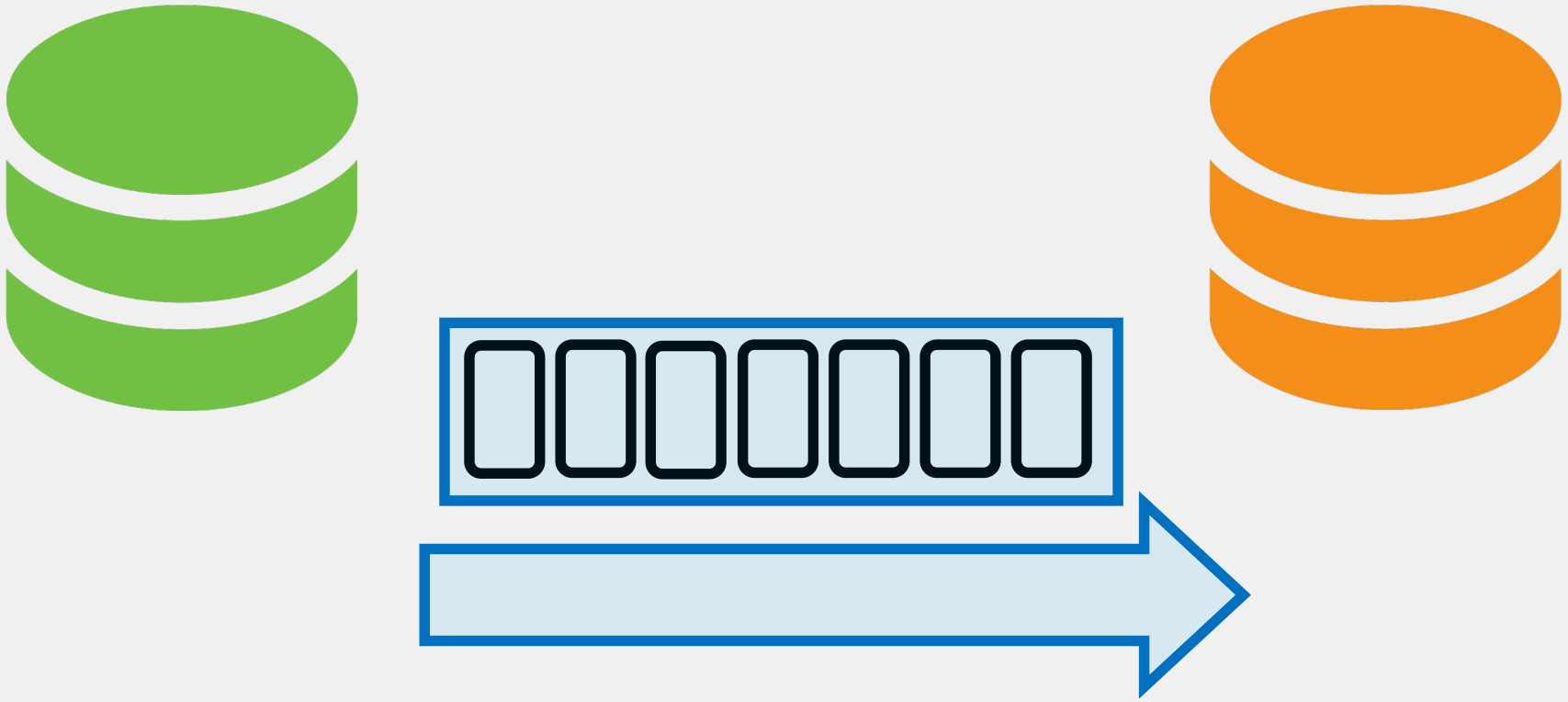
The Dangers of Logical Replication and a Practical Solution

