

## ABSTRACT

Oblivious RAM (ORAM) technology has

## 1. INTRODUCTION

With an increasing amount of confidential data being stored on outsourced storage, the privacy of this data is of critical importance. As demonstrated in previous work [4], simply encrypting the data is not enough. Even on encrypted data, the sequence of locations read and written to the storage can leak information regarding the user’s *access pattern* and the data stored.

Oblivious RAM (ORAM) is a cryptographic primitive that allows a client to hide its data access patterns from an untrusted storage hosting the data. Informally, the ORAM adversarial model prevents an adversary from distinguishing between multiple equal length sequence of queries made by the client to the server.

Since the original ORAM construction by Goldreich and Ostroevsky [2], a large volume of previous literature [3, 5, 6, 8–10] has been dedicated to developing more efficient ORAM constructions. PathORAM [8], based on the original binary tree ORAM construction by Shi *et al.* [6] is widely accepted to be asymptotically the most *bandwidth efficient* ORAM. RingORAM [5] further improves on the practical overhead of PathORAM [8] by optimizing the constants. Even for ORAMs that divide the data into multiple sub-ORAMs such as ObliviStore [7] and CURIOUS [1], [1] shows that PathORAM [8] is the most suitable ORAM for sub-ORAM design in terms of cost and bandwidth.

Although, recent tree based ORAM designs have achieved near-optimal *bandwidth* for single client scenarios, one critical challenge, yet to be addressed, is to make these ORAMs compatible for concurrent non-overlapping access (access for different data items) for multi-client scenarios, while maintaining security guarantees. As a motivating example, consider an enterprise that offloads confidential data to a remote storage that deploys an ORAM, and provides access to a group of employees (users). These users should be able to perform non-overlapping queries without a significant performance overhead compared to a scenario where there is only one user accessing the ORAM.

Note that it is trivial to deploy a standard tree based ORAM without concurrency to support multiple clients by sharing the key to the ORAM and storing all related datastructures (the stash and the position map) on the storage server to ensure consistency of state. In this case, only *one* client can access the position map, the stash and the tree at one time while the other concurrent clients must wait for this client to finish. This reduces the overall throughput and increases the query response time by a factor of the number of concurrent clients. A client (in the worst case) might need to wait for *all* other clients to finish before retrieving the required data item. Since, ORAMs have high latency of access (due to the retrieval of multiple items for one access), this implies that a client would need to wait a significant amount of time before being able to proceed with the query.

In this paper, we propose ConcurORAM, a mechanism to support multi-client concurrency for tree-based ORAMs

without sacrificing security. Our work is based on the concurrency scheme proposed by Williams *et al.* [10]. However, there are significant challenges to directly adapting the techniques proposed in [10] for tree based ORAMs. In the following, we discuss these challenges.

**Concurrency for position map.** First, tree based ORAMs use a position map to store mappings from the logical IDs of data items to the leaf IDs in the tree they are mapped to. Specifically, a data item mapped to leaf ID  $l$  can reside in any of the nodes along the path to leaf  $l$  from the root. In a single client scenario, the position map can be stored at the client side. For a multi-client scenario the position map must be stored on the server to ensure consistency among the clients. As introduced in [6], the position map can also be stored at the server (to reduce client side storage) in recursively smaller ORAMs. In this case, the position map is divided into fixed size blocks. Thus, an access in this case, requires reading the position map from the smaller ORAMs to obtain the leaf ID for the required data item and then reading the corresponding path to retrieve the data item. Since, the position map is stored recursively, an ORAM storing the position map also has a position map. To ensure that each successive position map is smaller (to ensure that the recursion terminates with an ORAM that has a constant size position map), each block in the ORAMs must store multiple position map entries. However, using this in a multi-client scenario allows the server to correlate two client accesses if they access the same position map block. Note that two concurrent clients may access the same position map block even if they are not accessing the same data item.

As one of the main insights, ConcurORAM stores the entries of the position map in a pyramid ORAM ([2, 10]) with multiple levels and uses a hash function to map position map entries to buckets in a level. Note that since the location of an entry is randomized (due to the uniform hash function used), concurrent clients accessing the same bucket, does not leak any correlation between the items queried by the clients. Specifically, ConcurORAM uses the concurrent version of PD-ORAM as used in PrivateFS [10] to ensure concurrency for queries.

**Decoupling fetching and eviction.** Tree based ORAMs divide accesses into two parts – fetching data (reading a root to leaf path) and eviction (writing back the read data to a root to leaf path). To ensure consistency in multi-client scenarios, the fetching and eviction cannot proceed concurrently. Thus, the fetching and eviction must be decoupled. Fortunately, RingORAM [5] provides a mechanism to evict data after a fixed number of fetches. ConcurORAM uses RingORAM and support a fixed number of concurrent queries followed by an eviction by a single client.

ConcurORAM has been implemented and shows an increase in throughput by a factor of [TODO: Anrin: this number to be filled] over a standard implementation of RingORAM [5] used non-concurrently for multiple clients.

## 2. REFERENCES

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