FAKULTÄT
FÜR !NFORMATIK
Faculty of Informatics

Cryptographic Methods For Elektra

BACHELORARBEIT

zur Erlangung des akademischen Grades

Bachelor of Science

im Rahmen des Studiums

Software and Information Engineering

eingereicht von

Peter Nirschl
Matrikelnummer 1025647

an der Fakultät für Informatik
der Technischen Universität Wien

Betreuung: DI Markus Raab

Wien, 6. Mai 2018

Peter Nirschl   Markus Raab

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BACHELOR'S THESIS

submitted in partial fulfillment of the requirements for the degree of

Bachelor of Science

in

Software and Information Engineering

by

Peter Nirschl
Registration Number 1025647

to the Faculty of Informatics

at the Vienna University of Technology

Advisor: DI Markus Raab

Vienna, 6th May, 2018

Peter Nirschl   Markus Raab

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Peter Nirschl

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Wien, 6. Mai 2018

Peter Nirschl

Acknowledgements

A big thank you to all the people who supported me during the long time this thesis took me to write.

A special thank you goes to DI Markus Raab, who patiently waited, corrected, gave feedback and helped me to improve my writing skills.

Also a friendly shout-out to the whole Elektra team. You guys are great and I enjoyed our meetings very much.

Last but not least I want to thank my family and my friends for never letting me down.

Sorry to all the great people who are not explicitly mentioned here!

Abstract

Storing login credentials in application configurations is a common problem. Implementing cryptographic systems is complicated and increases the development effort. We solve the problem by contributing new plugins to the configuration management software Elektra. The new plugins are: `fcrypt` plugin for file-based encryption and decryption, and `crypto` plugin for the encryption and decryption of single configuration values. Applications can use the plugins by including them in Elektra's backend configuration. No additional development effort is required.

We study the runtime and memory impact of the introduction of cryptographic methods. We learn that when comparing libgcrypt, OpenSSL and Botan, that libgcrypt has the lowest runtime impact in our benchmark. The benchmark also shows that file-based encryption and decryption is faster than the encryption and decryption of single configuration values.

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CHAPTER 1

Introduction

Login credentials in this thesis refer to data that grant access to a system, for example:

1. passwords, and
2. access tokens (like OAuth tokens[DHM12]).

Login credentials are seen as part of configuration settings of applications.

Applications prefereably store login credentials to related systems in configuration files. A typical example is an application that connects to a database system. The login credentials are often saved as plain text, leaving them vulnerable to attack. We introduce the problem by giving two examples:

1. WordPress is a typical web application with a backend connecting to a database. WordPress reads the login credentials for the database server from a configuration file.[wor17].
2. Hibernate, a popular object-relational mapping (ORM) tool, is written in Java. Hibernate expects that its login credentials for the database server are provided in an XML configuration file as plain text.[hib17]

Both applications expect the login credentials to be unencrypted, but storing passwords this way is a major security risk. However, introducing cryptography to an application results in increased development efforts and possibly slower runtime behavior. By using third party software libraries an application encounters an increased memory consumption.

Hypothesis H_1: Introducing cryptography to an application increases the runtime of the application.

Hypothesis H_2: Introducing cryptography to an application increases the memory consumption of the application.

In order to mitigate the risks of leaking plain text login credentials, they should be encrypted before they are persisted to a storage. To keep the development effort low for application developers, a software library can abstract the cryptographic operations.

Cryptography as a security measure might also bring drawbacks in usability. In this thesis we are not going to discuss any possible drawbacks regarding usability, but focus solely on the performance analysis.

Cryptographic algorithms and their application have been studied and benchmarked in different contexts.[KWdR03, SL16, TK11] The scope of this thesis is the performance analysis of cryptography applied to application configuration settings.

1.1 Elektra

1.1.1 What is Elektra?

The Elektra Initiative is a configuration management tool, that consists of a library and a set of programs. The core idea of Elektra is to have a centralized hierachical key-value database for configuration settings. The core of Elektra's source code is written in the C programming language. Elektra is extensible by a plugin system. Different language bindings offer availability of Elektra in other programming languages (for example: Java, Python, and Ruby). Elektra supports common configuration file formats out of the box, for example:[ele18, Raa10]

1. INI,
2. JSON,
3. XML, and
4. Yaml.

All technical details, the source code, and the documentation are available online.[1]

1.1.2 Elektra And Cryptography

We choose Elektra as our reference because of its focus on configuration and because of its extensibility. Elektra offers many features, but stores login credentials as plain text originally. Therefore during the writing of this thesis we developed plugins for Elektra that provide transparent encryption and decryption capabilities.

[1] Elektra Initiative page: `https://www.libelektra.org`

Elektra combined with the new plugins solves the problem of transparent encryption and decryption of configuration settings. This combination is the basis for our experimental evaluation.

1.2 Cryptography

In this section we define the terms cryptography, encryption and decryption.

1.2.1 Algorithms

There are many cryptographic algorithms and there are even more implementations. We can not cover them all, but focus on a typical setting that is viable for most applications.

Symmetric Cipher

The Advanced Encryption Standard (AES) is a widely used symmetric block-cipher that is specified in the Federal Information Processing Standards Publication (FIPS) 197. The FIPS 197 is published by the National Institute of Standards and Technology (NIST).[oSN01] AES supports three key lengths:

1. 128 bits,
2. 192 bits, and
3. 256 bits.

AES operates on data blocks with a size of 128 bits.[oSN01, Sta14] For the scope of this thesis we choose Cipher Block Chaining (CBC) Mode as the operation mode for AES. In CBC mode the XOR operation is applied to the plain text and the previous ciphertext block before the actual encryption happens.[Sch96, Sta14]

In this thesis we use AES with a key length of 256 bits in CBC mode as a typical symmetric cipher and refer to this combination as *AES-256-CBC*. We are going to apply AES-256-CBC to single configuration values. This enables us to protect login credentials within configuration settings.

Hybrid – Combining asymmetric and symmetric cryptography

Asymmetric ciphers tend to be slower than symmetric ciphers. To mitigate performance problems both asymmetric ciphers and symmetric ciphers are often combined into a public-key cryptographic system. Such systems utilize asymmetric cryptography to protect a key for a symmetric cipher. The symmetric cipher protects the actual data. This way the encrypted payload can be shared among multiple parties without the need to re-encrypt for every recipient.[Sta14]

The OpenPGP protocol defines such a public-key cryptographic system. It is specified in the RFC 4880.[CCD+07] We are going to apply the OpenPGP protocol to encrypt configuration files. This will protect confidential configuration settings (for example: configuration files that only hold login credentials).

1.2.2 Providers of Cryptographic Functions

We defined which cryptographic algorithms we want to examine. Next we explain which providers of cryptographic functions we want to use for the examination.

GnuPG and libgcrypt

The GnuPG project is a FLOSS implementation of the OpenPGP protocol. GnuPG supports:

1. encryption,
2. decryption,
3. digital signatures, and
4. key management.[gnu17]

The libgcrypt library is a part of the GnuPG project. The developers of GnuPG encapsulated the low-level implementations of the cryptographic algorithms within libgcrypt.

The source code of GnuPG and libgcrypt is written in the C programming language and is available at the GnuPG project homepage.[2]

OpenSSL

The OpenSSL project offers implementations of the Transport Layer Security (TLS) and the Secure Sockets Layer (SSL) protocols. It also provides its own implementations of the underlying cryptographic operations, which are accessible via the interfaces of the libcrypto library.

The source code of OpenSSL is written in the C programming language. It is available at the OpenSSL project homepage.[3]

[2] GnuPG project homepage: `https://www.gnupg.org`
[3] OpenSSL project homepage: `https://www.openssl.org/`

Botan

The Botan library is another provider of cryptographic functions. The source code is written in the C++ programming language and is available at Github.[4]

The three providers of cryptographic functions are chosen because we have the most experience with them.

1.3 Research Questions

In this thesis we examine the following research questions:

Question RQ_1**:** Which provider of cryptographic functions is the best fit when comparing the runtime and memory performance of AES-256-CBC?

Question RQ_2**:** What is the average runtime and memory overhead if AES-256-CBC is applied to configuration values?

Question RQ_3**:** What is the average runtime and memory overhead if OpenPGP encryption, and decryption are applied to configuration files?

[4]Botan's Github page: `https://github.com/randombit/botan`

CHAPTER 2

Implementation

This chapter covers the following topics:

1. concepts in Elektra that are relevant for this thesis, and
2. the plugins and enhancements we contributed to Elektra.

2.1 Elektra Concepts

First we explain the internal details of the configuration database that is provided by Elektra. Then we elaborate on how Elektra's plugin system works.

2.1.1 Key and Keyset

Elektra abstracts configuration settings in a hierarchical key-value database. A *keyset* holds zero or more keys. The *key* holds:

1. its path within the configuration hierarchy,
2. its configuration value either as a string value or as a binary value, and
3. optionally its meta-keys, which are keys that further describe the key itself.

Elektra uses meta-keys for different purposes:

1. state information of the key (for example: encrypted, encoded, ...),
2. data validation (for example: numeric value, binary value, ...), and

3. formatting (for example: position in file, number of spaces between parameters, ...).

In order to avoid ambiguity we do not use Elektra's terms in this thesis. We refer to a *configuration setting* rather than to a *keyset*. We refer to *configuration values* rather than to Elektra *keys*, in order to avoid confusion with cryptographic *keys*. From now on if we refer to a *key*, we mean a *cryptographic key*.

2.1.2 Plugin

The core of Elektra is kept small, meaning that it provides mainly the database abstraction as well as a plugin system. All the configuration access operations are performed by plugins.[Raa10] Every plugin should fulfill a single purpose. This design decision was inspired by the UNIX philosophy. Let us illustrate what plugins can do by giving some examples:

1. The `crypto` plugin encrypts and decrypts configuration values.
2. The `base64` plugin encodes and decodes binary values to and from Base64 strings.
3. The `ini` plugin reads from and writes to ini files.

Plugins can be divided into two categories:

1. filter plugins, and
2. storage plugins.

A *filter plugin* modifies configuration values before they are written to a file or after they have been read from a file. A *storage plugin* directly reads from or writes to a configuration file.

A plugin can export different methods in order to fulfill its purpose. They are enumerated below:

open

The `open` method is called to initialize the plugin.

close

The `close` method is called to properly shutdown the plugin and release all resources.

set

For storage plugins the `set` method is called when changes made to the key-value database should be persisted. Filter plugins export this method to modify the keyset (for example: encode binary values using the Base64 schema).

get

The `get` method is called when the content of the key-value database is requested by an application. Filter plugins provide this method to transform data in the keyset (for example: decoding Base64 encoded strings back into their corresponding binary value). Storage plugins typically perform read operations within this method.

checkconf

A plugin implements this method to validate the backend configuration as well as the plugin configuration. The plugin may modify the configuration or report that the configuration is incomplete or wrong in some way.

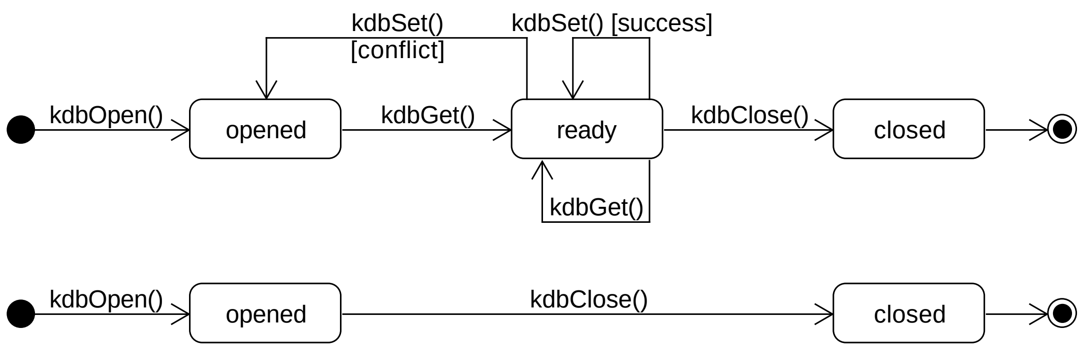
We added this method during the writing of this thesis. Its introduction was neccessary for the development of the `crypto` plugin as well as the `fcrypt` plugin.

2.1.3 Elektra State Sequence

First Elektra invokes `open` and changes its state to "opened". Afterwards Elektra can either be closed by a `close` call or the configuration can be read by calling `get`. After the first call of `get` Elektra is "ready". Now the configuration held by Elektra may be modified with a call of `set` or the data may be read again by calling `get`. After all `get` and `set` calls are done, Elektra is closed by a call of `close`.[ele18]

Figure 2.1 on page 9 illustrates how the states in Elektra change by the calls of the methods mentioned above in Section 2.1.2 on page 8.

Figure 2.1: State changes in Elektra



2.1.4 Backend

Backends are one or more plugins combined into a unit that interact with a single configuration file. The backend is mounted into Elektra's configuration hierachy. This process is similar to the mounting process in UNIX-like file systems, where a device can be mounted to a specific directory in the virtual file system. In terms of Elektra the virtual file system is the key-value database and the device is the configuration file. Every backend has its own configuration itself (i.e. backend configuration), which specifies the runtime behavior of the plugins within the backend.

2.1.5 Compilation Variants

Elektra's build scripts provide a functionality called *compilation variants*, which means a plugin is being compiled multiple times with minor differences. Let us demonstrate this idea using the `crypto` plugin. Cryptographic functions are provided by different libraries (see Section 1.2.2 on page 4) interchangeably. The basic structure of the plugin stays the same for every compilation variant except for the library-specific calls. These calls are encapsulated using C preprocessor directives, which form the actual compilation variants. Listing 2.1 on page 10 further illustrates the use of compilation variants, showing how the crypto libraries are initialized by the `crypto` plugin.

Listing 2.1: Example of how to use compilation variants in Elektra

```
static int elektraCryptoInit (Key * errorKey)
{
#if defined(ELEKTRA_CRYPTO_API_GCRYPT)
	return elektraCryptoGcryInit (errorKey);
#elif defined(ELEKTRA_CRYPTO_API_OPENSSL)
	return elektraCryptoOpenSSLInit (errorKey);
#elif defined(ELEKTRA_CRYPTO_API_BOTAN)
	return elektraCryptoBotanInit (errorKey);
#else
	return 1;
#endif
}
```

As we can see every crypto library is handled differently but the code frame of the plugin stays the same for all compilation variants.

2.2 Crypto Plugin

2.2.1 Reasons For Developing The Plugin

In order to evaluate our research questions we need a reference application with a high degree of modularity. The modularity is required to gain profound insight in the runtime behavior of the reference application. By combining different Elektra plugins we can test a variety of possible use cases.

Elektra originally did not provide any cryptographic functions when we started working on this thesis. So we decided to develop the `crypto` plugin for Elektra. The `crypto` plugin enables the use of Elektra as benchmark environment. It will help us with the research questions 1 and 2 (see Section 1.3 on page 5).

2.2.2 Benefits For The Elektra Project

Elektra is a configuration database and as such it will be used for storing sensitive configuration values (for example: login credentials) at some point. Leaving these values unencrypted is a security threat. The `crypto` plugin is a way of tackling this threat by providing transparent encryption and decryption. This means that the configuration values are stored encrypted on the filesystem and are decrypted by Elektra whenever the application requests its configuration. Thus the encryption and the decryption work transparent to both the user and the application. The `crypto` plugin can simply be added to a backend and thus integrates well with other Elektra plugins.

2.2.3 Challenges

The first challenge was to design the `crypto` plugin in a way that supports more than one provider of cryptographic functions. With the goal of comparability in mind, the encryption and decryption schema will be identical for each provider. Otherwise no conclusions can be drawn from differing benchmark results. Elektra's compilation variants enable the support for multiple providers. For every provider we want to integrate, a new compilation variant is added to the `crypto` plugin.

The next problem was how to generate, derive and restore the keys for the cryptographic functions. This part of the plugin is crucial from a security perspective. Any kind of wrongdoing in this module could lead to leaks, endangering the confidentiality of the protected data. The first design that came to mind was a password based schema that utilizes the Password-Based Key Derivation Function 2 (PBKDF2).[1] However, this approach is not suitable for any kind of batch operation as the program flow would be interrupted to ask for a password input. So we decided to delegate the handling of cryptographic keys to an existing key store: GnuPG. GnuPG in combination with the `pinentry` utilities turned out to be a great way of managing keys. In addition the users benefit from this approach because they can simply use their existing PGP keys and even smart-cards for securing their data with Elektra.

2.2.4 Technical Aspects

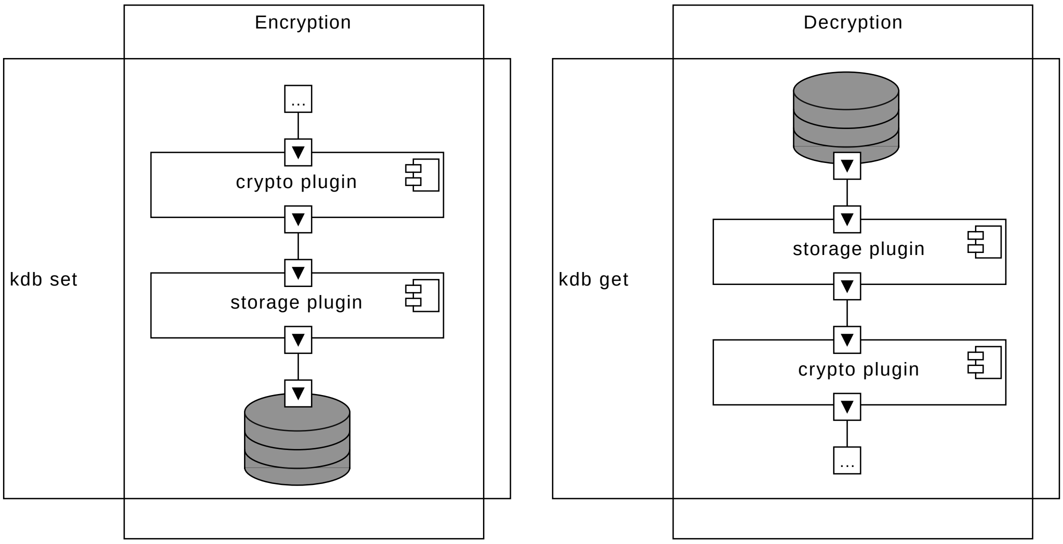
In this section we are going to dive deeper into the technical details of the implementation of the `crypto` plugin.

