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Bachelor of Computer Science and Engineering

Trusted and Privacy-Enhanced In-Memory Data Stores

Dissertation submitted in partial fulfillment
of the requirements for the degree of

Master of Science in
Computer Science and Engineering

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FACULDADE DE
CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

June, 2019

Trusted and Privacy-Enhanced In-Memory Data Stores

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ACKNOWLEDGEMENTS

The acknowledgements. You are free to write this section at your own will. However, usually it starts with the institutional acknowledgements (adviser, institution, grants, workmates, ...) and then comes the personal acknowledgements (friends, family, ...).

ABSTRACT

The recent advent of hardware-based trusted execution environments provides isolated execution even from an untrusted operating system and possible hardware-based attacks. As the processor provides such “shielded” execution environments, their use will allow cloud users to run applications securely, for example on the remote cloud servers, whose operating systems and hardware are exposed to potentially malicious remote attackers and non-controlled system administrators’ staff.

This dissertation will design, implement and evaluate experimentally a Trusted and Privacy-Enhanced In Memory Data Structure Store. The solution combines partial homomorphic encryption constructions, allowing that operations on the data store will be supported directly over in-memory encrypted data. Complementarily, the proposal will be designed to run on a trusted execution environment supported by Intel SGX technology, offering high availability for data store access, built-in replication, a LRU eviction model, support for transactions and options for on-disk persistence.

Keywords: Privacy-Enhanced Data Store; Homomorphic Encryption; Trusted Computing; Availability; Reliability.

RESUMO

Independentemente da língua em que está escrita a dissertação, é necessário um resumo na língua do texto principal e um resumo noutra língua. Assume-se que as duas línguas em questão serão sempre o Português e o Inglês.

O *template* colocará automaticamente em primeiro lugar o resumo na língua do texto principal e depois o resumo na outra língua. Por exemplo, se a dissertação está escrita em Português, primeiro aparecerá o resumo em Português, depois em Inglês, seguido do texto principal em Português. Se a dissertação está escrita em Inglês, primeiro aparecerá o resumo em Inglês, depois em Português, seguido do texto principal em Inglês.

O resumo não deve exceder uma página e deve responder às seguintes questões:

- Qual é o problema?
- Porque é que ele é interessante?
- Qual é a solução?
- O que resulta (implicações) da solução?

E agora vamos fazer um teste com uma quebra de linha no hífen a ver se a \LaTeX duplica o hífen na linha seguinte...

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-lhe zzz zzzz zzz zzzz

Sim! Funciona! :)

Palavras-chave: Palavras-chave (em Português) ...

CONTENTS

1	Introduction	1
1.1	Context and Motivation	1
1.2	Objective	1
1.3	Planned Contributions	2
1.4	Report Organization	2
2	Related Work	3
2.1	Key-Value Stores	4
2.1.1	Memcached	5
2.1.2	Redis	5
2.1.3	Amazon Dynamo DB	6
2.1.4	Microsoft Azure Cosmos DB	6
2.1.5	Microsoft Azure Redis Cache	6
2.1.6	Aerospike	6
2.1.7	Discussion	6
2.2	Trusted Computing Environments	6
2.2.1	TPM – Trusted Platform Modules	6
2.2.2	TPM - Enabled Software Attestation	7
2.2.3	HSM – Hardware Security Modules	7
2.2.4	Trusted Execution Environments	8
2.2.5	Intel SGX	8
2.2.6	Sanctum	8
2.2.7	ARM Trust Zone	8
2.2.8	Discussion	8
2.3	TEE/SGX Enabled Key Value Stores	8
2.3.1	Trusted Execution with Intel SGX	8
2.3.2	Circumvention of SGX Limitations	8
2.3.3	SGX-Enabled Secure Databases	9
2.3.4	Discussion	9
2.4	Related Work Balance and Critical Analysis	9
3	3. Approach to Elaboration Phase	11

