
AWS
re:Invent

DAT401

Amazon Aurora storage demystified

Anupriya Mathur

Senior Product Manager, Amazon Aurora

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Agenda

What is Amazon Aurora?

Cloud-native database architecture

How storage grows and resizes

Durability at scale

Aurora backups

What is Amazon Aurora?

ENTERPRISE-CLASS CLOUD NATIVE DATABASE

- 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

Cloud-native database architecture

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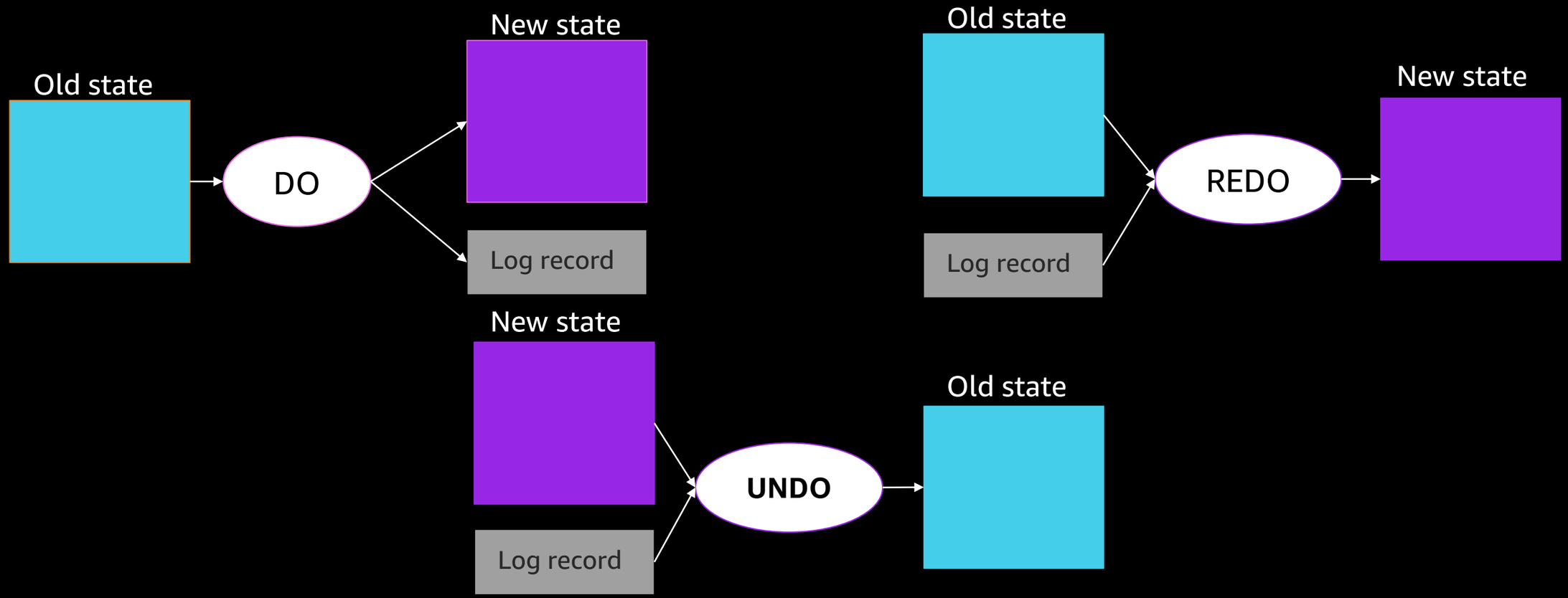
Quick recap: DO-REDO-UNDO protocol

