WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

CS 764: Topics in Database Management Systems

Lecture 24: Amazon Aurora

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11/28/2022

Announcement

Project report (DDL: Dec. 19)

- Sample reports available from the course website
- 5–7 pages sufficient. Content is more important than length
- **Submit to the Hotcrp website** (like the proposal)

Today’s Paper

Amazon Aurora: Design Considerations for High Throughput Cloud-Native Relational Databases

Alexandre Verbitski, Anurag Gupta, Debanjan Saha, Murali Brahmadesam, Kamal Gupta, Raman Mittal, Sailesh Krishnamurthy, Sandor Maurice, Tengiz Kharatishvili, Xiaofeng Bao

Amazon Web Services

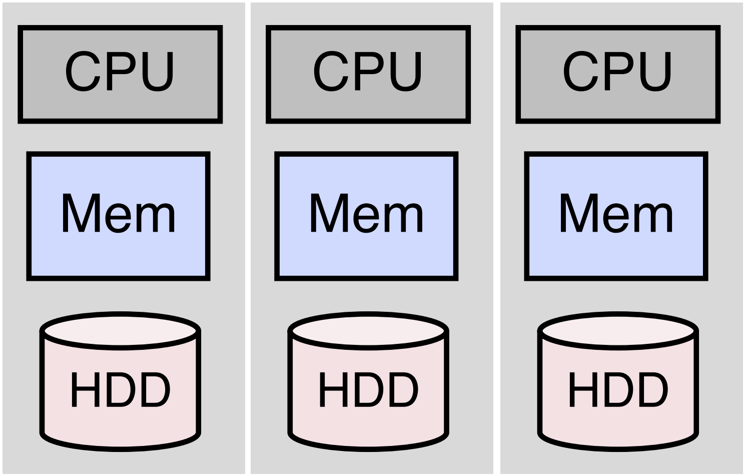
ABSTRACT
Amazon Aurora is a relational database service for O
workloads offered as part of Amazon Web Services (AWS
this paper, we describe the architecture of Aurora and the de
considerations leading to that architecture. We believe the ce
constraint in high throughput data processing has moved
compute and storage to the network. Aurora brings a n
architecture to the relational database to address this constr
most notably by pushing redo processing to a multi-tenant s
out storage service, purpose-built for Aurora. We describe
doing so not only reduces network traffic, but also allows fo
crash recovery, failovers to replicas without loss of data,
fault-tolerant, self-healing storage. We then describe how Au
achieves consensus on durable state across numerous sto

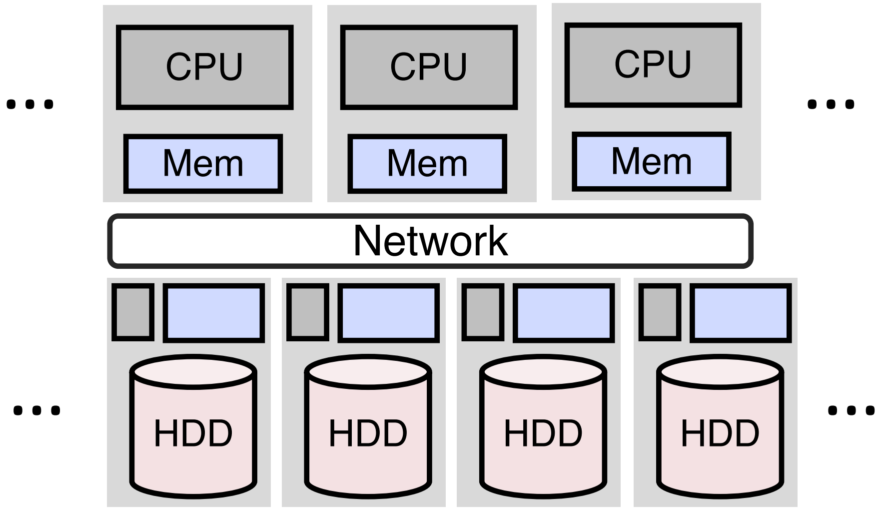
SIGMOD 2017

Amazon Aurora development team wins the 2019 ACM SIGMOD Systems Award*

By Werner Vogels on 04 July 2019 10:00 AM | Permalink | Comments (2)

Cloud Database Architecture





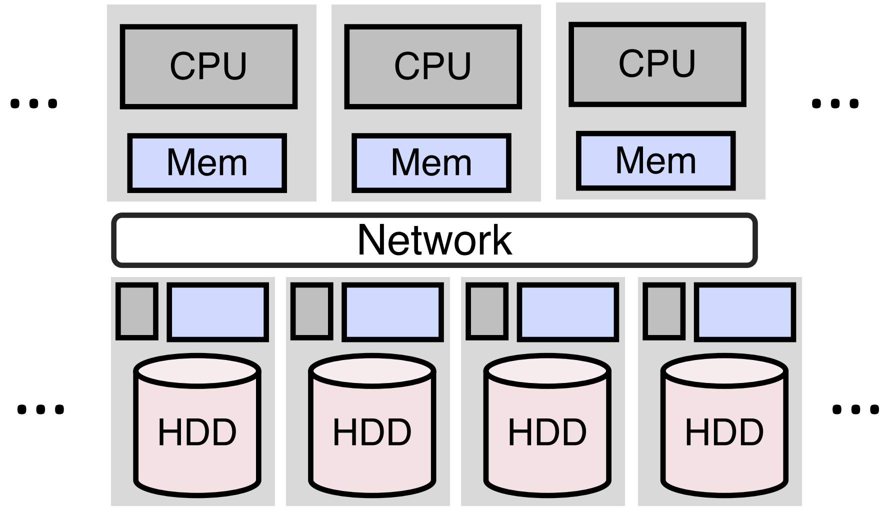
On-premises

- Fixed and limited hardware resources
- Shared-nothing architecture

Cloud

- Virtually infinite computation & storage, Pay-as-you-go price model
- Disaggregation architecture

Storage-Disaggregation Architecture



Feature 1: Computation and storage layers are disaggregated

- Autoscaling computation and storage nodes

Feature 2: Limited computation can happen in the storage layer

- REDO processing

Disadvantage: Network bottleneck

- Lower bandwidth and higher latency

Computation Pushdown in Cloud OLTP

What functions to push to the storage layer?

- Concurrency control
- Indexing
- Buffer manager
- Logging

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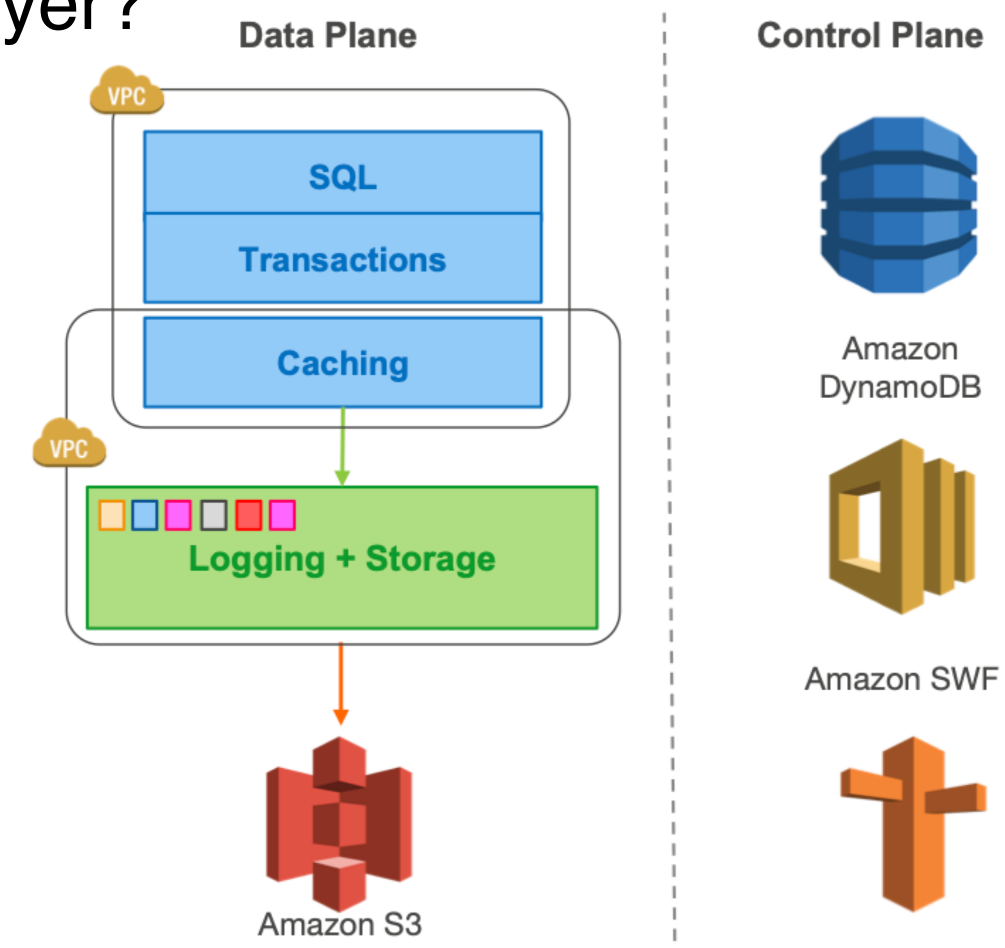
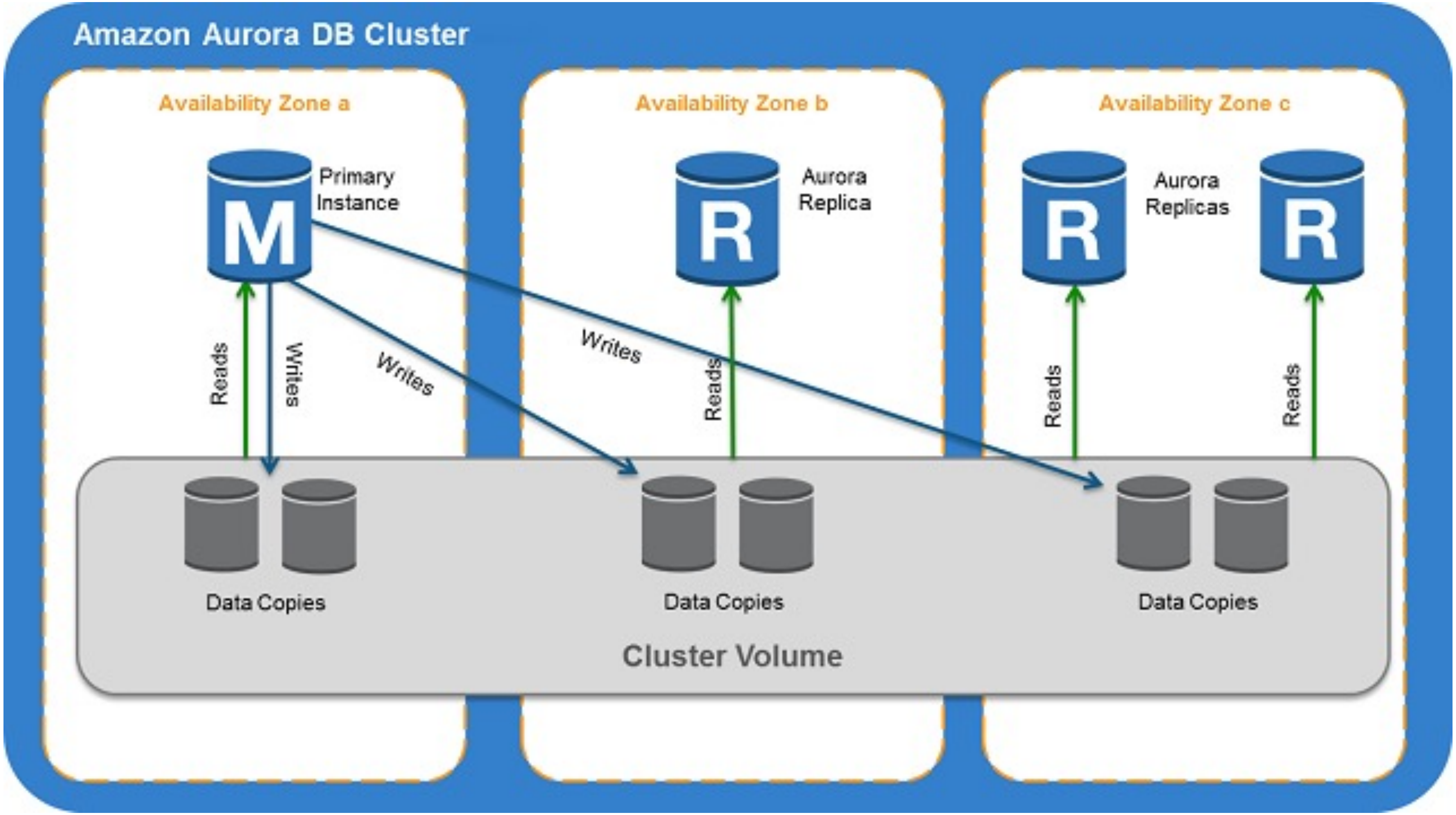
- Logging



