TaoStore
Overcoming Asynchronicity in Oblivious Data Storage

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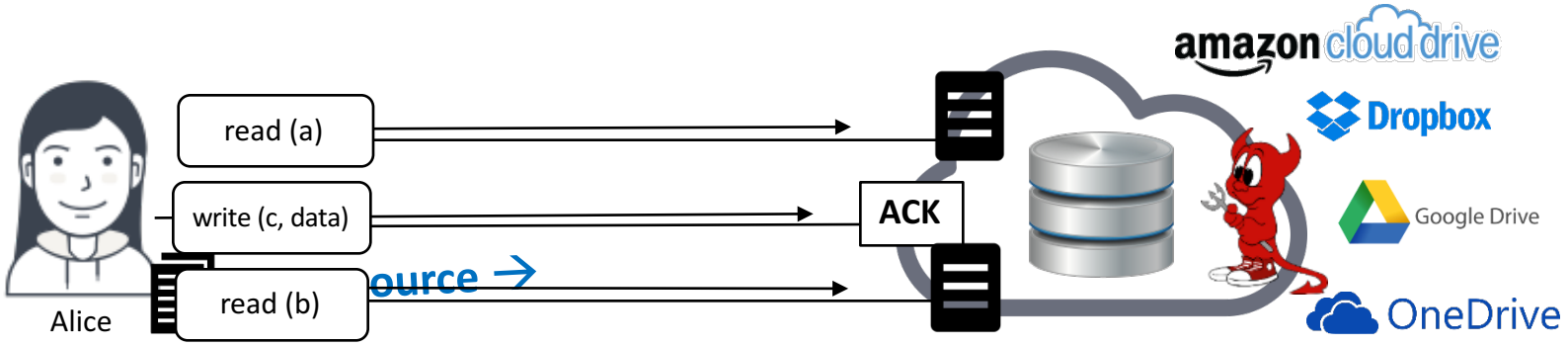
Outsourced Private Data



Security Concerns?

Confidentiality of Data

Encryption

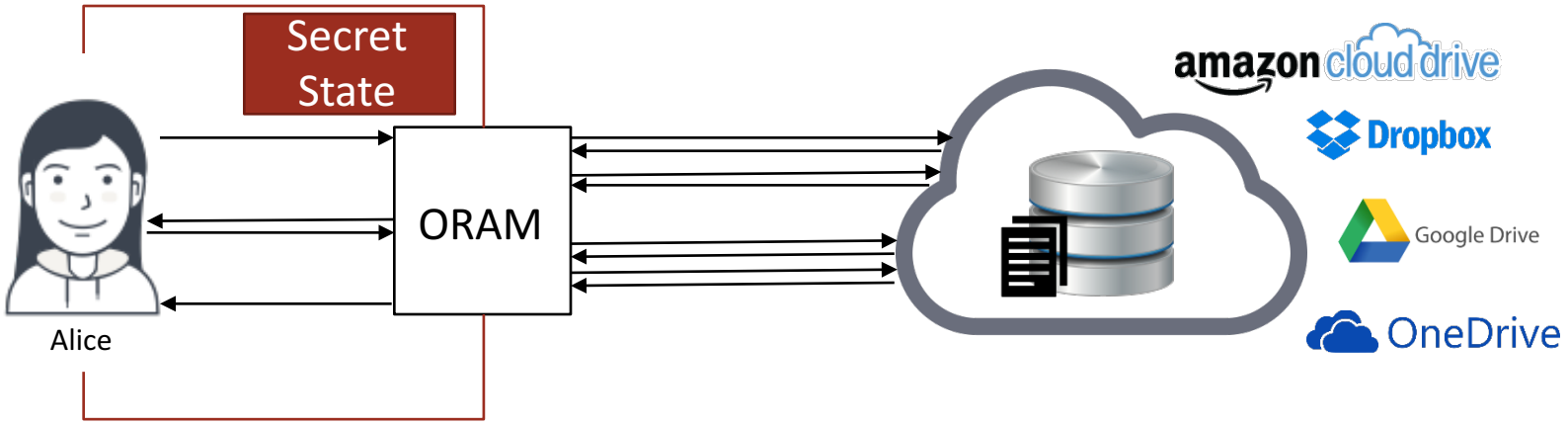
Is encryption enough?

Encryption alone is not enough!!!

Access patterns can leak sensitive information
[Islam et al. NDSS'12]

read(1), read(1) vs read(1), write(3)

Outsourced Private Data



Goal: Oblivious Access

Translate each logical access
to a sequence of random-looking accesses

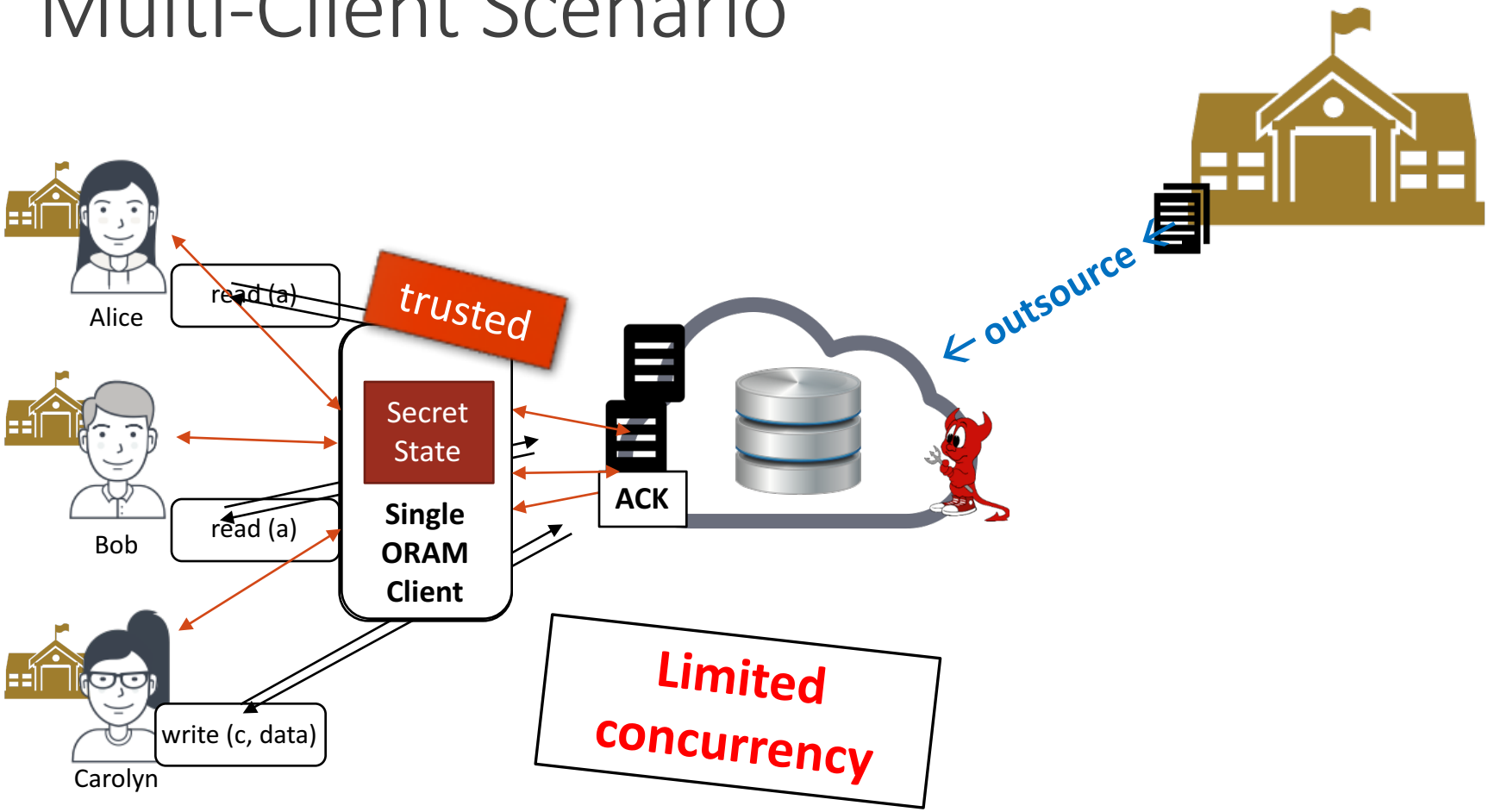
OBLIVIOUS RAM (ORAM)

