Diving into most common performance problems and how to fix them

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Agenda

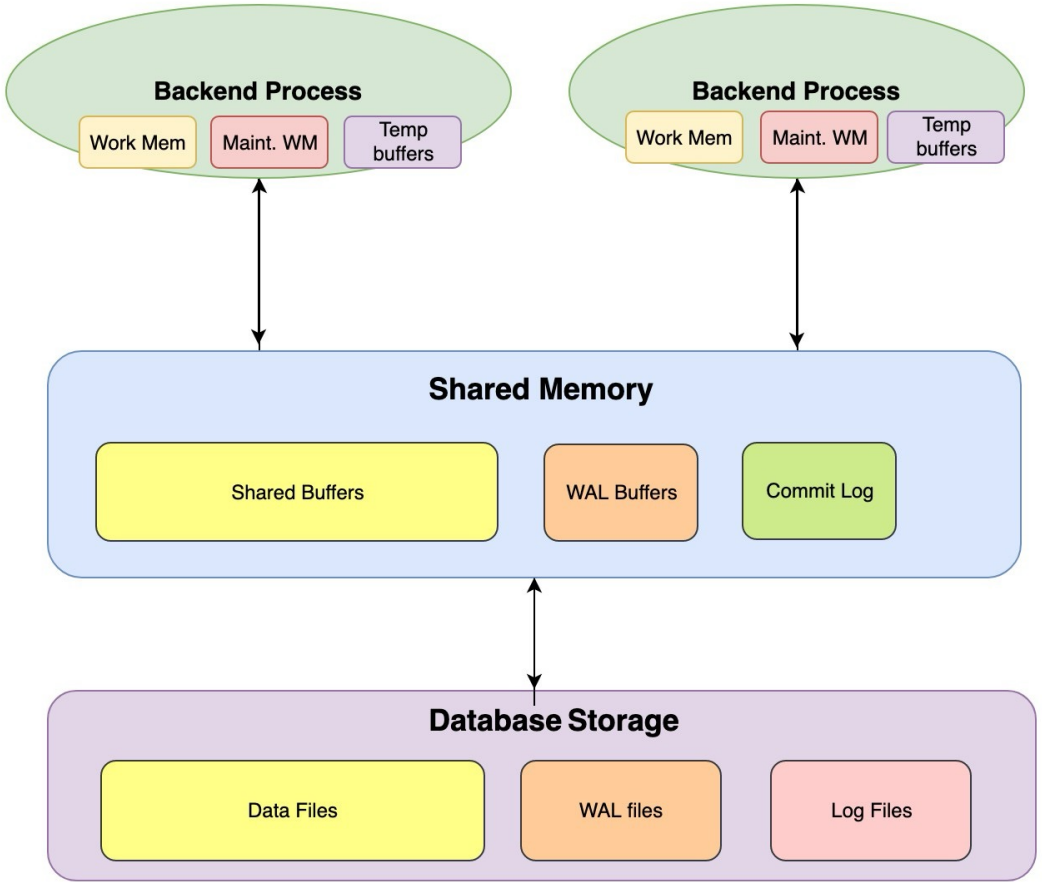
- Memory Management and Checkpointing
- Storage and Data Management
- Replication
- Vacuum processing
- Query performance
- PostgreSQL Happiness Hints

Memory management

Customer questions

- How do we tune shared_buffers and work_mem?
- How do we pre-load a relation/index in the cache?
- Why do we see spikes in write IOPs/throughput at constant intervals?
- How to manage temporary files in PostgreSQL?

PostgreSQL Memory



Shared buffers tuning

- default value – 128MB (mostly)
- Reasonable setting - 25% of system memory to start with
- Can try up to a value of 40%
- pg_buffercache - examining what's happening in the shared buffer cache in real time.
- pg_prewarm – load data into the OS cache or shared buffers

pg_buffercache and pg_prewarm

```
postgres=> select * from pg_extension where extname='pg_buffercache' OR extname='pg_prewarm';
  oid  |    extname     | extowner | extnamespace | extrelocatable | extversion | extconfig | extcondition
-------+----------------+----------+--------------+----------------+------------+-----------+--------------
 16403 | pg_buffercache |       10 |        16400 | t              | 1.3        |           |
 24836 | pg_prewarm     |       10 |        16400 | t              | 1.2        |           |
(2 rows)
```

```
postgres=> SELECT n.nspname, c.relname, count(*) AS buffers
             FROM pg_buffercache b JOIN pg_class c
             ON b.relfilenode = pg_relation_filenode(c.oid) AND
                b.reldatabase IN (0, (SELECT oid FROM pg_database
                                      WHERE datname = current_database()))
             JOIN pg_namespace n ON n.oid = c.relnamespace where nspname='public'
             GROUP BY n.nspname, c.relname ORDER BY buffers desc LIMIT 5;
 nspname |     relname     | buffers
---------+-----------------+---------
 public  | rctest          |  211219
 public  | test            |   27038
 public  | emp             |       5
 public  | pgbench_history |       4
 public  | pgbench_tellers |       4
(5 rows)
```

pg_buffercache and pg_prewarm

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 public  | test            |   27038
 public  | emp             |       5
 public  | pgbench_history |       4
 public  | pgbench_tellers |       4
(5 rows)
```

```
postgres=> SELECT pg_prewarm('rctest');
 pg_prewarm
------------
    1409825
(1 row)
```

```
postgres=> SELECT n.nspname, c.relname, count(*) AS buffers
             FROM pg_buffercache b JOIN pg_class c
             ON b.relfilenode = pg_relation_filenode(c.oid) AND
                b.reldatabase IN (0, (SELECT oid FROM pg_database
                                      WHERE datname = current_database()))
             JOIN pg_namespace n ON n.oid = c.relnamespace where nspname='public'
             GROUP BY n.nspname, c.relname ORDER BY buffers desc LIMIT 5;
 nspname | relname | buffers
---------+---------+---------
 public  | rctest  |  239121
(1 row)
```

Work Memory (work_mem)

- The working memory available for work operations (sorts, hash tables, joins).
- Depends on the the number of “work nodes” per query.
- Set reasonable amount globally.
- Use per database/user/session level for aggressive allocation
- work_mem and hash_mem_multiplier

Managing Temporary Files

- When the work_mem is not sufficient, temporary files are created to store the results.
- Written to disk and automatically removed after the query completes.

Managing Temporary files

- log_temp_files

```
2023-02-06 23:48:35 UTC:205.251.233.182(12456):adminuser@postgres:[31236]:LOG: temporary
file: path "base/pgsql_tmp/pgsql_tmp31236.5", size 140353536
2023-02-06 23:48:35 UTC:205.251.233.182(12456):adminuser@postgres:[31236]:STATEMENT: select
a.aid from pgbench_accounts a, pgbench_accounts b where a.bid=b.bid order by a.bid limit 10;


