Detecting Cryptographic Ransomware by Examining File System Activity

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by

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Detecting Cryptographic Ransomware by Examining File System Activity

Meltem AKAY

Abstract

Cryptographic ransomware, which locks a victim's files and demands payment to re-establish access, is one of the most dangerous and popular cyber crimes of today as it gives attackers a golden opportunity to extort money. Although many different approaches are presented to detect and prevent this troublesome malware, recent research suggests that none of these approaches are flawless and they can be bypassed.

In this thesis, we propose CRYPTOCOP, a protection system that stops a ransomware attack in the early stages. The defense mechanism limits the applications' capability of executing file write functions, which is excessively performed by a typical ransomware. We define an adaptive threshold mechanism for file write requests of each running process, which facilitates benign file system operations while terminating the malicious activity. The results of experiments show that CRYPTOCOP is able to stop 706 out of 736 (~96%) ransomware samples with minimal loss of files – less than 5 – and a negligible performance overhead.

Keywords: Ransomware, Malware, Engineering, File System Examination, User Data Protection

Dosya Sistemi Aktivitelerini İzleyerek Fidye Yazılımların Tespiti

Meltem Akay

Öz

Kriptografik Fidye Yazılımları, üzerinde çalıştığı sistemdeki dosyaları gelişmiş kriptografik yöntemlerle şifreleyen ve kullanıcının tekrar erişim sağlayabilmesi için fidye talep eden yazılımlardır. Saldırganlara, kullanıcılardan kolayca para koparmayı sağlaması sebebiyle günümüzün en popüler ve tehlikeli siber tehditlerinden biridir. Kriptografik fidye yazılımlarını yakalamak ve durdurmak için çeşitli yöntemler sunulmuş olmasına rağmen son yapılan araştırmalarla beraber, bu yaklaşımların atlatılmak için kullanılabilecek hataları bulunmuştur.

Tez kapsamında, kriptografik fidye saldırılarını başladıktan kısa bir süre sonra durduracak bir yaklaşım, CryptoCop, sunmaktayız. Kriptografik fidye yazılımlarının ayırt edici özelliği aşırı dosya yazma işlemi olması sebebiyle, tanımladığımız korunma mekanizması çalışan uygulamaların dosya yazma isteklerini sınırlamaktadır. Belirlediğimiz eşik değeri iyi huylu uygulamaların çalışmaya devam etmesine olanak verecek şekilde uyarlanmaktadır. Elde ettiğimiz verilere göre, CryptoCop ihmal edilebilir performans kaybı ve az sayıda dosya kaybı ile kötümcül yazılımların bu türünü durdurmayı %96 lık bir oranla başarmaktadır.

Anahtar Sözcükler: Fidye Yazılımları, Zararlı Yazılım, Dosya Sistemi Gözetlenmesi

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The greatest thanks are to my parents, for their support throughout my whole life.

Contents

List of Figures

List of Tables

List of Listings

Abbreviations

API	**A**pplication **P**rogramming **I**nterface
ASLR	**A**ddress **S**pace **L**ayout **R**andomization
AV	**A**nti **V**irus
C&C	**C**ommand-and-**C**onquer
CPU	**C**entral **P**rocessing **U**nit
CSPRNG	**C**ryptographically **S**ecure **P**seudo **R**andom **N**umber **G**enerator
DEP	**D**ata **E**xecution **P**revention
DLL	**D**ynamic **L**ink **L**ibrary
DNS	**D**omain **N**ame **S**ystem
IAT	**I**mport **A**ddress **T**able
I/O	**I**nput/**O**utput
IP	**I**nternet **P**rotocol
KVM	**K**ernel-based **V**irtual **M**achine
LCM	**L**east **C**ommon **M**ultiple
NAS	**N**etwork **A**ttached **S**torage
OS	**O**perating **S**ystem
RaaS	**R**ansomware-**as**-**a**-**S**ervice
SDN	**S**oftware **D**efined **N**etworking
SMS	**S**hort **M**essage **S**ervice
SSD	**S**olid **S**tate **D**isk
SSDT	**S**ystem **S**ervice **D**ispatch **T**able
VGA	**V**ideo **G**raphics **A**rray
VM	**V**irtual **M**achine

Chapter 1

Introduction

Ransomware is a type of malware that locks a victim's data and demands money to re-establish access. Based on the locking method used, ransomware can be categorized into two groups: *computer locker* and *cryptovirus* [35]. The former locks the functions on the target computer system while the data remains intact. The latter, however, encrypts the victim's data using modern cryptographic techniques, e.g., the infamous CryptoWall [7] family. The scope of this thesis is the second category which is also known as *cryptographic ransomware*, or shortly *ransomware*.

Once infected, ransomware uses strong cryptography for encrypting user's files on both local and network attached storage devices and demands a reasonable ransom (or higher amounts in some cases) in exchange for the decryption keys [23]. The payment is asked using cryptocurrencies which makes it harder to be traced by the authorities. In order to increase their revenue, cyber-criminals try to propagate the ransomware as much as possible. To this end, ransomware primarily targets Windows operating system (OS) [2, 43], as it has the largest market share on desktop computers [38]. For instance, WannaCry authors exploited a zero-day vulnerability in Windows OS and performed a global attack [48] (more details about numerous incidents will be discussed in Section 2). Security intelligence companies warn that the dimensions of the ransomware threat increase every day. The potential targets include individuals, public institutions and enterprises. It is expected that a business will be attacked by ransomware every 14 seconds by the end of 2019 [29]. Apart from its economical damage, affected critical infrastructures or public services may stop functioning and lose their reputation [30].

1.1 Problem Definition

Ransomware detection and termination is a challenging task for traditional anti-virus (AV) solutions because of the following two reasons. Firstly, ransomware with metamorphic capability [49] can alter itself, resulting an executable with a different signature. Consequently, it is unfeasible to keep the signature databases of AV vendors up-to-date. Secondly, ransomware's basic cryptographic operations such as key generation and encryption are very common methods, which are also performed by benign programs such as web browsers, password managers, office applications and zip utilities in addition to legitimate cryptographic applications. As a result, limited heuristics capability dramatically increases the chance of false positives and damages the user experience.

Anti-ransomware solutions are developed with the purpose of dealing specifically with the ransomware threat. That said, these approaches focus on today's variants, however, ransomware is getting more sophisticated over time [44], as it happens with the other malware types. Furthermore, existing techniques for ransomware detection are insufficient to tackle the problem due to various limitations, such as, key escrow being sensitive to obfuscation and behavioral analysis being evaded by adaptive attack techniques [12]. Therefore, we propose an approach that tackles the ransomware problem in a more fundamental way.

