Obladi: Oblivious Serializable Transactions in the Cloud

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This talk

Obladi

a cloud-based **transactional key-value store**

that supports **ACID transactions**

but **hides** from the cloud **what, when, and how** data is accessed

Why Obladi – Cloud Privacy Concerns

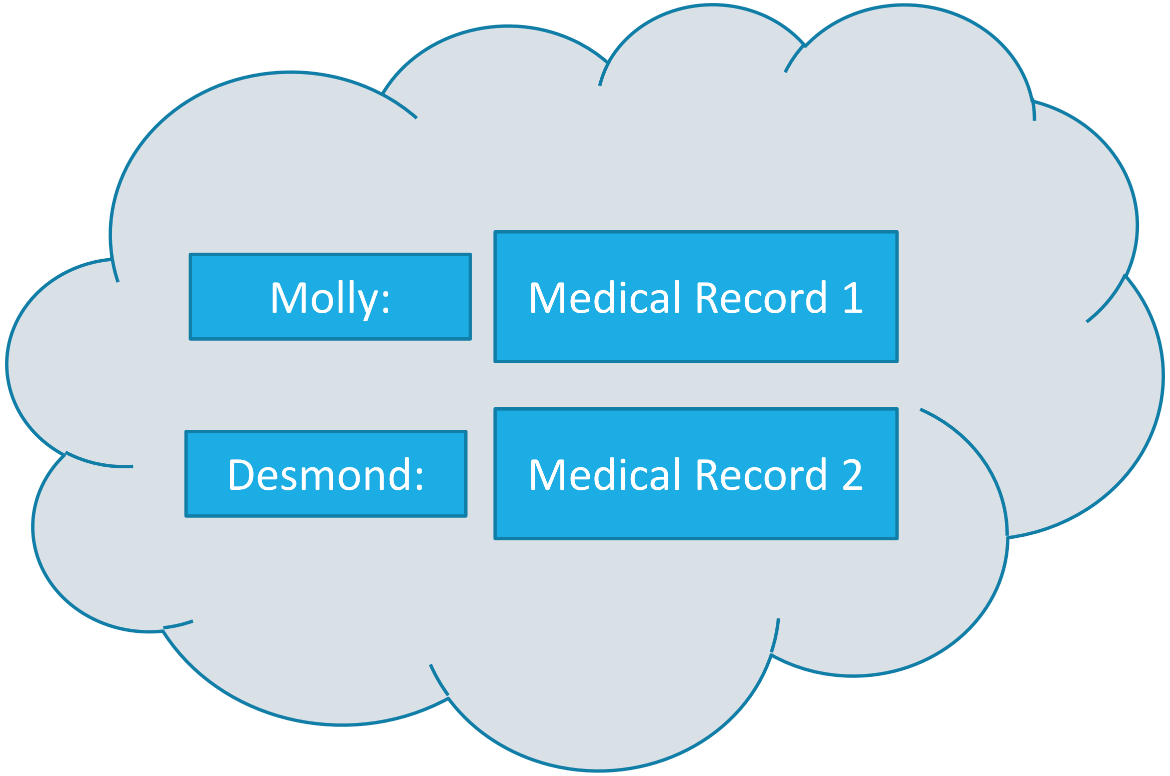
Applications are moving to the cloud

Applications store sensitive information

Cloud storage means sharing data with an untrusted party

Cloud services can be the target of hacking, subpoena

Protecting sensitive information



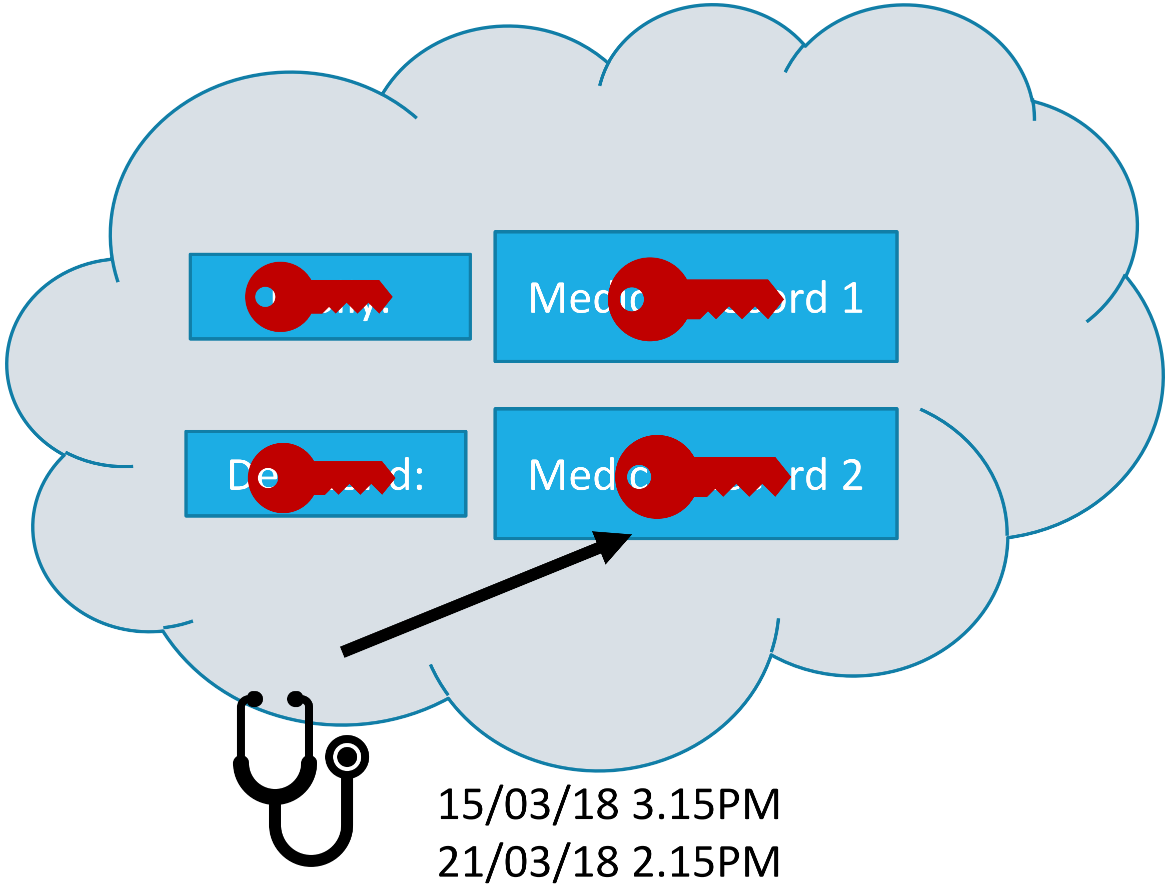
Electronic Health Record (EHR) systems

- store/manage patient data
- underpin large hospitals

openEMR CLOUD

powered by aws

Protecting sensitive information



Use encryption to hide **contents** of the data

Still leaking information about **what** data is being accessed

Still leaking information about **when** data is being accessed

Guaranteeing *obliviousness*

Hiding
access patterns
(*obliviousness*)

➡

what data is being accessed

when data is being accessed

how data is being accessed

How to maintain functionality?