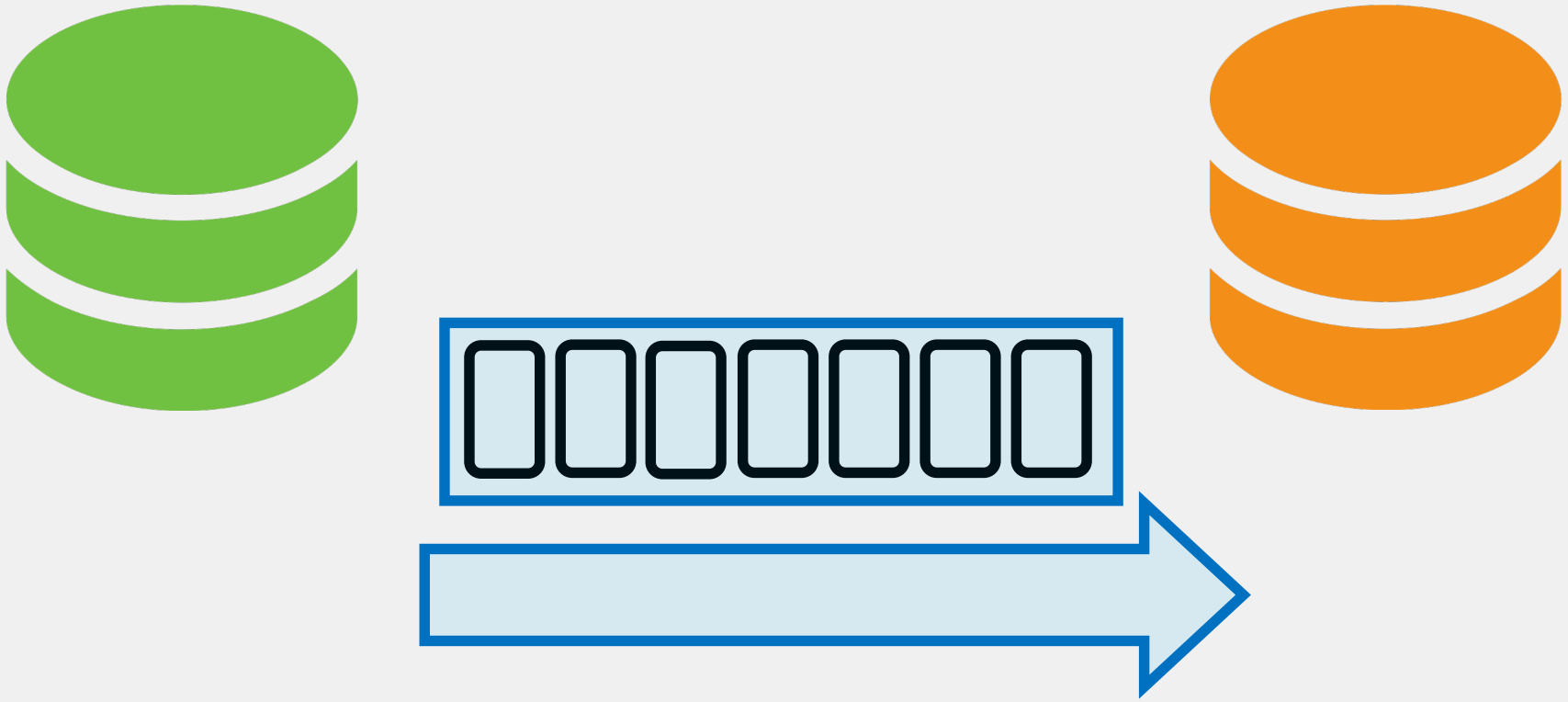
Jose M. Faleiro
Microsoft Research

with
Daniel Abadi, Jeff Helt, Wyatt Lloyd, Abhinav Sharma

Log-shipping replication



Replication lag



Primary-backup parallelism gap

Cannot reuse primary's concurrent execution mechanisms

Multi-threading, synchronization

Weak isolation

Backup must be serial-equivalent

Transaction scheduling

Why now?

Before: Parallelism gap hidden behind I/O bottleneck

Multi-threading used to mask over I/O latency on primary

Backups: Read-ahead into the log to prefetch pages

I/O bottleneck is less relevant today

Servers equipped with increasingly large DRAM

Larger portion of working set can fit in memory

Lower bufferpool miss penalty

Servers equipped with SSDs

100x lower latency than HDDs

Increasing hardware parallelism with multi-cores

Replication lag in the wild

Github

“Maintaining low replication lag is challenging”

Investment in monitoring and throttling (freno)

Booking.com

Reported cases where backups lagged by **90 minutes**

VividCortex

“… suffering some serious delays. The worst was behind by at least **16 hours**”

GitLab incident

19:00 UTC – GitLab experiences incr

Feb 10, 2017 - GitLab

Postmortem of database outage of January 31

Postmortem on the database outage of January 31 2017 with the lessons we learned.

Primary drops log records needed for replication

GitLab Database Incident – Live Report (docs.google.com)

1162 points by sbuttgereit on Feb 1, 2017 | hide | past | web | favorite | 598 comments

Attempt to restore backup from checkpoint

Lots of Ops "holier than tho" over the GitLab outage. Sure, they made some mistakes, but let they without Ops sin cast the 1st stone.

5:39 AM - 1 Feb 2017

GitLab.com melts down after wrong directory deleted, backups fail

Upstart said it had outgrown the cloud – now five out of five restore tools have failed