1.2 Methodology

The thesis starts with literature survey to learn the details of Ransomware and examines previous work that detect various families of malware in infected computers. After examining general behaviour of ransomware, the distinguishing characteristic which is *excessive file write requests* was considered as worth to experiment as an indicator. Our initial expectation was that it would give us the advantage of combating ransomware without affecting system response time.

After deciding the approach, following steps are taken in order to evaluate the approach:

- A test environment, a hardened 32-bit version of Windows 7 OS virtual machine, is created. The OS selection has been based on the fact that Windows platform being the main target of ransomware [2], and version 7 being one of the most widely used edition of the OS [39]. That said, the proposed technique in this thesis can be easily adopted to the other operating systems such as Linux or macOS.
- Ransomware samples are collected and filtered active samples in order to test the functionality and effectiveness.

- A prototype, called CryptoCop, which is a dynamic linked library intercepting Windows File Application Programming Interface (API) functions calls, evaluating the activities and terminating suspicious processes is implemented.
- The effectiveness of the prototype is evaluated over 736 active ransomware samples.
- The usability of the prototype is evaluated over common applications.
- Performance experiments are run to measure the overhead added by our prototype.

1.3 Organization

The remainder of this thesis is organized as follows. Chapter 2 contains the characterization of ransomware and its history. Chapter 3 includes the previous work related to detection methods. In Chapter 4, we discuss our approach design principle and CryptoCop architecture in detail. Chapter 5 gives the details of evaluation process of the approach. The prototype implementation details, test environment setting up, experiments, tools used in the process are described. Chapter 6 details our finding about detection capability, usability and performance. Chapter 7 discusses the limitations of the approach and the prototype, and compares to the previous works. Finally, Chapter 8 contains our conclusion based on our findings.

Chapter 2

Background

This chapter provides background information to the readers that are not familiar enough with Ransomware about classification and evolution process of ransomware.

2.1 Classification of Ransomware

Ransomware is a type of malware that locks the access and demands money to re-establish access. Based on the locking method used, ransomware can be categorized into two groups:

1. *Computer Locker*: locks the functions on the target computer system via heavily consuming system resources while the data remains intact.
2. *Cryptovirus*: encrypts the victim's data using military grade encryption.

Even though both types have the same objectives, their approaches are quite different [35]. The scope of this thesis is the second variant which is also known as *cryptographic ransomware.*

A typical execution of cryptographic ransomware can be exemplified as follows. After infected, cryptographic ransomware immediately gets encryption keys. Then, it scans directories to find files with predefined extensions and tries to encrypt them silently. It aims to catch any valuable data which the victim would willingly pay the ransom to retrieve. When the encryption phrase is completed, an information text file is placed in every affected directory. It also displays a warning banner with a countdown timer. The banner informs the victim that her/his files has been encrypted and all data will be destroyed if they do not pay the ransom in the given time. However, generally the infected computer remains functional.

Ransomware is generally developed with hybrid cryptosystem to be more secure, which is the system providing data protection with the symmetric algorithms and key protection with asymmetric algorithms. Thus, ransomware generally creates symmetric keys on a victim's computer and encrypts files, then encrypts these symmetric keys with the public key.

Ransomware generally follows a sequential approach for file processing. In other words, it encrypts plain-text data, stores the encrypted data, removes the original file and then moves on the next file. The main motivation points for processing this way are as follows: (i) Lower code complexity (ii) Minimal disk usage (iii) Increasing the chances of having some valuable files encrypted in case getting detected before encrypting all data

Ransomware can be classified into three groups regarding their way of processing files [36]:

1. This group of ransomware overwrites the file with the encrypted form of the original data. Some of them also change the name of the file.
2. This type first moves the file to the another directory, reads the data and writes having encrypted data to the same file. Lastly, it moves the file to the previous folder. They might also change the original file name.
3. This group creates a new file and writes encrypted data after reading and performing encryption and then deletes the original file. Different than the rest, this type uses two different stream to write and read operations.

Ransomware uses various methods for propagating including social engineering, spam email, short message service (SMS) message, downloader, data breach, exploit kits, bot infections. Even some cyber criminals specialized in this area are paid in return for defeating the strong defenses and distributing the malware.

2.2 The Evolution Process

The history of ransomware starts with the `AIDS Trojan` created by Joseph L. Popp in 1989. The virus was distributed via floppy disk and encrypted file names by using a weak symmetric encryption algorithm [34].

In 2005, `GPCode` or `PGPCoder` was the first modern example of ransomware that encrypts user data on infected computers and demands a ransom for data recovery [35]. Its first variants had some flaws such as weak custom-encryption algorithms, using only symmetric encryption which made the attack revertible easily [15–17]. The enhanced variant called `Gpcode.ax` appeared in late November 2010. The new one used stronger cryptographic algorithms, RSA-1024 and AES-256. Unlike the previous variants, it worked by overwriting the data in files instead of creating new file and deleting the one, which prevented recovery via data-recovery tools [18].

In 2006, `Trojan.Cryzip` attacked victims' data by creating a password-protected ZIP file for each user file with the target extensions [40]. However, it was quickly overcome since the password was embedded inside the source code [35].

`Trojan.Archiveus` also came forward in 2006. Differently, the victims were requested to buy some medications from certain online pharmacies and share the order ID [35] to obtain the password to recover their data.

In 2008, the first locker ransomware called `Trojan.Randsom.C.` emerged. In 2011, it was the large-scale locker ransomware outbreak, 60,000 new ransomware samples were identified. The demanded ransom was around US$150 to US$200 [35] per victim.

Between 2012 and 2014, locker ransomware disguised as law enforcement was used as an effective way to force victims to pay. For example, the version of the `lyposit` toolkit called `Reveton`, notified victims with a pop-up message that their computers have been locked by the FBI or U.S. Justice Department downloading copyrighted material, or due to some other criminal activity [34]. However, these locker ransomware variants could be removed using security softwares [35]. With increasing awareness of the threat and easy recovery methods, cybercriminals' income started to decrease.

In time, cybercriminals focused on cryptographic ransomware again, learned the critical component of encryption and achieved to create successful ransomware.

In November 2013, one of the famous attacks, `CyptoLocker`, was made. It spread via email attachments or an existing infrastructure of `Gameover ZeuS` botnet, encrypted 67 different file types, utilized RSA encryption algorithm and demanded a payment around two Bitcoins equivalent of US$100 at that time within 72 or 100 hours. In May 2014, the variants of CyptoLocker were reported to have infected 500 000 machines and have received ransom from 1.3 percent of victims [34]. In June 2014, to thwart this threat, Cryptolocker distribution servers were taken down by a consortium constituting a group of law enforcement agencies, security software vendors, and several universities [34].

