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DAT309-R

Amazon Aurora storage demystified: How it all works

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Agenda

- What is Amazon Aurora?
- Quick recap: Database internals & motivation for building Aurora
- Cloud-native database architecture
- Durability at scale
- Performance results

Features & demos

- Global databases
- Fast database cloning
- Database backtrack

What is Amazon Aurora ?

Enterprise class cloud native database

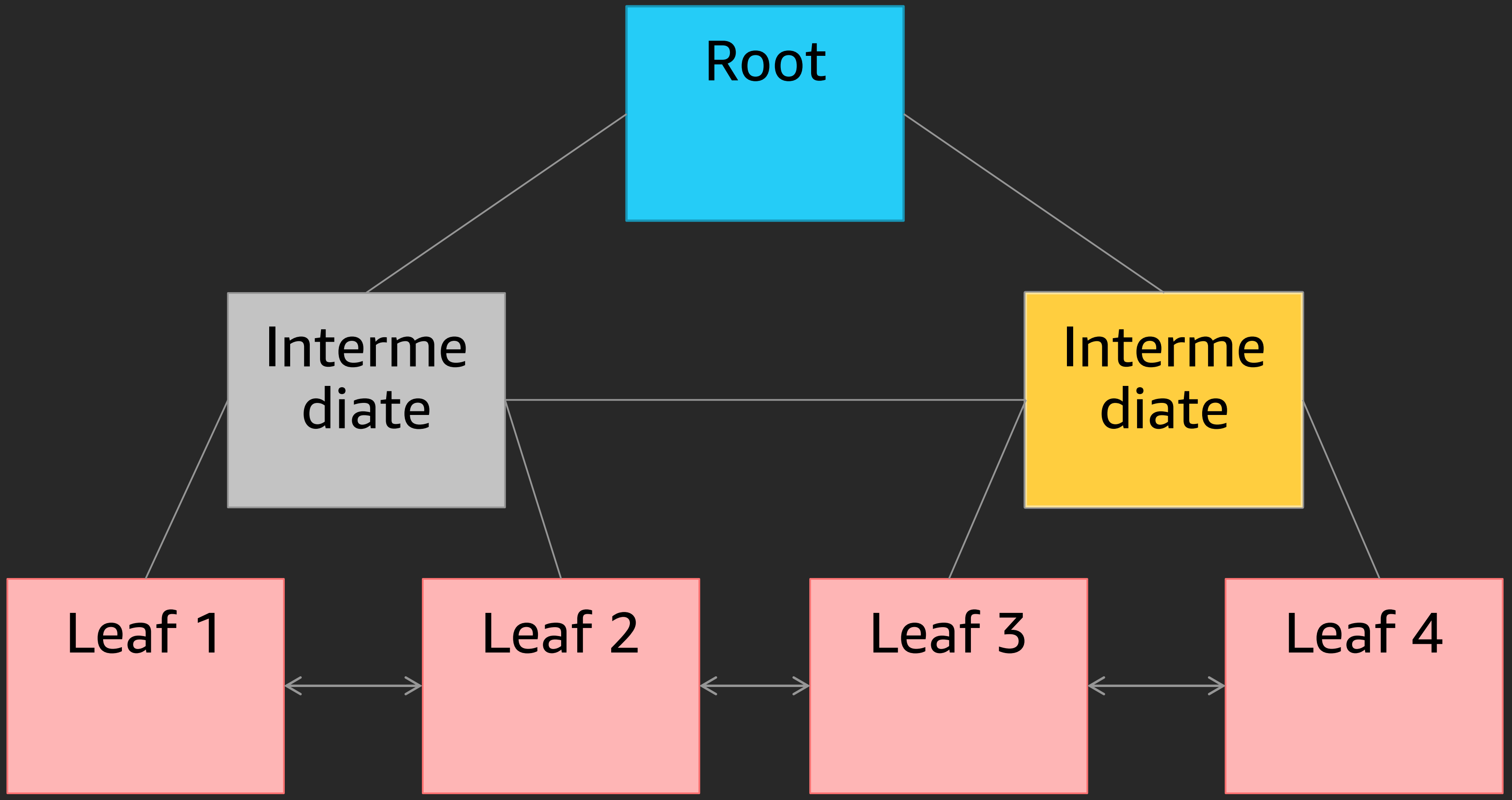
Amazon Aurora

- ☑ Speed and availability of high-end commercial databases
- ☑ Simplicity and cost-effectiveness of open-source databases
- ☑ Drop-in compatibility with MySQL and PostgreSQL
- ☑ Simple pay-as-you-go pricing

Delivered as a managed service

Quick recap: Database internals

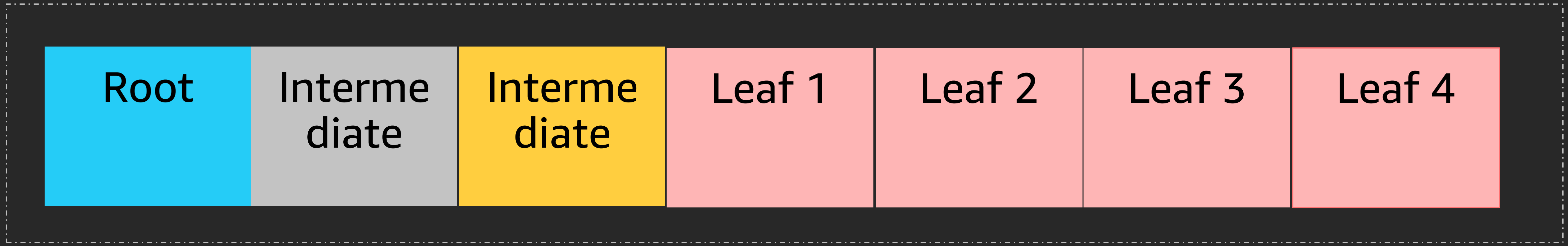
Quick recap: Database B+ Tree



Data is organized in memory as fixed sized "pages", e.g. 16KB

(aka "buffer-pool")

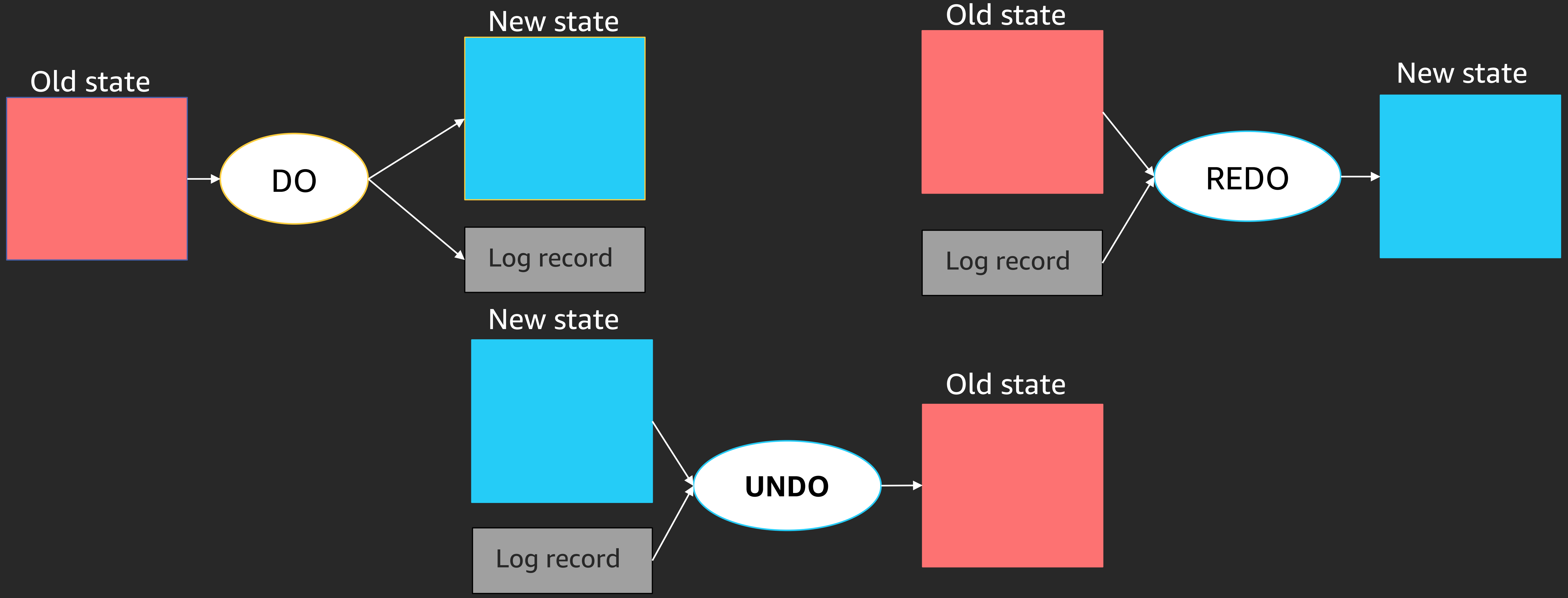
Pages are serialized into durable storage (aka "checkpoint") periodically



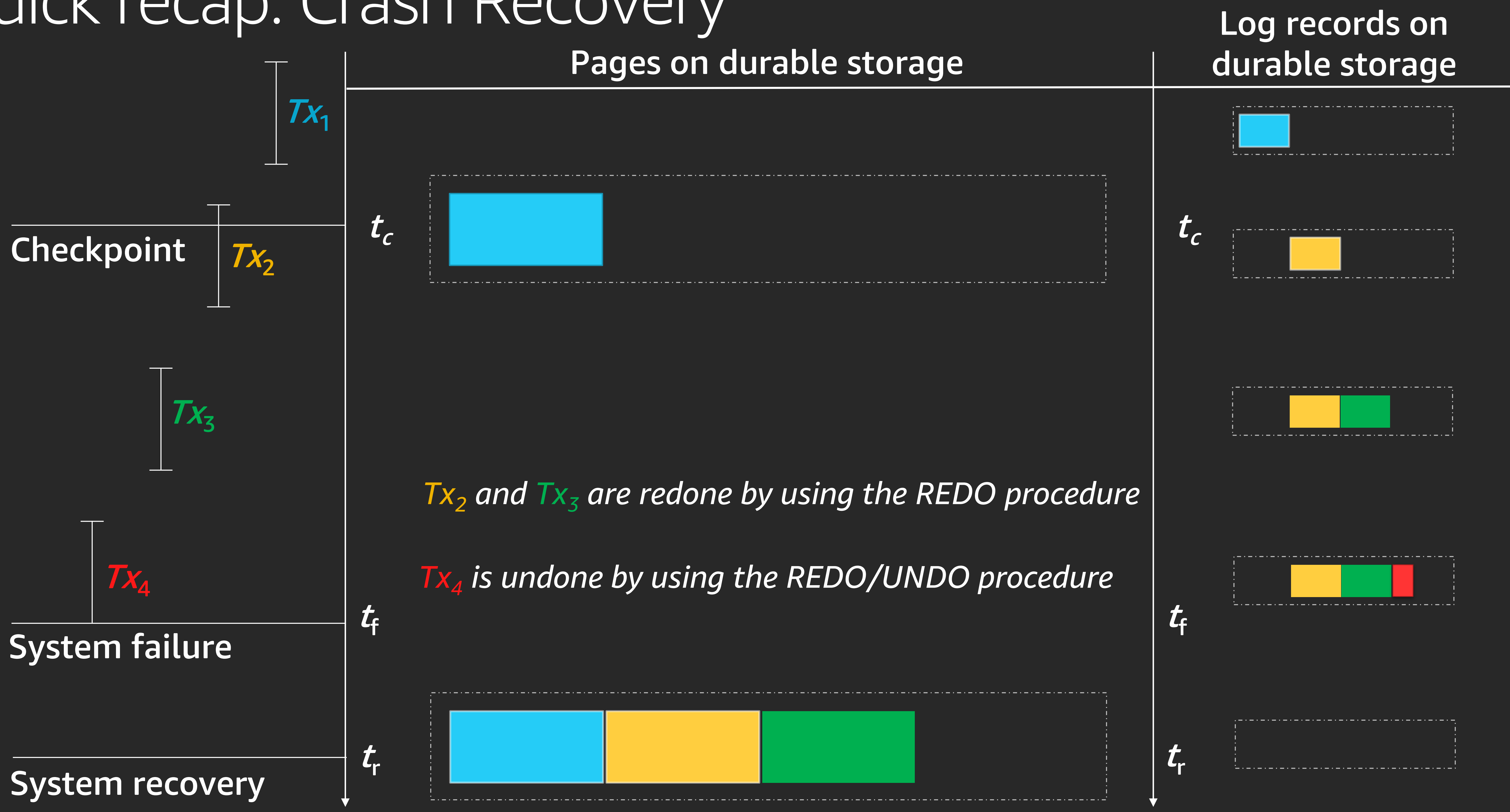
Quick recap: DO-REDO-UNDO protocol

Data is modified “in-place” in the buffer-pool using a DO/REDO/UNDO operation

Log records with before and after images are stored in a write-ahead log (WAL)



Quick recap: Crash Recovery



Quick recap: I/Os required for persistence

Pages on durable storage | Log records on durable storage

Log record write:
typically few bytes

Torn page protection write:
page sized, e.g. 16KB

Checkpoint write:
page sized, e.g. 16KB

User data change size << I/O size (32KB+)

Databases are all about I/O

Cloud native database architecture

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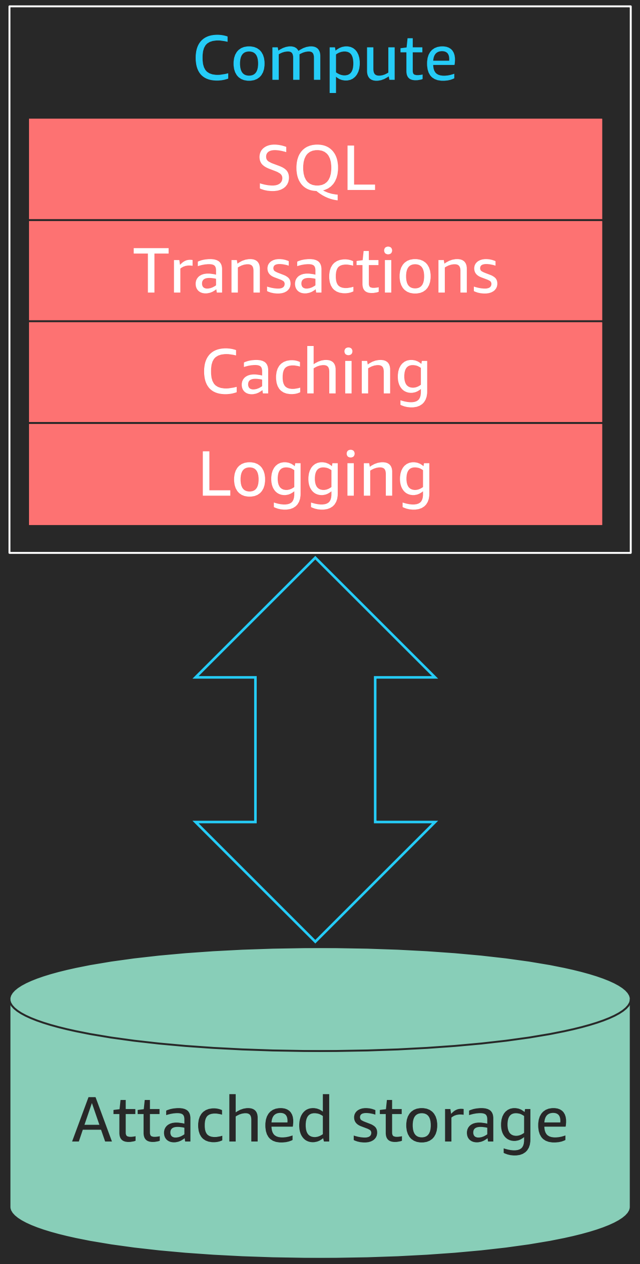
Traditional database architecture

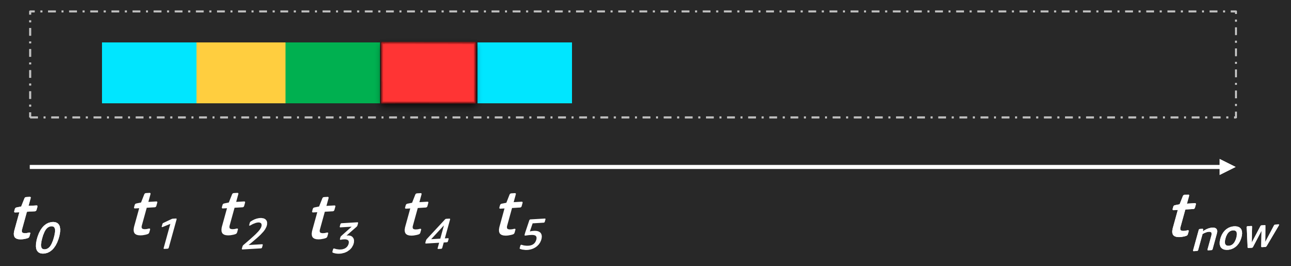
Databases are all about I/O

Design principles for > 40 years
- Increase I/O bandwidth
- Decrease number of I/Os !



