Tencent Cloud

TDSQL-Boundless:
A Distributed Database System for Large-scale Heterogeneous Multi-Table Workloads

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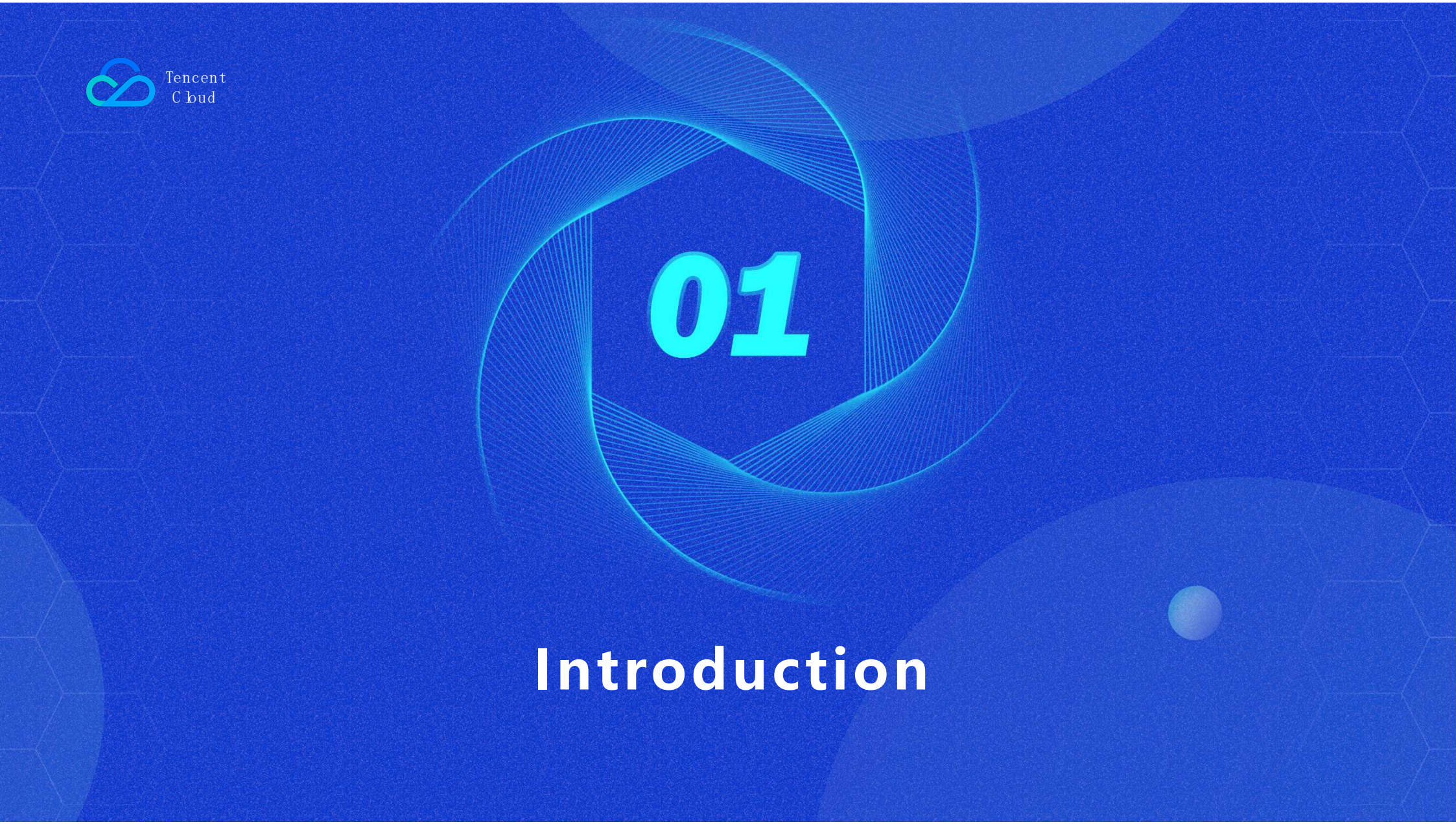
Content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01
Introduction

Tencent: Who we are?