Goldreich and Ostrovsky '96

More practical solutions: MG'11, DB'11, ES'11, EK'12, ES'12, PW'12, ES'13, CG'13, KC'13, KC'14, LR'15, TM'15 , SD'16, …

Single client

Multi-Client Scenario



PrivateFS [Williams et al. CCS'12]

ObliviStore [Stefanov et al. Oakland'13]

CURIOUS [Bindschaedler et al. CCS'15]

Concurrency

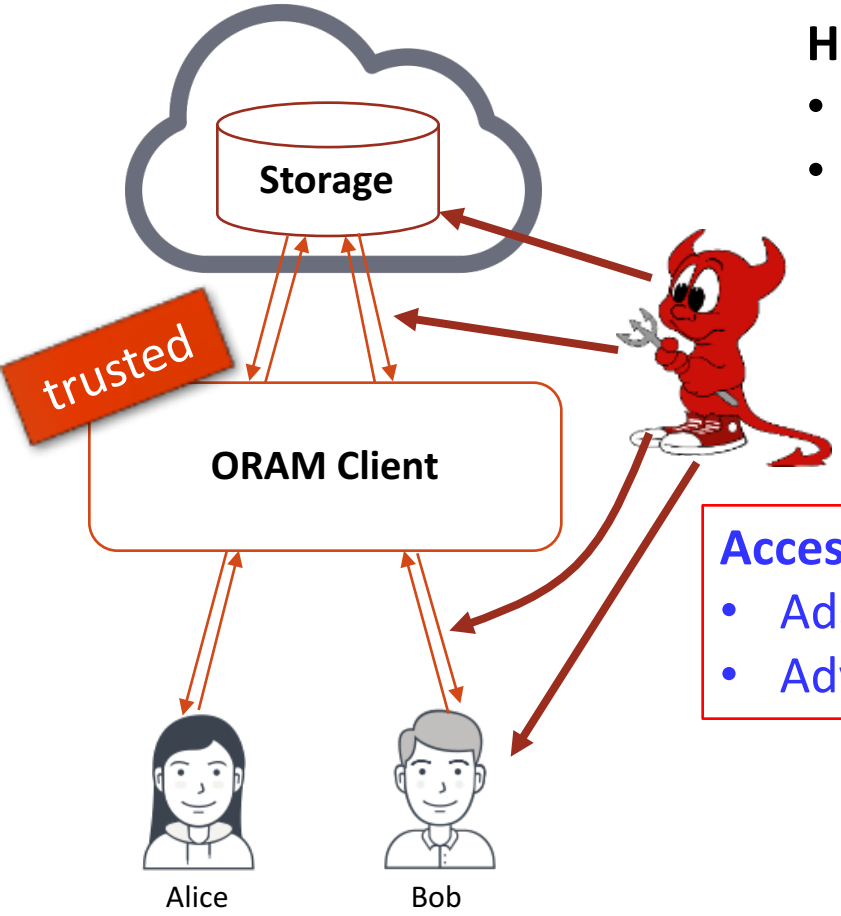
Asynchronicity

Contributions

A security model for asynchronous ORAM and attack

TaoStore: A new asynchronous and concurrent tree-based oblivious storage

Asynchronous ORAM – Threat Model



Honest-but-curious adversary

- Sees raw storage data
- Network communication

Asynchronous links

- Adversarially controlled schedule

Access operations

- Adaptively scheduled by adversary
- Adversary learns response timing

New

Important:

- Network Intruder
- Adaptive Scheduling
- Side Channel

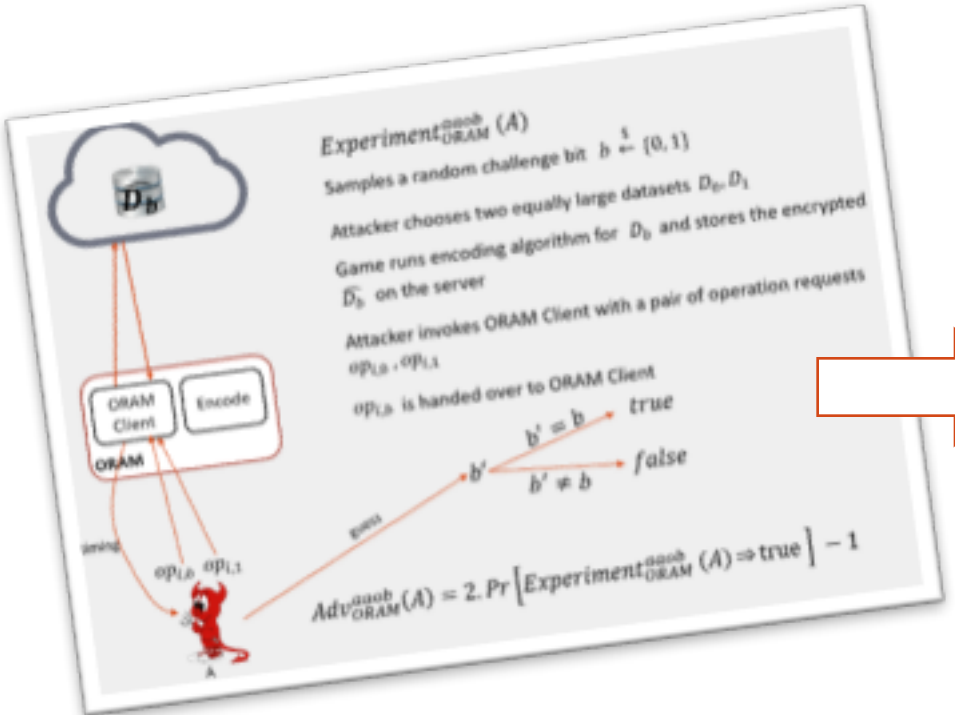
ObliviStore [Stefanov et al'13]
non-adaptive scheduling + no response time

Asynchronous ORAM - Security

We formalize obliviousness in this setting

Two timing-consistent executions should be indistinguishable in threat model

aaob-security: adaptive asynchronous obliviousness



Indistinguishability-based security definition.

See the paper!

Are existing systems aaob-secure?

ObliviStore is not secure [Bindschaedler et al.]