Large body of work on analytical queries

but no way to run ACID transactions obliviously

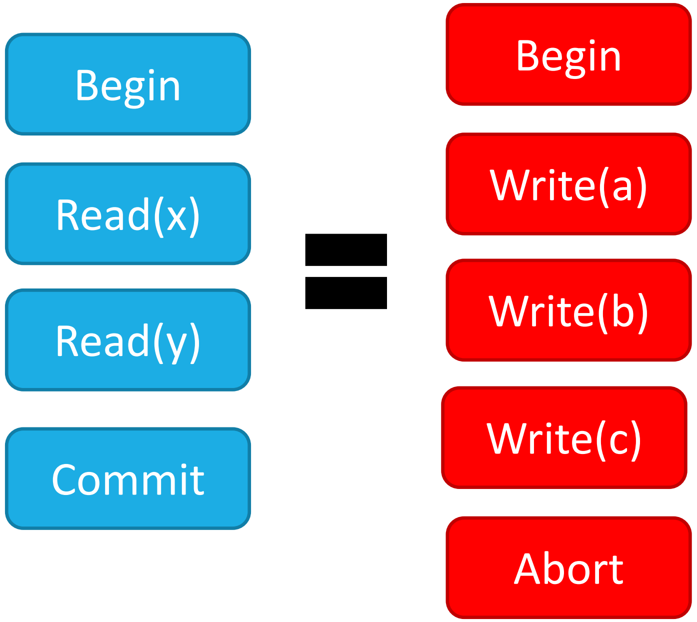
This talk:

How to obliviously and efficiently implement serializable ACID transactions on top of untrusted cloud storage

Security Guarantees

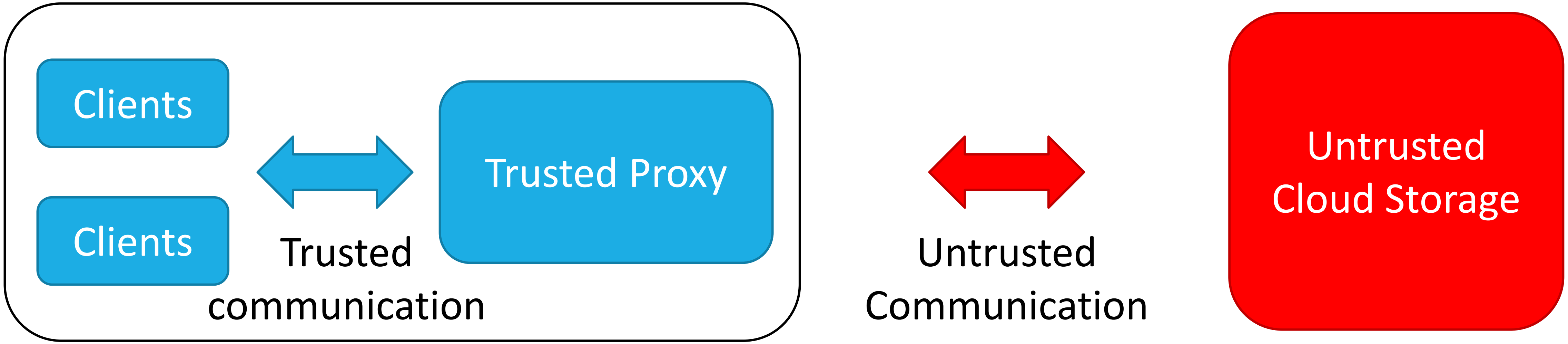
The adversary should learn no information about

1. the **data accessed** by ongoing transactions
2. the **type of operations** in ongoing transactions
3. the **size** of ongoing transactions
4. the **outcome** of ongoing transactions



Threat Model

Obladi adopts the **trusted proxy model**

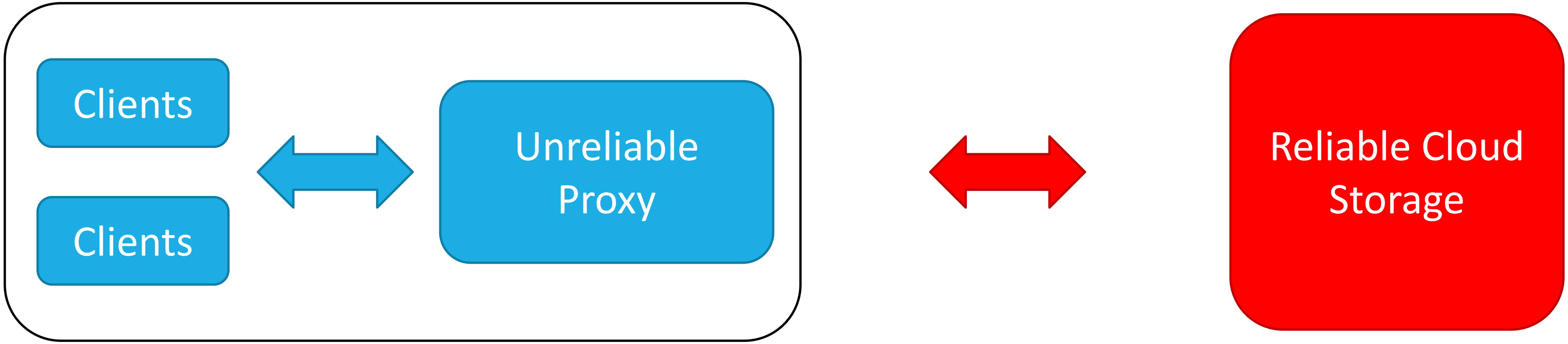


Doctors communicating over hospital LAN

Cloud storage (Dynamo,S3, etc.) accessed over WAN

Failure Model

Obladi assumes clients and proxy can fail



But that cloud storage is reliable

Obladi's security in a nutshell

Workload Independence

Obladi ensures that the request pattern sent to the untrusted cloud is independent of ongoing transactions

The paradox of transactions

Transactions make guaranteeing obliviousness **harder**

Isolation and durability
add structure
to read/write operations

Transactions make improving efficiency **easier**

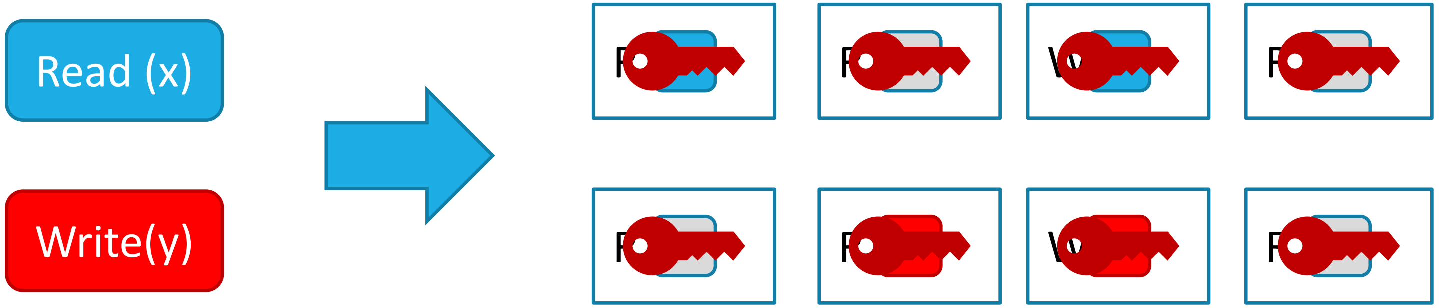
ACID must hold
at commit time
only

Oblivious RAM [Goldreich1996]

Obladi builds on **Oblivious RAM (ORAM)**

ORAM hides access patterns for read and write operations by making requests to untrusted storage independent of workload

ORAM from 1000 feet



Generate physical read/write requests from logical operations

Send requests to (encrypted) dummy data to hide what is being requested

Challenges of Transactional ORAM

ORAM guarantees workload independence for read/write operations.