By Simon Sharwood 1 Feb 2017 at 02:02 143 SHARE ▼

GitLab offline after catastrophic database error loses mountains of data

Addressing replication lag in MySQL at Facebook

Published work on deterministic execution for multi-cores

… but I wanted a compelling real-world use case

Log shipping-based replication seemed like a perfect fit

Parallelize the execution of totally ordered log records

Talked to lots of real-world practitioners

Mark Callaghan pointed me to relevant folks at Facebook

Replication mechanism used fairly widely in production

Requirements

Backups must use at least as much parallelism as primaries

Robust to innovations in concurrency control

Robust to weak isolation

Backups must provide snapshot isolation for read requests

Reads must observe complete log prefix

Primer on MySQL replication

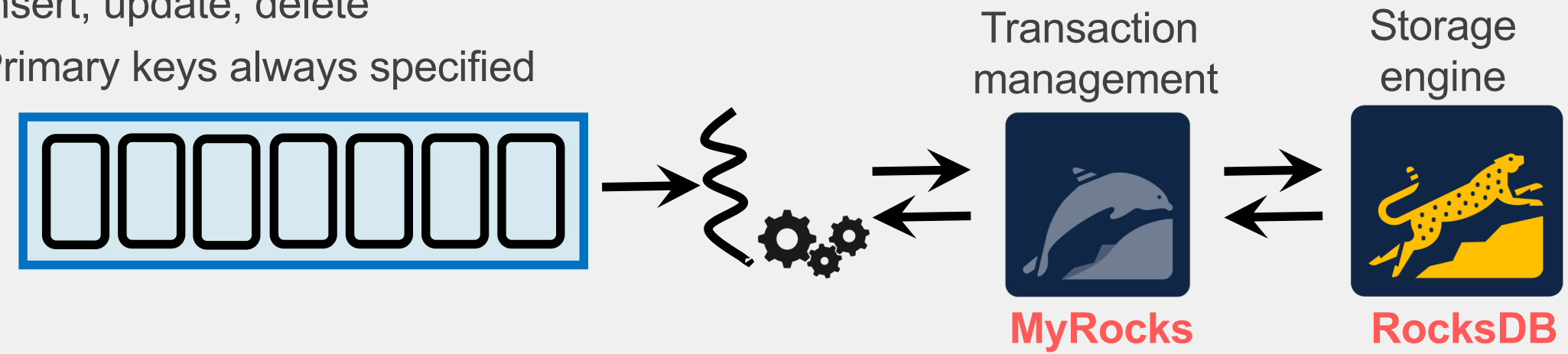
Single threaded log application

Log records are logical

Transaction statements

Insert, update, delete

Primary keys always specified

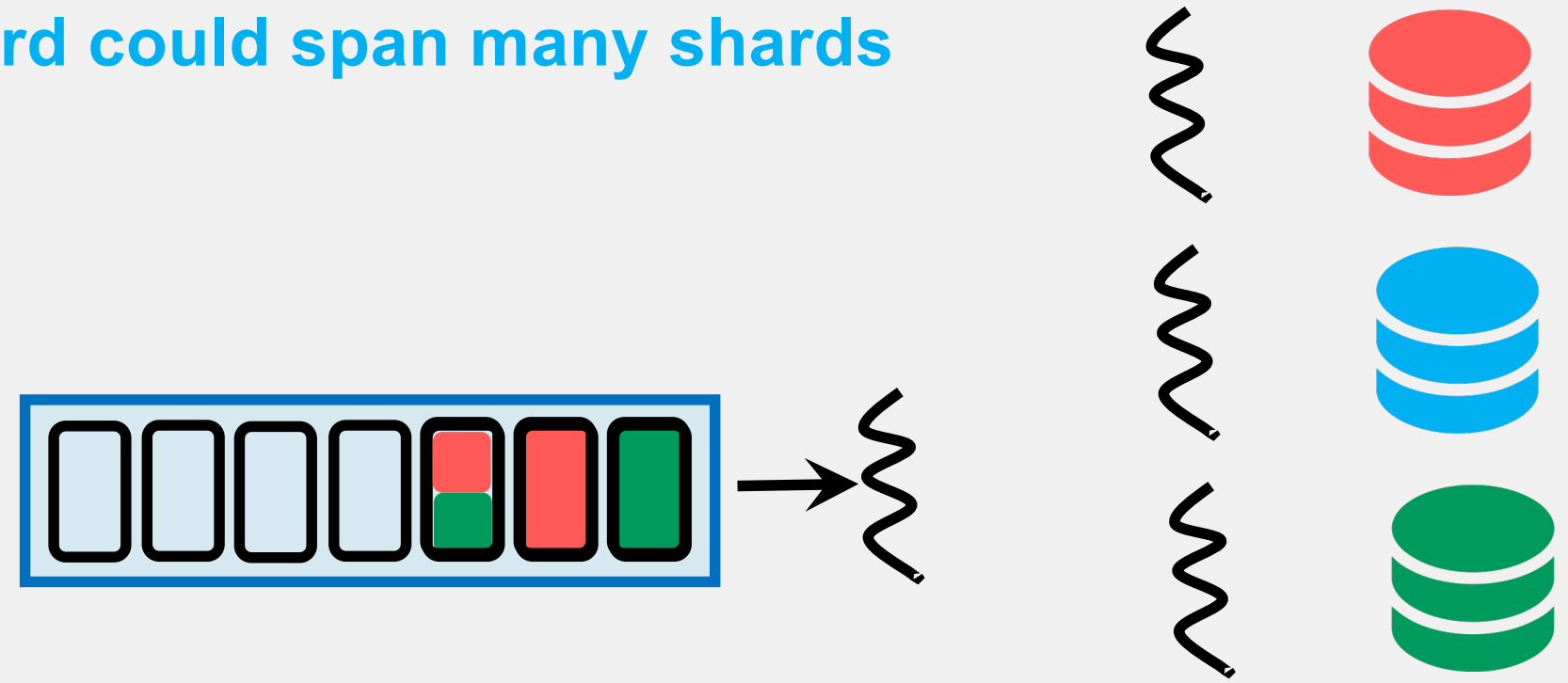


Parallelization strategy: Single threaded shards

Soft partition DB

Route log records to appropriate partitions

Log record could span many shards



Issues with single threaded shards

Each write must be wrapped in its own transaction

Extra overhead to begin and commit transactions (compared to primary)

