Anatomy of Table-Level Locks in PostgreSQL

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Select * from me;

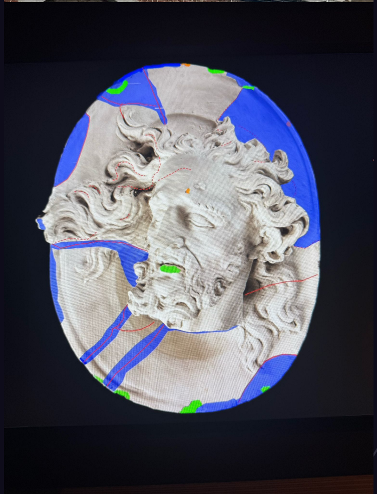
Current:

- Staff Engineer at Xata
- Postgres Contributor
- Co-founder of Prague PostgreSQL Meetup
- Co-founder & General Coordinator of Kadin Yazilimci (Women Devs Turkey)
- Co-founder & Chair of Diva: Dive into AI Conference

Past:

- Board Member at Postgres Europe
- Staff Engineer at EDB, 2ndQuadrant

First time in Mons! Excited to be here!



Agenda

01 MVCC

02 DDL Locks

03 Postgres Lock Queue

04 Reducing Locking Impact

05 pgroll

Locks

- Concurrency primitive
- Ensures conflicting actions don’t happen in parallel
- Used everywhere

Postgres lock avoidance

- Uses MVCC for DML
- Writes make new copy of data
- Reads don’t block writes, writes don’t block reads
- But even reads still lock objects (tables, types, views)

MVCC example

Transaction 1 (txid: 100)	Transaction 2 (txid: 101)	Row Versions
BEGIN;		(0,1) | 1 | Alice | 50000 | 99 | null
SELECT ctid, id, name, salary, xmin, xmax FROM employees WHERE id = 1; – Sees: salary = 50000		(0,1) | 1 | Alice | 50000 | 99 | null
	BEGIN;	(0,1) | 1 | Alice | 50000 | 99 | null
	UPDATE employees SET salary = 60000 WHERE id = 1;	(0,1) | 1 | Alice | 50000 | 99 | 101 (0,2) | 1 | Alice | 60000 | 101 | null
SELECT ctid, id, name, salary, xmin, xmax FROM employees WHERE id = 1; – Sees: salary = 50000		(0,1) | 1 | Alice | 50000 | 99 | 101 (0,2) | 1 | Alice | 60000 | 101 | null
	COMMIT;	(0,1) | 1 | Alice | 50000 | 99 | 101 (0,2) | 1 | Alice | 60000 | 101 | null
SELECT ctid, id, name, salary, xmin, xmax FROM employees WHERE id = 1; – Sees: salary = 60000		(0,1) | 1 | Alice | 50000 | 99 | 101 (0,2) | 1 | Alice | 60000 | 101 | null
COMMIT;		(0,1) | 1 | Alice | 50000 | 99 | 101 (0,2) | 1 | Alice | 60000 | 101 | null

Why we lock

- Reduces the throughput
- May increase latency - Loss of performance
- Correctness - Different Isolation Levels

DDL

- Often needs stronger lock modes on objects
- Especially things like ALTER TABLE, VACUUM FULL
- May block other DDL, DML or even SELECTs accessing same object
- Every DDL command (and sometimes sub-command) is different

Takeaway #1:

MVCC will protect you from writes blocking reads, but not from object locks taken by DDL.

Different variants of the same DDL command may need very different lock strength.

Table-level lock modes

- ACCESS SHARE - SELECTs
- ROW SHARE - SELECT FOR UPDATE/SHARE
- ROW EXCLUSIVE - DML (INSERT/UPDATE/DELETE/MERGE)
- SHARE UPDATE EXCLUSIVE - VACUUM, ANALYZE, CREATE INDEX CONCURRENTLY
- SHARE - CREATE INDEX
- SHARE ROW EXCLUSIVE - CREATE TRIGGER
- EXCLUSIVE - REFRESH MATERIALIZED VIEW CONCURRENTLY
- ACCESS EXCLUSIVE - DROP TABLE, TRUNCATE, some forms of ALTER TABLE, VACUUM FULL

Table-level lock modes

- Different modes conflict with different other modes
- ACCESS EXCLUSIVE conflicts with everything, including ACCESS SHARE (SELECT)
- Postgres has many optimizations to take weaker lock modes when it can
- But nothing is perfect, it will still take strong locks on some DDL
- Once a transaction takes a lock, it holds it even when the statement has finished

Takeaway #2:

DDL may block writes and/or reads for the whole run time of the transaction.

Don’t mix commands that need strong locks with other commands in the same transaction.