CONTENTS

3.1	Refinement of Objectives and Contributions	11
3.2	System Model Approach	11
3.3	Planned Architecture and Implementation	11
3.4	Planned Testbench Environments	11
3.5	Relevant Evaluation Criteria	11
4	Workplan	15
	Bibliography	19
	Apêndices	21
A	Appendix 1 Lorem Ipsum	21
B	Appendix 2 Lorem Ipsum	23
	Annexes	25
I	Annex 1 Lorem Ipsum	25

LIST OF FIGURES

3.1 A figure with two sub-figures!	12
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LIST OF TABLES

LISTINGS

2.1	Redis Set & Get	4
2.2	How Fast is Redis	5

GLOSSARY

aliquam	tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.
computer	An electronic device which is capable of receiving information (data) in a particular form and of performing a sequence of operations in accordance with a predetermined but variable set of procedural instructions (program) to produce a result in the form of information or signals.
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ACRONYMS

DBMS	Database Management System
KVS	Key-Value Store
LRU	Least Recently Used
SASL	Simple Authentication and Security Layer

SYMBOLS

*

INTRODUCTION

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1.1 Context and Motivation

The *novathesis* was originally developed to help MSc and PhD students of the Computer Science and Engineering Department of the Faculty of Sciences and Technology of NOVA University of Lisbon (DI-FCT-NOVA) to write their thesis and dissertations Using \LaTeX . These student can easily cope with \LaTeX by themselves, and the only need some help in the bootstrap process to make their life easier.

However, as the template spread out among the students from other degrees at FCT-NOVA, the demand for an easier-to-use template has grown. And the template in its current shape aims at answering the expectations of those that, although they are not familiar with programming nor with markup languages, so still feel brave enough to give \LaTeX a try and rejoice with the beauty of the texts typeset by this system.

1.2 Objective

It is up to you, the student, to read the FCT and/or NOVA regulations on how to format and submit your MSc or PhD dissertation.

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1.3 Planned Contributions

It is up to you, the student, to read the FCT and/or NOVA regulations on how to format and submit your MSc or PhD dissertation.

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1.4 Report Organization

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CHAPTER 2

RELATED WORK

This chapter presents and briefly discusses the related work and the study performed beforehand in order to guide and give some context to the reader. It will present work that was used as the basis of this thesis, existent technologies and their relation with this project, and some comparisons between those exiting technologies, the problem addressed in this thesis and the solutions proposed to solve, or better address, those very same problems.

First, in section 2.1 we explain and discuss for the first time the definition of a Key-Value Store. We present some use cases, current technology available, their differences and most importantly their security models and concerns.

Having discussed the software, section 2.2 will then address the environment on where the previously talked software will run, most specifically the hardware. It explains and present the different ways to secure and authenticate the hardware, prevent hardware-based attacks and discuss some of the current products available and how they will be used across this thesis.

Section 2.3 will then make the bridge between software and hardware. It explains how Key-Value stores are currently being run on secure environments. This chapter will be focused on the Intel SGX secure model and explain the advantages and disadvantages of this module

To conclude the chapter, section 2.4...

//TODO: complete

Along the next chapter we summarize the main relevant ideas that can be retained from each section for our objectives and expected goals.

2.1 Key-Value Stores

Key value stores are the simplest form of what computer scientists call a database. The simplicity lies on associating a value to a certain key and storing that pair, as well as retrieving the values of known keys. [3]

Listing 2.1: Redis Set & Get

```
1 redis> SET mykey "Hello"
2 "OK"
3 redis> GET mykey
4 "Hello"
5 redis>
```

Is this simplicity that makes this technology very attractive to developers. The ease of use, its high performance and speed are key aspects in favour of this technologies. However, simply working with keys and values might not be enough to more complex applications, and that is why Key-Value store product developers are introducing new features in order to make them appealing to a broader mass of users, always keeping them lightweight and fast.

For that lightweight and fast attributes, most of the key-value stores work in the computer memory. This allows fast get and write operations as opposed to persistent disk storage. Although, they work mainly in memory, most of the solutions offer some persistent mechanism so we can make use of its performance but still persist data in case of a disaster, server failure or any crash.