Aurora approach: Log is the database

Log stream from beginning of the database



Any version of a database page can be constructed using the log stream

Blue-page at t_5 can be created using log records from t_1 and t_5

Aurora approach: Offload checkpointing to the storage fleet

Problem 1:

Relying only on log stream for page reads is not practical (too slow)

Solution:

Use periodic checkpoints

Problem 2:

Database instance is burdened with checkpointing task

Solution:

Use a distributed storage fleet for continuous checkpointing

Aurora approach: compute & storage separation

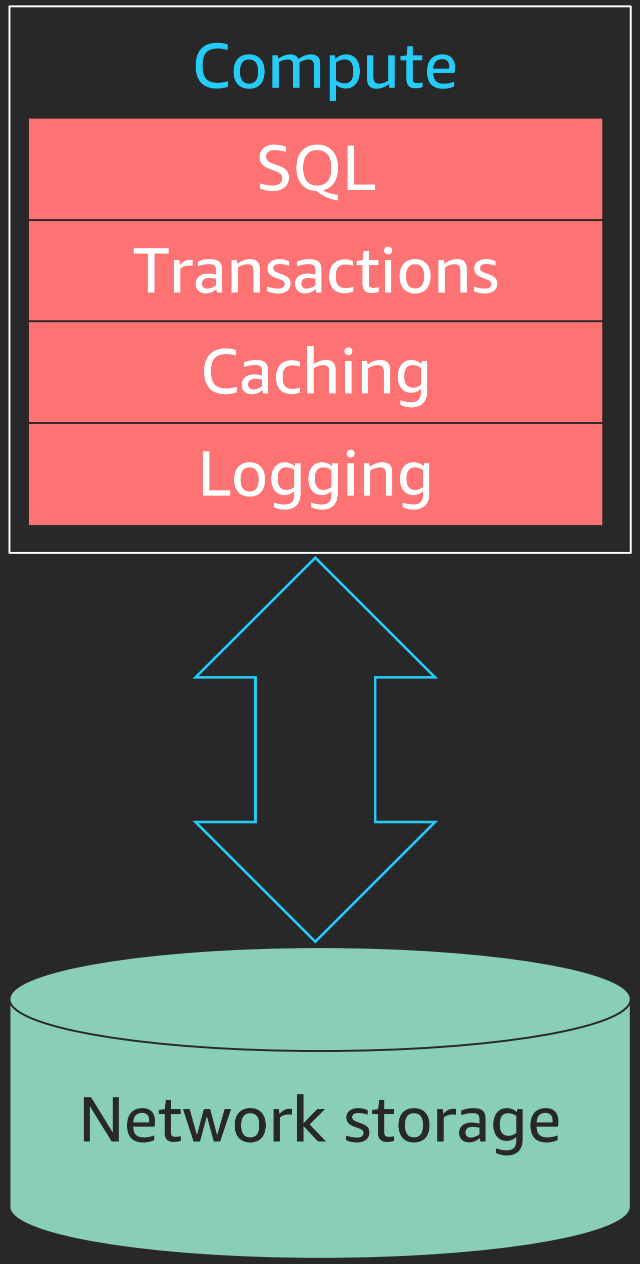
Compute & storage have different lifetimes

<u>Compute instances</u>

- fail and are replaced
- are shut down to save cost
- are scaled up/down/out on the basis of load needs

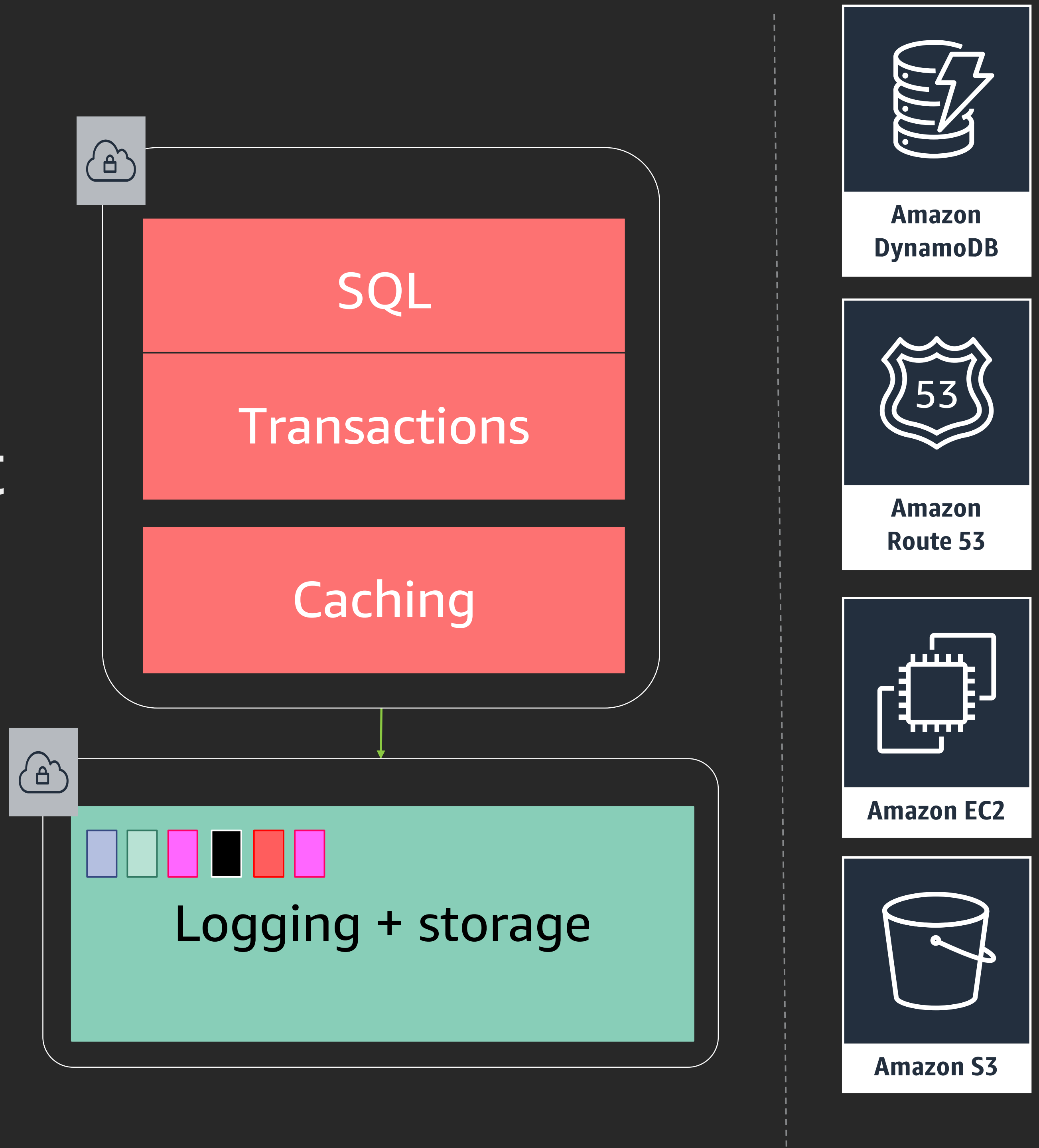
<u>Storage</u>, on the other hand, has to be long-lived

Decouple compute and storage for scalability, availability, durability

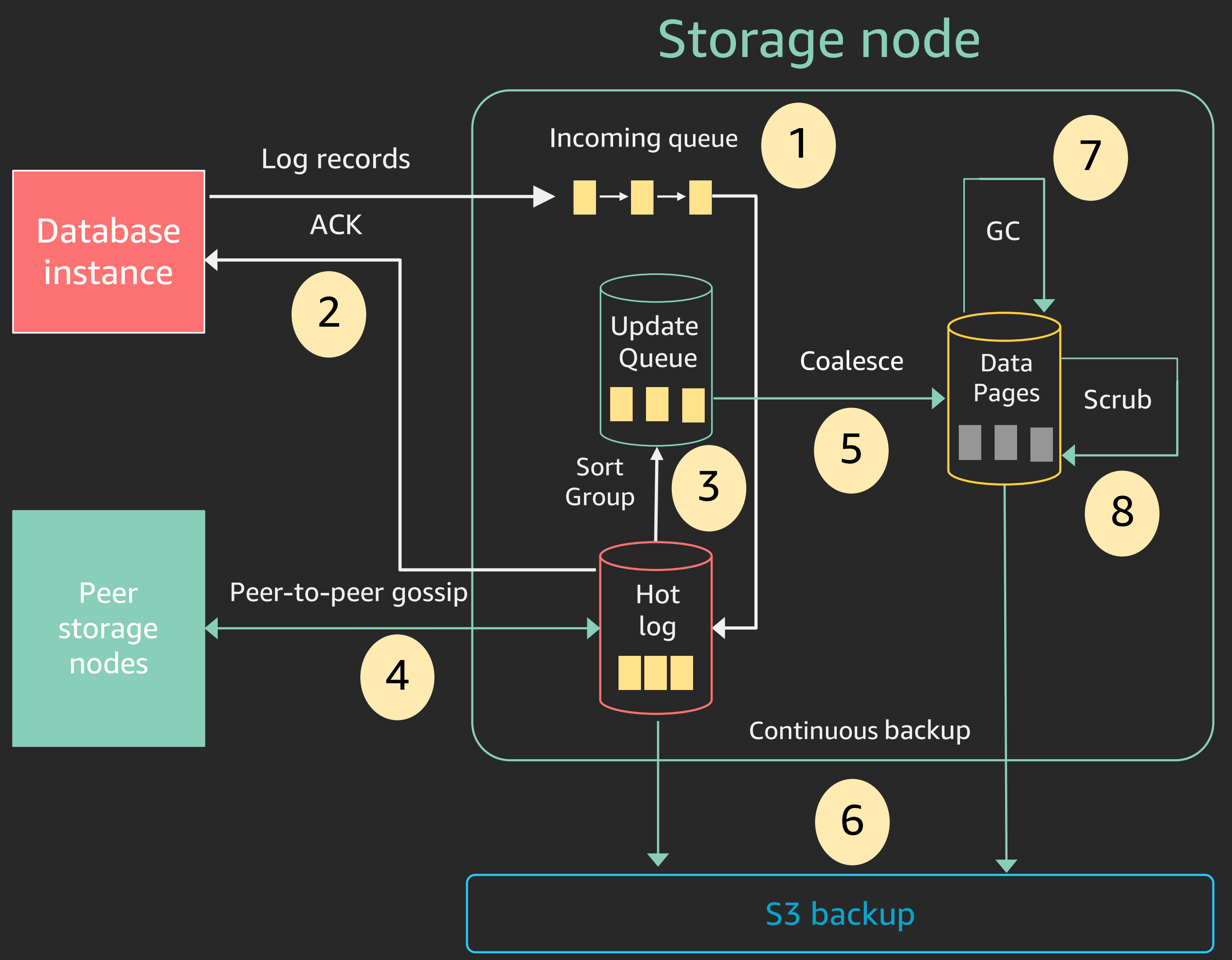


Aurora uses service-oriented architecture

We built a log-structured distributed storage system that is multi-tenant, multi-attach, and purpose-built for databases



I/O flow in Amazon Aurora storage node



1. Receive log records and add to in-memory queue and durably persist log records
2. ACK to the database
3. Organize records and identify gaps in log
4. Gossip with peers to fill in holes
5. Coalesce log records into new page versions
6. Periodically stage log and new page versions to S3
7. Periodically garbage collect old versions
8. Periodically validate CRC codes on blocks

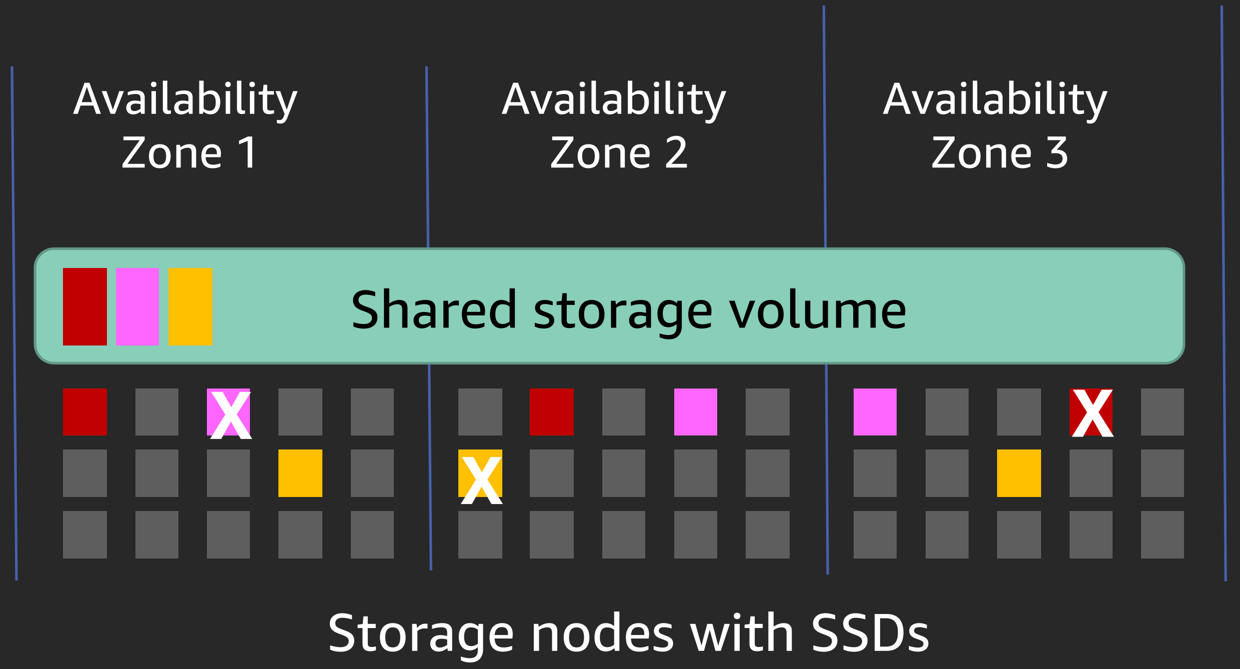
Note:

- All steps are asynchronous
- Only steps 1 and 2 are in the foreground latency path

Durability at scale

Uncorrelated and independent failures

At scale there are continuous independent failures due to failing nodes, disks, and switches.