How can we preserve workload independence but also

1) Guarantee **I**solation and **A**tomicity? — *No concurrency control*

2) Guarantee **C**onsistency and **D**urability? — *Write-back ordering for security vs for durability*

3) Guarantee good performance? — *Limited Concurrency*

Delayed Visibility

Obladi centers its design around the notion of

delayed visibility

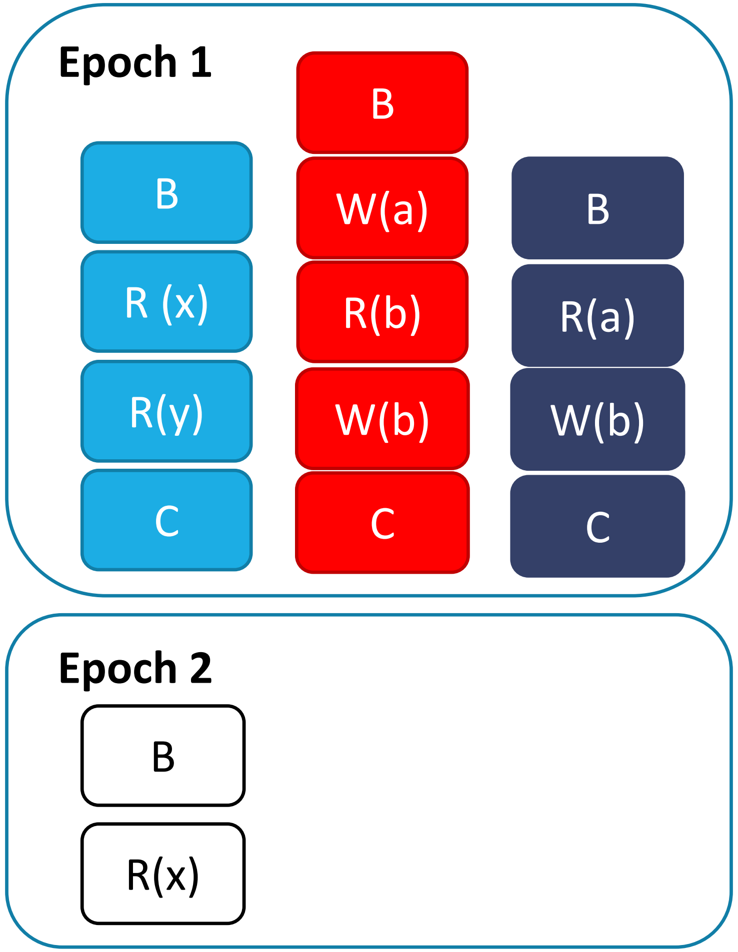
On the one hand, ACID guarantees apply only when transactions commit

On the other, commit operations can be delayed

The secret sauce: epochs

Obladi uses delayed visibility to partition transaction into fixed-sized epochs

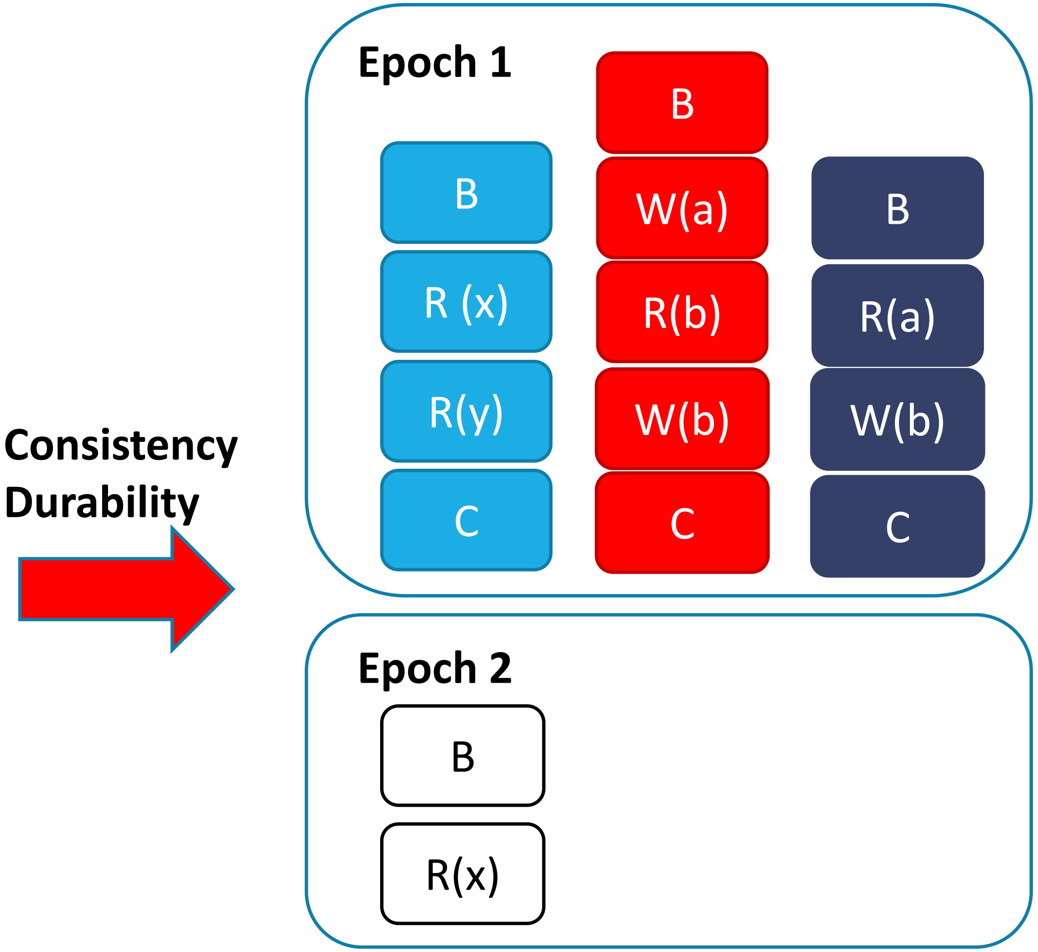
Delays commit notifications until the epoch ends