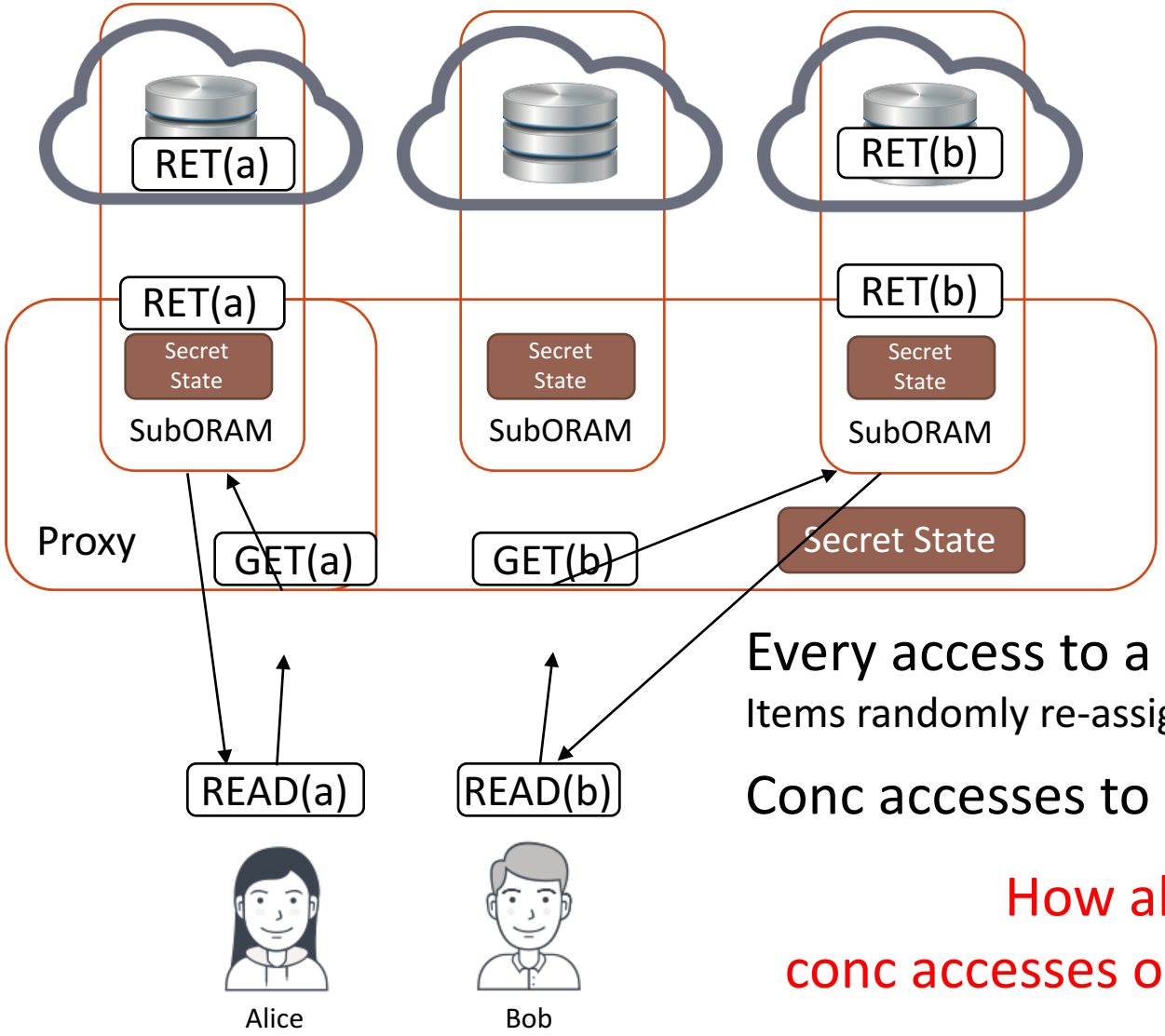
CURIOUS is secure in ObliviStore's threat model

We show

CURIOUS is not aaob-secure

Note: No claims are incorrect in CURIOUS

CURIOUS [Bindschaedler et al CCS'15]



Partition storage space

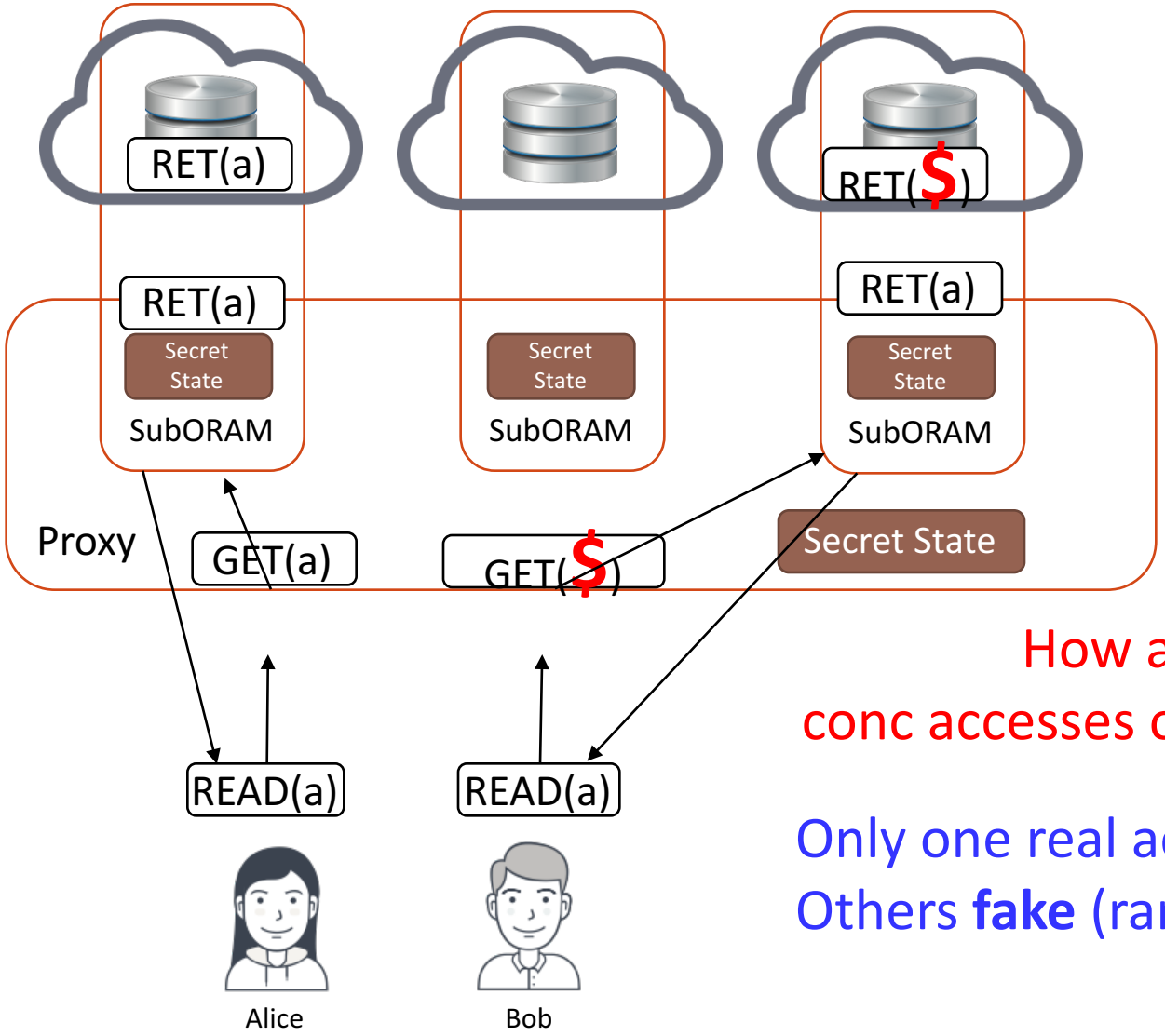
Every access to a random partition

Items randomly re-assigned after every access

Conc accesses to diff partitions

How about conc accesses on **same** item?