<u>The solution is replication</u>

One common straw man:

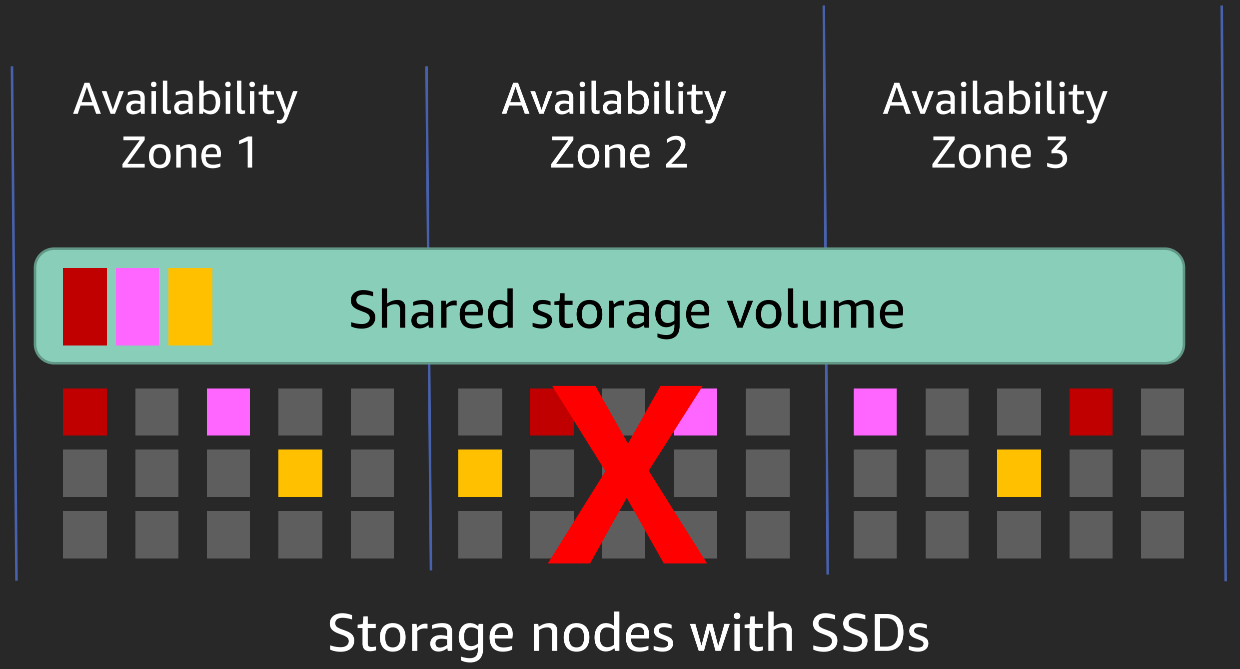
- Replicate 3-ways with 1 copy per AZ
- Use write and read quorums of 2/3

What about AZ failure?

⇒ Still have 2/3 copies

⇒ Can establish quorum

⇒ No data loss



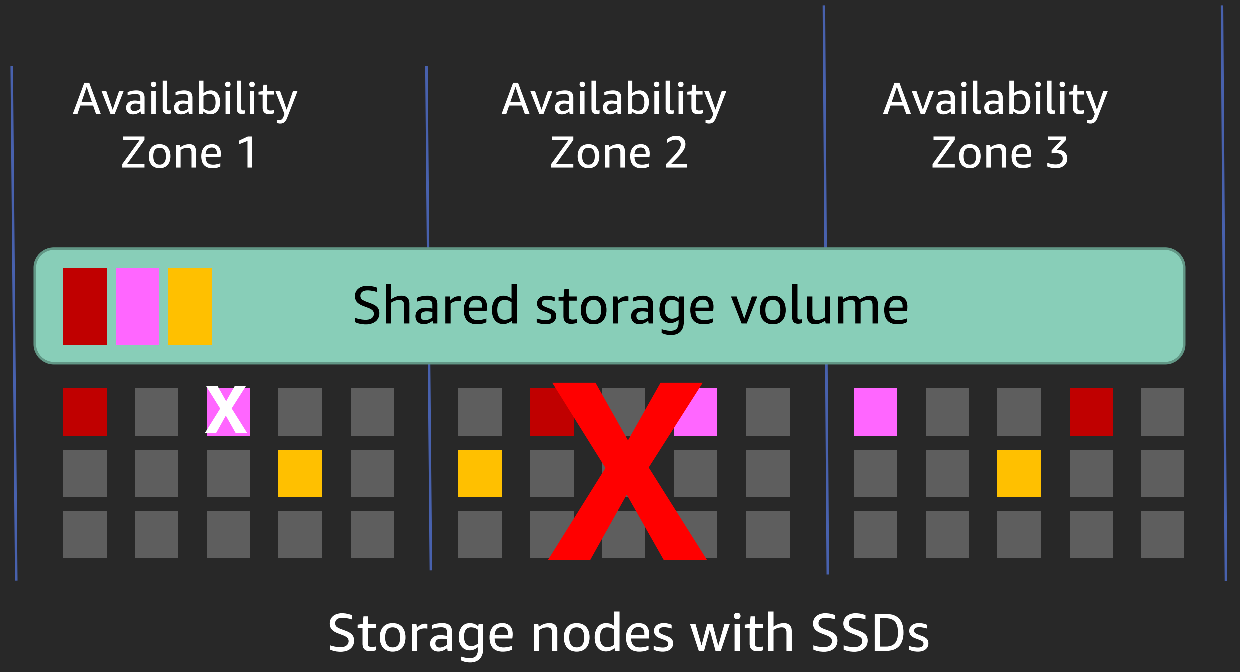
What about AZ + 1 failures?

Losing 1 node in an AZ while another AZ is down

⇒ Lose 2/3 copies

⇒ Lose quorum

⇒ Lose data



Aurora tolerates AZ + 1 failures

Replicate 6-ways with 2 copies per AZ

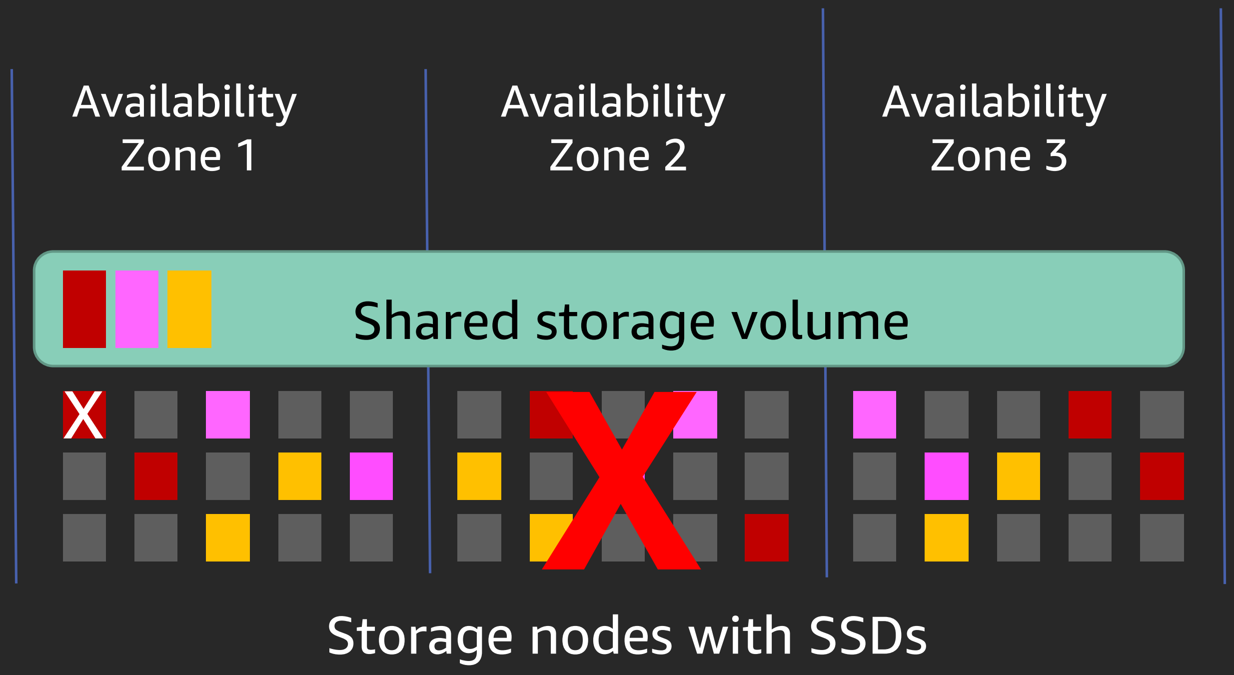
Write quorum of 4/6

What if an AZ fails?

⇒ Still have 4/6 copies
⇒ Maintain write availability

What if there is an AZ + 1 failure ?

⇒ Still have 3 copies
⇒ No data loss
⇒ Rebuild failed copy by copying from 3 copies
⇒ Recover write availability



Aurora uses segmented storage

- Partition volume into n fixed-size segments
  - Replicate each segment 6 ways into a protection group (PG)

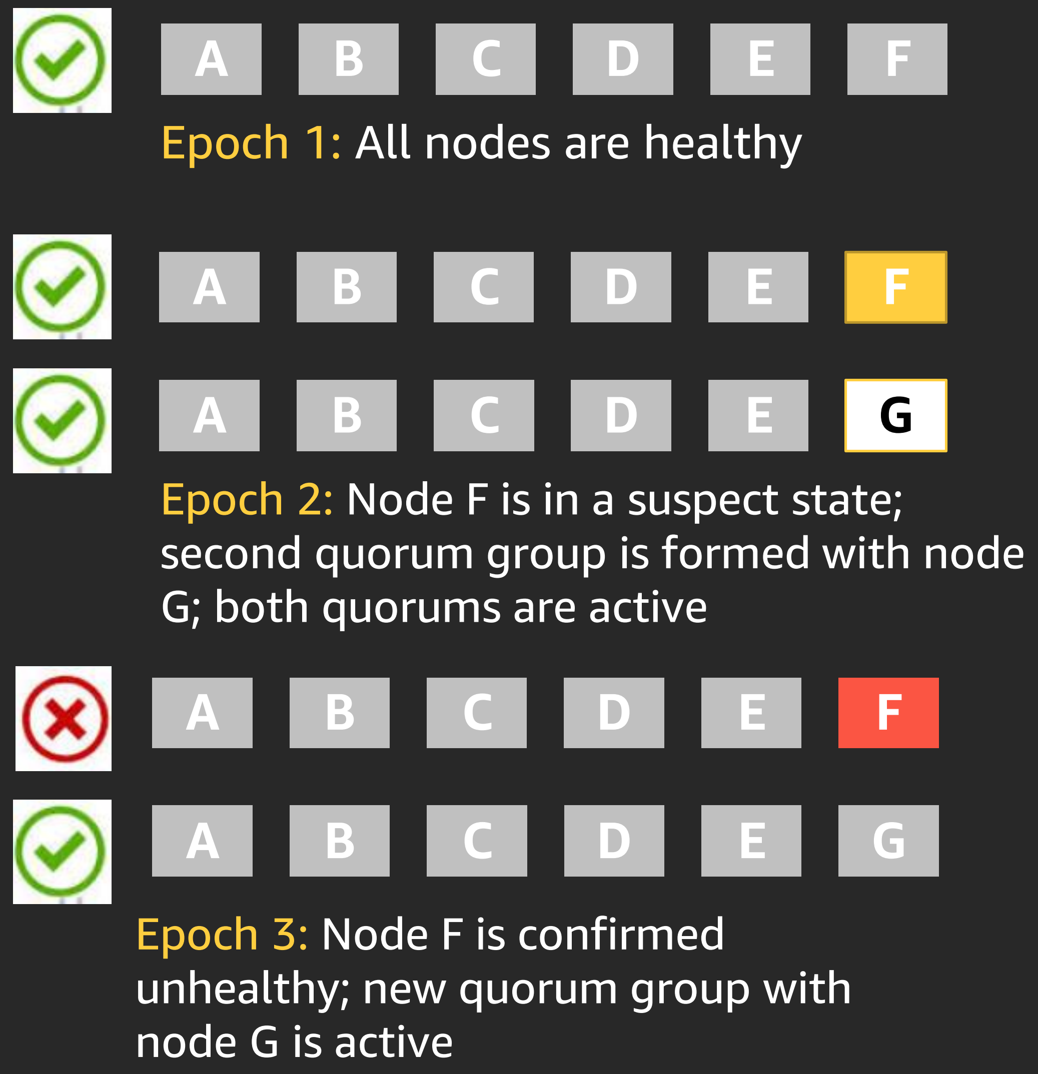
- Trade-off between likelihood of faults and time to repair
  - If segments are too small, failures are more likely
  - If segments are too big, repairs take too long

- Choose the biggest size that lets us repair “fast enough”
  - We currently picked a segment size of 10 GB, as we can repair a 10-GB segment in less than a minute

Fast and reversible membership changes

Use quorum sets, and epochs to

- Enable quicker transitions with epoch advances
- Create richer temporary quorums during changes
- Reverse changes by more quorum transitions



Performance results

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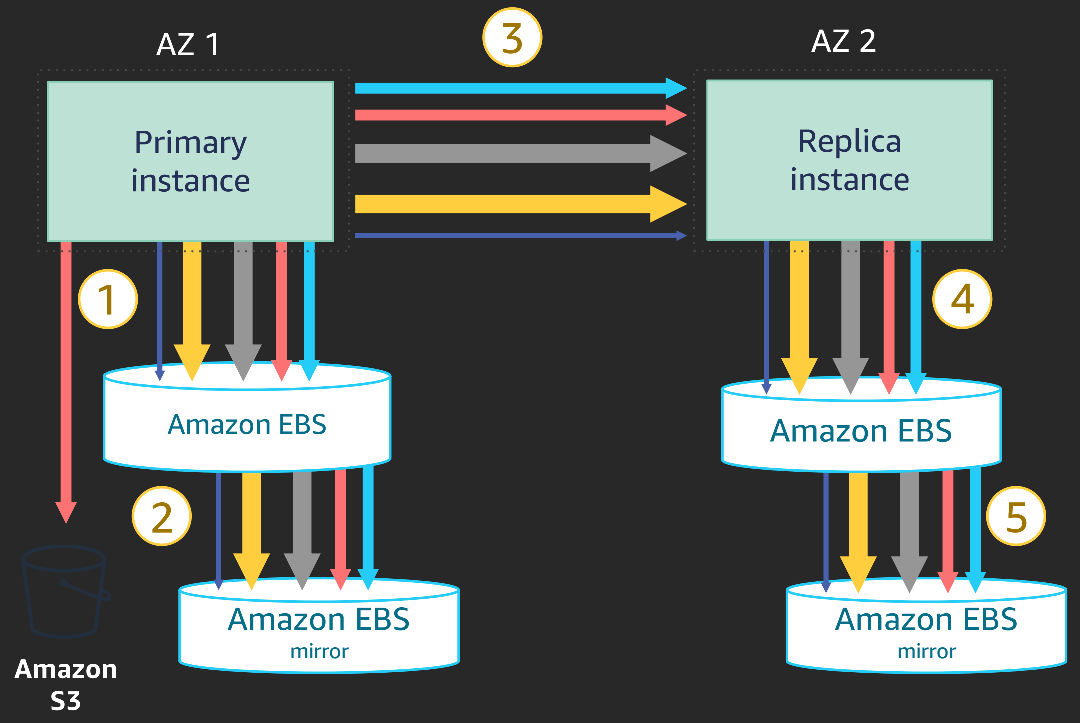
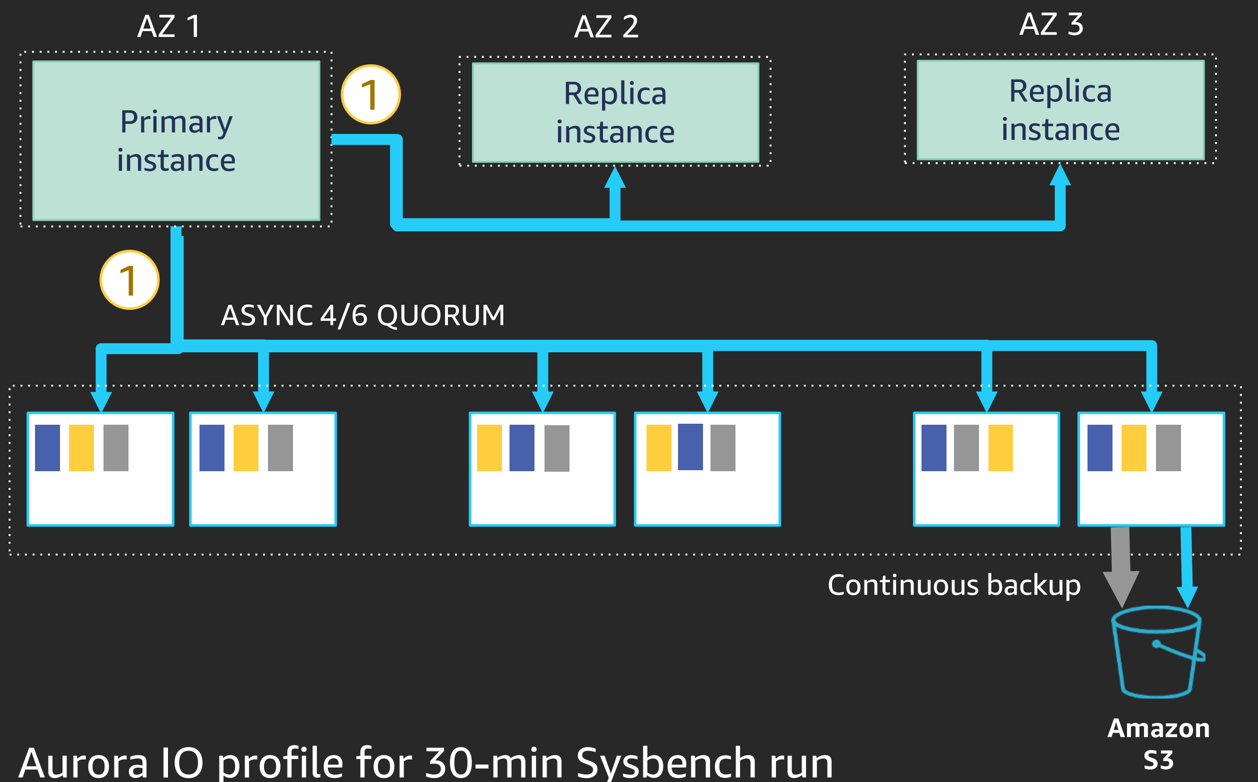
Aurora I/O profile