Restrict each log record to a single write on primary

Adds overhead on primary

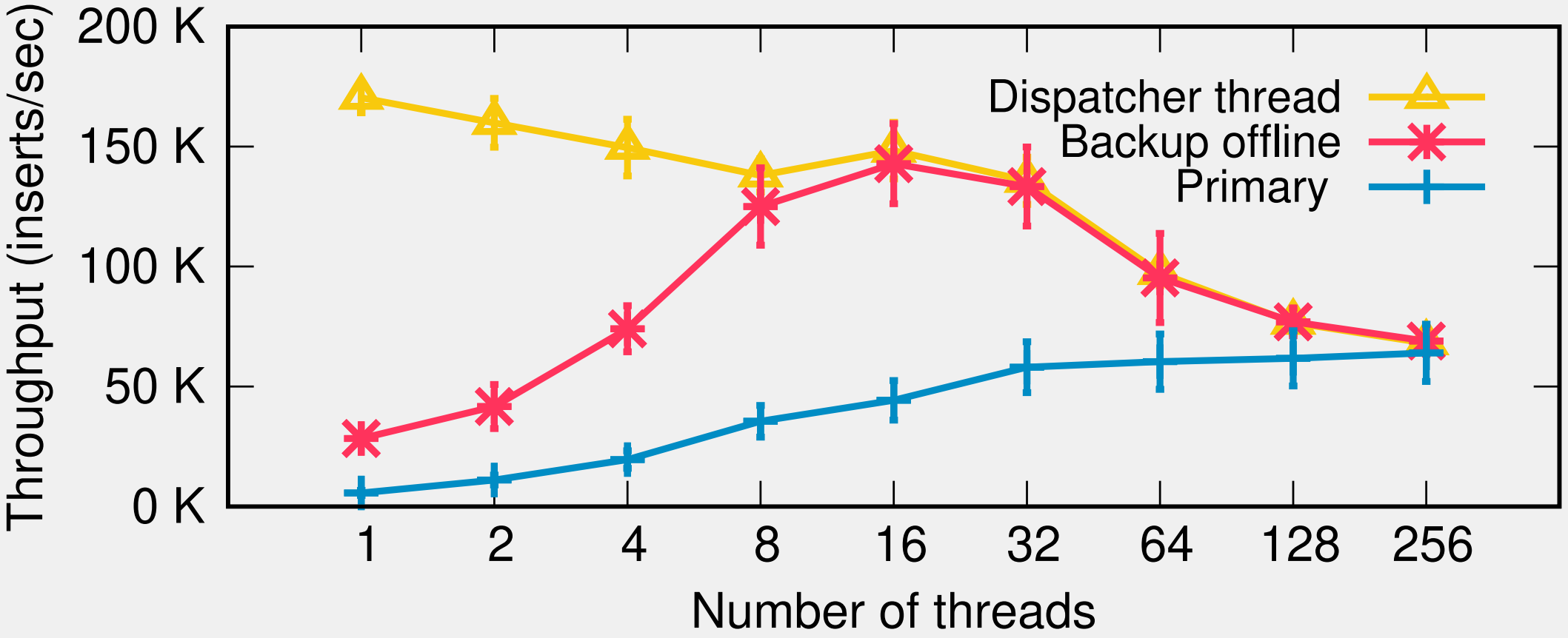
Not general enough, breaks compatibility