Amazon Aurora

Push redo processing into the storage service

Aurora – Single Master



Quorum-Based Voting Protocol

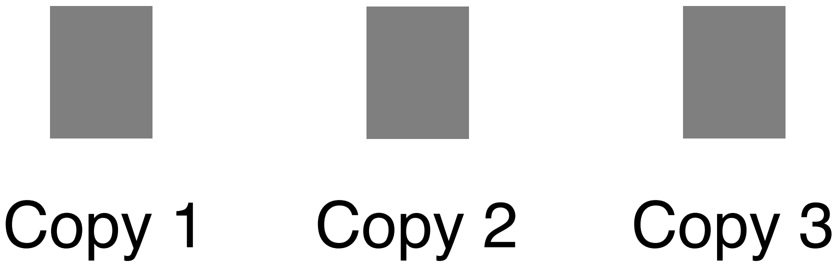
Data replicated into V copies

A write must acquire votes from V_w copies

A read must acquire votes from V_r copes

$$V_w + V_w > V \Rightarrow V_w > V / 2$$

$$V_r + V_w > V$$



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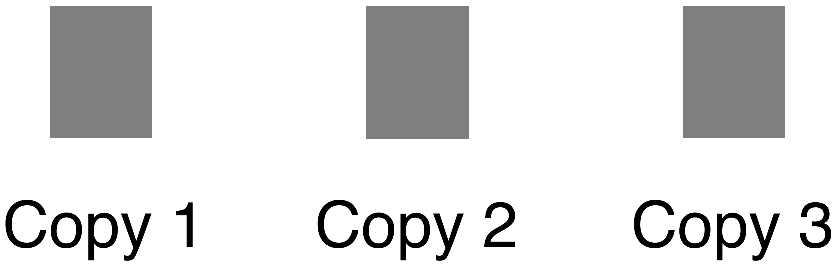
For three copies

$$V_w \geq 2$$

$$V_r \geq 2$$



Quorum-Based Voting Protocol

Data replicated into V copies

A write must acquire votes from V_w copies

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$V_w + V_w > V \implies V_w > V / 2$

$V_r + V_w > V$

For three copies

$V_w \geq 2$

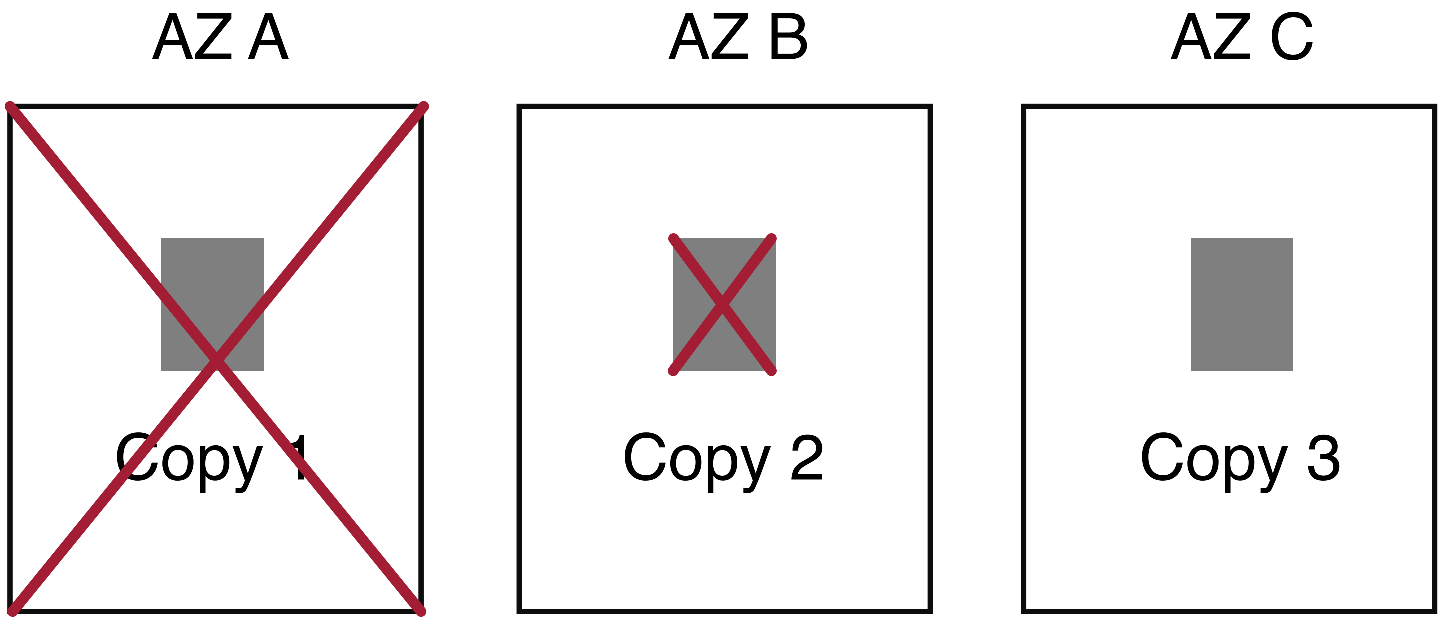
$V_r \geq 2$

For six copies

$V_w \geq 4$

$V_r \geq 3$

3-Way Replication

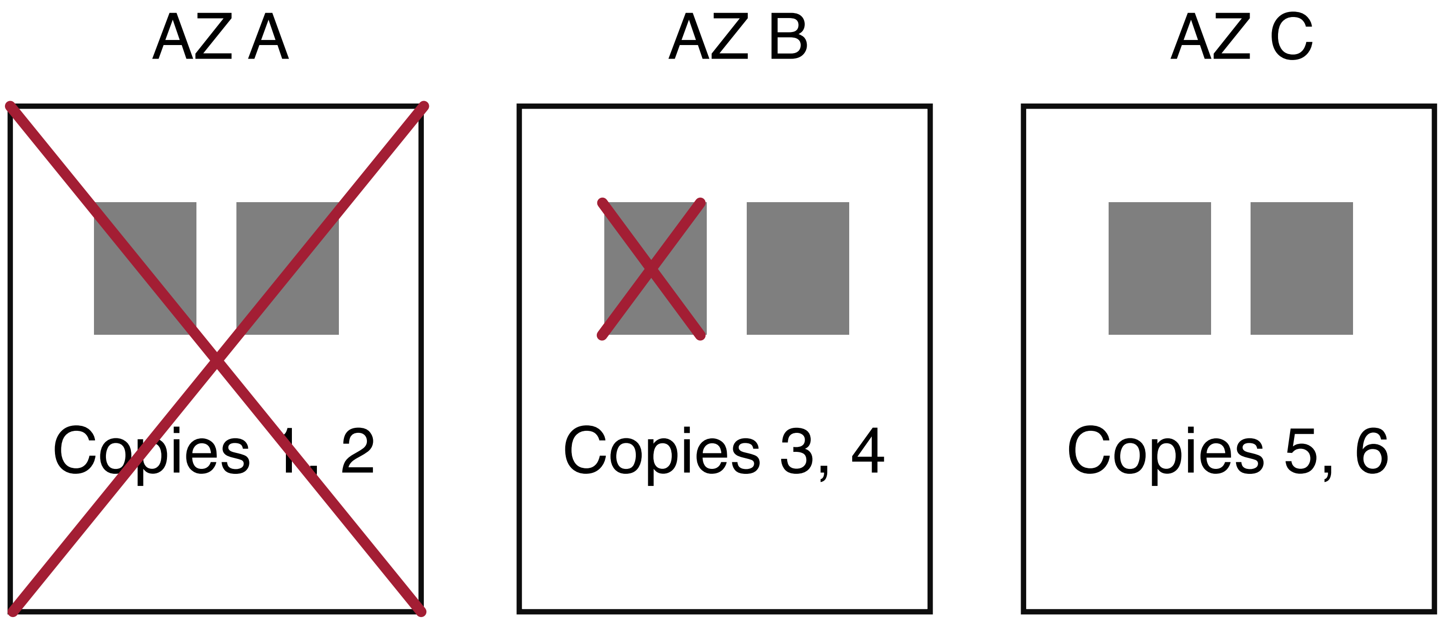


AZ: Availability zone

- AZs fail independently

Data is unavailable if one AZ is unavailable and one other copy is unavailable

6-Way Replication



Can read if one AZ fails and one more node fails (AZ+1)

- Allow to rebuild a write quorum by adding additional replica

Can write if one AZ fails

Segmented Storage

Availability is determined by

- MTTF: Mean time to failure
- MTTR: Mean time to repair

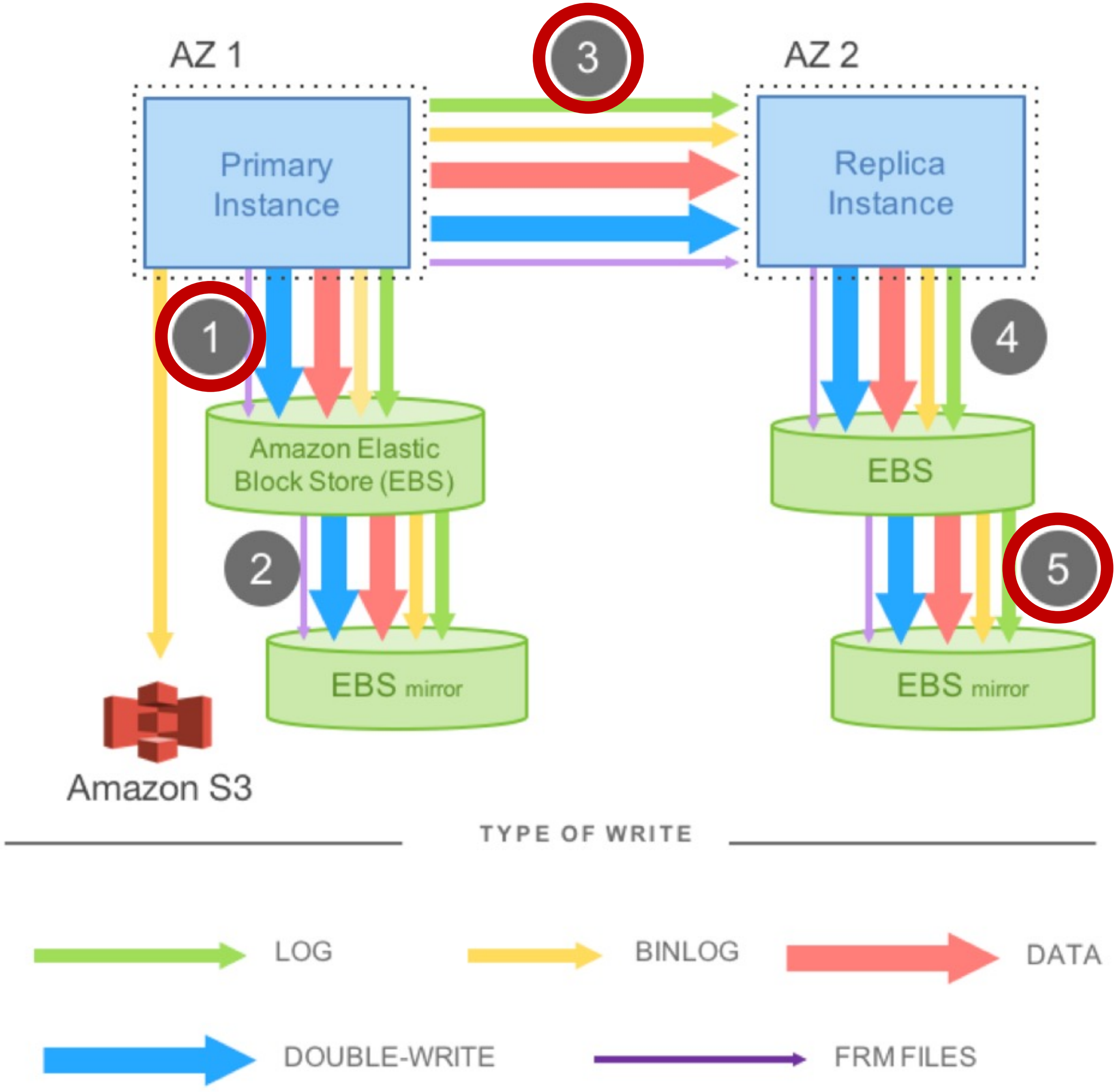
Maximize availability

=> Minimize MTTR (MTTF is hard to reduce)