MySQL with replica



MySQL I/O profile for 30-min Sysbench run
- 780K transactions
- Average 7.4 I/Os per transaction

Aurora

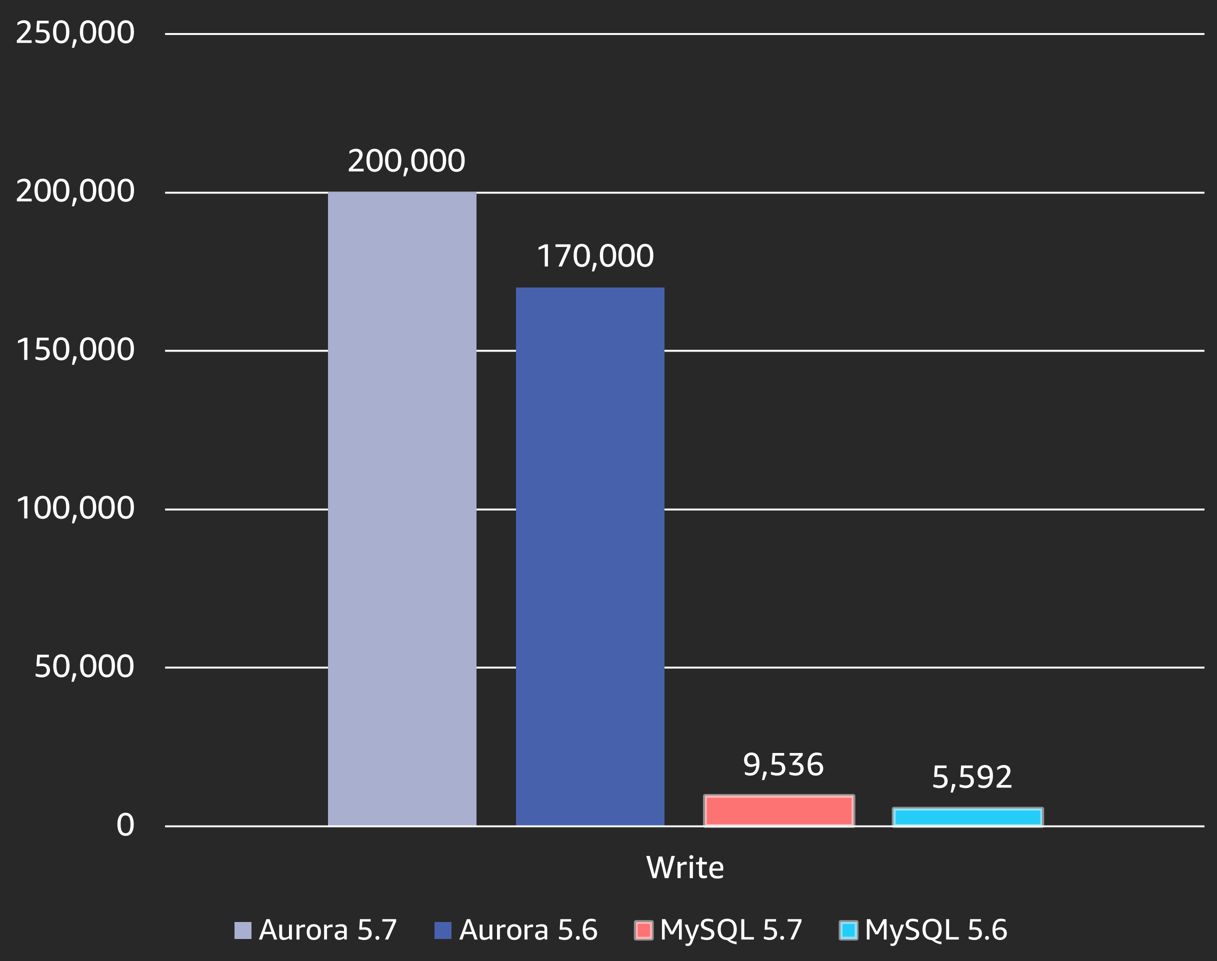


Aurora IO profile for 30-min Sysbench run
- 27M transactions: 35× more
- 0.95 I/Os per transaction (6× amplification): 7.7× less

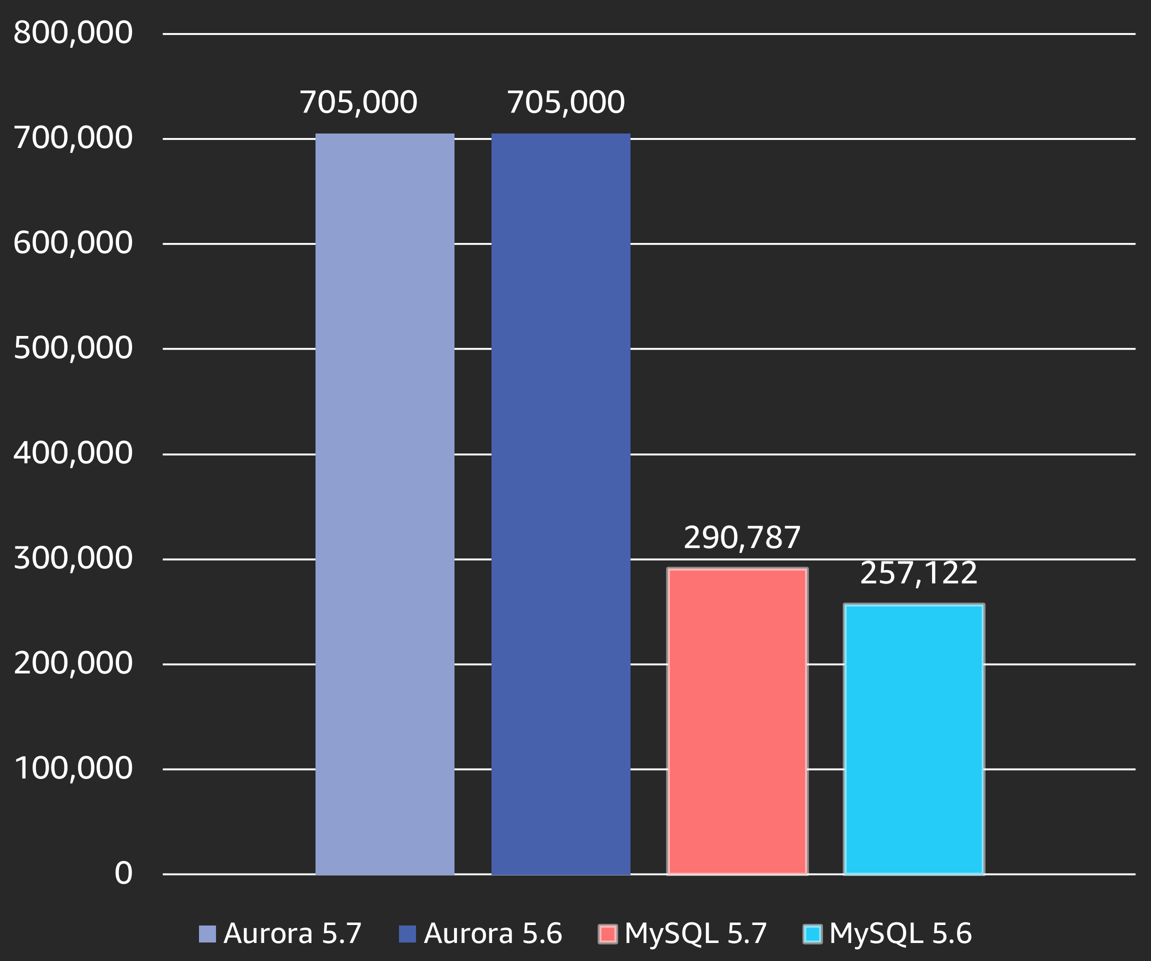
Log | Binlog | Data | Double-write | Frm files

Write and read throughput

Aurora MySQL is 5× faster than MySQL



Write throughput

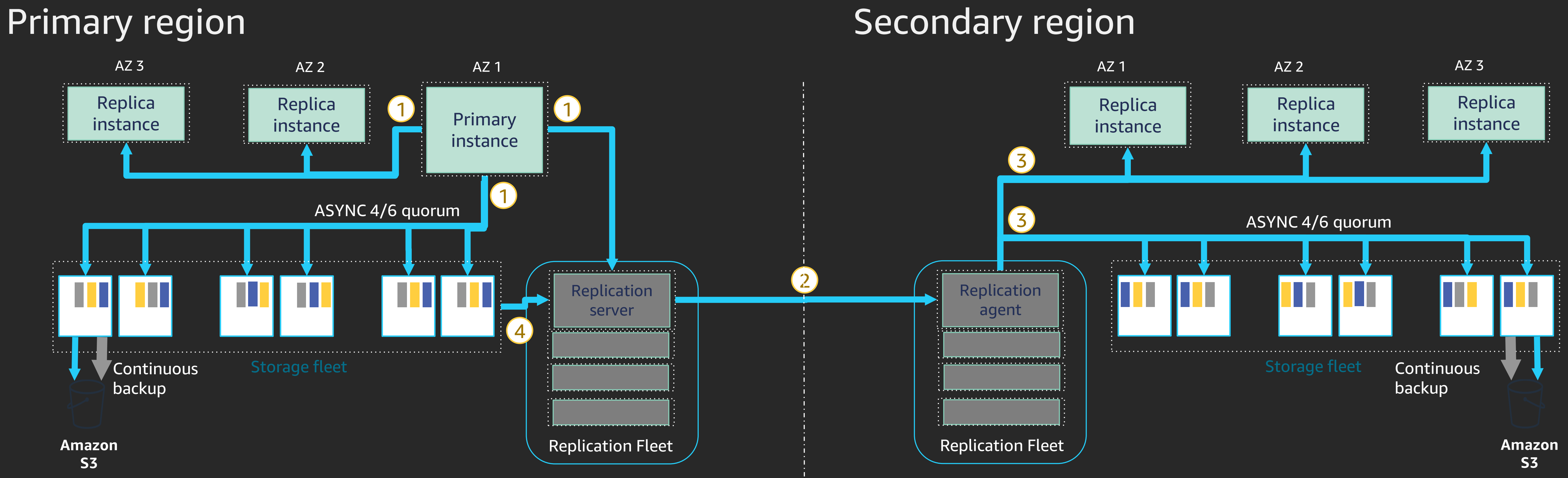


Read throughput

Using Sysbench with 250 tables and 200,000 rows per table on R4.16XL

Global databases

Global physical replication



1. Primary instance sends log records in parallel to storage nodes, replica instances, and replication server
2. Replication server streams log records to replication agent in secondary region
3. Replication agent sends log records in parallel to storage nodes and replica instances
4. Replication server pulls log records from storage nodes to catch up after outages

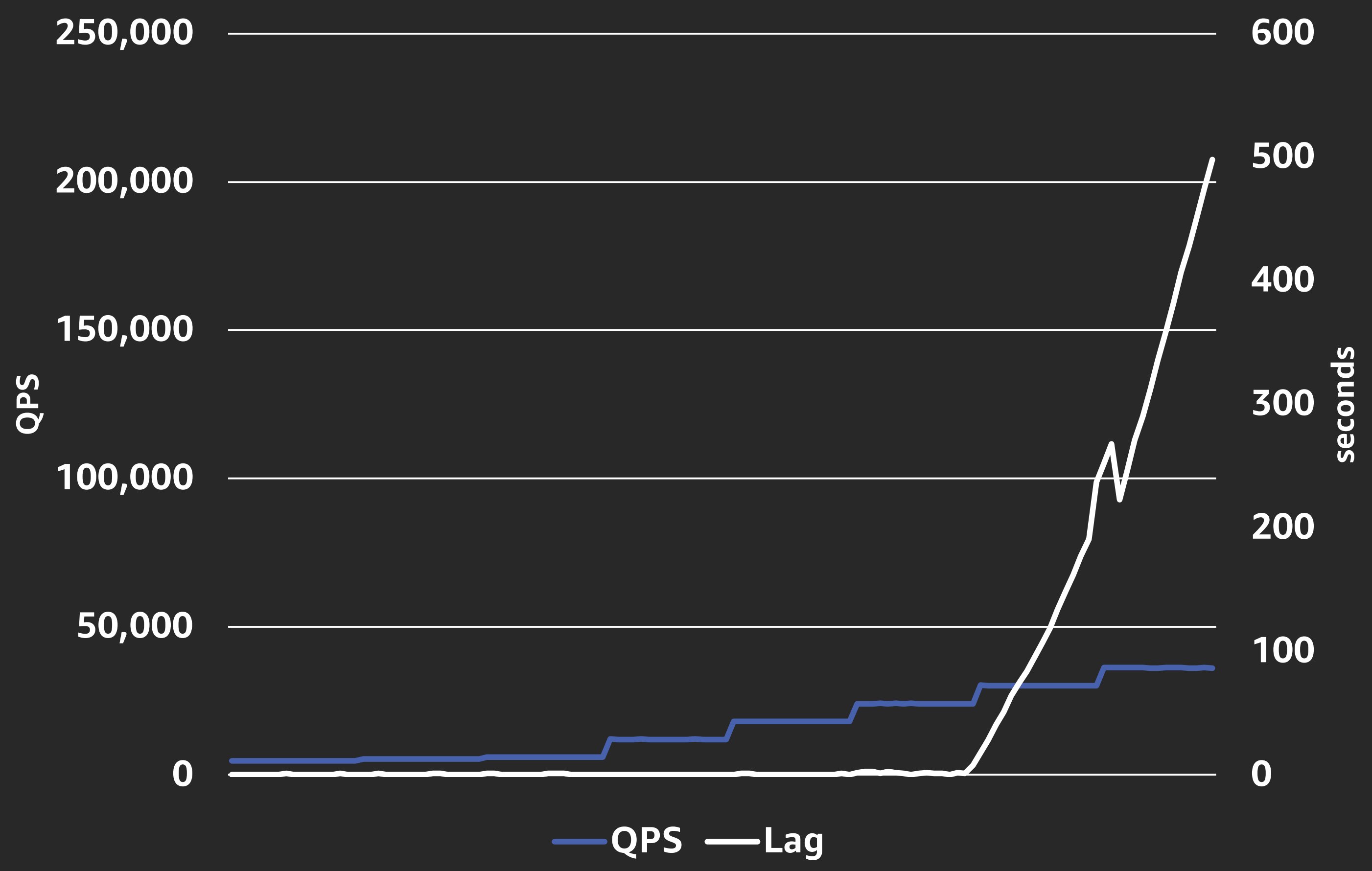
High throughput: Up to 150K writes/second; negligible performance impact

