HEY, I'M USING THAT!

Fixing lock contention in OLTP

ANTS AASMA

PGConf.de 2026

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 . . .
```


What's happening

Request A:

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

-- waiting for client



COMMIT;
```

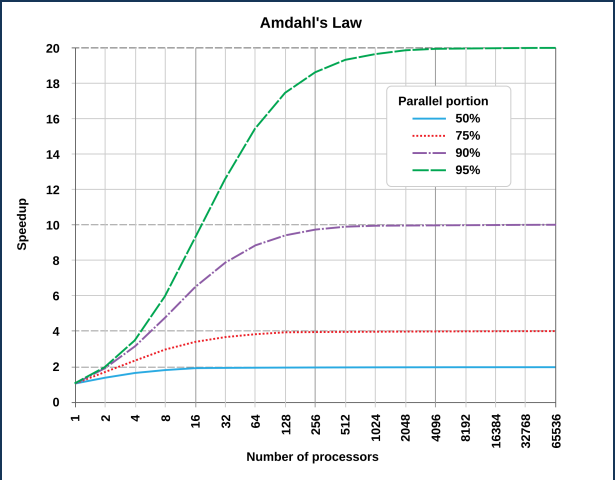
Request B:

```


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 account updates for every transaction.
- Some accounts are very hot.
  - “The Bank”
  - “The Payment Processor”
- Throughput is limited by update rate on the hot account.

Amdahl’s law strikes again



By Daniels220 at English Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=6678551

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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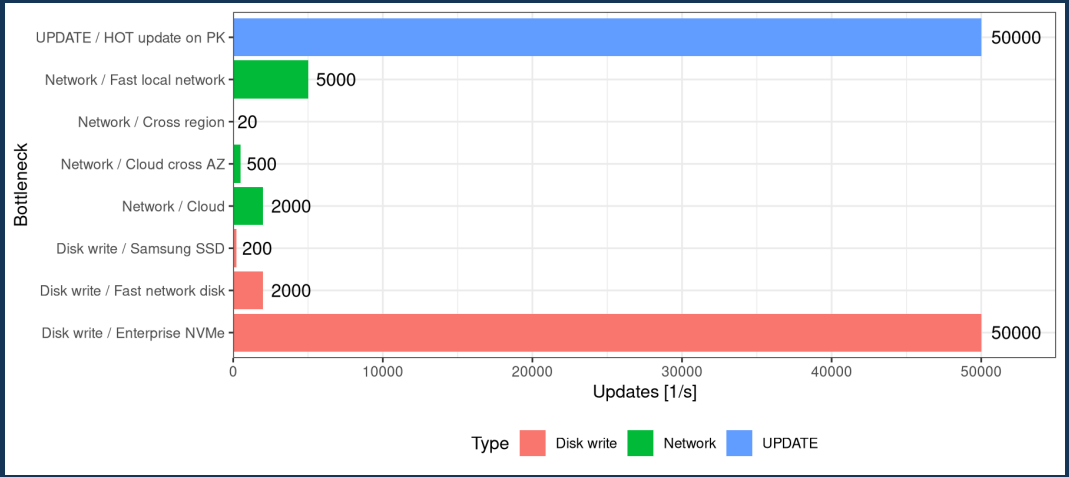
SELECT ...;
COMMIT;
```