2023-02-06 23:48:35 UTC:205.251.233.182(12456):adminuser@postgres:[31236]:LOG: temporary
file: path "base/pgsql_tmp/pgsql_tmp31236.4", size 180428800
2023-02-06 23:48:35 UTC:205.251.233.182(12456):adminuser@postgres:[31236]:STATEMENT: select
a.aid from pgbench_accounts a, pgbench_accounts b where a.bid=b.bid order by a.bid limit 10;
```

Managing Temporary files

- temp_file_limit - cancels any query exceeding the size of temp_files in KB

```
postgres=> select * from pgbench_accounts, pg_class, big_table;
.
.
.
ERROR: temporary file size exceeds temp_file_limit (64kB)
```

Managing Temporary files

- pg_ls_tmpdir() function

```
postgres=> select replace(left(name, strpos(name, '.')-
1),'pgsql_tmp','') as pid, count(*), sum(size) from pg_ls_tmpdir()
group by pid;


 pid  | count |  sum
      +
------+-------+------------
 8355 |     2 | 2144501760
 8351 |     2 | 2090770432
 8327 |     1 | 1072250880
 8328 |     2 | 2144501760
(4 rows)
```

Managing Temporary files

- **pg_stat_statement** - temp_blks_read, temp_blks_written
- EXPLAIN (ANALYZE,BUFFERS)

```
Aggregate  (cost=5348342.29..5348342.30 rows=1 width=8) (actual time=77984.568..78001.306 rows=1 loops=1)
  ->  Unique  (cost=1250433.88..5173254.71 rows=14007007 width=17) (actual time=24939.464..77045.024 rows=14448223 loops=1)
        ->  Merge Join  (cost=1250433.88..4898815.51 rows=54887840 width=17) (actual time=24939.462..69413.044 rows=53255128 loops=1)
              Merge Cond: ((cs_le.cs_company_id)::text = (cs_search.cs_company_id)::text)
              ->  Gather Merge  (cost=1250432.03..2934134.22 rows=14456539 width=17) (actual time=24932.628..41042.679 rows=14463238 loops=1)
                    Workers Planned: 2
                    Workers Launched: 2
                    ->  Sort  (cost=1249432.00..1264490.90 rows=6023558 width=17) (actual time=24866.655..29748.967 rows=4821079 loops=3)
                          Sort Key: cs_le.cs_company_id, cs_le.rank
                          Sort Method: external merge  Disk: 102936kB
                          Worker 0:  Sort Method: external merge  Disk: 103736kB
                          Worker 1:  Sort Method: external merge  Disk: 103152kB
                          ->  Parallel Seq Scan on cs_legal_entities_2024 cs_le  (cost=0.00..324048.58 rows=6023558 width=17) (actual time=1.
              ->  Index Only Scan using cs_search_2024_cc_int_cs_company_id_idx on cs_search_2024 cs_search  (cost=0.56..1204504.77 rows=5318
                    Heap Fetches: 0
Planning Time: 0.632 ms
Execution Time: 78018.690 ms
```

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Checkpointing

- Checkpointing - every "*checkpoint_timeout*" seconds, or if "*max_wal_size*" is about to be exceeded, whichever comes first
- causes an I/O load
- "*full_page_writes*"
- Recovery impact

WAL option with **EXPLAIN** now can be used to see WAL record generation including Full Page Images (fpi).
This option can only be used along with **ANALYZE**.

Checkpointing process

```
2023-06-24 18:45:03 UTC::@:[377]:LOG: checkpoint starting: time
2023-06-24 18:45:03 UTC::@:[377]:LOG: checkpoint complete: wrote 2 buffers (0.0%); 0 WAL file(s) added, 0
removed, 1 recycled; write=0.105 s, sync=0.003 s, total=0.118 s; sync files=2, longest=0.002 s,
average=0.002 s; distance=65536 kB, estimate=65536 kB

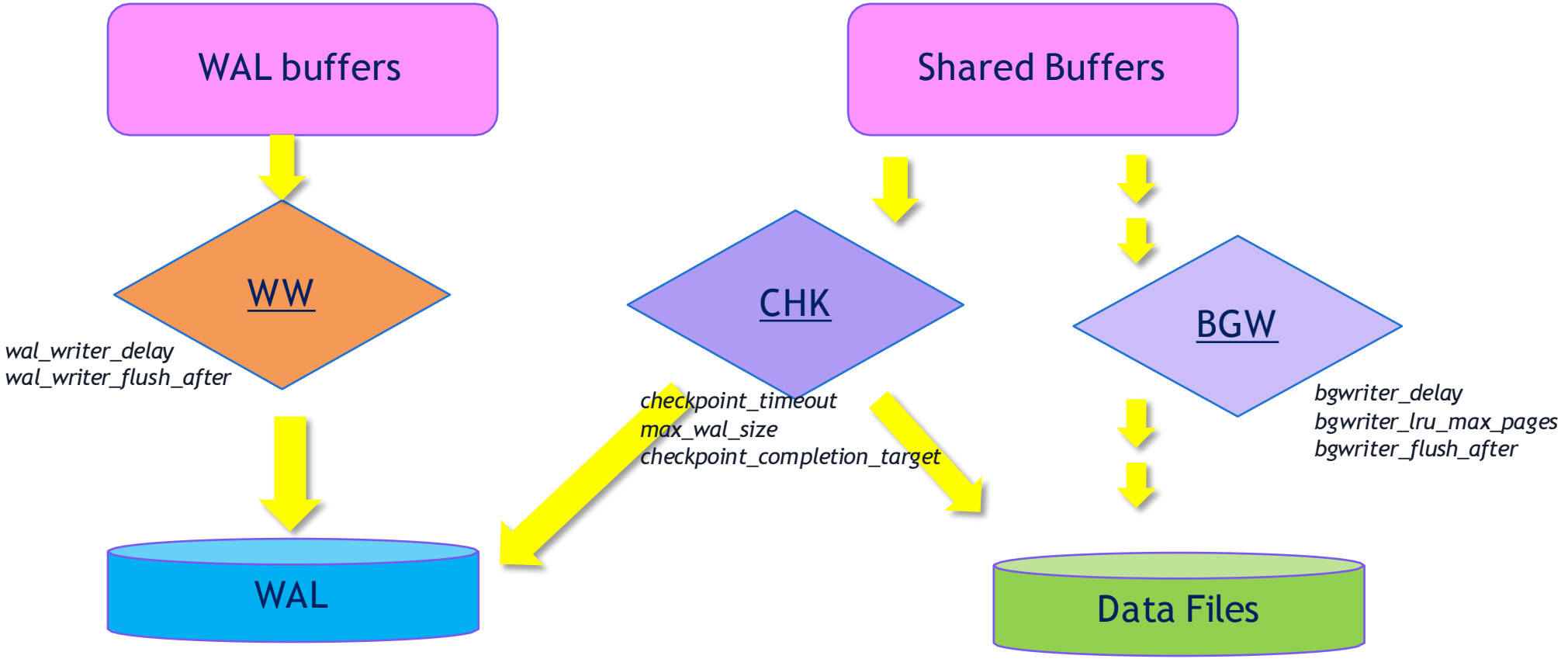

2023-06-24 18:45:16 UTC::@:[377]:LOG: checkpoint starting: immediate force wait
2023-06-24 18:45:16 UTC::@:[377]:LOG: checkpoint complete: wrote 0 buffers (0.0%); 0 WAL file(s) added, 0
removed, 0 recycled; write=0.004 s, sync=0.001 s, total=0.012 s; sync files=0, longest=0.000 s,
average=0.000 s; distance=0 kB, estimate=58982 kB
```

Checkpointing