The `crypto` plugin acts as a filter that is applied to the configuration setting before the storage plugin reaches its `kdb set` phase. Later on, when the encrypted configuration is requested, the plugin decrypts the configuration setting after the storage plugin read

[1]PBKDF2 is specified in RFC 2898.

the configuration file in its `kdb get` phase. Figure 2.2 on page 12 further illustrates how the process works.

Figure 2.2: Crypto Plugin: Overview of the encryption and decryption process



Not all configuration values in the configuration settings are considered for encryption or decryption. The `crypto` plugin uses a meta-key to identify which configuration values have to be processed. If a meta-key with name "`crypto/encrypt`" is set to a value of "`1`" then the configuration value is marked for encryption. The plugin checks the meta-key and only encrypts values if the meta-key is set accordingly. The decryption works analogous. All other configuration values, which are not marked, are ignored and left unchanged by the `crypto` plugin.

2.2.5 Cryptographic Details

In this section we elaborate the details of how the encryption and decryption process works.

Data Structures

The `crypto` plugin defines a single data structure, which is propagated throughout the plugin:

elektraCryptoHandle is a structure that abstracts the library specific data types which hold keys and initialization data for the cryptographic functions.

Listing 2.2 on page 13 shows the definition of the `elektraCryptoHandle` for the OpenSSL plugin variant.

Listing 2.2: Definiton of elektraCryptoHandle for the OpenSSL crypto plugin variant

```
typedef struct
{
        EVP_CIPHER_CTX * encrypt;
        EVP_CIPHER_CTX * decrypt;
} elektraCryptoHandle;
```

Message Structure

The `crypto` plugin operates on configuration values. During its work it modifies the value as well as the meta-data. The value is always transformed into binary data. In order to restore the value to its original type during decryption, some header information is required.

Table 2.1 on page 13 shows the information which is encoded into the first cryptographic block during encryption.

Table 2.1: Structure of the crypto message header

element	**offset**	**length**	**data type**	**encrypted**
magic number "#!crypto"	0	8 B	character	no
payload version	8	2 B	character	no
length of the salt L_S	10	4 B	unsigned long integer	no
salt	14	L_S B	byte	no
original data type	$14 + L_S$	1 B	byte	yes
original content length	$15 + L_S$	4 B	unsigned long integer	yes

The salt is a sequence of random bytes and is used in cryptography to prevent table-based key guessing attacks. The content length is saved because most provider of cryptographic functions do not support padding out of the box, which means that they always operate on whole blocks of data, where the block size depends on the cryptographic algorithm that is used.

Key Derivation

As mentioned before, GnuPG is used for managing the users' asymmetric keys. GnuPG is executed to store and receive a *master password*, which is a part of the plugin configuration of the `crypto` plugin. Whenever a cryptographic key is required, the master password is fetched from the plugin configuration and decrypted using GnuPG. Then the PBKDF2 is applied to the decrypted master password together with the salt, so that a cryptographic key as well as an initialization vector can be derived.

Crypto Plugin Methods

The `crypto` plugin implements the following Elektra's plugin methods (see Section 2.1.2 on page 9). In the following section the program flow of the plugin methods is explained.

open initializes the provider of cryptographic functions.

close properly shuts down the provider of cryptographic functions.

get The `get` method takes a configuration setting as input. The `crypto` plugin iterates over the configuration setting and checks for every configuration value if it has been encrypted. This is done by using the meta-key mentioned before. If the configuration value is encrypted, the `crypto` plugin decrypts it and thus restores the configuration value to the original state it was in before the encryption took place.

Figure 2.3 on page 15 illustrates how the `get` method works in detail.

set The `set` method takes a configuration setting as input. The `crypto` plugin iterates over the configuration setting and checks every configuration value if it has been marked for encryption. Marking a configuration value for encryption is done by using a meta-key. If the meta-key is present, the `crypto` plugin generates a message header (see Section 2.2.5 on page 13) including a random salt and encrypts the configuration value.

Figure 2.4 on page 16 illustrates how the `set` method works in detail.

checkconf The `checkconf` method ensures that a master password is available in the plugin configuration of the `crypto` plugin. If an encrypted master password is provided, a decryption run is started to see if the user owns the required GnuPG private key. If no master password exists, a random master password is created, encrypted using GnuPG and stored in the plugin configuration.

The GnuPG key ID, that is used for encrypting and decrypting the master password, has to be specified within the plugin configuration. If no such GnuPG private key is specified, the `crypto` plugin generates an error message.

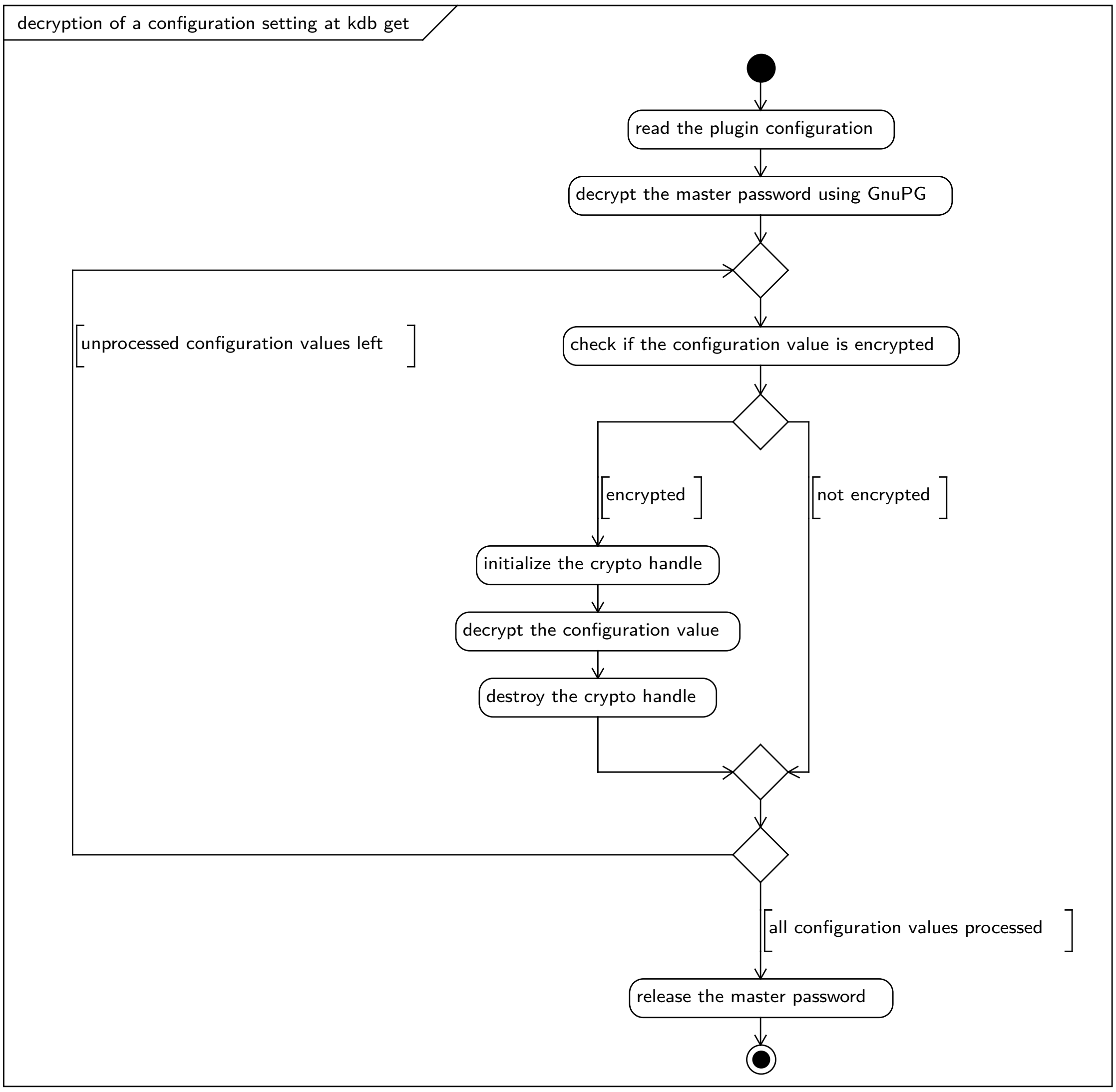
Figure 2.5 on page 17 illustrates how the `checkconf` method works in detail.

Compilation Variants

For every provider of cryptographic functions (see Section 1.2.2 on page 4) a compilation variant of the `crypto` plugin is created. The following compilation variants exist:

1. `crypto_gcrypt` for libgcrypt
2. `crypto_openssl` for the OpenSSL library
3. `crypto_botan` for the Botan library

Figure 2.3: Crypto Plugin: Decryption of a configuration setting at the kdb get method



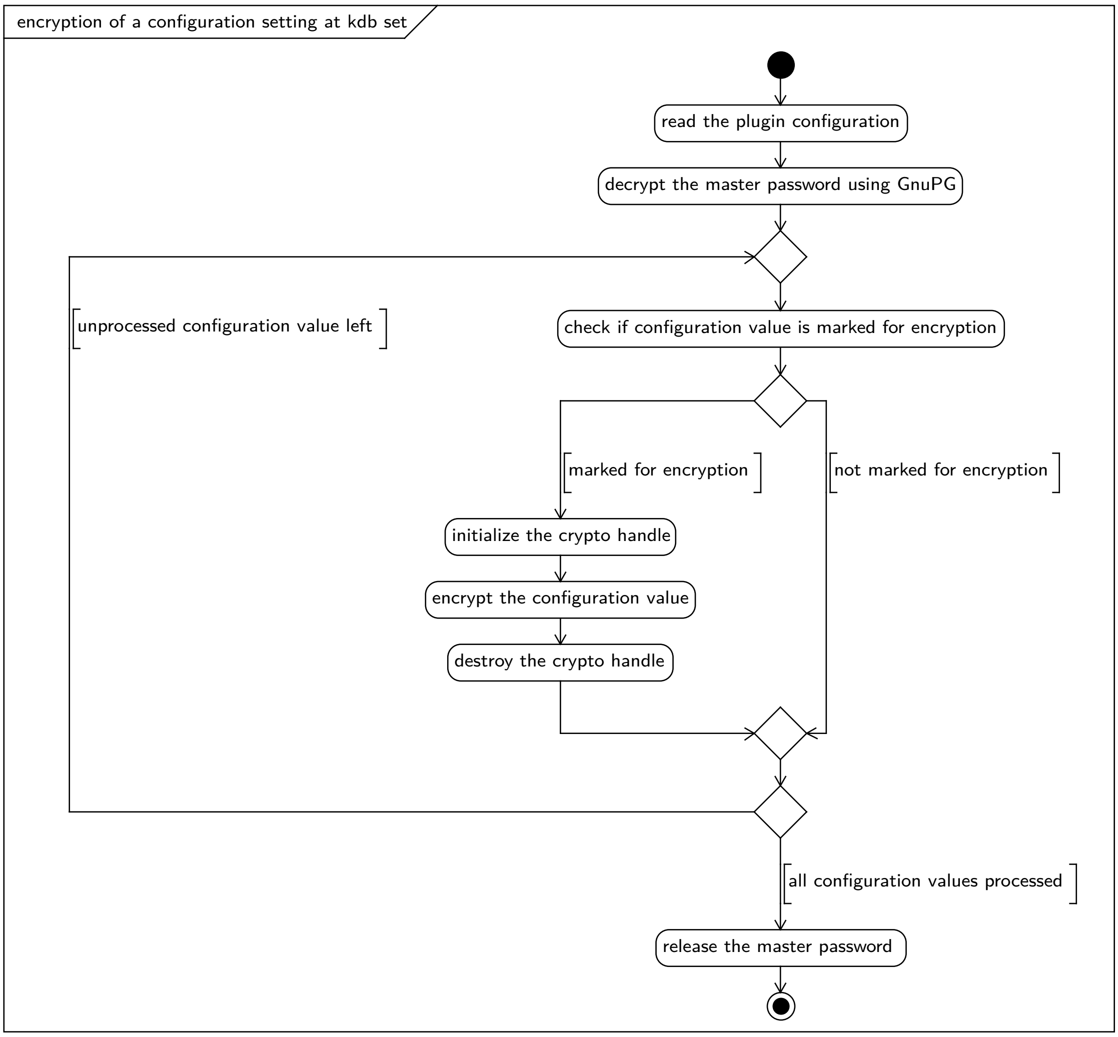
2.2.6 Details About The Providers of Cryptographic Functions

In this section we explain the details about the provider of cryptographic functions, which are relevant for the performance of the `crypto` plugin.

libgcrypt

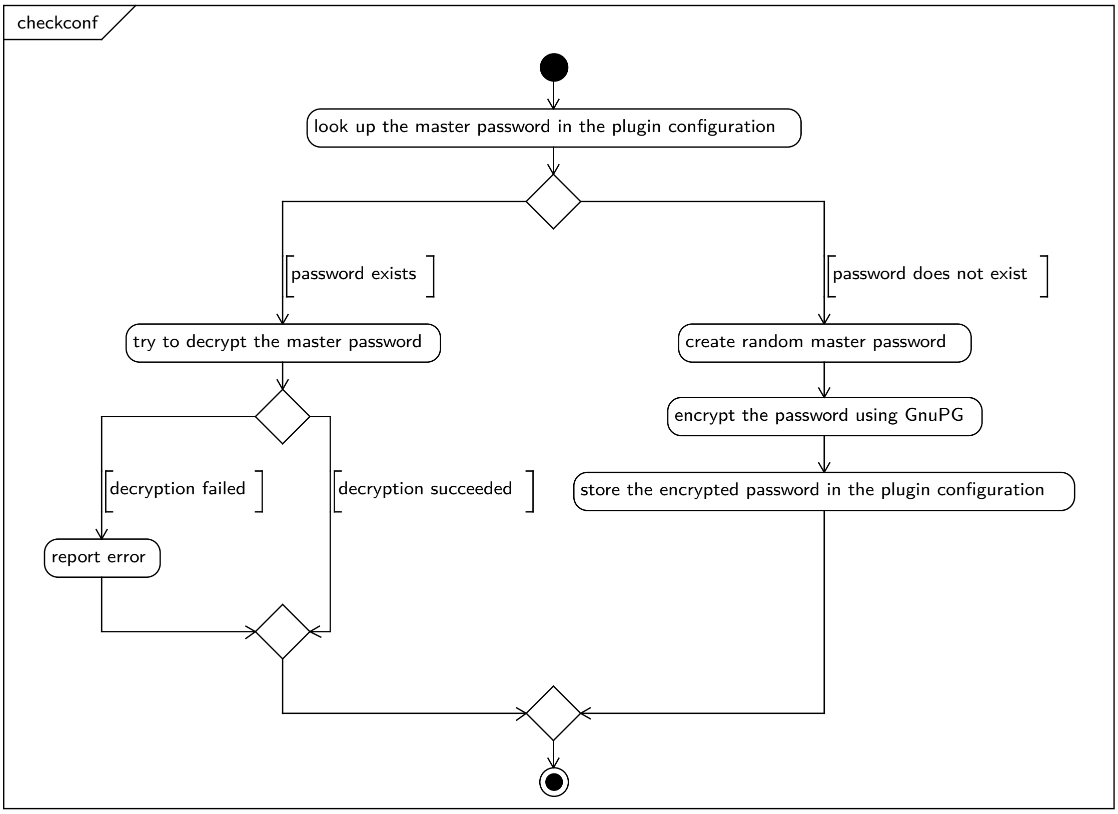
libgcrypt provides the data structure `gcry_cipher_hd_t` for communicating cryptographic keys to the API, thus it is used directly as `elektraCryptoHandle`.

Figure 2.4: Crypto Plugin: Encryption of a configuration setting at the kdb set method



libgcrypt does not provide any internal mechanism for data manipulation, meaning it operates directly on memory buffers. Encryption and decryption happen in-place, so only a single buffer is used. Before the encryption call the buffer holds the plain text. After a successful encryption call the buffer holds the cipher text. Decryption works analogous. The size of the buffer must be a multiple of a block, thus it depends on the cryptographic algorithm in use. For AES-256-CBC the buffer size must be set to 16 bytes (128 bits).[gnu17]

Figure 2.5: Crypto Plugin: The kdb checkconf method



OpenSSL

OpenSSL exports the data structure `EVP_CIPHER_CTX` for communicating cryptographic keys to the API. The definition of the `elektraCryptoHandle` structure has already been shown in listing 2.2 on page 13.

OpenSSL provides the `BIO` API for data manipulation. The `BIO` API is basically an I/O stream abstraction for handling data streams and data transformation. We use the `BIO` API for temporarily storing the encrypted/decrypted content. Listing 2.3 on page 18 demonstrates how encryption works in OpenSSL and how the `BIO` API is used for storing the encrypted content.

Listing 2.3: Encryption in the OpenSSL crypto plugin variant

```
BIO * encrypted = BIO_new (BIO_s_mem ());

EVP_EncryptUpdate (encrKey, cipherBuffer,
        &written, plainTxt, plainTxtLen);
if (written > 0)
{
        BIO_write (encrypted, cipherBuffer, written);
}
```

Botan

Since Botan is written in the C++ programming language the encryption and decryption process is encapsulated into classes. The cryptographic key is represented by the class `SymmetricKey` and the initialization vector is represented by the class `InitializationVector`.