After the success of Cryptolocker, the attackers focused on developing new techniques. The number of ransomware families increased by 250% between 2013 and 2014 [35]. In February 2014, `CryptoDefense` appeared. Despite the poor implementation of the cryptographic functionality, the ransomware earned $34,000 in its first month [41].

`CryptoWall`, the more sophisticated form of CryptoDefense, appeared in April 2014. The family propagates via malicious attachment and links in spam emails and unfortunately its variants are still a threat today [26]. Its third variant had earned more than US$325 million from a mix of end users and businesses alone [7]. `Koler.a` is also launched in April 2014 and infected around 200 000 Android users. Another ransomware detected in 2014 is `SynoLocker` targeting Synology network storage.

In May 2015, Ransomware as a Service (RaaS) appeared, which offers a service for attackers to create, launch and maintain their ransomware without having any technical skills [35]. 342 000 new variants were seen in that year [42].

While new enhanced versions of existing ransomware appeared such as the fourth iteration of CryptoWall [8], new ransomware targeting different OS appeared. In September, `LockerPin` was released to infect Android systems. In November, `Linus.Encoder.1` targeting Linux systems was discovered by Dr. Web, a Russian computer security firm [34].

In 2016, although the number of new variants decreased to 241 000 when compared to 2015, the infection rate increased to 361 000 from 470 000 [42]. Attackers started to use Javascript which allows to perform multi-platform attacks, including Linux and macOS, and infected thousands of WordPress web sites [34].

In this year, many other ransomware families were seen, including `Petya`, `Locky`, `Cerber`, `Sage`, `Mamba`. Additionally, in 2015-2016, the demanded ransom increased by a factor of three from US $294 to US $1077 [42].

In May 2017, the trend changed and the number of variants started to increase. Two important outbreaks were seen in this year: `WannaCry` and `Petya`. They propagated by exploiting critical vulnerabilities (later named as EternalBlue) in Windows OS and infected thousands of computers in more than 150 countries within a matter of hours. Other major ransomware families were `Jaff`, `Globalmposter`, Cerber, Locky, Sage, Mamba. In that year, the average amount of demanded ransom was stabilized at approximately US $544 [42].

The ransomware kept hitting companies and causing financial and reputational damage in 2017. For instance, South Korean web hosting firm Nanaya hit by `Erebus`. The company ended up paying approximately US $1 million but also its stock price fell by over 3% due to the attack. Another incident was Danish shipping giant AP Moller-Maersk being hit by a variant of Petya and declared to lose up to US $300 million [42].

Chapter 3

Related Work

This chapter gives information about previous work related to this thesis work that tries to detect ransomware to gain better understanding.

3.1 Practical Limitations of Backup Strategies

At first glance, one can consider that ransomware can be mitigated by backing-up all critical data regularly and restoring the files in case of an attack. However, this strategy is not an effective and efficient way because of common bad habits such as insufficient back-up frequency, non-comprehensive file coverage, or insecure configuration of back-up locations that can be accessed by ransomware. This has been confirmed by a survey on backup practices [9] which reports that only 42% of users were able to fully restore their data after a ransomware attack.

3.2 Literature Review

Naturally, the growing threat of ransomware gained the attention of security professionals. In the cryptographic literature, there have been several proposals to combat ransomware. These can be classified into six groups regarding their defense strategy: (i) access control; (ii) behaviour analysis; (iii) key escrow; (iv) decoy files; (v) hardware-assisted protection; and (vi) network-level defense.

- **Access Control**: In the context of ransomware defense, this approach protects the system *before* file modification by controlling accesses to the cryptographic functions. For example, UShallNotPass [11] proposes a mechanism that all processes, except white-listed ones, need to get permission from the user to call the critical cryptographically secure pseudo-random number generator (CSPRNG) function. UShallNotPass leverages the necessity of generating secure random numbers to perform strong encryption. Differently, Palisse et al. [32], an earlier proposal, replaces the cryptographic service provider in Microsoft Cryptographic API (MS CAPI) to control built-in encryption functions.

- **Behaviour Analysis**: This approach attempts to detect ransomware *during* the attack by monitoring process behaviors and looks for anomalies, such as aggressive modification of different files types. For example, UNVEIL [20] considers repetitive I/O requests for multiple files as an anomaly. All I/O requests are fingerprinted (process, file, I/O type, write buffer entropy) by and recorded in a sequence. Repeated entries in this list are interpreted as ransomware activity. CryptoDrop [36] monitors modification of file header, change of file's entropy and dissimilarity between file contents before and after a write operation. A process which triggers all these indicators or reaches the threshold is considered as ransomware. ShieldFS [4] looks at low-level I/O activity and searches for excessive file read/rename/write, directory traverse, high entropy write operations and file type coverage. Different from the two previous works, ShieldFS creates shadow copies of all modified files to prevent data loss. Similarly, Redemption [19] uses the same indicators, but applies the write requests to sparse files and commits the changes later. Lastly, DaD [33] calculates the chi-square goodness-of-fit test on the write buffer of processes to detect random looking content which may be a encryption method outcome.

- **Key-escrow**: This approach leverages the fact that the symmetric algorithms must be employed for feasible encryption of files. Obtaining the secret keys used in the victim's computer would therefore enable to recover the encrypted files. In this regard, [24] and PayBreak [22] intercepts crypto API calls and logs the parameters in a secret vault. After the attack, the correct keys are searched by the brute-force method within this vault. In a slightly different method, [21] proposes to put a backdoor in CSPRNG of the host to reproduce the keys generated by ransomware and recover the files.

- **Decoy Files:** Another strategy to detect cryptographic ransomware is to employ decoy files to detect malicious file system activity. In this strategy, carefully-crafted fictitious files are placed in the file system among real files. The user is informed about the decoys and is not supposed to write on them, so any write request to the decoy files is treated as an indicator of ransomware activity. RWGuard [27] uses this technique –in addition to behavioral analysis– to mitigate ransomware threat in real time. Moreover, there are commercial applications, e.g., CryptoStopper [47] which use decoy files to detect cryptographic ransomware.

- **Hardware-assisted Protection:** Different from software-based solutions, FlashGuard [13] is a hardware-level anti-ransomware that leverages the capabilities of Solid State Disks (SSDs). To protect the data, FlashGuard patches the device's firmware and modifies the garbage collection mechanism of the SSD to keep the copies of the data encrypted by ransomware. When the victim is aware of the ransomware attack, the files can be recovered by using the copies available on the disk.

- **Network-level Defense:** An alternative protection strategy is to mitigate ransomware at the network level. Certain ransomware families download encryption keys from a remote location, i.e., Command-and-Conquer (C&C) servers. If this communication is disrupted, i.e., the malicious server's IP is blacklisted and the network firewall blocks the connection, the keys cannot be delivered. Towards this goal, [3] proposed a software-defined networking (SDN) based approach to block C&C servers after a threat is detected. Furthermore, [6] employed machine learning techniques and developed an SDN-based system to prevent delivery of keys on HTTPS traffic which malware is shifting towards to utilize.