```
postgres=> select * from pg_stat_bgwriter;
-[ RECORD 1 ]---------+------------------------------
checkpoints_timed     | 24251
checkpoints_req       | 25
checkpoint_write_time | 4615057
checkpoint_sync_time  | 101547
buffers_checkpoint    | 808661
buffers_clean         | 513394
maxwritten_clean      | 5130
buffers_backend       | 3898039
buffers_backend_fsync | 0
buffers_alloc         | 3347563
stats_reset           | 2023-03-25 17:41:58.47806+00
```

From Magnus' talk this morning, we know that these two columns have been moved to a new view called "**pg_stat_checkpointer**" from v17+

Auxiliary processes – WAL writer, Checkpointer, bgwriter



Storage and Data Management

Customer questions

- How to manage increasing load on our production instance/server?
- Our main production table is growing too much and performance is degrading, what should we do?
- What is the impact of using temporary tables?

Storage and Data Management

- Splitting reads and writes
- Sharding
- Partitioning
- Selective Archival of Data

Storage and Data Management - Splitting reads and writes

- Offloading reads reduces overall load on the primary server, leaving more resources for write workload
- Target the list of “candidate queries” to move to readers - not dependent on immediate “read after write” consistency.
- Take into consideration the replica lag when moving read queries to a replica – not to have stale data

Storage and Data Management – Sharding

- Storing a large database across multiple servers
- Improved response time
- Avoid total service outage
- Scale efficiently
- Eg. – Range based sharding, Geo sharding etc.
- AWS - Aurora Limitless – managed sharding solution for Aurora PostgreSQL users

Storage and Data Management – Partitioning

- Provides for faster queries on large tables
- Partition Pruning – less I/O - **partition key must be used in the WHERE clause**
- Know your workload patterns in advance to design better from the start
- Large number of partitions - server's memory consumption may grow significantly over time
- Dropping partitions – avoiding table bloat
- **Never just assume that more partitions are better than fewer partitions, nor vice-versa.**

Storage and Data Management – Selective archival of data

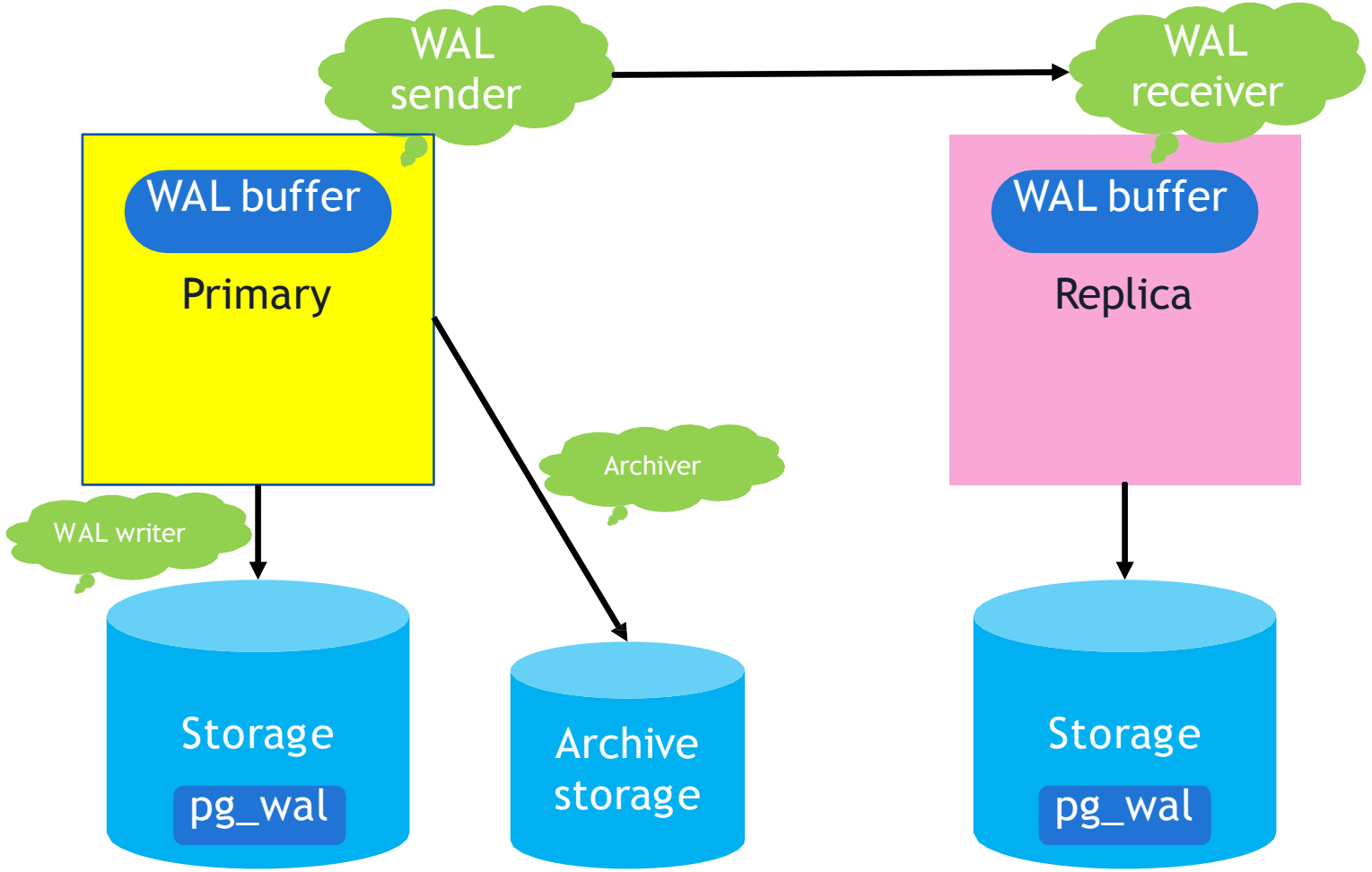
- Segregate historical data from live data, for example using a live table and an archive table in the same database
- Use partitions to move data from the recent dataset - detaching a partition from the recent table and attaching it to the old table
- Move old data to another “archive” storage (Eg. Amazon S3 – cheaper than RDS)
- Keep only live data in the database

Replication

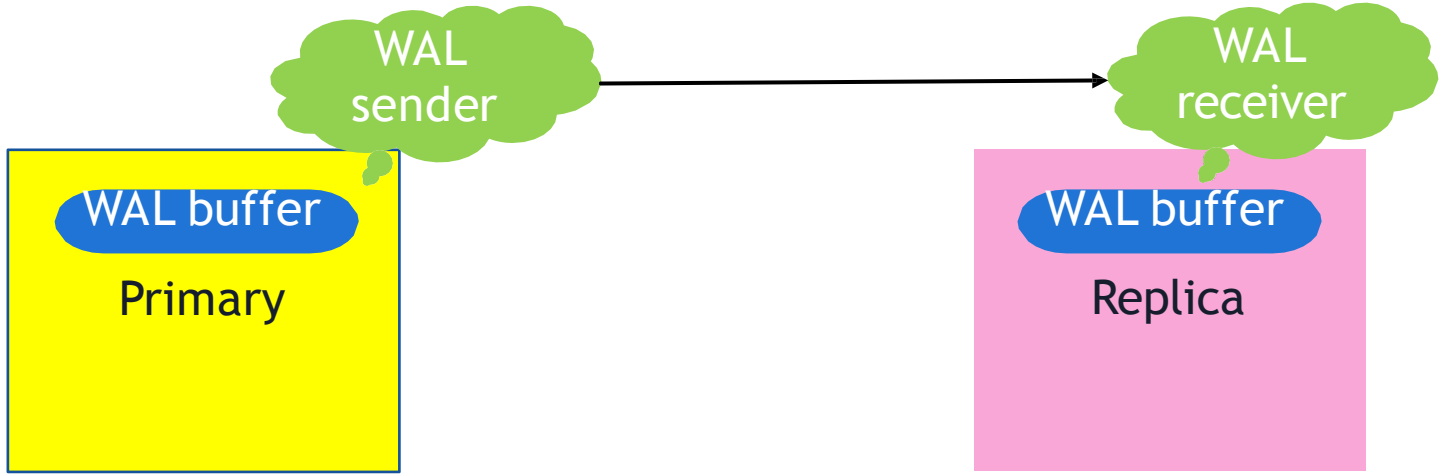
Customer questions

- How to deal with replica lag?
- Relation between vacuum and replication process?
- How to manage query cancelations on replicas?

Physical Streaming Replication Basics



Recovery Conflicts And Replication Lag



- *Auto commit is ON*
- *Synchronous commit is ON*

Time	Primary	Replica
t0	-	Reading from “A”
t1	WAL generating operation on ”A”	Reading from “A”
t2	WAL generating operation completed	Still Reading from “A”
t4	-	Cancelling statement due to conflict with recovery

What causes recovery conflicts? – most common reasons

- Vacuum cleaning up records on primary and sending same info in WAL to standby - standby snapshots can still “see” some rows which are to be removed.
- Application of WAL on standby waiting due to long running on standby as it is still seeing old snapshot of data.

Important parameters (to be set on standby)

- For “Delaying” conflicts with recovery:
  max_standby_streaming_delay
  max_standby_archive_delay

- For “Avoiding” conflicts due to vacuum on primary: hot_standby_feedback

Other factors for replication lag

- Network issue
- Server bottleneck – compute/storage
- wal_keep_segments
- New replica? – check logs to see if recovery is from archive location

Vacuum and Autovacuum

Customer Questions

- Why does a select from a table take a lot of time?
- Why are index scans taking time?
- Why does a table with only few rows occupying a lot of space?
- Why is vacuum taking time?
- Why is autovacuum not running/slow running?
- When do I need a manual vacuum?

Vacuum and Autovacuum

- Vacuum is a SQL command that performs certain maintenance operations
- Autovacuum processes run the “Vacuum” and/or “Analyze” command based on certain thresholds OR when the system is approaching towards “Transaction ID Wraparound”

Autovacuum – automatic execution of vacuum and analyze

- When the number of dead tuples generated since the last VACUUM exceeds the “vacuum threshold”