The secret sauce: epochs

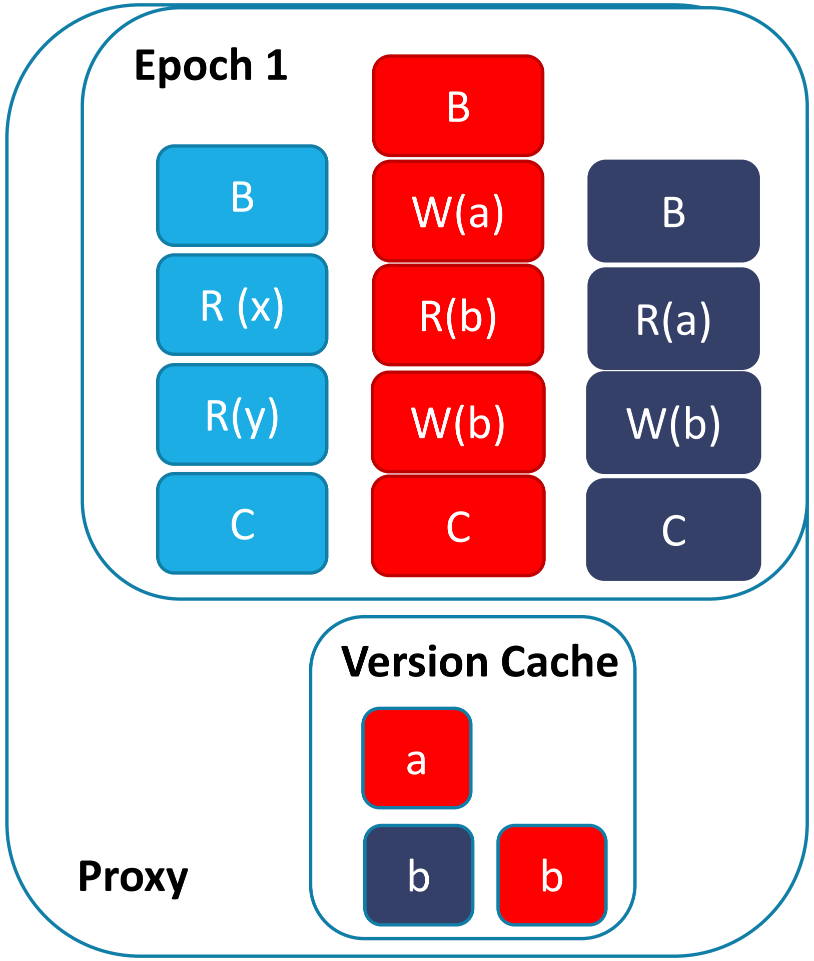
ACID guarantees only hold for committed transactions

Enforce durability and consistency at epoch boundaries only



The secret sauce: epochs

Within an epoch, Obladi executes transactions at the trusted proxy, buffering writes until epoch ends