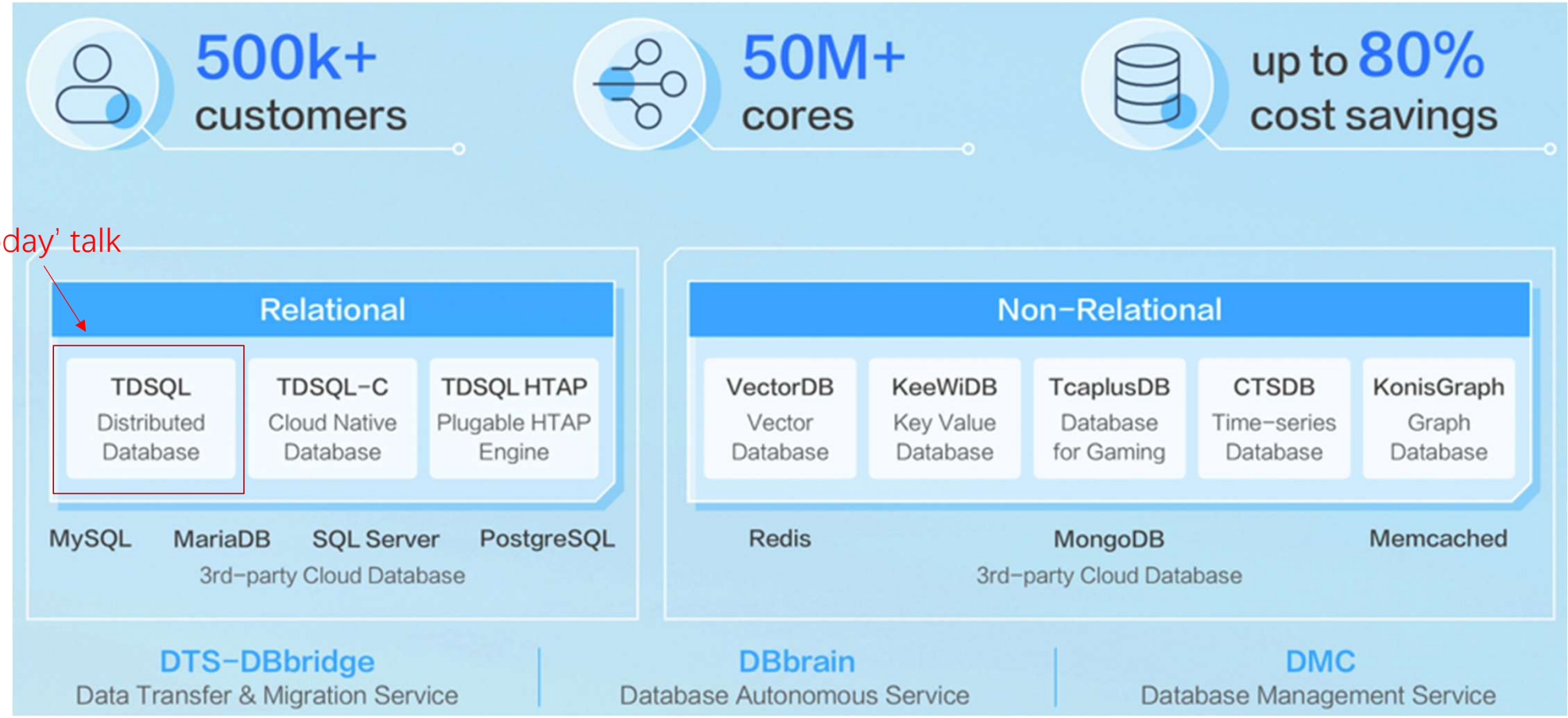
Social media	• 1.3 billion monthly active users
Gaming	• Honor of Kings, League of Legends
Investment	• Epic Games, Spotify, JD.com, PDD

TDSQL: Who we are?

Tencent Distributed SQL

Phase 1 from 2007	• **Internal:** TDSQL was created when Tencent experienced explosive business growth
Phase 2 from 2009	• **External:** Tencent launched its open platform, and TDSQL expanded its services beyond internal usage to cater to the industry internet
Phase 3 from 2014	• **Financial:** TDSQL entered the third stage by targeting prominent financial clients
Phase 4 from 2022	• **Scaling:** TDSQL aims to reproduce the current technology to scale to various industries

TDSQL Product Matrix



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02

Applications

Scale and User Cases

Financial

Active users: 1.3 billion

Daily transaction: 1 billion

(0.58 billion from Visa Global 2023)

Entertain ment

Active users: 100 million

Daily transaction: 10 million

(The player count is much higher)