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

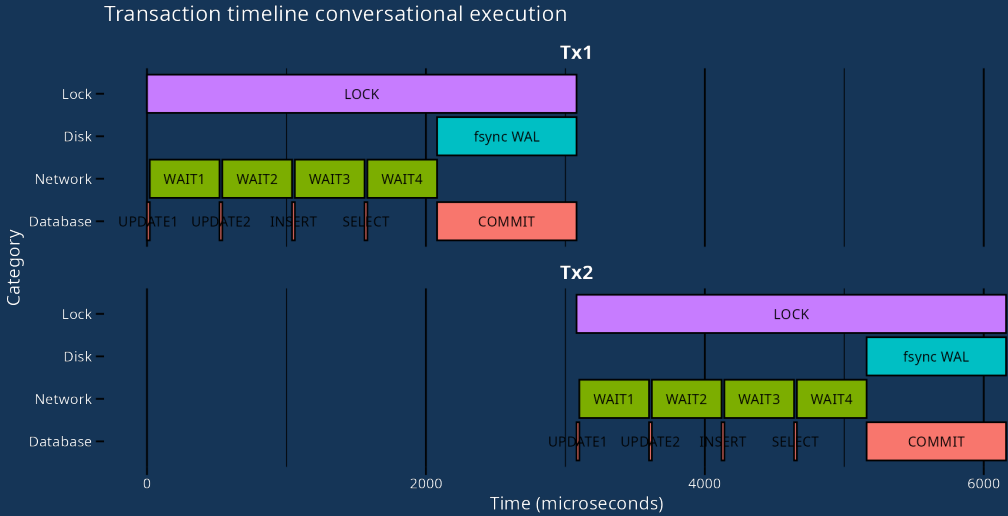
Ballpark numbers

- 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
  - Samsung SSD: 5ms

Lock rate


UPDATE / HOT update on PK
Network / Fast local network
Network / Cross region
Network / Cloud cross AZ
Network / Cloud
Disk write / Samsung SSD
Disk write / Fast network disk
Disk write / Enterprise NVMe
Bottleneck
50000
5000
20
500
2000
200
2000
50000
0
10000
20000
30000
40000
50000
Updates [1/s]
Type
Disk write
Network
UPDATE

What 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

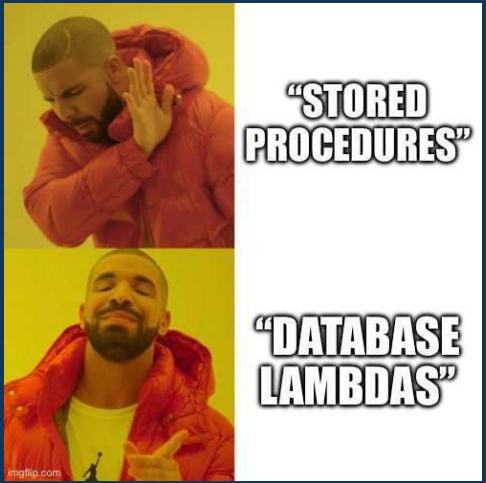
```
WITH update1 AS (UPDATE ... RETURNING ...),
     update2 AS (UPDATE ... RETURNING ...),
     insert1 AS (INSERT ...
                 SELECT .. FROM update1, update2
                 RETURNING ...),
SELECT ... FROM insert1;
```

Will get quite hairy if the logic is more complicated.

Option 2: Pipeline mode

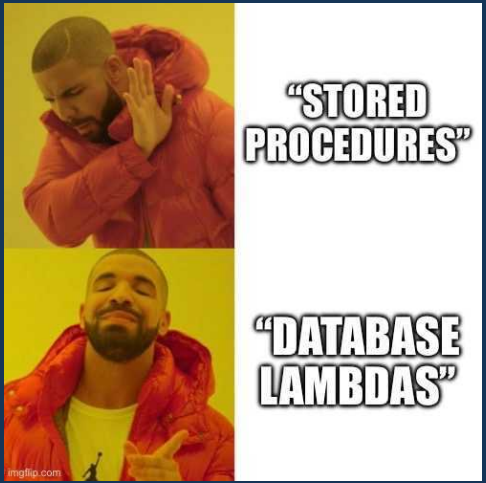
- Send multiple commands to PostgreSQL in a single roundtrip.
- If any command errors the whole pipeline is cancelled.
- Command must raise errors on failure.
- Very few client drivers support it. (libpq, psycopg)

Option 3: Stored procedures



Write the data logic as a single stored function.

Option 3: Stored procedures



Write the data logic as a single stored function.

If you really really hate stored procedures, you can use `DO` block to achieve the same result.