Low replica lag: <1 second cross-region replica lag under heavy load

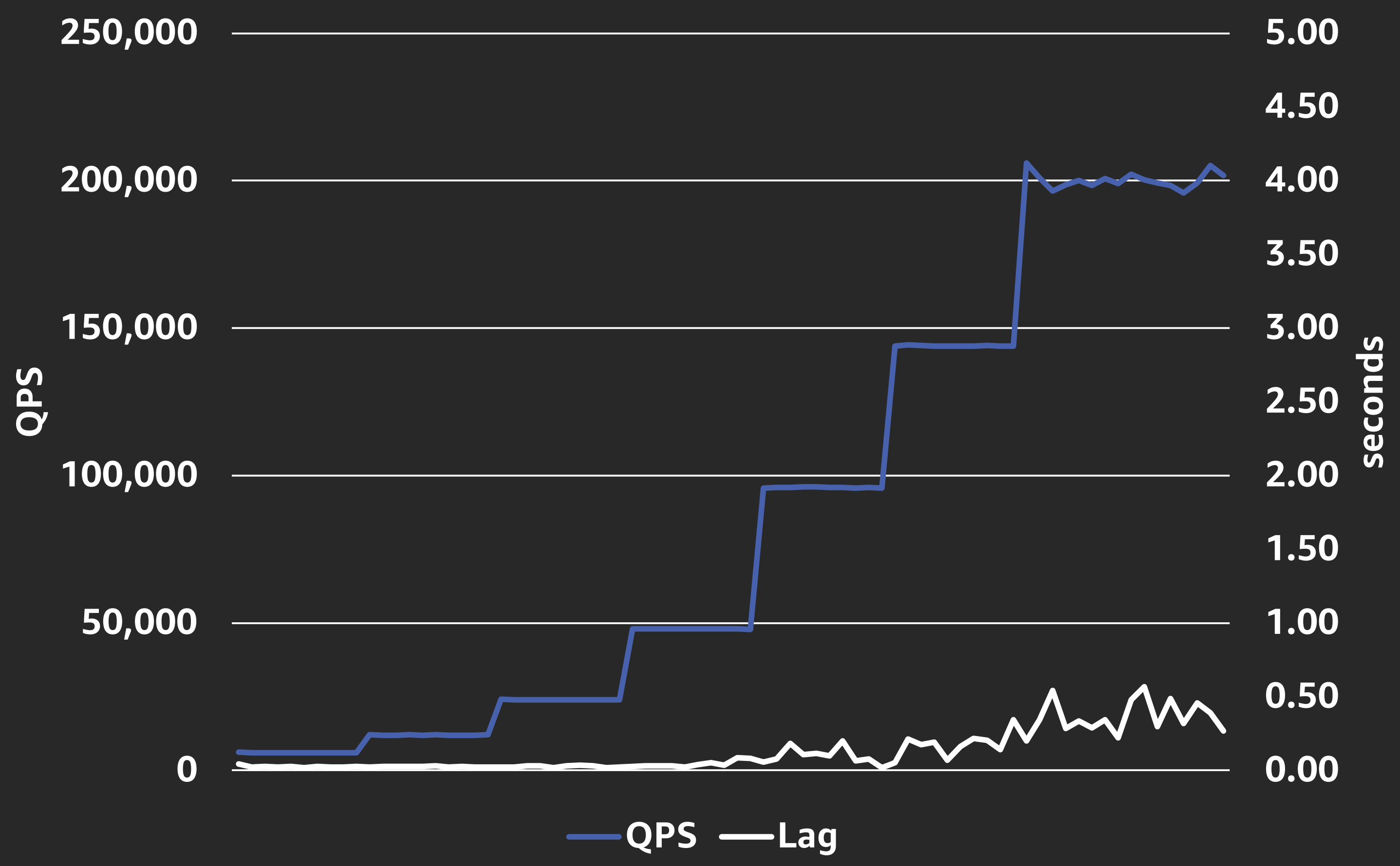
Fast recovery: <1 minute to accept full read-write workloads after region failure

Global replication performance

Logical vs. physical replication



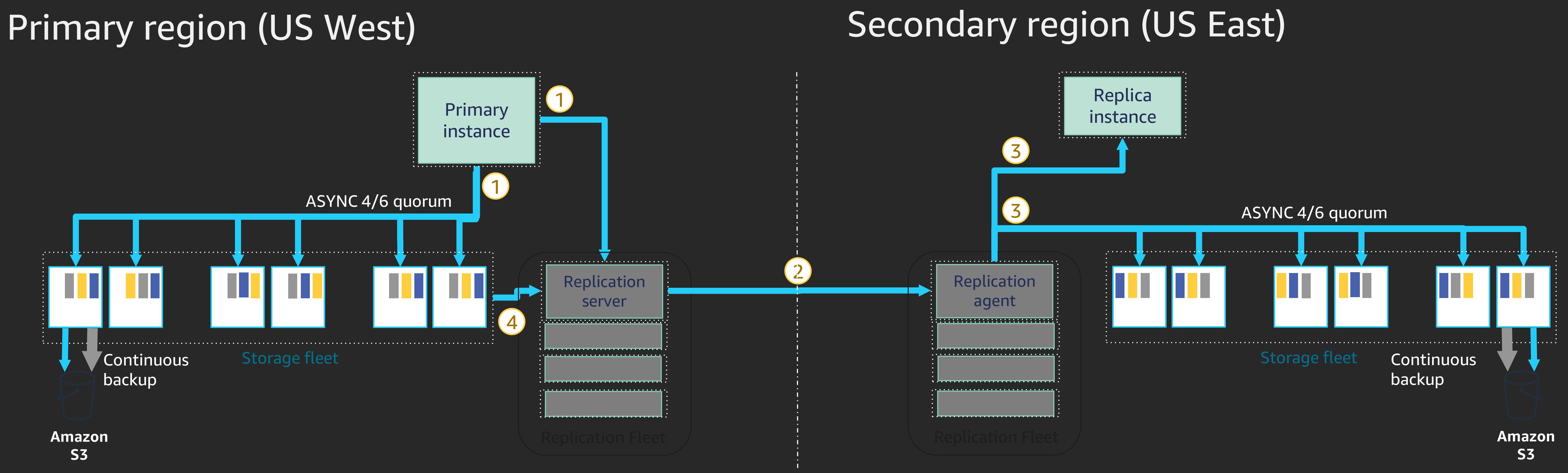
Logical replication



Physical replication

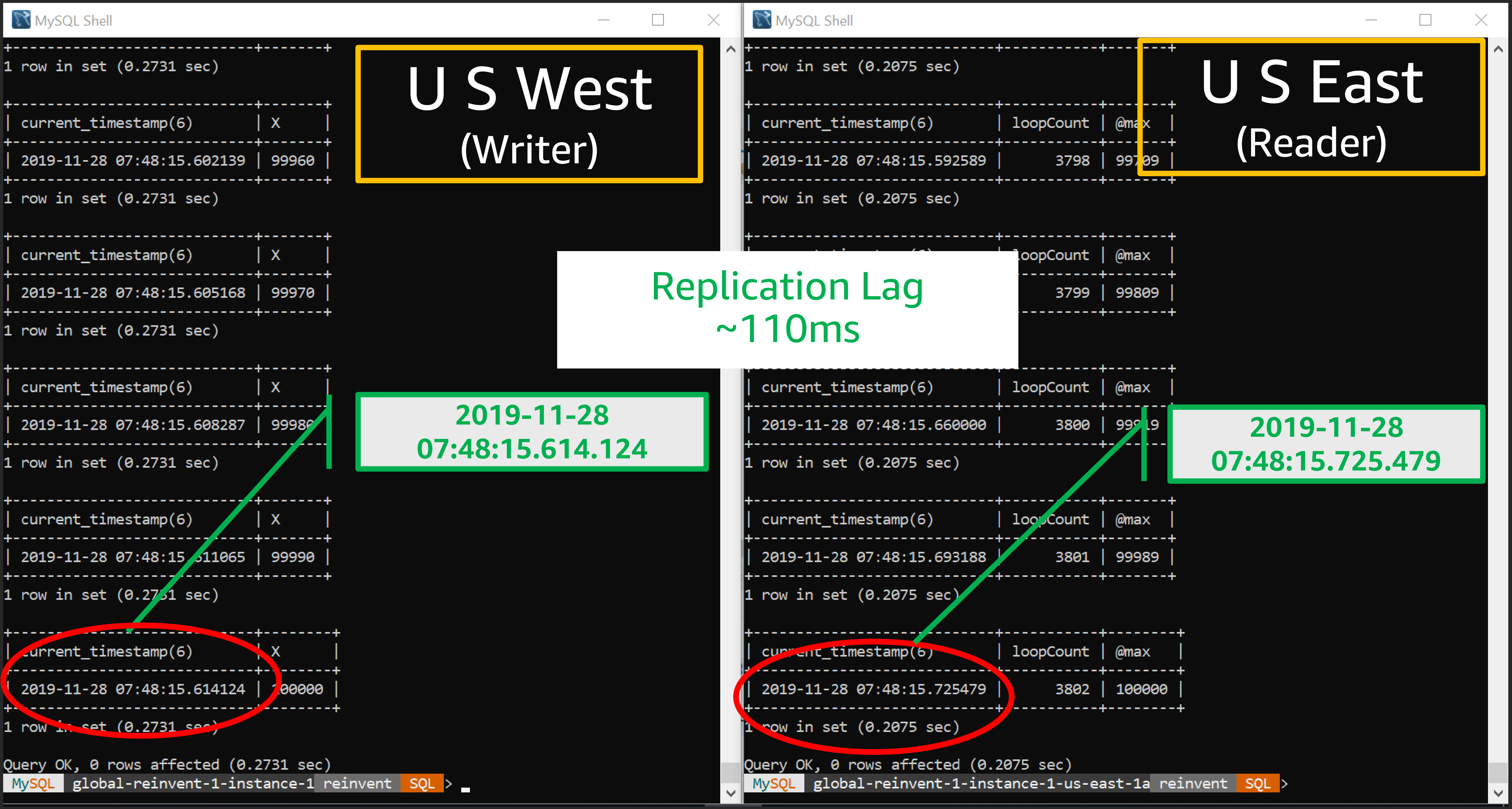
Global databases - Demo

Global databases



Continuous Inserts

Continuous Reads

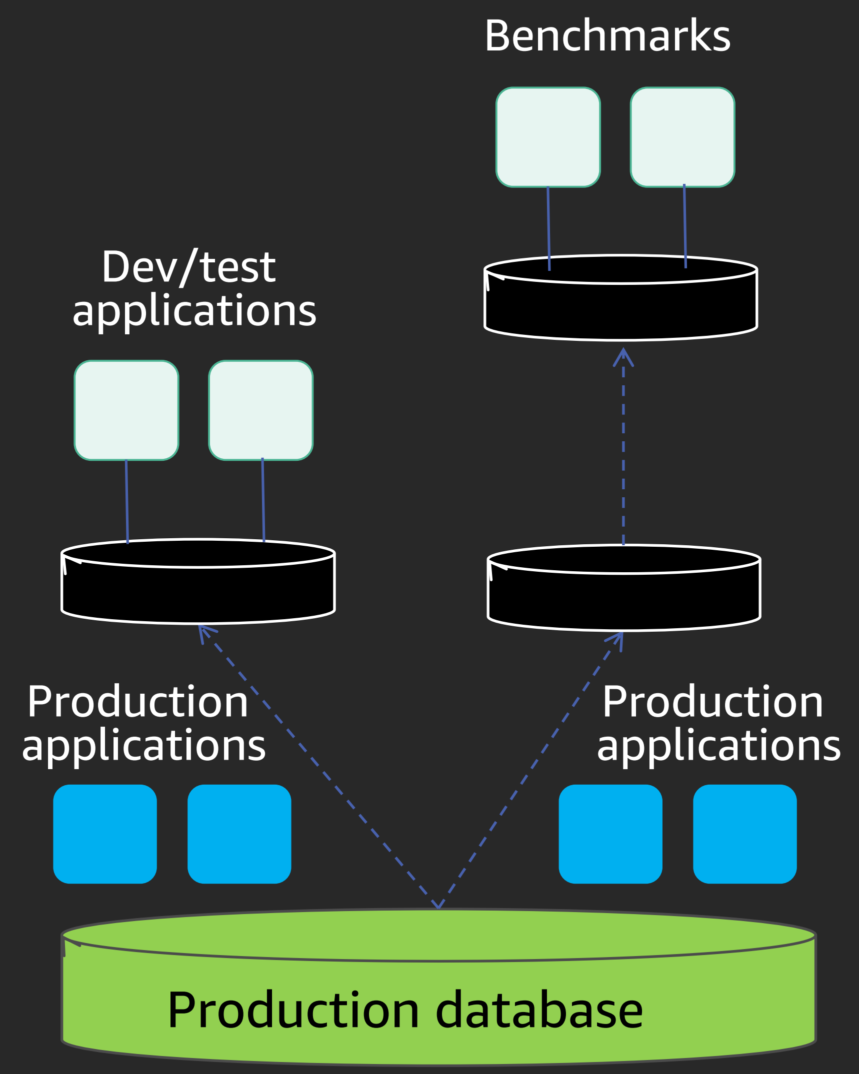

MySQL Shell
U S West
(Writer)
1 row in set (0.2731 sec)
current_timestamp(6)	X
2019-11-28 07:48:15.602139	99960
2019-11-28 07:48:15.605168	99970
2019-11-28 07:48:15.608287
current_timestamp(6)	X
2019-11-28 07:48:15.614124
Query OK, 0 rows affected (0.2731 sec)
MySQL global-reinvent-1-instance-1 reinvent SQL
2019-11-28
07:48:15.614.124
Replication Lag
~110ms
MySQL Shell
U S East
(Reader)
1 row in set (0.2075 sec)
current_timestamp(6)	loopCount
2019-11-28 07:48:15.592589	3798
3799	99809
current_timestamp(6)	loopCount	@max
2019-11-28 07:48:15.660000	3800
2019-11-28 07:48:15.693188	3801	99989
2019-11-28 07:48:15.725479	3802	100000
Query OK, 0 rows affected (0.2075 sec)
MySQL global-reinvent-1-instance-1-us-east-1a reinvent SQL
2019-11-28
07:48:15.725.479

Fast database cloning

Fast database cloning

Create a copy of a database without duplicate storage costs

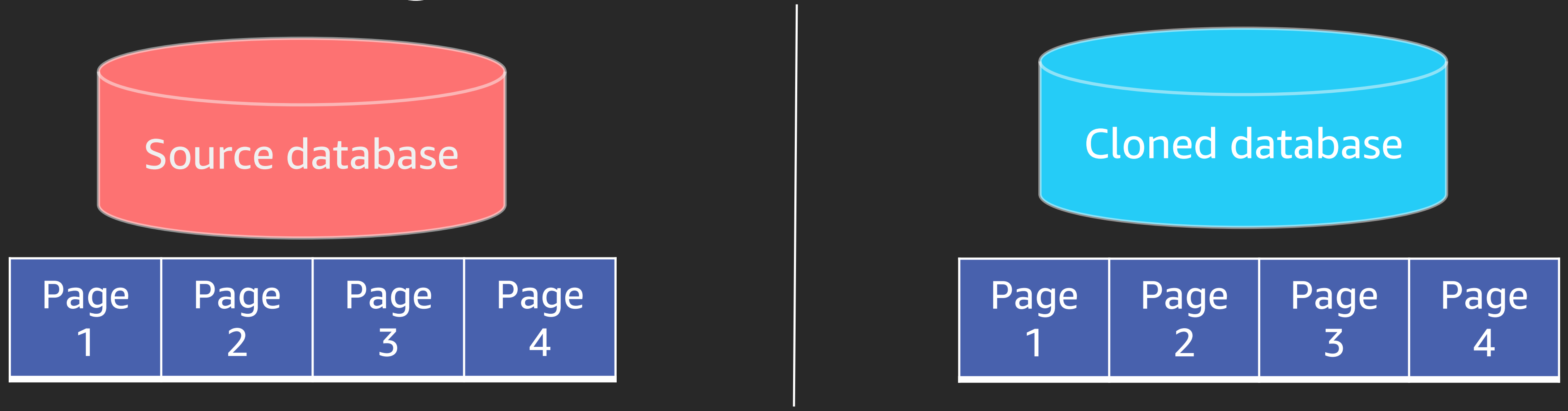
- Creation of a clone is instantaneous because it doesn't require deep copy
- Data copy happens only on write, when original and cloned volume data differ