Chapter 4

CryptoCop Design

We proposed CryptoCop as an early warning system to detect and stop the malicious activity of cryptographic ransomware. In order to present our approach in detail, this chapter begins with design principles that are considered while mitigating ransomware. Next, the prototype, called CryptoCop, security assumption and architecture are described.

4.1 Design Principles

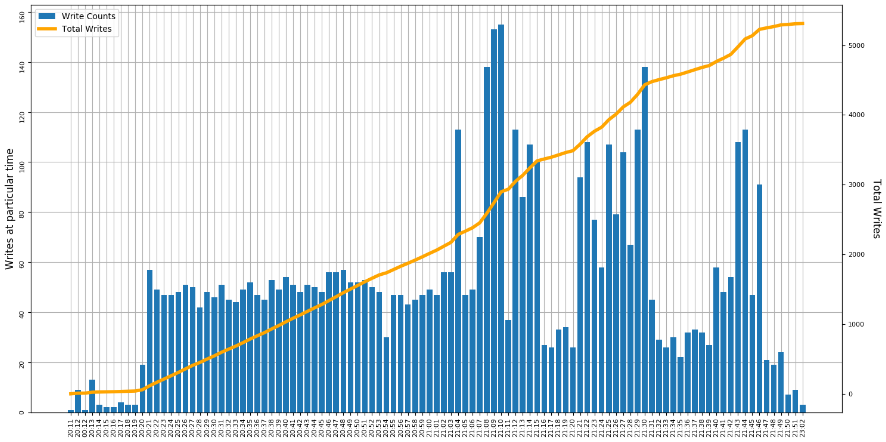
We developed our defense method by not only using the observations on the behaviour of a wide set of cryptographic ransomware families but also considering the attack surface extension possibilities.

To the best of our knowledge, the requirements of a successful ransomware campaign with a mass impact is first analyzed in detail by [10].

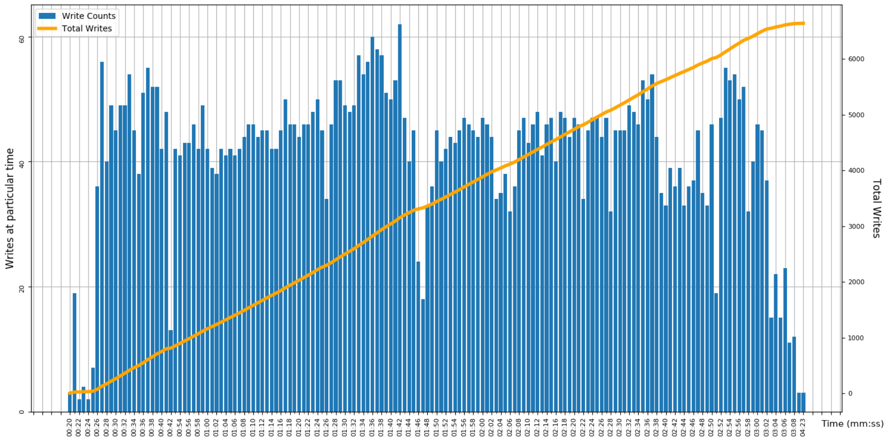
Among others, it is crucial to note that cryptographic ransomware needs to perform two fundamental tasks to achieve its nefarious aims:

- **Encrypt plaintext data.** Access to original data should be locked using a reversible mechanism which can be performed by only the attacker. Cryptographic ransomware employs encryption algorithms to lock access to the victim's data.
- **Destroy plaintext data.** The original data must be inaccessible, i.e., deleted or overwritten, in order to force the victim to pay the ransom.

As we reviewed the previous work in Chapter 3, cybersecurity community proposed efficient defense systems to address the ransomware threat. However, the combat against



(a) Write activity of a TeslaCrypt sample



(b) Write activity of a Bitman sample

FIGURE 4.1: The bars represent the number of unique files modified by ransomware at given time point. The yellow line shows the number of written files at a specific time.

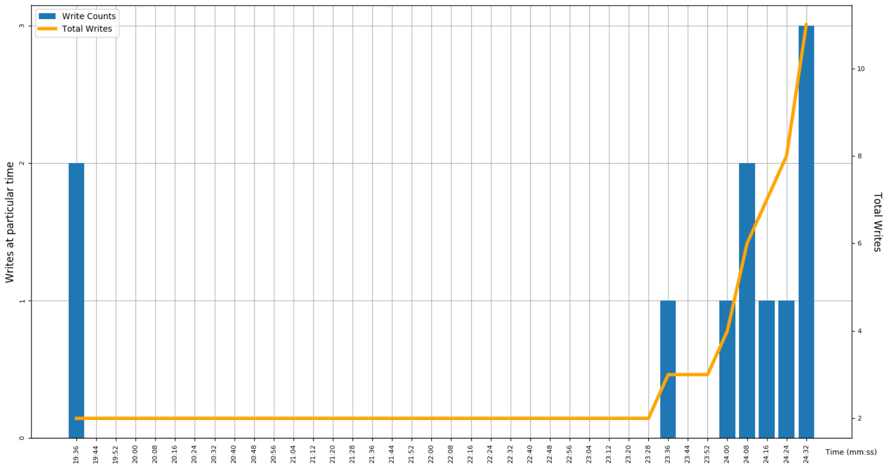
malware is a never-ending war, and the history suggests us that the ransomware, although today mostly fairly contained, will evolve to bypass current defenses. For example, [12] showed that next generation ransomware may use alternative techniques to evade detection. It should be noted that the damage of ransomware might be irreversible, especially when the encryption methods are used properly. We designed CRYPTOCOP to be ready for this potential threat.

The following principles are considered when designing CRYPTOCOP.