Segment: 10 GB block. Basic unit of failure and repair

Protection Group (PG): Six replication copies of a segment

Network IO in MySQL



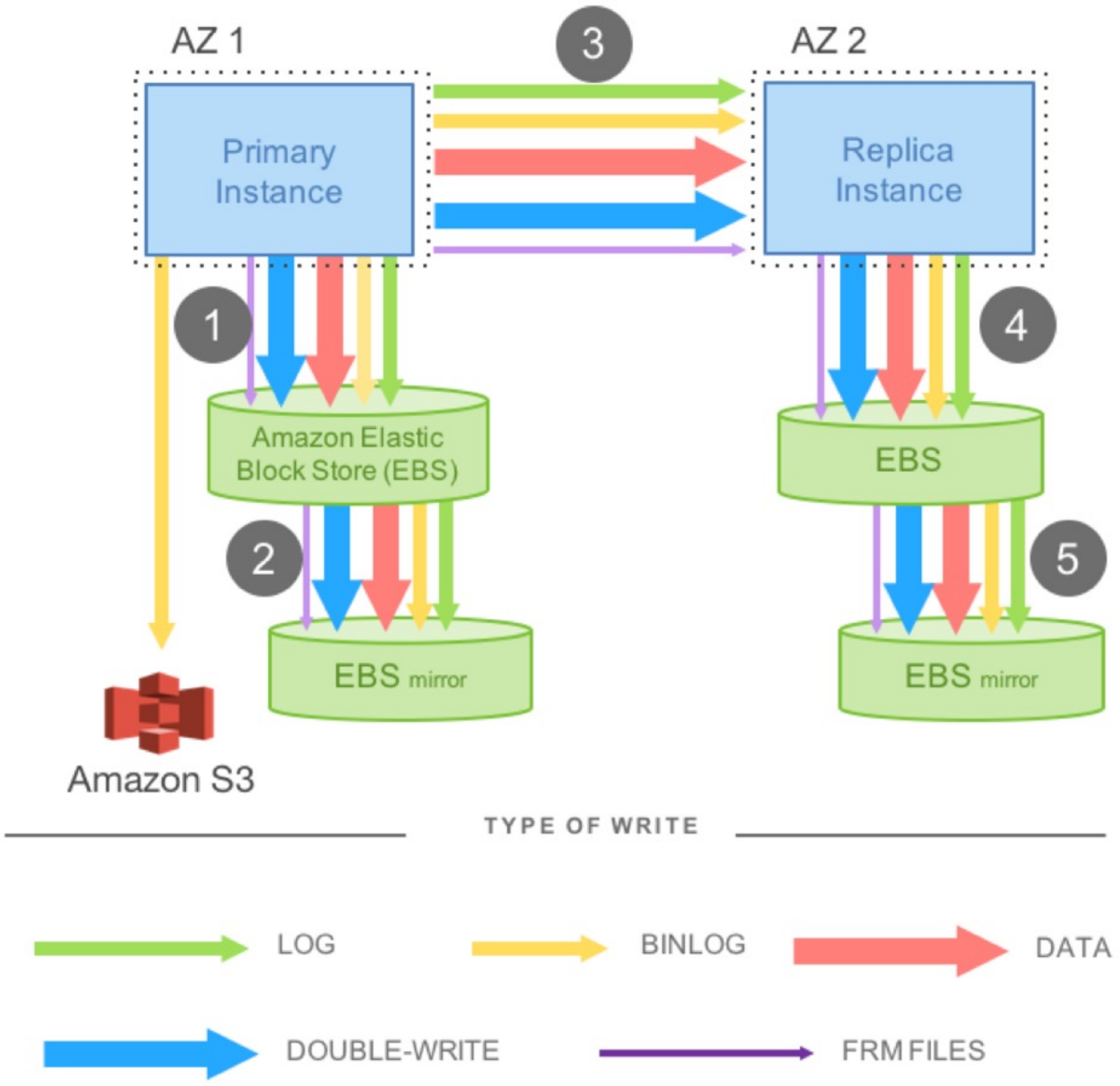
IO traffic

- **REDO Log**
- Binary log
- **Data**
- Double-write
- metadata (FRM)

Latency

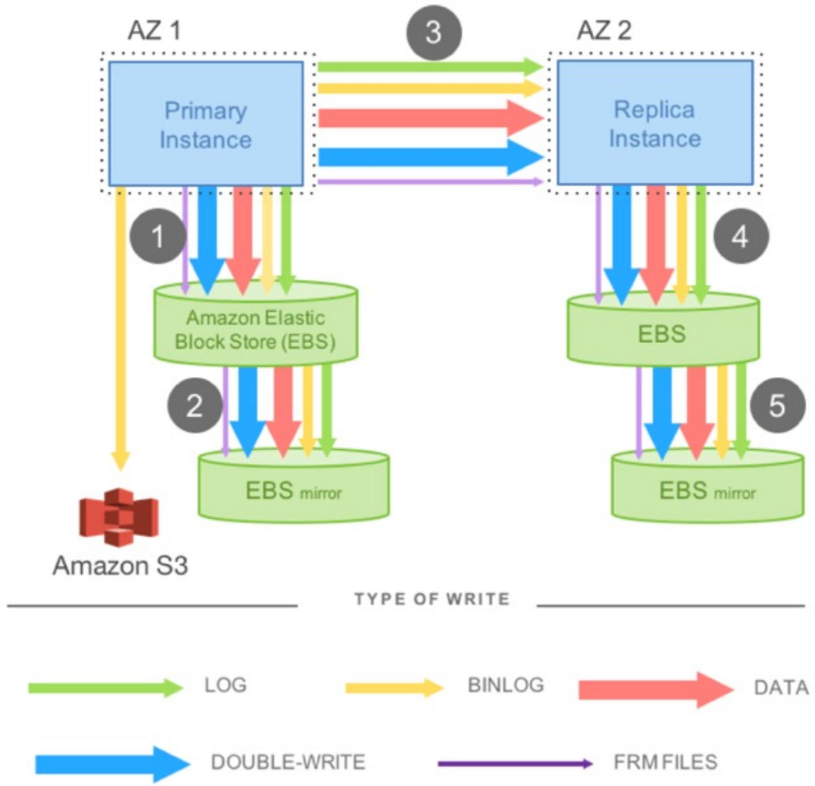
- Steps 1, 3, and 5 are sequential and synchronous

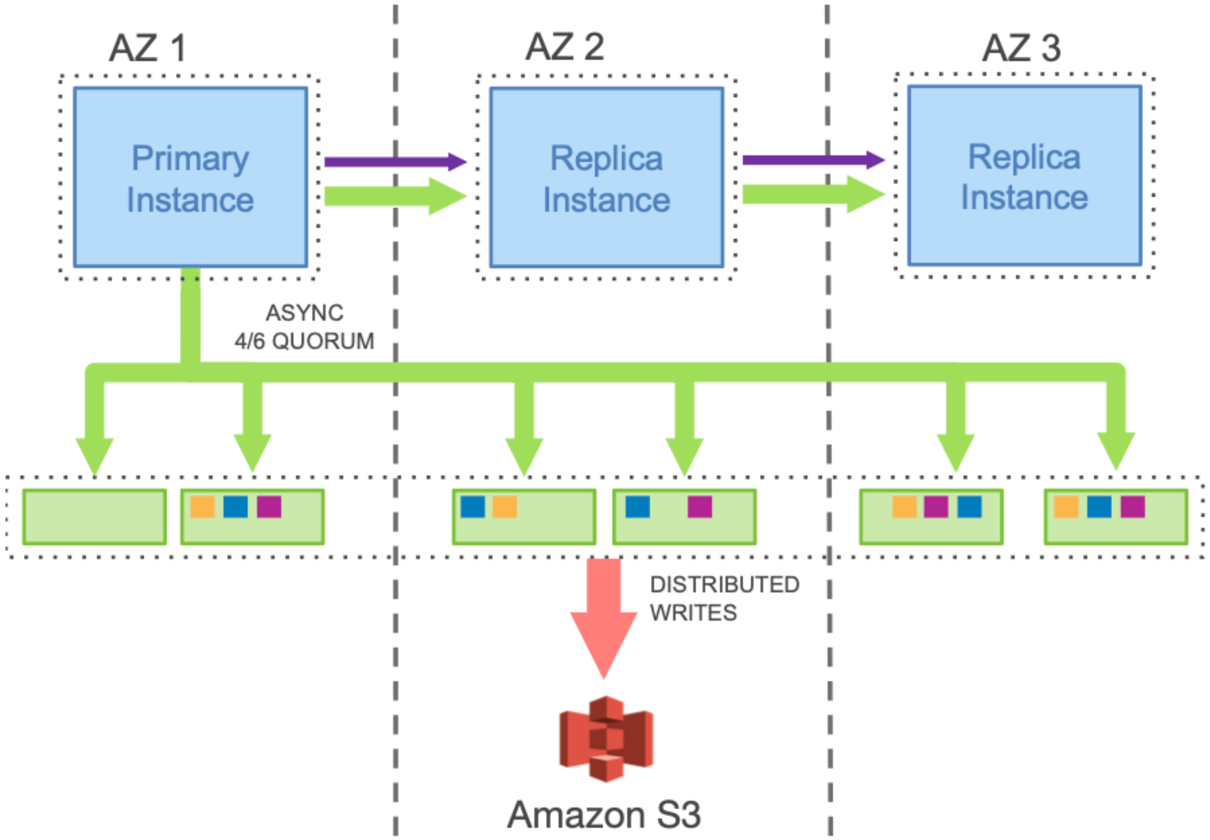
Binary Log vs. REDO Log in MySQL



1. REDO log generated by InnoDB; Binlog generated by MySQL and supports other storage engines
2. REDO log is physical, Binlog can be either physical or logical
3. A transaction writes a single Binlog record but potentially multiple REDO records

MySQL vs. Aurora





MySQL: DB writes both log and data pages to storage

Aurora: DB writes only REDO log to storage

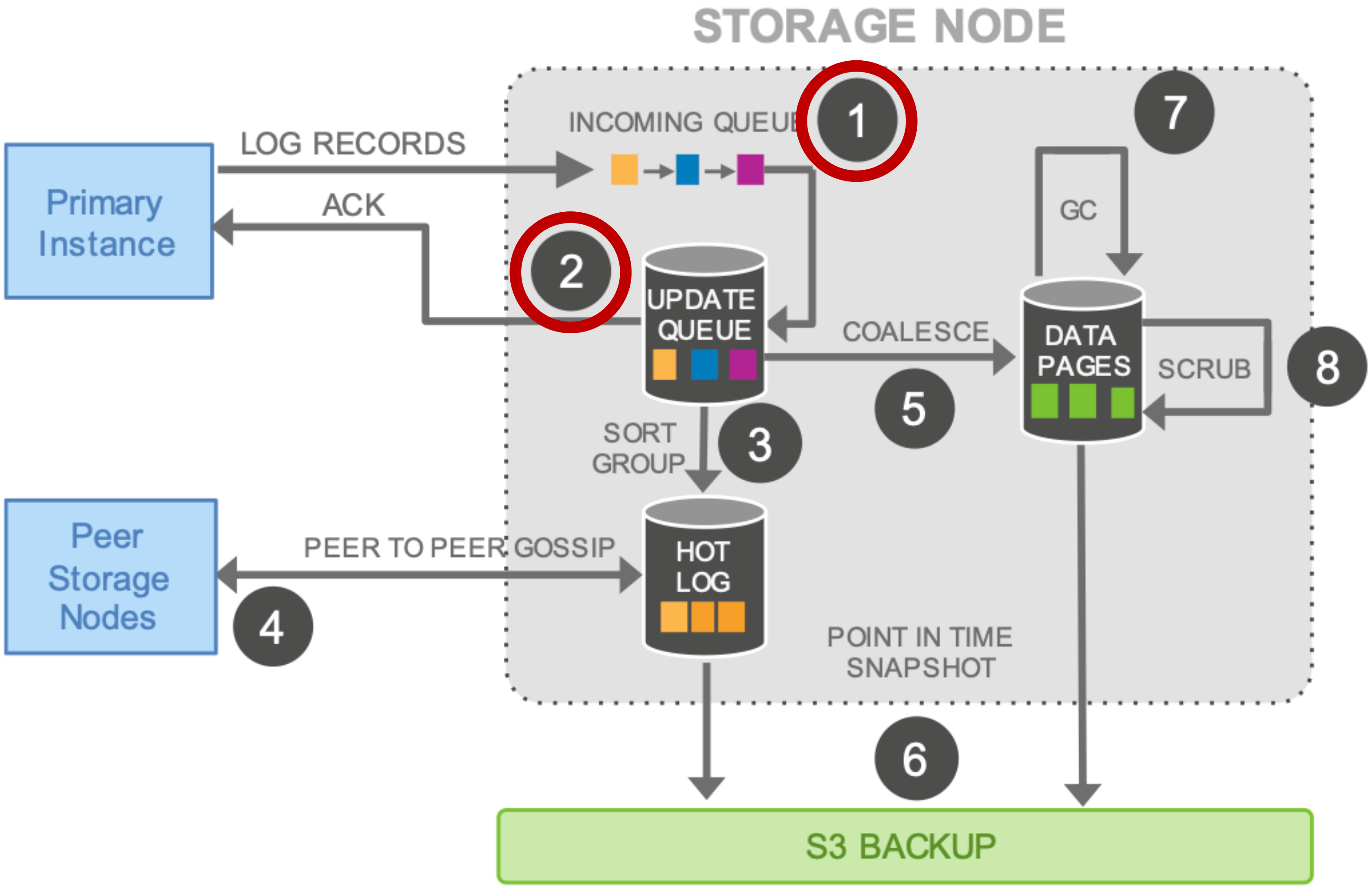
- The storage layer replays the log into data pages