CURIOUS [Bindschaedler et al CCS'15]

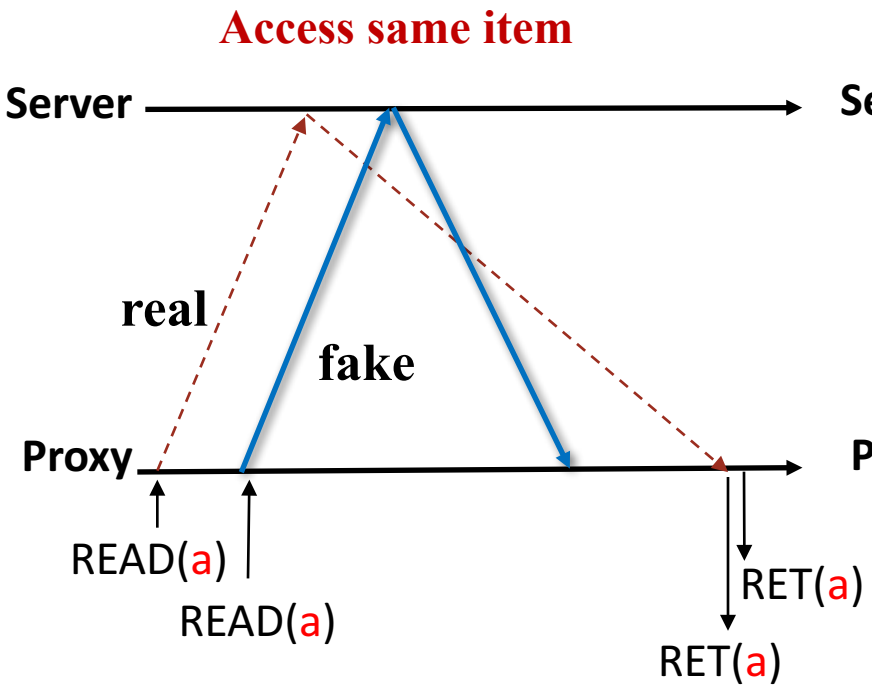


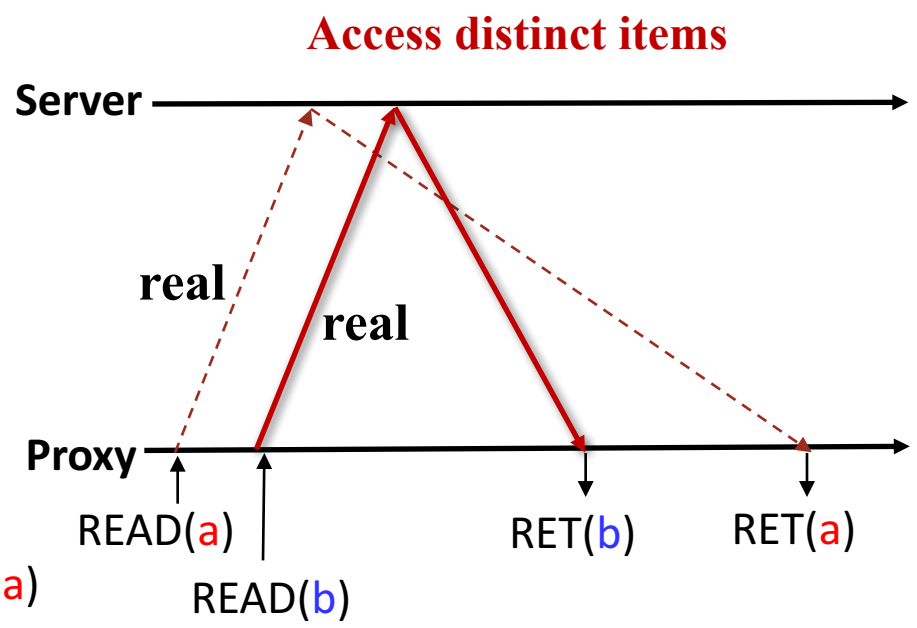
How about
conc accesses on **same** item?

Only one real access
Others **fake** (random) accesses

Attack Against CURIOUS

Reminder
Controls scheduling of messages + operations
Knows response timings





Attacker learns whether the accesses are on same item or not

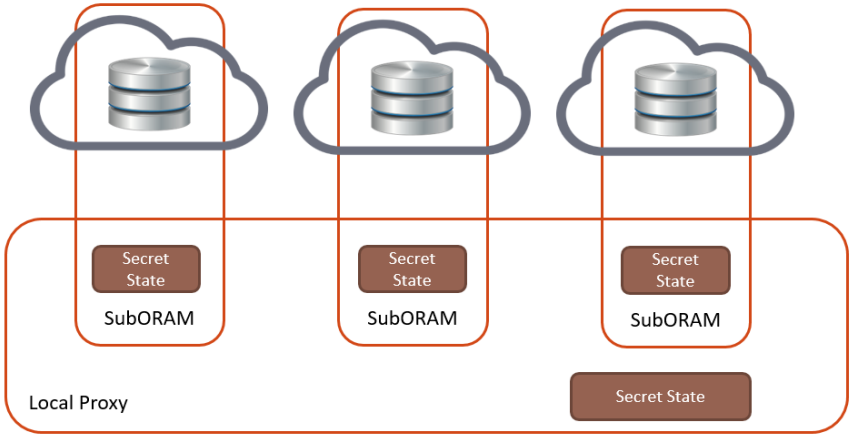
Fix? See later …

Contributions

A security model for asynchronous ORAM and attack

TaoStore: A new asynchronous and concurrent tree-based oblivious storage

CURIOUS: Modular, but two drawbacks



1. Security: Not aaob-secure

2. Efficiency: partitioning → concurrency
   (Underlying single-client ORAM not concurrent)

Wanted: Native concurrency!

Partitioning as simple add-on

Our solution – TaoStore

Tree-Based Asynchronous Oblivious Store

aaob-secure

Atomic semantics

Simple

Fully concurrent

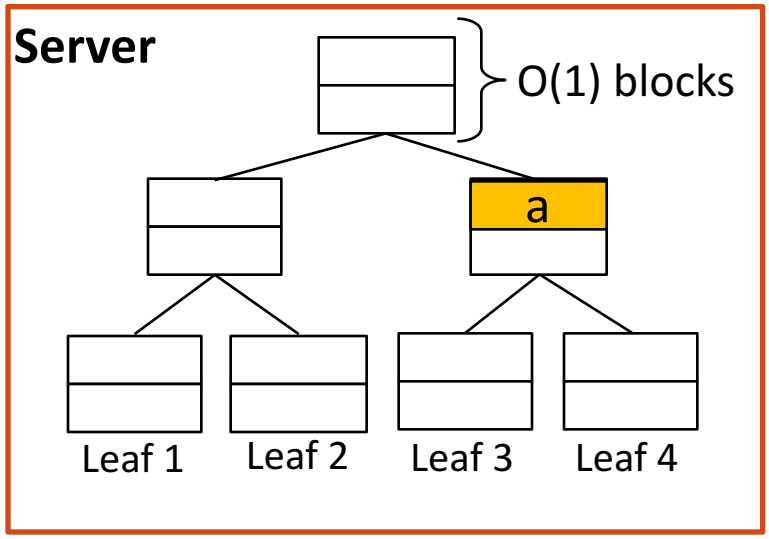
Enables easy partitioning

Many tree-based single-client ORAMs available: ES'11, ES'13, CG'13, KC'13, KC'14, XW'15, LR'15, SD'16, TM'15, …

Main challenge

How to make tree-based ORAM concurrent?