Botan provides an API for data manipulation, similar to OpenSSL. A `Pipe` abstracts I/O operations in Botan. We use the `Pipe` for encryption and decryption by attaching a corresponding filter to the `Pipe`.

Listing 2.4 on page 18 shows an example of how the encryption works in Botan.

Listing 2.4: Encryption in the Botan crypto plugin variant

```
// initialize the pipe
Pipe encryptor (get_cipher ("AES-256/CBC",
        *cryptoKey, *cryptoIv, ENCRYPTION));

// encrypt the message
encryptor.start_msg ();
encryptor.write (static_cast<const byte *> (&plainTxt),
        sizeof (byte));
encryptor.end_msg ();

// receive the encrypted data
const size_t msgLength = encryptor.remaining ();
const size_t buffered = encryptor.read (buffer, msgLength);
```

2.3 Fcrypt Plugin

2.3.1 Reasons For Developing The Plugin

Elektra did not provide any facilities to encrypt or decrypt configuration files as a whole. Also there was no way of signing configuration files. The `fcrypt` plugin was developed during the writing of this thesis to provide these two features:

1. file based encryption and decryption using GnuPG
2. file based signatures using GnuPG

Both features can be used separately and they can be combined together.

The `fcrypt` plugin will help us with research questions 3 (see Section 1.3 on page 5).

2.3.2 Benefits For The Elektra Project

GnuPG has been around for a long time. With the `fcrypt` plugin users can combine a well known and established public key cryptographic system together with Elektra's configuration capabilities.

The `fcrypt` plugin does not have any compile-time dependencies. Only the `gnupg` or `gnupg2` binary is required at runtime. Both versions of GnuPG (version 1 and version 2) are supported.

2.3.3 Technical Aspects

The `fcrypt` plugin uses GnuPG as provider of cryptographic functions for all its operations. Doing so the plugin acts as a connector between Elektra and GnuPG, but it can also be seen as frontend to GnuPG. All invocations that the `fcrypt` plugin produces can be executed in a shell without Elektra. The invocations rely on the `fork` and the `execv` system functions.

File Based Encryption and Decryption

The `kdb set` method of the `fcrypt` plugin provides the encryption capabilities. Listing 2.5 demonstrates how a typical encryption call will look like.

Listing 2.5: Fcrypt: encryption command

```
gpg2 --batch -o /tmp/config.asc --yes -r 7F230E8D -e /tmp/plaintext.ini
```

The decryption is done in a similar way and is implemented in the `kdb get` method. Listing 2.6 demonstrates how a typical decryption call will look like.

Listing 2.6: Fcrypt: decryption command

```
gpg2 --batch -o /tmp/plaintext.ini --yes -d /tmp/config.asc
```

File Based Signatures

The signature — like the encryption — is created in the `kdb set` method. If a signature is requested, the `fcrypt` plugin appends the private key with the `-u` command line option of GnuPG. Also the `--clearsign` or the `-s` switch is added to the GnuPG command line options.

Listing 2.7 provides an example of how a signature call to GnuPG can look like.

Listing 2.7: Fcrypt: signature command

```
gpg2 --batch -o /tmp/config.asc --yes -u 7F230E8D \
        --armor --clearsign /tmp/plaintext.ini
```

The verification of the signatures works like a regular decryption, which has already been shown in Listing 2.6 on page 19.

2.4 Base64 Plugin

2.4.1 Motivation and Functionality

The `crypto` plugin causes trouble in text-only configuration file formats like INI, as it produces binary data. To mitigate this problem we developed the `base64` plugin.

During the `kdb set` method the `base64` plugin iterates over the configuration setting and encodes all binary values using the Base64 schema, which is specified in the RFC 4648.[JS16] During the `kdb get` method the `base64` plugin decodes all Base64 strings back to its binary representatiton.

In order to distuingish between Base64 strings and other strings, the prefix `@BASE64` is added to each Base64 encoded string.

2.4.2 Base64 Examples

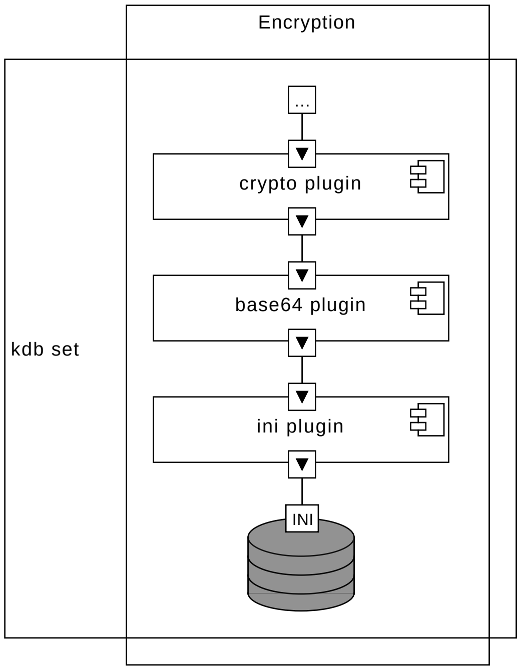
Figure 2.6 on page 21 shows an example of an Elektra backend configuration with the `crypto` plugin and the `base64` plugin.

Listing 2.8 on page 20 demonstrates how an INI file, that has been produced by the backend described in Figure 2.6 on page 21, might look like.

Listing 2.8: Base64 example INI output

```
[section1]
#@META crypto/encrypt = 1
optionA = @BASE64IyFjcnlwdG8wMBEAAACFq0cCnjyfuwVy9/VtcpYCceYJVmnyTfF...
```

Figure 2.6: Base64 Plugin: Example backend configuration with the base64 plugin



2.5 Implementation Summary

This chapter explained the Elektra plugin system and how we used it to introduce cryptographic methods to the Elektra project. We learned about the contributions that were made to Elektra during the writing of this thesis. We have an understanding of the `crypto` plugin, the `fcrypt` plugin and the `base64` plugin. Now we have a complete set of plugins to start the evaluation.

CHAPTER 3

Applications

In this chapter we present how the `crypto` plugin and the `fcrypt` plugin solve the problem of:

1. transparently encrypting/decrypting configuration values in a configuration setting with Elektra, and
2. transparently encrypting/decrypting entire configuration files with Elektra.

Finally we demonstrate how the `base64` plugin and the `crypto` plugin are combined to protect configuration values within an INI-file.

3.1 Encrypted Configuration Values With Elektra

This scenario covers how a password is protected inside a configuration setting using Elektra with the `crypto` plugin. First of all, we add the `crypto` plugin to the backend. Listing 3.1 demonstrates how a backend is mounted with the `crypto` plugin enabled. Note that `DDEBEF9EE2DC931701338212DAF635B17F230E8D` refers to the GnuPG key that is used to protect the master password. In Section 2.2 on page 10 we explain in detail how the `crypto` plugin works.

We use the `crypto_gcrypt` plugin variant in this chapter. The other plugin variants `crypto_openssl`, and `crypto_botan` operate the same way. It is possible to exchange the plugin variants of the `crypto` plugin seamlessly.

Listing 3.1: Mounting an Elektra backend with the `crypto` plugin

```
kdb mount demo.ecf user/demo crypto_gcrypt \
    "crypto/key=DDEBEF9EE2DC931701338212DAF635B17F230E8D"
```

Now we have a backend mounted and we can add configuration values to it. We store the password under `user/demo/password` in our configuration. First we tell the `crypto` plugin to encrypt the password by setting the meta-key `crypto/encrypt` to `1`.

Listing 3.2 shows how the password is marked for encryption and how it is stored within the configuration.

Listing 3.2: Marking a configuration value for encryption

```
kdb setmeta user/demo/password crypto/encrypt 1
kdb set user/demo/password "secret"
```

As a result the password "secret" is being stored as encrypted binary string in the configuration file. In Listing 3.3 we show how the password is received from the configuration.

Listing 3.3: Receiving an encrypted configuration value

```
kdb get user/demo/password
```

3.2 Encrypted Configuration Files With Elektra

Our second scenario shows how an entire configuration file is encrypted with the `fcrypt` plugin. Like in the previous section, `DDEBEF9EE2DC931701338212DAF635B17F230E8D` refers to the GnuPG key that is used for encrypting and decrypting the configuration file. See Section 2.3 on page 18 for further details about the `fcrypt` plugin.

Listing 3.4 demonstrates how an Elektra backend is mounted with the `fcrypt` plugin enabled.

Listing 3.4: Mounting an Elektra backend with the `fcrypt` plugin

```
kdb mount fcrypt.ecf user/fcrypt fcrypt \
    "encrypt/key=DDEBEF9EE2DC931701338212DAF635B17F230E8D"
```

As opposed to the `crypto` plugin, the `fcrypt` plugin does not require to set any meta-keys, because it encrypts the entire configuration file. Listing 3.5 shows how configuration values are added to the configuration setting.

Listing 3.5: Adding configuration values with the `fcrypt` plugin

```
kdb set user/fcrypt/password "entirely.secret"
```

The resulting configuration file is a valid GnuPG file and can not only be decrypted by Elektra but also with GnuPG directly.

3.3 Protecting a Password inside an INI-File

It is hardly feasible for configuration files to contain binary data (for example: INI or XML). In this scenario we demonstrate how to add the `base64` plugin to the backend, so that all binary values are transformed into Base64 strings. All technical details about the `base64` plugin were given in Section 2.4 on page 20.

Listing 3.6 shows how an INI-file is mounted together with the `crypto` plugin, and the `base64` plugin plugins.

Listing 3.6: Mounting an INI-file with the `crypto` plugin and the `base64` plugin

```
kdb mount test.ini user/test crypto_gcrypt \
    "crypto/key=DDEBEF9EE2DC931701338212DAF635B17F230E8D" \
    base64 ini
```

We add our password under `user/test/password`, analogous as shown in Listing 3.2 before. The resulting INI-file is presented in Listing 3.7.

Listing 3.7: Encrypted values in an INI-file

```
#@META crypto/encrypt = 1
password = @BASE64IyFjcnlwdG8wMBEAAADwPI+lqp+X2b6BIfLdRYgwxmAhVUPurqk \
QVAI78Pn4OYONbei4NfykMPvx9C9w91KT
```

CHAPTER 4

Experimental Evaluation

The focus of this chapter is:

1. the setup of the benchmark system,
2. the definition of the benchmarks, and
3. the results of the benchmarks.

4.1 Benchmark System

4.1.1 Hardware Setup

The processor of the benchmark system is an Intel® Core™ i7-4771 CPU that is clocked at 3.50 GHz. The processor has 4 cores and hyperthreading enabled (which means that 8 threads are available). The benchmark system has a total amount of 16 GB of DDR3 RAM installed. The RAM is clocked at 1333 MHz.

The root partition of the operating system is located on a "Samsung SSD 840" solid state drive (SSD). It is installed on an ext4 filesystem.

The `hdparm` program gives an idea of how much throughput the SSD can handle. The results are listed in the table 4.1 on page 27.

Table 4.1: Read performance of the benchmark SSD

	data read	**time**	**result**
Timing cached reads	28536 MB	1.99 s	14316.64 MB/s
Timing buffered disk reads:	1608 MB	3.00 s	535.47 MB/s

All benchmarks are performend on the SSD.

4.1.2 Software Setup

The operating system Fedora 27 is used for executing the benchmarks. Elektra version 0.8.21 at the git commit `dfa9bb8`[1] is installed on the system.

The most important program versions are listed below:

- clang version 5.0.1 (tags/RELEASE_501/final)
- Botan version 1.10.17-1.fc27
- OpenSSL version 1.1.0g-1.fc27
- libgcrypt version 1.8.2-1.fc27
- GnuPG version 2.2.4-1.fc27

Listing 4.1 shows how Elektra is compiled on the benchmark system.

Listing 4.1: Elektra compile options for the benchmarks

```
mkdir build && cd build
cmake -GNinja \
    -DBUILD_STATIC=OFF \
    -DCMAKE_C_COMPILER=clang \
    -DCMAKE_CXX_COMPILER=clang++ \
    -DBUILD_DOCUMENTATION=OFF \
    -DCMAKE_INSTALL_PREFIX=/usr \
    ..
ninja install
```

4.1.3 Time Measurement

The runtime of a benchmark is measured using the system time, which is returned by the system function `gettimeofday ()`. The time measurement is abstracted in a class called `Timer`. Listing 4.2 on page 29 demonstrates how a benchmark is written.

[1]The full commit hash is dfa9bb89ada39996cac5c1abd21481e1e2181ad9.

Listing 4.2: Time measurement for the benchmarks

```
void do_benchmark ()
{
  Timer t();

  // begin of measurement
  t.start ();

  action_to_be_measured ();

  // end of measurement
  t.end ();
}
```

4.1.4 Statistical Method

Every benchmark run is repeated 11 times. For the sorted set of results $\{r_1, ..., r_{11} | r_n \leq r_{n+1}\}$ the median $\tilde{x}$ is given as: $\tilde{x} = r_6$.

The median is chosen as measurement result because of its robustness against outliers. When we speak of the result of a benchmark, we always refer to the median $\tilde{x} = r_6$ of the 11 benchmarks runs.

4.2 Benchmark 1 – Runtime Comparison

This benchmark examines the runtime performance of the `crypto` plugin. The benchmark compares the duration of the `kdb set` and `kdb get` methods:

1. without the `crypto` plugin,
2. with the `fcrypt` plugin,
3. with the `crypto_openssl` plugin variant,
4. with the `crypto_gcrypt` plugin variant, and
5. with the `crypto_botan` plugin variant.

For each benchmark variant an Elektra backend is set up. For every backend a configuration setting with a preset size is generated. First the duration of the `kdb set` method of Elektra is being measured, which represents the performance of the encryption process. Then the duration of the `kdb get` method of Elektra is being measured, which represents the performance of the decryption process. The benchmark is repeated with the following configuration setting sizes:

{1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 15, 17, 20, 25, 30, 31, 32, 35, 40, 50, 51, 52, 55, 56, 57, 60, 70, 80, 90, 100, 150, 175, 200, 250, 300, 350, 400, 500, 1000}.

For better reproducibility we provide a script, that executes the benchmark as we do in this thesis. The script is available at Github[2].

4.2.1 Benchmark Code

The source code of the benchmark is distributed with Elektra, and it is located at `libs/tools/benchmarks/benchmark_crypto_comparison.cpp`.

Listing 4.3 on page 30 is an excerpt of the benchmark code. The listing gives an idea about how the measurement is accomplished. The listing has been slightly modified to improve readability, but the execution flow has not been altered.

Listing 4.3: Excerpt of Benchmark 1

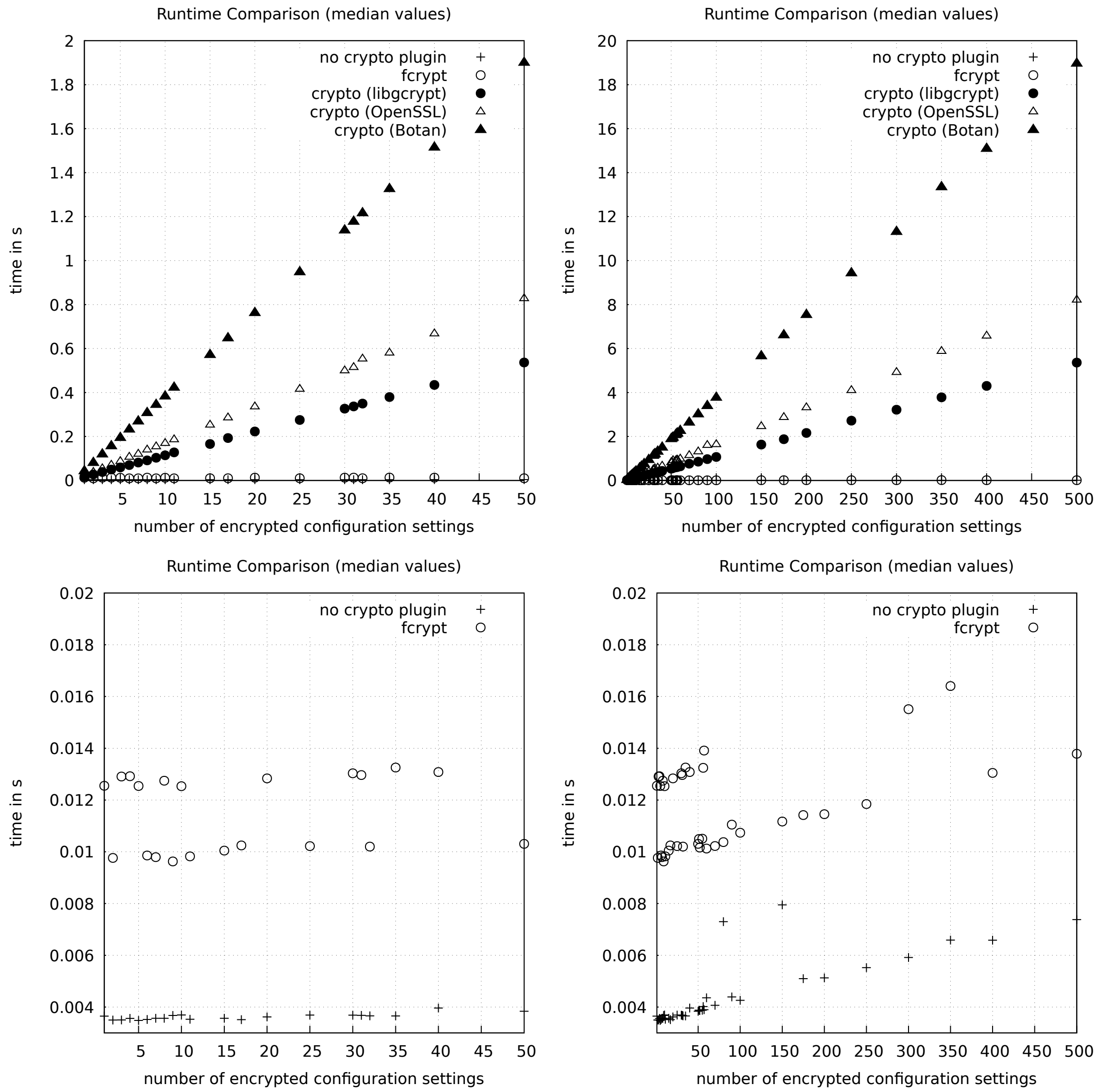
```
static Timer t (plugin_variant_names[VARIANT]);
Key mp = mountBackend<VARIANT> (iteration);
{
  KDB kdb;
  KeySet ks;

  kdb.get (ks, mp);
  // n = size of the configuration setting
  for (int i = 0; i < n; ++i)
  {
    ks.append (Key (mp.getName () + "/k" + std::to_string (i),
      KEY_VALUE, "value",
      KEY_META, "crypto/encrypt", "1",
      KEY_END));
  }

  t.start (); // start of the measurement
  kdb.set (ks, mp);
  t.stop (); // end of the measurement

  kdb.close ();
}
std::cout << t;
```

[2] `https://github.com/petermax2/libelektra-crypto-benchmarks/blob/master/scripts/start-crypto-comparison.sh`

4.2.2 Results of the Runtime Comparison

The runtime results of all benchmark runs are listed in Chapter A on page 47. The results are also published at Github[3]. Figure 4.1 on page 31 compares the benchmark results of all tested variants for the `kdb set` method. Figure 4.2 on page 32 provides a comparison of the benchmark results of all tested variants for the `kdb get` method.