1,000,000 +

Tencent Cloud Database
Core Number

100 + PB

Tencent Cloud Database
Billing Storage

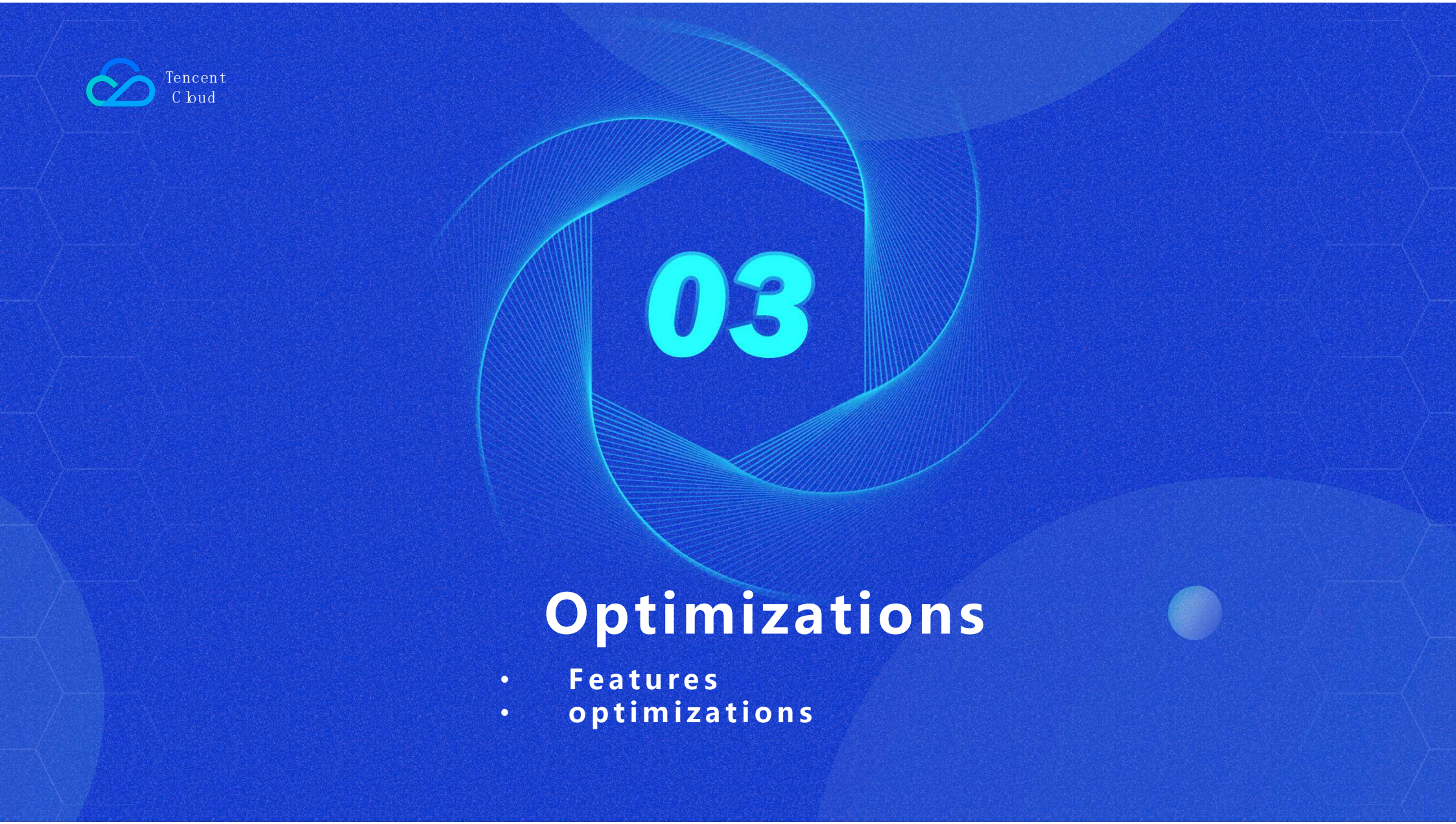
Typical Workloads for This Paper

Tencent

6,000+	500K+	10TB+	50%
Tables per cluster in real deployments	Writes per second at peak load	Metadata for 100K+ regions	Storage wasted by cross-table overhead

Key observations:

- Table count grows unbounded as microservices decompose monoliths
- Each table needs its own partitioning strategy, indices, and lifecycle
- Cross-table operations (JOINs, foreign keys) become prohibitively expensive
- Metadata management becomes the bottleneck, not data processing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03
Optimizations
Features
optimizations

System Evolution

Shared Disk | Oracle RAC era

Single DB, multiple nodes share storage

- Scalability limited by shared storage
- Cache coherence overhead
- Single point of contention

Shared Nothing | MySQL Sharding era (TDSQL (Our traditional architecture))

Each node owns its data subset

- Manual shard management nightmare
- Cross-shard JOINs expensive
- Rebalancing ~= downtime

Compute-Storage Separation | Current generation (TiDB, CockroachDB)

Compute & storage scale independently

- Better scalability achieved
- BUT: metadata scales with tables
- Transaction cost still high even single node
- Storage inefficiency remains

Our solution: TDSQL-Boundless

SQLEngine (Compute)

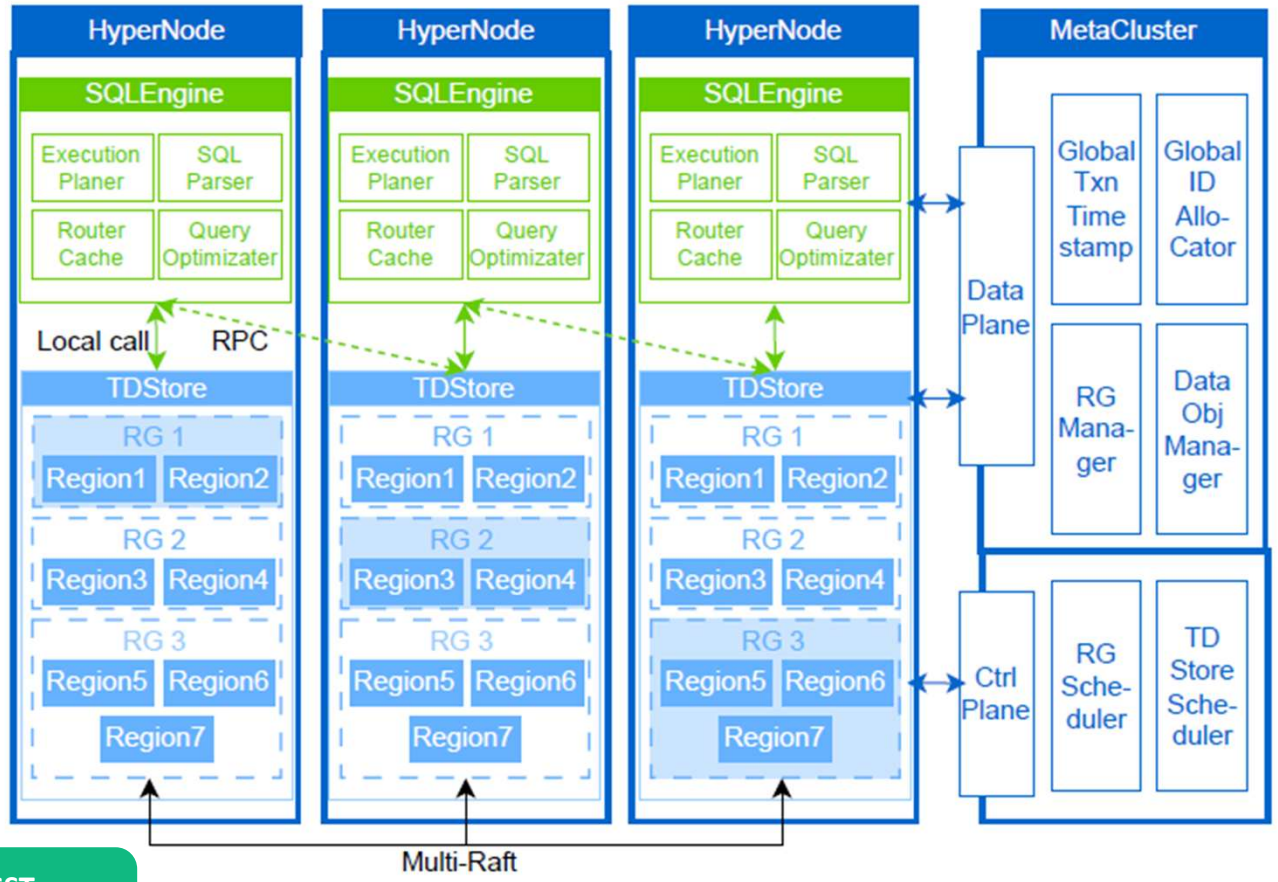
- Stateless SQL parsing & optimization
- Distributed transaction coordination
- Sends requests to TDStore