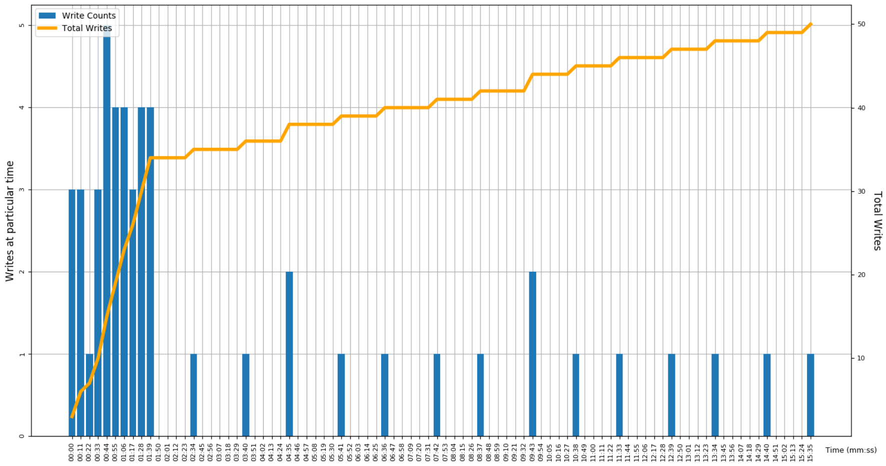
- **Statistical anomaly indicators can be evaded.** Behavioral analysis-based defenses try to detect ransomware activities by looking for the statistical anomalies by utilizing chi square goodness-of-fit test, entropy, etc. If a ransomware finds a way that does not trigger such indicators, it would not be detected, see [12] for instance. Therefore we do not adopt statistical measures in our defense strategy.

- **Controlling crypto APIs can be nullified.** There are long-tested and publicly accessible cryptographic libraries that can be utilized by ransomware. In addition, ransomware can leverage obfuscation which makes intercepting/controlling these operations unfeasible. Consequently, we abandon this strategy and do not use in the defense system.

In the light of these tenets, we recognize only one indicator of ransomware that cannot be hidden or substituted: *aggressive increase in the calls to file write API* of the host OS.Figure 4.1 distinguishably displays the dense write activity of two ransomwares, namely TeslaCrypt and Bitman, as compared to activity of benign application in Figure 4.2.



(a) Write activity of compression and decompression of 5 files (1GB) with WinZip



(b) Write activity of downloading a torrent of 22 files(3GB) with µtorrent

FIGURE 4.2: The bars represent the number of unique files modified by ransomware at given time point. The yellow line shows the number of written files at a specific time.

4.2 Security Model and Assumptions

As a defense system, CryptoCop aims to protect the host from cryptographic ransomware. Non-cryptographic ransomware variants are beyond the scope of this paper. We also consider that the ransomware is able to encrypt victim's data using any algorithm. That is, we do not make any assumption on the encryption technique.

We designed CryptoCop as a software module running on the environment provided by the host OS. As a natural consequence, we assume that the host OS prevents vertical privilege escalation, otherwise the attacker may obtain administrator rights and disarm CryptoCop. It should be noted that, even if the host OS is up-to-date, an attacker with the knowledge of a zero-day vulnerability may disable the protection.

Furthermore, no modern OS allows direct disc access, i.e., processes need to call the specific APIs provided by the host OS in order to write data to disk. For example, on Windows platform, user mode processes invoke `WriteFile` API for disk I/O. Therefore, we assume that ransomware must use system APIs to write encrypted data back to disk.

4.3 Architecture

In essence, CryptoCop is a file system monitor which tracks the most fundamental activity of ransomware: writing (encrypted) data. By controlling the calls to file write API, CryptoCop maintains a malice score for processes and allows only the normal-behaving applications to write to disk. Otherwise, for instance, if an application goes beyond the security threshold, it is terminated immediately. Figure 4.3 depicts the workflow of CryptoCop.

4.3.1 Controlling File Write API

User-mode processes need to use APIs provided by modern OS to write data to disk. Since these file write functions are well-known and their number is limited, it is feasible for CryptoCop to monitor and control them.

4.3.2 Malice Score Computation

CryptoCop maintains a malice score for each process, based on the file write activity. It should be noted that malice score is a value maintained individually inside each process hence no additional synchronization is required among processes.

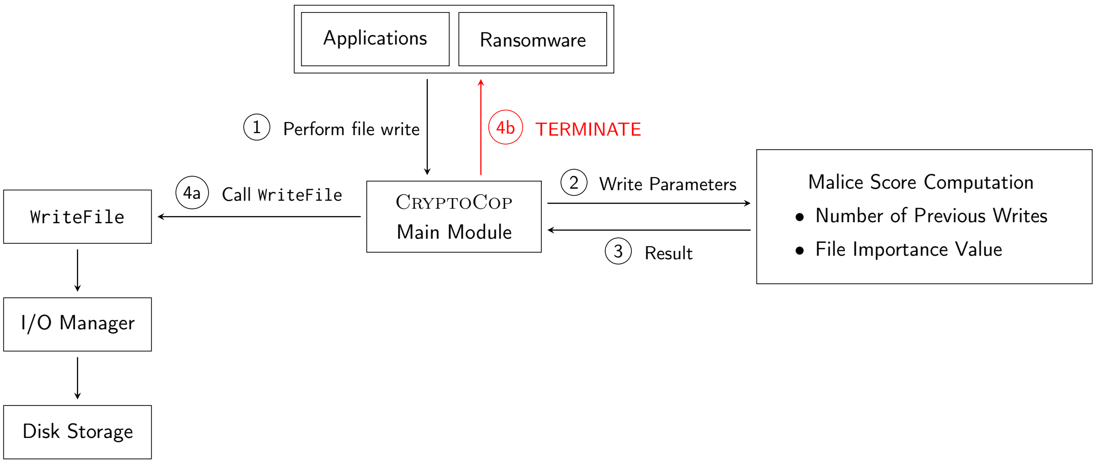


Figure 4.3: Design overview of CryptoCop. The module intercepts file write calls and updates the malice score accordingly. If the malice score of a process exceeds the threshold, the related process tree is terminated. Otherwise, the call is dispatched to the I/O Manager.

Let F denote the set of files and $F_p \subseteq F$ be the files modified by the process p. Malice score of p, denoted M_p, is the sum of importance values, v_f, assigned to the modified file f for all $f \in F_p$. Thus, we have

$$M_p = \sum_{f \in F_p} v_f \tag{4.1}$$

For all processes, M_p is recalculated after each intercepted call to `WriteFile` API if the modified file f is being accessed for the first time by the process p. If M_p exceeds T, where T is the security threshold, CryptoCop blocks the call and terminates p. Otherwise, the call is forwarded to the I/O manager and control is routed to p.

4.3.2.1 Determining Security Threshold

The values for T and v_f are configurable and have to be assigned according to the users' requirements. The main motivation behind this flexibility is to capture various use cases that can arise from the fact that users have different number of files and file types, and different level of importance per each file etc. For instance, while an office computer containing confidential data needs to keep more files safe, a commodity user might tolerate losing a larger number of files. Furthermore, highly critical files such as databases can even be assigned importance values higher than the threshold in order to make sure only database user can modify them. However, it needs to be underlined that setting v_f too strict will cause an increase in the rate of false positives. In other words, the strictness of these parameters is a trade-off that has to be made by the user between usability and accepted risk of file loss.