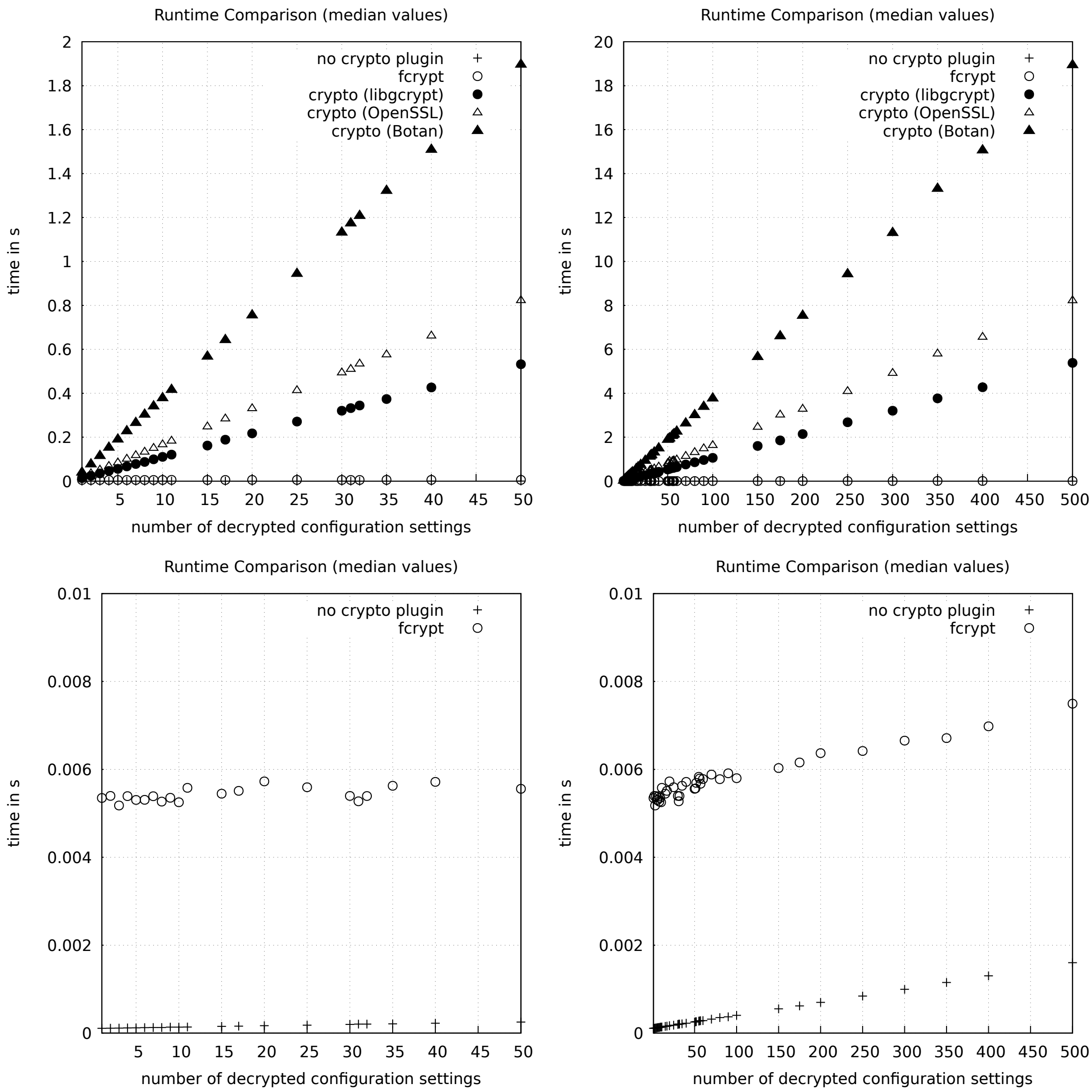
Figure 4.1: Runtime comparison of `kdb set`



As we can see from the benchmark results, the runtime behavior has a tendency to

[3] `https://github.com/petermax2/libelektra-crypto-benchmarks/tree/master/results`

Figure 4.2: Runtime comparison of `kdb get`



increase linearly with the number of encrypted/decrypted configuration values.

The boxplot in Figure 4.3 on page 34 shows that the benchmark results for the `kdb set` are stable. There are no noteworthy outliers. Figure 4.4 on page 35 reveals analogous insights for the `kdb get` method.

4.3 Benchmark 2 – Memory Analysis

This benchmark examines the memory allocations of the `crypto` plugin . The benchmark code is the same as for Benchmark 1 (see Section 4.2 on page 29).

4.3.1 Massif Analysis

The benchmark code of benchmark 1 is analysed using Valgrind's Massif tool. Massif-Visualizer is used to produce a visualization of the data, that is collected by Massif.

The benchmark is started with the following configuration setting sizes n:

$\{10, 100, 200\}$.

4.3.2 Results of the Memory Analysis

The results of the memory analysis are published on Github [4].

The following figures show the visualizations, that have been produced by Massif-Visualizer:

- Figure 4.5 on page 36,
- Figure 4.6 on page 37, and
- Figure 4.7 on page 38.

The memory analysis reveals a constant memory consumption overhead for OpenSSL and Botan. Libgcrypt does not use a custom allocator function, so its memory use is not distinguishable from the rest of the memory, that has been allocated by Elektra.

Table 4.2 on page 33 shows the results for OpenSSL and Botan.

Table 4.2: Allocated heap sizes of the crypto plugins

	memory heap size
libgcrypt	not available
OpenSSL	70.0 kiB
Botan	64.0 kiB

[4] https://github.com/petermax2/libelektra-crypto-benchmarks/tree/master/massif

Figure 4.3: Boxplots of the `kdb set` runtime with $n = 500$ configuration settings

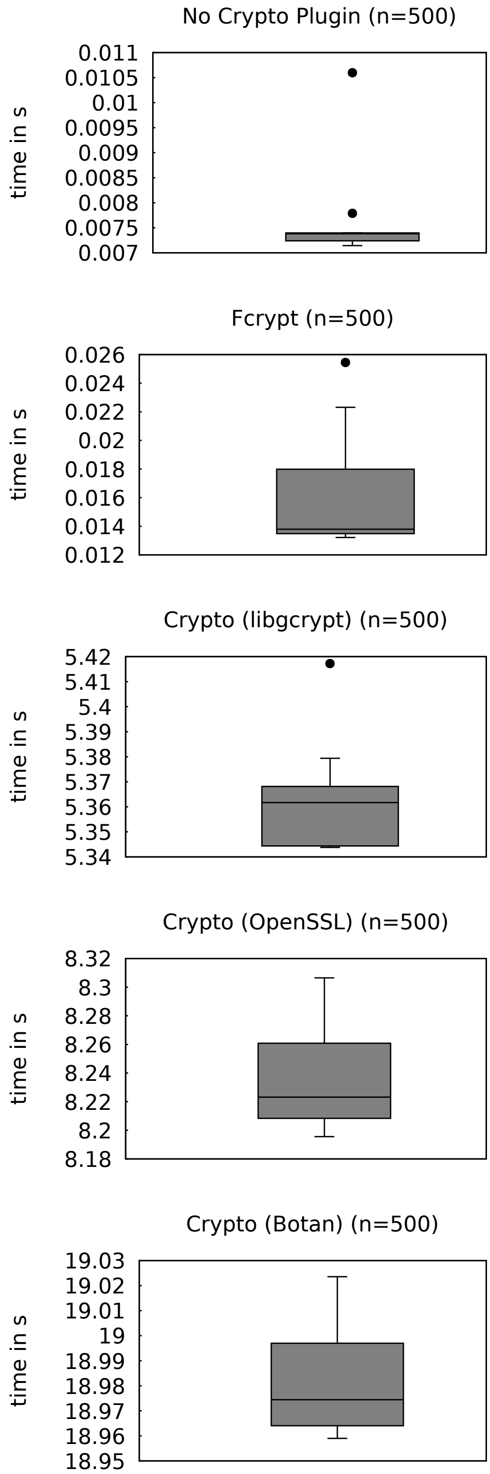
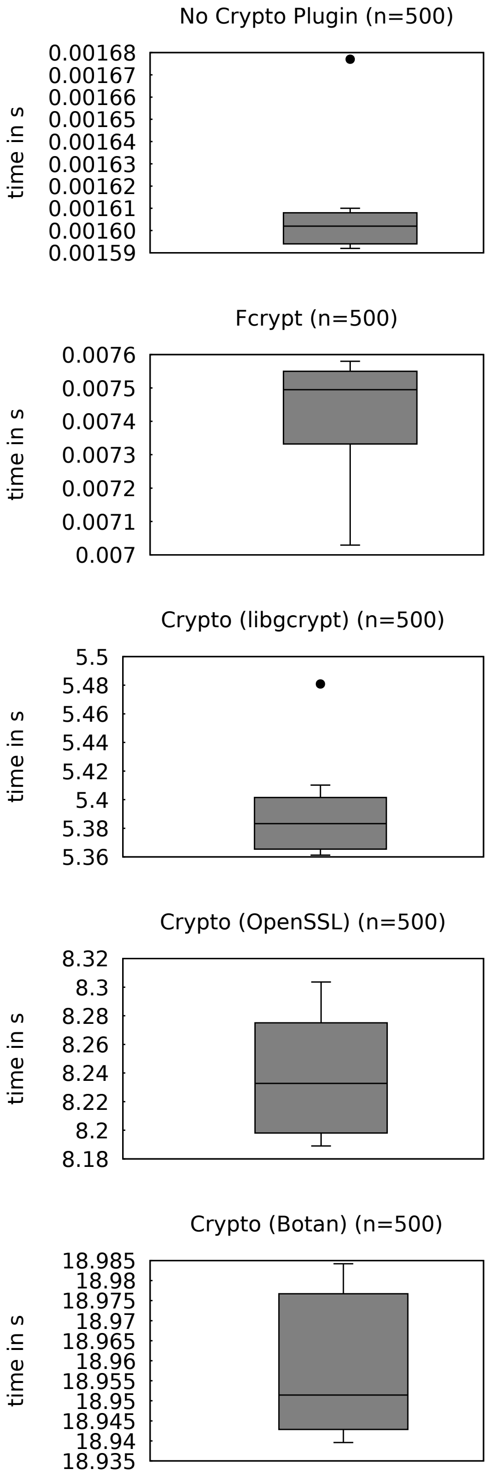


Figure 4.4: Boxplots of the `kdb get` runtime with $n = 500$ configuration settings