```
vacuum threshold = vacuum base threshold + vacuum scale factor * number of tuples
```

where the vacuum base threshold is autovacuum_vacuum_threshold, the vacuum scale factor is autovacuum_vacuum_scale_factor, and the number of tuples is `pg_class.reltuples`.

- When the number of tuples inserted since the last vacuum has exceeded the defined insert threshold (**v13+**)

```
vacuum insert threshold = vacuum base insert threshold + vacuum insert scale factor * number of tuples
```

where the vacuum insert base threshold is autovacuum_vacuum_insert_threshold, and vacuum insert scale factor is autovacuum_vacuum_insert_scale_factor.

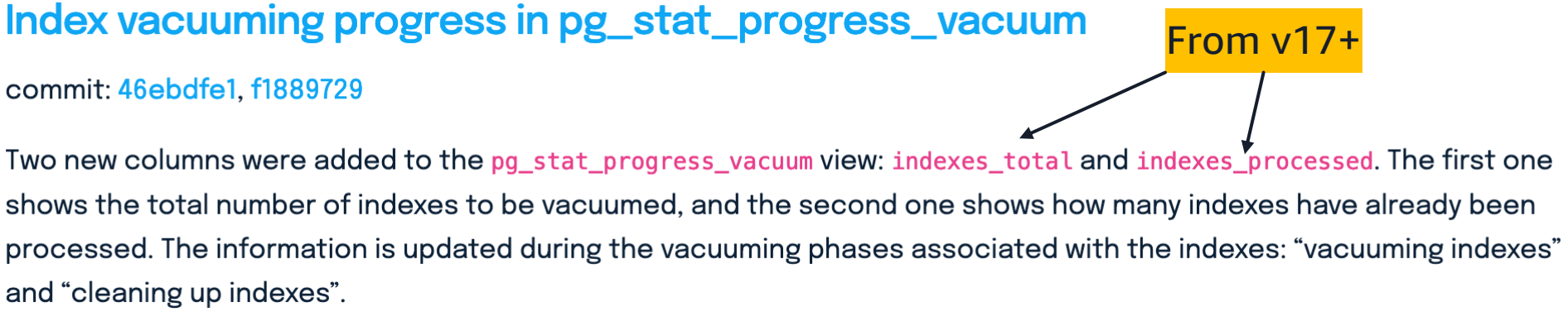
Autovacuum – automatic execution of vacuum and analyze

- When the total number of tuples inserted, updated, or deleted since the last ANALYZE exceeds the “analyze threshold”