The secret sauce: epochs

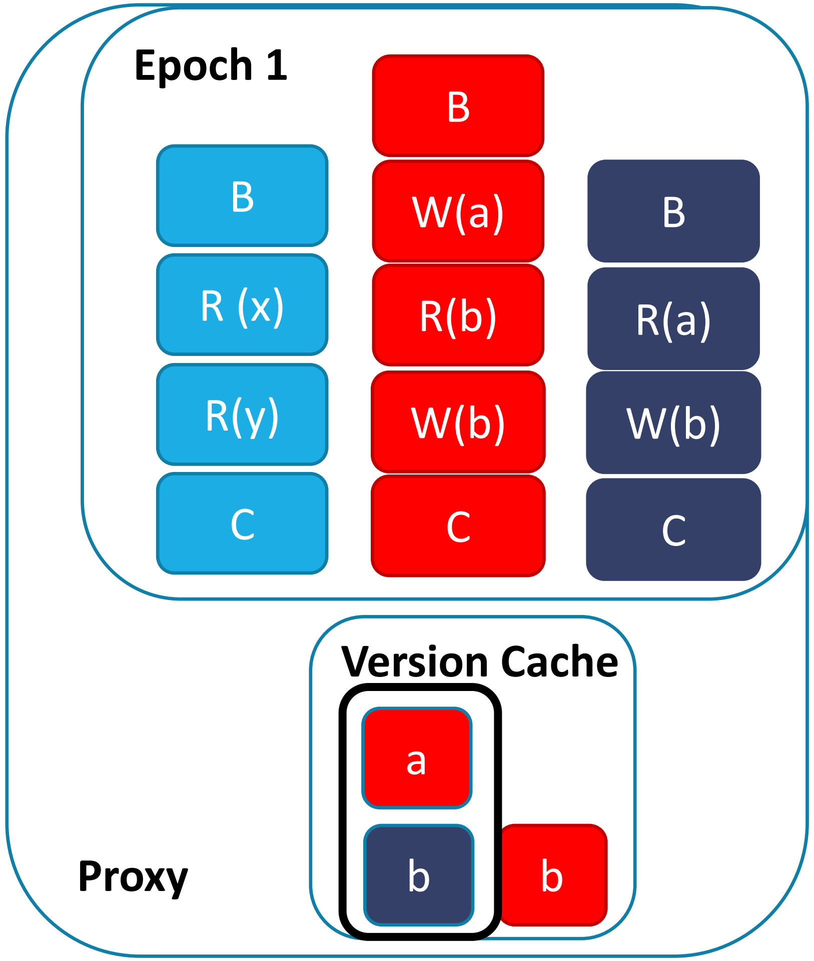
Delayed visibility improves performance

1. Reduces number of requests sent to ORAM

   Only write the last version of every key

2. Implement multi-versioned concurrency control algorithm on top of single-versioned ORAM

   Better support for read-only transactions

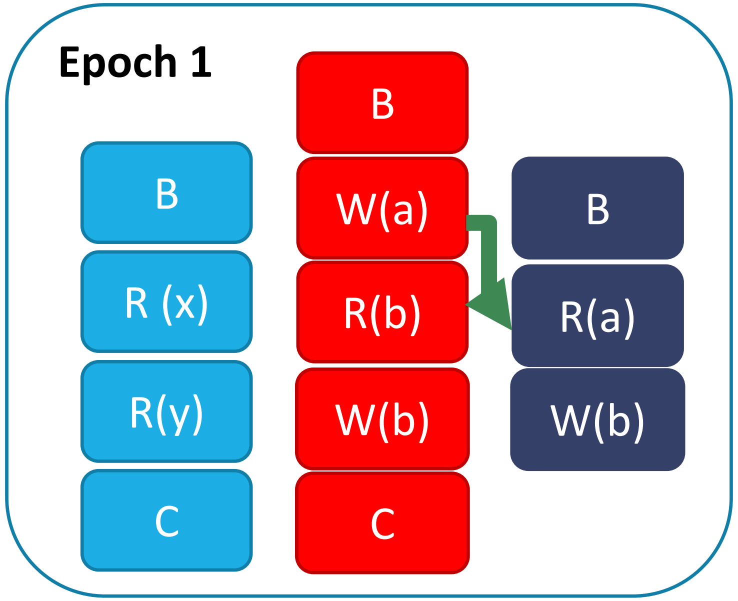


The secret sauce: epochs

Delayed visibility should not increase contention

Should allow transactions in the same epoch to see each other's effects

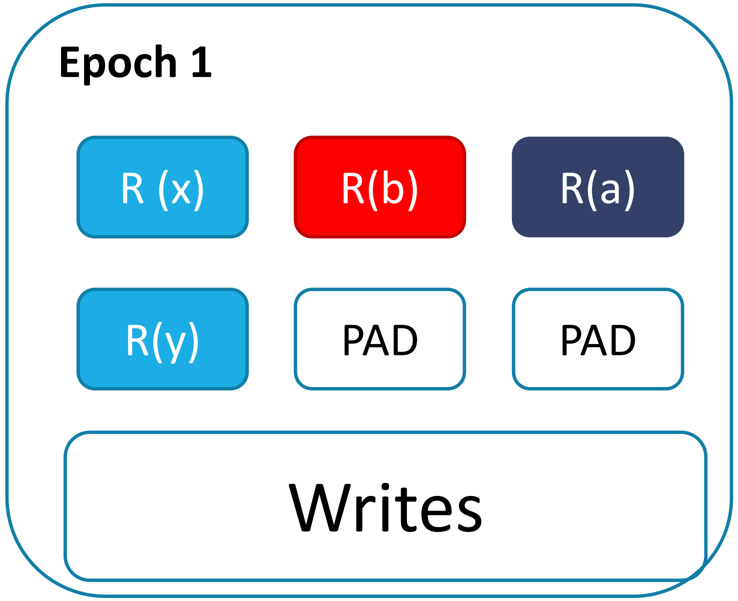
Obladi chooses a concurrency control that optimistically exposes uncommitted writes to ongoing transactions



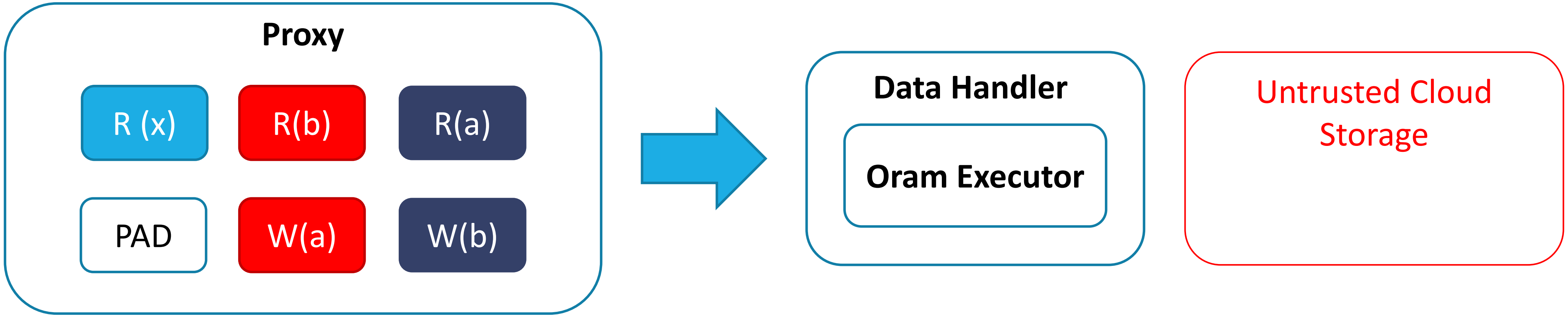
The secret sauce: epochs

The fixed structure of epochs helps guarantee **workload independence.**

ORAM observes the **same sequence** of reads followed by the buffered writes



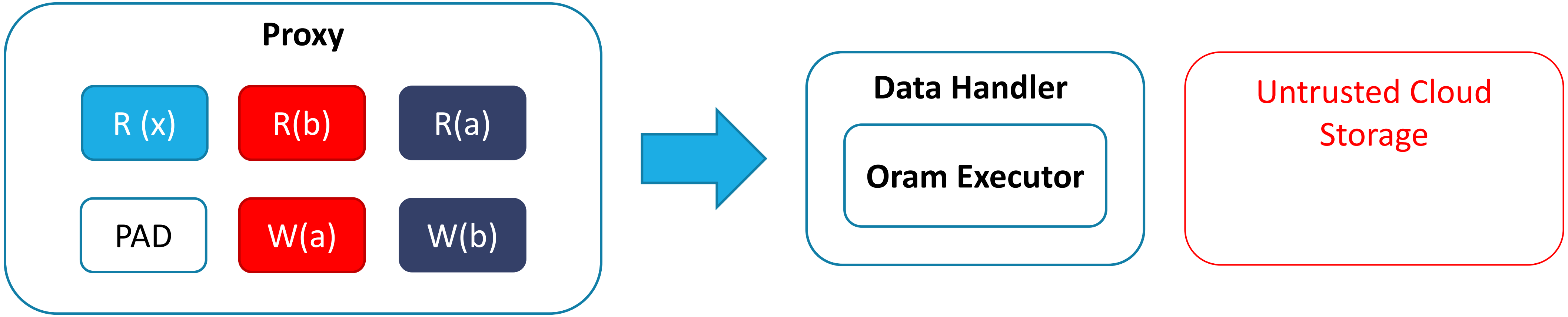
How to guarantee good performance?



Send batches of requests to ORAM

But ORAM constructions are largely sequential

Parallelising ORAM

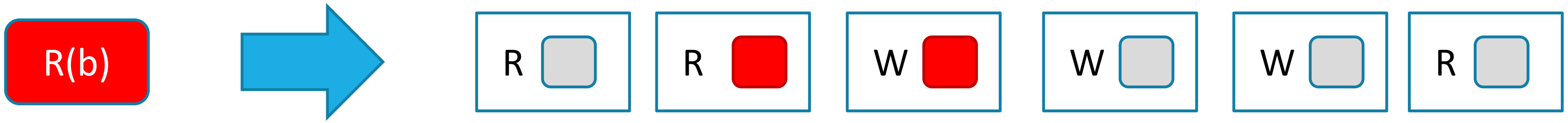


How can we parallelise ORAM?

For correctness: parallelization should be linearizable

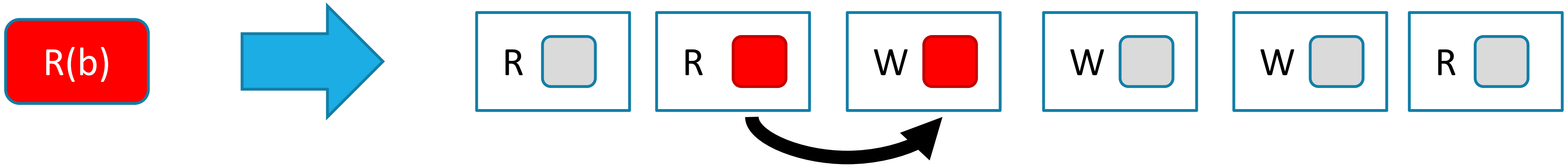
For security: parallelization should be workload independent