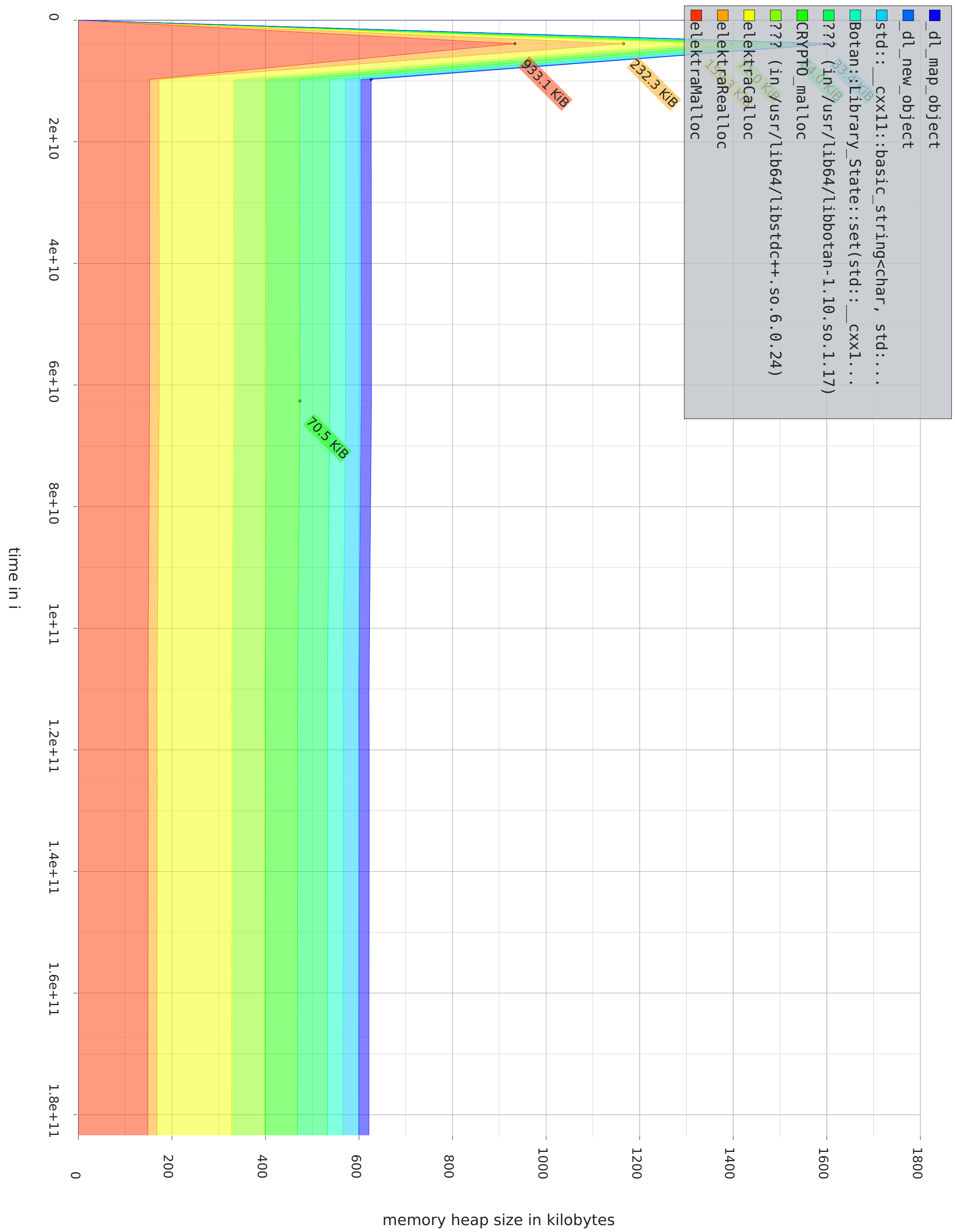


Figure 4.5: Result Of The Memory Analysis with $n = 10$ configuration settings

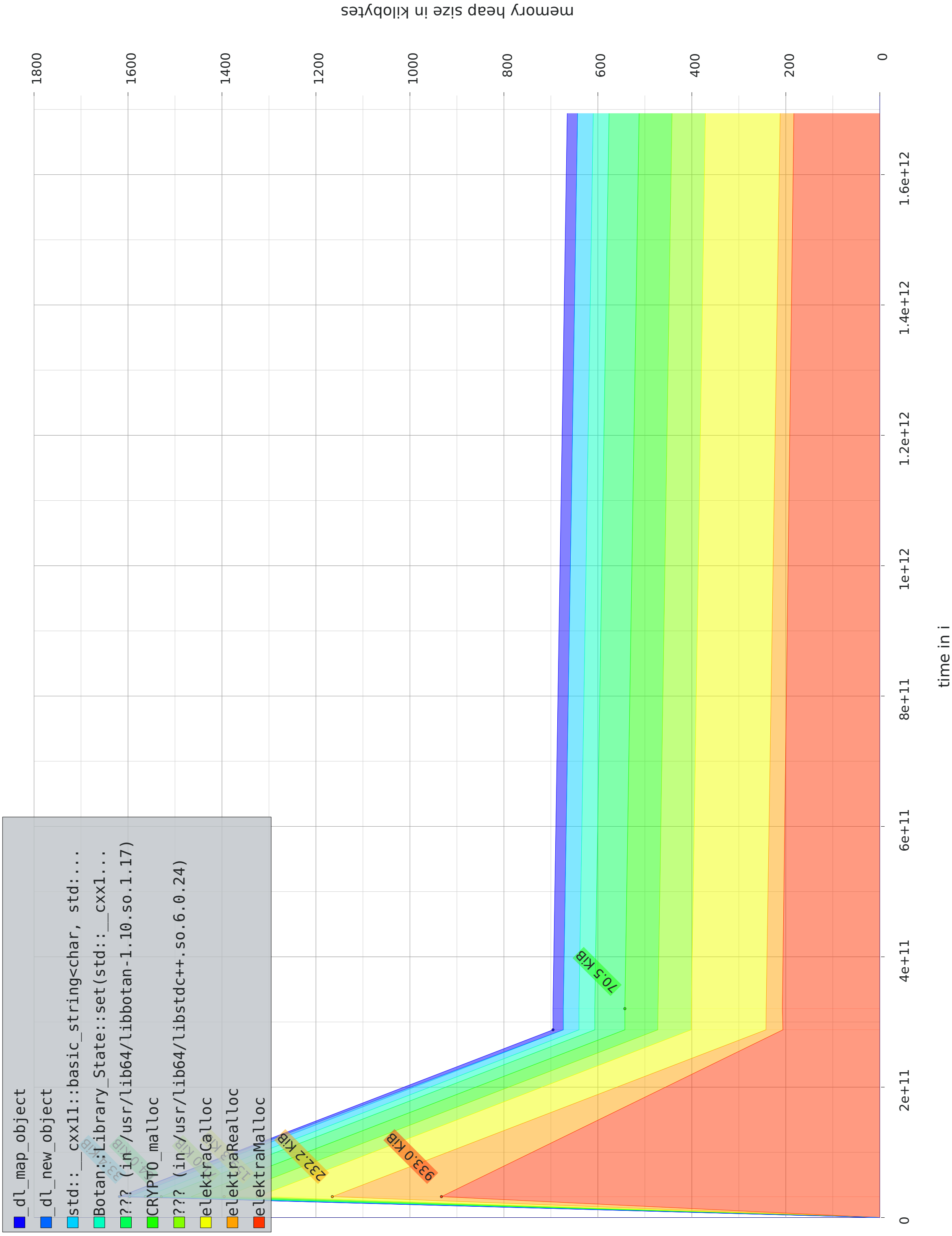


Figure 4.6: Result Of The Memory Analysis with $n = 100$ configuration settings

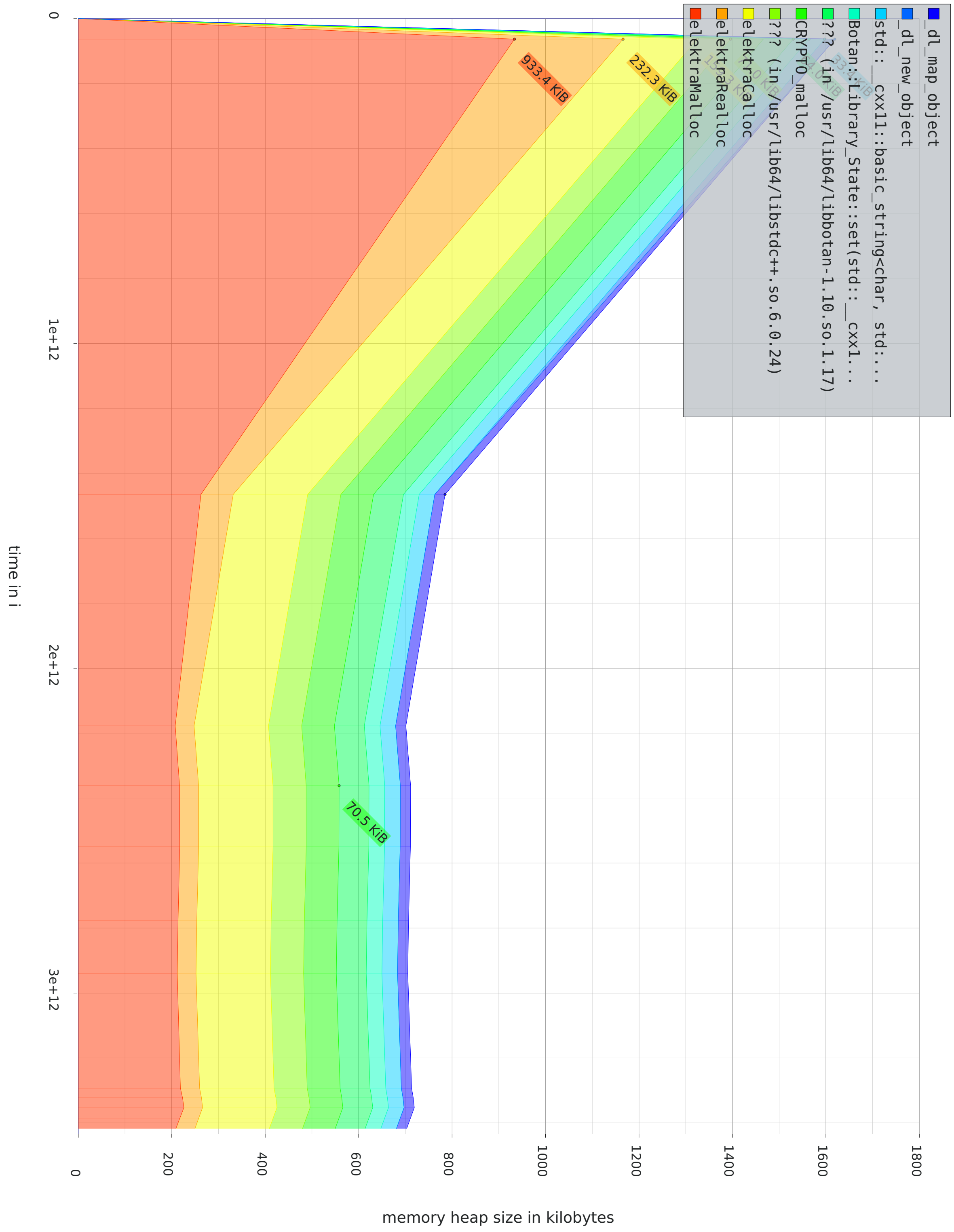


Figure 4.7: Result Of The Memory Analysis with $n = 200$ configuration settings

CHAPTER 5

Related and Future Work

5.1 Related Work

Performance analysis of cryptographic operations has already been studied in different contexts.

5.1.1 Comparing AES Implementations

The paper ”DES, AES and Blowfish: Symmetric Key Cryptography Algorithms Simulation Based Performance Analysis“ [TK11] compares implementations of symmetric cryptographic algorithms. The authors' goal is to find the most performant algorithm. However, the paper does not answer how much overhead the introduction of cryptographic methods actually costs.[TK11]

5.1.2 Cryptography in Operating Systems

In ”The Design of the OpenBSD Cryptographic Framework“ [KWdR03] developers of OpenBSD describe their kernel interface that abstracts the use of hardware accelerated cryptographic operations. The authors mainly argue about the performance gain the OCF brings to applications. But rather than concentrating on a single application the focus of the paper is overall system performance in scenarios where multiple applications perform cryptographic operations simultaneously. Another aspect the paper covers is the load-balancing capability OCF has to offer, if multiple hardware acceleration cards are available on a system.

The paper's focus is the kernel and operating system performance rather than single application performance. The paper measures speed-up in comparison to cryptographic operations performed in user-space.[KWdR03]

”Improving High-Bandwidth TLS in the FreeBSD kernel“ [SL16], another performance study, has been conducted by FreeBSD developers. They tried to get higher TLS throughput on their high-performance network appliances for Netflix, a video on-demand streaming service. The focus of the paper is the networking aspect considering different network adapters and tuning options in the FreeBSD kernel. Again the focus is not a single application but rather the improvement of the TLS stack in the FreeBSD operating system.[SL16]

5.2 Future Work

In this section we suggest further research topics, which we could not cover within this thesis.

5.2.1 Cryptographic Schemas without GnuPG

GnuPG is a great solution for cryptographic systems, because of its key handling capabilities and its integration with Smart Cards. However, other cryptographic schmeas should be inspected and evaluated as well.

An example of another key handling form is to use simple key files. This method may be less secure but may be much faster than the GnuPG based cryptographic schema.

5.2.2 Other criteria for choosing providers of cryptographic functions

Performance is not the only factor to be taken into account when choosing a provider of cryptographic functions. Robustness against attacks (for example: side channel attacks) and correctness of the code are two important dimensions, that should also be considered.

Also the usability and the user acceptance play an important role in the decision process. We did not cover any of those aspects due to the limited context of the thesis.

5.2.3 Cryptographic Signatures

Cryptographic signatures present a way of detecting unauthorized configuration changes.[Sch96] Further studies might examine:

1. the performance impact of cryptographic signatures in the context of configuration, and
2. applications of cryptographic signatures.

CHAPTER 6

Conclusions

6.1 Findings

6.1.1 Hypotheses Are Not Refuted

In Chapter 1 on page 1 we formulated two hypotheses, which we can not refute after the evaluation.

Hypothesis H_1: Introducing cryptography to an application increases the runtime of the application.

The evaluation revealed a linear increase in runtime in the interval of $[1, 1000]$ configuration settings. We can not refute H_1 with our benchmark results.

Hypothesis H_2: Introducing cryptography to an application increases the memory consumption of the application.

The evaluation shows a measureable but constant memory overhead in the interval of $[1, 200]$ configuration settings. We can not refute H_2 with our benchmark results.

6.1.2 Answers to the Research Questions

In Section 1.3 on page 5 we defined our research questions. After what we learned during the evaluation we are able to give some answers.

Question RQ_1: Which provider of cryptographic functions is the best fit when comparing the runtime and memory performance of AES-256-CBC?

When comparing the following providers of cryptographic functions:

1. libgcrypt,
2. OpenSSL, and
3. Botan,

libgcrypt has to lowest runtime impact in the interval of $[1, 1000]$ configuration settings.

The lowest memory impact could not be found in the evaluation, because libgcrypt does not use a custom allocator. When comparing OpenSSL against Botan with $n \in \{10, 100, 200\}$ configuration settings, Botan allocates 6.0 kiB less heap memory.

Question RQ_2**:** What is the average runtime and memory overhead if AES-256-CBC is applied to configuration values?

Let i be the number of configuration settings in a benchmark result. Let x_i denote the runtime without the `crypto` plugin. Furthermore let y_i denote the runtime with a plugin variant of the `crypto` plugin. Then the overhead h_i is given as: $h_i = y_i - x_i$.

Let n be the number of measurements. Then the average runtime overhead h is given as: $h = (1/n) \sum_{i=1}^{n} (y_i - x_i)$.

The average runtime overhead factor f is given as: $f = (1/n) \sum_{i=1}^{n} (y_i / x_i)$.

Table 6.1 on page 42 shows the overhead h for every plugin variant of the `crypto` plugin in the interval $[1, 1000]$ configuration settings.

Table 6.1: Average overhead of the `crypto` plugin

	Decryption		Encryption	
	h (s)	f	h (s)	f
libgcrypt	1.168 s	1837.868	1.171 s	192.912
OpenSSL	1.805 s	2835.492	1.808 s	297.236
Botan	4.125 s	6459.077	4.124 s	675.795

The question for the memory overhead can only be partially answered, due to the lack of a custom allocating function in libgcrypt. The results are given in Table 4.2 on page 33.

Question RQ_3**:** What is the average runtime and memory overhead if OpenPGP encryption, and decryption are applied to configuration files?

Table 6.2 on page 43 shows the overhead h for the `fcrypt` plugin in the interval $[1, 1000]$ configuration settings.

The question for the memory overhad can not be answered after the evaluation. Further benchmarks are required to gain more insights.

Table 6.2: Average overhead of the `fcrypt` plugin

	Decryption		Encryption	
	h (s)	f	h (s)	f
fcrypt	0.005 s	25.609	0.007 s	2.791

6.2 Discussion

In this section we:

1. discuss drawbacks of the methodology we used in our thesis, and
2. interpret the meaning of the evaluation results.

6.2.1 Isolated Performance Test

The benchmarks are designed as isolated (artificial) tests. The test results do not neccessarily correlate with "real-world" use cases. For example: we did not run benchmarks with configuration settings, that contain values that are not to be encrypted (mixed configuration settings).

6.2.2 Variety of Cryptographic Schemas

We evaluated only two cryptographic schemas:

1. the `crypto` plugin, and
2. the `fcrypt` plugin.

Altough the plugins are carefully designed, it is possible that the runtime overhead is distorted by the plugin design. Other reference environments than Elektra should be used to repeat the benchmarks.

6.2.3 Limited Hardware

The benchmarks were executed on a single system. Especially older processors without built-in AES support, will probably show a higher runtime overhead. The benchmarks should therefore be repeated with different hardware configurations.

6.2.4 Interpretation of the Results

When encrypting and decrypting configuration settings and configuration files, the expected runtime overhead increases linear with the number of configuration values. The explanation for this behavior is the process of how the plugins operate. The `crypto` plugin iterates over the whole configuration setting, thus the linear increase in runtime.

The `fcrypt` plugin encrypts and decrypts whole files. The bigger the size of the configuration setting, the bigger the size of the resulting configuration file. Both plugins have a tendency towards linear runtime overhead.

The increase of memory consumption is constant, due to the design of the plugins. The `crypto` plugin encrypts and decrypts single configuration values only, so only one configuration value is being processed at a time. Since every configuration value in our benchmark has the same size, the memory allocations stay the same, even when the size of the configuration setting increases.

CHAPTER 7

Résumé

After introducing the problem of missing cryptographic methods for software configuration, we presented Elektra. We learned about Elektra's configuration database and the plugin system. We explained how the `crypto` plugin, the `fcrypt` plugin and some helper plugins have been designed and developed to study our research questions and solve the problem of encrypting and decrypting configuration settings.

Our evaluation revealed a linear increase in runtime overhead when cryptography is applied to configuration settings in our benchmark setup. The memory analysis showed that the increase in memory overhead is constant in our benchmark setup for different configuration setting sizes. Therefore we were not able to refute the hypotheses, that we stated in the introduction.

If we compare the evaluated cryptographic schemas, then the `fcrypt` plugin is faster than the `crypto` plugin. In comparison to Botan and OpenSSL, libgcrypt shows the best runtime performance in our benchmark setup.

APPENDIX A

Benchmark 1 Results

Table A.1: No crypto plugin / kdb get benchmark results

size (n)	run 1	run 2	run 3	run 4	run 5	run 6	run 7	run 8	run 9	run 10	run 11
1	0.000108	0.000109	0.000112	0.000109	0.000104	0.000116	0.000108	0.000106	0.000108	0.000107	0.000107
2	0.000109	0.000111	0.000118	0.000113	0.000129	0.000114	0.000112	0.000112	0.000141	0.000112	0.000112
3	0.000113	0.000113	0.000141	0.000131	0.000118	0.000113	0.000111	0.000129	0.000110	0.000110	0.000111
4	0.000121	0.000117	0.000114	0.000142	0.000118	0.000121	0.000116	0.000118	0.000144	0.000118	0.000114
5	0.000125	0.000120	0.000120	0.000122	0.000120	0.000117	0.000117	0.000116	0.000118	0.000120	0.000124
6	0.000123	0.000124	0.000128	0.000125	0.000121	0.000126	0.000124	0.000127	0.000121	0.000124	0.000127
7	0.000126	0.000129	0.000134	0.000122	0.000125	0.000128	0.000125	0.000127	0.000136	0.000126	0.000151
8	0.000126	0.000127	0.000127	0.000138	0.000135	0.000126	0.000126	0.000125	0.000126	0.000129	0.000126
9	0.000133	0.000130	0.000131	0.000134	0.000137	0.000130	0.000135	0.000135	0.000162	0.000135	0.000141
10	0.000135	0.000166	0.000138	0.000135	0.000136	0.000133	0.000136	0.000134	0.000133	0.000133	0.000135
11	0.000137	0.000138	0.000144	0.000138	0.000140	0.000135	0.000146	0.000138	0.000162	0.000136	0.000144
15	0.000152	0.000175	0.000150	0.000186	0.000149	0.000151	0.000157	0.000156	0.000171	0.000150	0.000147
17	0.000156	0.000155	0.000160	0.000188	0.000155	0.000158	0.000189	0.000155	0.000159	0.000157	0.000154
20	0.000164	0.000170	0.000165	0.000178	0.000173	0.000168	0.000167	0.000207	0.000210	0.000164	0.000163
25	0.000176	0.000187	0.000179	0.000175	0.000176	0.000179	0.000179	0.000252	0.000178	0.000176	0.000181
30	0.000200	0.000194	0.000196	0.000196	0.000197	0.000195	0.000194	0.000200	0.000200	0.000198	0.000205
31	0.000313	0.000199	0.000198	0.000196	0.000204	0.000238	0.000222	0.000223	0.000196	0.000209	0.000198
32	0.000203	0.000222	0.000204	0.000234	0.000219	0.000204	0.000199	0.000204	0.000210	0.000227	0.000200
35	0.000211	0.000210	0.000220	0.000334	0.000207	0.000205	0.000215	0.000207	0.000231	0.000207	0.000217
40	0.000221	0.000223	0.000272	0.000223	0.000275	0.000220	0.000221	0.000246	0.000220	0.000221	0.000224
50	0.000251	0.000251	0.000289	0.000251	0.000250	0.000305	0.000253	0.000286	0.000250	0.000249	0.000306
51	0.000254	0.000251	0.000324	0.000254	0.000312	0.000253	0.000261	0.000258	0.000263	0.000262	0.000258
52	0.000259	0.000256	0.000257	0.000324	0.000258	0.000310	0.000257	0.000258	0.000264	0.000268	0.000269
55	0.000270	0.000310	0.000267	0.000274	0.000334	0.000273	0.000274	0.000272	0.000334	0.000274	0.000298
56	0.000275	0.000347	0.000341	0.000275	0.000273	0.000268	0.000341	0.000278	0.000270	0.000282	0.000279
57	0.000280	0.000294	0.000276	0.000273	0.000321	0.000292	0.000271	0.000315	0.000356	0.000282	0.000276
60	0.000285	0.000280	0.000342	0.000354	0.000285	0.000280	0.000277	0.000344	0.000289	0.000367	0.000282
70	0.000317	0.000322	0.000463	0.000317	0.000316	0.000403	0.000316	0.000346	0.000318	0.000317	0.000321
80	0.000339	0.000414	0.000354	0.000423	0.000338	0.000421	0.000353	0.000341	0.000344	0.000354	0.000338
90	0.000376	0.000469	0.000371	0.000370	0.000367	0.000378	0.000367	0.000368	0.000382	0.000402	0.000367
100	0.000395	0.000405	0.000411	0.000395	0.000407	0.000399	0.000500	0.000397	0.000403	0.000407	0.000399
150	0.000542	0.000544	0.000546	0.000623	0.000549	0.000552	0.000670	0.000570	0.000623	0.000594	0.000551
175	0.000621	0.000620	0.000623	0.000623	0.000619	0.000615	0.000618	0.000615	0.000622	0.000617	0.000737
200	0.000695	0.000697	0.000686	0.000687	0.000685	0.000700	0.000702	0.000698	0.000701	0.000842	0.000723
250	0.000849	0.000845	0.000833	0.000857	0.000831	0.000839	0.000840	0.000829	0.001048	0.001023	0.000843
300	0.000992	0.000992	0.001016	0.000995	0.001075	0.000999	0.001207	0.000989	0.001211	0.000986	0.000997
350	0.001137	0.001385	0.001138	0.001152	0.001276	0.001141	0.001276	0.001160	0.001137	0.001140	0.001403
400	0.001325	0.001299	0.001296	0.001332	0.001302	0.001294	0.001316	0.001297	0.001589	0.001344	0.001297
500	0.001677	0.001597	0.001592	0.001608	0.001602	0.001594	0.001606	0.001596	0.001592	0.001603	0.001610
1000	0.003026	0.003298	0.003079	0.003041	0.003112	0.003061	0.003067	0.003064	0.003075	0.003064	0.003052