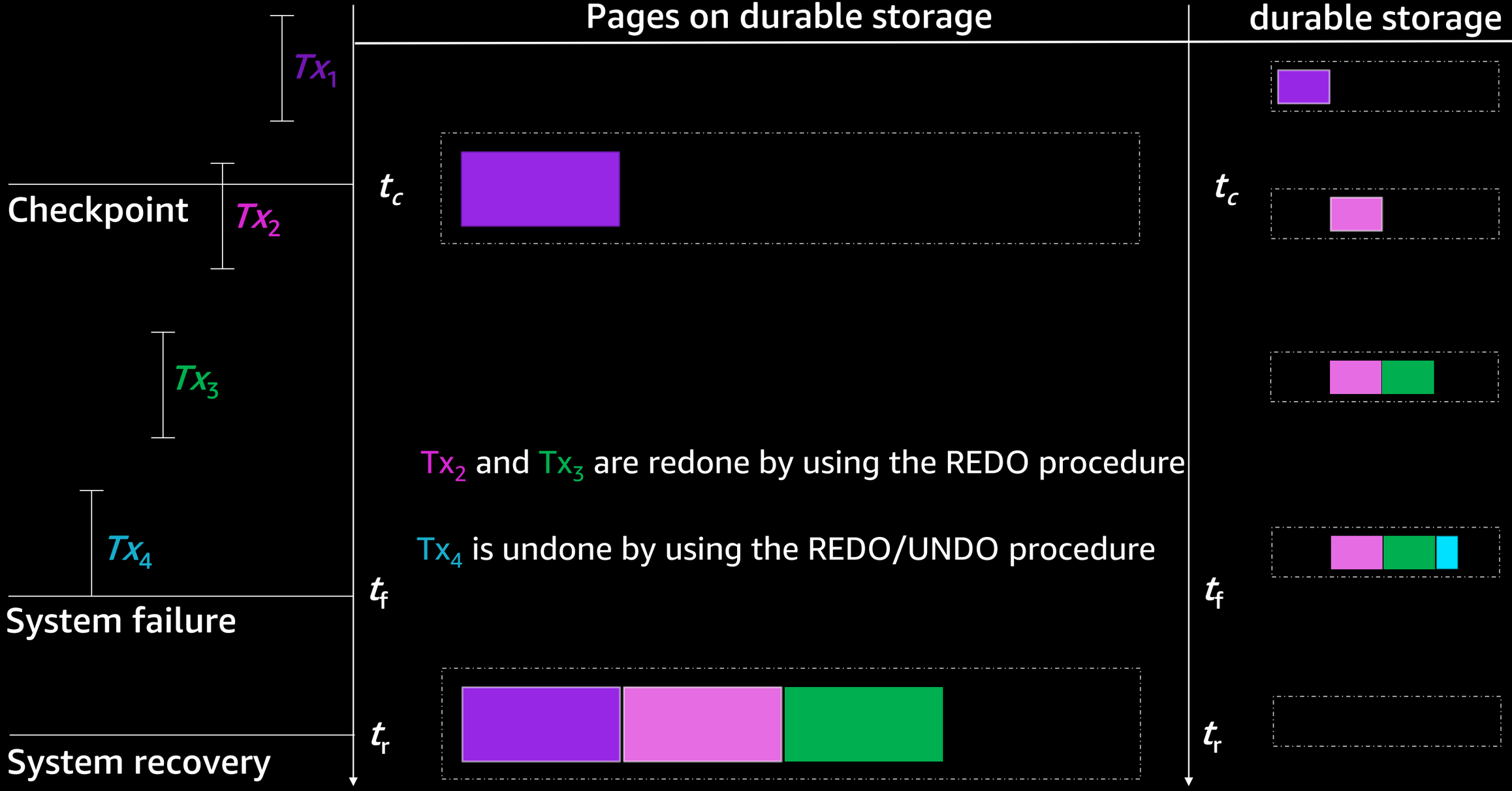
Data is modified “in-place” in the buffer-pool using a DO/REDO/UNDO operation