Chapter 5

Evaluation Process

This chapter discusses development and evaluation process of our solution. In other words, it can be called as our road map. It starts with giving information of our prototype, CryptoCop, implementation details. The important steps of experimental environment set-up are listed. Finally, the critical tools used in the development process are mentioned.

5.1 CryptoCop Implementation

To evaluate the effectiveness of the selected indicator, we developed a prototype[1] of CryptoCop. On Windows platform, applications call `WriteFile` API to write data to the disk. Therefore, our prototype intercepts each call made to `WriteFile` API and computes the malice score of the caller process in real-time. To accomplish this goal, our CryptoCop implementation comprises two modules:

- Main Module, which intercepts the invocations of `WriteFile` API, determines the identity of the caller process and dispatches it to the malice score computer, and takes the appropriate action according to the computation result.
- Authorization Module, which receives information about the `WriteFile` API calls of the process, maintains the table for malice score computation and returns an authorization response according to the predefined threshold.

5.1.1 Intercepting WriteFile API Calls

On Windows platform, controlling file write operations can be achieved in two different ways:

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[1] Available under GNU v3 at `https://github.com/melparmaksiz/cryptocop`

- user mode, by injecting a Dynamic Link Library (DLL) into target process or modifying the Import Address Table (IAT); or
- kernel mode, by modifying the System Service Dispatch Table (SSDT) or utilizing a file system filter driver.

In our research, we employed DLL injection technique to run our controller code in the target processes. Concordantly, Main Module of CryptoCop is implemented as a DLL. For its technical simplicity, we used AppInit_DLLs method to inject our Main Module into all starting processes. To take control of the program control flow, we utilized Detours library [14] developed by Microsoft Research. Once Main Module is loaded into the target process, it hooks `WriteFile` function, that is, whenever `WriteFile` API is called by a process, the program flow is routed to CryptoCop.

Using AppInit_DLLs Method

The following operations should be performed to utilize `AppInit_DLLs` technique for DLL injection.

- Run Registry Editor Windows Start » Run type regedit.exe ↲
- Navigate to : HKLM\SOFTWARE\Microsoft\WindowsNT\CurrentVersion\Windows
- Create a string with the name `AppInit_DLLs`, and assign the value `PATH\TO\cryptoCop.dll`
- Create a DWORD with the name `LoadAppInit_DLLs`, and assign the value `00000001`.

After this point, each new process that loads `user32.dll` will also load `cryptoCop.dll`.

5.1.2 Maintaining Malice Score

At each call of `WriteFile` API, CryptoCop acquires the control flow, obtains the location of the file-to-be-written, f. This information is then sent to Authorization Module, which adds f to the trace record of current process p, denoted $Tr(p)$. Each process maintains its own trace record individually by using a hash set such that, at each call, the path of the target file is added here while no two elements are the same.

In our experiments, we assumed that the user has three categories of files:

- *high importance*: files that are critical for the user, i.e., the files for which the user would be willing to pay ransom;

- *low importance*: files that do not contain important data, but losing them would still cause trouble; and
- *dispensable*: files that do not have any value for the user, e.g., temporary files.

Therefore, we defined three possible values for v_f: *high*, *low*, and *none*. Furthermore, we assumed that the user can tolerate the loss of 5 highly important files or 100 low importance files at most. Our model brings the following requirement for the security threshold:

$$5 \times v_f^{high} = 100 \times v_f^{low} \geq T \tag{5.1}$$

The simplest integral solution to Eq 5.1 can be found by computing the least common multiple (LCM) of 5 and 100. Thus, we set

$$T = LCM(5, 100) \tag{5.2}$$

which yields $T = 100$, and accordingly, we have *high*$= 20$ and *low*$= 1$. Finally, we set *none*$= 0$ for dispensable files.

To make the decision of authorization for p, Authorization Module instantiates Eq. 4.1 with $F_p = Tr(p)$, updates M_p and calculates $\Delta_p = M_p - T$. The computation proceeds with checking if $\Delta_p < 0$. If so, then Authorization Module returns ALLOW, the data is written to f and Main Module returns the control to p. Otherwise, i.e., if the process has written some number of files causing the threshold excess, Authorization Module returns DENY and p is terminated.

5.1.3 Malicious Process Termination

Once a process exceeds the security threshold, all subsequent requests of that process are blocked. The process' topmost ancestor is detected. Then, the process tree, of which the topmost ancestor is the root, is terminated in a bottom-up order (i.e from leaves to root).

5.2 Test Environment

This section mentions the steps taken while creating the environment for our experiments for this thesis. We used a Virtual Machine named ransomwareTest with 2 GB memory and dynamically allocated 160 GB hard disk for our tests.

5.2.1 Hardening Windows 7 x86 on VirtualBox

In order to prevent ransomware detecting that it runs in a virtual machine, in which case it doesn't show any malicious activity, the following steps were taken to remove the traces of virtualization from the Virtual Machine (VM).

- **Set Accelaration Type**
  Ransomware checks hypervisor fields in CPUId to look for known VM vendors. Switching `Accelaration Type` from `ParaVirtualization` to `None` helps bypassing this control.

- **Set Processor Count and Disk Size**
  We decided to set processor count to a value greater than one since some ransomware assume single processors as virtual machines as most of the commodity computers today are multi-core. Similarly, since today's computers have large disk capacity, we determined the disk size of 160 GB.

- **Change MAC Address**
  The MAC address of the machine has to be changed, since the default prefix `080027` is a virtual box indicator.

- **Remove VBOX Keywords**
  In order to remove `VBOX` keywords from the output of `sysinfo` console command and Disk properties, we assigned new values to the following keys by using the following command.

  ```
  $ VBoxManage setextradata ransomwareTest key new_value
  ```

  Table 5.1: List of properties with VBOX keyword

Key	Value
VBoxInternal/Devices/pcbios/0/Config/DmiBIOSVendor	LENOVO
VBoxInternal/Devices/pcbios/0/Config/DmiBIOSVersion	LENOVO 1230 Ver 1.00PARTTBL
VBoxInternal/Devices/pcbios/0/Config/DmiBIOSReleaseDate	09/16/13
VBoxInternal/Devices/pcbios/0/Config/DmiSystemVendor	LENOVO
VBoxInternal/Devices/pcbios/0/Config/DmiSystemProduct	Lenovo – 1230 Ver 1.00PARTTBL

- **Antivmdetection Script**
  The AntivmDetection python script developed by Mikael Keri helps to get done additional settings to make VM detection harder such as modification of ProductKey, removing Video Graphics Array (VGA) device.