MySQL vs. Aurora – Network IO

Table 1: Network IOs for Aurora vs MySQL

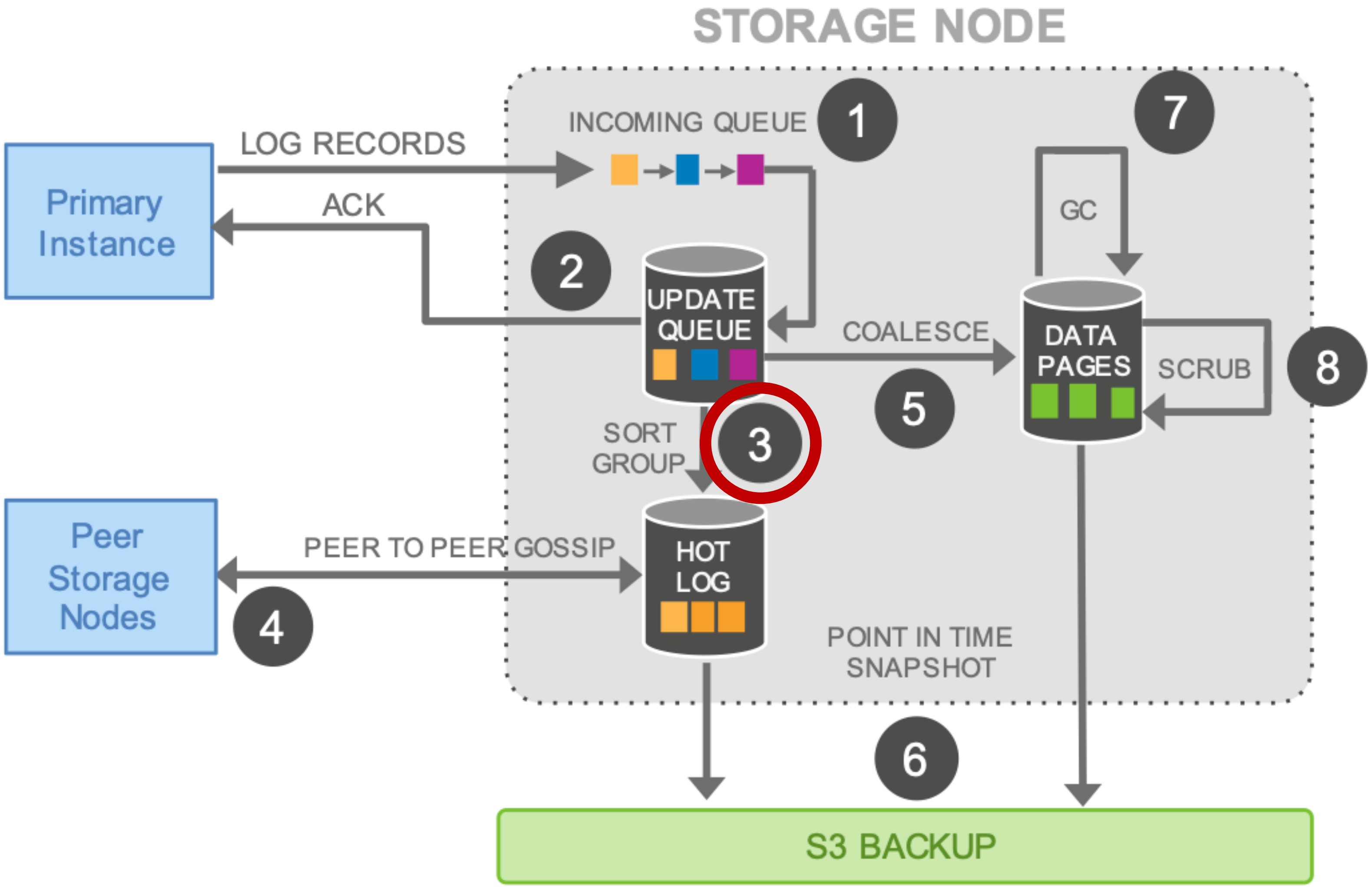
Configuration	Transactions	IOs/Transaction
Mirrored MySQL	780,000	7.4
Aurora with Replicas	27,378,000	0.95