TDStore (Storage)

- Multi-Raft consistency (Innovation #1)
- Three-tier: DataObject->Region->RG
- SST Boundary Alignment (Innovation #2)
- LSM-tree based KV storage

MetaCluster (Management)

- Cluster metadata management (etcd-based)
- Unified timestamp oracle
- Intelligent load balancing
- One-primary-multi-secondary deployment



Innovation #1: Multi-Table Raft Group

Innovation #2: SST Boundary Alignment

Three Tier Storage Model

DataObject — Smallest unit

1 SST file per table-partition

- Logical container for single (table, partition)
- Maps to exactly 1 SST file on disk
- Independent lifecycle per table
- ~10KB memory footprint each

Region — Replication unit

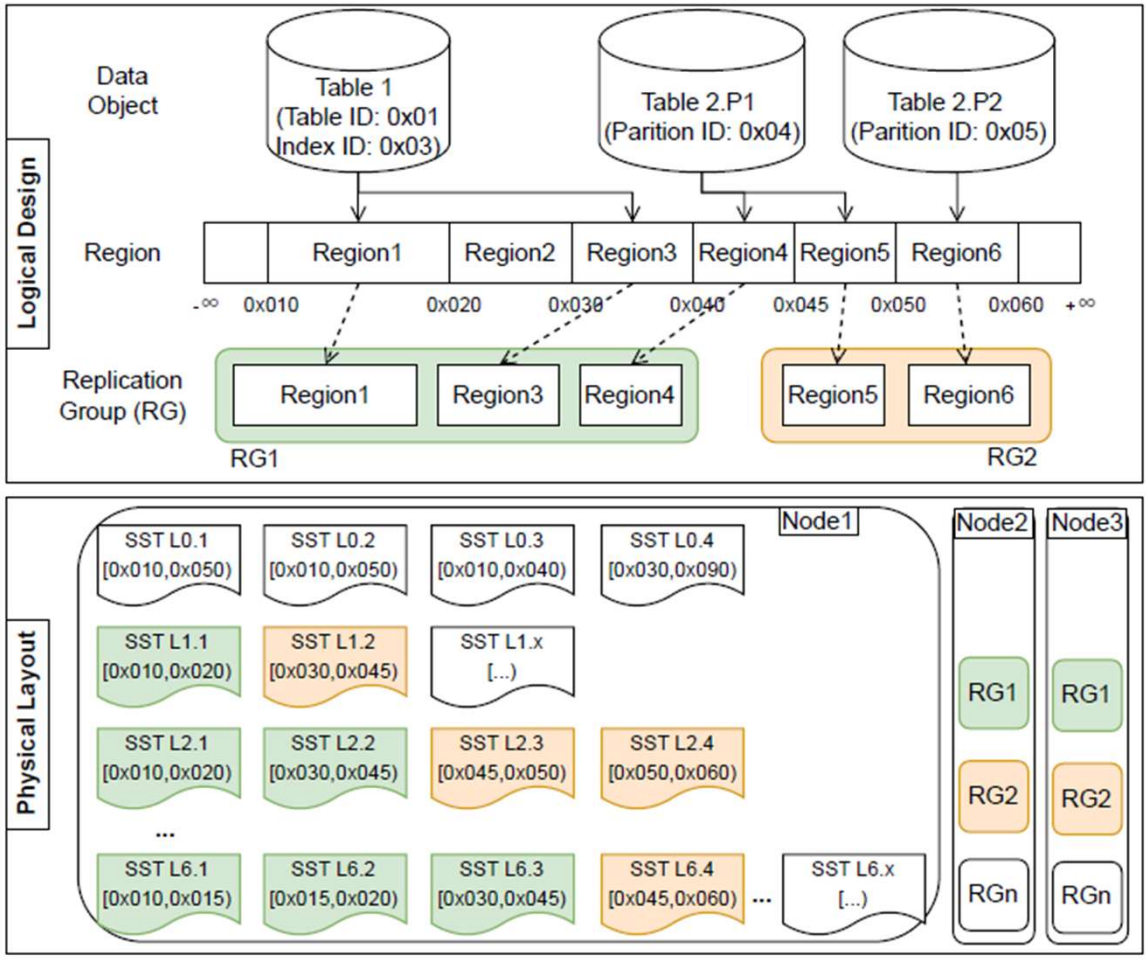
Set of DataObjects forming Raft group

- Multiple DataObjects form one Raft group
- Shared consensus across tables
- Reduces Raft groups from N×K to K
- Metadata reduced by 10-100x