Unpack log record on dispatcher thread

Additional overhead on a centralized component

Memory management overhead

Dispatcher thread performance



Parallelization strategy: Short-duration locks

Assign each transaction to worker threads

1:1 correspondence between primary and backup transactions

But avoid long-duration locks

Dispatcher determines schedules based on conflicts

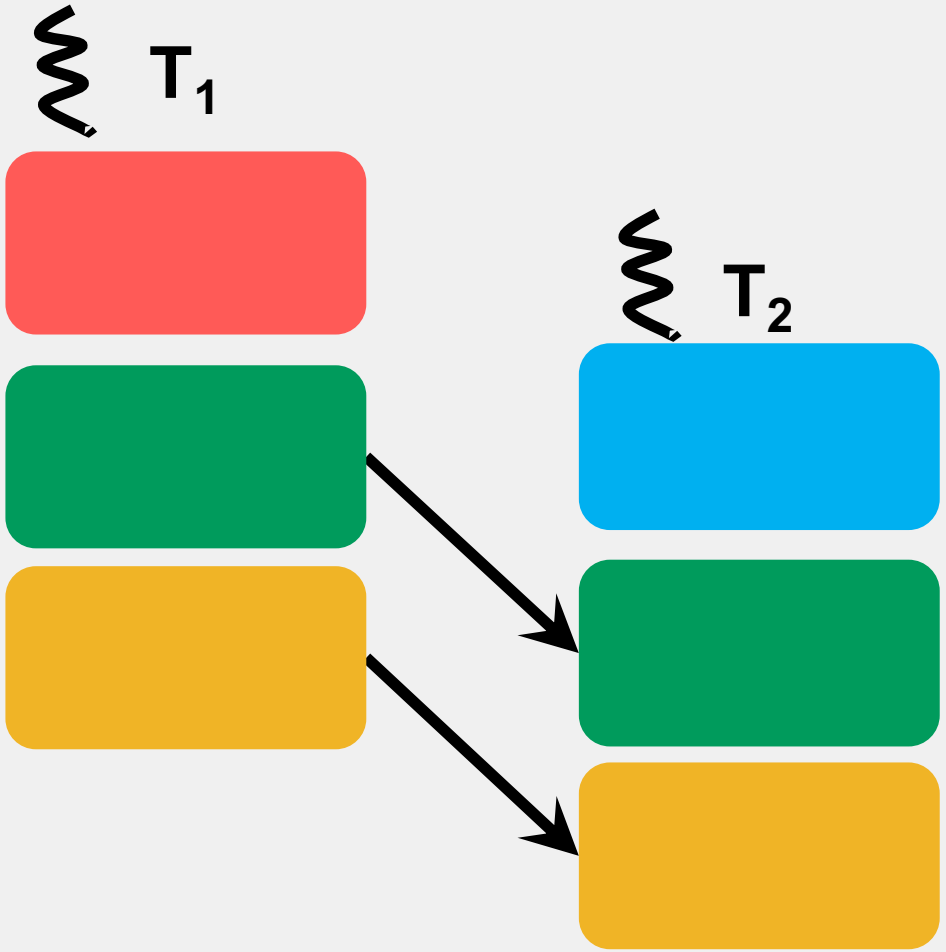
Locks released after statement finishes executing

Short-duration locks example

Dispatcher correctly determines dependencies prior to execution

No deadlocks

No logical aborts



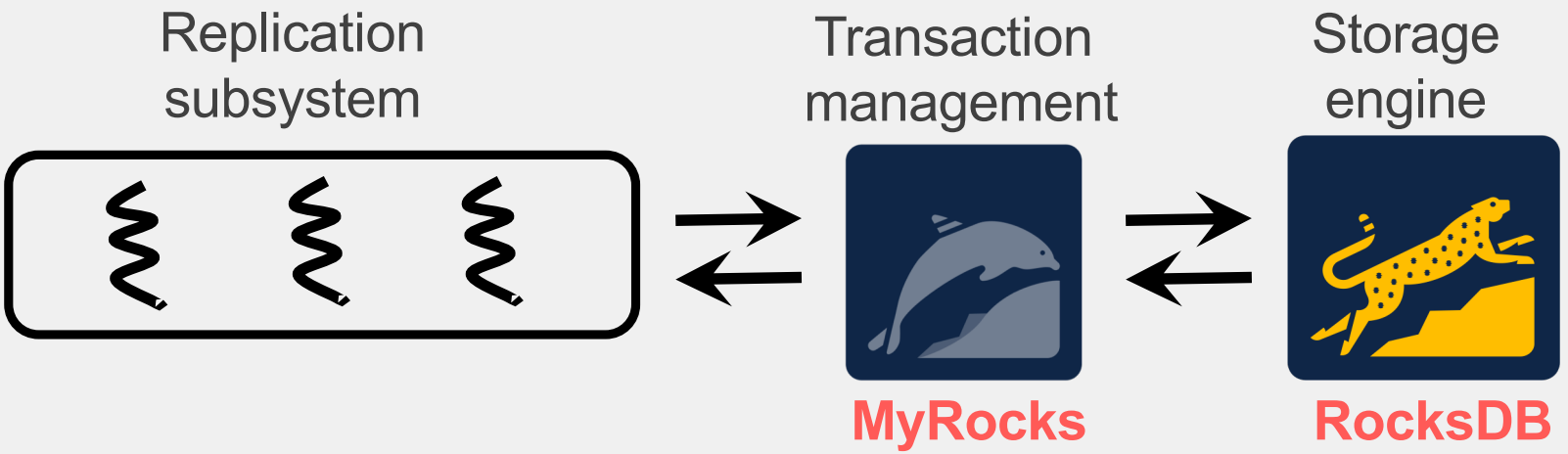
Issues with short-duration locks

Chain of uncommitted writes on each record

In addition to being uncommitted, each needs to be visible

Need help from storage engine

Compromise: Short-duration at replication subsystem, but long-duration within MyRocks