```
analyze threshold = analyze base threshold + analyze scale factor * number of tuples
```

Vacuum Best practices

- In order to remember the tuples maintenance_work_mem is used, make sure you have enough of it!
- The more the indexes, the more time it will take, irrespective of the size of the indexes. Therefore, check and drop unused indexes (pg_stat_user_indexes).



Vacuum Best practices

- In order to remember the tuples maintenance_work_mem is used, make sure you have enough of it!
- The more the indexes, the more time it will take, irrespective of the size of the indexes. Therefore, check and drop unused indexes (pg_stat_user_indexes).
- Vacuum cleans both tables and associated indexes, however, this causes bloat in the indexes. Therefore, it might be useful to re-index to remove index bloat.

Vacuum Best practices

- Vacuum full is not recommended unless absolutely needed – Try CTAS instead of deleting a major chunk of data OR partitioning approach for managing data (discussed earlier)
- autovacuum_vacuum_cost_limit is divided amongst autovacuum_max_workers – so increase them both if you need to.
- Know when to run manual vacuum

Troubleshooting autovacuum not running/slow running

- Is autovacuum threshold met?
- Is ‘autovacuum’ set to ’off’ in the parameter group?
- Is autovacuum disabled for the relation?
- Any bottlenecks observed on compute/storage level when AV is running? – pg_stat_progress_vacuum

Troubleshooting autovacuum not running/slow running

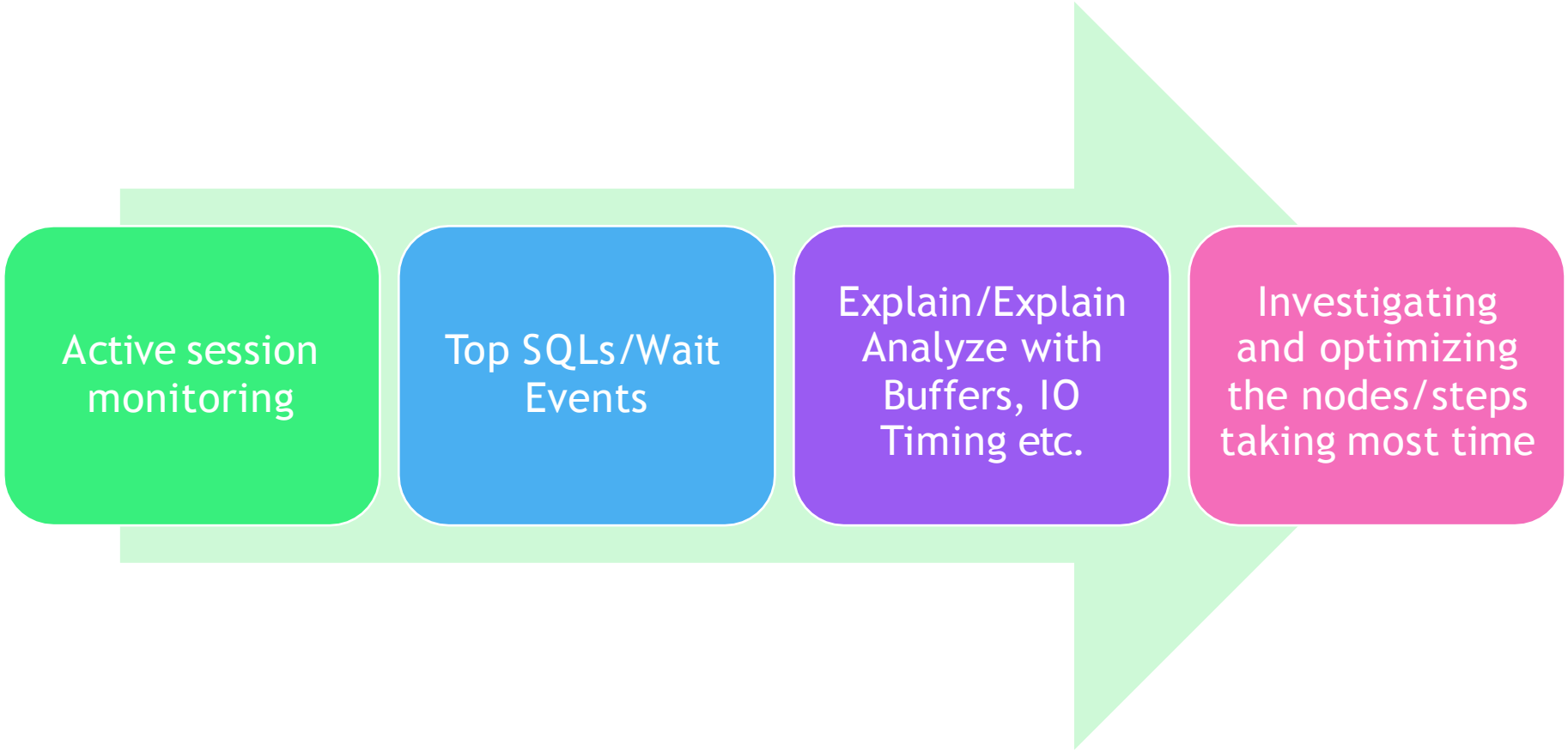
- Are there any open/long running transactions blocking AV to run? – *pg_stat_activity view ;idle_in_transaction_session_timeout parameter*
- Any locks conflicting with AV, taken by another transaction on the same resource? – *pg_stat_activity and pg_locks view*
- Is hot_standby_feedback enabled on the replica?
- Any open prepared transactions? - *max_prepared_transactions parameter ; pg_prepared_xacts view*

Query Tuning

Customer Questions

- How do we identify slow queries?
- How to identify which queries to be tuned?
- What are the things to look for in an EXPLAIN plan?
- What are some techniques for query tuning?

Query tuning Methodology



Active Session Monitoring

pg_stat_activity : One row per server process showing information related to the current activity of that process

```
postgres=> select pid,query,state,wait_event_type, wait_event from pg_stat_activity;
  pid  |                                                                                query                                                                                | state  | wait_event_type |     wait_event
-------+-------------------------------------------------------------------------------------------------------------------------------------------------------------------+--------+-----------------+---------------------
   381 |                                                                                                                                                                   |        | Activity        | AutoVacuumMain
   383 |                                                                                                                                                                   |        | Activity        | LogicalLauncherMain
 30924 | SELECT value FROM rds_heartbeat2                                                                                                                                  | idle   | Client          | ClientRead
   394 | START_REPLICATION SLOT "rds_eu_west_1_db_l6m3njkhwqhgbpfvpo5w7i2lhu" 239/48000000 TIMELINE 1                                                                      | active | Activity        | WalSenderMain
 30969 | COMMIT                                                                                                                                                            | idle   | Client          | ClientRead
 11641 | select pid,query,state,wait_event_type, wait_event from pg_stat_activity;                                                                                         | active |                 |
   378 |                                                                                                                                                                   |        | Activity        | BgWriterHibernate
   382 |                                                                                                                                                                   |        | Activity        | ArchiverMain
   377 |                                                                                                                                                                   |        | Activity        | CheckpointerMain
   380 |                                                                                                                                                                   |        | Activity        | WalWriterMain
(10 rows)
```

- Check if the query is blocked by joining **pg_stat_activity** with **pg_locks**
- Monitor and understand wait events
- Parameters to tune for session management : **idle_session_timeout, idle_in_transaction_session_timeout**

EXPLAIN options