  It creates two scripts : *.sh and *.ps1. While the file with the sh extension must be run on the host machine, the latter runs on the virtual machine.

```
$ apt-get install python-dmidecode libcdio-utils acpidump mesa-utils
$ wget https://download.sysinternals.com/files/VolumeId.zip
$ wget https://www.nirsoft.net/utils/devmanview.zip
$ git clone https://github.com/nsmfoo/antivmdetection.git
$ echo "meltem" > user.lst
$ echo "meltem-pc" > computer.lst
$ sudo python antivmdetection.py
```

Listing 5.1: Completing the requirements of `antivmdetection.py`.

- **Install Windows 7**

  For our experiments, we decided to work on the X86-32 version of Windows 7 since it is still one of the most common OS.

- **Install Common Applications**

  In order to reflect an authentic user environment, we installed popular applications such as document viewer, office suite, web browser, media player and other system utilities.

  We also cared for special attention to prevent any leakage about the virtualization. In this context, we avoid installing software packages that are developed to improve user experience on guests as they bring virtual device drivers which reveal the virtual environment, e.g., vendor information and known device names.

- **Create Using History**

  In order to thwart advanced fingerprinting of user environment, widely used plugins where appropriate are installed and run the applications for a while to create a usage history.

- **Place Decoys**

  Some decoy files that would be the target of ransomware were generated and placed into the well-known directories such as Desktop, Documents and Pictures.

5.2.2 Making Virtual Machine Vulnerable

In order to further increase the probability of ransomware activity, the following steps were taken to make the VM more vulnerable by turning off the defense mechanisms other than CryptoCop.

- **Disable User Access Control**
  - Open Local Group Policy Editor Windows Start » Run type GPEdit.msc ↵

  - Navigate to : Computer Configuration > Windows Settings > Security Settings > Local Policies > Security Options
  - Set value of:
    - Behavior of the elevation prompt for administrators in Admin Approval Mode to Evaluate Without prompting
    - Detect application installations and prompt for elevation to Disable
    - Run all administrators in Admin Approval Mode to Disable

- **Disable Windows Defender**
  - Open Local Group Policy Editor Windows Start » Run type GPEdit.msc ↲
  - Navigate to : Computer Configuration > Administrative Templates > Windows Components > Windows Defender Antivirus
  - Set value of Turn off Windows Defender to Enable
- **Disable Windows Firewall**
  - Open Control Panel Windows Start » Run type control ↲
  - Navigate to : System and Security > Windows Firewall > Turn Windows Firewall on or off
  - Set value : Turn off Windows Firewall.
- **Disable Windows Updates**
  - Open Control Panel Windows Start » Run type control ↲
  - Navigate to : System and Security > Windows Update > Turn automatic updating on or off
  - Set value : Never check for updates.
- **Deactivate Address Space Layout Randomization (ASLR)**
  ASLR is a memory protection mechanism which prevents buffer-overflow attacks by randomizing the location of system executables in the memory. We deactivated this protection in case this attack might be used by some ransomware.
  - Run Registry Editor Windows Start » Run type regedit.exe ↲
  - Navigate to: HKLM\SYSTEM\CurrentControlSet\Control\SessionManager\Memory Management
  - Create a DWORD with a name MoveImages, and assign the value 00000000.

- **Deactivate Data Execution Prevention (DEP)**
  DEP is a security feature that prevents non-authorized programs to run code from reserved system memory locations. This protection is also disabled to make system more vulnerable by executing the following command in an administrative session of a command prompt.
  `bcdedit.exe /set current nx AlwaysOff`

- **Allow Execution of Powershell Scripts**
  To allow running Powershell scripts, the following command was executed in the power shell with admin rights.
  `Set-ExecutionPolicy Unrestricted`

- **Install Visual C++ Runtime and .NET Framework**
  In order to facilitate the malware samples that leverage Visual C++ runtime and .NET framework, the mentioned software packages were installed.

5.2.3 Network Configuration

In order to work with Cuckoo Sandbox, the VM internet access should be via host-only networking. The following configurations steps were taken to succeed it.

- **Creating a host-only Network**

```
$ vboxmanage hostonlyif create
$ vboxmanage hostonlyif ipconfig vboxnet0 --ip 192.168.100.10
```

LISTING 5.2: Create Host-Only Network

- **Assign Windows Static IP**
  - Open Control Panel Windows Start 》Run type control ↲
  - Navigate to : Network and Sharing Center > Change Adapter Settings > Local Area Connection > Properties > Internet Protocol Version 4
  - Set the values of :
    - IP address to 192.168.100.20
    - Default gateway to 192.168.100.10
    - Preferred DNS server to 8.8.8.8

- **Iptables Rules**

```
$ sudo iptables -A FORWARD  -o wlp1s0  -i vboxnet0 -s 192.168.100.10/24  -m conntrack
 ↪   --ctstate NEW  -j ACCEPT
$ sudo iptables -A FORWARD  -m conntrack --ctstate ESTABLISHED,RELATED -j ACCEPT
$ sudo iptables -A POSTROUTING  -t nat -j MASQUERADE
$ sudo sh -c "echo 1 > /proc/sys/net/ipv4/ip_forward"
```

Listing 5.3: Iptables Rules For Host-Only Network.

5.3 Cuckoo Sandbox

Cuckoo [5] is an automatic malware analysis system that monitors suspicious files by running them in an isolated environment. We have leveraged Cuckoo to automate our experiments for each ransomware.

5.3.1 VM Snapshots

After creating the test virtual machine described in section 5.2, the Agent file, Cuckoo script that runs inside the Guest and handles the communication and the exchange of data with the Host script, is placed into the VM and run.

We created two different snapshots on this VM for two phases of our experiment :

- Snapshot1: The clean system snapshot to test if a ransomware is still active
- Snapshot2: The hooked system snapshot which CryptoCop is deployed as described in section 5.1.1 without changing any other configuration .

5.3.2 Configuration

The following files stored in the cuckoo configuration directory ($CWD/conf) should be changed.

- In cuckoo.conf, set the values of:
  - machinery to virtualbox
  - ip to 10.0.0.106 (the IP of the host machine on the virtual network interface virbr0)
- In virtualbox.conf, set the values of:

  - under [virtualbox]
    - interface to vboxnet0
    - machines to ransomwareTest
  - under [ransomwareTest]
    - platform to windows
    - ip to 192.168.100.20 (virtual box ip)
    - snapshot to SnapshotX where X $\in \{1, 2\}$

5.3.3 Customization

In order to keep the generated log files separate and secure from being encrypted by ransomware, we customized Cuckoo to create a new directory for each task in a shared directory and to move all related files to this directory. The steps are as follows:

- Processing module should be enabled in the processing.conf (in the cuckoo configuration directory)

```
[cryptocop]
enabled = yes
```

- Processing module should be enabled under the processing label in the common/config.py (in the installation folder)

```
''cryptocop'': {
''enabled'': Boolean(True), },
```

- The script moving files to the shared folder should be placed under the processing directory.