Starting point – Path ORAM [Stefanov et al CCS'13]



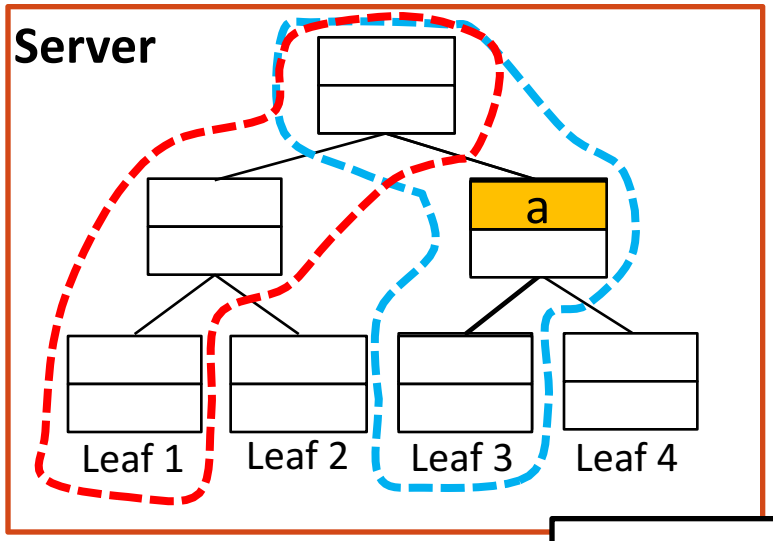
Storage is organized as a binary tree

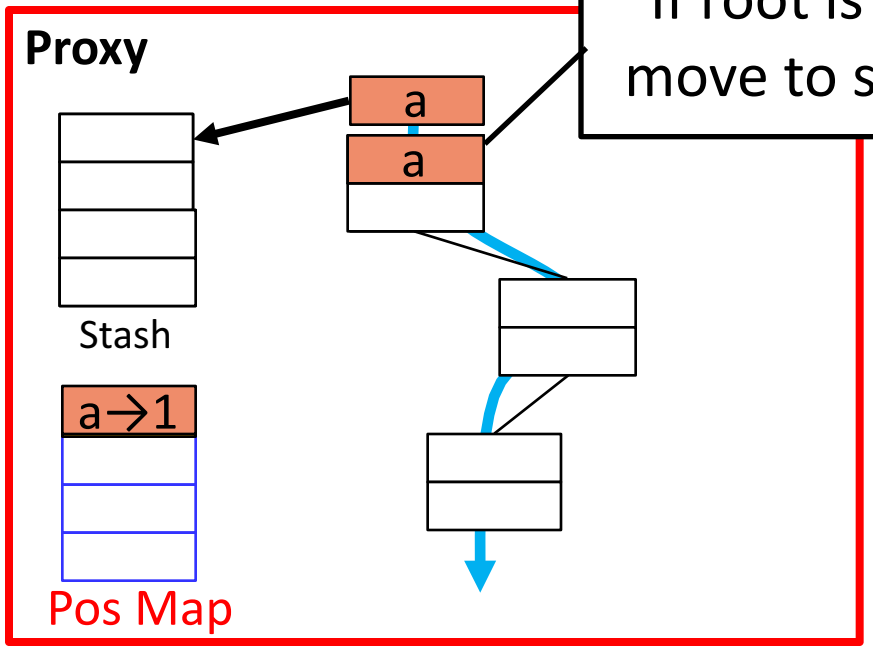
Every access to a random path

Items randomly re-assigned after every access

Possible to outsource position map recursively

Starting point – Path ORAM





If root is full move to stash

Read/Write block a

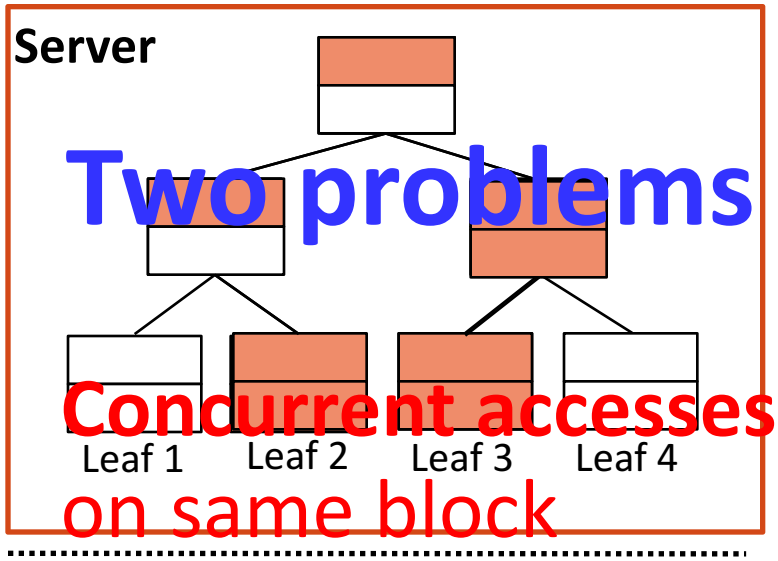
1) Read path
- Fetch associated path
- Read/Modify block
- Assign block to a new random path in position map

2) Flush

Push every block to the lowest non-full node that intersects with its assigned path (otherwise→stash)

3) Write-back
- Re-encrypt w/ fresh randomness

TaORAM – Basic Approach

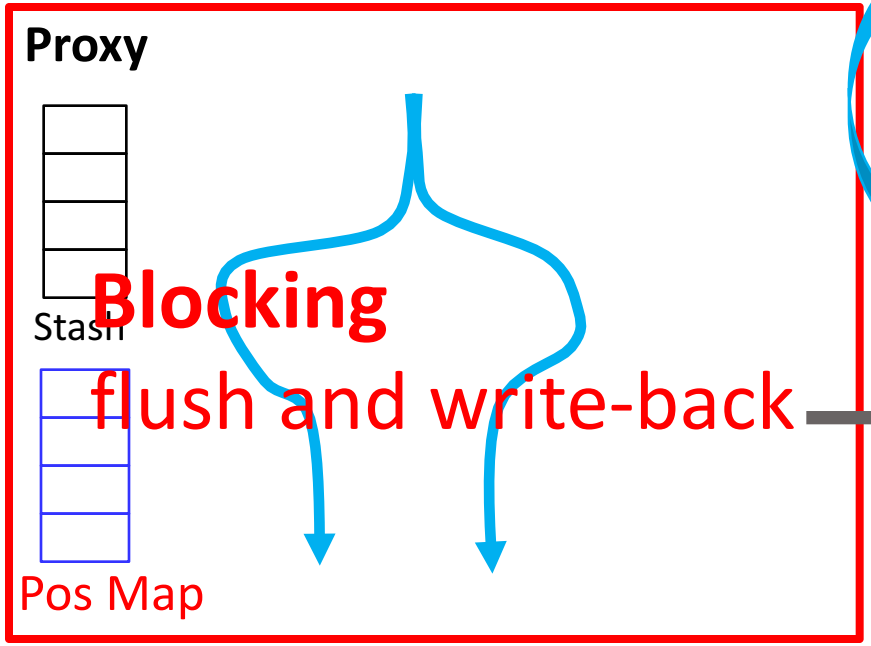


How to handle
≤ k concurrent requests?