```
postgres=> EXPLAIN (ANALYZE, WAL, BUFFERS) DELETE FROM test WHERE random() < 0.5;
                                                  QUERY PLAN
------------------------------------------------------------------------------------------------------------
 Delete on test  (cost=0.00..14.80 rows=0 width=0) (actual time=0.424..0.425 rows=0 loops=1)
   Buffers: shared hit=283 dirtied=8
   WAL: records=269 fpi=7 bytes=22733
   ->  Seq Scan on test  (cost=0.00..14.80 rows=173 width=6) (actual time=0.006..0.058 rows=269 loops=1)
         Filter: (random() < '0.5'::double precision)
         Rows Removed by Filter: 251
         Buffers: shared hit=7
 Planning:
   Buffers: shared hit=11
 Planning Time: 0.100 ms
 Execution Time: 0.457 ms
(11 rows)
```

- If using ANALYZE, run inside transaction block for DMLs
- Actual vs Estimated Rows
- Execution Time

The information about WALs can be most useful for understanding the generation of ‘full page images’ and hence, tuning checkpoints

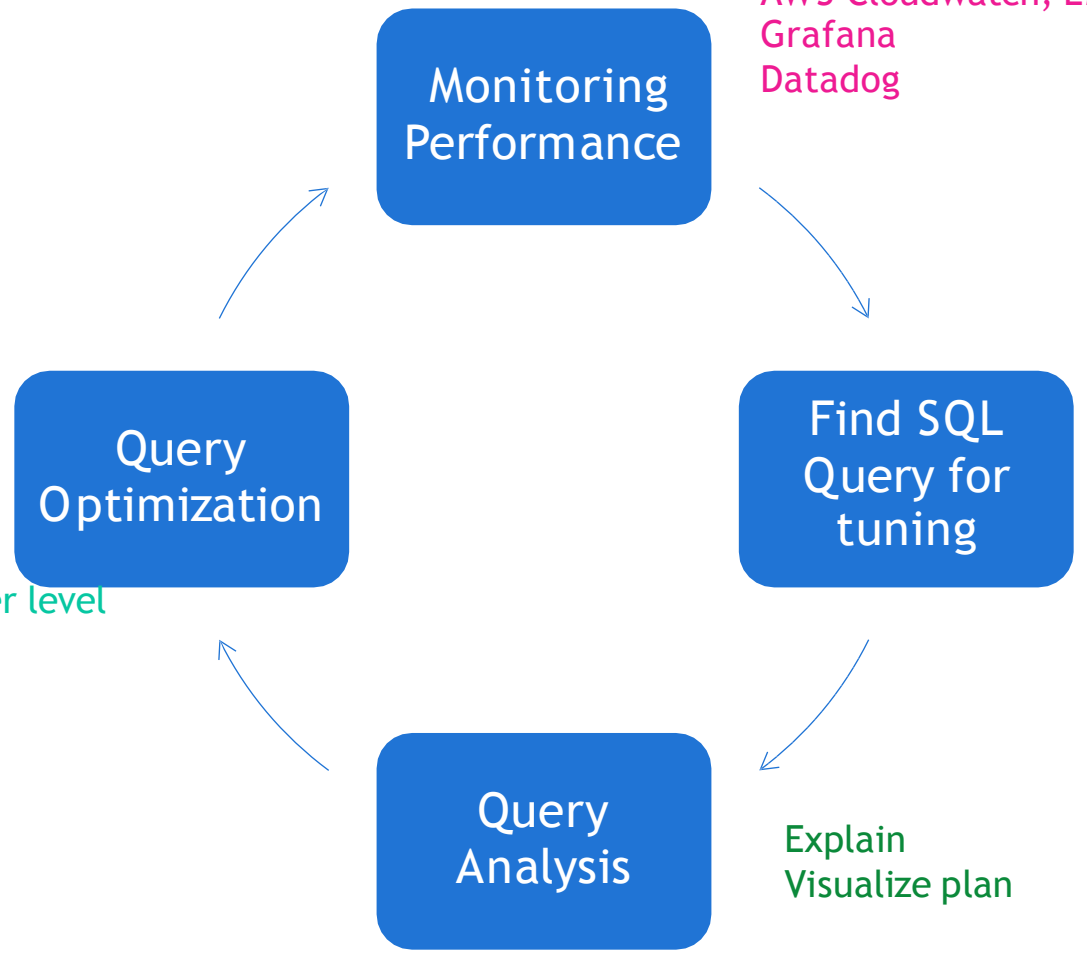
https://www.postgresql.eu/events/nordicpgday2024/schedule/session/5100-explain-explained-undertanding-the-postgresql-planner-better/

Actions to take after slow query investigation

- Collect more statistics (default_statistics_target) or extended statistics
- Modify relevant parameters – work_mem ; maintenance_work_mem etc.
- Fix the query plan, if needed using pg_hint_plan
- Add relevant indexes and drop unused ones
- Implement or change table partitioning strategy
- Have another cache in front of the database (eg – ElastiCache in front of RDS)

https://www.postgresql.eu/events/pgconfde2024/schedule/session/5369-understanding-postgresql-statistics-to-optimize-performance/

Query Tuning Cycle



AWS Cloudwatch, EM and PI for RDS/ Aurora
Grafana
Datadog

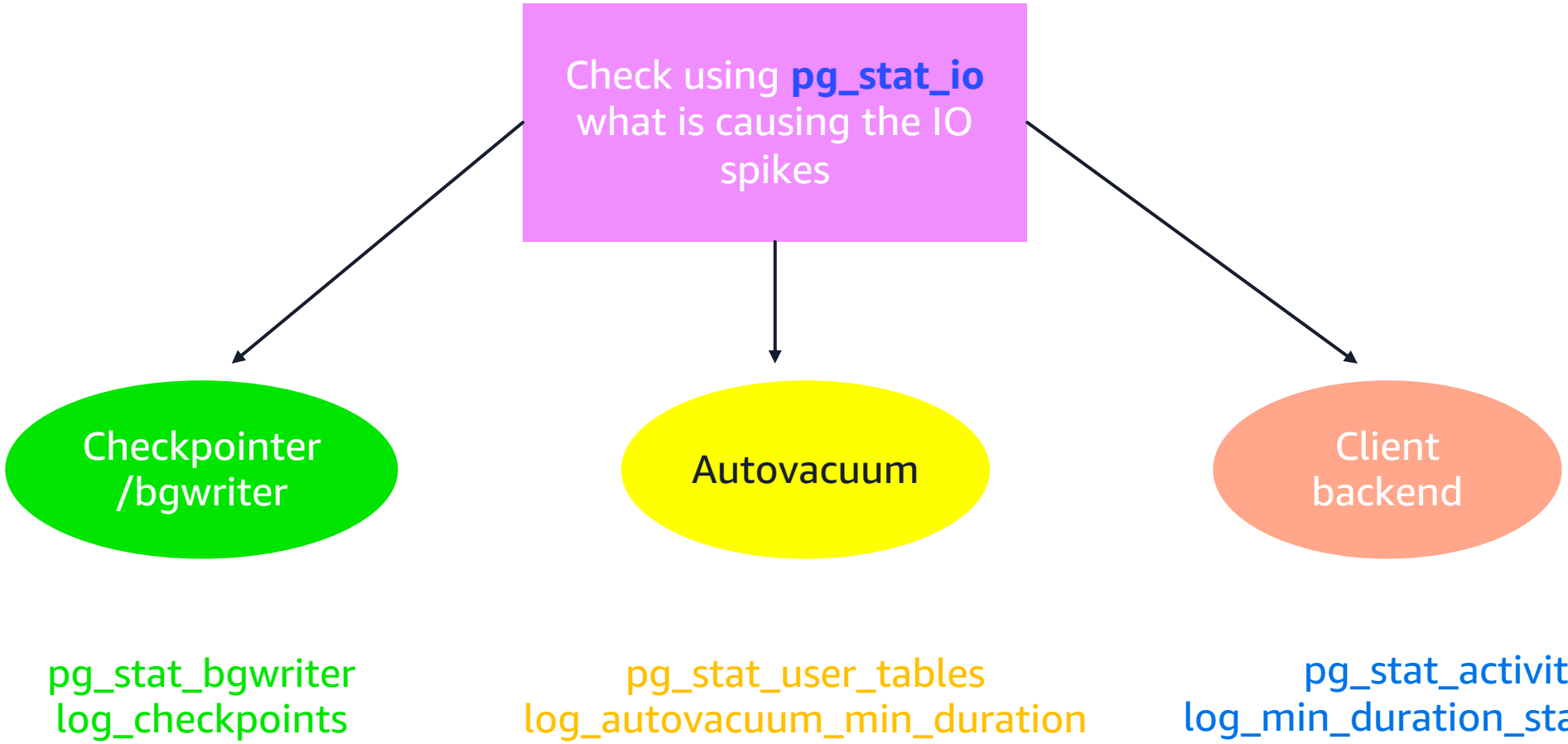
Logging paramters/Error Log
pg_stat_statement
auto_explain extension

Explain
Visualize plan

Collecting more statistics
Relevant indexes (create/drop)
pg_hint_plan
update parameters database/session/user level

Troubleshooting Example

#1 - I see very high write IO spikes in my metrics. What should I do?



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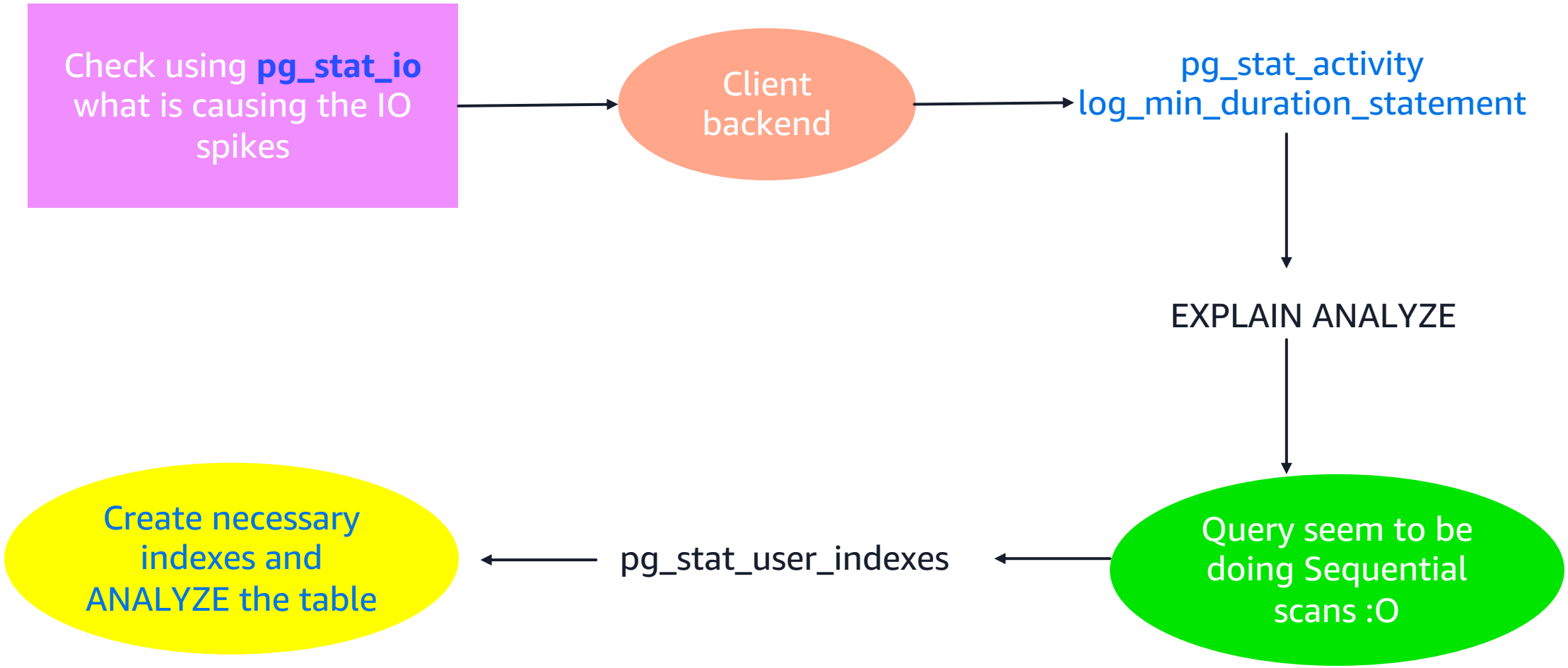


Version Upgrades

Customer Questions

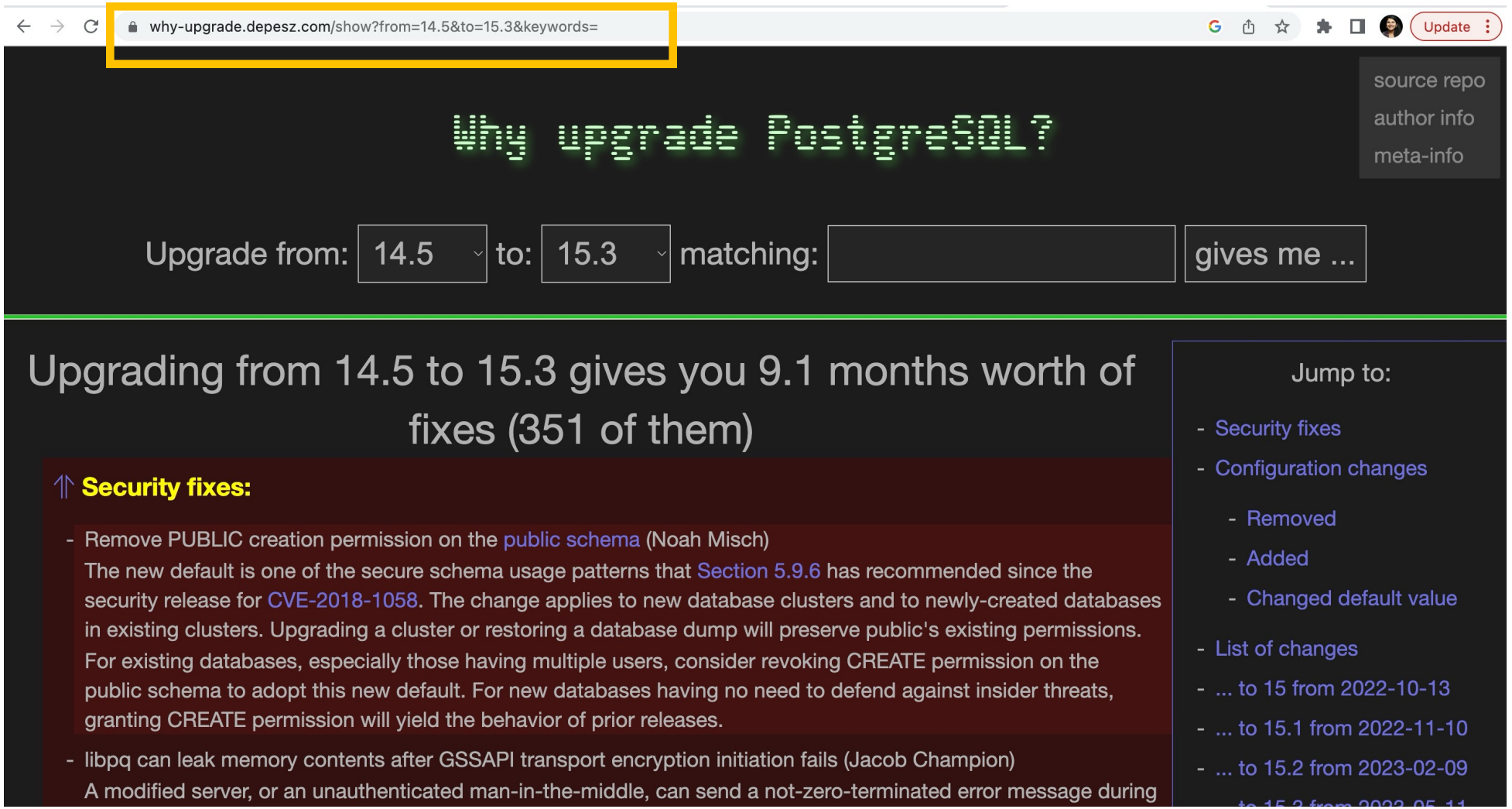
- Why to upgrade?
- When to upgrade?