Requirements

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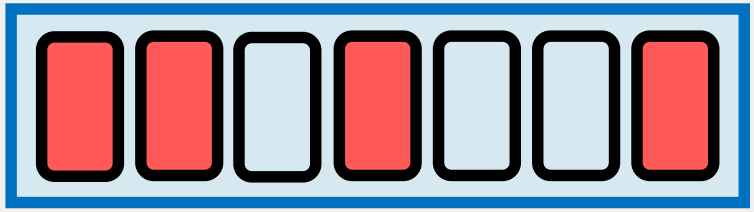
Reads must observe complete log prefix

Snapshot isolation for reads

Snapshot is a complete prefix of transaction log

No guarantee that committed transactions are complete prefix

Need a mechanism for correctly capturing snapshots



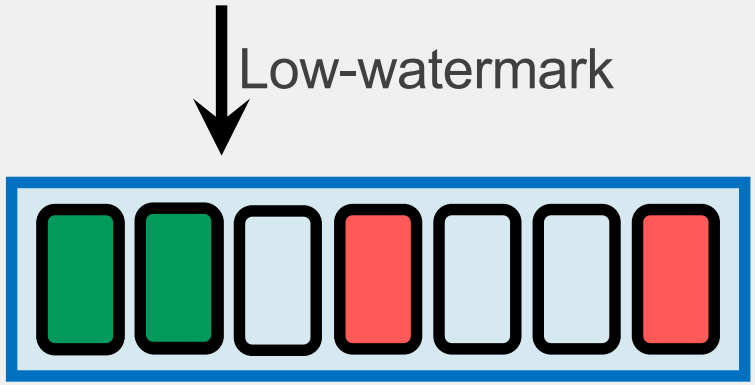
Snapshot strategy: Low-watermarks

No guarantee that committed transactions are complete prefix

But a subset of committed transactions forms a complete prefix

Maintain a low-watermark corresponding to this subset

Serve reads off this low-watermark



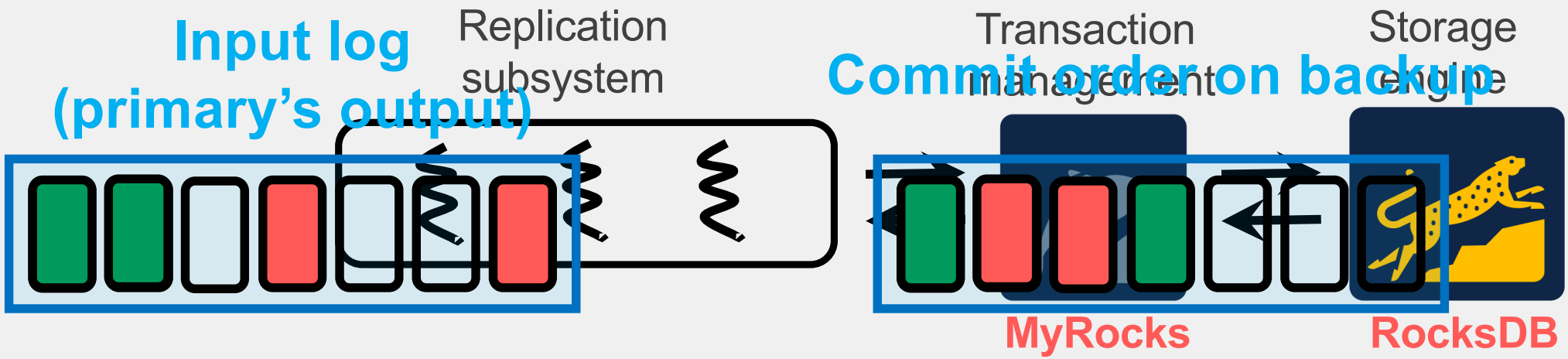
Issues with low-watermarks

Replication subsystem can’t pick timestamps