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

Pages from buffer-pool are written to durable storage (checkpoint) periodically



Quick recap: Crash Recovery

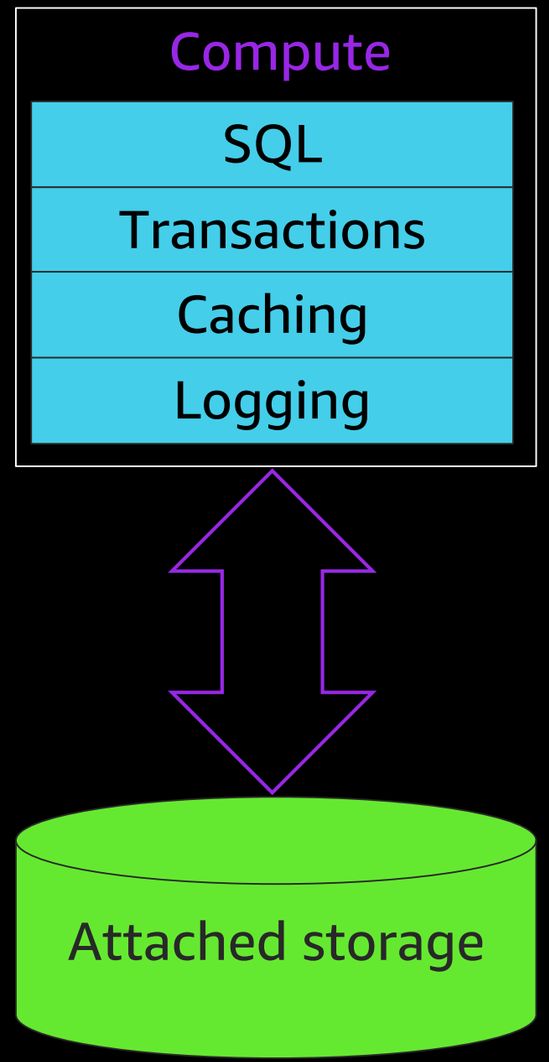


Traditional database architecture

Databases are all about input / output

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