KVSs have been evolving for years and some are now more than a single key-value store module. A lot of them are now supporting a multi-model storage. That means that a value can be more than a single integer or a string. For example, Redis [7] as a multi-model store is not only a key-value store, but also [8]:

- Document Store - *"nonrelational database that is designed to store and query data as JSON-like documents"* [1]
- Graph **DBMS** - *"Graph databases are purpose-built to store and navigate relationships. Use nodes to store data entities, and edges to store relationships between entities"* [2]
- Search Engine - *"nonrelational database that is dedicated to the search of data content. Use indexes to categorize the similar characteristics among data"* [12]
- Time Series **DBMS** - *"Provides optimum support for working with time-dependent data. Each entry has a timestamp, the data arrives in time order and time represents a primary axis for the information."* [13]

So, the **KVS** world is becoming more and more versatile as the years pass.

In the next subsections its discussed and presented the overview of the current **KVS** technology. We picked the some top KVSs technologies nowadays according to db-engines [4].

2.1.1 Memcached

Memcached [5] is a free and open source key-value store released in 2003. It is described as a high performance distributed memory object caching system.

It is design to hold small chunks of data (strings and objects) to work as a cache for results of database calls, API calls, or page rendering. Its biggest use case is for use in speeding up dynamic web applications by alleviating database load.

This system lies on the simpler key-value store spectrum. It takes advantages of the simplicity of a key-value store to edge ease of development, and solving many problems facing large data caches. Its API is available for most popular languages. It has a [LRU](#) eviction technique which means that items will expire a specified amount of time.

When it comes to system availability and reliability, Memcached has an interesting approach. In order to keep it blazing fast, there is no communication between server instances in a cluster. Memcached servers are unaware of each other. There is no crosstalk, no synchronization, no broadcasting, no replication. Adding servers will only increase the available memory.

As for its security context, Memcached spends very little, if any, effort in securing the systems for random internet connections. The servers only have support for SASL [11] authentication mechanism. This method of authentication is not implemented as end-to-end encryption, it only provides restriction access to the daemon, but it does not hide communications over the network. That means it is not meant to be exposed to the internet or to any untrusted users [6].

2.1.2 Redis

Redis [7] is an in-memory data structure store that can be used as a database, cache and also a message broker. Redis focuses on performance, so most of its decisions prioritize high performance and very low latency.

It has been benchmarked as the world's fastest database [9] and together with a their multi-model and its rich set of operations that can be performed over data it has been the leading key-value store according to use and popularity for a multiple set of years [4].

Listing 2.2: How Fast is Redis

```

1 redis-benchmark -t set -r 100000 -n 1000000
2 ===== SET =====
3 1000000 requests completed in 8.78 seconds
4 50 parallel clients
5 3 bytes payload
6 keep alive: 1
7
8 99.59% <= 1 milliseconds
9 99.98% <= 2 milliseconds
10 100.00% <= 2 milliseconds
11 113934.14 requests per second

```

As said before, Redis is now not a simple [KVS](#). It supports data structures such as strings, hashes, lists, sets, sorted sets with range queries, bitmaps, hyperloglogs, geospatial indexes with radius queries and streams. It also has built-in replication, server side scripting, [LRU](#) eviction, concept of transactions and different levels of persistence. It provides high availability and automatic partitioning as well.

Security is not Redis' primary concern (just like others). *"In general, Redis is not optimized for maximum security but for maximum performance and simplicity"* [10]. It is design to be access by trusted clients inside trusted networks. This means that it is not supposed to be publicly exposed. Redis implements a simple authentication system with a password on the configuration file for client authentication. It is also advised to run it behind a proxy to enable some ACL policies and SSL network security.

There are a few other security concerns that Redis addresses, but has we can now start to see, in this types of stores, security falls behind performance and usability.

2.1.3 Amazon Dynamo DB

Amazon Dynamo DB

2.1.4 Microsoft Azure Cosmos DB

Microsoft Azure Cosmos DB

2.1.5 Microsoft Azure Redis Cache

Microsoft Azure Redis Cache

2.1.6 Aerospike

Aerospike

2.1.7 Discussion

Discussion

2.2 Trusted Computing Environments

In this section we will provide some additional considerations about some of the customizations available as class options.