RegionGroup (RG) — Scheduling

Batch of Regions for placement

- Co-located for locality
- Atomic migration/split/merge
- Load balancing granularity
- Enables bulk operations



Innovation #1 Multi-Table LSM-tree Architecture

Traditional approach

Each table = separate LSM tree

N tables × K levels = N×K compaction tasks

TDSQL-B approach

One shared LSM tree, tagged SST files

N tables share K levels = K compactions total

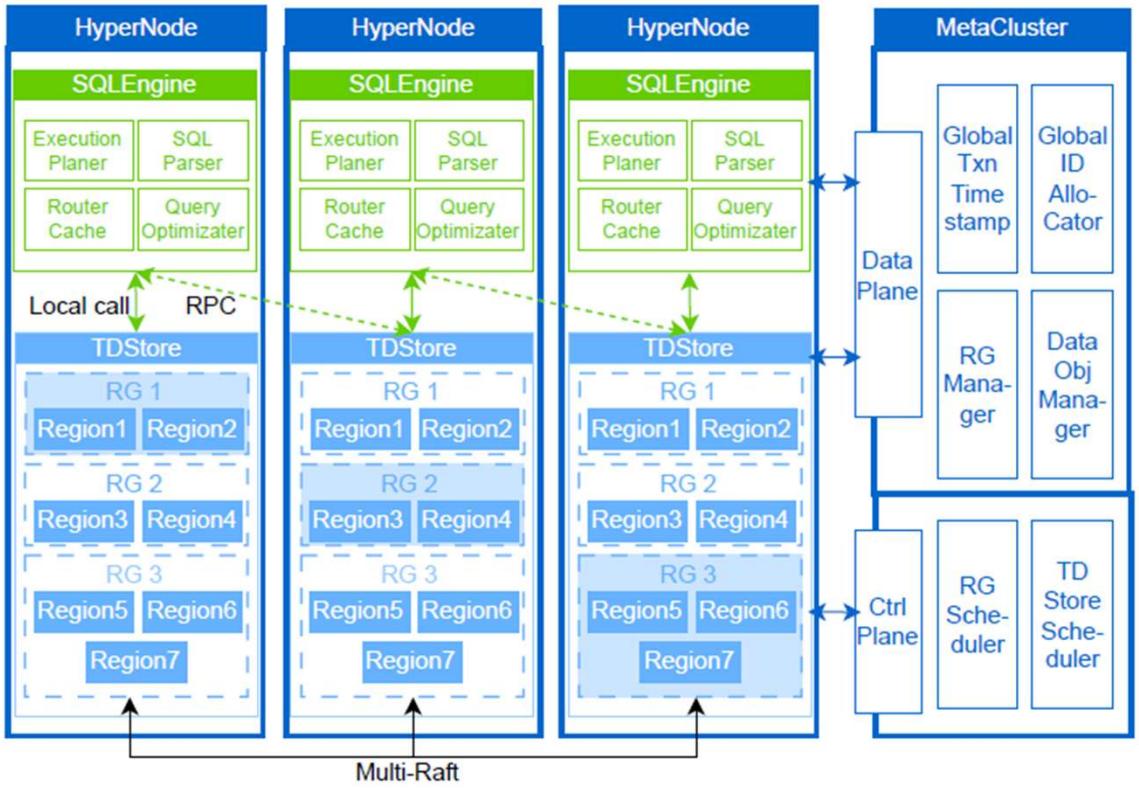
Benefits:

✓ Compaction I/O amortized across all tables

✓ L0 bloom filter shared (no per-table overhead)

✓ Write amplification reduced significantly

✓ Small tables don't trigger unnecessary major compactions



KEY RESULT: 6000 tables × 100 partitions = 100 RegionGroups (not 600,000 individual Raft groups!)

Innovation #2 SST File Boundary Alignment

Core Idea

SST file boundaries are aligned so that each SST contains data from ONLY ONE table. No cross-table mixing within an SST.

