Design Document

Architecture Overview

This project implements a Path ORAM system in Python, consisting of a `Client` and a `Server`:

- **Server**: Stores the data as a binary tree of encrypted buckets. Each bucket contains a fixed number of blocks, and each block can hold a data item.
- **Client**: Maintains a stash (temporary storage), a position map (mapping block IDs to leaf indices), and handles encryption/decryption. The client is responsible for all logic related to data access, privacy, and remapping.

Data Flow

1. **Initialization**: The client generates encryption keys and initializes the server's tree with encrypted dummy blocks.
2. **Store Data**: The client:
    - remaps the block to a new random leaf
    - fetches and decrypts the path from the server
    - updates the stash with real blocks from the path
    - writes the new data
    - rebuilds the path with blocks from the stash and encrypts the path
    - sends it back to the server
3. **Retrieve Data**: The client:
    - remaps the block to a new random leaf
    - fetches and decrypts the path from the server
    - updates the stash with real blocks from the path
    - retrieves the data
    - rebuilds the path with blocks from the stash and encrypts the path
    - sends it back to the server
4. **Delete Data**: The client:
    - remaps the block to a new random leaf
    - fetches and decrypts the path from the server
    - updates the stash with real blocks from the path
    - removes the block from the stash and the map
    - rebuilds the path with blocks from the stash and encrypts the path
    - sends it back to the server

Security and Privacy

- All data on the server is encrypted with a key only known to the client.
- I used `cryptography.fernet` package, that uses `AES` in `CBC` mode with a 128-bit key for encryption and `HMAC` using `SHA256` for authentication.
- The access pattern is obfuscated by always reading and writing a full path from the root to a random leaf, regardless of the operation.
- The stash ensures that blocks are not lost during path rebuilding.

Requirements Satisfied

- **Obliviousness**: The server cannot distinguish which data is being accessed due to the randomized remapping and full-path operations.
- **Encryption**: All data is encrypted at rest and in transit between client and server.

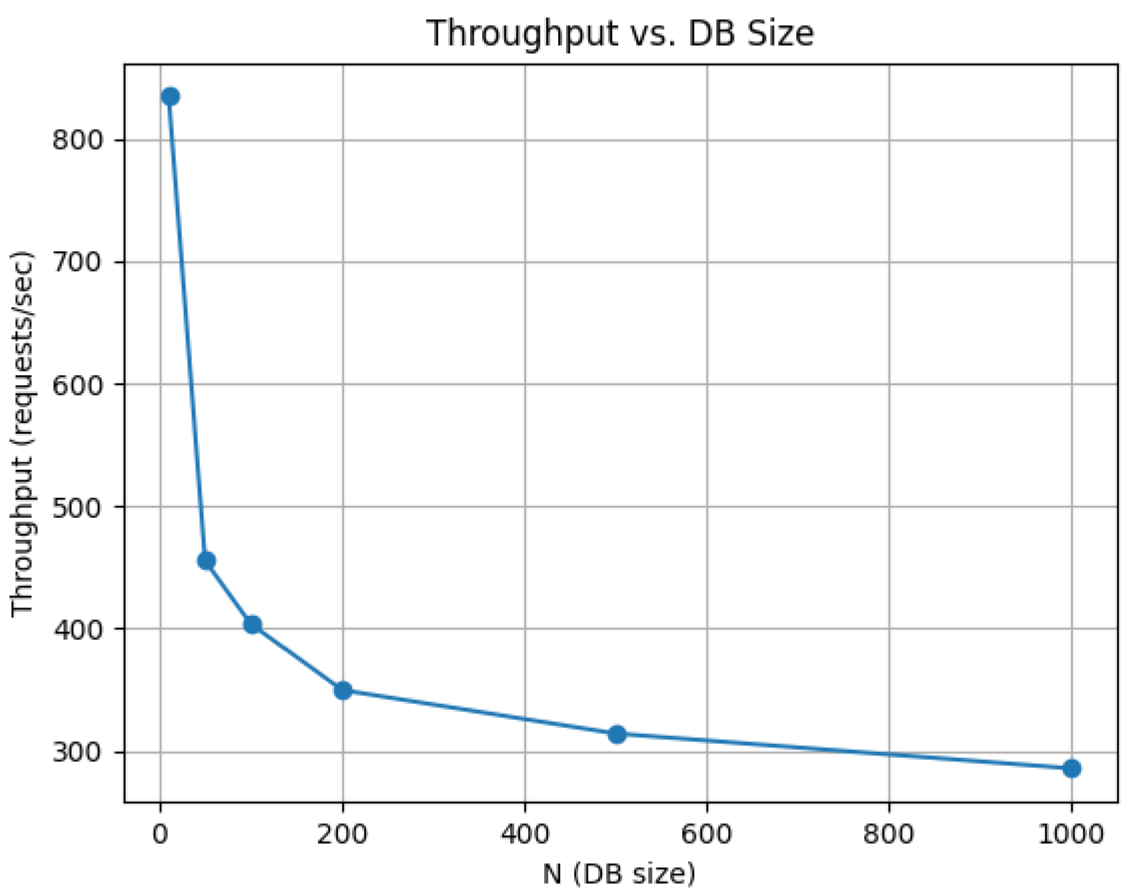
Benchmarks

The benchmark considers each client's API call as a request. It iterates over different DB sizes, and for each one it:

- calls `store_data` and the `retrieve_data` `N` times
- calls `retrieve_data` and `delete_data` `N` times
- repeats this maximum 1000 times, depends on `N`

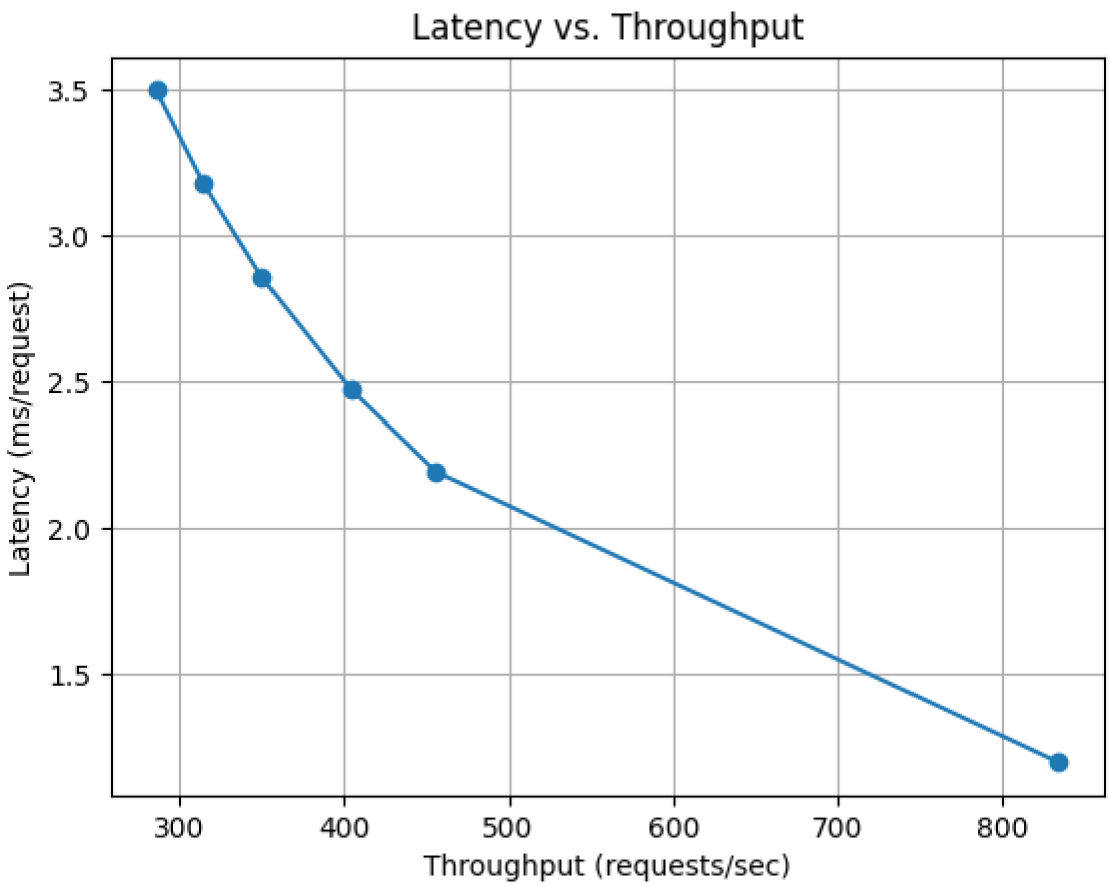
In total it runs `1000 * 4` requests for each DB size.

Throughput (requests/sec) vs. DB Size (blocks)



We can see that throughput decreases as the database size increases, which is expected due to the increased complexity of path traversal.

Latency (msec) vs. Throuput (requests/sec)



We can see that when throughput increases, latency decreases. It makes sense because when the throughput is high, the DB size is smaller, and the path traversal is simpler.

Multicore Benefits

The current implementation is single-threaded and does not natively benefit from multicore CPUs. Also it is designed for sequential operations.

However, the architecture could be extended to support parallelism, for example by:

- Running multiple client operations in parallel
- Parallelizing encryption/decryption of buckets or blocks.