2.2.1 TPM – Trusted Platform Modules

The choice of the main language with the option “lang=OPT” affects:

- **The order of the summaries.** First is printed the abstract in the main language and then in the foreign language. This means that if your main language for the

document in English, you will see first the “abstract” (in English) and then the “resumo” (in Portuguese). If you switch the main language for the document for Portuguese, it will also automatically switch the order of the summaries to “resumo” and then “abstract”.

- **The names for document sectioning.** E.g., “Chapter” vs. “Capítulo”, “Table of Contents” vs. “Índice”, “Figure” vs. “Figura”, etc.
- **The type of documents in the bibliography.** E.g., “Technical Report” vs. “Relatório Técnico”, “PhD Thesis” vs. “Tese de Doutoramento”, etc.

No matter which language you chose, you will always have the appropriate hyphenation rules according to the language at that point. You always get Portuguese hyphenation rules in the “Resumo”, english hyphenation rules in the “Abstract”, and then the main language hyphenation rules for the rest of the document.

2.2.2 TPM - Enabled Software Attestation

You must choose the class of text for the document. The available options are:

1. **bsc** — BSc graduation report.
2. ***mscplan** — Preparation of MSc dissertation. This is a preliminary report graduate students at DI-FCT-NOVA must prepare to conclude the first semester of the two-semester MSc work. The files specified by `\dedicatoryfile` and `\acknowledgmentsfile` are ignored, even if present, for this class of document.
3. **msc** — MSc dissertation.
4. **phdprop** — Proposal for a PhD work. The files specified by `\dedicatoryfile` and `\acknowledgmentsfile` are ignored, even if present, for this class of document.
5. **prepphd** — Preparation of a PhD thesis. This is a preliminary report PhD students at DI-FCT-NOVA must prepare before the end of the third semester of PhD work. The files specified by `\dedicatoryfile` and `\acknowledgmentsfile` are ignored, even if present, for this class of document.
6. **phd** — PhD dissertation.

2.2.3 HSM – Hardware Security Modules

You must choose how your document will be printed. The available options are:

1. **oneside** — Single side page printing.
2. ***twoside** — Double sided page printing.

2.2.4 Trusted Execution Environments

You must select the encoding for your text. The available options are:

1. **11pt** — Eleven (11) points font size.
2. ***12pt** — Twelve (12) points font size. You should really stick to 12pt...

2.2.5 Intel SGX

You must choose the font size for your document. The available options are:

1. **latin1** — Use Latin-1 ([ISO 8859-1](#)) encoding. Most probably you should use this option if you use Windows;
2. **utf8** — Use [UTF8](#) encoding. Most probably you should use this option if you are not using Windows.

2.2.6 Sanctum

Let's have a look at a couple of examples:

- Preparation of PhD thesis, in portuguese, with 11pt size and to be printed single sided (I wonder why one would do this!)
`\documentclass[prepphd,pt,11pt,oneside,latin1]{thesisdifct-nova}`
- MSc dissertation, in english, with 12pt size and to be printed double sided
`\documentclass[msc,en,12pt,twoside,utf8]{thesisdifct-nova}`

2.2.7 ARM Trust Zone

ARM Trust Zone

2.2.8 Discussion

Discussion

2.3 TEE/SGX Enabled Key Value Stores

2.3.1 Trusted Execution with Intel SGX

Trusted Execution with Intel SGX

2.3.2 Circumvention of SGX Limitations

Circumvention of SGX Limitations

2.3.3 SGX-Enabled Secure Databases

SGX-Enabled Secure Databases

2.3.3.1 Enclave DB

Enclave DB

2.3.3.2 Pesos DB

Pesos DB

2.3.3.3 Speicher

Speicher

2.3.3.4 ShieldStore

ShieldStore

2.3.4 Discussion

Discussion

2.4 Related Work Balance and Critical Analysis

Foo Bar

3. APPROACH TO ELABORATION PHASE

This Chapter aims at exemplifying how to do common stuff with \LaTeX . We also show some stuff which is not that common! ;)

Please, use these examples as a starting point, but you should always consider using the *Big Oracle* (aka, [Google](#), your best friend) to search for additional information or alternative ways for achieving similar results.