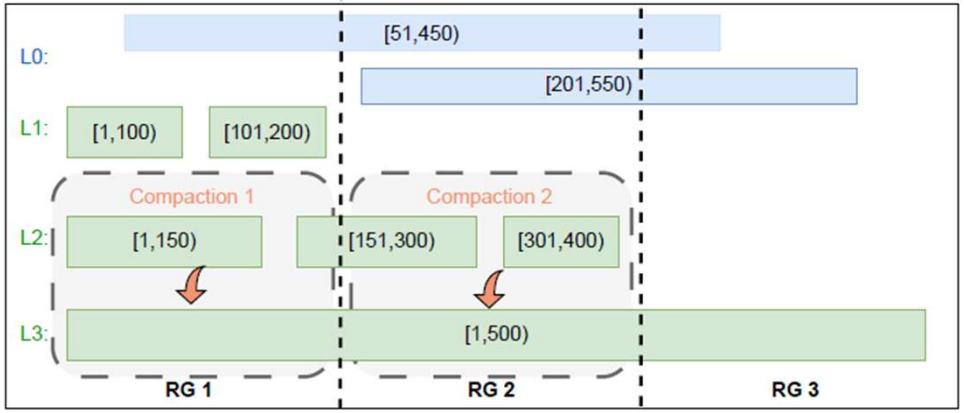
BEFORE

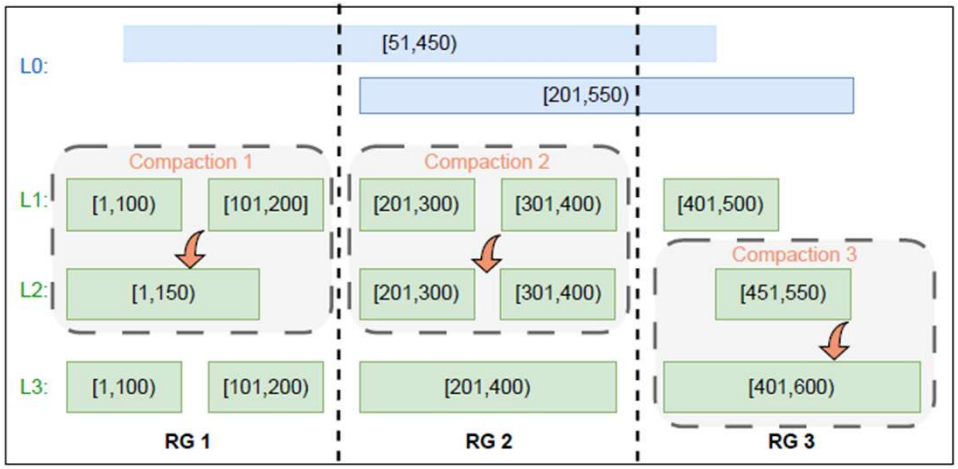
SST contains mixed data from multiple tables -> Read must scan & filter irrelevant data -> Bloom filter can't eliminate false positives

AFTER (TDSQL-B)

SST aligned to single table boundary -> Point query reads exactly 1 SST -> Range scan skips non-matching SSTs entirely

Result: Up to 10x reduction in read I/O for multi-table workloads, especially when hot and cold tables are co-located.





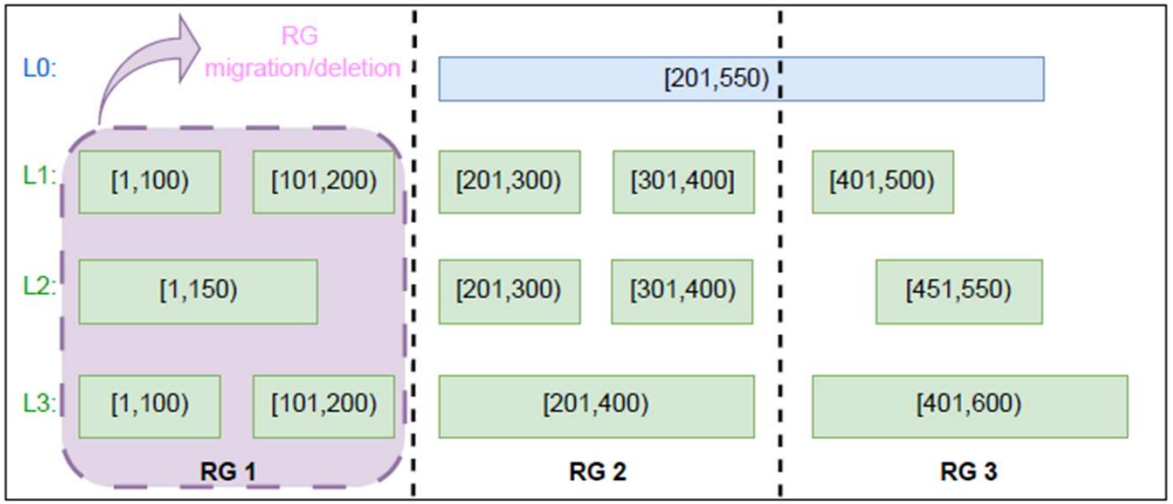
Efficient SST-Level Migration

Problem with Traditional Migration

✗ Migration triggers full compaction of source SSTs
✗ All tables in the region must be compacted together
✗ Migration time proportional to TOTAL region size
✗ Blocks writes during compaction (STW)

TDSQL-B: SST-Level Copy-on-Write

✓ Track SST ownership via manifest (not physical layout)
✓ Migration = update pointers, copy only changed SSTs
✓ Unchanged SSTs shared between source and destination
✓ Zero-downtime: background copy + atomic switch



Measured Improvement

Migration latency: 85% reduction
Data copied: Only delta (avg 12% of region size)

Evaluation Methods

How we measure improvement?