- How to upgrade?

Version Upgrades

- **Minor version upgrades**
  - Patches to the binaries
  - No new functionality
  - May contain important security fixes

- **Major version upgrades**
  - Tracks the community yearly release cycle
  - Introduces new functionality
  - May change system catalogs and page formats
  - Supports skip version in-place upgrade

Why should you upgrade?



Why should you upgrade?

Replication

	16	15	14	13	12	11
ALTER SUBSCRIPTION ... SKIP	Yes	Yes	No	No	No	No
Cascading streaming replication	Yes	Yes	Yes	Yes	Yes	Yes
Configure max WAL retention for replication slots	Yes	Yes	Yes	Yes	No	No
Logical replication	Yes	Yes	Yes	Yes	Yes	Yes
Logical replication avoids replication loops	Yes	No	No	No	No	No
Logical replication column lists	Yes	Yes	No	No	No	No
Logical replication for partitioned tables	Yes	Yes	Yes	Yes	No	No
Logical replication from standbys	Yes	No	No	No	No	No

https://www.postgresql.org/docs/13/runtime-config-replication.html#GUC-MAX-SLOT-WAL-KEEP-SIZE

Things to remember for upgrades

- Update DB engine, when a new release becomes available (recommended) – A major version is depreciated every 5 years
- Set an appropriate maintenance window
- Read replica can have different **minor** version than primary – can be used for testing newer versions for **major** (promote and upgrade replica)
- Use pglogical or native logical replication for minimum downtime major version upgrade (alternatives to pg_upgrade)
- Test engine update process in a representative pre-prod environment
- Run "Analyze” after upgrade to make sure statistics are up-to-date for planners use
- A PostgreSQL engine upgrade doesn't upgrade most PostgreSQL extensions, make sure you upgrade them after upgrade (ALTER EXTENSION UPDATE).

PostgreSQL Happiness Hints

version: jer_s/2022-04-26

Checksums and Huge Pages Enabled

Connection Pooling

- Centralized (e.g. pgbouncer) and decentralized (e.g. JDBC) architectures
- Recycle server connections (e.g. server_lifetime)
- Limit or avoid dynamic growth when practical – queue at a tier above the DB

Default Limits: Temp Usage, Statement & Idle Transaction Timeout

- Timeouts 5-15 minutes or lower, increase at session level if needed

Scaling

- Measure conn count in hundreds (not thousands), table count in thousands (not hundreds of thousands), relation size in GB (not TB), indexes per table in single digits (not double digits)