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 the 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

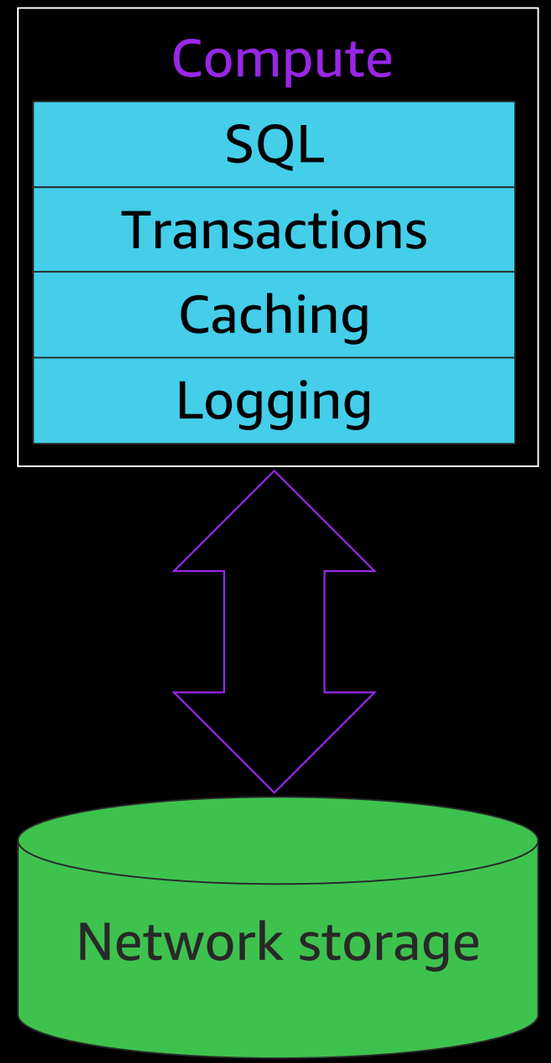
Compute & storage have different lifetimes

Compute instances

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

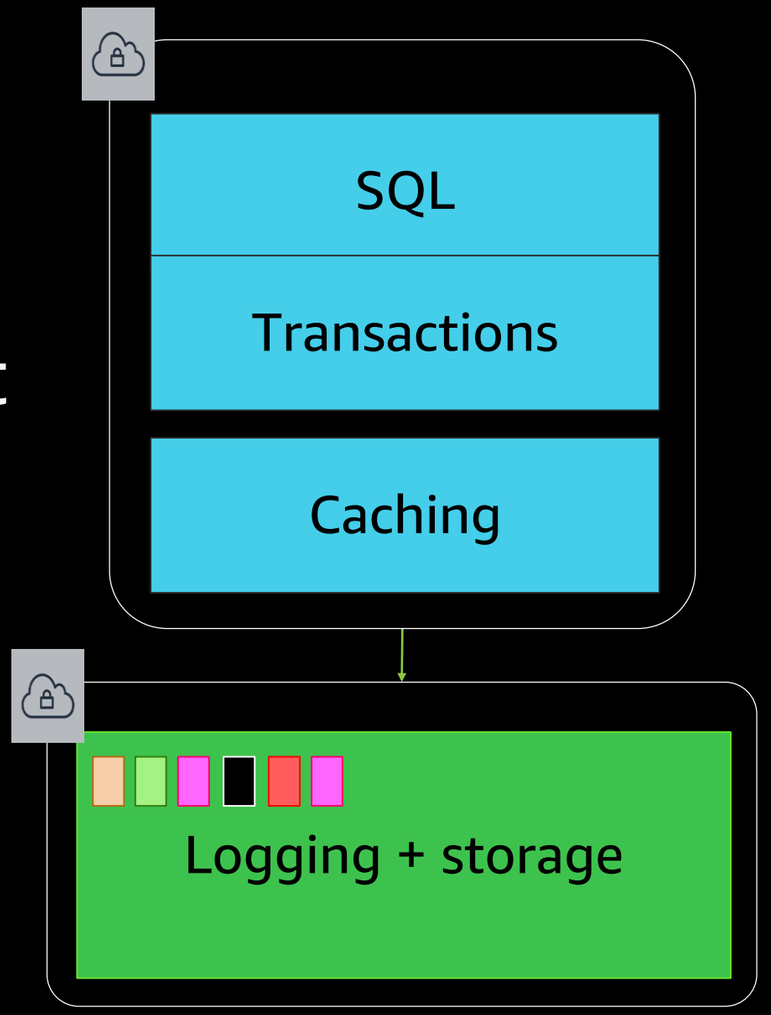
Storage, on the other hand, has to be long-lived

