FIXING LOCK CONTENTION IN OLTP

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PGUG Estonia meetup 2025

CYBERTEC
POSTGRESQL SERVICES & SUPPORT

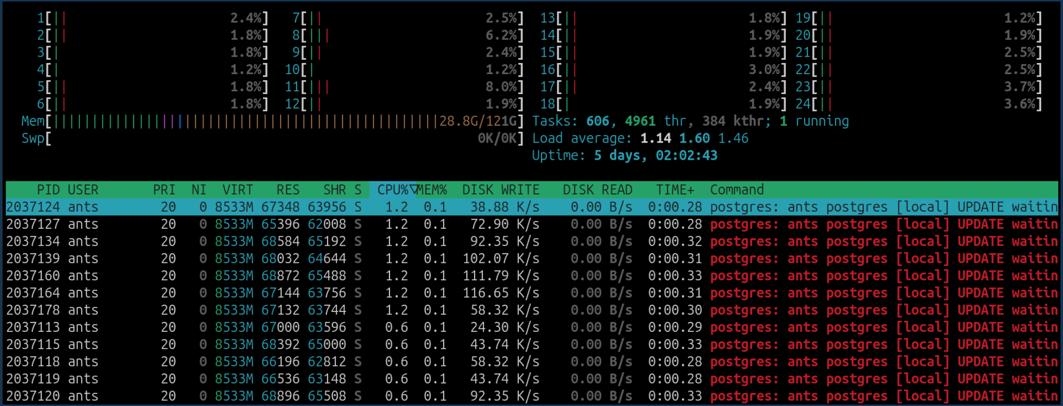
Hello

About me

- Cybertec Lead Database Consultant
- PostgreSQL contributor
- Performance, HA, extensions, etc.