Stored procedure implementation

```
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;

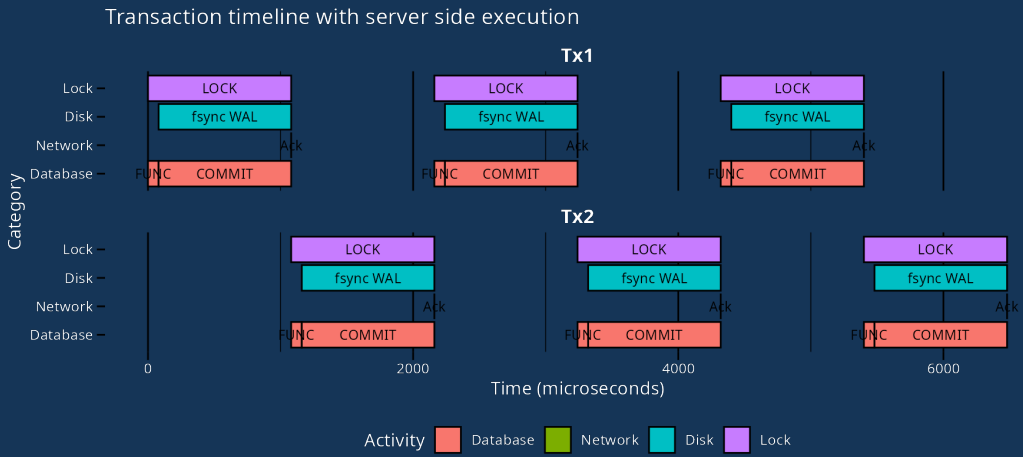
    INSERT INTO transactions (src, dest, amount)
        VALUES (p_src, p_dest, p_amount)
        RETURNING id INTO tx_id;

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


Avoiding all roundtrips

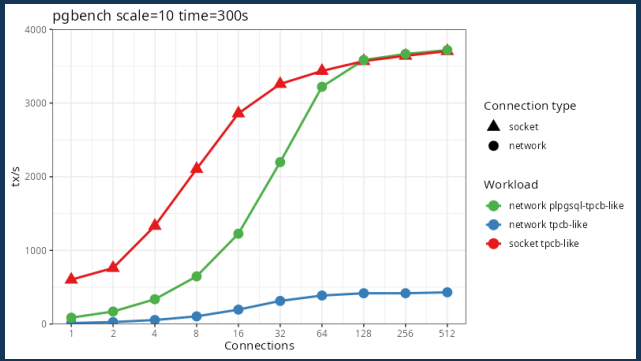
- Send the function call outside explicit transaction.
- Starts implicit transaction in database.
  - If command fails gets rolled back.
  - If command succeeds gets committed automatically.
- Some drivers need special handling for this.
  - psycopg - `autocommit=True`
  - JDBC - `conn.setAutoCommit(true);`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

What server side execution looks like



The benefit

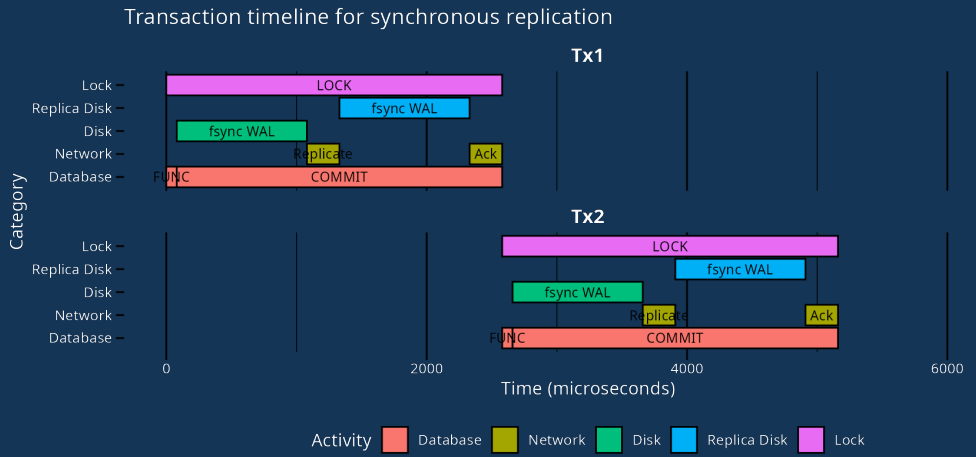
Network has 10ms roundtrip latency.



plpgsql-tpcb-like implementation from Hannu Krosing's patch (pgbench - adding pl/pgsql versions of tests)

Tested on Ryzen 9 9900X, Samsung SSD 990 Pro 2TB

Synchronous replication