Storage Node

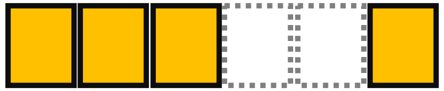


Only Steps 1 & 2 are in the foreground path

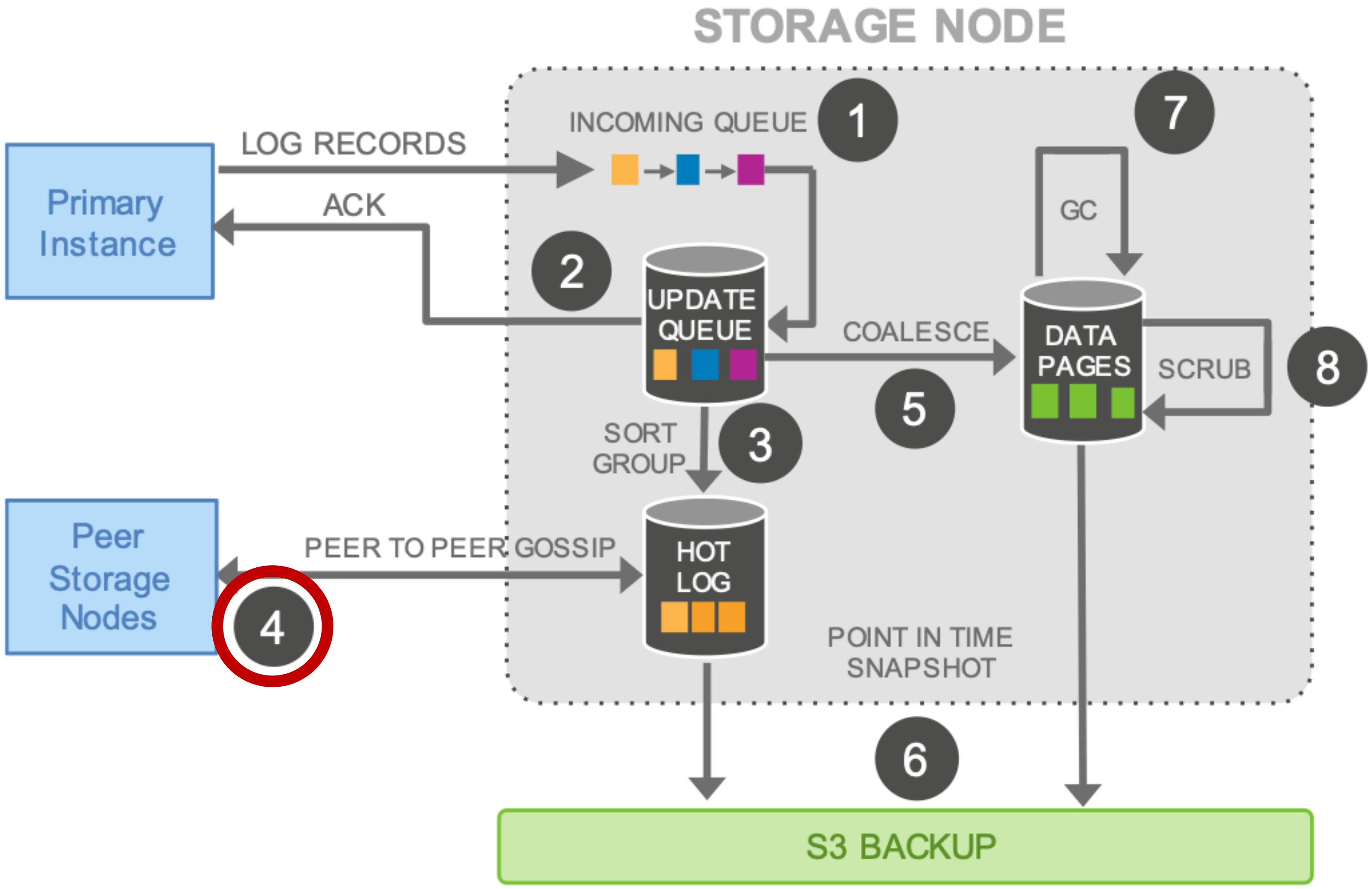
Storage Node



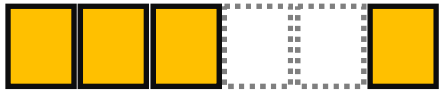
Identify gaps in the log



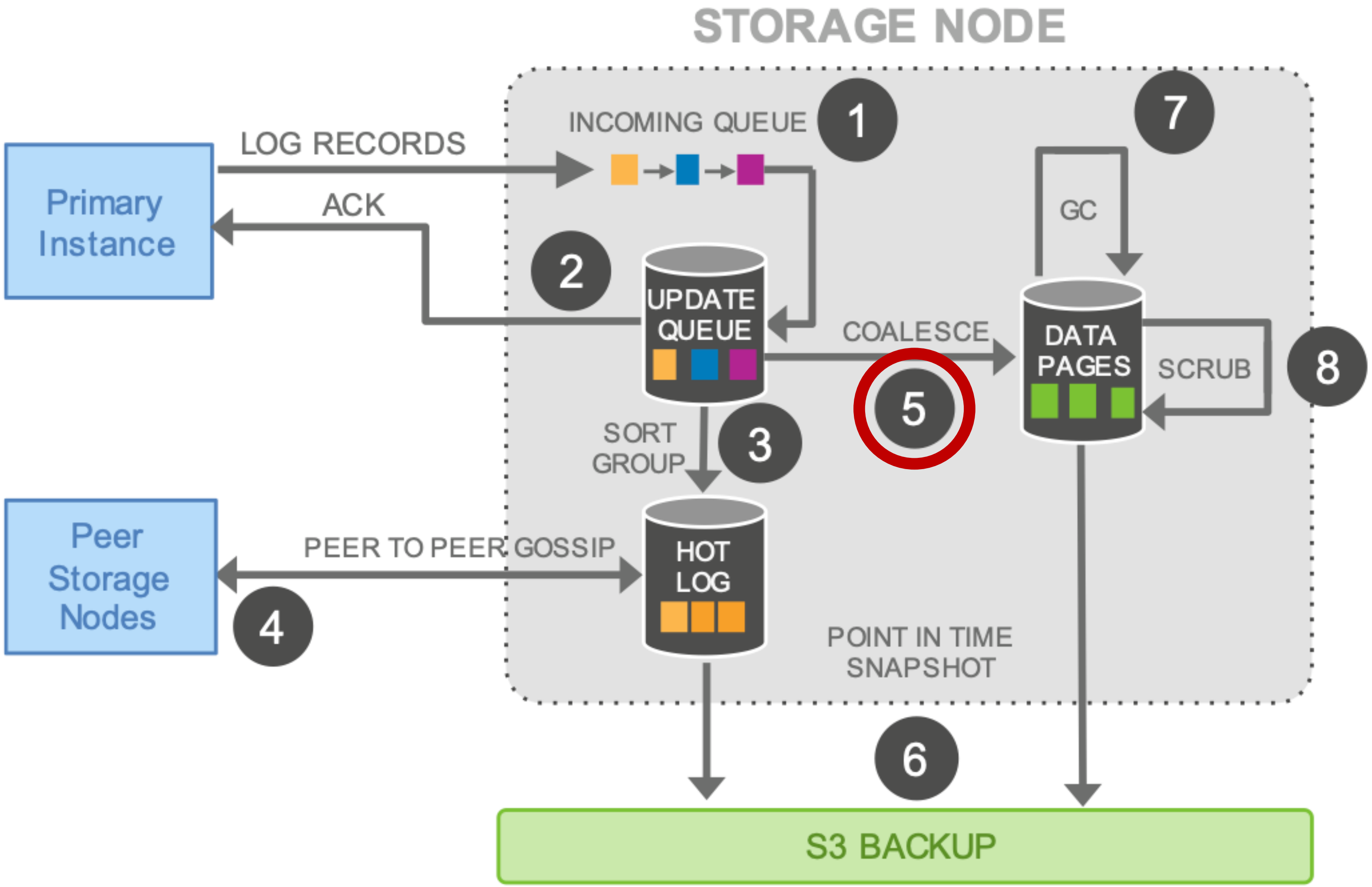
Storage Node



Gossip with peers to fill gaps

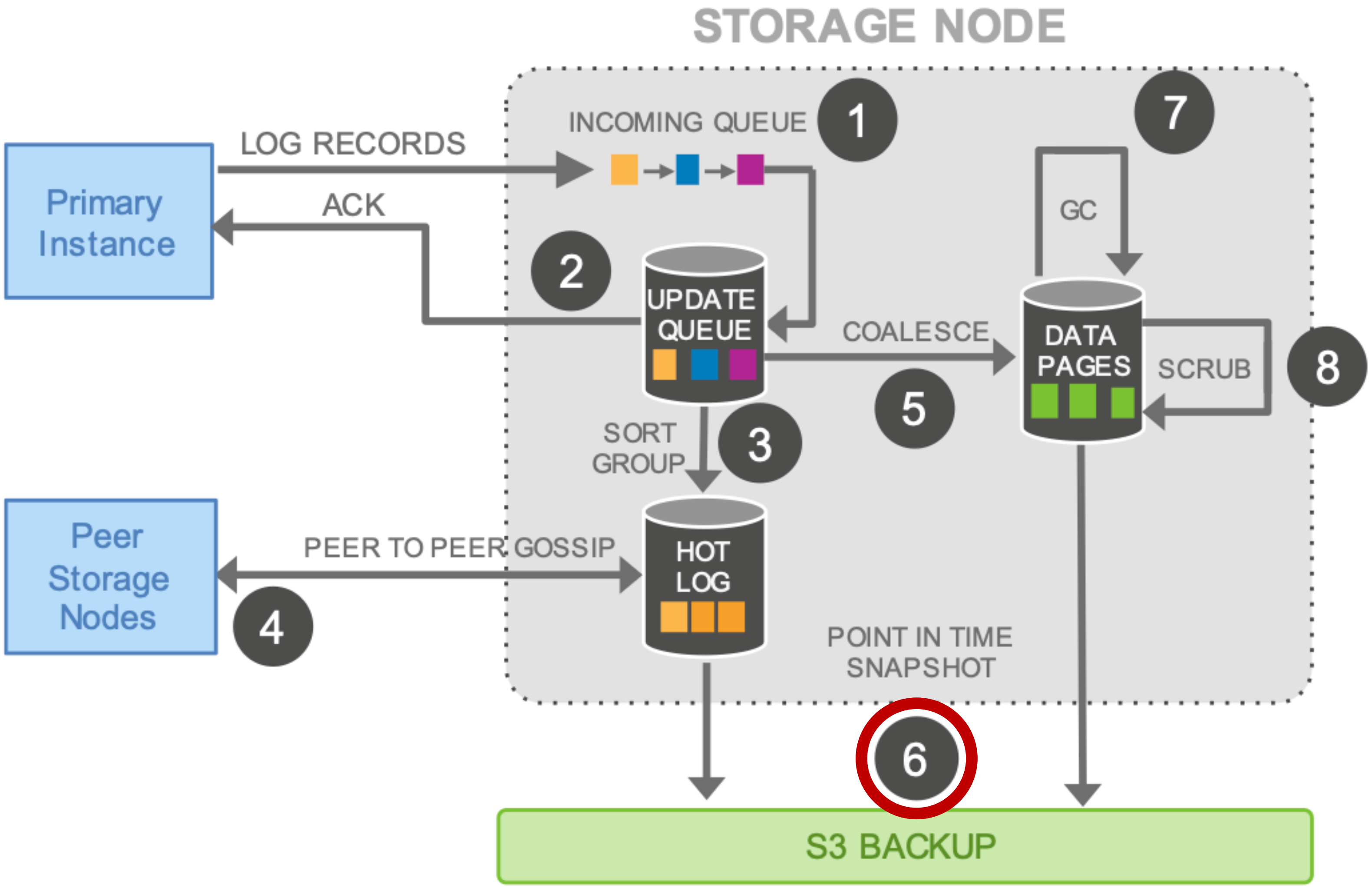


Storage Node



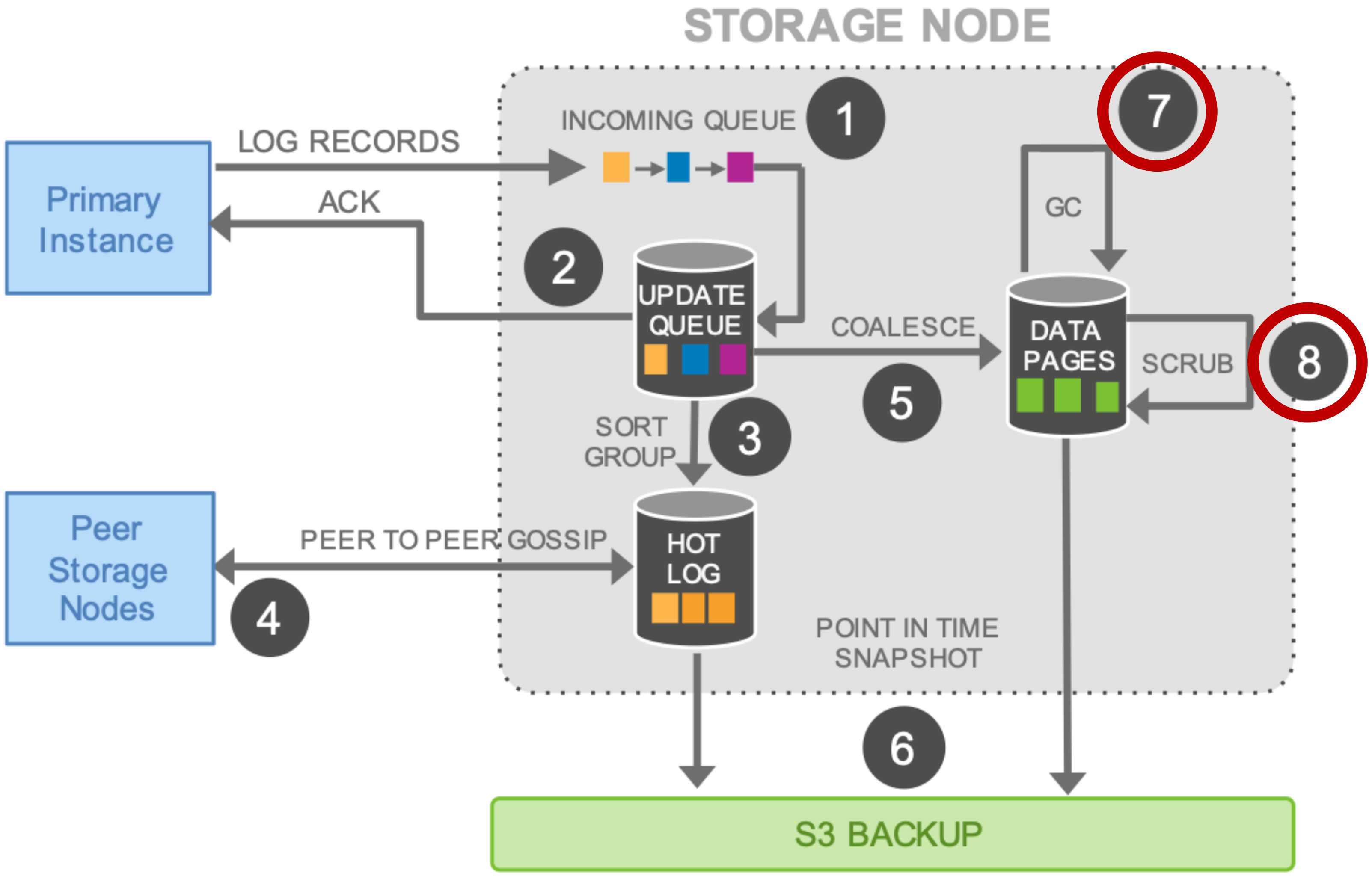
Coalesce log records into data pages

Storage Node



Periodically stage log and pages to S3

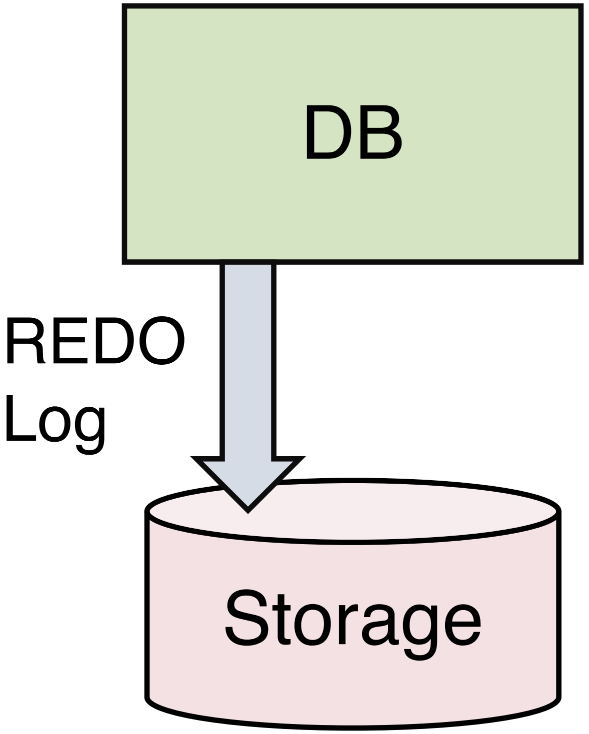
Storage Node



Periodically garbage collect old versions and periodically validate CRC code on pages

* Cyclic redundancy check (CRC) is an error-detecting code

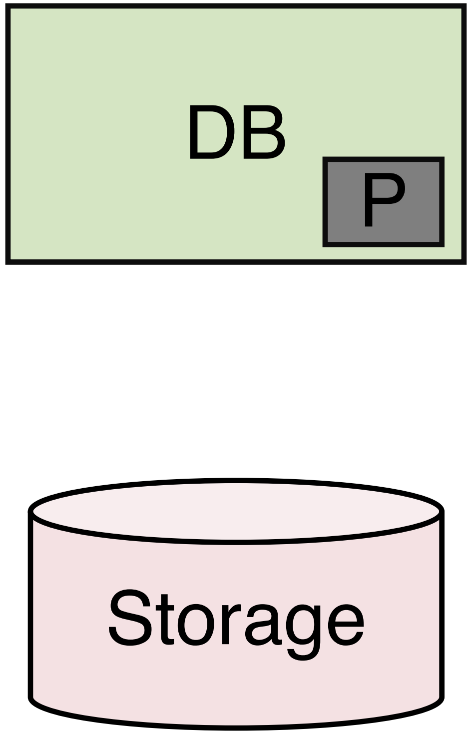
Forward Processing – Write and Commit



Write: flush REDO log to storage

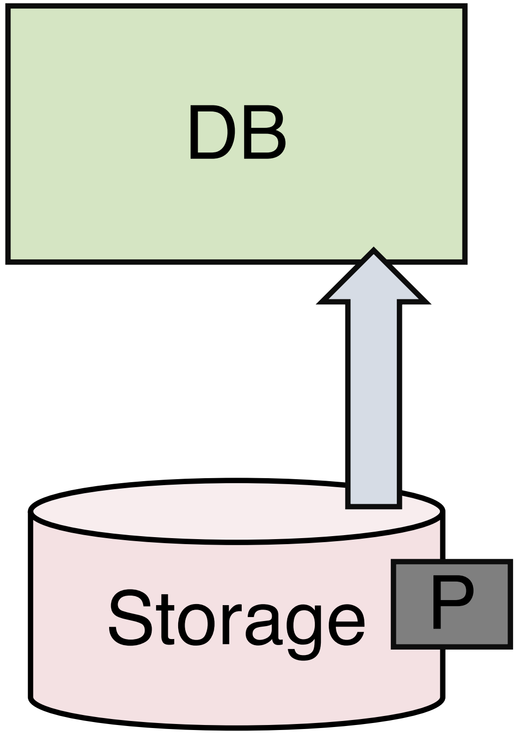
Commit: after all the log records are properly flushed