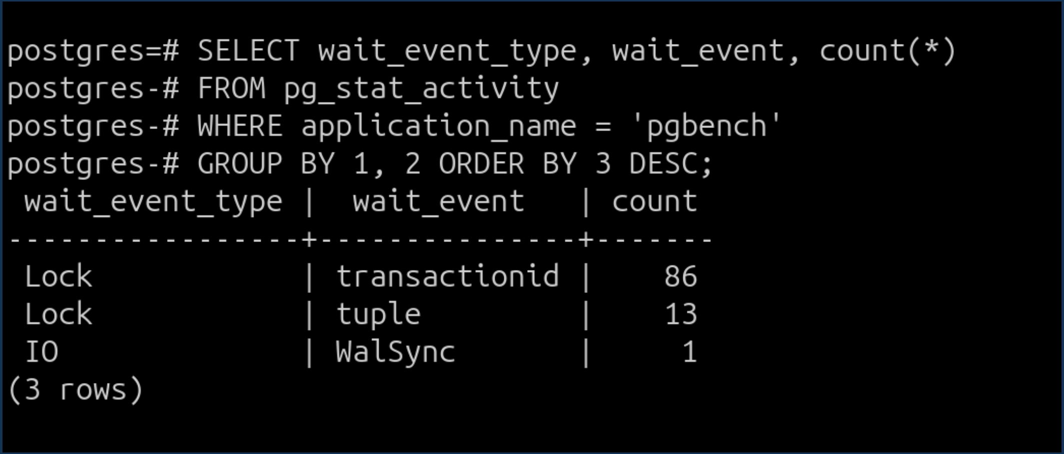
The problem statement

Help, the app is too slow



```
    1[||                    2.4%]   7[||                      2.5%]  13[||                     1.8%]  19[||                     1.2%]
    2[||                    1.8%]   8[|||                     6.2%]  14[||                     1.9%]  20[||                     1.9%]
    3[|                     1.8%]   9[||                      2.4%]  15[||                     1.9%]  21[||                     2.5%]
    4[|                     1.2%]  10[|                       1.2%]  16[||                     3.0%]  22[||                     2.5%]
    5[||                    1.8%]  11[|||                     8.0%]  17[||                     2.4%]  23[||                     3.7%]
    6[||                    1.8%]  12[||                      1.9%]  18[|                      1.9%]  24[||                     3.6%]
  Mem[||||||||||||||||||||||||||||||||||||||||||||||||||||28.8G/121G] Tasks: 606, 4961 thr, 384 kthr; 1 running
  Swp[                                                       0K/0K] Load average: 1.14 1.60 1.46
                                                                     Uptime: 5 days, 02:02:43

    PID USER      PRI  NI  VIRT   RES   SHR S  CPU%▽MEM%  DISK WRITE   DISK READ    TIME+  Command
2037124 ants       20   0 8533M 67348 63956 S   1.2  0.1   38.88 K/s    0.00 B/s  0:00.28 postgres: ants postgres [local] UPDATE waitin
2037127 ants       20   0 8533M 65396 62008 S   1.2  0.1   72.90 K/s    0.00 B/s  0:00.28 postgres: ants postgres [local] UPDATE waitin
2037134 ants       20   0 8533M 68584 65192 S   1.2  0.1   92.35 K/s    0.00 B/s  0:00.32 postgres: ants postgres [local] UPDATE waitin
2037139 ants       20   0 8533M 68032 64644 S   1.2  0.1  102.07 K/s    0.00 B/s  0:00.31 postgres: ants postgres [local] UPDATE waitin
2037160 ants       20   0 8533M 68872 65488 S   1.2  0.1  111.79 K/s    0.00 B/s  0:00.33 postgres: ants postgres [local] UPDATE waitin
2037164 ants       20   0 8533M 67144 63756 S   1.2  0.1  116.65 K/s    0.00 B/s  0:00.31 postgres: ants postgres [local] UPDATE waitin
2037178 ants       20   0 8533M 67132 63744 S   1.2  0.1   58.32 K/s    0.00 B/s  0:00.30 postgres: ants postgres [local] UPDATE waitin
2037113 ants       20   0 8533M 67000 63596 S   0.6  0.1   24.30 K/s    0.00 B/s  0:00.29 postgres: ants postgres [local] UPDATE waitin
2037115 ants       20   0 8533M 68392 65000 S   0.6  0.1   43.74 K/s    0.00 B/s  0:00.33 postgres: ants postgres [local] UPDATE waitin
2037118 ants       20   0 8533M 66196 62812 S   0.6  0.1   58.32 K/s    0.00 B/s  0:00.28 postgres: ants postgres [local] UPDATE waitin
2037119 ants       20   0 8533M 66536 63148 S   0.6  0.1   43.74 K/s    0.00 B/s  0:00.28 postgres: ants postgres [local] UPDATE waitin
2037120 ants       20   0 8533M 68896 65508 S   0.6  0.1   92.35 K/s    0.00 B/s  0:00.33 postgres: ants postgres [local] UPDATE waitin
```

Wait events to the rescue



```
postgres=# SELECT wait_event_type, wait_event, count(*)
postgres-# FROM pg_stat_activity
postgres-# WHERE application_name = 'pgbench'
postgres-# GROUP BY 1, 2 ORDER BY 3 DESC;
 wait_event_type |  wait_event   | count
-----------------+---------------+-------
 Lock            | transactionid |    86
 Lock            | tuple         |    13
 IO              | WalSync       |     1
(3 rows)
```

What’s happening

Request A:

```
BEGIN;
UPDATE acct SET b = b + 15 WHERE id = 1;
```

Request B:

What’s happening

Request A:

```
BEGIN;
UPDATE acct SET b = b + 15 WHERE id = 1;

-- waiting for client
```

Request B:

```


BEGIN;
UPDATE acct SET b = b - 5 WHERE id = 1
                                AND b > 5;
-- Blocks . . .
```

What's happening

Request A:

```
BEGIN;
UPDATE acct SET b = b + 15 WHERE id = 1;

-- waiting for client



COMMIT;
```