Decouple compute and storage for scalability, availability, durability

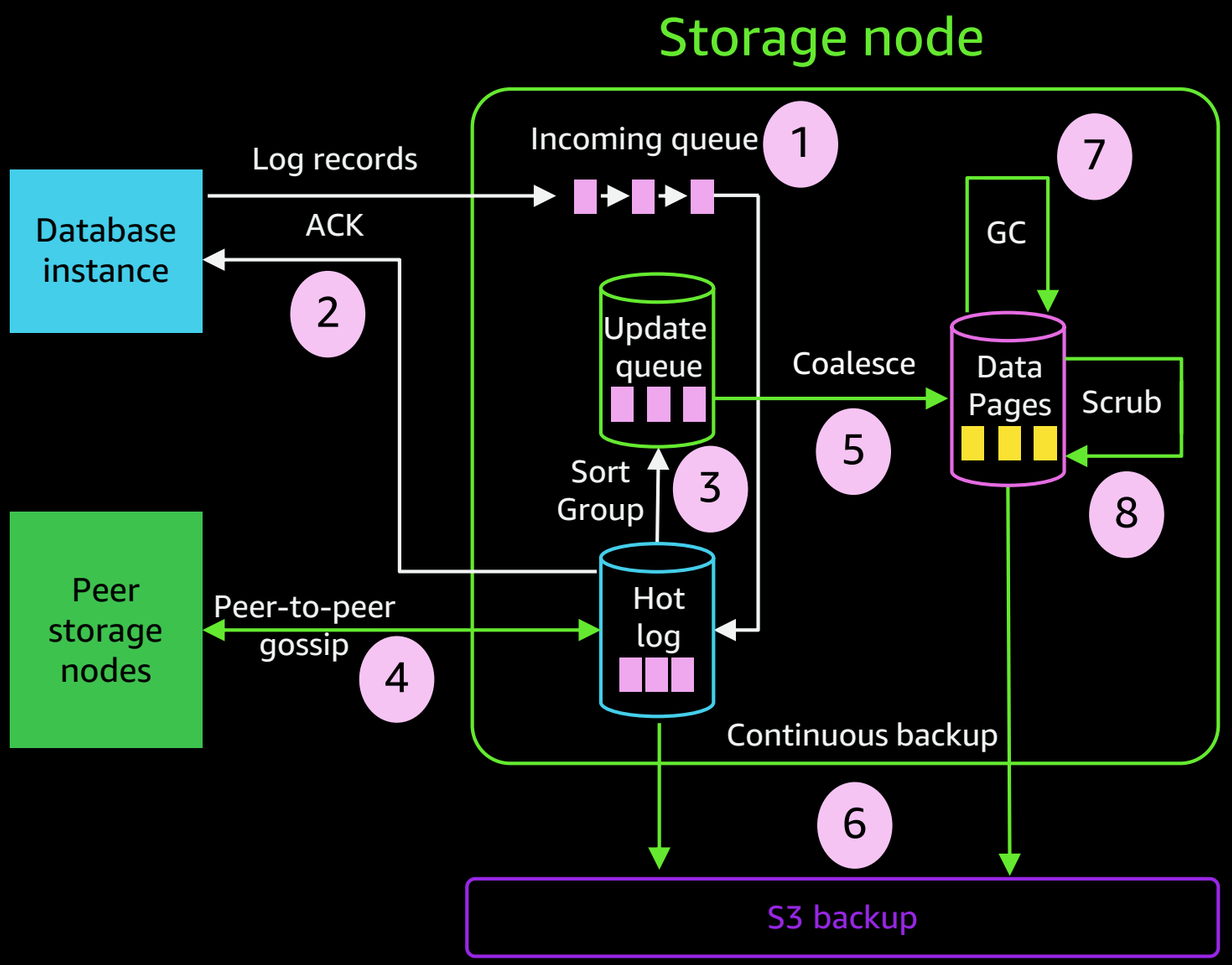


Aurora uses service-oriented architecture

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



I/O flow in Aurora storage node



① Receive log records, 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

How Aurora storage grows and resizes

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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, because we can repair a 10 GB segment in less than a minute

Database resizing

Volume size increases when data is written

- Grows in increments of 10 GB
- Maximum size of a DB cluster is 128 TB

Volume size decreases when data is deleted

- Storage is freed at page granularity
- Resizing happens dynamically and as data is deleted

Monitoring

- Amazon CloudWatch metrics to monitor storage usage: Volume Bytes Used

Example: Database resizing

```
[21:46:49][rdsop][~]$ LD_LIBRARY_PATH=/rdsdbbin/aurora/lib /rdsdbbin/aurora/bin/psql -U rdsadmin -p $(awk '/^port = [0-9]+$/ {print $3}' /rdsdbdata/config/postgresql.conf)
Password for user rdsadmin:
psql (11.8)
Type "help" for help.

rdsadmin=# create database vsTest;
CREATE DATABASE
rdsadmin=# CREATE TABLE t (id int, pkpad char(64) not null, x int, r4k int, r1m int, did int, idxpad varchar(256), vc varchar) with (fillfactor = 10);
CREATE TABLE
rdsadmin=# INSERT INTO t SELECT generate_series(1, 132000000, 1), ' ', 0, floor(4096*random()), floor(1048576*random()), floor(2147483646*random()), ' '::varchar(128), 'X'::varchar(256);
INSERT 0 132000000
rdsadmin=# \q
[22:17:52][rdsop][~]$ LD_LIBRARY_PATH=/rdsdbbin/aurora/lib /rdsdbbin/aurora/bin/psql -U rdsadmin -p $(awk '/^port = [0-9]+$/ {print $3}' /rdsdbdata/config/postgresql.conf)
Password for user rdsadmin:
psql (11.8)
Type "help" for help.

rdsadmin=# CREATE TABLE t1 (id int, pkpad char(64) not null, x int, r4k int, r1m int, did int, idxpad varchar(256), vc varchar) with (fillfactor = 10);
CREATE TABLE
rdsadmin=# INSERT INTO t1 SELECT generate_series(1, 132000000, 1), ' ', 0, floor(4096*random()), floor(1048576*random()), floor(2147483646*random()), ' '::varchar(128), 'X'::varchar(256);
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INSERT 0 132000000
rdsadmin=# drop table t1;
DROP TABLE
rdsadmin=# drop table t;
DROP TABLE
```