Table A.2: Crypto (OpenSSL) / kdb get benchmark results

size (n)	run 1	run 2	run 3	run 4	run 5	run 6	run 7	run 8	run 9	run 10	run 11
1	0.019106	0.019493	0.019318	0.019548	0.020126	0.020168	0.019702	0.020091	0.019825	0.019274	0.019326
2	0.035684	0.036220	0.035922	0.035559	0.035758	0.036376	0.036529	0.035702	0.036411	0.036093	0.036694
3	0.052350	0.051586	0.051926	0.052327	0.052701	0.052502	0.052143	0.051790	0.052695	0.052676	0.052330
4	0.068674	0.068509	0.068932	0.074033	0.069303	0.069261	0.069081	0.069448	0.068821	0.069099	0.069629
5	0.084847	0.086081	0.084704	0.085630	0.085687	0.084705	0.085089	0.085229	0.084912	0.085134	0.085397
6	0.102441	0.102142	0.103138	0.102280	0.101936	0.101980	0.102461	0.101786	0.102446	0.101946	0.101674
7	0.118112	0.117638	0.118249	0.119149	0.118725	0.119025	0.118817	0.118436	0.118334	0.118102	0.119864
8	0.133952	0.133147	0.140413	0.134206	0.134669	0.134158	0.134187	0.134948	0.134566	0.134245	0.134310
9	0.151133	0.151394	0.150463	0.151489	0.155961	0.150897	0.151547	0.155186	0.151417	0.152115	0.151871
10	0.167447	0.168038	0.167140	0.167192	0.167625	0.167140	0.167869	0.167517	0.167576	0.168644	0.168485
11	0.183921	0.183600	0.188512	0.184445	0.186407	0.183456	0.184306	0.183984	0.183349	0.183989	0.183465
15	0.249082	0.249136	0.260151	0.249046	0.248899	0.248819	0.249553	0.249795	0.249688	0.249218	0.252313
17	0.283523	0.284885	0.286503	0.284658	0.285224	0.293421	0.285208	0.284853	0.314798	0.288659	0.286127
20	0.332602	0.330650	0.331555	0.331458	0.332260	0.331791	0.331478	0.332617	0.331485	0.333575	0.333138
25	0.415218	0.414051	0.413353	0.417011	0.412725	0.413410	0.413174	0.419609	0.413181	0.414127	0.424323
30	0.494789	0.494597	0.494073	0.495479	0.495719	0.502185	0.494462	0.495492	0.493701	0.495446	0.495085
31	0.509923	0.510319	0.511091	0.511315	0.511611	0.511653	0.509250	0.510807	0.514879	0.511194	0.510733
32	0.534686	0.572115	0.539954	0.533790	0.543749	0.538967	0.535497	0.535207	0.533512	0.532138	0.537942
35	0.576764	0.585017	0.575869	0.576995	0.576499	0.577088	0.577542	0.584968	0.577635	0.576585	0.582493
40	0.662732	0.662353	0.675167	0.665267	0.661621	0.662293	0.662191	0.660319	0.667363	0.662734	0.663024
50	0.822010	0.823423	0.822045	0.823645	0.825094	0.822421	0.870433	0.829308	0.823946	0.871561	0.823214
51	0.840409	0.839296	0.838830	0.847197	0.839071	0.841548	0.840995	0.839648	0.840361	0.839463	0.842546
52	0.918945	0.924425	0.917451	0.916574	0.916797	0.922361	0.917744	0.917859	0.918603	0.916616	0.916141
55	0.903981	0.916233	0.904484	0.905156	0.908645	0.906397	0.906629	0.905451	0.931994	0.918168	0.903719
56	0.927478	0.940305	0.926616	0.972815	0.925468	0.925368	0.931157	0.923885	0.929628	0.950770	0.929009
57	0.935589	0.941970	0.940453	0.938819	0.938382	0.942869	0.939047	0.936821	0.939840	0.938347	0.936806
60	0.987045	0.986850	0.985844	0.985888	0.985945	0.986464	0.987978	0.986126	0.990678	0.988372	0.988414
70	1.151348	1.151068	1.151429	1.151822	1.162766	1.150500	1.152885	1.150049	1.151203	1.151578	1.156338
80	1.318126	1.316492	1.320604	1.319162	1.330473	1.317369	1.337937	1.333779	1.318621	1.326121	1.327114
90	1.569392	1.493429	1.497271	1.500871	1.493853	1.495288	1.492880	1.500103	1.502549	1.499455	1.494033
100	1.645525	1.643997	1.641346	1.638501	1.674659	1.644927	1.638406	1.644130	1.637074	1.784840	1.642844
150	2.472021	2.459184	2.470929	2.464726	2.455564	2.516300	2.608414	2.576765	2.462609	2.488534	2.462541
175	3.015162	3.030083	3.028133	3.130669	3.139086	3.029557	3.019923	3.033275	3.029643	3.021501	3.038056
200	3.301826	3.313739	3.290038	3.291292	3.292536	3.312082	3.417187	3.287592	3.464195	3.288169	3.288560
250	4.099789	4.103806	4.227536	4.099148	4.102502	4.102067	4.102851	4.130434	4.101508	4.099958	4.095367
300	4.915201	4.926065	4.928836	4.930378	4.928449	5.038341	4.921983	4.976804	4.919224	4.919849	4.921130
350	5.808056	5.834985	5.808688	5.913375	5.796697	5.806803	5.823371	6.357305	5.803105	5.757831	5.741849
400	6.583391	6.572334	6.565796	6.615653	6.551437	6.566439	6.553900	6.548495	6.570032	6.622150	6.581622
500	8.207802	8.275084	8.190037	8.266980	8.303596	8.279787	8.198080	8.232770	8.189081	8.225321	8.274256
1000	16.657685	16.423004	16.714214	16.659074	16.490285	16.576172	16.658430	16.639539	16.586751	16.582807	16.663801

Table A.3: Crypto (libgcrypt) / kdb get benchmark results

size (n)	run 1	run 2	run 3	run 4	run 5	run 6	run 7	run 8	run 9	run 10	run 11
1	0.013730	0.013484	0.013708	0.014000	0.014211	0.013785	0.014222	0.014041	0.014320	0.013771	0.013528
2	0.024070	0.024367	0.024022	0.023993	0.024328	0.024281	0.024542	0.024392	0.024869	0.025458	0.024741
3	0.035580	0.034636	0.034597	0.034477	0.035350	0.034588	0.034504	0.034943	0.035474	0.034947	0.035927
4	0.045772	0.046404	0.045611	0.046841	0.045713	0.045820	0.045619	0.046450	0.046495	0.047260	0.047127
5	0.055820	0.055473	0.055904	0.056125	0.056056	0.055458	0.055816	0.055780	0.056071	0.055658	0.056513
6	0.066766	0.067075	0.066860	0.067385	0.067394	0.067043	0.067718	0.066707	0.067502	0.066492	0.067133
7	0.078110	0.079494	0.077851	0.079546	0.078842	0.078304	0.077610	0.078357	0.078030	0.078233	0.079471
8	0.087530	0.087337	0.088155	0.087230	0.088599	0.087910	0.087949	0.087380	0.087932	0.087596	0.087406
9	0.100666	0.099023	0.099446	0.099264	0.101758	0.099140	0.099429	0.098827	0.099444	0.099198	0.099459
10	0.110525	0.111025	0.109811	0.111592	0.110206	0.111081	0.109951	0.111354	0.111349	0.110539	0.110328
11	0.121379	0.120430	0.120388	0.120077	0.122913	0.119988	0.120487	0.120630	0.122750	0.120623	0.120545
15	0.161763	0.161754	0.161971	0.161629	0.162263	0.161714	0.162361	0.162586	0.162741	0.162213	0.162502
17	0.188489	0.188672	0.188284	0.188403	0.188163	0.193918	0.188686	0.188895	0.189179	0.188962	0.188427
20	0.216675	0.217360	0.217387	0.219036	0.217022	0.217180	0.218270	0.217292	0.217095	0.219029	0.218079
25	0.272339	0.271415	0.272376	0.270480	0.271116	0.270834	0.271080	0.271225	0.271863	0.272501	0.272616
30	0.320788	0.320142	0.320362	0.320476	0.320430	0.320701	0.339904	0.320651	0.320694	0.320649	0.320808
31	0.331344	0.332289	0.331868	0.334133	0.334437	0.331229	0.331258	0.330699	0.333062	0.334636	0.336529
32	0.344131	0.344160	0.344912	0.351408	0.344775	0.344164	0.344420	0.344707	0.344107	0.351619	0.344418
35	0.372879	0.373466	0.384865	0.377455	0.373379	0.373632	0.373909	0.373461	0.374081	0.377290	0.374442
40	0.426670	0.426279	0.426384	0.427503	0.427050	0.426663	0.426459	0.431359	0.427073	0.431339	0.426753
50	0.533092	0.531935	0.536542	0.532066	0.537174	0.532219	0.531771	0.532081	0.532212	0.532198	0.533854
51	0.556144	0.555787	0.557490	0.555983	0.556456	0.556076	0.556334	0.556383	0.556303	0.556332	0.556414
52	0.557920	0.557648	0.558020	0.558200	0.558435	0.558856	0.558604	0.569929	0.559261	0.559329	0.571092
55	0.588677	0.589028	0.589638	0.593912	0.590196	0.594263	0.593816	0.594435	0.589970	0.593834	0.594841
56	0.600899	0.600345	0.601025	0.600022	0.603763	0.603805	0.607717	0.604161	0.602450	0.611464	0.600609
57	0.610152	0.613569	0.610925	0.610390	0.610890	0.612082	0.611329	0.611216	0.611278	0.610385	0.611732
60	0.637620	0.637654	0.638169	0.637870	0.638136	0.638009	0.644802	0.645173	0.644842	0.638533	0.639251
70	0.758352	0.758604	0.759274	0.759311	0.765776	0.767977	0.759368	0.758753	0.759253	0.764103	0.759368
80	0.860255	0.859703	0.850205	0.849779	0.859900	0.850310	0.859419	0.861298	0.875273	0.850088	0.861273
90	0.983901	0.962634	0.962888	0.986639	0.963651	0.963892	0.963236	0.963529	0.963944	0.964068	0.963128
100	1.072557	1.063216	1.061258	1.061206	1.062297	1.060727	1.061643	1.088364	1.061378	1.062740	1.062417
150	1.635725	1.615209	1.602875	1.601940	1.604481	1.619095	1.640558	1.601387	1.604138	1.602744	1.609964
175	1.872327	1.897882	1.874000	1.854995	1.855636	1.853456	1.874635	1.853591	1.853930	1.853100	1.854098
200	2.137304	2.140461	2.156742	2.143404	2.153729	2.136081	2.145374	2.147923	2.137121	2.154495	2.180811
250	2.677629	2.680727	2.679535	2.722106	2.678923	2.680495	2.726351	2.686690	2.688809	2.721911	2.675150
300	3.267595	3.201955	3.249962	3.220627	3.392250	3.273372	3.202228	3.206254	3.201989	3.201910	3.205894
350	3.769388	3.788092	3.787437	3.768530	3.768404	3.767957	3.768708	3.709199	3.708023	3.769271	3.784427
400	4.276919	4.288799	4.267639	4.271185	4.277110	4.273348	4.269238	4.269709	4.268256	4.314191	4.274750
500	5.366885	5.480891	5.361237	5.381409	5.384927	5.389319	5.410172	5.401497	5.365456	5.383245	5.363266
1000	10.858614	10.716860	10.764414	10.705930	10.815519	10.877432	10.681656	10.761507	10.708561	10.644858	10.654203

Table A.4: Crypto (Botan) / kdb get benchmark results

size (n)	run 1	run 2	run 3	run 4	run 5	run 6	run 7	run 8	run 9	run 10	run 11
1	0.040303	0.040749	0.040511	0.040786	0.041011	0.041097	0.041317	0.040785	0.040924	0.040524	0.040674
2	0.078003	0.078142	0.077878	0.078150	0.078320	0.077858	0.078035	0.080337	0.078762	0.078939	0.078117
3	0.116463	0.116133	0.115681	0.115674	0.116357	0.115765	0.115467	0.115703	0.116705	0.117114	0.116196
4	0.153482	0.153808	0.154019	0.153844	0.153863	0.154719	0.153939	0.153443	0.153960	0.153435	0.158135
5	0.191163	0.191134	0.191531	0.196207	0.191360	0.191251	0.190744	0.191138	0.191159	0.191204	0.190918
6	0.228624	0.229177	0.228656	0.229772	0.229240	0.229459	0.229373	0.230905	0.229176	0.228940	0.229544
7	0.266487	0.268835	0.266226	0.266353	0.267940	0.266763	0.266980	0.267373	0.267743	0.266857	0.266888
8	0.308108	0.304468	0.306537	0.304448	0.303908	0.304672	0.305212	0.306102	0.303871	0.304607	0.304225
9	0.342268	0.342461	0.342197	0.342084	0.346871	0.344335	0.342427	0.341816	0.342158	0.342778	0.344857
10	0.380183	0.380042	0.379205	0.379966	0.379541	0.379788	0.379428	0.380163	0.379377	0.379549	0.379470
11	0.417058	0.417375	0.417238	0.416994	0.418698	0.418012	0.417889	0.417080	0.417429	0.417441	0.417287
15	0.567647	0.569070	0.567646	0.567742	0.568005	0.568187	0.569606	0.568418	0.570910	0.569949	0.575819
17	0.644010	0.643790	0.647466	0.643352	0.643912	0.644368	0.644677	0.642906	0.643781	0.643861	0.643889
20	0.757718	0.756270	0.756429	0.757967	0.756517	0.756313	0.770859	0.755966	0.756914	0.756444	0.756327
25	0.963809	0.953977	0.946101	0.944267	0.944245	0.945162	0.952568	0.945262	0.944806	0.945417	0.944727
30	1.132920	1.132453	1.132900	1.132998	1.133912	1.133459	1.132648	1.137737	1.132633	1.143145	1.133669
31	1.171516	1.170889	1.181236	1.185020	1.190390	1.182012	1.170991	1.171068	1.176145	1.170588	1.174693
32	1.208846	1.208999	1.209413	1.210806	1.208151	1.226910	1.210039	1.210554	1.208981	1.207331	1.208315
35	1.328421	1.322104	1.325395	1.324449	1.321865	1.321279	1.323530	1.322952	1.324720	1.321395	1.322415
40	1.509840	1.509794	1.509992	1.509966	1.509937	1.509680	1.509447	1.597192	1.519036	1.510672	1.510204
50	1.896864	1.897605	1.897800	1.896968	1.896511	1.908217	1.898260	1.897472	1.897632	1.897186	1.896690
51	1.928545	1.928599	1.926034	1.924528	1.925992	1.926344	1.923381	1.926918	1.925888	1.926010	1.939740
52	1.960376	1.961119	1.966467	1.963695	1.961976	1.961818	1.966941	1.985151	2.050867	1.972329	1.965021
55	2.074962	2.084959	2.084518	2.093712	2.083935	2.108868	2.076150	2.075145	2.074785	2.074501	2.075819
56	2.117523	2.112583	2.117639	2.137155	2.131876	2.112873	2.133702	2.114374	2.115208	2.128772	2.113649
57	2.151733	2.150470	2.156514	2.150345	2.157618	2.150586	2.153934	2.150848	2.151045	2.150093	2.152556
60	2.266159	2.281736	2.261591	2.262972	2.329000	2.267899	2.272975	2.262712	2.274875	2.349934	2.272937
70	2.647386	2.639332	2.659216	2.649833	2.639167	2.638790	2.652682	2.640419	2.639892	2.658254	2.650187
80	3.017064	3.022594	3.016533	3.024644	3.024759	3.020776	3.103851	3.019241	3.081553	3.016450	3.018346
90	3.782254	3.437929	3.393389	3.401007	3.461103	3.401218	3.418227	3.393932	3.419520	3.393731	3.394171
100	3.778074	3.816467	3.783766	3.779621	3.781122	3.779966	3.791639	3.789940	3.844532	3.782478	3.778118
150	5.666140	5.673333	5.698925	5.676666	5.665192	5.740264	5.653247	5.652235	5.652412	5.653058	5.905870
175	6.638581	6.619319	6.620885	6.610207	6.609689	6.610748	6.623119	6.609365	6.609444	6.612800	6.619630
200	7.543020	7.547438	7.546554	7.539577	7.543666	7.562795	7.540030	7.603080	7.547587	7.916007	7.546352
250	9.511980	9.443963	9.422911	9.436708	9.420366	9.431640	9.442518	9.423256	9.422472	9.457261	9.436793
300	11.309613	11.323636	11.366553	11.376399	11.448015	11.308224	11.329311	11.312847	11.300242	11.304520	11.314334
350	13.428509	13.302087	13.356522	13.276408	13.367175	13.323003	13.355316	13.285788	13.234009	13.469045	13.242594
400	15.079224	15.066904	15.091189	15.072009	15.096080	15.068310	15.069814	15.066099	15.070649	15.073917	15.071094
500	18.939592	18.984201	18.951439	18.941700	18.942845	18.943191	18.982077	18.976695	18.957476	18.954440	18.948109
1000	38.055497	38.059056	38.079469	38.081887	38.102791	37.949753	38.864855	37.895749	38.004146	38.032261	38.664388