Forward Processing – Read



Buffer hit: read from main memory of the DB server

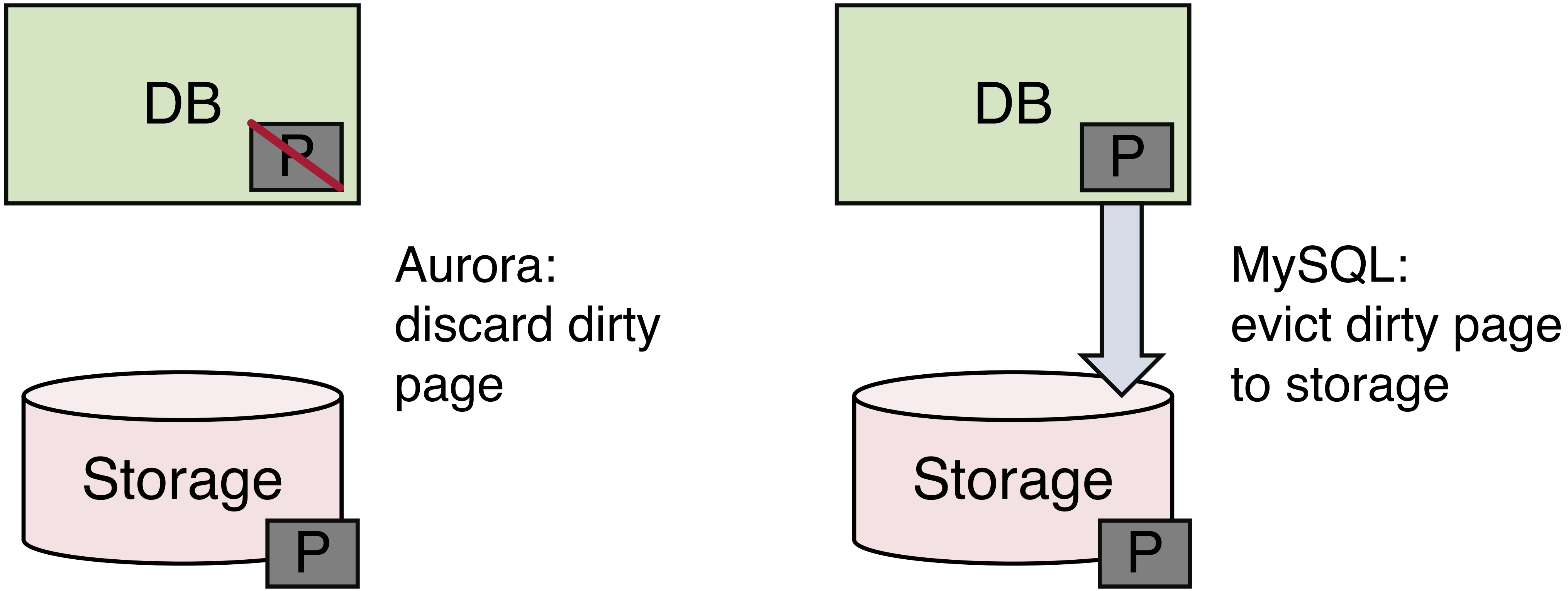
Forward Processing – Read



Buffer hit: read from main memory of the DB server

Buffer miss: read page from storage

Forward Processing – Eviction



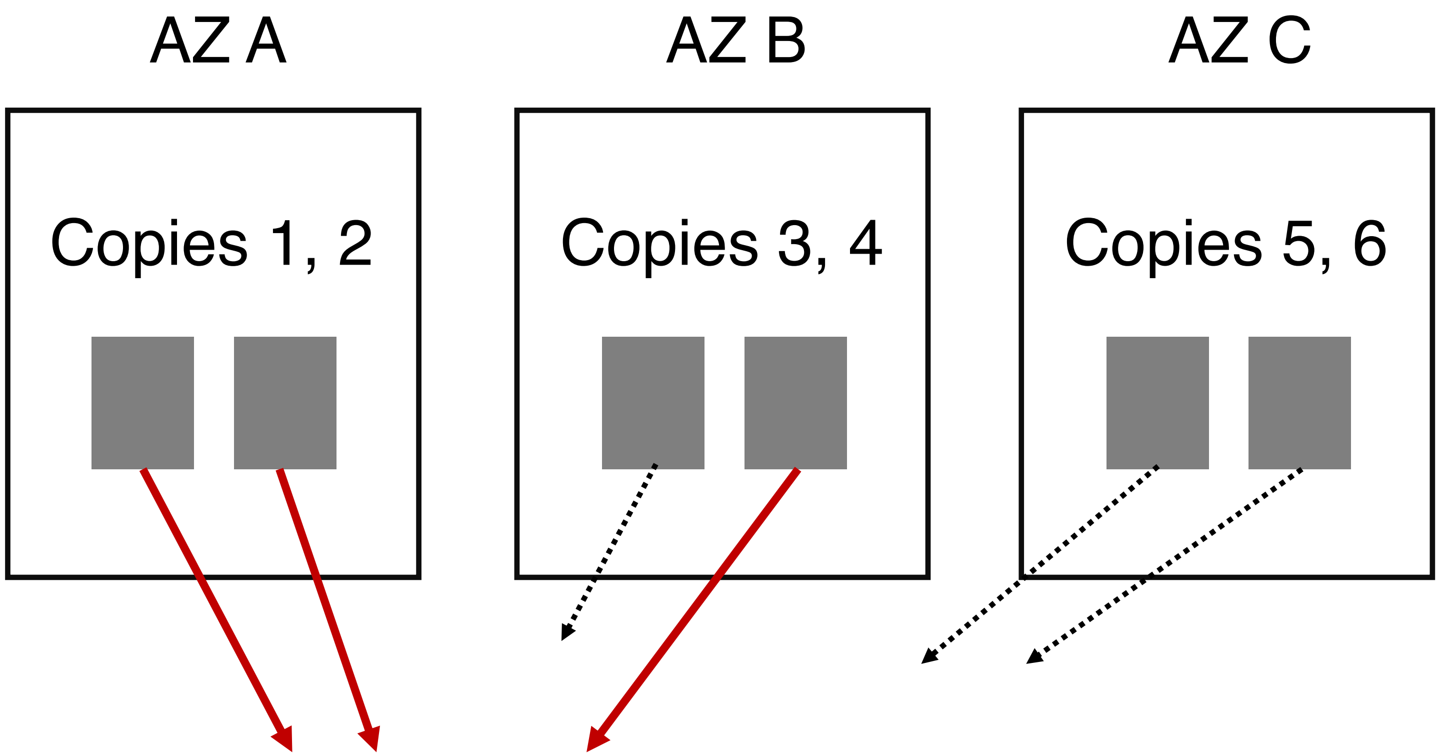
Buffer hit: read from main memory of the DB server

Buffer miss: read page from storage

Dirty eviction: discard dirty page (no write back to storage)

- The page in storage will be updated through replaying the REDO log

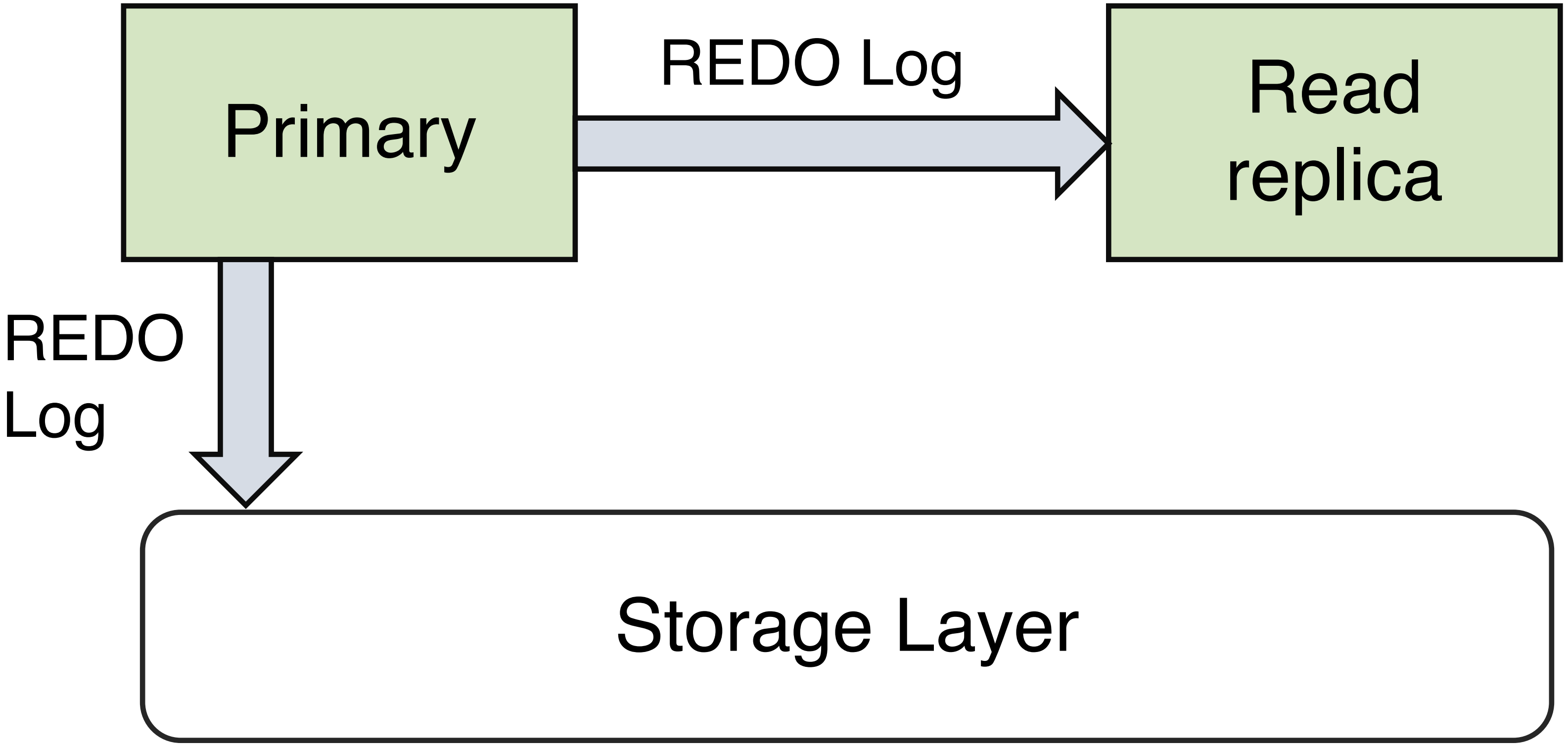
Read from One Quorum



Three votes to read data

The DB server knows which node contains the latest value
=> A single read from the update-to-date node