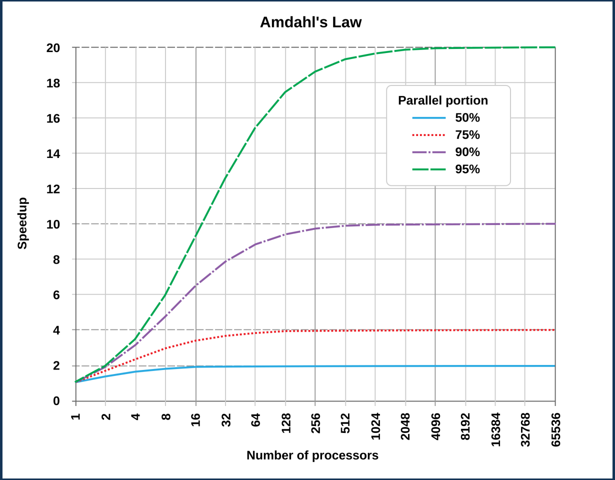
Request B:

```


BEGIN;
UPDATE acct SET b = b - 5 WHERE id = 1
                                AND b > 5;
-- Blocks . . .



-- Update completes

COMMIT;
```

Why this is a big problem

- Double entry accounting requires two accounts for every transaction.
- Some accounts are very hot.
  - “The Bank”
  - “The Payment Processor”
- Throughput limited by update rate on the hot account.

Amdahl’s law strikes again



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The trouble with SQL

Interactive protcol

```
BEGIN;
UPDATE accounts .. WHERE act = :a1 ..;
UPDATE accounts .. WHERE act = :a2 ..;
INSERT INTO transactions ...;
SELECT ...;
COMMIT;
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Interactive protcol

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```
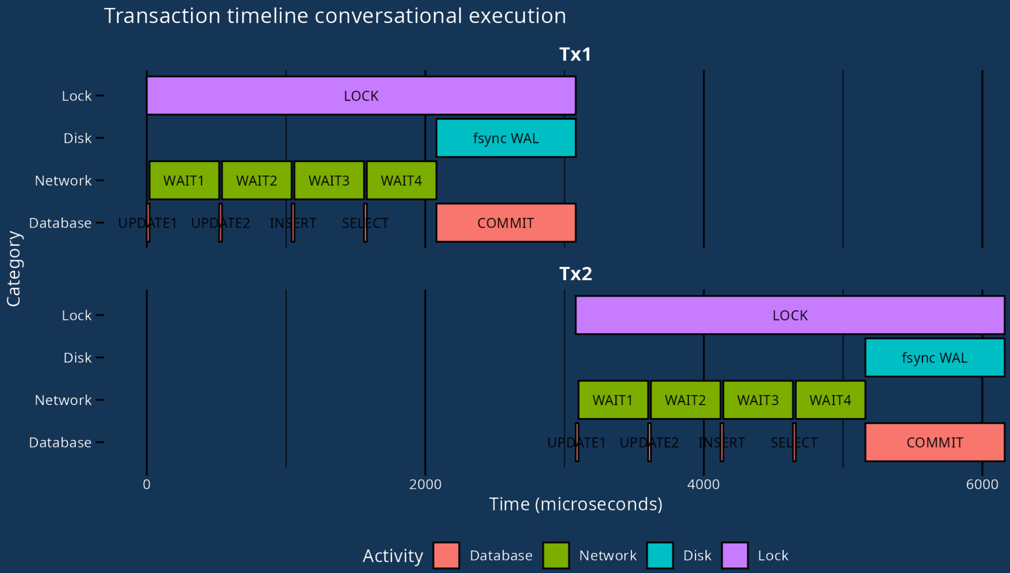

- Database has no idea what will happen next.
- Every command is a network roundtrip.

Ballpark numbers

- UPDATE:
  - HOT update using PK: 0.02 ms
- Network roundtrip:
  - Fast network: 0.1 .. 0.2 ms
  - Cloud network: 0.5ms
  - Cloud cross AZ: 0.5 .. 2 ms
  - Cross region: 10 .. 50ms
- Disk roundtrip:
  - Enterprise NVMe: 0.02 ms
  - Good network disk: 0.5ms

How it looks like



Simple optimizations

- Minimize network roundtrip time.
- Do locking actions late to minimize lock hold time.

Taking the logic to the data

Option 1: CTEs