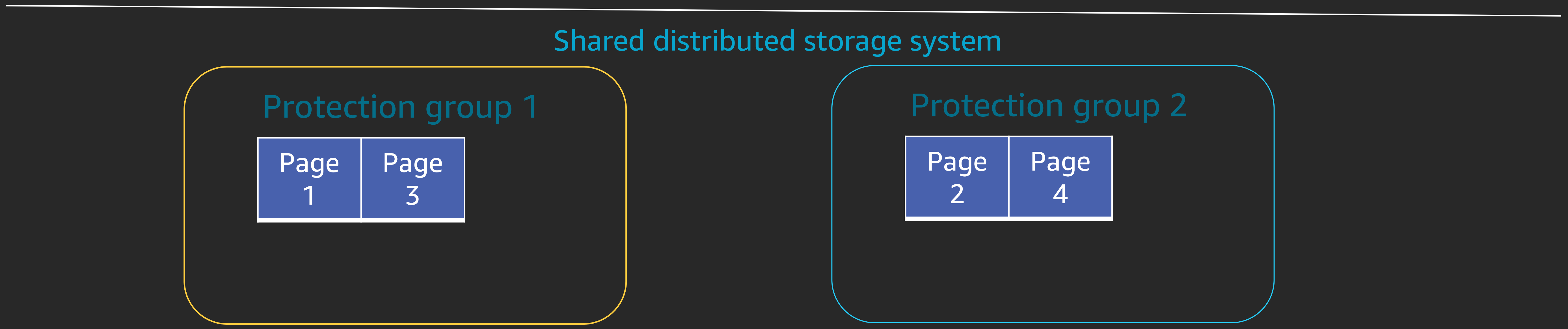
Typical use cases

- Clone a production database to run tests
- Reorganize a database
- Save a point-in-time snapshot for analysis without impacting production system

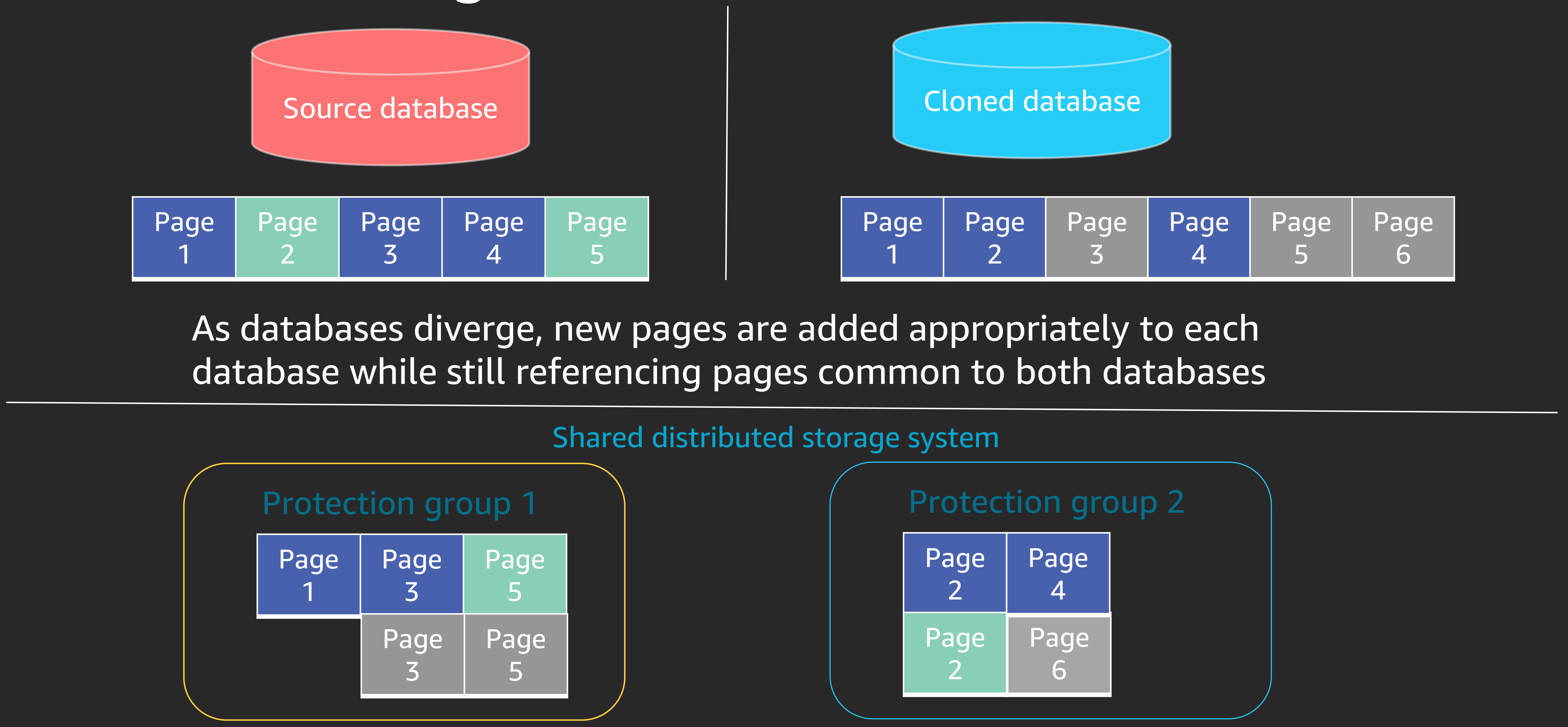
Database cloning: How does it work?



Both databases reference the same pages on the shared distributed storage system



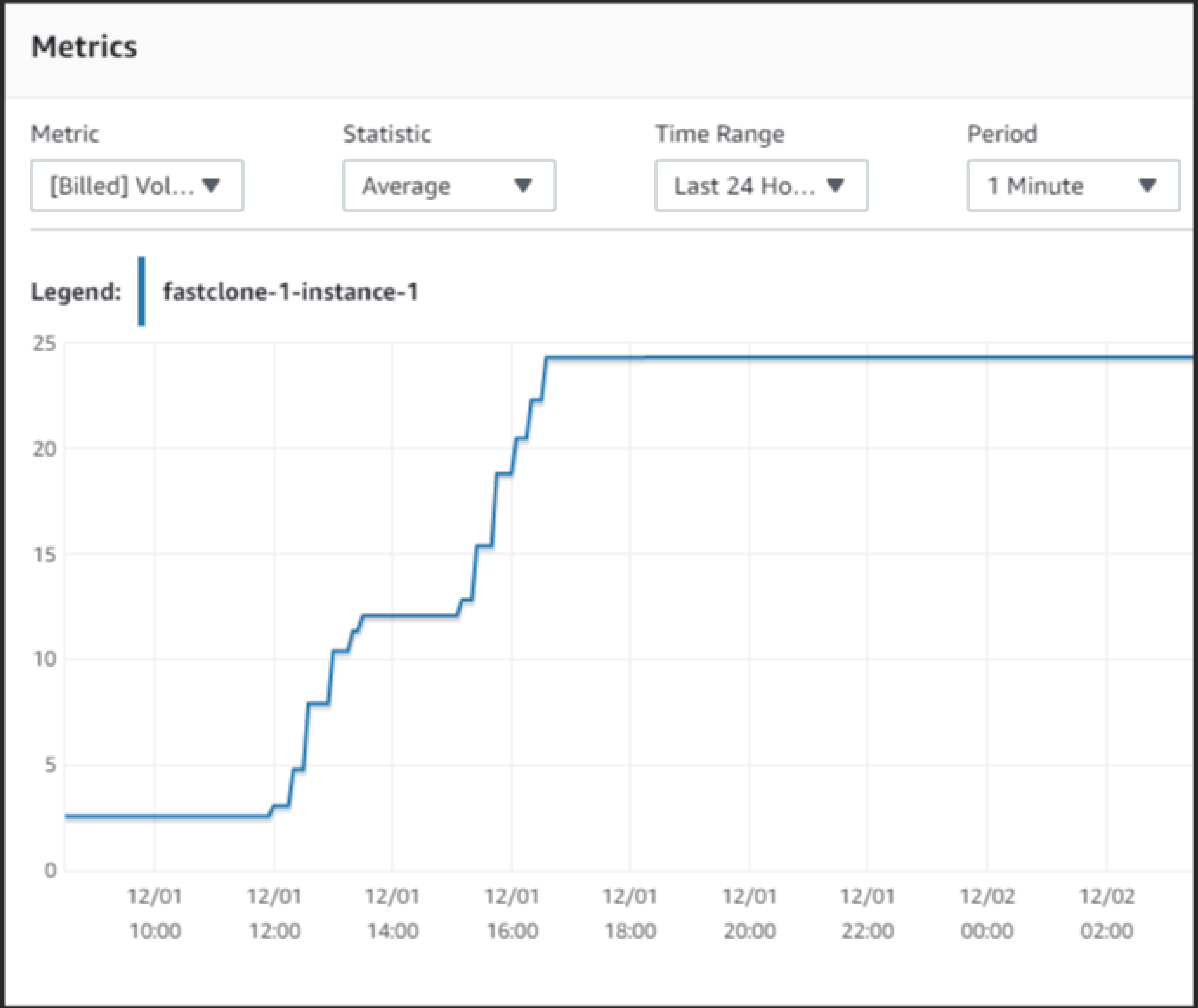
Database cloning: How does it work?