Avoiding the commit latency

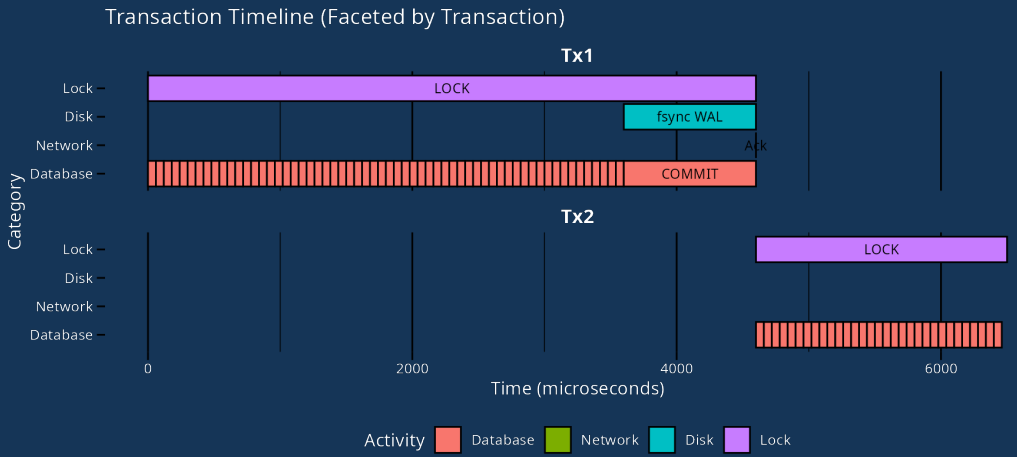
The naughty option

- `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.

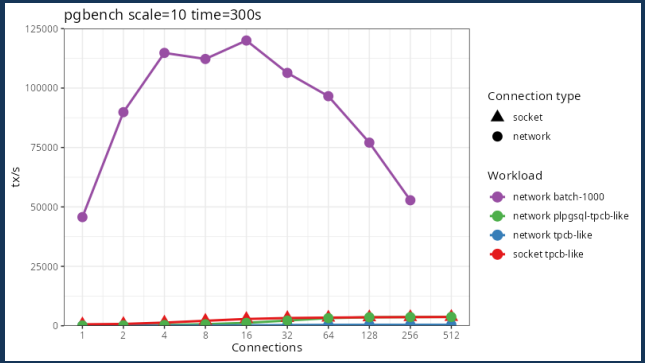
The clever option

- 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.

What 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

`REPEATABLE READ` is almost unusable for contended workloads.

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

Be careful with correctness

- Read committed allows a single query to see different database states.
- Quite complicated to prove if this affects application correctness.

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.
- Periodically update baseline to limit work needed.
- Only usable when transactions do not depend on each other.

Write skew anomaly

Two tables.

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

Starting condition: only 2 free seats on a flight.

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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;
```