3.1 Refinement of Objectives and Contributions

Refinement of objectives and contributions

3.2 System Model Approach

System model approach

3.3 Planned Architecture and Implementation

Planned architecture and implementation

3.4 Planned Testbench Environments

Planned testbench environments

3.5 Relevant Evaluation Criteria

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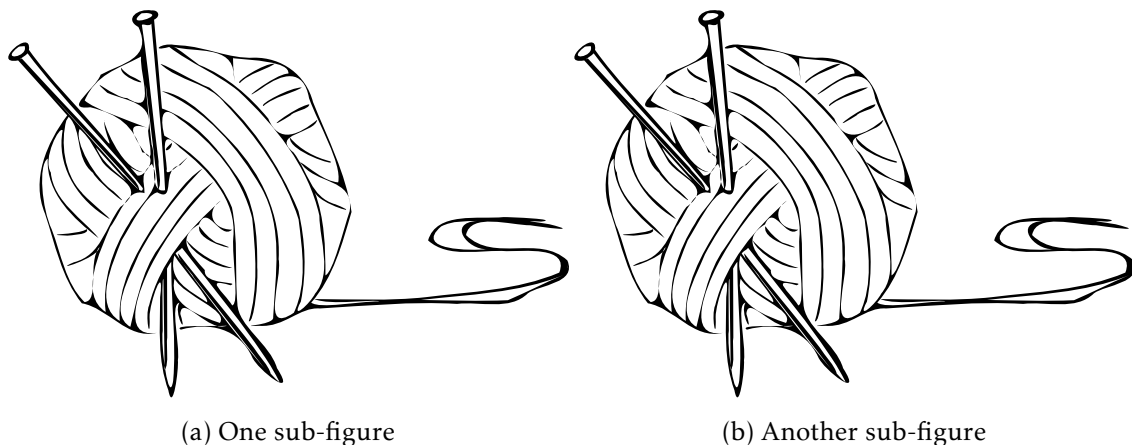


Figure 3.1: A figure with two sub-figures!

And this is a small text that references the [Figure 3.1](#) and its Subfigures [3.1a](#) and [3.1b](#).

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WORKPLAN

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BIBLIOGRAPHY

- [1] *Document Store*. <https://aws.amazon.com/nosql/document/>. Accessed: 2019-06-16.
- [2] *Graph DBMS*. <https://aws.amazon.com/nosql/graph/>. Accessed: 2019-06-16.
- [3] S. IT. *Key-Value Stores*. <https://db-engines.com/en/article/Key-value+Stores>. Accessed: 2019-06-16.
- [4] S. IT. *Key-Value Stores Ranking*. <https://db-engines.com/en/ranking/key-value+store>. Accessed: 2019-06-16.
- [5] *Memcached*. <https://github.com/memcached/memcached/wiki/Overview>. Accessed: 2019-06-16.
- [6] *Memcached*. <https://github.com/memcached/memcached/wiki/Overview>. Accessed: 2019-06-16.
- [7] *Redis*. <https://redis.io>. Accessed: 2019-06-16.
- [8] *Redis Multi Model Store*. <https://db-engines.com/en/system/Redis>. Accessed: 2019-06-16.
- [9] *Redis Performance Benchmark*. <https://redislabs.com/docs/nosql-performance-benchmark/>. Accessed: 2019-06-16.
- [10] *Redis Security*. <https://redis.io/topics/security>. Accessed: 2019-06-16.
- [11] *SASL Rfc*. <https://tools.ietf.org/html/rfc2222>. Accessed: 2019-06-16.
- [12] *Search Engine Database*. <https://aws.amazon.com/nosql/search/>. Accessed: 2019-06-16.
- [13] *Time Series Databases*. <https://www.forbes.com/sites/metabrown/2018/03/31/get-the-basics-on-nosql-databases-time-series-databases/>. Accessed: 2019-06-16.



APPENDIX 1 LOREM IPSUM

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APPENDIX 2 LOREM IPSUM

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