Example: Database resizing

Volume bytes increase with inserts in tables t and t1

Volume bytes decrease when table t1 is dropped

```
[21:46:49][rdsop][~]$ LD_LIBRARY_PATH=/rdsdbbin/aurora/lib /rdsdbbin/
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INSERT 0 132000000
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INSERT 0 132000000
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rdsadmin=# drop table t1;
DROP TABLE
rdsadmin=# drop table t;
DROP TABLE
```
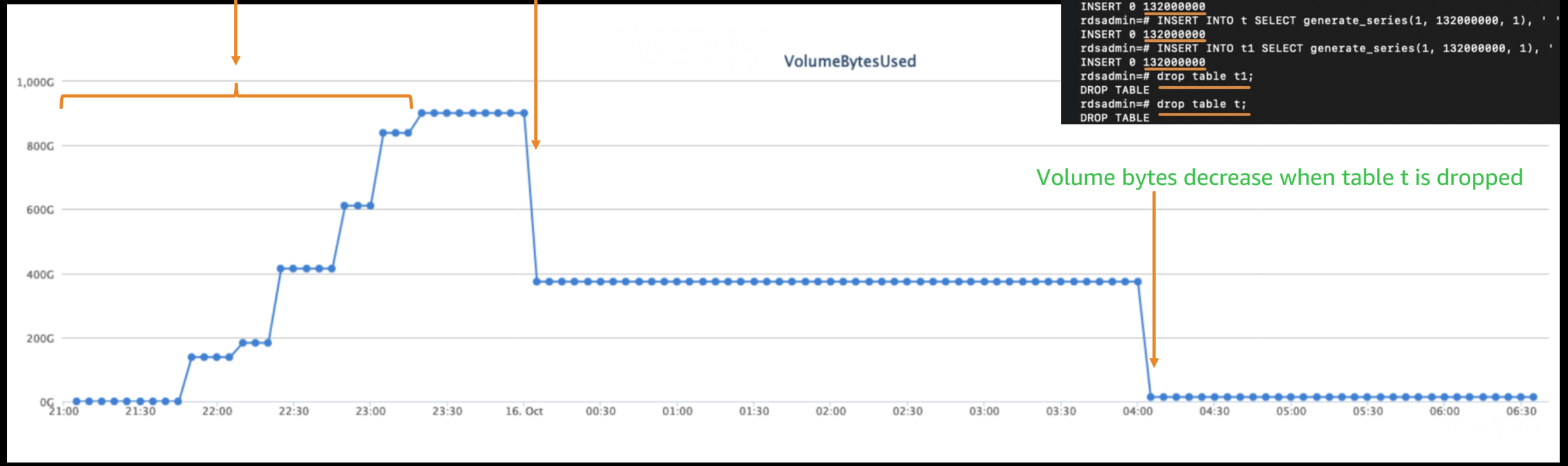