```
WITH update1 AS (UPDATE ... RETURNING ...),
     update2 AS (UPDATE ... RETURNING ...),
     insert1 AS (INSERT ...
                 SELECT .. FROM update1, update2
                 RETURNING ...),
SELECT ... FROM insert1;
```

Will get quite hairy if the logic is more complicated.

Option 2: Pipeline mode

- Send multiple commands to PostgreSQL in a single roundtrip.
- If any command errors the whole pipeline is cancelled.
- Command must raise errors on failure.
- Very few client drivers support it. (libpq, psycopg)

Option 3: Stored procedures

Write the data logic as a single stored function.

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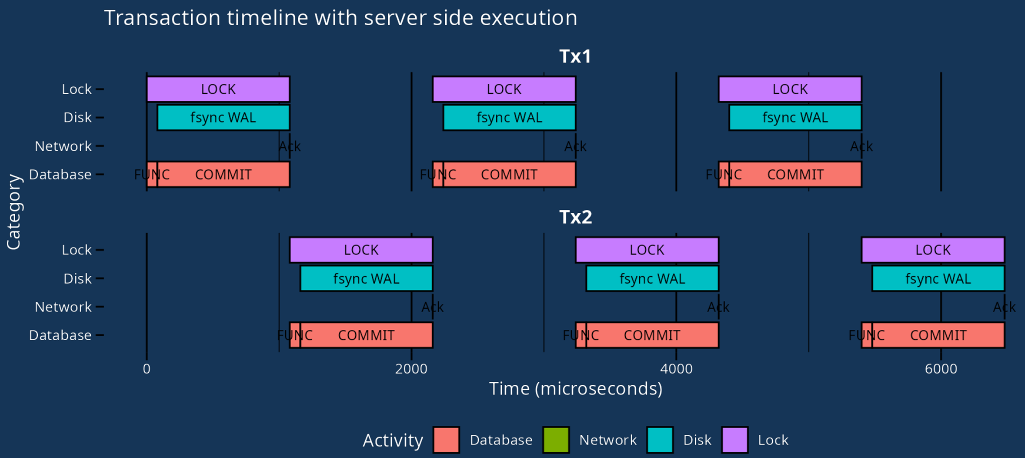
Write the data logic as a single stored function.

```sql
CREATE FUNCTION transfer(p_src int, p_dest int, p_amount numeric) RETURNS int8 AS $$
DECLARE new_balance numeric; tx_id int8;
BEGIN
    UPDATE accounts SET balance = balance - p_amount
        WHERE id = p_src RETURNING balance INTO new_balance;
    IF new_balance < 0 THEN RAISE EXCEPTION 'Not enough funds in %', p_src; END IF;

    UPDATE accounts SET balance = balance + p_amount
        WHERE id = p_dest RETURNING balance INTO new_balance;
    IF new_balance < 0 THEN RAISE EXCEPTION 'Not enough funds in %', p_dest; END IF;

    INSERT INTO transactions (src, dest, amount)
        VALUES (p_src, p_dest, p_amount)
        RETURNING id INTO tx_id;