STAGE 1

Process *k* operations

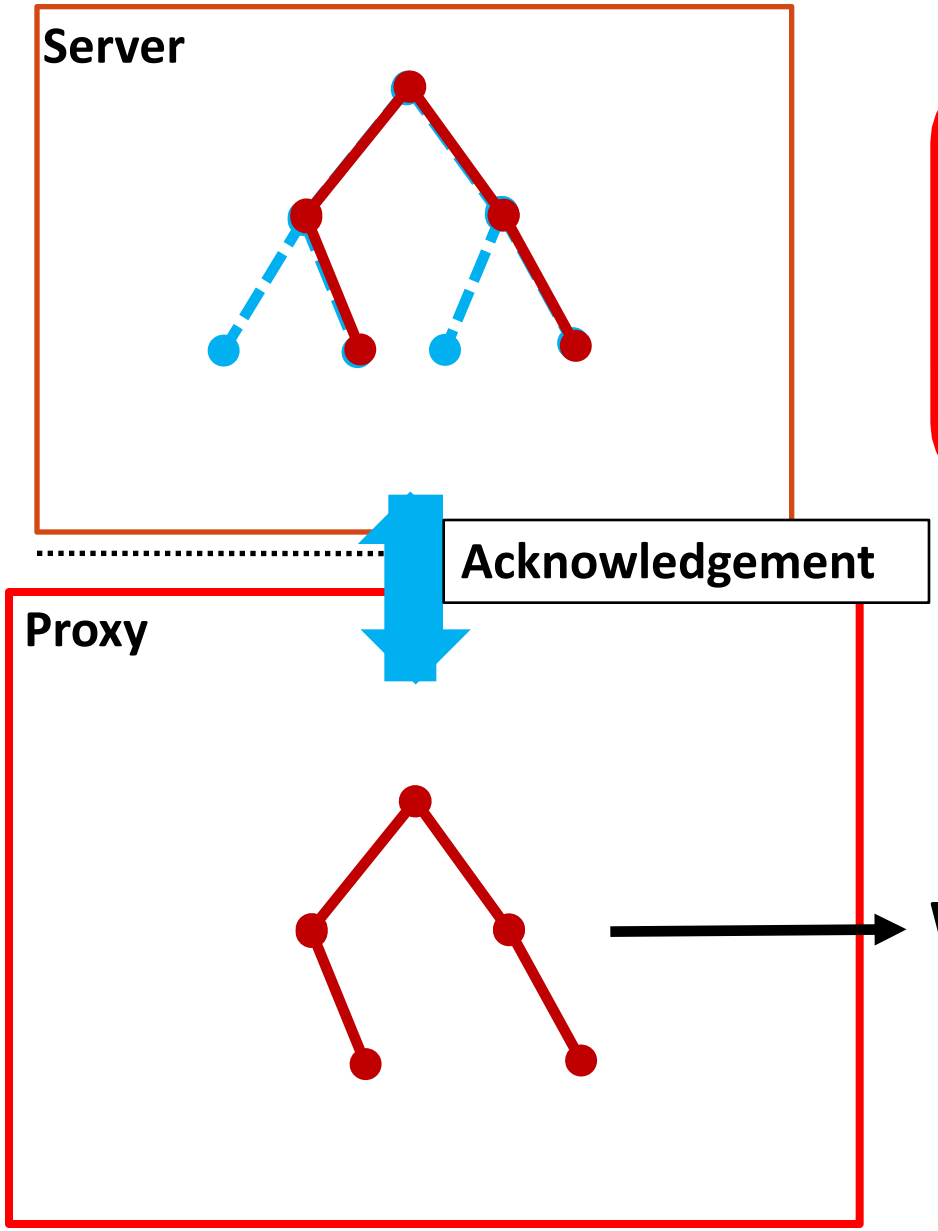
- Fetch corresponding *k* paths
- Form a *subtree* in proxy



STAGE 2

- Re-assign *k* items to new random paths
- Flush along the entire subtree and write-back