Cluster Configuration

- 3 servers (compute + storage mixed)
- Each server: 375GB RAM, 12x3.5 TB SSD
- Intel(R) Xeon(R) Platinum 8255C 96 cores
- Tencent tLinux release 4.14

Workload Characteristics

- SysBench variant: 6,000 tables (scaled up)
- Benchmark: TPC-C e-commerce scenarios
- Finance: 100 GB daily writes
- Games' Log Stream service: 500k data records write per second

Comparison Baselines

- TDSQL (shared-nothing storage)
- TiDB v7.6.0 (per-range Raft)
- HBase (NoSQL, manual region splitting)
- TokuDB (Storage-compressed baseline)

Metrics Measured

Throughput:	ops/sec at varying concurrency levels
Latency:	p50, p99, max at steady state
Memory Usage:	metadata memory vs table count scaling
Storage Amplification:	Actual disk usage / logical data size
Migration Time:	Time to migrate 1TB RegionGroup

Evaluation – Baseline System

2.0x
Throughput
vs TDSQL

2.0x
Throughput
vs TiDB

3.0x
Throughput
scale to 1024 threads

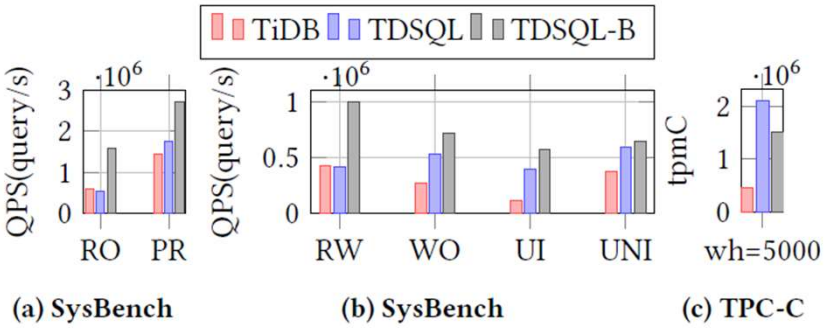
-90%
Memory usage
@ 8K tables

Scaling Behavior

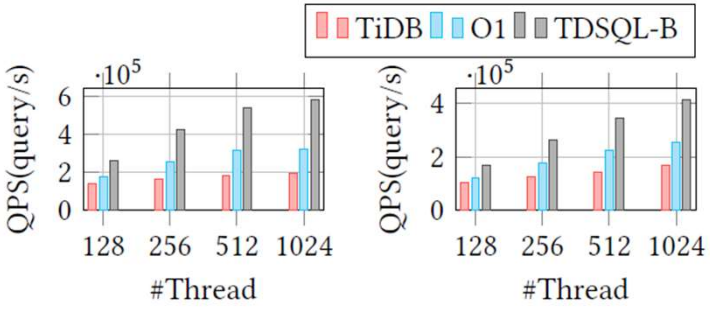
✓ Throughput improvement vs baselines
✓ Metadata memory stays flat (not O(table_count))
✓ Throughput improvement scales 1024 threads
✓ Compaction overhead decreases with more tables (amortized)

Key Insight

Unlike traditional systems where performance DEGRADES with more tables,
TDSQL-B improves efficiency as table count grows due to better amortization of compaction, Raft, and metadata overhead.



(a) SysBench (b) SysBench (c) TPC-C



(a) Read-write(RW) (b) Write-only (WO)

Evaluation – Ablation Study

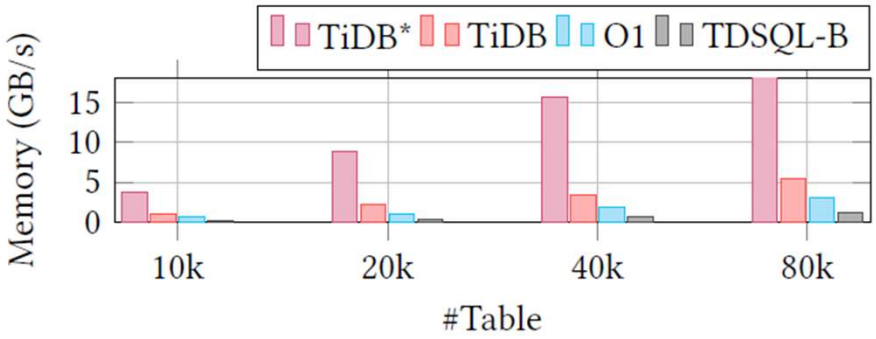
Ablation: Feature Contribution

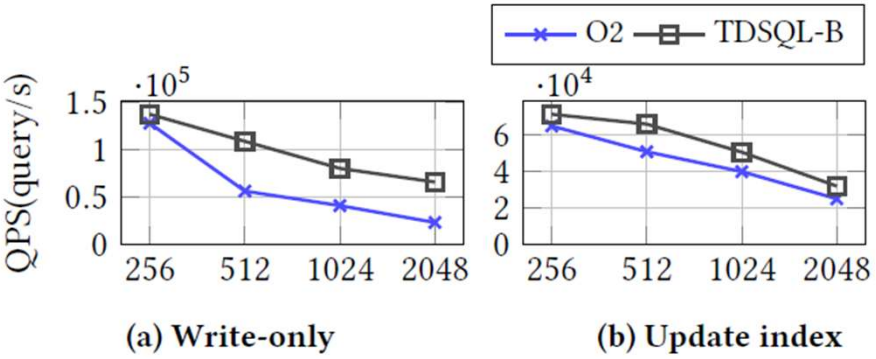
Baseline (no innovations)	1.0x
+ O1:Multi-Table Raft only	~1.65x
+ O2:SST Alignment only	~1.37x
+ Both innovations	~2.26x
+ Physical Migration.	~10x