    RETURN tx_id;
END;
$$ LANGUAGE plpgsql;
```

Avoiding all roundtrips

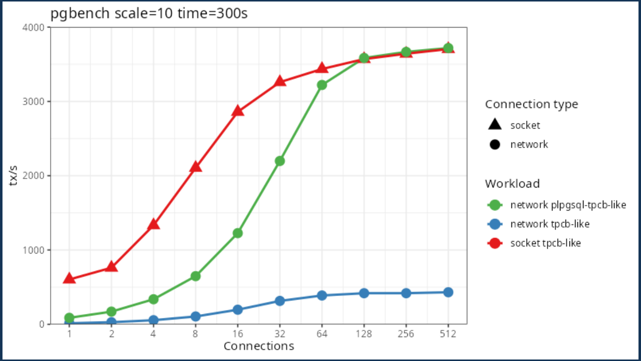
- Send the function call outside explicit transaction.
- Starts implicit transaction in database.
  - If command fails gets rolled back.
  - If command succeeds gets committed automatically.
- Some drivers need special handling for this.
  - psycopg - `autocommit=True`
  - JDBC - `conn.setAutoCommit(true);` (default)

How server side execution looks like

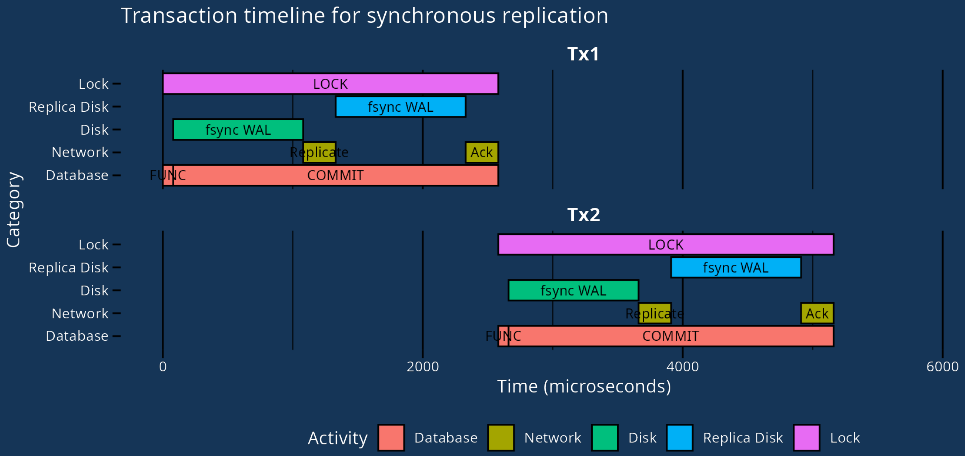


The benefit

Network has 10ms roundtrip latency.



Synchronous replication



Avoiding the commit latency

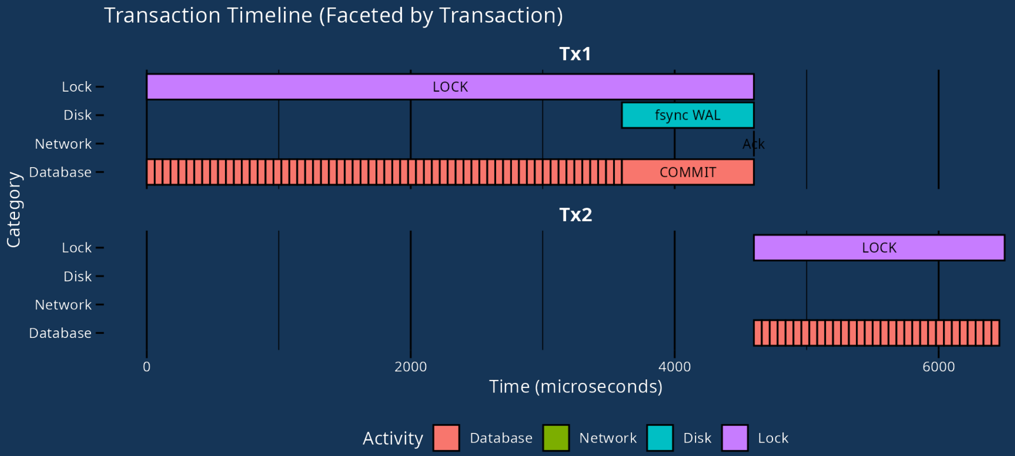
The naughty option

- `synchronous_commit=off` disables WAL flush.
- From 800 tps to 80’000 tps.
- On any crash/failover you will lose transactions.
- Typically less than `wal_writer_delay = 200ms`
- May be ok if you can detect crashes and replay transactions.

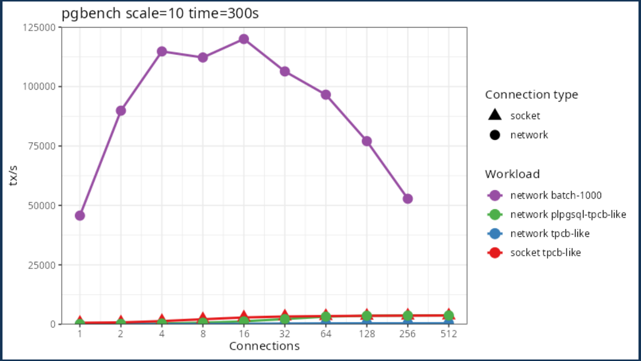
The clever option

- Amortize the durability cost across multiple transactions.
- Collect batch of transactions in application.
- Send to server function for execution.
- Server returns list of result statuses.

How batching looks like



Effect on performance



Downsides

- Complicated work needed to manage batches.
- Need to be careful to limit latency hit.

Transaction isolation

Isolation levels

When two transactions update same row:

READ COMMITTED

1. Block until locker finishes.
2. Look at the new version.
3. Recheck if WHERE condition matches.
4. Update new version.

REPEATABLE READ / SERIALIZABLE

1. Block until locker finishes.
2. If locker committed then raise serialization error.

Contention hell

- Any contention will cause concurrent transaction to fail/retry.
- Extremely inefficient use of database resources.
- Optimistic concurrency control and contention do not mix.
- Can’t use even table level locks - requesting a lock acquires a snapshot.

Be careful with correctness

- Read committed allows a single query to see different database states.
- Quite complicated to know if this is correct.

Possible workaround

Session level advisory locks allow snapshot to be released after locking.