RocksDB does, and they are assigned when transactions commit

Backup timestamps don’t match those on the primary

Transactions might commit in different order

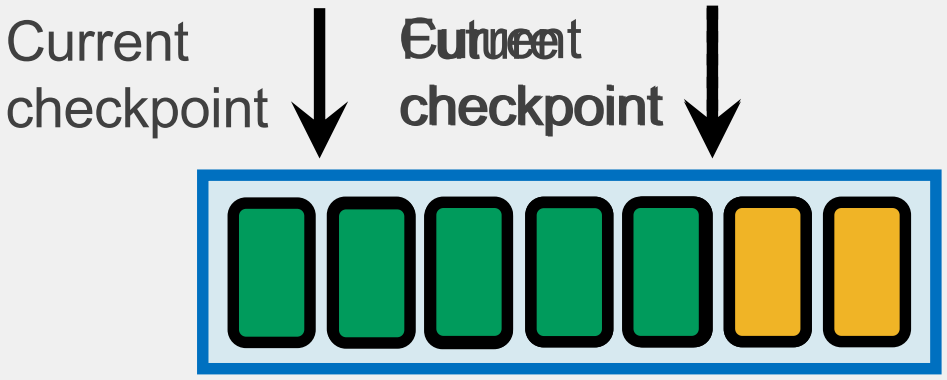


Snapshot strategy: Asynchronous checkpointing

Pick a future point in the log at which to checkpoint

Allow transactions before that point to commit

Allow transactions after that point to execute, but not commit



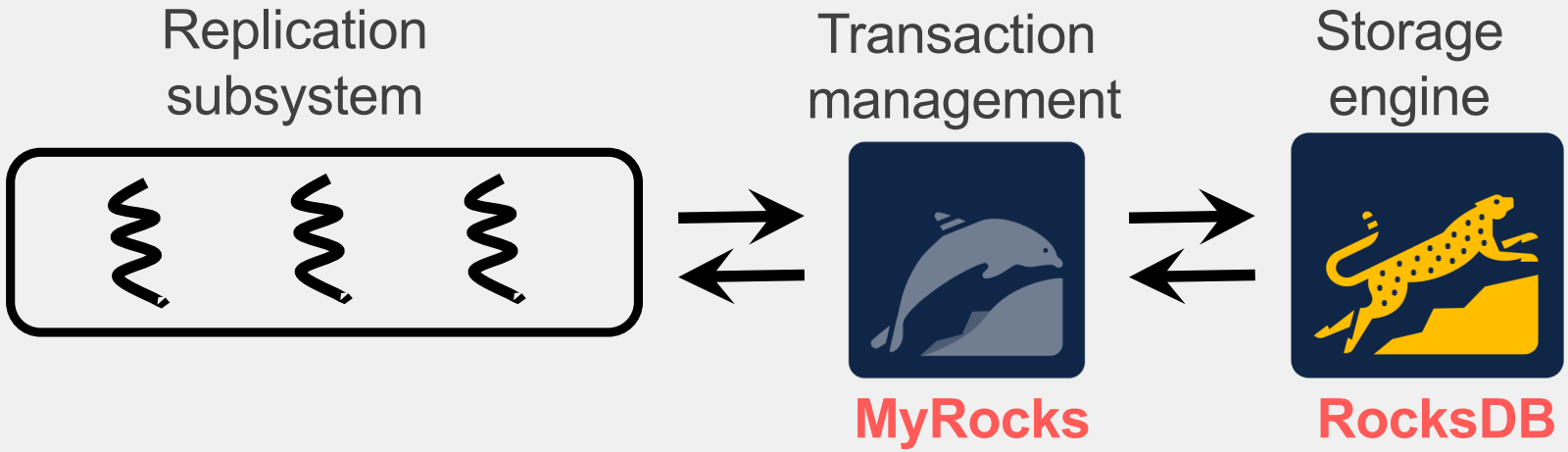
We implemented asynchronous checkpointing (with some difficulty)

Transactions not in the checkpoint execute but don't commit

Implicitly assumes that cost of execution >> cost of commit

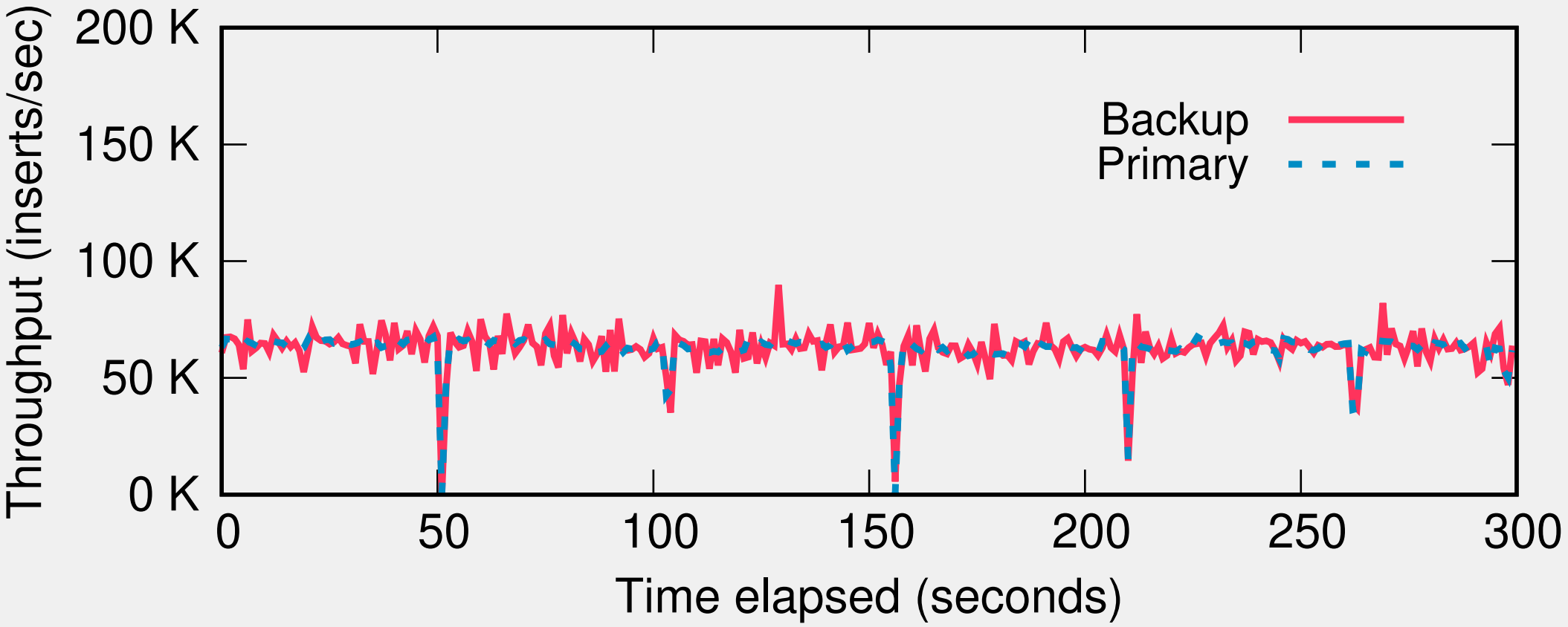
This was not always true of RocksDB… but thankfully true when we got to work