- Higher ranges work, but often require budget for experienced & expensive PostgreSQL staff
- To scale workloads, shard across instances or carefully partition tables

Updates and Upgrades

- PostgreSQL quarterly stable “minors” = security and critical fixes only
  - On Aurora: minors can have new development work
- Before major version upgrade, compare plans and latencies of top SQL on upgraded test copy
- Remember to upgrade extensions; it’s not automatic
- Stats/analyze after major version upgrade

Logging

- Minimum 1 month retention (on AWS: use max retention and publish to Cloudwatch)
- Log autovacuum minimum duration = 10 seconds or lower
- Log lock waits
- Log temp usage when close to the default limit
- On AWS: autovacuum force logging level = WARNING

Multiple Physical Data Centers (= Multi-AZ on AWS)

Physical Backups

- Minimum 1 month retention
- Regular restore testing

Logical Backups (at least one)

- Scheduled exports/dumps and redrive/replay
- Logical replication

Active Session Monitoring (= Performance Insights on AWS)

- Save snapshots of pg_stat_activity making sure to include wait events
- Keep historical data, minimum 1 month retention (hopefully much more)

SQL and Catalog and Other Database Statistics Monitoring

- Preload pg_stat_statements
- Save snapshots of pg_stat_statements and key statistics
  - Exec plans (eg. auto_explain or others), relation sizes (bytes & rows incl catalogs), unused indexes
  - Rates: tuple fetch & return, WAL record & fpi & byte, DDL, XID, subtransaction, multixact, conn
- Keep historical data, minimum 1 month retention (hopefully much more)

OS Monitoring (= Enhanced Monitoring on AWS)

- Granularity of 10 seconds or lower (1 second if possible)
- Keep historical data, minimum 1 month retention (hopefully much more)

Alarms

- **Average active sessions** (= dbload cloudwatch metric on AWS)
- Memory / swap
- Disk space: %space and %inodes (and free local storage on Aurora)
- Hot standby & logical replication lag / WAL size (disk space) on primary
- Unexpected errors in the logs, both database and application tier
- Maximum used transaction IDs (aka time to wraparound)
- Checkpoint: time since latest & warnings in log (doesn’t apply to Aurora)

Thank you!

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