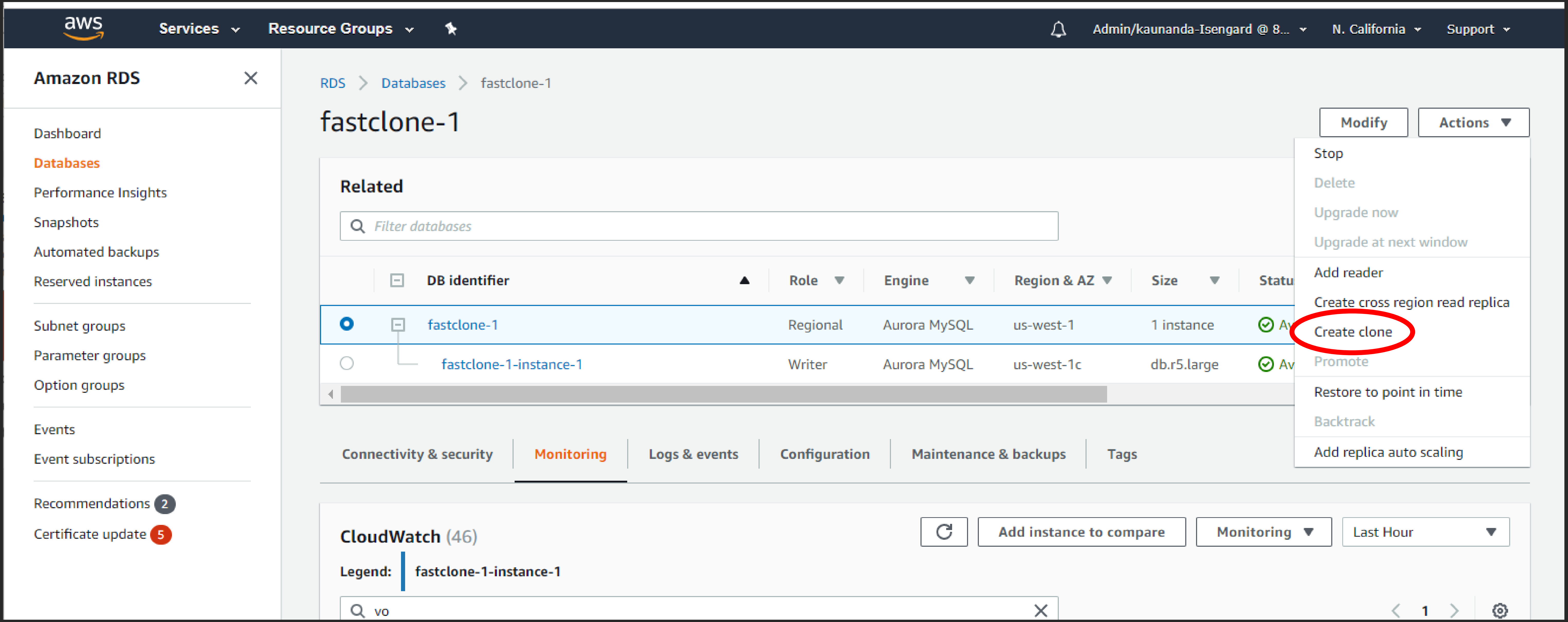
Fast database cloning - Demo

Database State

- ~40M rows
- ~25GB space used



Clone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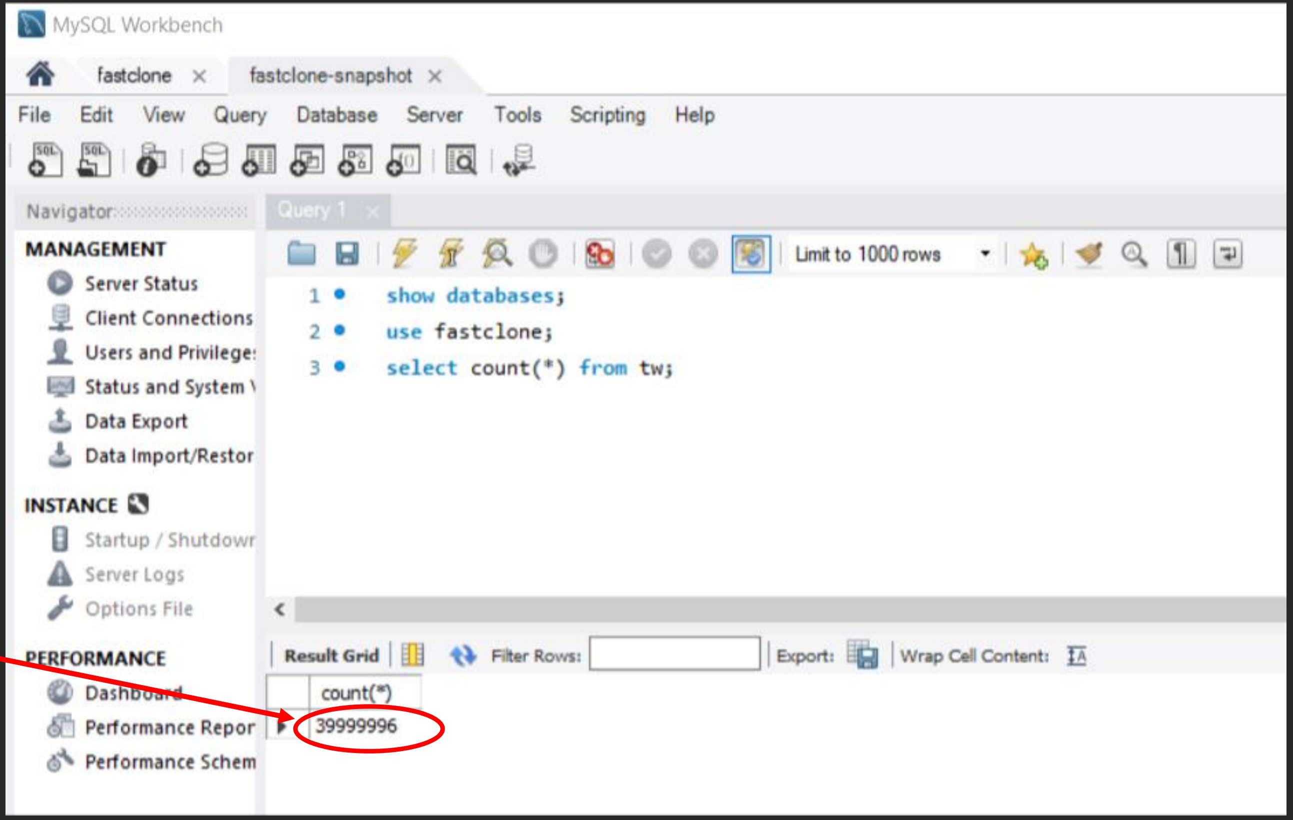
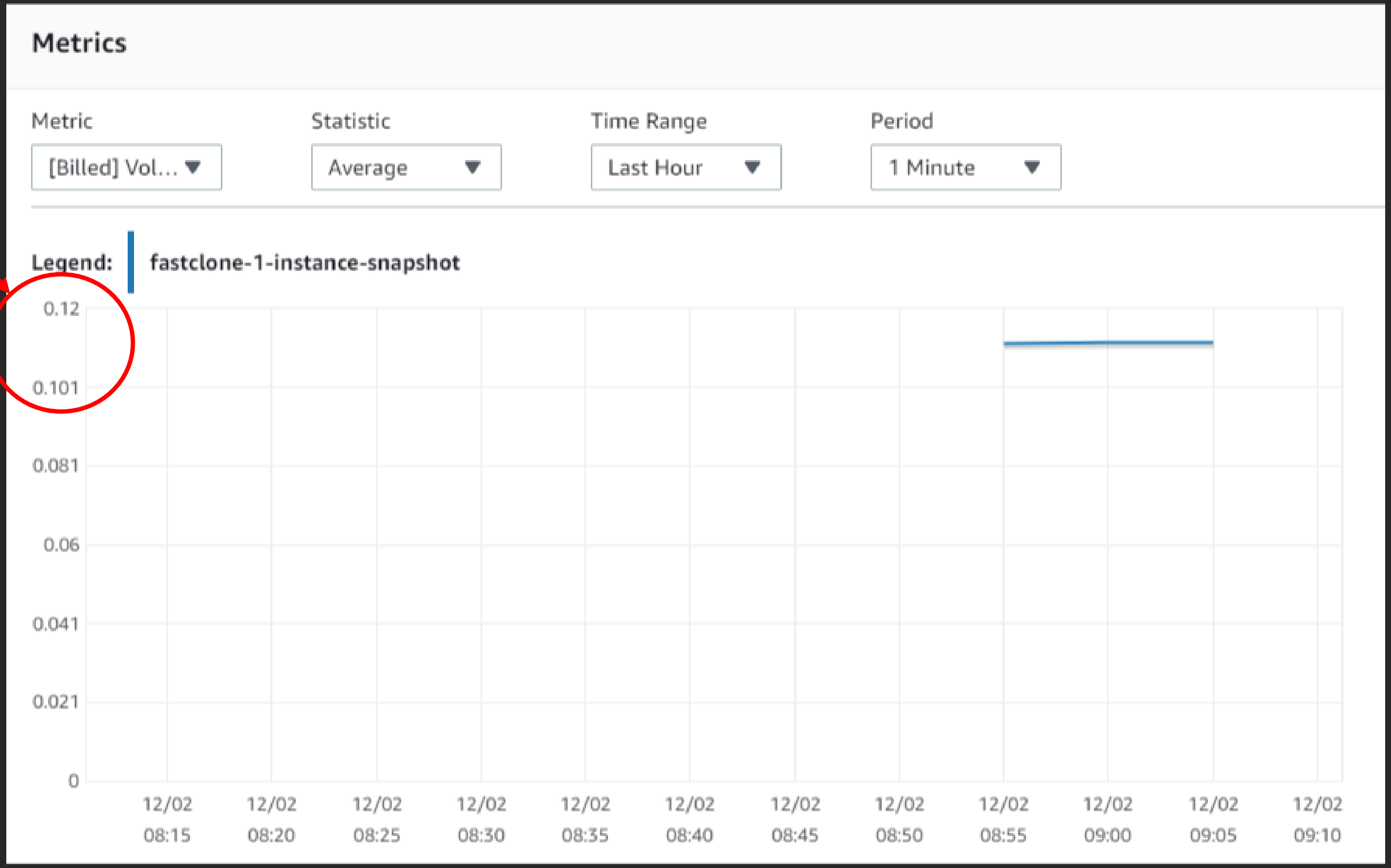
Services
Resource Groups
Admin/kaunanda-Isengard @ 8...
N. California
Support
Amazon RDS
Dashboard
Databases
Performance Insights
Snapshots
Automated backups
Reserved instances
Subnet groups
Parameter groups
Option groups
Events
Event subscriptions
Recommendations 2
Certificate update 5
RDS > Databases > fastclone-1
fastclone-1
Modify
Actions
Stop
Delete
Upgrade now
Upgrade at next window
Add reader
Create cross region read replica
Create clone
Promote
Restore to point in time
Backtrack
Add replica auto scaling
Related
Filter databases
DB identifier
Role
Engine
Region & AZ
Size
Statu
fastclone-1
Regional
Aurora MySQL
us-west-1
1 instance
fastclone-1-instance-1
Writer
Aurora MySQL
us-west-1c
db.r5.large
Connectivity & security
Monitoring
Logs & events
Configuration
Maintenance & backups
Tags
CloudWatch (46)
Add instance to compare
Monitoring
Last Hour
Legend:
fastclone-1-instance-1
vo
1

Database State (Cloned)

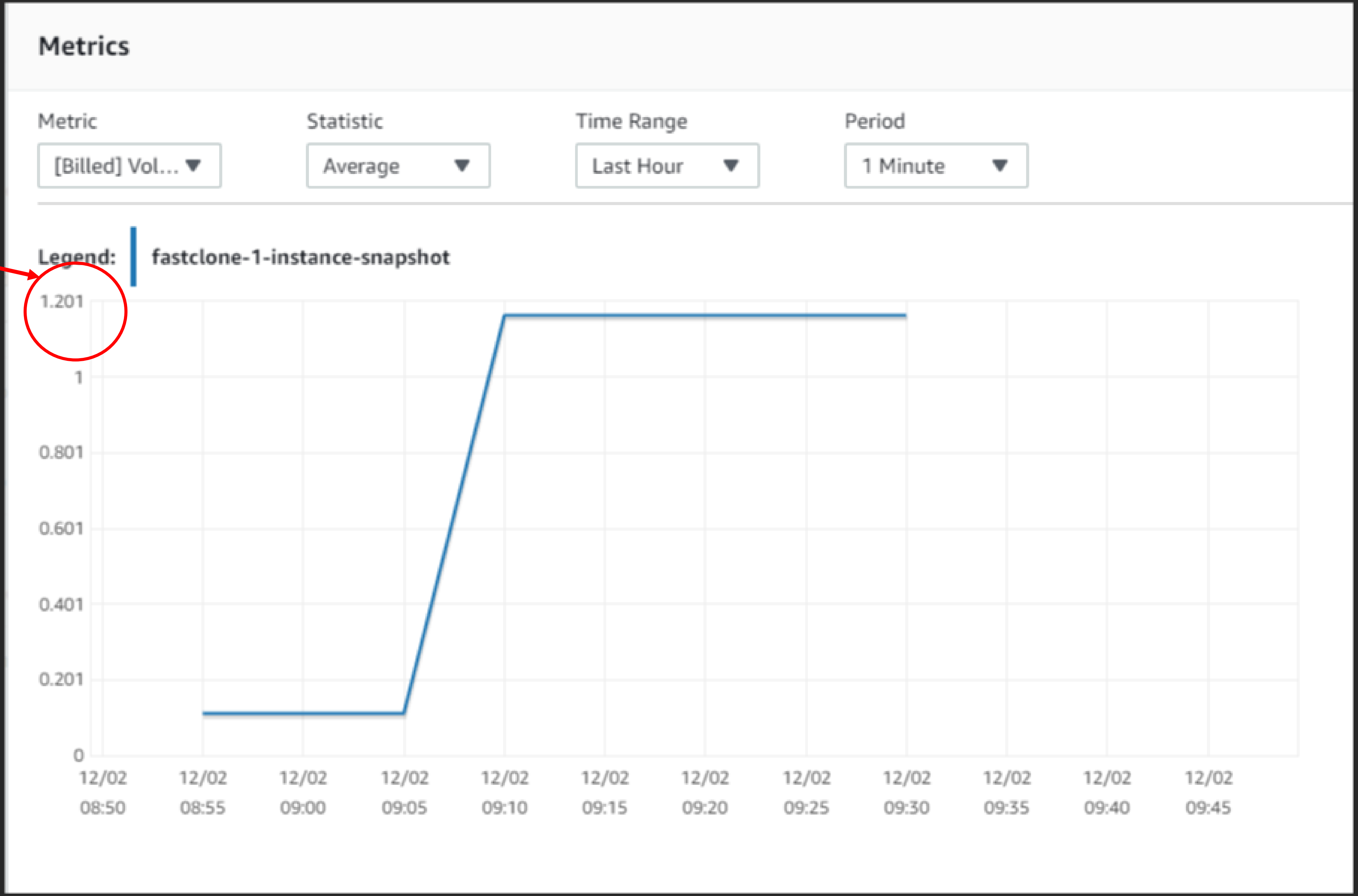
- See ~40M rows
- **~0.1GB space used in clone! (vs. 25GB)**





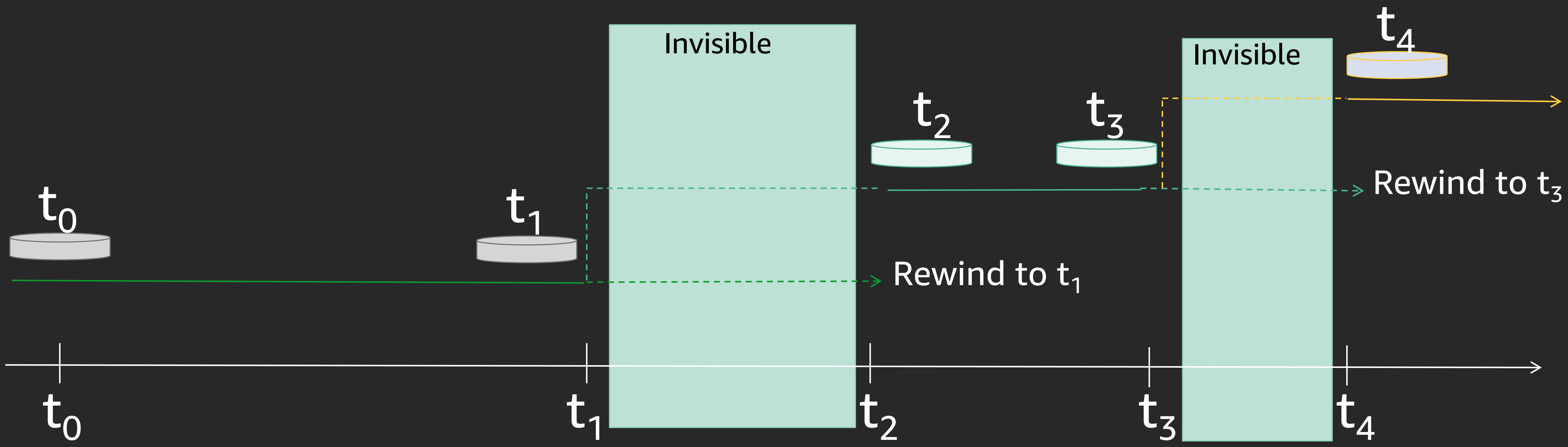
Database State (Cloned)

- Update ~10M rows
- **Now ~1.2 GB! vs 25GB**



Database backtrack

Database backtrack



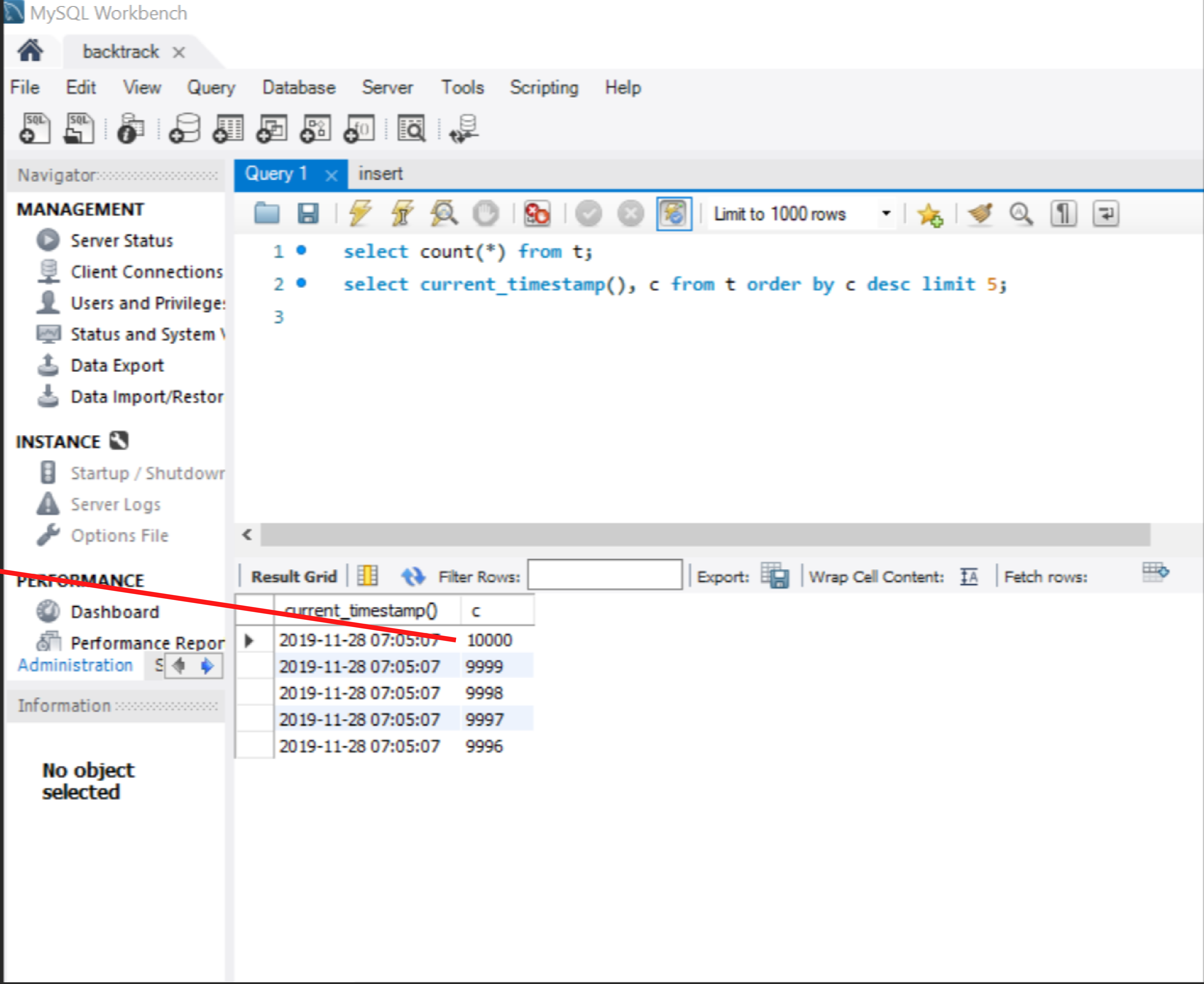
Backtrack is a quick way to bring the database to a particular point in time without having to restore from backups