Issue with uncommitted chains of writes

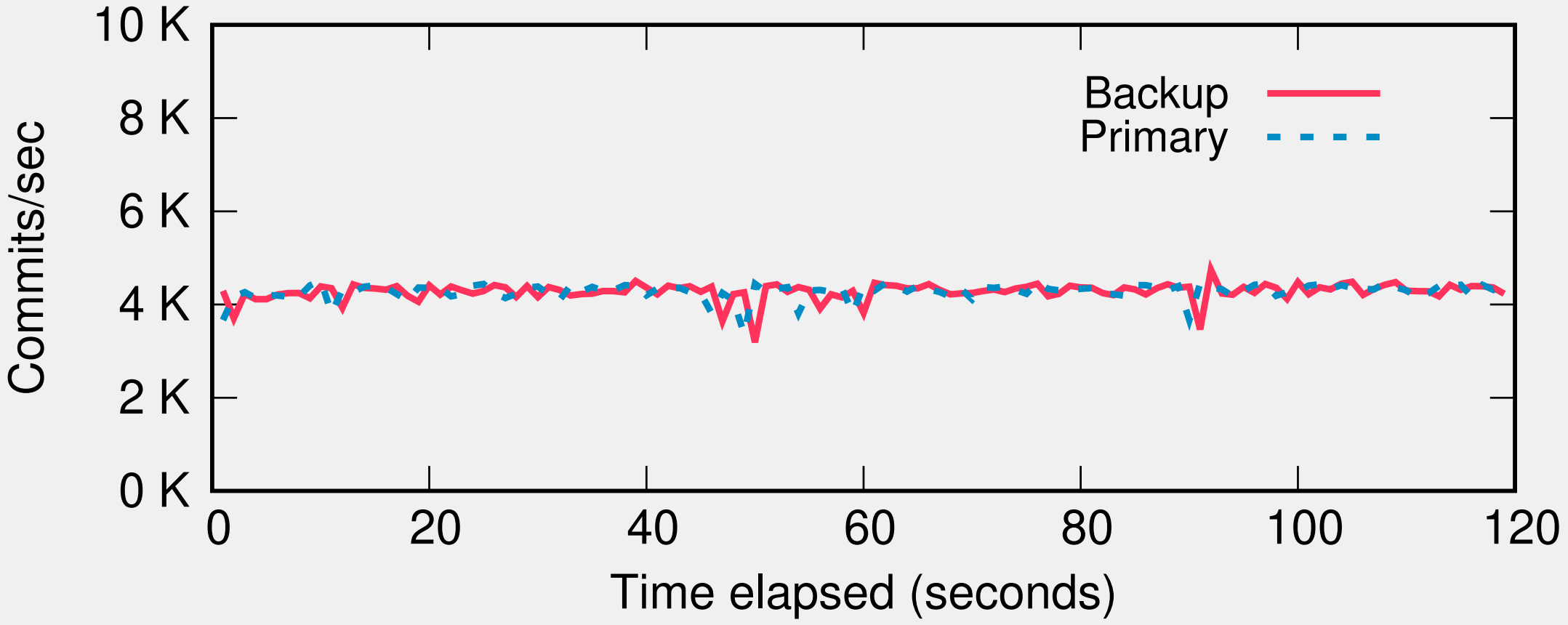


Performance

Point inserts



TPC-C NewOrder



Lessons / Random stuff

Replication must be a first-class citizen of any design

… if not, you're entering a world of pain

Building modular high-performance systems is very tricky

But worth it, code is easier to work with and evolve

Doesn't work with InnoDB due to implicit gap locking, which can deadlock

Higher levels of stack now complain that replication is too fast

Conclusions

Replication lag can be a serious emergent issue

Impact on operations, availability, user experience

Parallel replication subsystem for MySQL

Parallel log playback + snapshot isolation reads

Deployed at Facebook

Be prepared for lag despite best efforts

Lag detection mechanisms

Log archiving

Q&A

jmf@microsoft.com
Github: facebook/mysql-5.6