Volume bytes decrease when table t is dropped

Durability at scale

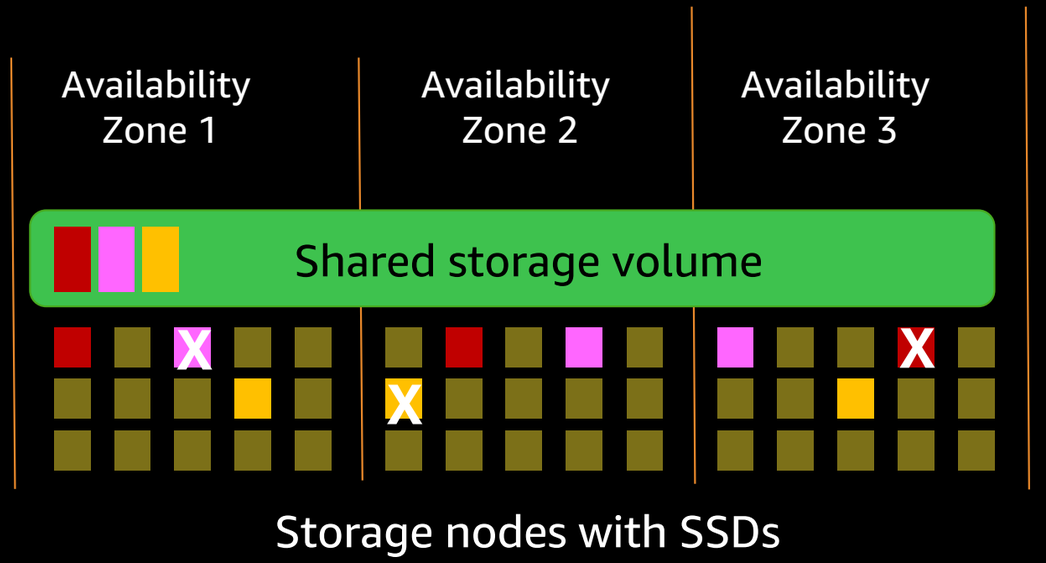
Uncorrelated and independent failures

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

The solution is replication

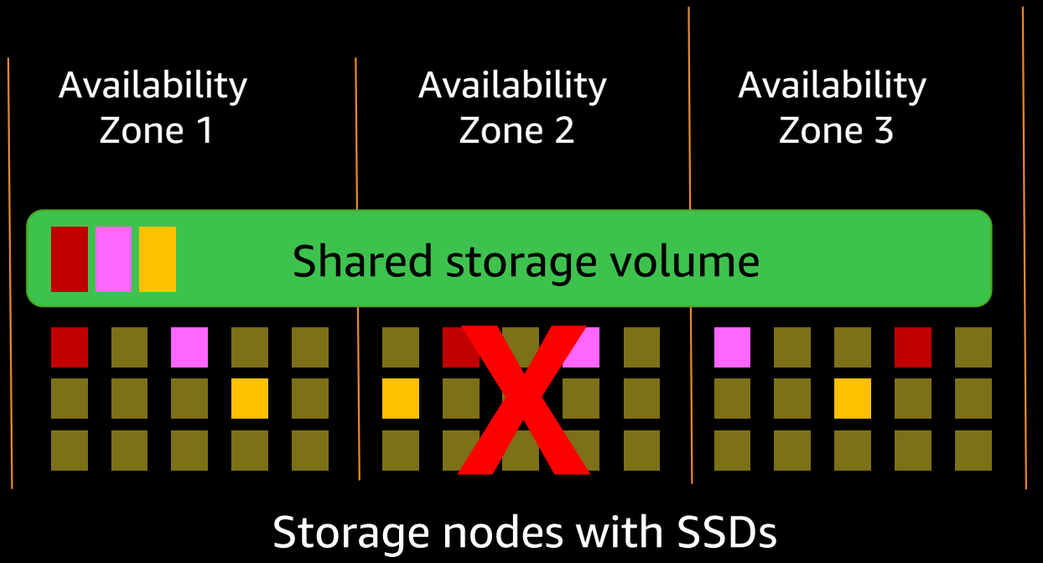
One common straw man

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



What about AZ failure?

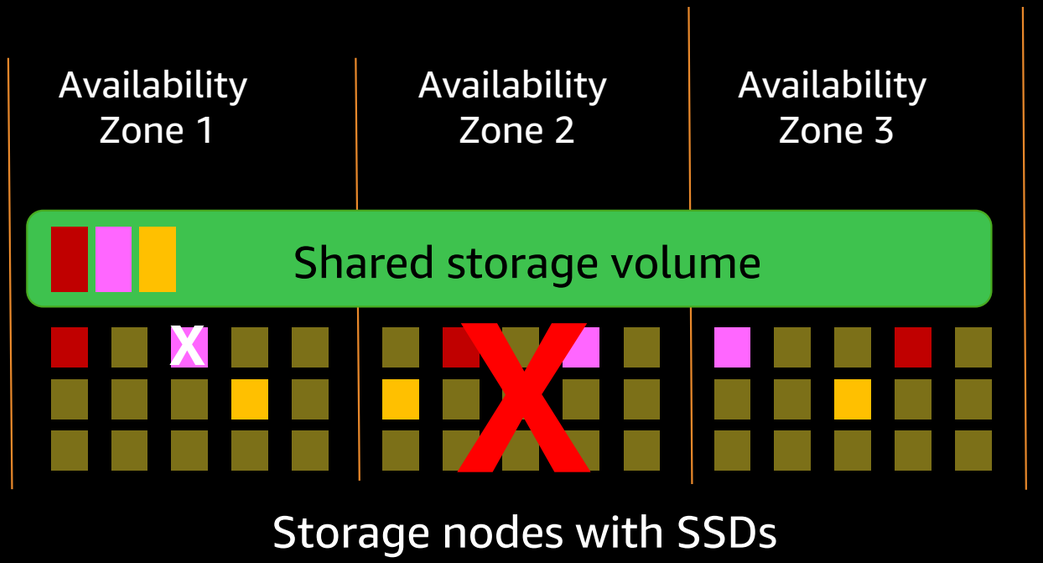
- Still have 2/3 copies
- Can establish quorum
- No data loss