Table A.5: Fcrypt / kdb get benchmark results

size (n)	run 1	run 2	run 3	run 4	run 5	run 6	run 7	run 8	run 9	run 10	run 11
1	0.005803	0.005316	0.005349	0.004935	0.005213	0.005199	0.005676	0.005599	0.005681	0.005164	0.005808
2	0.005051	0.005107	0.005588	0.005404	0.005414	0.005313	0.005145	0.005385	0.005693	0.005397	0.005497
3	0.005006	0.005210	0.005089	0.005178	0.005470	0.005046	0.005139	0.005160	0.005206	0.005301	0.005454
4	0.005097	0.005392	0.005270	0.005378	0.005233	0.005607	0.005364	0.005714	0.005690	0.005514	0.005522
5	0.005551	0.005271	0.005437	0.005122	0.005265	0.005061	0.005041	0.005555	0.005498	0.005378	0.005304
6	0.005211	0.005307	0.005101	0.005274	0.005441	0.005289	0.005524	0.005410	0.005540	0.005593	0.005197
7	0.005267	0.005498	0.005441	0.005389	0.005527	0.005490	0.005342	0.005360	0.005786	0.005285	0.005376
8	0.005187	0.005242	0.005659	0.005305	0.005209	0.005107	0.005175	0.005300	0.005268	0.005282	0.005487
9	0.005195	0.005201	0.005151	0.005257	0.005387	0.005682	0.005577	0.005355	0.005616	0.005311	0.005471
10	0.005136	0.005523	0.005252	0.005408	0.005086	0.005108	0.005165	0.005185	0.005374	0.005444	0.005866
11	0.005420	0.005418	0.005094	0.005919	0.005747	0.005366	0.005746	0.005306	0.005848	0.005581	0.005821
15	0.005051	0.005354	0.005422	0.005557	0.005448	0.005473	0.005436	0.005432	0.005774	0.005611	0.005700
17	0.005512	0.005652	0.005180	0.005491	0.005345	0.005403	0.005852	0.005557	0.005274	0.005841	0.005585
20	0.005801	0.005239	0.005387	0.005726	0.005688	0.005757	0.005624	0.005632	0.005834	0.005898	0.005740
25	0.005594	0.005858	0.005441	0.005773	0.005167	0.005477	0.005558	0.005741	0.005378	0.005687	0.005738
30	0.005276	0.005184	0.005585	0.005263	0.005395	0.005239	0.005390	0.005546	0.005422	0.005657	0.005396
31	0.005322	0.005291	0.005489	0.005184	0.005196	0.005204	0.005236	0.005256	0.005273	0.005476	0.005407
32	0.005456	0.005541	0.005247	0.005048	0.005393	0.005701	0.005331	0.005757	0.005277	0.005314	0.005405
35	0.005232	0.005425	0.005577	0.005627	0.005785	0.005497	0.005550	0.005642	0.005756	0.005946	0.005941
40	0.005513	0.005380	0.005290	0.005528	0.005798	0.005549	0.005995	0.005717	0.005719	0.005902	0.005716
50	0.005500	0.005404	0.005476	0.005480	0.005341	0.005721	0.005664	0.005557	0.005583	0.005653	0.005590
51	0.005349	0.005467	0.005501	0.005566	0.005423	0.005567	0.005837	0.005846	0.005591	0.005956	0.005499
52	0.005518	0.005626	0.005526	0.005693	0.005563	0.005898	0.005923	0.006305	0.005555	0.006057	0.005892
55	0.005253	0.005791	0.005340	0.005681	0.005830	0.005667	0.005838	0.005854	0.005904	0.005857	0.005880
56	0.005548	0.005500	0.005537	0.005741	0.005896	0.005790	0.005876	0.006128	0.005939	0.005791	0.006242
57	0.005414	0.005757	0.005431	0.005808	0.005509	0.005625	0.005611	0.005674	0.006220	0.005949	0.005946
60	0.005770	0.005779	0.005675	0.005799	0.005849	0.005710	0.005596	0.005681	0.005815	0.005914	0.005913
70	0.005876	0.005727	0.005841	0.005882	0.005554	0.005937	0.005937	0.005881	0.006099	0.005986	0.005992
80	0.005548	0.005618	0.005893	0.005714	0.005711	0.005715	0.005910	0.005922	0.005777	0.006080	0.006187
90	0.005772	0.005721	0.005809	0.005916	0.005910	0.005921	0.005812	0.005899	0.006165	0.006033	0.006091
100	0.005806	0.005706	0.005948	0.005770	0.005831	0.005799	0.005772	0.005747	0.006045	0.006074	0.005623
150	0.005943	0.006175	0.005997	0.006030	0.005767	0.005983	0.006154	0.005985	0.006218	0.006476	0.006404
175	0.006374	0.005958	0.005959	0.006089	0.006072	0.006207	0.005859	0.006424	0.006156	0.006279	0.006268
200	0.005911	0.006055	0.006152	0.005863	0.006371	0.006501	0.006657	0.006481	0.006163	0.006430	0.006497
250	0.006281	0.006343	0.006643	0.006604	0.006385	0.006163	0.006620	0.006418	0.006360	0.006875	0.007131
300	0.006670	0.007440	0.006934	0.006582	0.006709	0.006458	0.006555	0.006559	0.006654	0.006581	0.006716
350	0.006588	0.006874	0.006603	0.006712	0.006482	0.006477	0.006988	0.006878	0.006720	0.006598	0.006819
400	0.006697	0.006748	0.006622	0.007080	0.007150	0.006980	0.006860	0.007102	0.006906	0.007147	0.007445
500	0.007029	0.007406	0.007580	0.007283	0.007417	0.007575	0.007495	0.007499	0.007550	0.007515	0.007332
1000	0.009147	0.009454	0.009707	0.008928	0.009226	0.009538	0.009784	0.009652	0.009631	0.009703	0.009461

Table A.6: No crypto plugin / kdb set benchmark results

size (n)	run 1	run 2	run 3	run 4	run 5	run 6	run 7	run 8	run 9	run 10	run 11
1	0.003515	0.006612	0.003647	0.003453	0.003382	0.007613	0.003466	0.006888	0.003386	0.006810	0.010676
2	0.007393	0.003262	0.003441	0.003462	0.003497	0.007496	0.003743	0.003348	0.006957	0.003543	0.003386
3	0.007504	0.006849	0.003331	0.003413	0.006695	0.003801	0.006780	0.003486	0.003386	0.003460	0.003500
4	0.006929	0.003345	0.003605	0.003409	0.003508	0.003374	0.003425	0.003562	0.007511	0.006985	0.003936
5	0.003389	0.003357	0.006760	0.003336	0.007921	0.003649	0.007004	0.003482	0.003423	0.003513	0.003430
6	0.005114	0.003483	0.003569	0.003457	0.003525	0.003413	0.003451	0.006812	0.003519	0.006801	0.003505
7	0.003473	0.007512	0.003512	0.007319	0.003427	0.003635	0.003680	0.003552	0.006844	0.003566	0.003523
8	0.007619	0.003443	0.007597	0.003521	0.003562	0.007576	0.003552	0.007670	0.006652	0.003567	0.003407
9	0.003400	0.003606	0.003529	0.003677	0.008051	0.007643	0.007524	0.003603	0.007646	0.006828	0.003669
10	0.006901	0.003610	0.003579	0.003694	0.003561	0.007054	0.003646	0.008035	0.003662	0.006912	0.006812
11	0.003518	0.006667	0.003527	0.003483	0.003517	0.003468	0.006922	0.003683	0.003571	0.003480	0.003744
15	0.007497	0.003564	0.006889	0.007740	0.003363	0.003559	0.003560	0.003528	0.003317	0.006852	0.007674
17	0.003469	0.003526	0.003593	0.003613	0.003383	0.003513	0.003475	0.007713	0.003455	0.007474	0.003470
20	0.003806	0.003503	0.003593	0.007036	0.003611	0.003505	0.003669	0.003596	0.007500	0.003617	0.003649
25	0.007183	0.003566	0.003597	0.006928	0.008080	0.007711	0.007275	0.003675	0.003599	0.003691	0.003671
30	0.003514	0.003616	0.003617	0.003634	0.003687	0.003818	0.003722	0.003665	0.003821	0.008216	0.006906
31	0.003698	0.003637	0.003602	0.003667	0.003777	0.007580	0.003675	0.003591	0.003841	0.007013	0.003680
32	0.003573	0.003703	0.003643	0.003661	0.003701	0.007824	0.003770	0.003521	0.003604	0.003602	0.003678
35	0.003591	0.003655	0.003620	0.003917	0.003692	0.003642	0.004348	0.003584	0.003729	0.004146	0.003613
40	0.004044	0.003598	0.011430	0.007890	0.003583	0.003599	0.007708	0.007209	0.003733	0.003962	0.003723
50	0.003690	0.003838	0.008241	0.007182	0.007877	0.003767	0.003792	0.004178	0.003766	0.003784	0.007787
51	0.004336	0.003810	0.003854	0.004019	0.007034	0.003862	0.003725	0.003758	0.007096	0.003878	0.008210
52	0.003865	0.003889	0.007970	0.003759	0.004257	0.004103	0.007052	0.003726	0.003835	0.003856	0.003781
55	0.003679	0.004000	0.003726	0.003871	0.003874	0.003979	0.003838	0.004040	0.004059	0.003749	0.004284
56	0.003773	0.003981	0.007473	0.003823	0.004103	0.007252	0.007207	0.003768	0.004018	0.003722	0.004280
57	0.003834	0.004051	0.003858	0.004140	0.003858	0.003931	0.003758	0.003826	0.004208	0.003901	0.003896
60	0.007240	0.003823	0.003920	0.003866	0.008098	0.003909	0.004357	0.003767	0.007224	0.007896	0.007206
70	0.003870	0.003986	0.003993	0.004188	0.007413	0.004090	0.003902	0.007264	0.004031	0.004069	0.008209
80	0.003889	0.003926	0.004154	0.008085	0.007299	0.007936	0.004101	0.008188	0.008134	0.004070	0.008083
90	0.004128	0.004006	0.007476	0.004392	0.007427	0.007660	0.008081	0.004112	0.008014	0.004073	0.004086
100	0.004261	0.004151	0.007568	0.004145	0.004033	0.008240	0.008182	0.004201	0.007691	0.004458	0.004152
150	0.008655	0.008097	0.004655	0.007947	0.004693	0.008141	0.008011	0.008229	0.004637	0.007918	0.004613
175	0.005097	0.004769	0.008616	0.008751	0.008248	0.008129	0.004915	0.008864	0.004742	0.004794	0.004943
200	0.005128	0.004796	0.005366	0.005110	0.009417	0.008223	0.008216	0.004887	0.008534	0.004937	0.004975
250	0.005337	0.008664	0.005395	0.005522	0.005447	0.008704	0.005564	0.005398	0.005327	0.008703	0.008522
300	0.005611	0.010177	0.005580	0.005794	0.005842	0.009882	0.006235	0.009762	0.008968	0.005914	0.005625
350	0.006143	0.006184	0.006648	0.006784	0.006136	0.010321	0.006588	0.009525	0.006150	0.010232	0.006340
400	0.006275	0.006582	0.010643	0.006545	0.006587	0.006535	0.006425	0.006828	0.006471	0.009669	0.010393
500	0.007385	0.007193	0.007144	0.007390	0.007381	0.007788	0.007397	0.007345	0.010597	0.007240	0.007321
1000	0.011003	0.010908	0.011091	0.011301	0.010979	0.015145	0.010848	0.010769	0.015970	0.014340	0.011089

Table A.7: Crypto (OpenSSL) / kdb set benchmark results

size (n)	run 1	run 2	run 3	run 4	run 5	run 6	run 7	run 8	run 9	run 10	run 11
1	0.021967	0.022576	0.022204	0.026459	0.022767	0.022585	0.022747	0.023070	0.027077	0.026704	0.027273
2	0.038809	0.038600	0.038644	0.038582	0.042940	0.039283	0.038624	0.038844	0.039238	0.039354	0.043268
3	0.054839	0.055078	0.054973	0.055596	0.060993	0.055426	0.058952	0.055417	0.059054	0.056107	0.056330
4	0.071363	0.071838	0.071673	0.071196	0.071584	0.075478	0.071563	0.071658	0.075153	0.072160	0.071891
5	0.087678	0.091957	0.091667	0.091405	0.088084	0.088341	0.091640	0.091908	0.088388	0.088323	0.088173
6	0.108959	0.104343	0.104679	0.107747	0.107637	0.112050	0.109068	0.105060	0.105538	0.109396	0.105117
7	0.122838	0.123806	0.121134	0.120865	0.121231	0.120940	0.125414	0.121231	0.123386	0.121454	0.125915
8	0.137446	0.141192	0.137867	0.141811	0.137851	0.137613	0.141383	0.141126	0.138419	0.140679	0.144366
9	0.164502	0.153686	0.153566	0.157756	0.158121	0.154223	0.153657	0.154186	0.158725	0.155519	0.156099
10	0.170208	0.170926	0.169993	0.170331	0.170323	0.170480	0.170631	0.171125	0.171229	0.171496	0.170317
11	0.186862	0.193274	0.186641	0.187184	0.186935	0.187144	0.187115	0.190333	0.187826	0.192458	0.187017
15	0.253941	0.255415	0.252830	0.267221	0.257847	0.253255	0.252270	0.252572	0.253838	0.253903	0.253706
17	0.286261	0.284840	0.306606	0.284945	0.301138	0.292826	0.286570	0.288961	0.285097	0.285120	0.290090
20	0.346873	0.342328	0.337364	0.334702	0.335137	0.335475	0.337706	0.337030	0.334336	0.334784	0.339337
25	0.416099	0.417611	0.416242	0.416440	0.420773	0.416097	0.420293	0.416774	0.415267	0.416775	0.418751
30	0.507586	0.499674	0.507599	0.501661	0.508009	0.511873	0.499573	0.497145	0.498612	0.500523	0.499341
31	0.515626	0.514107	0.546083	0.520651	0.542307	0.514533	0.514808	0.513891	0.515532	0.519983	0.517731
32	0.559430	0.552853	0.553577	0.552181	0.557229	0.557091	0.555264	0.554469	0.562128	0.552670	0.553935
35	0.592797	0.579593	0.579986	0.581220	0.584209	0.580979	0.584573	0.580079	0.585159	0.581495	0.585394
40	0.672693	0.669885	0.693191	0.666197	0.673152	0.668847	0.667597	0.671424	0.666777	0.665755	0.667059
50	0.832791	0.825165	0.823984	0.829645	0.828763	0.829879	0.828308	0.825172	0.826659	0.832252	0.830161
51	0.847310	0.844626	0.841950	0.844914	0.892596	0.849867	0.845935	0.841116	0.873945	0.851789	0.847107
52	0.926303	0.922931	0.928129	0.919732	0.919590	0.924740	0.936559	0.922739	0.919020	0.928104	0.918972
55	0.911871	0.949286	0.908596	0.912639	0.910025	0.908737	0.910594	0.913092	0.907871	0.926227	0.921341
56	0.940897	0.942069	0.936135	0.937072	0.937215	0.935313	0.985471	0.939890	1.120269	0.936468	0.985418
57	0.946351	0.952435	0.946888	0.938202	0.941399	0.950793	0.946087	0.951249	0.948055	0.944111	0.944843
60	0.990452	1.037551	1.036469	0.991075	0.990381	0.996183	1.002917	0.990693	0.998088	0.995795	0.991824
70	1.154720	1.155978	1.153361	1.183036	1.153264	1.154855	1.155331	1.157135	1.160346	1.161261	1.155985
80	1.322312	1.386581	1.329155	1.320364	1.319705	1.329580	1.315817	1.320265	1.369675	1.321712	1.324652
90	1.613449	1.649112	1.609250	1.608794	1.632667	1.606802	1.616767	1.678885	1.615980	1.603733	1.634310
100	1.657521	1.647588	1.664932	1.648545	1.655569	1.667917	1.644642	1.647968	1.647666	1.652349	1.650206
150	2.755968	2.465179	2.472539	2.473794	2.461811	2.473734	2.475189	2.812171	2.475215	2.476299	2.463869
175	2.883862	2.897875	2.914335	3.093933	2.880238	2.897780	2.874945	2.876195	2.900576	2.876093	2.876138
200	3.323815	3.502725	3.337691	3.358107	3.316480	3.331677	3.329684	3.317987	3.500834	3.325740	3.325534
250	4.111518	4.109734	4.102020	4.099558	4.117185	4.101146	4.109605	4.106210	4.092771	4.119407	4.113593
300	4.955484	4.930575	4.929910	5.129448	4.926190	4.922224	4.929693	4.925606	4.942767	4.932784	4.930051
350	6.085079	5.855469	6.173019	5.895112	5.832150	5.815485	5.902402	5.821481	5.822304	5.889955	6.224909
400	6.586052	6.607470	6.588372	6.773640	6.569172	6.599478	6.574321	6.572453	6.569538	6.570925	6.605263
500	8.216612	8.260798	8.279199	8.231575	8.200430	8.208313	8.223169	8.306512	8.195531	8.217596	8.233149
1000	16.367820	16.364791	17.244173	16.745101	16.464378	16.454265	16.798638	16.640161	17.707055	16.711262	16.673151