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  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;
```


Write skew anomaly

`REPEATABLE READ` allows for double booking.

Incorrect results.

`SERIALIZABLE` will fail with serialization error.

Terrible performance with contention.

Sharded accounts

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

Far future features for fun

Insights

- We need locking to ensure ordered updates.
- We know the order once we have reserved WAL position.
- Waiting for flush/replication is needed for durability.
- We can speculatively start the next transaction.

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Detach visibility from durability.

Eventual durability

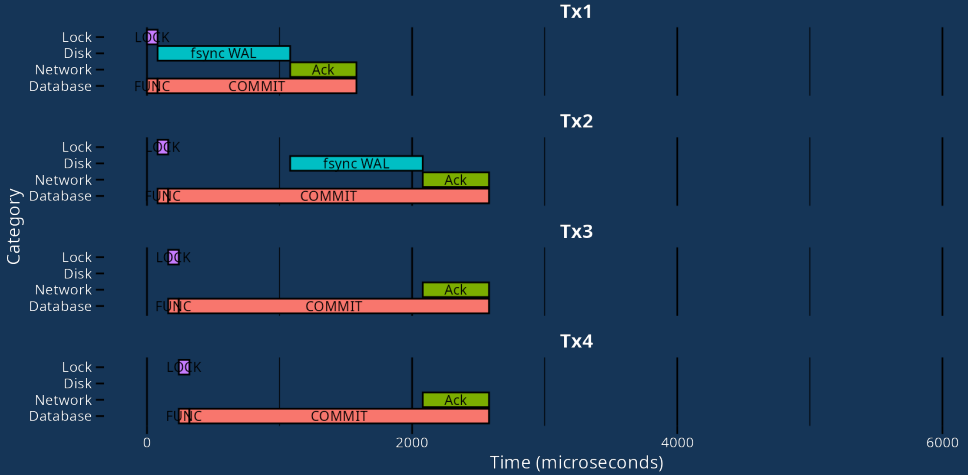
- Write tx commit releases locks immediately.
  - Write becomes visible to new transactions.
- Write tx commit response waits for durability.
- Read tx keep track of newest tx seen.
- Read tx wait for durability of all seen tx on commit.

Based on Eventual Durability paper from University of Waterloo

How to implement eventual durability

- Postpone wait for durability after releasing locks.
- When reading, keep track of latest transaction seen.
  - Need mapping xid -> commit LSN.
- On read-only transaction commit, wait for durability of seen LSN.

Eventual durability timeline

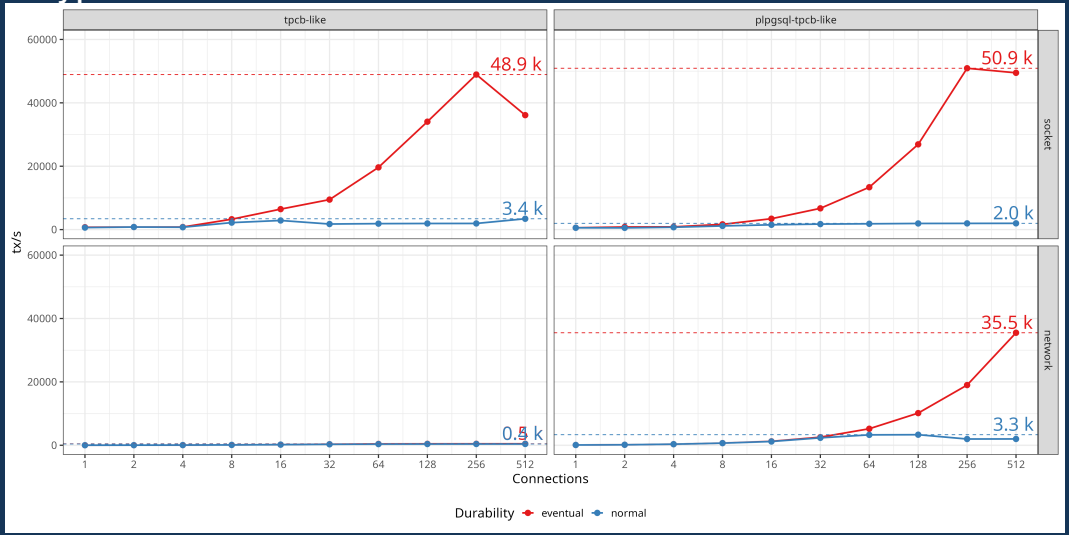


Eventual durability benefit

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

No client side batching needed.

Prototype!


tpcb-like
plpgsql-tpcb-like
socket
network
tx/s
60000
40000
20000
0
48.9 k
3.4 k
50.9 k
2.0 k
35.5 k
3.3 k
0.5 k
1
2
4
8
16
32
64
128
256
512
Connections
Durability
eventual
normal

Recap

What we learned today

- Avoid contended updates if you can.

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- 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?