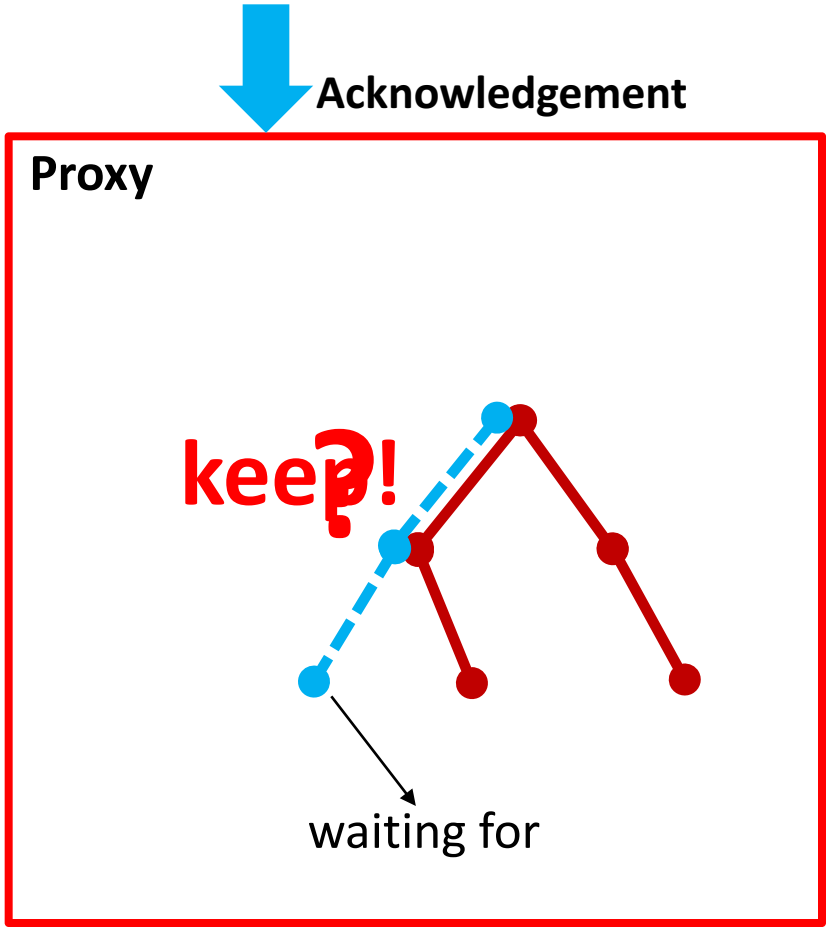
From Partial to Full Concurrency

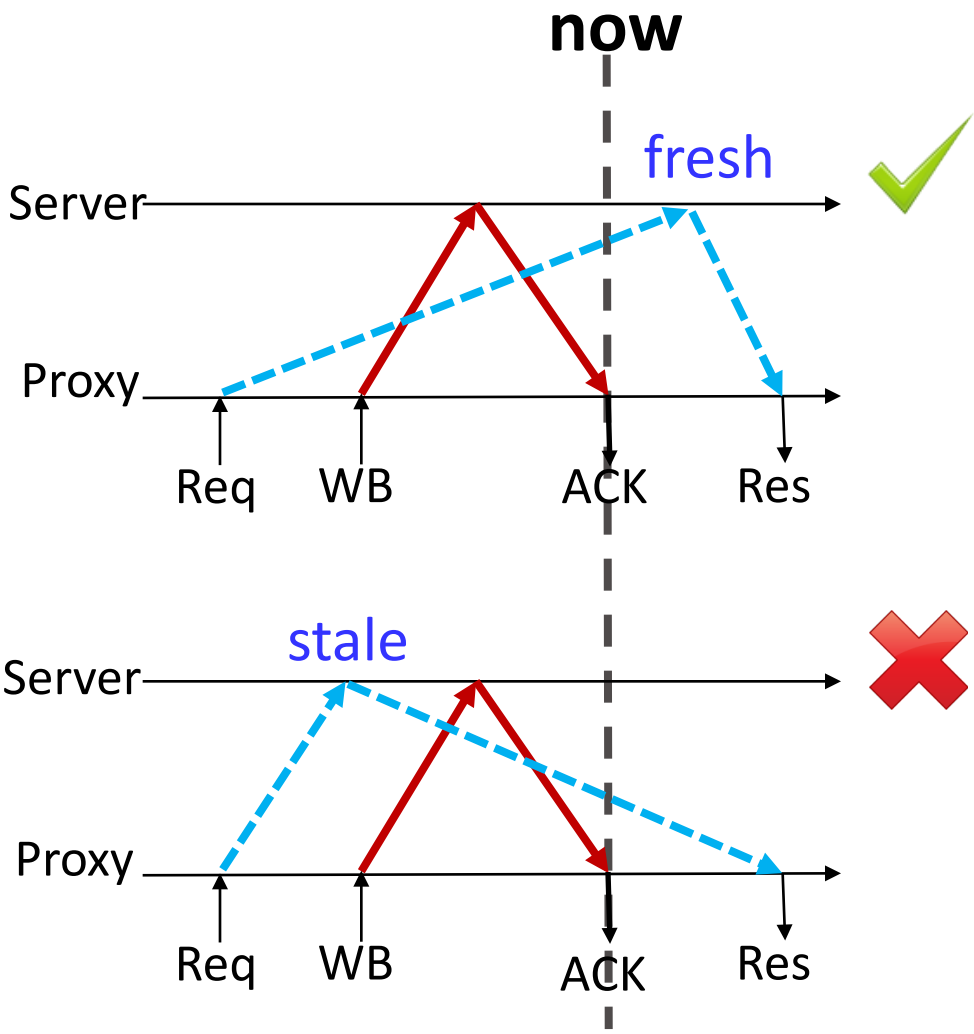


Non-blocking write-back
Continue processing operations while write-back is ongoing

What should we delete?

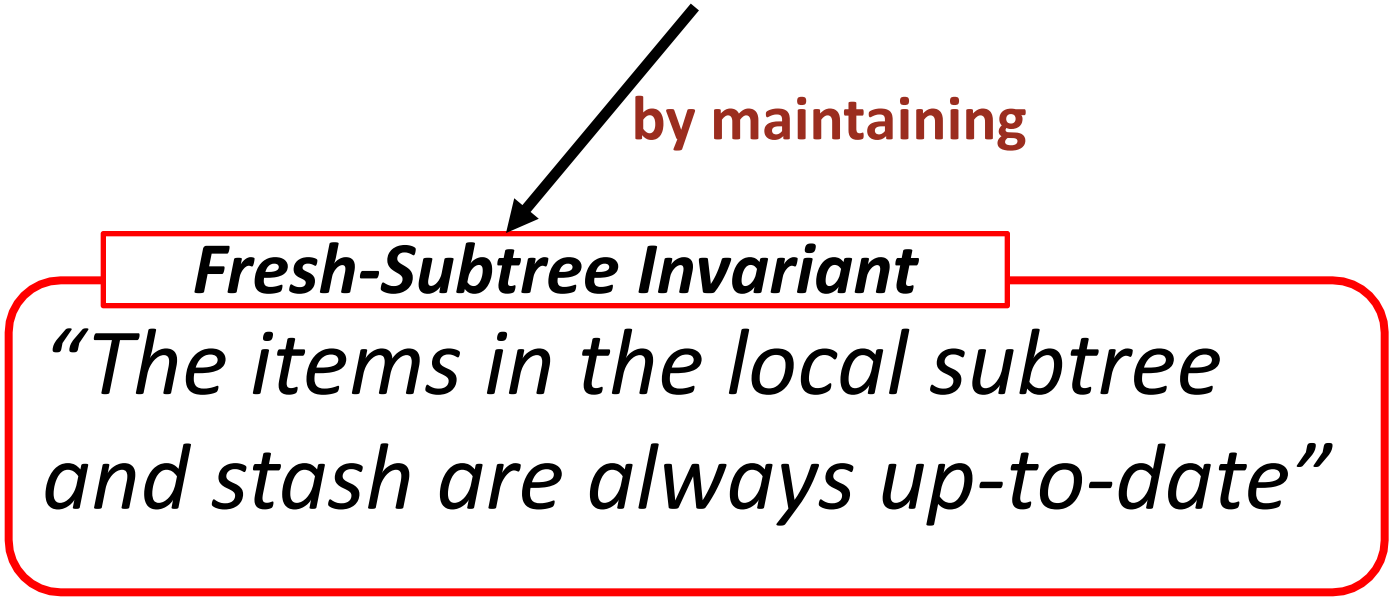
What should we delete?





+ more cases

TaoStore Achieves Full Concurrency



*See the correctness analysis in the paper.