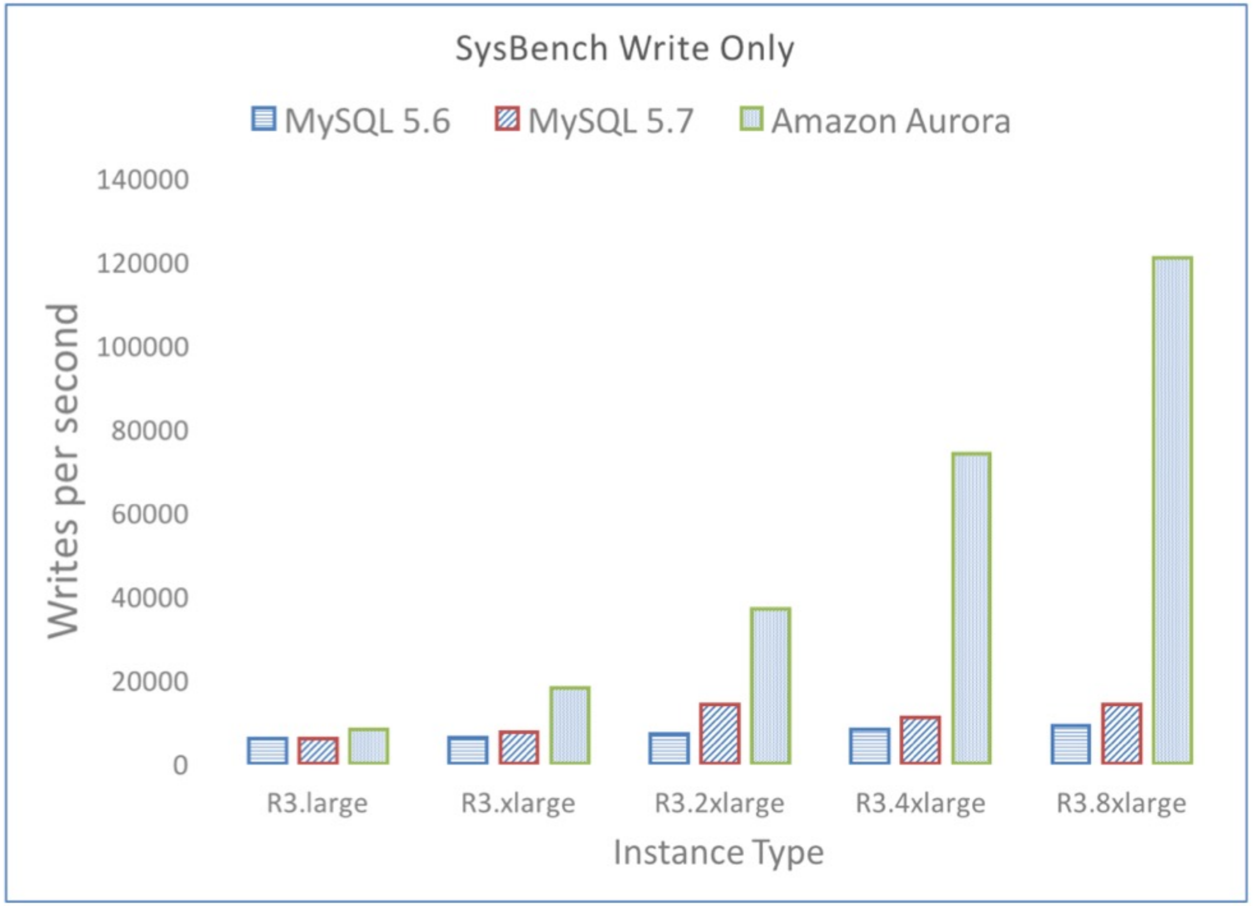
Replication

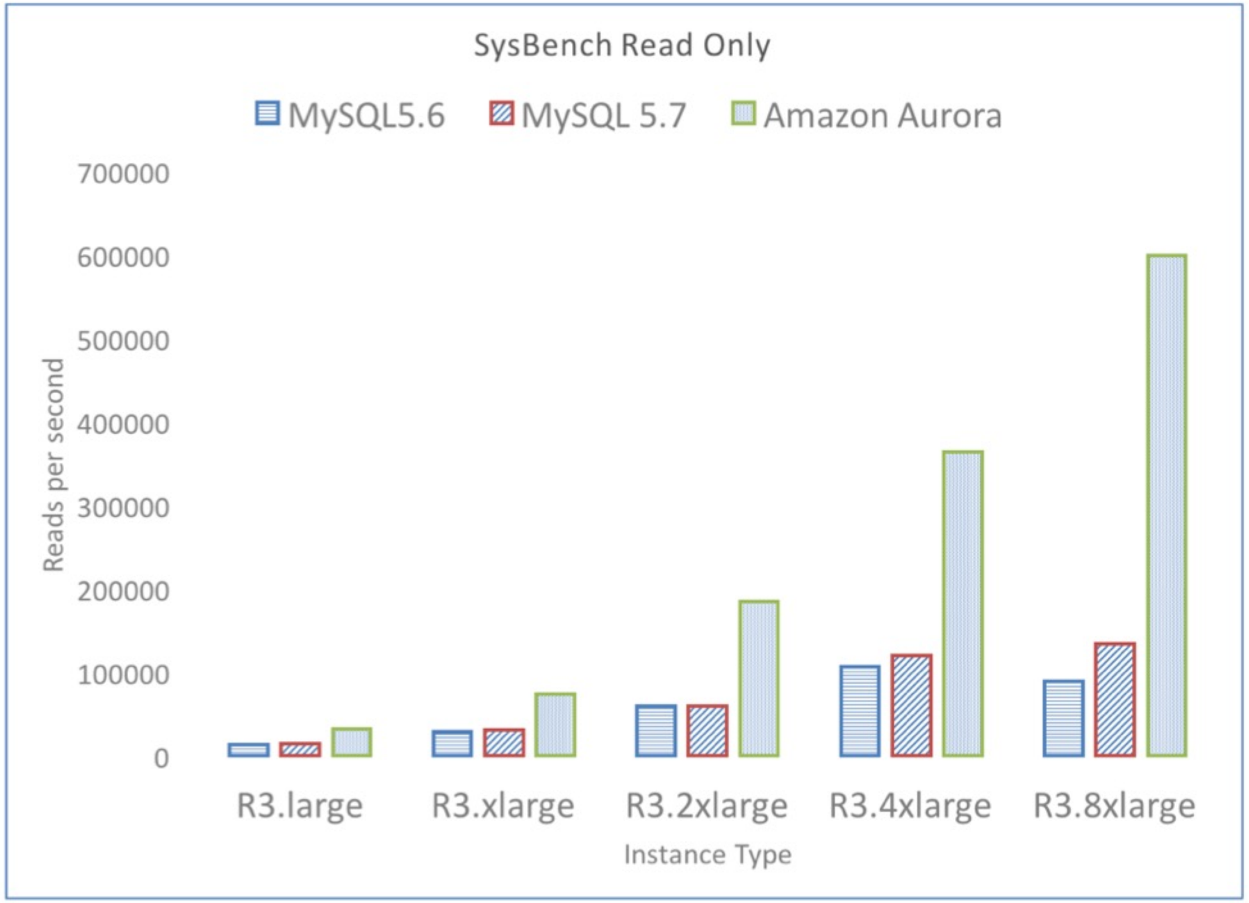


If page is in replica's local buffer, update the page

Otherwise, discard the log record

Evaluation – Aurora vs. MySQL





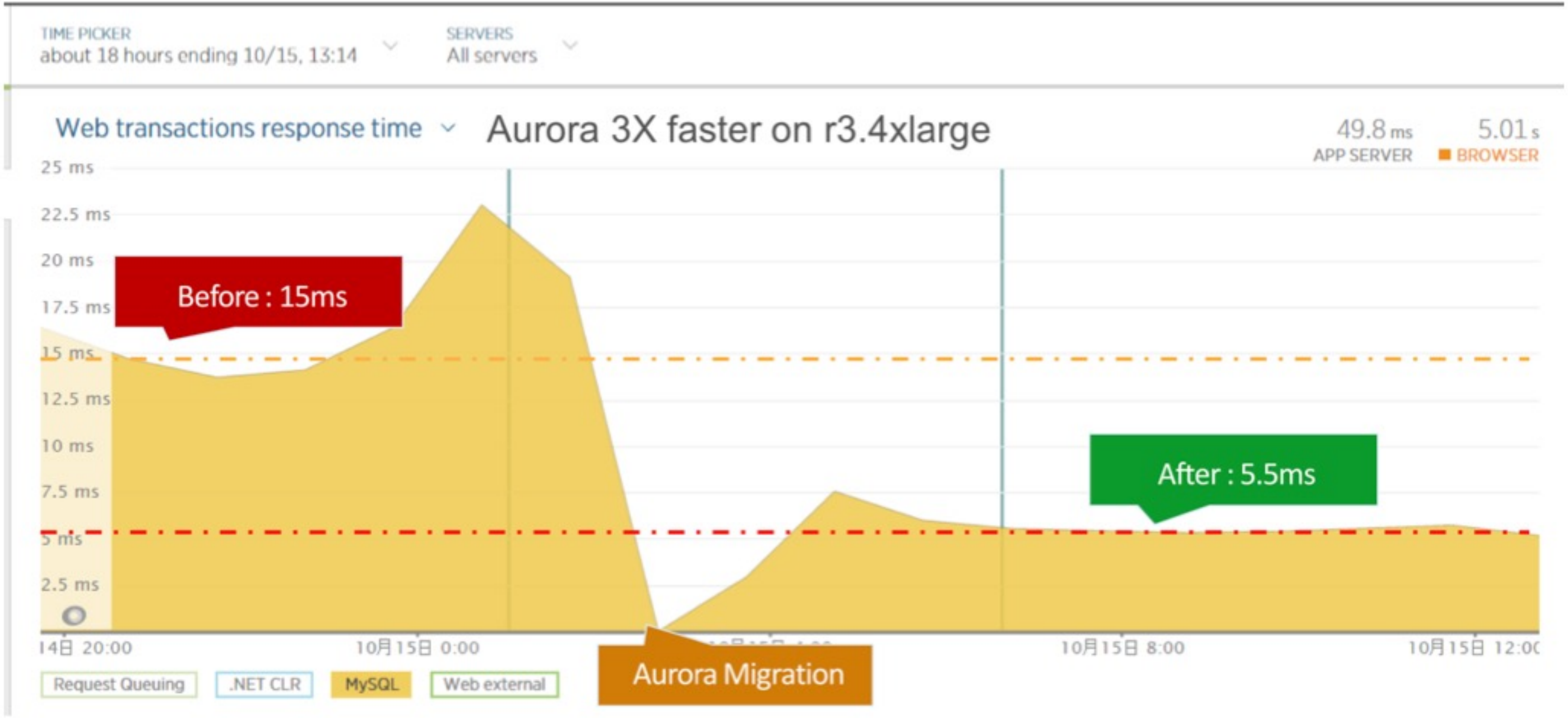
Evaluation – Varying Data Sizes

Table 2: SysBench Write-Only (writes/sec)

DB Size	Amazon Aurora	MySQL
1 GB	107,000	8,400
10 GB	107,000	2,400
100 GB	101,000	1,500
1 TB	41,000	1,200

Performance drops when data does not fit in main memory

Evaluation – Real Customer Workloads



Evaluation – Real Customer Workloads

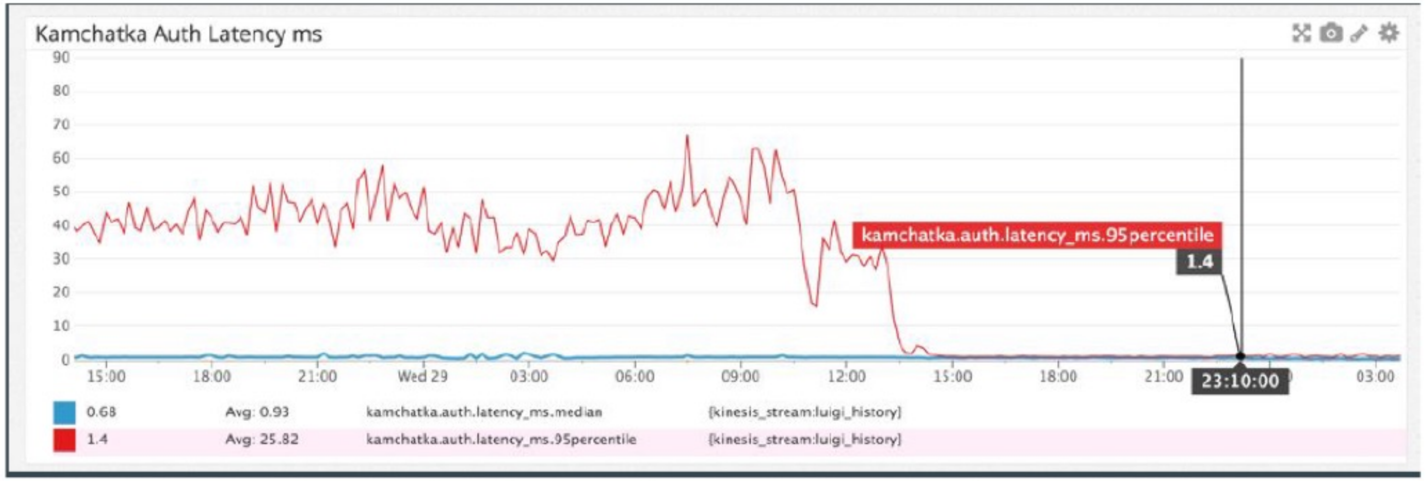


Figure 9: SELECT latency (P50 vs P95)

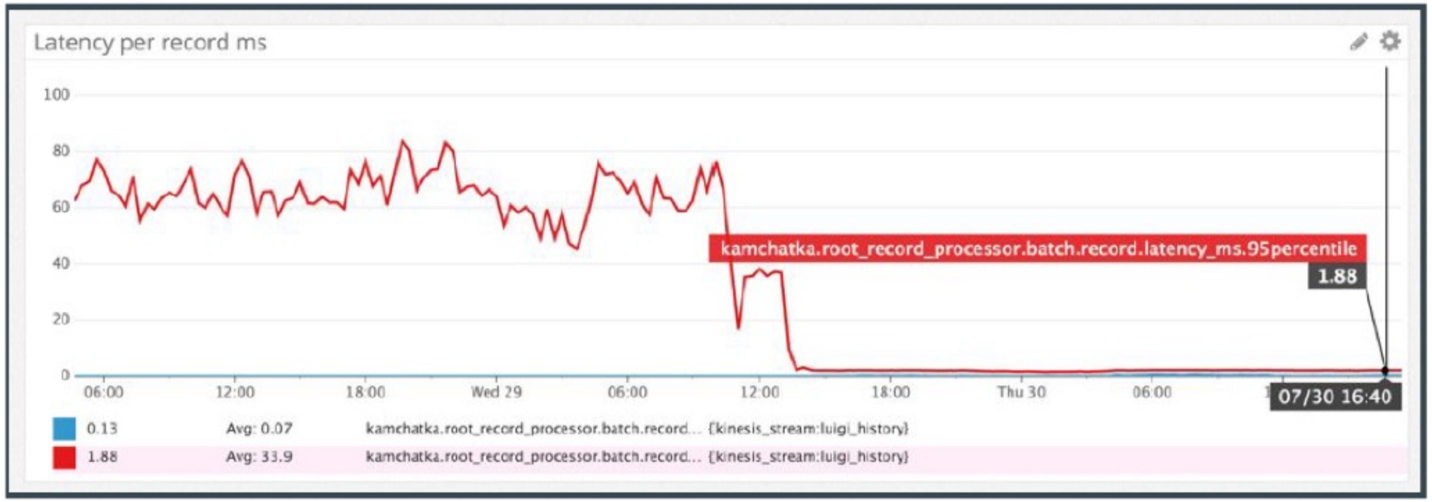
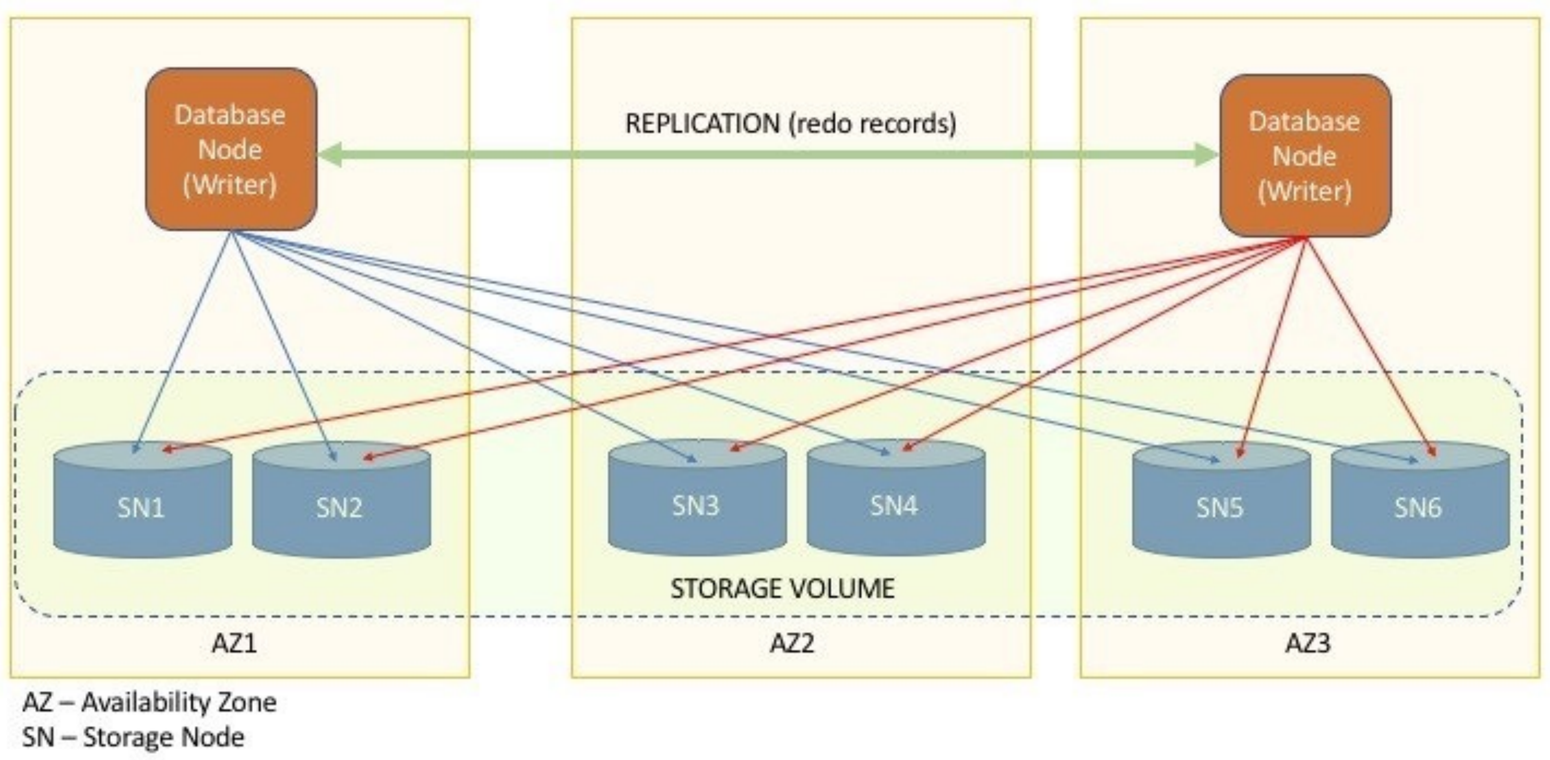


