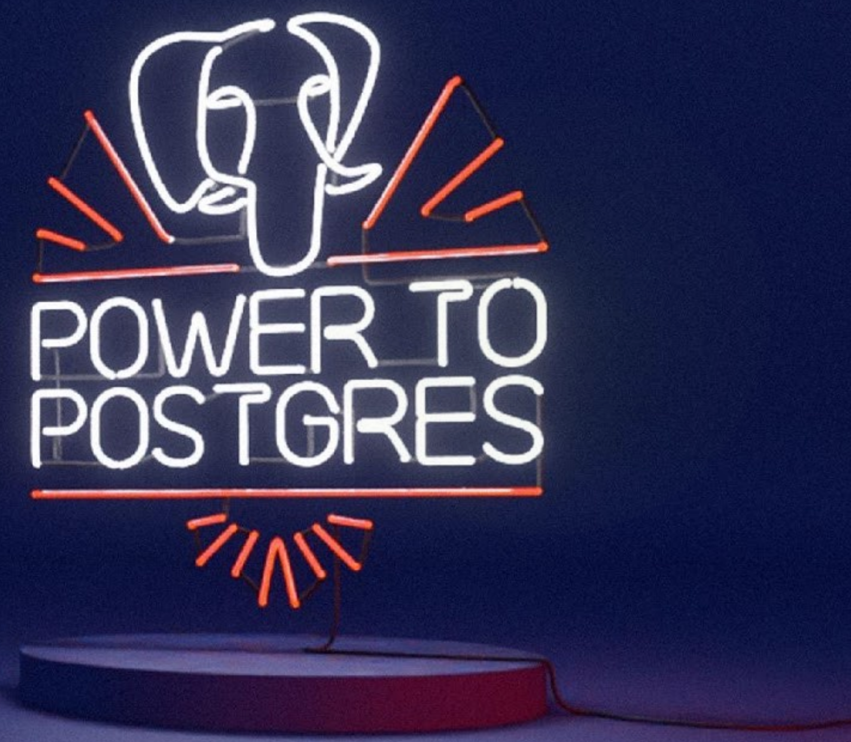
Slow things down to make them go faster



Jimmy Angelakos
Senior PostgreSQL Architect

FOSDEM 2022-02-06

We’ll be looking at PostgreSQL:

- High concurrency
- ACID & MVCC
- Locks
- High transaction rates
- Mitigation strategies

High concurrency in PostgreSQL

What is high concurrency?

- RDBMS context: The ability to have transactions execute concurrently, not serially
- Practically: Serve multiple sessions/users “simultaneously”
  - How to avoid conflicts? (dirty reads, lost updates, etc.)
  - Made possible via concurrency control methods
- Postgres designed to be able to provide high concurrency safely
  - Hundreds of activities at the same time

PostgreSQL is multi-process

CLIENT/SERVER IMPLEMENTATION

- "Process per user" model
- Every client process connects to exactly one backend process
- Co-ordinated by **postmaster** supervisor process
- IPC via semaphores & shared memory
- Risk: CPU context switching

ACID & MVCC

The I in ACID

Atomicity, Consistency, **Isolation**, Durability

- Isolation: how transaction integrity is visible by other sessions
- Anomalies: dirty/non-repeatable/phantom read, lost update, write/read-only transaction skew
- Lower isolation level: more sessions can access same data (at some risk)
- Higher isolation level: safer but increases resource usage & blocking
- Default PG isolation level: **READ COMMITTED**, highest isolation level: **SERIALIZABLE**
    - Each query sees only transactions committed before it started

MVCC

Multi-Version Concurrency Control

- MVCC rather than locking for high concurrency and high performance
- Reading never waits
  - Writing doesn’t block reading, reading doesn’t block writing
- Each write creates a new version of tuple
- Snapshot isolation: Timestamps & Transaction IDs (XIDs)

Transaction Snapshot

Provided by Transaction Manager

- Obtained by each transaction
- Contents:
  - Earliest transaction still active
  - First as-yet-unassigned transaction
  - List of active transactions
- Function: `pg_current_snapshot()`

SSI – Serializable Snapshot Isolation

The performance of MVCC with the safety of Serializable

- Checks for anti-dependency cycles and forbids them
  - Error instead of hazardous operation (serialization anomaly)
- Performance
  - Reduced concurrency, but:
  - No blocking, no explicit locks needed (SIReadLocks, rw-conflicts)
  - Just application-side retry after error
  - Best performance choice for some application types

Locks in PostgreSQL

Explicit locking

a.k.a. heavyweight locks – not what we're talking about here

- Table-level (e.g. **SHARE**) or row-level (e.g. **FOR UPDATE**)
- Conflict with other lock modes (e.g. **ACCESS EXCLUSIVE** with **ROW EXCLUSIVE**)
- Block read/write access totally leading to waits
- Disastrous for performance
  - Unless your application is exquisitely crafted
  - Hint: it isn't

Lightweight Locks (LWLocks) – i

a.k.a. “latches” in other DBs

- Protect data in shared memory
  - Remember? Multi-process
  - Ensure consistent reads/writes
  - Shared, Exclusive modes
- Enable fast MVCC
  - Generally held briefly
  - Sometimes protect I/O

Lightweight Locks (LWLocks) – ii

Under high concurrency

- Possible problem: a lock becomes heavily contended
  - Lots of lockers slow each other down
  - Throughput is reduced
  - No queuing, more or less random
  - May indicate existence of hot data
- Monitoring: **pg_stat_activity** (look for **wait_event_type**: **LWLock**)

Snapshot contention

Waiting for connections that are idle!