Parallelising ORAM



Recall: breakdown logical operations into physical read/writes to cloud storage

Guaranteeing linearizability

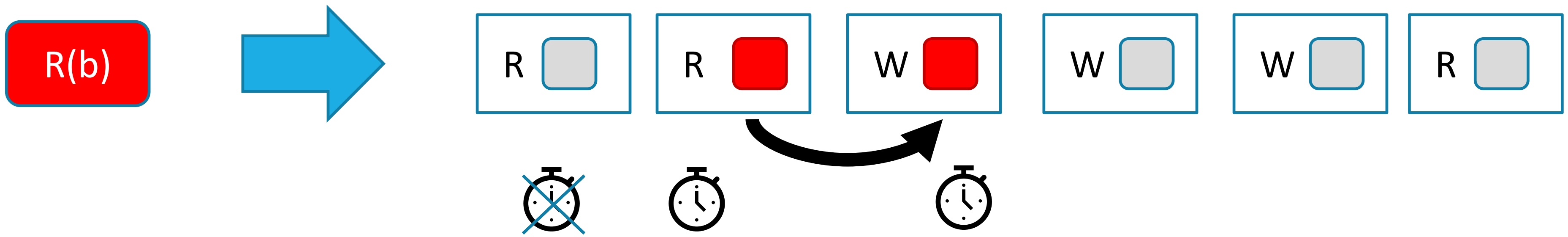


To ensure linearizability

Execute operations that do not have **data dependencies** in parallel

Data-dependent operations must be executed sequentially

Dependencies violate independence

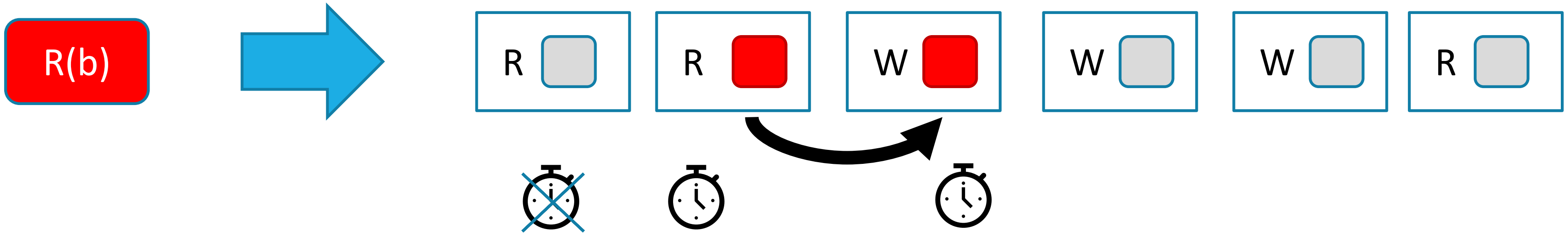


Wait for data dependencies to be satisfied introduces timing channels

Only exist between real objects, not dummies

Delaying reads for real objects causes delay, dummy objects don't

Introduces side-channel

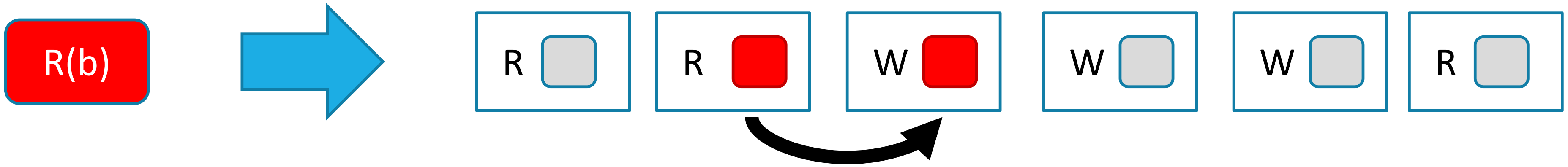


Must wait for all potential data dependencies

Can exist between any pairs of reads and writes

➡ Never secure to execute reads and writes in parallel

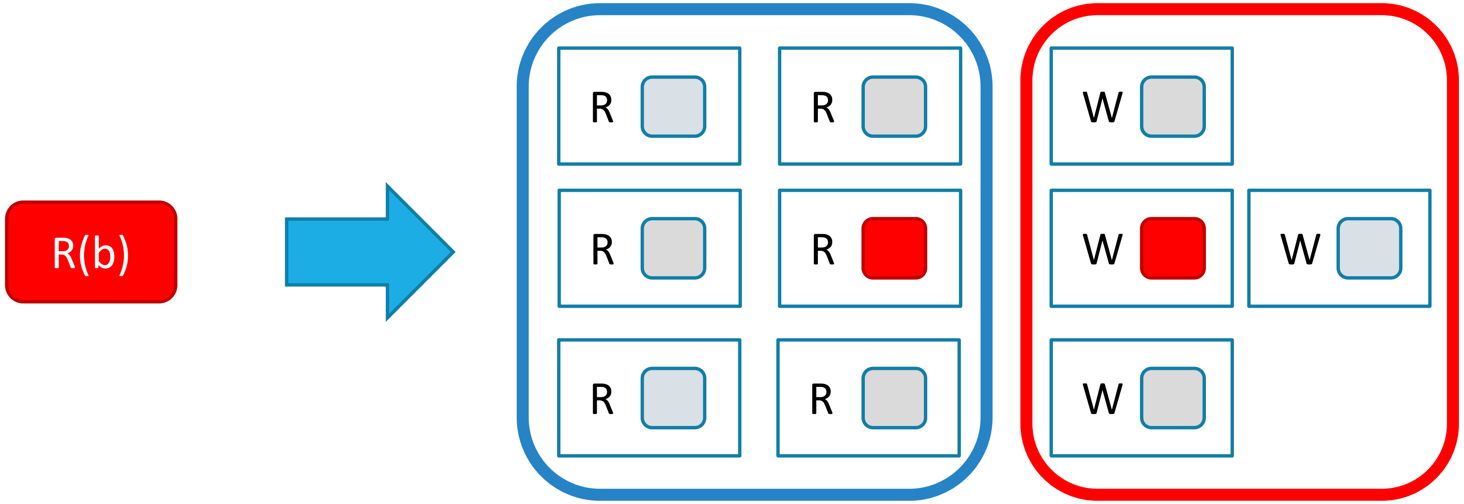
Delayed visibility to the rescue



Delayed visibility allows ORAM to be consistent at epoch boundaries only

→ Writes can be safely delayed to epoch end

Delayed visibility to the rescue

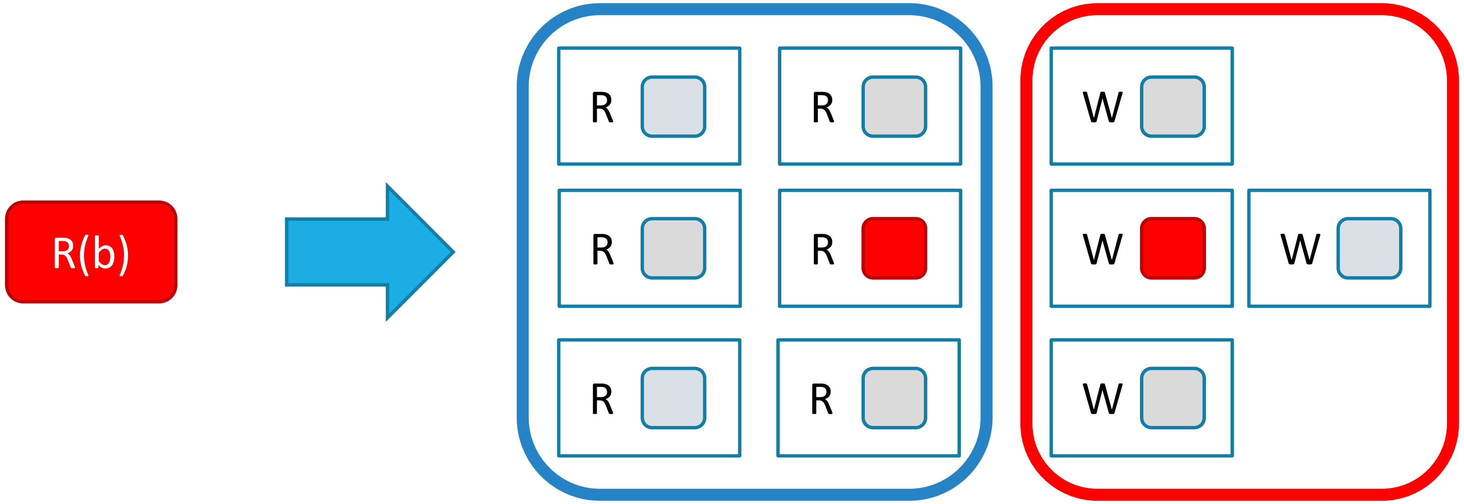


Separate ORAM execution into a read phase and a write phase

Read Phase: reads all necessary blocks

Write Phase: writes all necessary blocks