```
-- Block until all accounts available
SELECT pg_advisory_lock(x) FROM unnest(:batch) x ORDER BY x;

BEGIN ISOLATION LEVEL REPEATABLE READ;
   -- Do work ...
COMMIT;

-- Unlock
SELECT pg_advisory_unlock_all();
```

Getting rid of contention

Delta tables

- Calculate account balance based on transaction history.
- Only usable when transactions are not dependent.

Double booking problem

Two tables.

- `flight.seats` is total available seats.
- `booking.booked` is number of seats booked.

Starting condition: only 2 free seats on a flight.

Try to book 2 seats for A:

```
BEGIN;
  SELECT f.seats - SUM(b.booked) available
    FROM flight f JOIN booking b USING (flight_id)
    WHERE flight_id = 123 GROUP BY flight_id;

  IF available > 2 THEN
    INSERT INTO booking VALUES (123, 'tx A', 2);
  END IF;
COMMIT;
```

Try to book 2 seats for B:

```
BEGIN;
  SELECT f.seats - SUM(b.booked) available
    FROM flight f JOIN booking b USING (flight_id)
    WHERE flight_id = 123 GROUP BY flight_id;

  IF available > 2 THEN
    INSERT INTO booking VALUES (123, 'tx B', 2);
  END IF;
COMMIT;
```

Double booking problem

Repeatable read allows for double booking.

Serializable will fail with serialization error.

Sharded accounts

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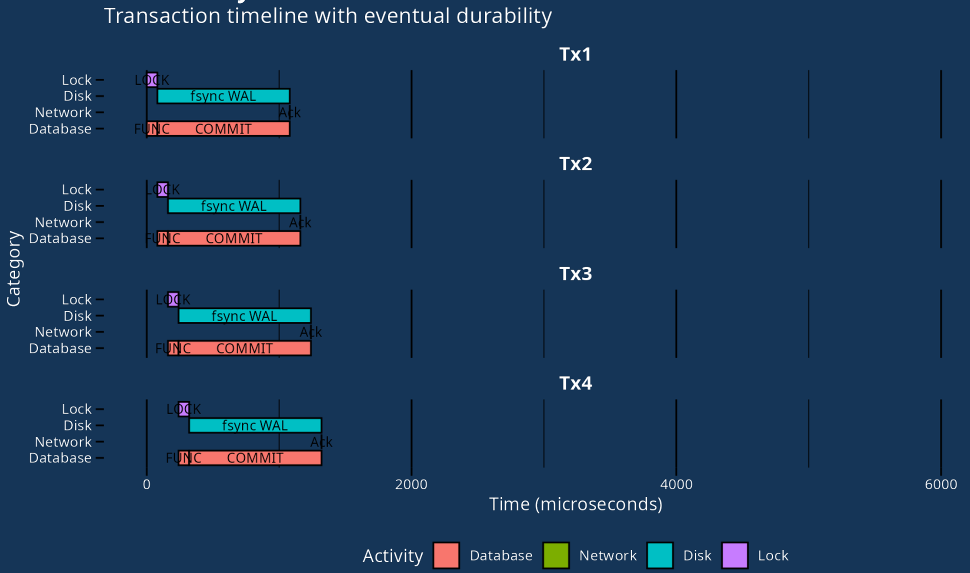
- Split hot accounts into multiple pieces.
- Balance updates between sub-accounts.
- Handle case when one sub-account is empty.
- Total balance can be calculated on demand.

Science fiction future features

Eventual durability

- Write tx commit releases locks immediately.
    - Write becomes visible to new transactions.
- Write tx commit response waits for durability.
- Read tx keep track of newest tx seen.
- Read tx wait for durability of all seen tx on commit.

Eventual durability timeline

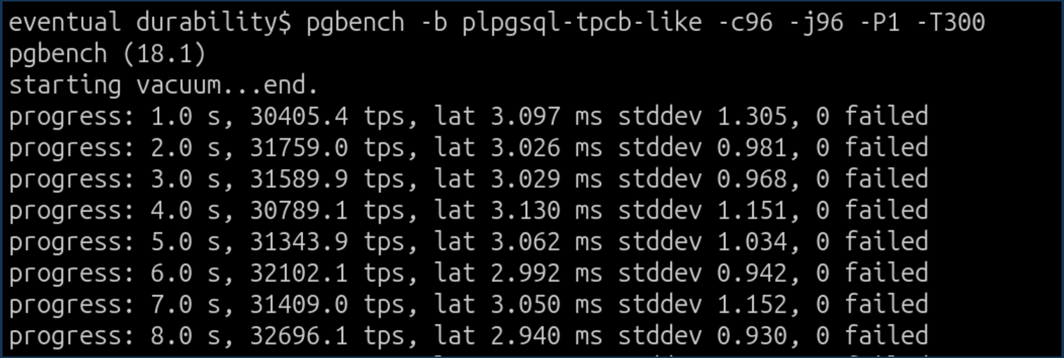


Eventual durability benefit

Almost `synchronous_commit=off` throughput on contended workloads with transactional guarantees.

No client side batching needed.

Prototype!



```
eventual durability$ pgbench -b plpgsql-tpcb-like -c96 -j96 -P1 -T300
pgbench (18.1)
starting vacuum...end.
progress: 1.0 s, 30405.4 tps, lat 3.097 ms stddev 1.305, 0 failed
progress: 2.0 s, 31759.0 tps, lat 3.026 ms stddev 0.981, 0 failed
progress: 3.0 s, 31589.9 tps, lat 3.029 ms stddev 0.968, 0 failed
progress: 4.0 s, 30789.1 tps, lat 3.130 ms stddev 1.151, 0 failed
progress: 5.0 s, 31343.9 tps, lat 3.062 ms stddev 1.034, 0 failed
progress: 6.0 s, 32102.1 tps, lat 2.992 ms stddev 0.942, 0 failed
progress: 7.0 s, 31409.0 tps, lat 3.050 ms stddev 1.152, 0 failed
progress: 8.0 s, 32696.1 tps, lat 2.940 ms stddev 0.930, 0 failed
```

Recap

What we learned today

- Avoid contended updates if you can.

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What we learned today

- Avoid contended updates if you can.
- Figure out if READ COMMITTED is good enough.
- Minimize transaction length.
- Get rid of network roundtrips using server side functions.
- Amortize durability delay by batching.

Thank you

Questions?