- Extremely high **max_connections** settings allow this
- Many idle open connections
  - Means: many snapshots
  - Can halve your performance in TPS
  - Even with simple R/O workload
- Improvement in PG14: snapshot caching (transaction completion counter)

Many connections...

PG13 Tests on AWS `r5.8xlarge` with `pgbench -j10 -C -c<clients> -T120 -b simple-update pgbenchdb`

- 100 connections
  - tps = 1560.134, latency average = 52.162 ms
- 300 connections
  - tps = 1307.431, latency average = 190.652 ms
- 1000 connections
  - tps = 1184.786, latency average = 668.470 ms

High transaction rates

Transaction ID

a.k.a. txid

- Postgres assigns an identifier to each transaction
  - Unsigned 32-bit integer (4.2B values)
- Circular space, with a visibility horizon
  - In transaction 10000: 9999 is the past (visible), 10001 the future (invisible)
  - 2.1B transactions into the past, 2.1B transactions in the future
- Basis for MVCC mechanism – just write into heap, each tuple has **xmin, xmax**
- Amazing write/rollback performance BUT requires maintenance operations

High transaction burn rate

Just because you can, doesn't mean you should

- Very heavy OLTP workloads can go through 2.1B transactions in a short time
- **XID wraparound:** you try to read a very old tuple that is > 2.1B XIDs in the past
  - For you, that's the future! (invisible)
- **Freezing:** Change tuple **xmin** to "frozen" txid **2** which is known to always be in the past
- Need to make sure **FREEZE** happens before XID wraparound
- Bloat
- Aborted transaction IDs remain

(Auto)VACUUM

The MVCC maintenance operation

- Removes dead tuples, freezes tuples
  - Among other things
- Has overhead
  - Scans tables & indices
  - Needs, obtains, and waits for locks
- Has limited capacity by default

Mitigation strategies

Lock contention

Waiting for explicit locks

- Avoid explicit locking!
- Use SSI (**SERIALIZABLE** isolation level)
- Make application tolerant
    - Allow it to fail and retry

LWLock contention

Too many connections to server

- Contention often caused by too much concurrency
- Insert a connection pooler between application and DB
- Allow fewer connections into the DB
- Make the rest queue for their turn
- Sounds counter-intuitive!

Connection pooling

PGBouncer is a pretty good solution

- “Throttle” application by reducing no. of connections reaching server
  - Leave **max_client_conn** to what app wants, only allow **max_db_connections**
  - Introduce latency on the application side, to save your server performance
  - Doesn’t necessarily slow anything down – queries may execute faster!
- **transaction** pool mode: PgBouncer reuses connection for user when transaction ends
- **statement** pool mode: PgBouncer reuses connection for next statement
  - No transaction control, for autocommit-type workloads

PgBouncer effect

Real world use case

- Misbehaving application with job parallelization, leaving jobs' connections open
- **max_connections** set to 5000, 2500+ open connections observed
- After PgBouncer in Transaction mode:
  - 30 connections used in Postgres (!)
  - Queries executed much faster
- Other solutions: Application side, Pgpool-II, Odyssey

Split your workload

With streaming/logical replication

- Adapt your application: Read Only and Read/Write connections
- Send write operations to primary server
- Send read operations to standby servers
    - Horizontal read scalability
- Set up R/O and R/W PgBouncer endpoints
- Use logical replication if partial dataset required

XID wraparound

- Can batching help?
  - Batch size 1000 will have 1/1000th the burn rate
- Increase effectiveness of autovacuum
  - More efficient **FREEZE**

Autovacuum

Make it work harder to avoid problems

- People are concerned about overhead
  - Alternative is worse! You can't avoid **VACUUM** in Postgres (yet).
  - You can outrun it (and then you'll need **VACUUM FULL)**
- Increase potency via:
  - **maintenance_work_mem** (1GB is good)
  - **autovacuum_max_workers**
  - **autovacuum_vacuum_cost_delay** / **autovacuum_vacuum_cost_limit**

Monitoring tools

Detect contention, wait events

- psql 😛
- UNIX tools: ps, top, iostat, vmstat
- pgAdmin
- pg_view, pgstats, pgmetrics, …
- check_postgres, check_pgactivity
- Proprietary

Disclaimer

Every workload is different!

- OLTP
  - R/W, shorter queries, high contention, sustained rate, fewer idle connections (?)
- Web server
  - R/O bias, shorter queries, less contention, more idle connections (?)
- Spark/batch/analytics
  - R/W, longer queries, high contention, more idle connections (?)

To conclude...

- Know your workload & application behaviour!
- Monitor for signs of high contention
- Not overwhelming Postgres is the key
- Split your workload
- Use connection pooling & autovacuum

Thank you!

Find me on Twitter: @vyruss