Delayed visibility to the rescue



Executing each phase in turn obscures data dependencies

Still allows high concurrency

How to guarantee durability?

Must ensure recovery to a consistent state

No partially executed transactions are included

Traditionally achieved through **redo/undo logging**

For consistency: pretend partial transactions never happened

For security: cannot “undo” what the adversary observed

May lead to access sequences that violate workload independence

More details in the paper

Durability and recovery logic details

Additional optimisations for performance

Discussion of our chosen ORAM construction: RingORAM [Ren15]

Formal proof of security

Evaluation

Applications

TPC-C

(10 Warehouses)

SmallBank

(1 million records)

FreeHealth

(7000 patients, 10 hospitals)

Baselines

Obladi

(Our system)

NoPriv Baseline

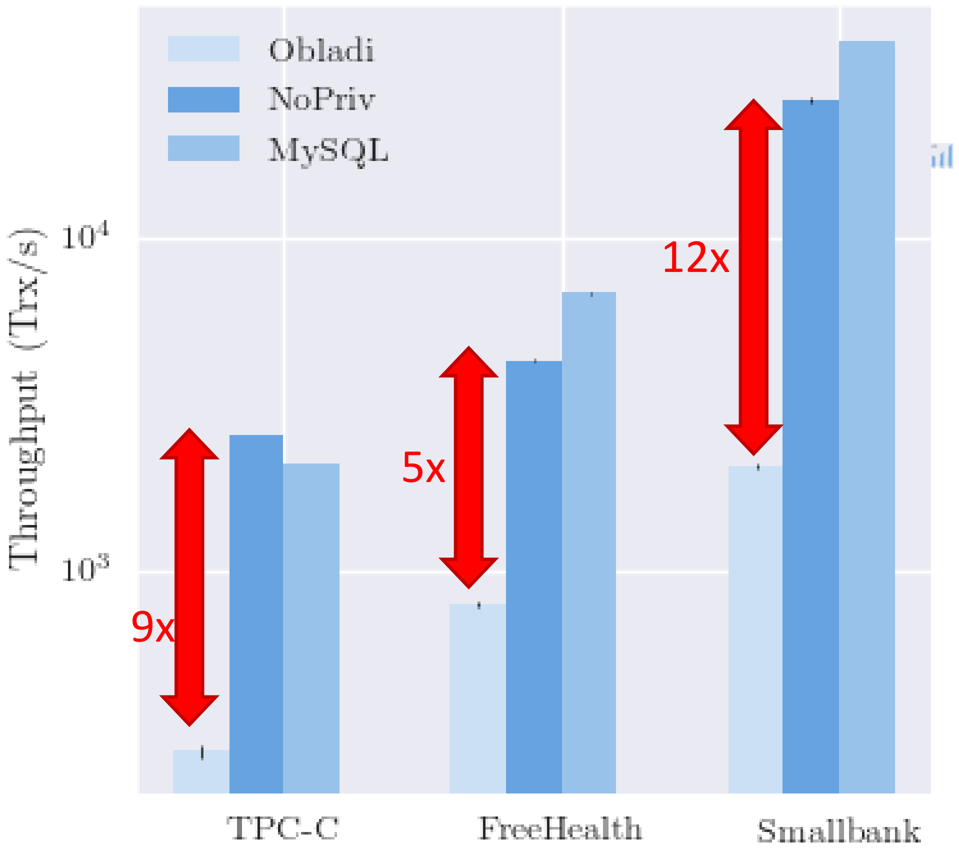
(Shares concurrency logic with Obladi)

MySQL 5.7 InnoDB Baseline

(Server co-located with clients)

c5.4xlarge AWS instances. 10 ms latency between proxy and storage

Performance Results: The Good

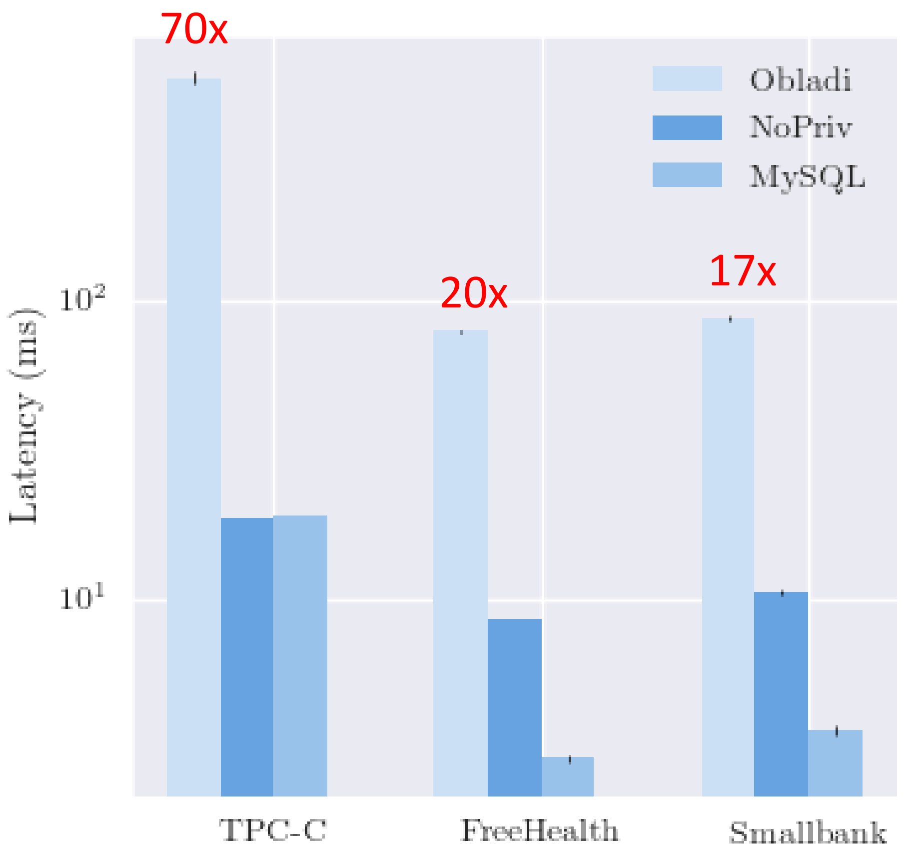


Obladi is slow, but not too slow

Between 5x and 9x lower throughput for contention-bottlenecked TPC-C and FreeHealth