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

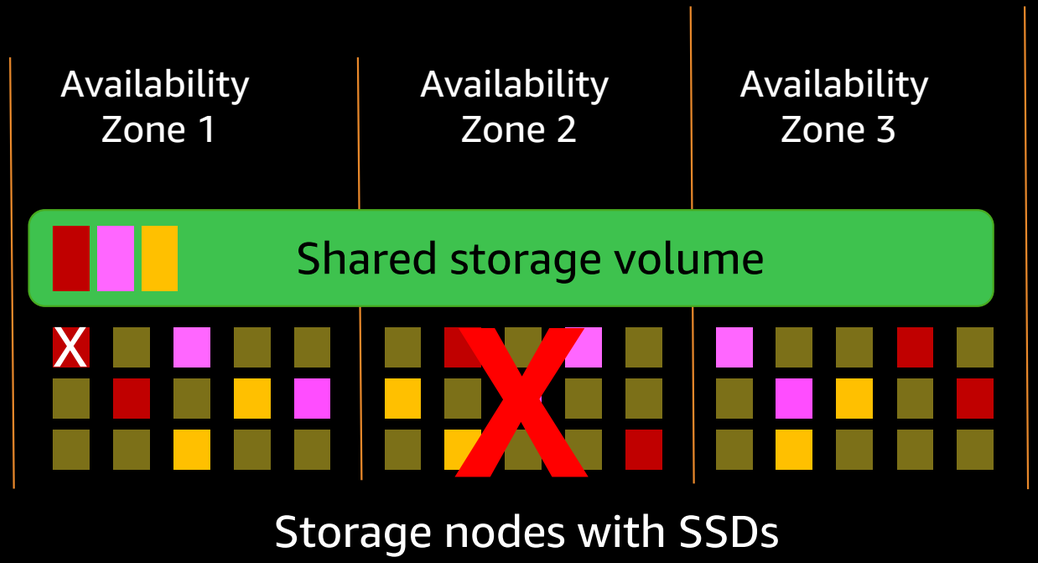
- Write quorum of 4/6

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



Backups

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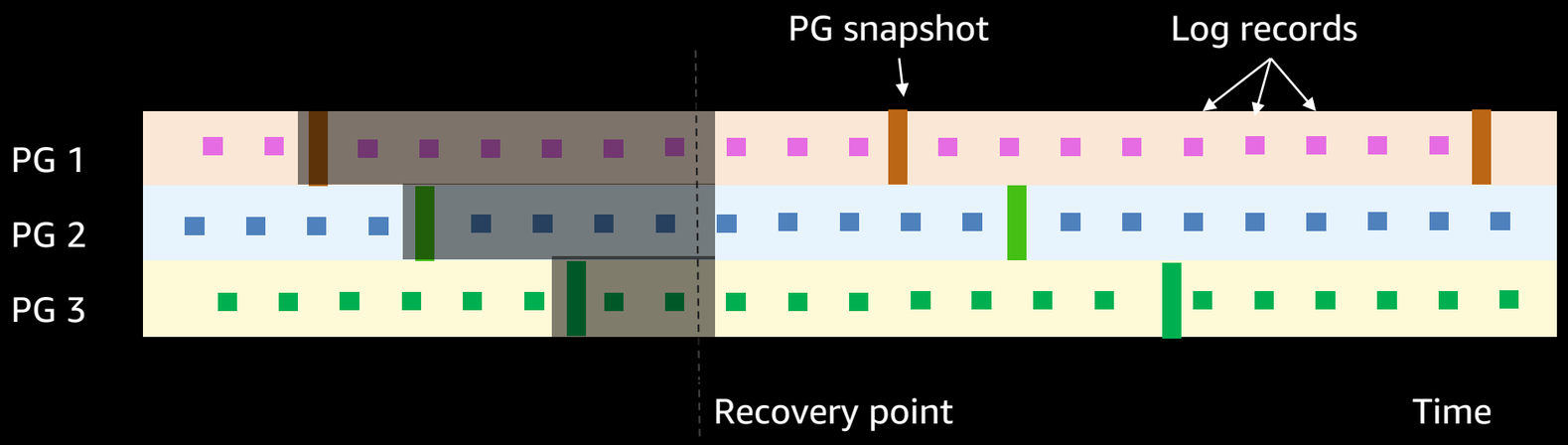
Continuous backups and snapshots



- Take a periodic snapshot of each PG in parallel; stream the redo logs to Amazon S3
- Backup happens continuously without performance or availability impact
- Volume level snapshot is a O(1) operation: a marker in the continuous backup stream
- At restore, retrieve the appropriate PG snapshots and log streams to storage nodes and apply log streams in parallel and asynchronously
- Volume level snapshots can be copied to x-region
- Snapshots can be managed via AWS Backups

References

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

Related sessions

DAT201

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Thank you!

Anupriya Mathur

anuma@amazon.com

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