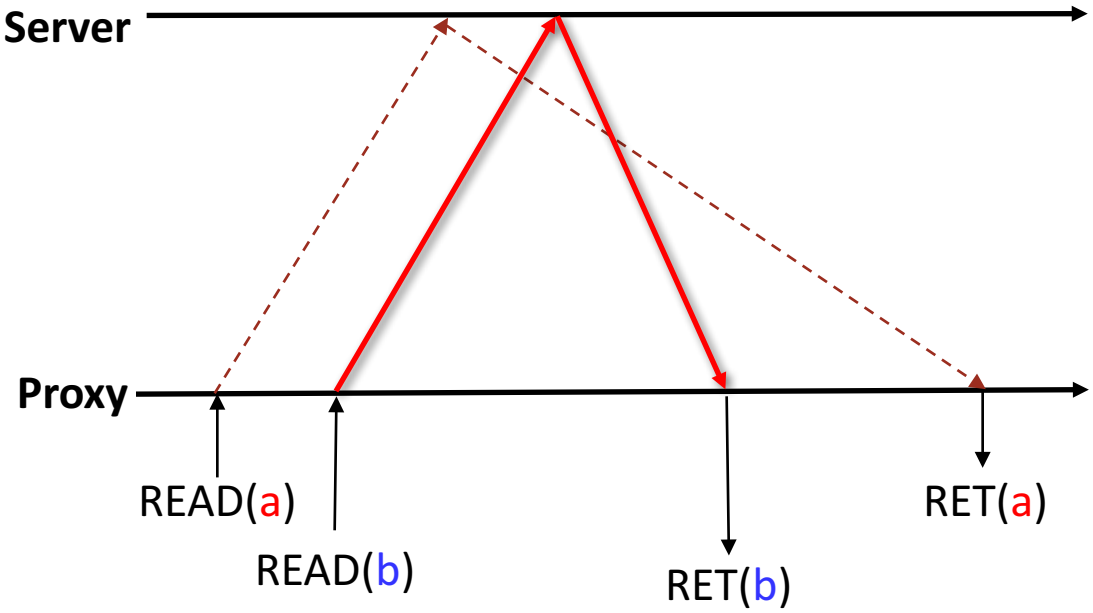
Concurrent accesses on same item

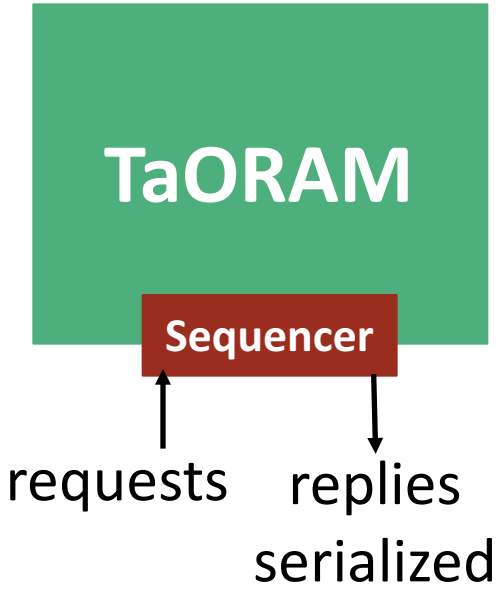
Use Fake Access (as in CURIOUS)

security problem

Our solution: Sequencer

Ensures logical requests replied in the same order they arrive

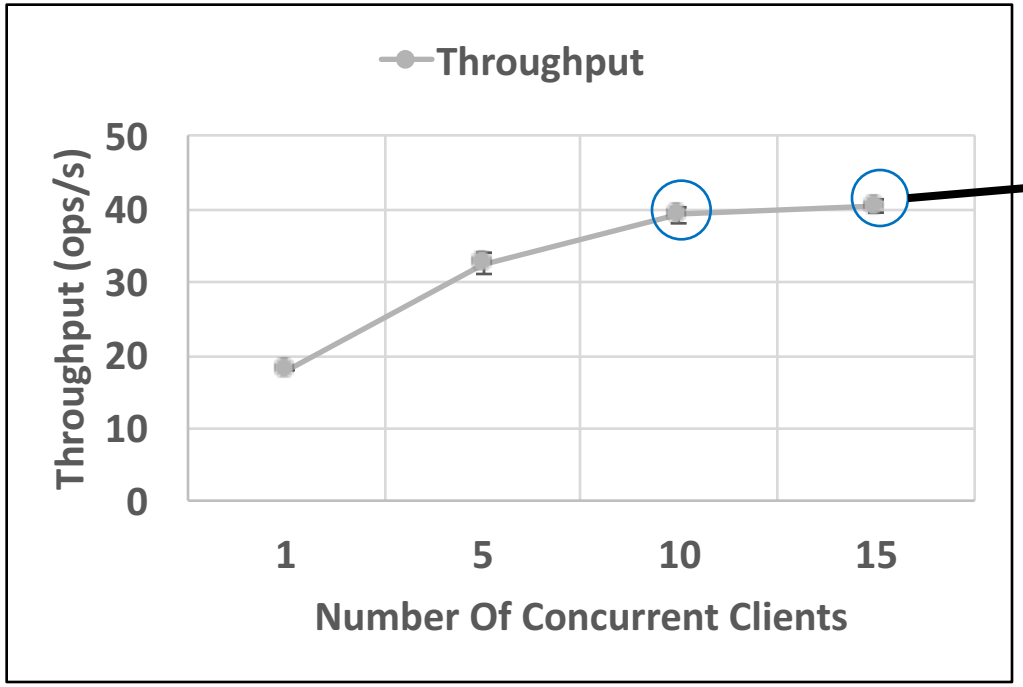




Generic solution: Also fixes CURIOUS

Cloud-based performance analysis

- Block Size: 4 KB - 1 GB dataset
- Proxy@UCSB (commodity workstation) + Storage Server: AWS EC2 (NorCal)
- Upstream/DownStream: 11 Mbytes/s. RTT: 12 ms
- Benchmark schedule: Adaptive requests



saturation due to bandwidth exhaustion

Bandwidth matters!

Cloud-based performance analysis

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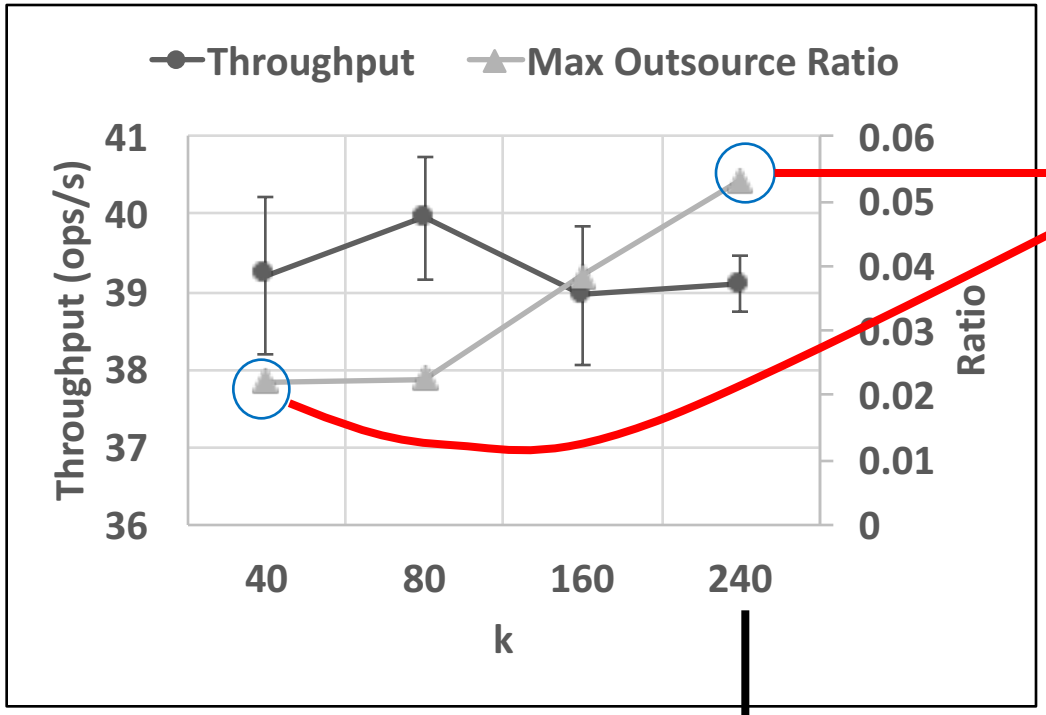

a low-memory utilization achieves similar performance

write-back in batches after k (240) path fetches

THANKS!

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