Table A.8: Crypto (libgcrypt) / kdb set benchmark results

size (n)	run 1	run 2	run 3	run 4	run 5	run 6	run 7	run 8	run 9	run 10	run 11
1	0.016691	0.017710	0.020288	0.016700	0.017153	0.017254	0.017352	0.017065	0.021019	0.017708	0.022011
2	0.027544	0.027601	0.028217	0.027380	0.027734	0.027637	0.028035	0.027615	0.028020	0.032063	0.028519
3	0.037973	0.038534	0.037987	0.038008	0.038153	0.038817	0.041569	0.038598	0.043094	0.039130	0.042919
4	0.048823	0.053051	0.053106	0.053127	0.049847	0.049456	0.049547	0.049792	0.052379	0.049890	0.050289
5	0.059118	0.059279	0.063256	0.059313	0.059554	0.058962	0.062395	0.059720	0.059946	0.059469	0.059486
6	0.073760	0.069442	0.069560	0.070099	0.069491	0.070016	0.070154	0.069741	0.070342	0.073417	0.073874
7	0.081113	0.080932	0.084003	0.084476	0.086497	0.081409	0.081401	0.081214	0.084764	0.085310	0.081776
8	0.091167	0.090576	0.091271	0.090805	0.095239	0.091083	0.091099	0.092087	0.092558	0.091256	0.091961
9	0.103558	0.102381	0.104354	0.102789	0.106305	0.103184	0.106377	0.102598	0.103746	0.112288	0.103044
10	0.114501	0.113515	0.117271	0.113829	0.118280	0.117249	0.113953	0.114049	0.117679	0.115028	0.114640
11	0.130303	0.124212	0.128403	0.127821	0.124539	0.128701	0.127806	0.128397	0.124690	0.124519	0.124476
15	0.166827	0.165930	0.165219	0.165667	0.166165	0.165516	0.170835	0.165927	0.171077	0.165774	0.169954
17	0.192189	0.199576	0.192125	0.192266	0.192778	0.196214	0.195532	0.197094	0.191883	0.201248	0.193014
20	0.222649	0.226127	0.222053	0.221967	0.225071	0.221907	0.228385	0.221223	0.221260	0.229850	0.223311
25	0.275459	0.277818	0.274226	0.276109	0.277982	0.274163	0.274563	0.274222	0.278349	0.275123	0.274241
30	0.328354	0.331919	0.326512	0.324538	0.324747	0.324400	0.326458	0.328266	0.331067	0.334915	0.325302
31	0.342335	0.334680	0.343173	0.334702	0.342093	0.336938	0.335047	0.340327	0.335369	0.335433	0.339002
32	0.349467	0.348534	0.353365	0.350285	0.349635	0.349579	0.350682	0.356010	0.348609	0.352864	0.349186
35	0.381449	0.378005	0.377975	0.378085	0.377958	0.381285	0.381276	0.377774	0.388297	0.386771	0.379371
40	0.434437	0.434967	0.430452	0.430702	0.430397	0.431012	0.436798	0.430631	0.434963	0.434849	0.438502
50	0.536648	0.536405	0.536701	0.536586	0.540548	0.537052	0.536075	0.536509	0.540399	0.536590	0.536980
51	0.557105	0.557195	0.566211	0.560847	0.562091	0.557858	0.559569	0.560978	0.557496	0.561953	0.563479
52	0.564529	0.561885	0.575675	0.566318	0.573941	0.562834	0.577936	0.572771	0.562258	0.562390	0.562292
55	0.595052	0.594645	0.602981	0.596185	0.595099	0.602320	0.595402	0.599451	0.599869	0.605678	0.600004
56	0.615288	0.604427	0.614728	0.615802	0.621194	0.621333	0.604883	0.604196	0.605101	0.616407	0.609022
57	0.622885	0.622307	0.613996	0.610747	0.610855	0.611079	0.615184	0.614466	0.612708	0.614317	0.610975
60	0.642117	0.642913	0.643582	0.646705	0.648744	0.643181	0.645971	0.650643	0.645201	0.646704	0.643100
70	0.762998	0.763652	0.773763	0.762986	0.767003	0.768898	0.762571	0.762828	0.762671	0.767221	0.764394
80	0.855173	0.860395	0.854818	0.906990	0.855053	0.857734	0.915716	0.858871	0.855466	0.855746	0.855758
90	0.992261	0.988032	0.967202	0.971758	0.983456	0.973854	0.968674	0.972237	1.044782	0.973183	0.984980
100	1.066718	1.066470	1.069781	1.082200	1.066103	1.071601	1.065445	1.073890	1.071568	1.067724	1.069374
150	1.667309	1.611565	1.636961	1.627617	1.638617	1.632020	1.607980	1.635712	1.635367	1.634990	1.617187
175	1.885365	1.879015	1.885438	1.882859	1.863534	1.863482	1.890059	1.862701	1.876867	1.860119	1.863745
200	2.143113	2.151486	2.155012	2.167419	2.144401	2.383488	2.177513	2.192953	2.163377	2.143060	2.160600
250	2.720689	2.725277	2.716682	2.717712	2.718730	2.717081	2.721362	2.734796	2.713863	2.716637	2.721920
300	3.214819	3.211110	3.222331	3.399748	3.226344	3.212911	3.215669	3.215762	3.217453	3.218689	3.211302
350	3.726684	3.803668	3.788931	4.055750	3.783413	4.085672	3.719355	3.720318	3.781363	3.715264	3.805318
400	4.276684	4.335402	4.300942	4.294484	4.309987	4.278655	4.280345	4.357857	4.334040	4.338346	4.284527
500	5.344331	5.355563	5.362674	5.361667	5.343763	5.366502	5.357077	5.417244	5.379377	5.368167	5.344344
1000	10.627460	10.613548	10.610223	10.618566	11.049206	10.720161	11.667215	10.690387	10.666350	10.861182	10.729885

Table A.9: Crypto (Botan) / kdb set benchmark results

size (n)	run 1	run 2	run 3	run 4	run 5	run 6	run 7	run 8	run 9	run 10	run 11
1	0.043172	0.046822	0.043417	0.043632	0.043664	0.043564	0.043865	0.045367	0.049263	0.044524	0.044075
2	0.081331	0.083875	0.081676	0.085626	0.082026	0.081789	0.081863	0.081600	0.085120	0.081872	0.081574
3	0.119024	0.119133	0.119112	0.121758	0.119847	0.120077	0.120407	0.121356	0.120123	0.119391	0.121328
4	0.163417	0.161564	0.157269	0.156801	0.156943	0.161296	0.160660	0.157475	0.157343	0.157692	0.158040
5	0.195821	0.199222	0.194973	0.199189	0.194761	0.194921	0.195277	0.195039	0.196748	0.195308	0.198207
6	0.233197	0.236570	0.236562	0.236251	0.232503	0.233067	0.234867	0.232404	0.233337	0.236744	0.232766
7	0.270453	0.273465	0.270044	0.269950	0.274653	0.270359	0.270751	0.270494	0.271201	0.270453	0.270601
8	0.307899	0.310904	0.310438	0.307950	0.308386	0.307953	0.308380	0.308173	0.308883	0.312240	0.308645
9	0.345980	0.345662	0.345524	0.345092	0.345643	0.345589	0.351809	0.345894	0.351110	0.346351	0.345631
10	0.383223	0.383540	0.383238	0.383799	0.383928	0.386428	0.384088	0.385125	0.383200	0.385901	0.388219
11	0.434850	0.425312	0.423895	0.425681	0.420748	0.421947	0.425489	0.421769	0.422130	0.421415	0.424247
15	0.571422	0.572264	0.576426	0.572034	0.571520	0.572378	0.572603	0.578932	0.576808	0.576594	0.571640
17	0.646433	0.652192	0.650816	0.834619	0.648642	0.648109	0.647498	0.647586	0.647502	0.654836	0.658513
20	0.778610	0.763375	0.764365	0.760709	0.760073	0.765860	0.776760	0.764895	0.760292	0.760564	0.760675
25	0.949351	0.948371	0.948596	0.955622	0.954038	0.948559	0.948764	0.948613	0.953275	0.948754	0.950019
30	1.136889	1.137860	1.136879	1.140865	1.138892	1.137786	1.141374	1.139641	1.141042	1.137617	1.140847
31	1.174946	1.174972	1.175939	1.179044	1.176566	1.201796	1.175842	1.178992	1.178565	1.179969	1.182225
32	1.218069	1.218076	1.212180	1.212480	1.214070	1.217021	1.217895	1.215149	1.214404	1.230085	1.217718
35	1.327032	1.324888	1.329011	1.330023	1.325305	1.325479	1.325951	1.338637	1.338710	1.325584	1.327127
40	1.514836	1.515065	1.516767	1.513589	1.513432	1.513949	1.520949	1.516557	1.515543	1.517568	1.515893
50	1.900535	1.900716	1.903641	1.915092	1.900924	1.912904	1.901660	1.903258	1.901569	1.907458	1.901138
51	1.938006	1.931295	1.949122	1.948047	1.930870	1.928677	1.940013	1.931850	1.934521	1.930191	1.930821
52	1.965487	1.966567	1.964892	1.965768	1.967908	1.964810	1.968907	1.975197	1.969561	1.965438	1.965424
55	2.081868	2.078245	2.095603	2.090705	2.081168	2.084153	2.082999	2.083035	2.078938	2.079727	2.078796
56	2.119934	2.122902	2.128461	2.137227	2.116831	2.119646	2.118188	2.304648	2.140553	2.127508	2.127464
57	2.156351	2.172586	2.154893	2.153307	2.168492	2.158415	2.182953	2.153862	2.155068	2.176393	2.154412
60	2.281498	2.273519	2.268564	2.266934	2.279099	2.266459	2.271990	2.278948	2.280399	2.267431	2.267655
70	2.657708	2.663761	2.648742	2.659117	2.647271	2.647894	2.643703	2.645745	2.644989	2.662223	2.644176
80	3.088944	3.066414	3.035974	3.021894	3.032746	3.071071	3.028593	3.021318	3.020424	3.028325	3.025977
90	3.410145	3.398586	3.399840	3.414521	3.397966	3.405512	3.399206	3.443842	3.402921	3.448100	3.457057
100	3.784479	3.780613	3.799054	3.781555	3.786589	3.774507	3.785860	3.774088	3.775454	3.776485	3.792837
150	5.667725	5.671700	5.663816	5.666965	5.675913	5.829027	5.677545	5.656791	5.664469	5.656502	5.664049
175	6.624531	6.622141	6.638356	6.622479	6.619940	6.618038	6.644144	6.618832	6.622760	6.621316	6.635974
200	7.542601	7.578545	7.547801	7.565824	7.547302	7.544137	7.545819	7.544423	7.546813	7.560929	7.556461
250	9.439364	9.432561	9.425121	9.425037	9.497541	9.464566	9.433106	9.467854	9.430011	9.447401	9.465669
300	11.350750	11.311524	11.367678	11.316328	11.316791	11.316772	11.367687	11.321180	11.322455	11.396654	11.344013
350	13.336586	13.358732	14.050845	13.402441	13.237258	13.251924	13.378475	13.355143	13.342363	13.444956	13.307368
400	15.078607	15.099211	15.100234	15.128147	15.082431	15.093744	15.097692	15.084862	15.168623	15.099994	15.122074
500	19.023578	19.006510	18.978295	18.959007	18.966583	18.964051	18.984232	18.996989	18.974469	18.968646	18.960620
1000	37.704169	37.741568	37.712419	38.784839	37.721318	38.389603	37.944436	37.753871	38.093513	37.946238	38.005610

Table A.10: Fcrypt / kdb set benchmark results

size (n)	run 1	run 2	run 3	run 4	run 5	run 6	run 7	run 8	run 9	run 10	run 11
1	0.013194	0.013377	0.009475	0.012549	0.013019	0.009276	0.017169	0.009749	0.013918	0.009775	0.009765
2	0.009119	0.012990	0.013443	0.018148	0.009638	0.017703	0.009555	0.009763	0.009729	0.009764	0.013111
3	0.009203	0.013251	0.012583	0.009084	0.012909	0.013143	0.009879	0.017374	0.017837	0.017178	0.009830
4	0.009164	0.013780	0.009263	0.012920	0.009344	0.013677	0.009764	0.017175	0.013883	0.009684	0.017489
5	0.012542	0.009112	0.009354	0.009600	0.014302	0.009363	0.013641	0.013822	0.013101	0.009695	0.013399
6	0.009440	0.013092	0.009242	0.016934	0.009154	0.009526	0.014080	0.014196	0.009617	0.009856	0.010208
7	0.009299	0.009362	0.013706	0.009326	0.009795	0.021004	0.012870	0.009489	0.013118	0.009723	0.013863
8	0.014003	0.012974	0.009316	0.012746	0.016824	0.009434	0.009427	0.013415	0.013038	0.009647	0.009883
9	0.009413	0.009154	0.009226	0.009475	0.009713	0.009471	0.009804	0.009626	0.009834	0.013188	0.017592
10	0.012534	0.009314	0.012687	0.009473	0.013432	0.009537	0.009483	0.014048	0.009577	0.013734	0.013242
11	0.009317	0.009567	0.009588	0.013542	0.009783	0.009824	0.018328	0.013862	0.017238	0.009737	0.013955
15	0.009037	0.020326	0.009622	0.013844	0.009364	0.013210	0.012960	0.013822	0.010045	0.009898	0.009840
17	0.012976	0.009202	0.009375	0.017130	0.009800	0.009545	0.009714	0.012974	0.013969	0.010244	0.017023
20	0.013268	0.009636	0.009798	0.012523	0.013042	0.013162	0.009661	0.013752	0.012836	0.010046	0.014189
25	0.009310	0.013688	0.013309	0.009536	0.012918	0.010057	0.013695	0.017064	0.010221	0.009981	0.010114
30	0.017053	0.013032	0.009741	0.013936	0.012657	0.009658	0.013177	0.014051	0.009983	0.013179	0.009947
31	0.009371	0.013480	0.012967	0.012959	0.012844	0.013917	0.017653	0.010060	0.014182	0.009952	0.017401
32	0.013683	0.009198	0.009557	0.017232	0.009449	0.010059	0.010244	0.010199	0.013520	0.009697	0.014632
35	0.009692	0.009555	0.013878	0.013257	0.009957	0.013419	0.017284	0.021858	0.009989	0.014332	0.009913
40	0.013359	0.009785	0.013084	0.009738	0.013171	0.009853	0.013905	0.013560	0.017858	0.010508	0.010043
50	0.013647	0.017389	0.009923	0.010129	0.009854	0.009829	0.018837	0.013442	0.010299	0.013470	0.010307
51	0.009610	0.009591	0.009758	0.014055	0.013814	0.010065	0.009926	0.014045	0.014234	0.010851	0.010494
52	0.017065	0.009776	0.012762	0.009645	0.013233	0.009819	0.010105	0.010161	0.010023	0.010318	0.010465
55	0.013110	0.009723	0.009827	0.013006	0.010507	0.014072	0.010215	0.010284	0.010350	0.013674	0.010554
56	0.009544	0.013293	0.009698	0.013789	0.010053	0.013244	0.013668	0.010411	0.014397	0.010056	0.018461
57	0.013388	0.010202	0.013266	0.014007	0.010206	0.013914	0.017629	0.014691	0.021369	0.013819	0.014512
60	0.009695	0.009582	0.009855	0.013898	0.009848	0.009898	0.010127	0.010193	0.010600	0.014338	0.010872
70	0.009926	0.010178	0.009563	0.010074	0.014732	0.010084	0.010646	0.010224	0.010562	0.013906	0.017434
80	0.009804	0.013729	0.013314	0.010278	0.010123	0.010330	0.010373	0.010328	0.010576	0.010735	0.014030
90	0.014102	0.010163	0.010168	0.014309	0.014357	0.010222	0.010841	0.010275	0.013856	0.014410	0.011050
100	0.014004	0.010333	0.010181	0.010807	0.010428	0.013874	0.014788	0.010319	0.010600	0.010736	0.011048
150	0.017966	0.014617	0.010590	0.013930	0.010788	0.014512	0.010969	0.010863	0.011171	0.011075	0.011479
175	0.010546	0.014734	0.014300	0.011321	0.011288	0.011655	0.011139	0.011172	0.011418	0.018827	0.011630
200	0.010874	0.023305	0.011283	0.011049	0.011209	0.011297	0.014559	0.011452	0.011679	0.011525	0.015767
250	0.011280	0.011512	0.011357	0.014924	0.011955	0.019803	0.015977	0.011846	0.011713	0.011728	0.019449
300	0.011962	0.015511	0.018851	0.011906	0.015978	0.020355	0.016267	0.016675	0.012721	0.012167	0.012210
350	0.016346	0.020866	0.012218	0.012370	0.017130	0.016405	0.020122	0.016875	0.012808	0.017005	0.015902
400	0.012324	0.019915	0.013048	0.012910	0.012650	0.012728	0.016403	0.013263	0.012855	0.016910	0.016545
500	0.013216	0.016648	0.013481	0.013481	0.013788	0.013643	0.017986	0.022313	0.013786	0.014310	0.025452
1000	0.020387	0.021105	0.017416	0.020814	0.017700	0.017603	0.021634	0.021788	0.021323	0.021124	0.018117

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