- Rewinding the database to quickly recover from unintentional DML/DDL operations
- Rewind multiple times to determine the desired point in time in the database state; for example, quickly iterate over schema changes without having to restore multiple times

Backtrack - Demo

Database State (@07:05:07)

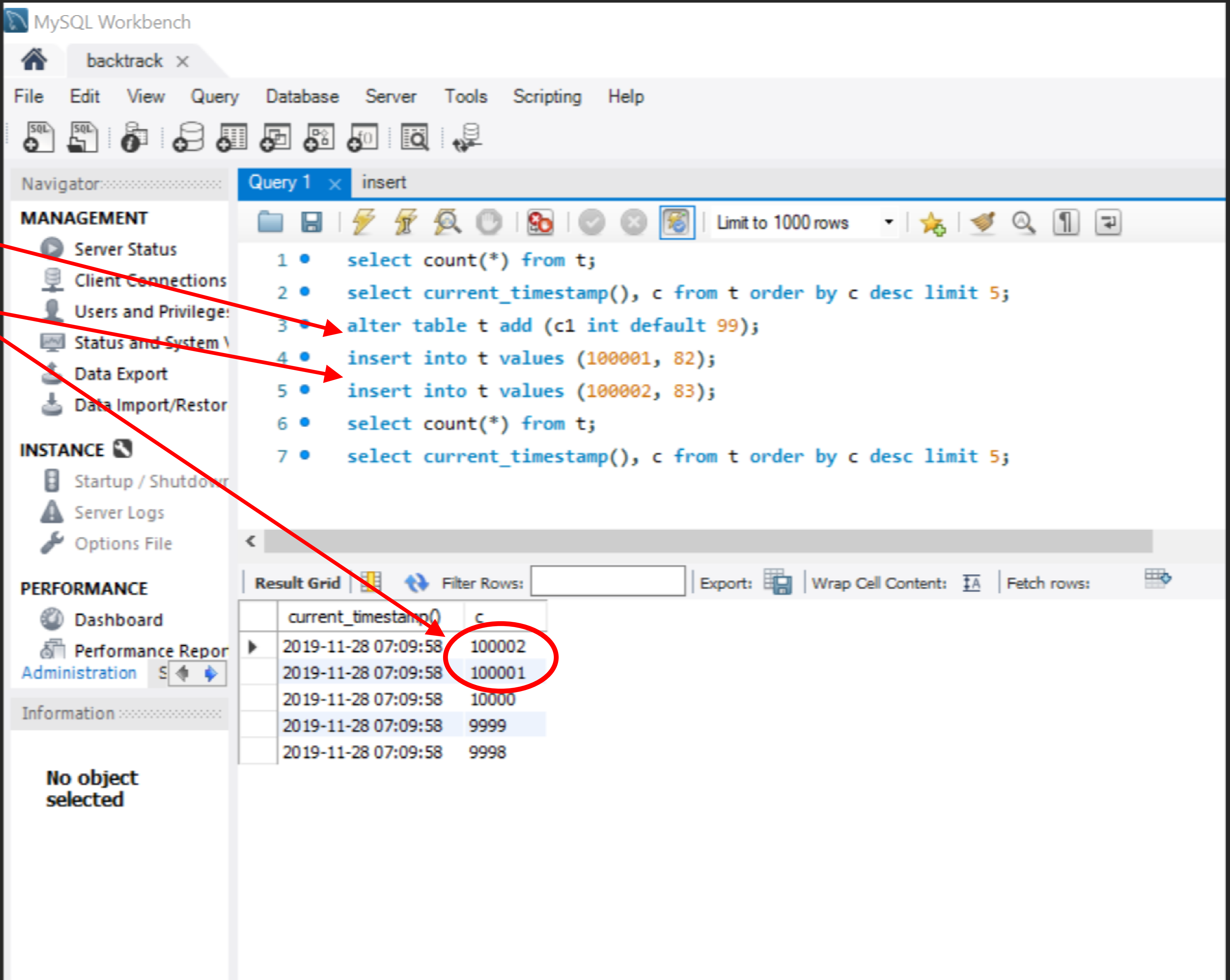
Table with ~10K rows



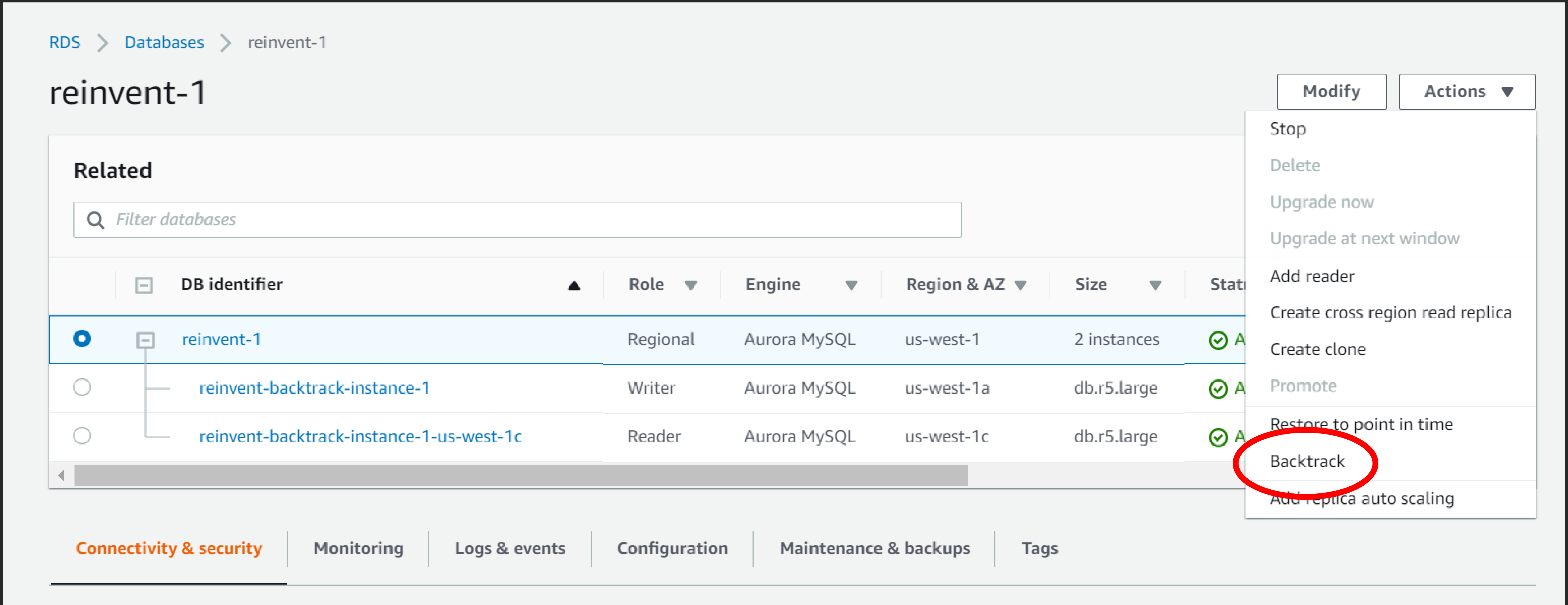
Database State (@07:09:58)

- Added a column
- Added two rows

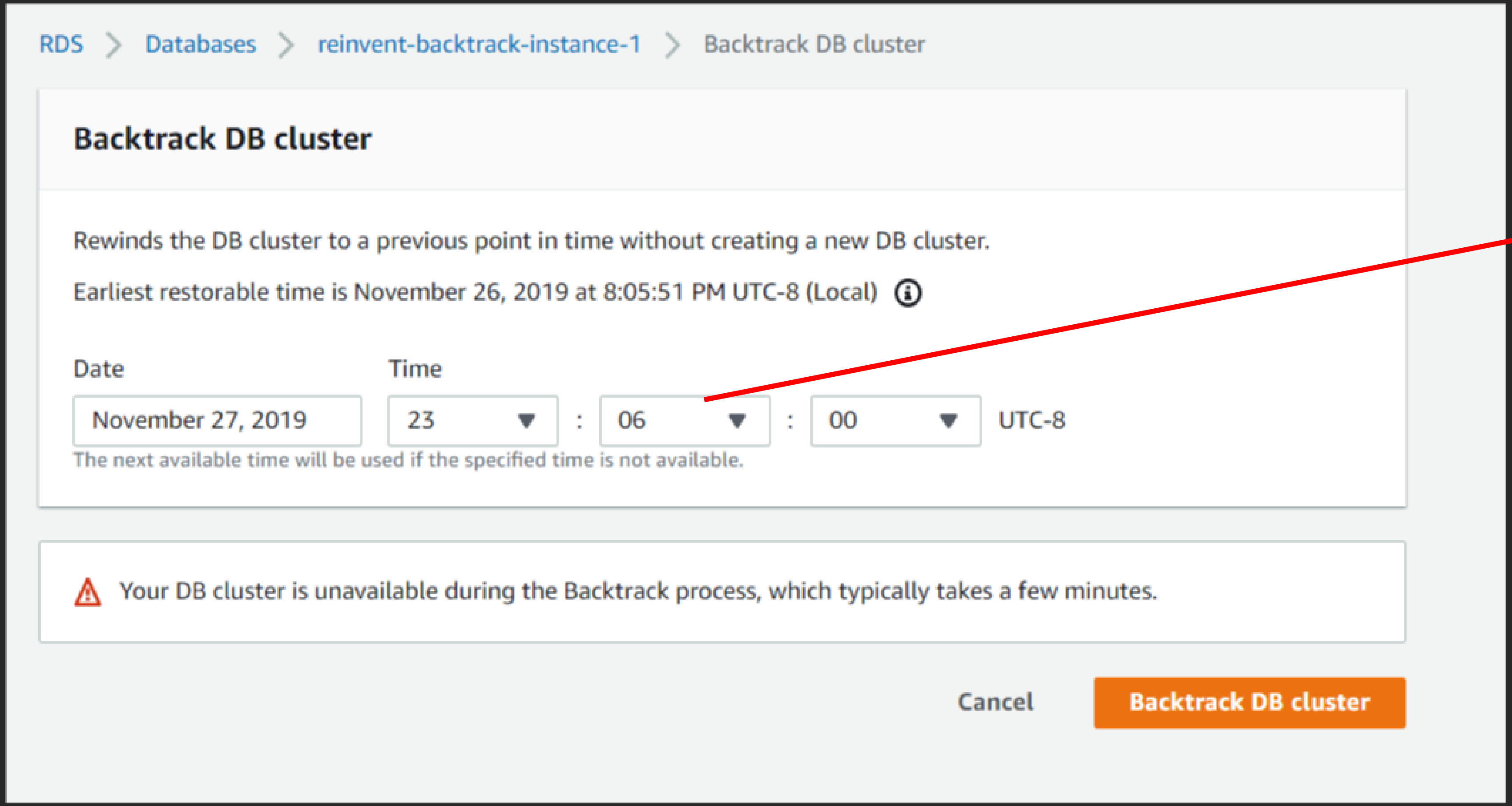
Oops!



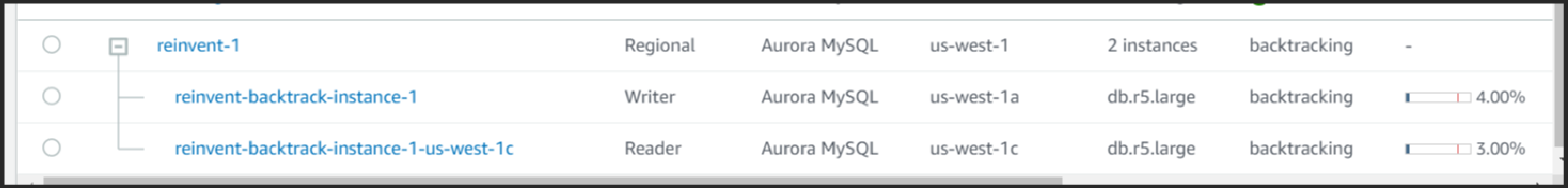
Let’s Backtrack



Let's Backtrack



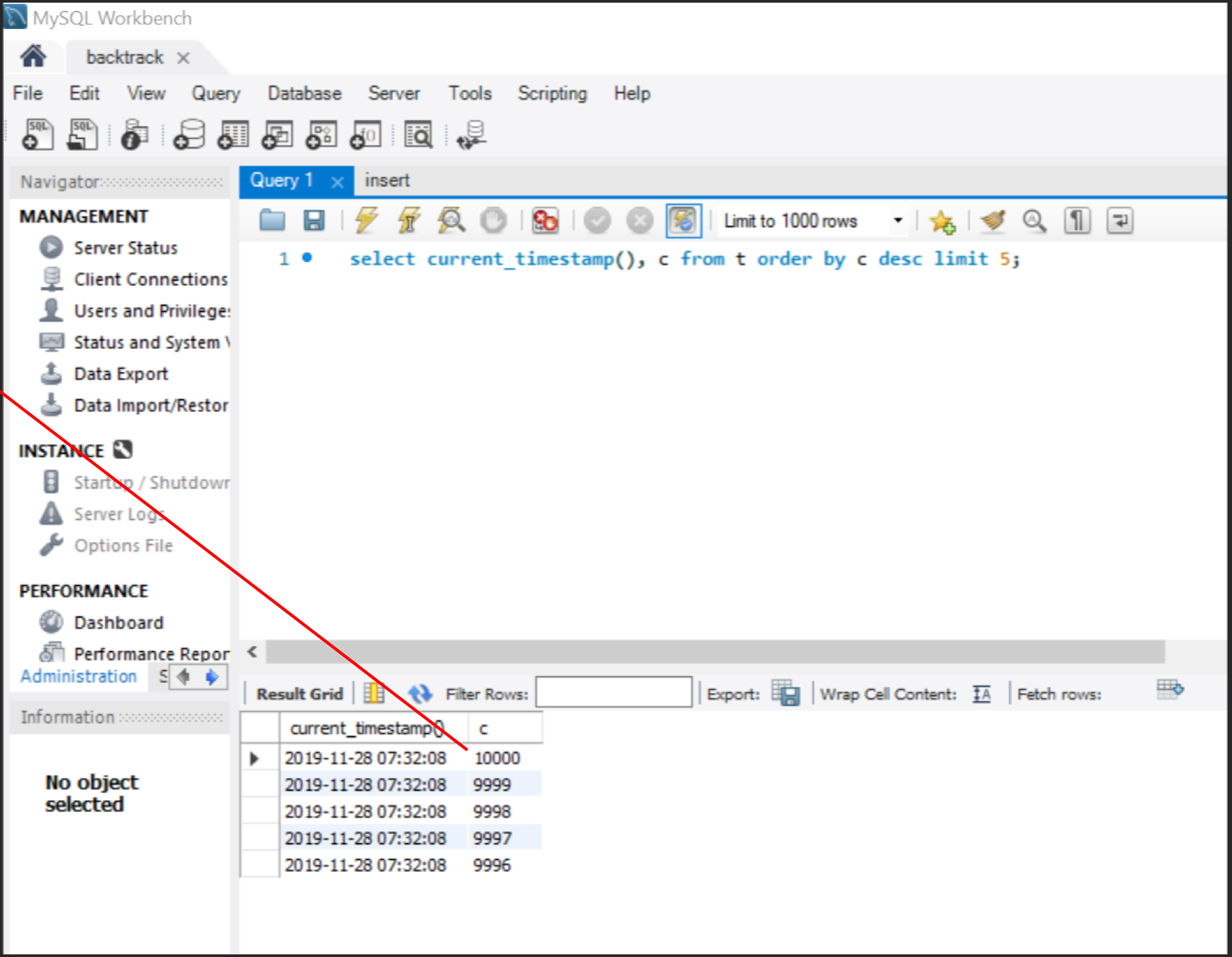
07:06:00



Database State (after Backtrack)

Rows added missing
Single column

The good old state!



References

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Publications

Amazon Aurora: Design Considerations for High Throughput Cloud-Native Relational Databases. *In SIGMOD 2017*

Amazon Aurora: On Avoiding Distributed Consensus for I/Os, Commits, and Membership Changes. *In SIGMOD 2018*

Thank you!

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