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Key derivation functions and their GPU implementation

BACHELOR'S THESIS

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Declaration

Hereby I declare, that this paper is my original authorial work, which I have worked out by my own. All sources, references and literature used or excerpted during elaboration of this work are properly cited and listed in complete reference to the due source.

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Abstract

TODO

Keywords

key derivation function, PBKDF2, GPU, OpenCL, CUDA, password hashing, disk encryption, password cracking, LUKS

Contents

1 Introduction

Encryption is the process of encoding information or data in such a way that only authorized parties can read it [6, 3]. The encryption uses a parameter – the key. The key is an information that is only known to the authorized parties and which is necessary to read the encrypted data. In general, any piece of information can be used as the key, but since it usually has to be memorized by a human, it often has the form of a password or passphrase.

Passwords and passphrases generally have the form of text (a variable-length sequence of characters), while most encryption algorithms expect a key in binary form (a long, usually fixed-size, sequence of bits or bytes). This means that for any password- or passphrase-based cryptosystem it is necessary to define the process of converting the password (passphrase) into binary form. Merely encoding the text using a common character encoding (e. g. ASCII or UTF-8) and padding it with zeroes is often not sufficient, because the resulting key might be susceptible to various attacks.

For this reason, a cryptographic primitive called *key derivation function* (KDF, plural KDFs) is used to derive encryption keys from passwords. KDFs are also often used for password hashing (transforming the password to a hash in such a way that it is easy to verify a given password against a hash, but infeasible to determine the original password from the hash) or key diversification (deriving multiple keys from a master key so that it is infeasible to determine the master key or any other derived key from one or more derived keys) [7, 1].

KDFs usually have various security parameters, such as the number of iterations of an internal algorithm, which control the amount of time or memory required to perform the derivation in order to thwart brute-force attacks. Another common parameter is the cryptographic salt, which is a unique or random piece of data that is used together with the password to derive the key. Its main purpose is to protect against dictionary and rainbow table attacks and it is usually not kept secret [5].

One possible application of KDFs is key derivation from passwords in disk encryption software. Disk encryption software en-

crypts the contents of a storage device (such as a hard disk or a USB drive) or its part (a disk volume or *partition*) so that the data stored on the device can only be unlocked by one or more passwords or passphrases. The password/passphrase is entered when the user boots an operating system from the encrypted device or when they mount the encrypted partition to the filesystem.

An example of a disk encryption program is *cryptsetup*[1] which uses the LUKS standard as its main format for on-disk data layout. In version 1 LUKS uses PBKDF2 as the only KDF for deriving encryption keys from passwords [2]. However, PBKDF2 has a range of weaknesses, one of them being high susceptibility to brute-force and dictionary attacks using GPUs[2], as this thesis aims to demonstrate.

1.1 Goals

The goal of this work is to compare the speed of a brute-force attack on a specific key derivation function (PBKDF2) performed on standard computer processors against an attack using GPUs. Modern GPUs can be programmed using various high-level APIs (such as OpenCL[3], CUDA[4], DirectCompute or C++ AMP) and can be used not only for graphics processing but also for general purpose computation. Due to their specific architecture GPUs are suitable for parallel processing of massive amounts of data. Tasks that can be split into many small subtasks which can be run in parallel can be processed by a single GPU several times faster than by a single CPU. As was shown by Harrison and Waldron[4], using GPUs it is possible to accelerate also various algorithms of symmetric cryptography.

This work also includes analysis of susceptibility of PBKDF2 to attacks using parallel processing and the implementation of an illustration program performing a brute-force attack on the password of a LUKS encrypted partition.

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1. https://gitlab.com/cryptsetup/cryptsetup/wikis/home
2. GPU = Graphics Processing Unit
3. https://www.khronos.org/opencl/
4. http://www.nvidia.com/object/cuda_home_new.html

1.2 Summary of results

TODO

1.3 Chapter contents

TODO

2 Key derivation functions

Key derivation functions are cryptographic primitives that are used to derive encryption keys from a secret value. Depending on the application, the secret value can be another key or a password or passphrase [7]. A KDF that is designed for deriving cryptographic key from another key is called a *key-based key derivation function* (KBKDF); a KDF that is designed to take a password or passphrase as input is called a *password-based key derivation function* (PBKDF).

2.1 Key-based key derivation functions

Key-based key derivation functions are most often used to derive additional keys from a key that already has the properties of a cryptographic key – that is, it is a truly random or pseudorandom binary string that is computationally indistinguishable from one selected uniformly at random from the set of all binary strings of the same length [1].

2.2 Password-based key derivation functions

3 Attacks on key derivation functions

4 Acceleration of algorithms using GPUs

5 Comparison of CPU and GPU attack speeds

6 Implementing PBKDF2 on GPUs

7 Conclusion

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