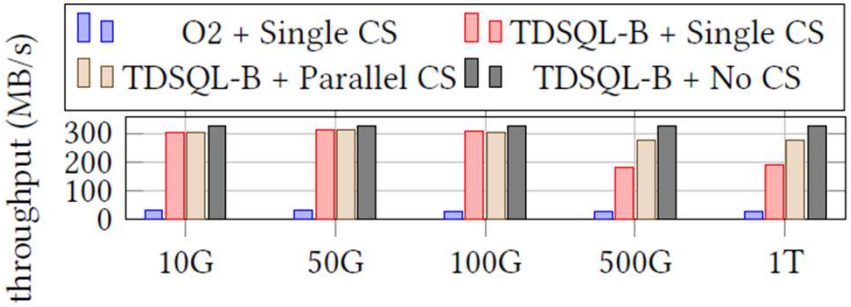
Takeaway

Both innovations are NECESSARY for maximum impact:
- Multi-Table Raft reduces coordination overhead (~65% gain)
- SST Alignment eliminates read waste (~37% gain)
- Combined effect is SUPERADDITIVE (over 2x)

They address different bottlenecks that compound.







Evaluation – Production Impact

Cloud Testing

A Competitor vs. TDSQL-B

- Sysbench
- Query speed: 70% faster for write-only
- Cloud cost: 20% of the cost

Financial Top-up Service

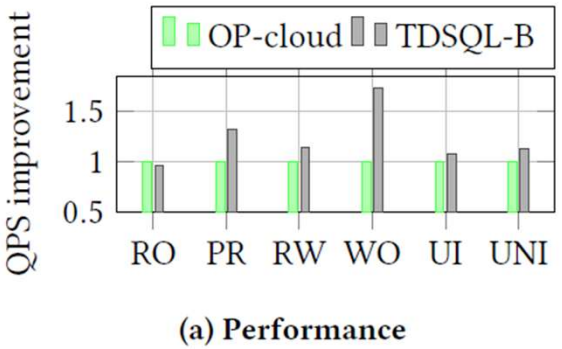
HBase → TDSQL-B

- 100GB data daily growth
- Storage: 35.3TB → 16.6TB (-51%)
- p99 latency: 150ms → 37ms (-76%)

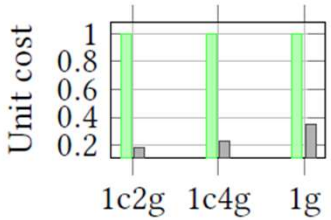
Tencent Game Log Streaming

TokuDB → TDSQL-B

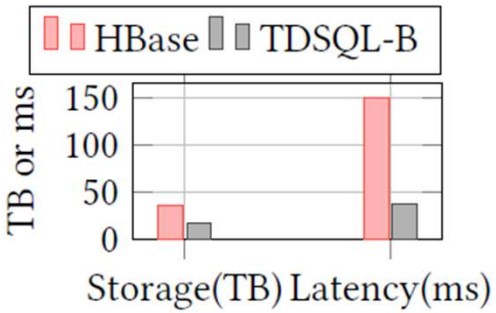
- high write throughput
- Max Writes: 80K/sec → 164K/sec (+100%)
- Nodes: 76 → 23 (-69%)

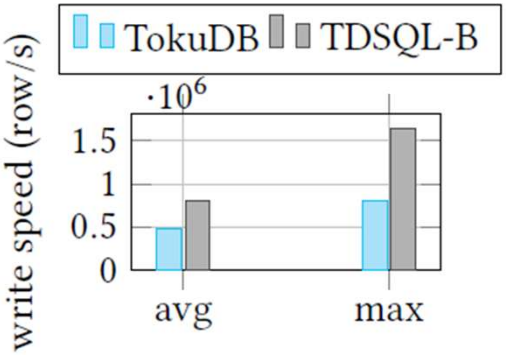


(a) Performance



(b) Cost





Average 50% storage reduction, 70% latency improvement, 60% infrastructure cost savings.

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04

Future Work

Research topics

TDSQL
VLDB 2024

TDSQL: Tencent Distributed Database System

TPC-C benchmark

TDSQL-Boundless
SIGMOD 2026

TDSQL-Boundless: A Distributed Database System for Large-scale Heterogeneous Multi-Table Workloads

Distributed-LSM Optimization

TDSQL-HTAP
2027

TODO1: HTAP Design and Optimization

TXSQL: Lock Optimizations Towards High Contented Workloads

2PL Optimization for Hotspot

TXSQL
SIGMOD 2025

Reaching the Pinnacle of TPC-DS: Co-design of Architecture, Executor, and Storage in TDSQL

TPC-DS benchmark

TDSQL
VLDB 2026

TODO2: Object Storage Design and Optimization

TDSQL-COS
2027

Contact us

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Qing Yun Plan (High-level Job Position for Graduates)

https://join.qq.com/qingyun.html

WeChat

Thanks

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Why Existing Architectures Fall short

Three critical failure modes in production

Metadata Explosion

- Partitions scale with table count
- 20-30GB RAM @ 100K regions
- Risk of Out-of-Memory crashes
- 5-table SQL may route to 50 partitions

~30GB
RAM metadata

Transaction Overhead

- Cross-partition txns require 2PC
- Even same-node cross-region pays cost
- Latency amplification from coordination
- Lock contention across partitions

2x+
Latency increase

Storage Inefficiency

- +40% data bloat (Oracle to MySQL)
- Shared LSM trees cause L0 bloating
- Reduced compaction efficiency
- Small tables suffer heavyweight ops

-40%
Storage loss

These are NOT edge cases - daily reality in banking, gaming, financial services.