OpenAI

Scaling Postgres to the next level at OpenAI

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About Myself

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Background

- **Postgres is the backbone of our most critical systems at OpenAI**
  - If Postgres goes down, many of our key features become unavailable
  - Postgres related incidents have had a significant impact to services like ChatGPT in the past

- **Scaling Postgres to meet OpenAI's demands is no trivial task**
  - We operated on a single primary instance in Azure without sharding for a long time
  - until we encountered write scalability limits…

Background

- **In a single-primary, multiple-replica architecture, write scalability remains a bottleneck**
  - Move write-heavy workloads that are shardable to other systems
  - New tables and workloads are not allowed
  - We did lots of optimizations to ensure the current architecture has sufficient runway to support existing read-heavy workloads and future growth

- **Postgres is not ideal for write-heavy workloads. But for OpenAI's read-heavy workloads, it can scale exceptionally well**

Challenges in write-heavy workloads

- **Known Issues in Postgres MVCC design**[1]
  - Table and index bloat
  - Autovacuum tuning complexities
  - Version churn from tuple copying
  - Increased index maintenance overhead

- **Difficult to scale read replicas**
  - Write-heavy workloads generate more WAL to ship, increasing replica lag
  - The problem worsens as the number of replicas grows — network bandwidth can become a bottleneck

[1] Bohan Zhang, Andy Pavlo: The part of PostgreSQL we hate the most (Apr 26, 2023)

Read-heavy workloads are still served by Unsharded Postgres in Azure

But How?

Why Postgres Remains Unsharded

- Shardable, write-heavy workloads have already been migrated to other systems.
- New tables are no longer allowed in Postgres. For feature additions that require new tables, use alternative systems.
- Sharding current workloads in Postgres is difficult due to the complexity of migrating hundreds of application endpoints.
- Current workloads are read-heavy, and with careful optimizations, the existing architecture has sufficient runway.
- Sharding is not a near-term priority but remains a possibility for the future.

Reduce Load on Primary

- **Mitigate write spikes in primary**
  - Migrate write-heavy workloads that were shardable from Postgres to other systems
  - Reduce the number of writes at the application level. We also identified bugs in the application that generate unnecessary writes
  - Use lazy writes where possible to smooth out write spikes
  - Set a rate limit when backfilling a field

- **Offload read queries from the primary to read replicas**
  - Offload read queries from the primary whenever possible to reduce primary load
  - Some reads cannot be moved due to transactions. Make sure those queries are efficient in primary

Query Optimization

- **Avoid long running idle queries by setting timeout**
  - Long-running queries can block autovacuum and consume resources
  - Set idle_in_transaction_session_timeout
  - Set statement_timeout
  - Set client side timeout

- **Avoid OLTP query anti-patterns**
  - We observed multi-way joins in Postgres queries, with the most expensive query joining 12 tables. Spikes in such queries have previously led to SEVs.
  - Avoid expensive multi-way joins by handling joins at the application level.
  - Developing with an ORM can easily lead to inefficient queries. Use it carefully!

Single Point of Failure

- **The primary instance can be a single point of failure**
  - We have a single writer; if it goes down, no writes can be performed
  - We have many read replicas; if one fails, applications can still read from others
  - Most critical requests are read-only and can continue to operate by fetching data from read replicas if the primary fails (SEV2)

- **Low priority vs High priority requests**
  - Categorize requests by priority. High-priority requests have a far greater impact on users when unavailable (SEV0), compared to low-priority ones (SEV2)
  - Allocate dedicated read replicas for high-priority requests to prevent them from being impacted by low-priority ones

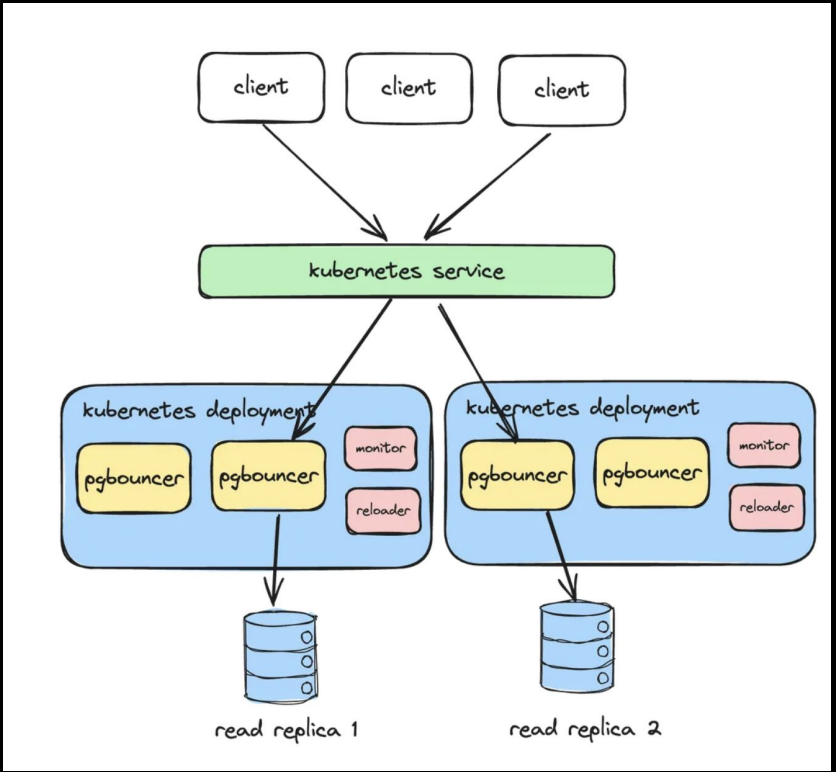
Rate Limit

- **A surge from a single expensive query can bring down the entire instance**
  - We had some expensive queries running on the primary (like 12-way joins), the volume was typically low
  - A sudden spike in one of these queries took down the entire instance

- **Rate Limiter**
  - Rate limit ***application-level functions*** to reduce load during peak traffic
  - Rate limit the creation of ***new connections*** to prevent connection pool exhaustion
  - Rate limit specified ***query digests*** to control the impact of expensive queries

Connection Pooling

- **PGBouncer as Postgres Proxy**
  - Acts as a connection pool, enabling connection reuse
  - Can significantly reduce connection latency (~5ms vs. 50ms)
  - Reduces the number of connections, which is important given the 5k connection limit on the primary
  - If a read replica fails, traffic is automatically rerouted to other available replicas



Schema Management

- **Only lightweight schema changes are permitted**
  - Creating new tables or introducing new workloads in Postgres is not allowed
  - We allow adding / removing columns in tables (with 5-seconds timeout). Any changes that require a table rewrite are not allowed
  - Indexes can be added or dropped concurrently

- **Schema changes can be blocked by consistent queries**
  - If long-running queries (e.g., >1s) are consistently present on the target table, the migration may fail
  - Fix those queries in applications, or move them to read replicas
  - SELECT * FROM pg_stat_activity WHERE query like '%table_name%' and now() - query_start > interval '1 seconds'

Results

- **Scaled Azure PostgreSQL to millions of QPS, powering OpenAI's critical services**
- **Added dozens of read replicas with no increase in replication lag**
- **Maintained low-latency across geo-distributed read replicas**
- **Only one SEV-0 incident involving PostgreSQL in the past 9 months**
- **Sufficient capacity headroom to sustain future growth**

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Thank you