Figure 10: INSERT per-record latency (P50 vs P95)

Aurora Multi-Master



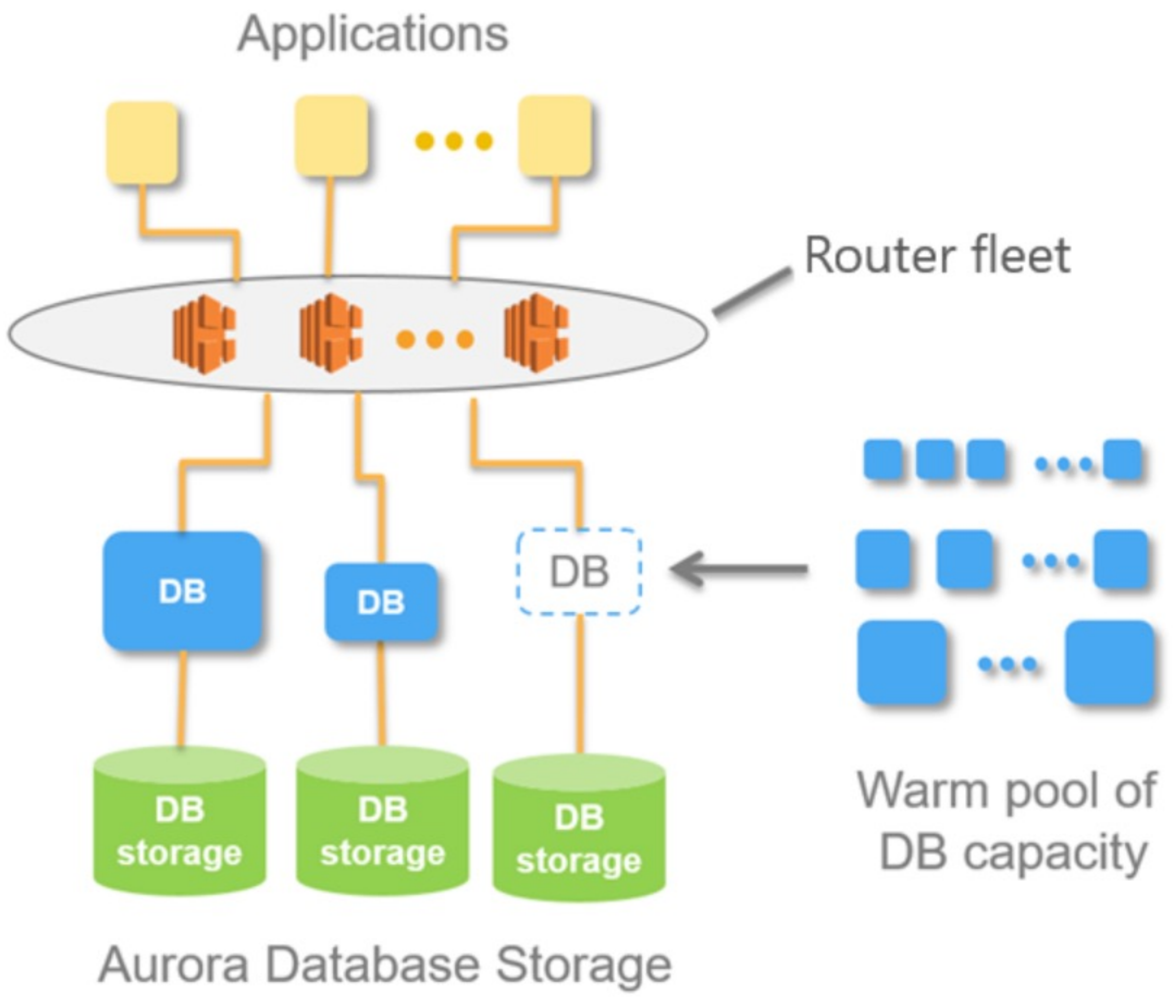
Any DB instance can access any data

The storage nodes detect conflicts at page granularity

- Pushing down concurrency control to the storage layer

* https://docs.aws.amazon.com/AmazonRDS/latest/AuroraUserGuide/aurora-multi-master.html

Aurora Serverless



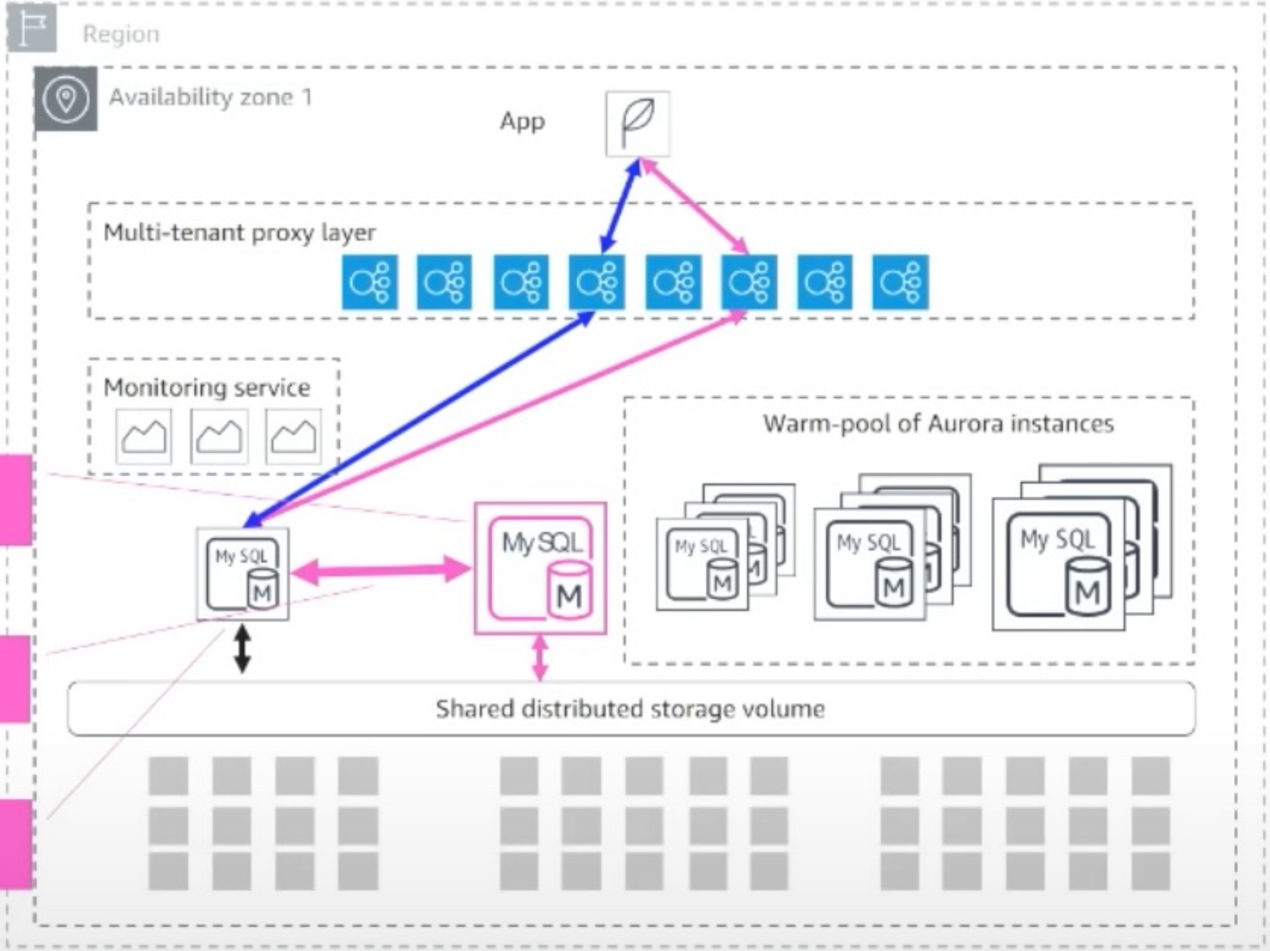
- https://docs.aws.amazon.com/AmazonRDS/latest/AuroraUserGuide/aurora-serverless.how-it-works.html

How does it work . . .

Get server from warm pool

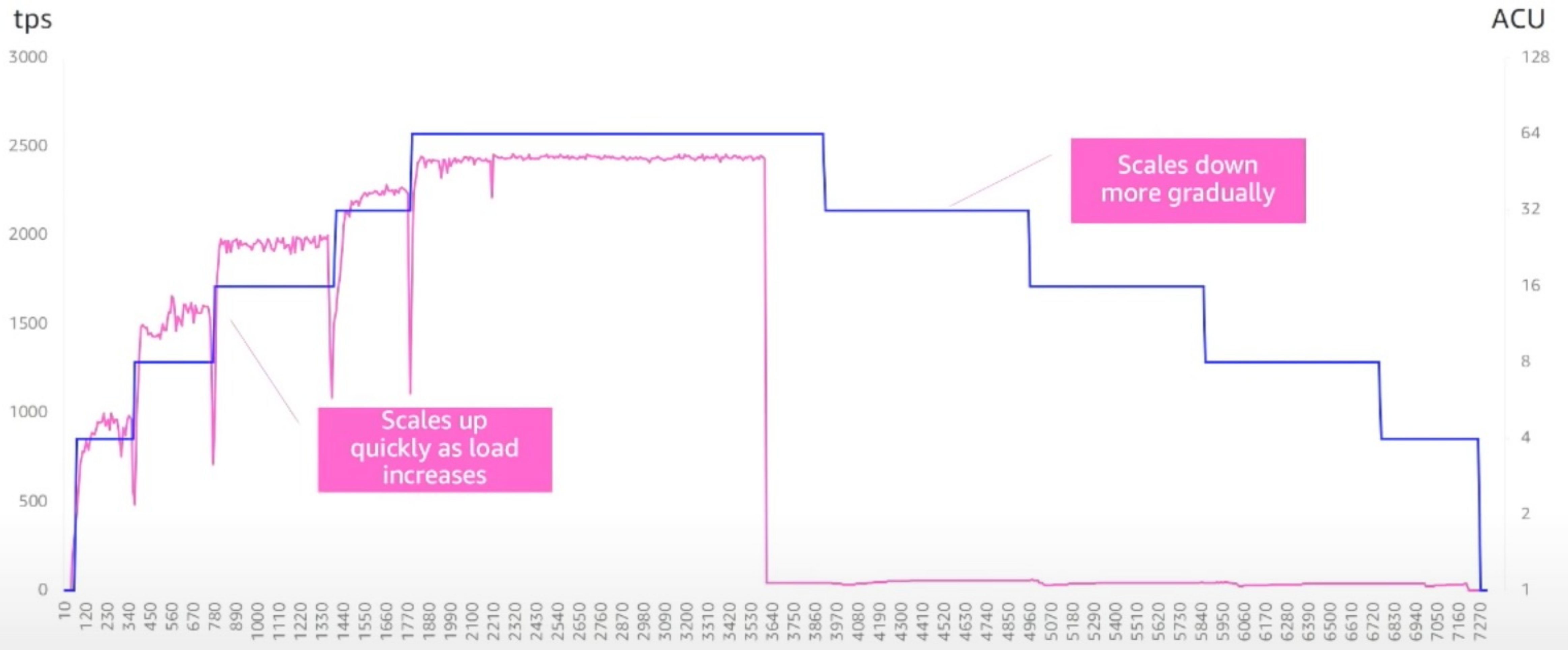
Transfer buffer pool

Look for safe scale point



* Aurora Serverless: Scalable, Cost-Effective Application Deployment (DAT336) - AWS re:Invent 2018

How does it work in practice?



AWS re:Invent

aws

* Aurora Serverless: Scalable, Cost-Effective Application Deployment (DAT336) - AWS re:Invent 2018

Amazon Aurora – Q/A

Any pitfalls of this design?

Alternative DBs in industry with innovations different from Aurora?

Does Aurora support geo-replication well?

Network vs. compute vs. storage, which one is the bottleneck?

Aurora depends on MySQL and Postgres; does that hinder its development?

How to handle case where storage node writes data but does not replicate to other replicas?

Is S3 used as WAL in Aurora?

Before Next Lecture

Submit review for

- Benoit Dageville, et al., The Snowflake Elastic Data Warehouse. SIGMOD, 2016