Lock queue

- When requested lock mode conflicts with already acquired lock mode by different backend, it needs to wait
- By default, it waits forever and can stall everything unless you specify lock_timeout
- Waiting locks form a lock queue
- The queue is not visible in pg_locks, use pg_blocking_pids() to see what other backends blocks a specific backend
- Locks that are ahead in the queue can block locks that are behind them in the queue

Takeaway #3:

Use lock_timeout to limit how long something waits for lock.

Using lock_timeout for DDL commands is often enough. You must be able to handle failures, for example retry the DDL again.

Lock queue blocking example

Let’s reiterate: Locks that are ahead in the queue can block locks that are behind them in the queue

1. Long running SELECT holds ACCESS SHARE LOCK
2. ALTER TABLE DETACH PARTITION needs brief ACCESS EXCLUSIVE LOCK
3. They conflict so ALTER TABLE is put into lock queue
4. Another ~30 backends try to do simple primary key lookup SELECTs
5. They conflict with the ALTER TABLEs lock, so they are put into the lock queue behind it
6. All access to the given table is now queued behind and no processing happens until the long running SELECT and ALTER TABLE both finish

Takeaway #4:

Any long-running query can cause blocking during schema changes.

The cumulative waiting effect can be mitigated by lock_timeout (remember takeaway #3).

Multiple ways to achieve the same result #1

Sometimes, there are less impactful ways to do something

- Use CONCURRENTLY commands
  - CREATE INDEX CONCURRENTLY
  - ALTER TABLE DETACH PARTITION CONCURRENTLY
- They use less locking, however
  - They take longer
  - Not transactional (can't be in transaction block, can't be rolled back)
  - Leave half-done work on failure (there are commands to clean up or finish the work)
- As a result: Treat them with care

Multiple ways to achieve the same result #2

Some actions can be split

- ALTER TABLE mytable ADD COLUMN newcol timestamptz NOT NULL DEFAULT clock_timestamp()
    - ACCESS EXCLUSIVE lock
    - Blocks everything else
    - Table rewrite - holds lock for a long time if table is big
- Can be done in steps
    - ALTER TABLE mytable ADD COLUMN newcol timestamptz DEFAULT clock_timestamp()
    - UPDATE TABLE mytable SET newcol = clock_timestamp() WHERE newcol IS NULL
        - You actually want to do the update in batches, remember any long running query can cause problems
    - ALTER TABLE mytable ALTER COLUMN newcol SET NOT NULL

Multiple ways to achieve the same result #2 continued

Some actions can be split

- ALTER TABLE mytable ALTER COLUMN newcol SET NOT NULL
  - Still takes long time and blocks writes
    - But does not block reads unlike the original command
- Can be further split into
  - ALTER TABLE mytable ADD CONSTRAINT mytable_newcol_not_null CHECK (newcol IS NOT NULL) NOT VALID
  - ALTER TABLE mytable VALIDATE CONSTRAINT mytable_newcol_not_null
  - This way the scan during VALIDATE CONSTRAINT does not block writes

Takeaway #5:

Try to find an approach that does less locking.

Postgres manual contains all the CONCURRENTLY commands.

Splitting actions takes expertise and some things are impossible (or very hard) to do without heavy locking from plain SQL.

Postgres improves over time

Let's look at slightly modified example from before

- ALTER TABLE mytable ADD COLUMN newcol int NOT NULL DEFAULT 1
- Still takes ACCESS EXCLUSIVE lock
    - Blocks everything else
- Does not rewrite table because 1 is constant and can be stored as metadata
    - Locks for very short time
- This used to rewrite in the old versions of Postgres just like the previous example

Takeaway #6:

Make sure you are running the newest version of Postgres.

Improvements in locking and even how long the command takes (and holds the lock) happens in newer versions.

New CONCURRENTLY command variants are added in newer versions.

Enter pgroll

Zero-downtime, reversible schema changes for Postgres

Motivation

(Some) Postgres schema changes are difficult

- Locking issues (most ALTER statements take the ACCESS EXCLUSIVE lock)
- Data backfill (e.g. add a column with unique constraints)
- Require multiple steps (e.g renaming a column)
- Backwards incompatible with old or new versions of the application (e.g. dropping a column)

How does pgroll work?

How does pgroll work?