12x lower throughput for resource-bottlenecked SmallBank

Performance Results: The Bad

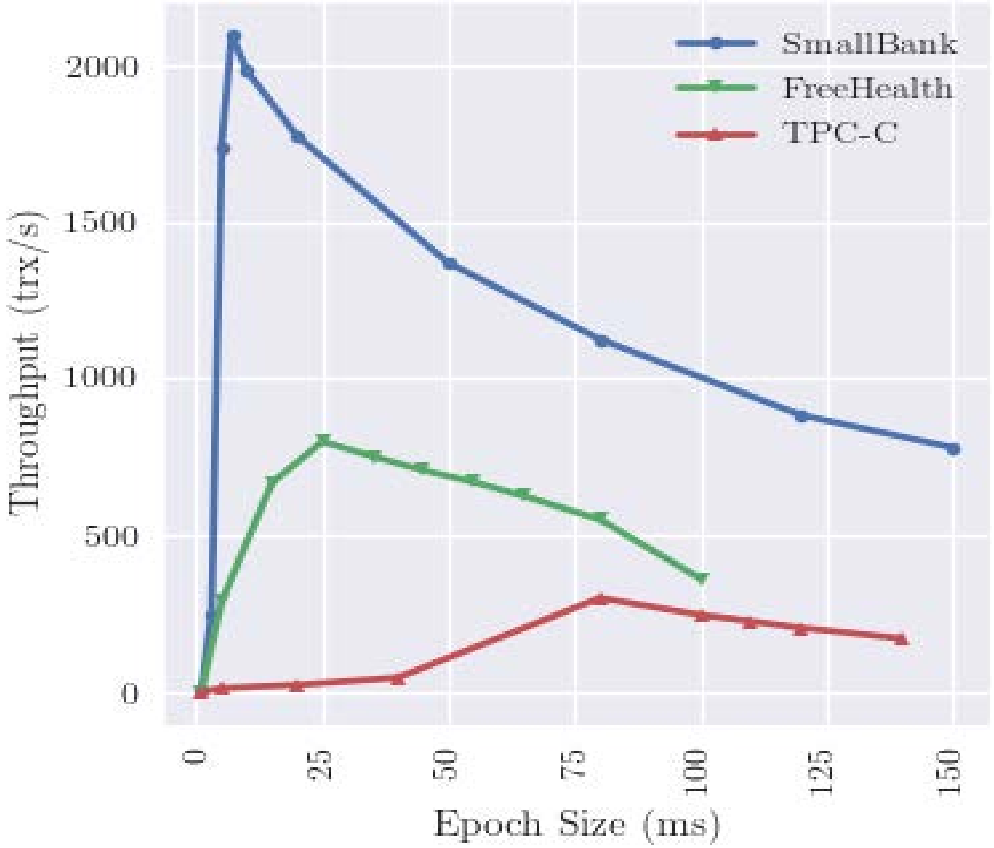


Batching significantly increases latency

Up to 70x on TPC-C

Better on other applications because of smaller write batches

Performance Results: The Ugly

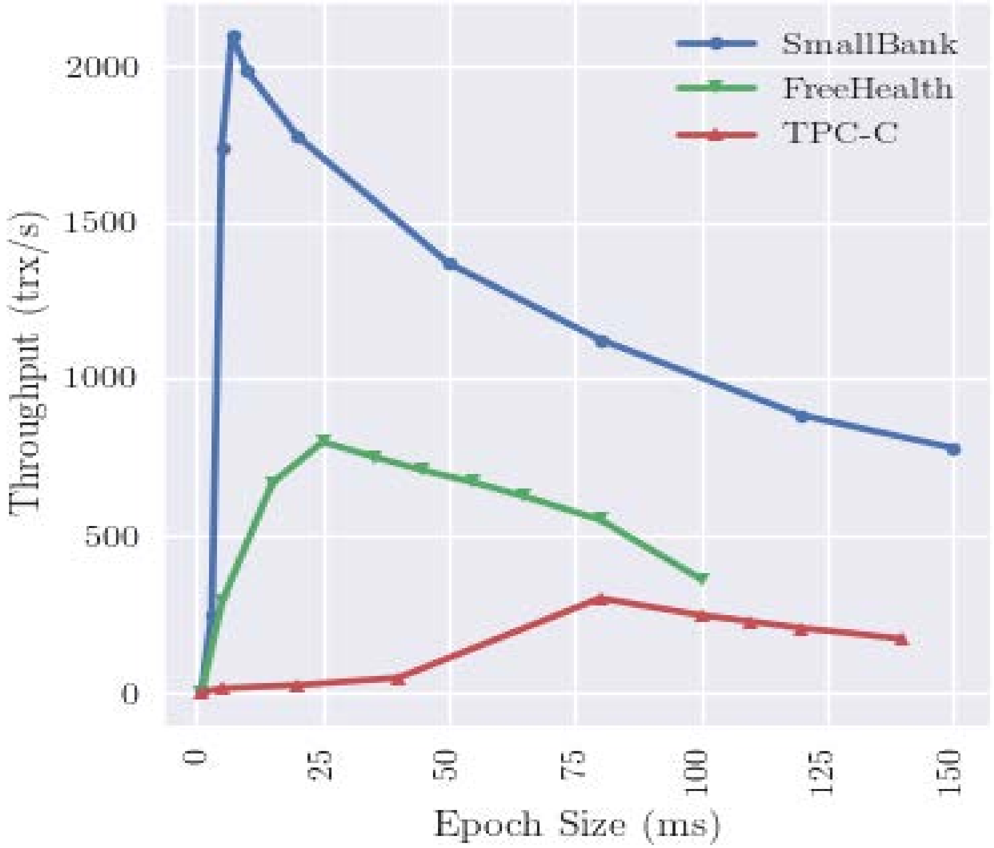


Performance is sensitive to good tuning of epoch size

If too low, transactions cannot finish

If too high, idle time

Performance Results: The Ugly



Performance is sensitive to good tuning of epoch size

If too low, transactions cannot finish

If too high, idle time

May reveal type of application!

Conclusion

Obladi, a cloud-based transactional key-value store

that **obliviously** supports **ACID transactions** using **delayed visibility**

Any questions?

Backup