * ((200 / vacuum_cost_page_dirty) * 8) KB = **3.9 MB** per second.

Transaction ID Wraparound

- Transaction with txid := n, inserted a record.
  t_xmin := n
- After some time, we are now at a txid := (2.1 billion + n)
  Tuple is visible to a SELECT now.
- Now let us say that the txid is := (2.1 billion + n + 1). The same SELECT fails as the txid := n is now considered to be the past.
- This is usually referred to as : Transaction ID Wraparpound in PostgreSQL.
- Vacuum in PostgreSQL re-writes the t_xmin to the frozen txid when the t_xmin is older than (current txid - vacuum_freeze_min_age)
- Until 9.3, xmin used to be updated with an invalid and visible txid : 3, upon FREEZE.
- Starting from 9.4, the XMIN_FROZEN bit is set to the t_infomask field of tuples and avoids re-writing the tuples.

Best Strategy

- Do not just add more autovacuum workers. See if you are fine for more IO caused by autovacuum and tune all the IO settings.
- Busy OLTP systems require your thorough supervision for automation of manual vacuum.
- Perform routine manual vacuum in low peak or non-business hours to ensure a less bloated database at all times.
- A database with finely tuned autovacuum settings and routine maintenance tasks is always healthy.

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Questions ??