- Higher level operations
- Automatic Expand/Contract pattern
- Multi-version schema views

Higher level operations

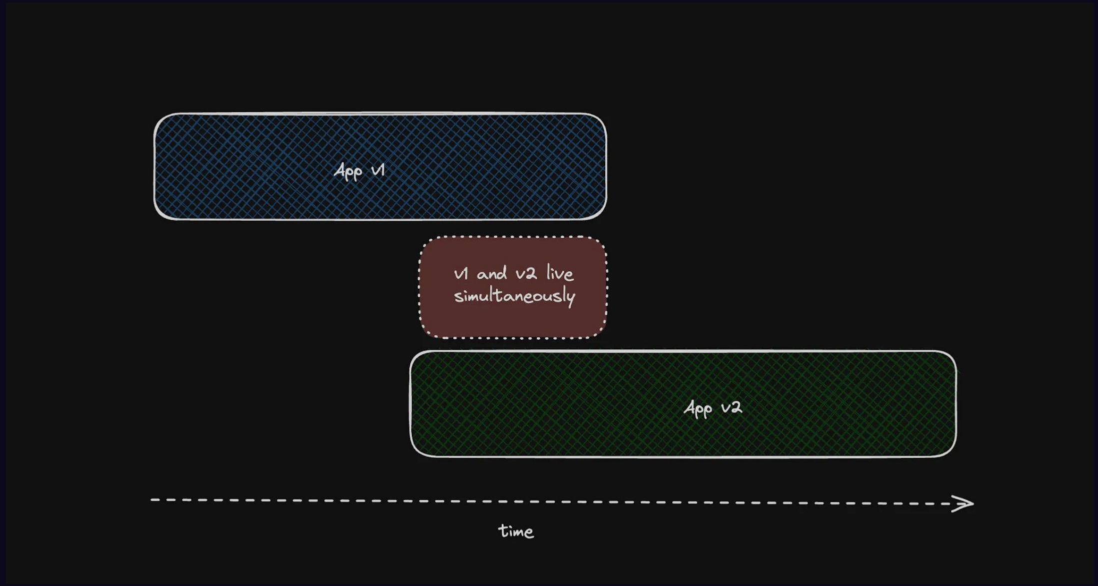
- Instead of ALTER statements, pgroll uses higher level operations:
  - Add column
  - Rename column
  - Change type of column
  - Add index
  - Add constraint
  - Etc.
- Backfilling of data is represented in the JSON

```
{
  "name": "18_change_column_type",
  "operations": [
    {
      "alter_column": {
        "table": "reviews",
        "column": "rating",
        "type": "integer",
        "up": "CAST(rating AS integer)",
        "down": "CAST(rating AS text)"
      }
    }
  ]
}
```

Automated Expand and Contract pattern

- Temporary columns are added to the physical table
- Data is backfilled and transformed in background
- Views hide or show the different columns
- Temporary columns are deleted when no longer needed

Multiple-schema versions via views

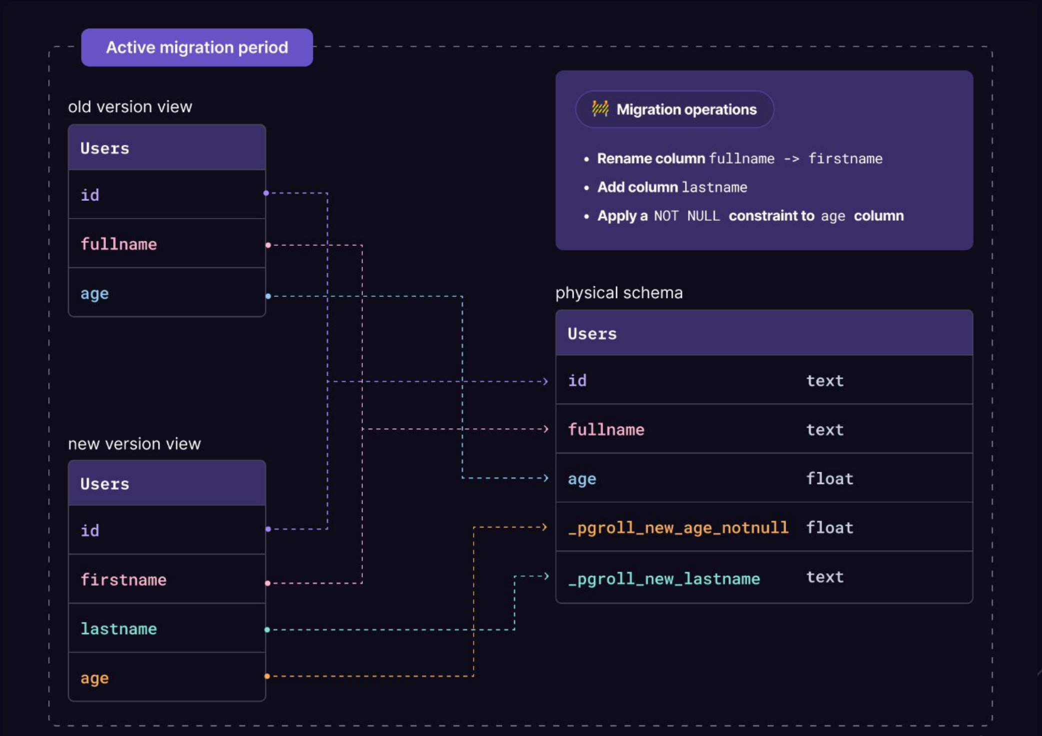


Workflow is always the same:

- Start migration
- Do a (rolling) upgrade of your application
- Finalize the migration

https://xata.io/blog/multi-version-schema-migrations

Different version of the schema are exposed via views



- Temporary columns are added to the physical table
- Data is backfilled and transformed in background
- Views hide or show the different columns

How - Application selects its version by setting the `search_path`

```sql
-- Switch back the new schema, which disallows `NULL`s in the `name` field
SET search_path TO mig_cq778qtlu0oe0bpredl0;

-- Attempt to insert a `NULL` value in the name field
INSERT INTO users(name) VALUES (NULL)
-- ERROR null value in column "name" of relation "users" violates not-null constraint

-- Switch back the old schema, which allows `NULL`s in the `name` field
SET search_path TO mig_cq778jdlu0oe0bpredk0;

-- Attempt to insert a `NULL` value in the name field
INSERT INTO users(name) VALUES (NULL)

-- Retrieve the data from the `users` table
SELECT * FROM users ORDER BY name DESC;
```

How - automatic backfilling

- The “up” SQL expression is used to convert or generate the required data
- You can control the batch size and rate

```
{
  "name": "18_change_column_type",
  "operations": [
    {
      "alter_column": {
        "table": "reviews",
        "column": "rating",
        "type": "integer",
        "up": "CAST(rating AS integer)",
        "down": "CAST(rating AS text)"
      }
    }
  ]
}
```

How - triggers update and downgrade data in both directions

What about new writes to the table?

- Triggers are installed to convert the data “up” and “down”

Note: dual write at the column level is necessary here, but you’d have to do it anyway.

```json
{
  "name": "18_change_column_type",
  "operations": [
    {
      "alter_column": {
        "table": "reviews",
        "column": "rating",
        "type": "integer",
        "up": "CAST(rating AS integer)",
        "down": "CAST(rating AS text)"
      }
    }
  ]
}
```

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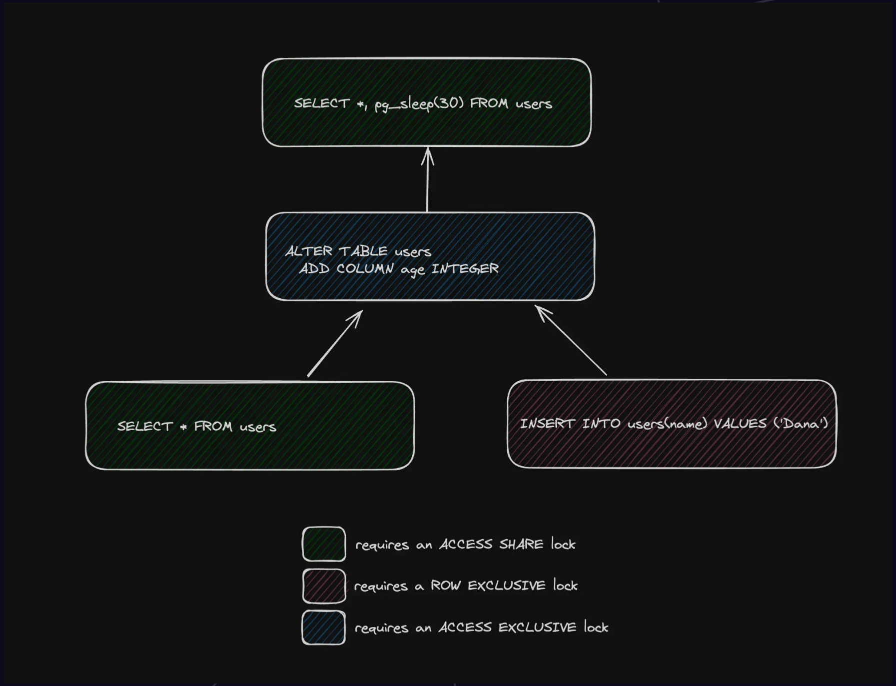
The "trylock" trick is built-in

- Generated ALTER is prefixed with a SET `lock_timeout` command
- Avoids issues with the lock queue



Benefits

- Rollback is easy - just drop the views and intermediary columns.
- The tool takes care of locking issues and common issues.
- The merging workflow is always the same:
  - Start the pgroll migration
  - Roll-out the application upgrade (can be blue-green)
  - Complete the pgroll migration

Final Takeway:

Smart tools like pgroll can help you avoid many common pitfalls.

Zero-downtime, reversible schema changes are possible.

For more

https://github.com/xataio/pgroll

Anatomy of table-level locks: reducing locking impact

By Gulcin Yildirim Jelinek Jan 20, 2025

Not all operations require the same level of locking, and PostgreSQL offers tools and techniques to minimize locking impact.

https://pgroll.com/blog

Merci beaucoup!