5.3.4 Analysis

Cuckoo starts with the console command : `cuckoo -d`
Cuckoo web starts with the console command : `cuckoo -d web -H 0.0.0.0 -p 8000`

After starting Cuckoo Sandbox, we submitted ransomware samples to analysis for ten minutes from Cuckoo Web Page.

5.4 Experiments

Our experiments can be divided into two phases: (i) building the set of ground truth for active ransomware; (ii) testing CryptoCop against the active ransomware samples.

5.4.1 Building the Ground Truth Set

To evaluate the effectiveness of CryptoCop, we needed to test our prototype implementation against active, real-world ransomware samples – samples that encrypt the user's files. In this respect, we collected malware samples from online repositories, mainly from VirusTotal Threat Intelligence [46] and ViruSign [45]. Next, to obtain the samples which are potentially ransomware, we performed a text-based filtering on malware tags provided by VirusTotal. We used the generic ransomware keywords such as *ransom*, *crypt* and *lock* in the search string and obtained 7132 potential malware samples.

Having the potential ransomware samples at hand, we used Cuckoo automated malware analysis system with the 'Snapshot1' configuration 5.3.1 to filter the active ransomware samples, i.e., collect the malicious executables that performs encryption on user's files.

Once the test system is ready, we initiated the tests by submitting the potential ransomware samples to Cuckoo. In our tests, Cuckoo run each malware sample on the clean snapshot we prepared for this test. While ransomware usually attacks the victim's files immediately after infection, i.e., encrypts the files soon after it is first run, we configured Cuckoo to run each sample at least 10 minutes before concluding the test. After each test, we checked if the decoy files we placed are modified, by comparing the old and new hash values under SHA256, which clearly indicates the existence of a malicious file system activity. If no change occurred during the test, the sample is not count in the ransomware class and excluded from our experiments.

At the end of the first phase of our experiments, we acquired 736 active ransomware samples which formed our ground set.

The reason that the number of active samples being significantly less than the initial set is twofold. First, identification by the AV vendors might not always be accurate. For example, a malware sample that connects to a domain which is also accessed by a ransomware might be mistakenly tagged as "ransomware". Apart from the misidentification, the second reason is that the ransomware may not show any malicious activity at all. There are a wide range of potential reasons that can lead to this result. The ransomware may experience an internal error due to a bug in itself. Also, for a non-autonomous ransomware, the connection to its C&C center may have failed. It may also be possible that our efforts to convince the ransomware that it is running on a real computer might have failed due to its advanced environmental fingerprinting capabilities.

Identifying Ransomware Families

In order to investigate the connections between ransomware samples and to understand the methods used by malware authors, we grouped the tested ransomware samples by their families. To this end, we utilized AVCLASS [37] tool, which automatically labels malware samples using the information provided by AV engines.

For family detection, we used VirusTotal service, which provides scan results that contains the labels assigned by multiple AV vendors. We wrote a Python script, `getVTReports.py`, to download the scan results from VirusTotal. Next, AVCLASS was used to process this information and output the family name based on plurality voting. Listing 5.4 shows the steps of family identification.

```
$ python getVTReports.py --outputDir vtdl
$ python avclass_labeler.py -hash sha256 -vtdir vtdl > labels.txt
$ cat labels.txt
000a77953565d43520dacf7446baef17252718d06fc8770727ee6aacb245db8a   bitman
00b56667d794895fe8342f4d616e303cea222b88d2af8f0042b8e264a759e975   bitman
0a68cf3e31426966aee7d9c76d52df906d7e1fa3380a78e3cde3b56b930f7680   bitman
...
```

LISTING 5.4: Identifying the family names using the VirusTotal reports and AVCLASS tool.

5.4.2 Assessment of CRYPTOCOP Efficiency

After having the ground set ready, we initiated the second phase of the experiment: evaluating the efficiency of the CRYPTOCOP. We tested the active ransomware samples against our CRYPTOCOP prototype by using Cuckoo automated malware analysis system with the 'Snapshot2' configuration 5.3.1. Then we analyzed the CRYPTOCOP reports to assess the detection capability, the number of damaged files and their importance level and the time passed until the detection.

The sample CRYPTOCOP report of a detected Bitman sample can be seen in Appendix A.

5.5 Tools Used In the Experiments

- **Pafish**
  Pafish [31] is a demonstration tool that observes the environment whether it is sandbox and analysis one. It was leveraged to make sure the system is hardened before taking the Snapshot of the test environment.

- **Xenos**
  Xenos [1] is a Windows DLL injector based on Blackbone library. It was used to quickly inject and test our code while developing CryptoCop.

- **Dependency Walker**
  Dependency Walker [28] is a utility tool that examines Windows modules and shows all dependent modules and functions calls from them. It helped to determine which file system function are called by ransomware. Additionally, it was used to make sure if ransomware has dependency on user32.dll, since selected DLL injection method, LoadAppInit_DLL, injects the DLL while being loaded user32.dll.

- **Process Hacker**
  Process Walker [25] is a utility tool that helps monitoring system resources. It was leveraged to discover the ransomware behaviour at runtime, such as which files are being used, disc access volume and frequency, and the processes created by ransomware.

Chapter 6

Results

6.1 Experimental Results

In this section, we report our findings which aim to answer the following research questions:

Q1 Can CryptoCop detect ransomware at an early stage such that the valuable data is protected?

Q2 How CryptoCop affects the activities of benign applications?

Q3 What is the performance overhead of CryptoCop on the host machine on which it acts as an early warning system?

These research questions need to be answered to verify the effectiveness of CryptoCop's design while ensuring its usability. In this regard, **Q1** addresses the security of the system against cryptographic ransomware. As a protection system, CryptoCop must also be usable, since otherwise the users may turn off the defense which makes them vulnerable to ransomware threat which is mostly irreversible. Therefore, we analyze the false positive rate of CryptoCop in **Q2** and its performance impact in **Q3**.

6.1.1 Detection Capability

In this section, we analyze the results of the second phase of our experiments to answer **Q1**, can CryptoCop stop ransomware in an early stage so that valuable data is protected?

We defined the files in Desktop, Downloads, Documents and Picture directories as high protected and set the file loss rate to be at most 5 percent of total files (5 files). We also limited the number of write requests as 100 for low importance files per process.

Table 6.1 demonstrates the detection capability of CryptoCop against real-world ransomware. *WriteFile Statistics* demonstrates the average of the activities of ransomware samples: the number of written files with high importance, the number of written files with low importance, and total execution time until detection, i.e., $\Delta_p \geq 0$. During the experiments, CryptoCop stopped 706 out of 736 ransomware samples once they reached the security threshold T. We left the discussion on the undetected samples to §7. The results prove that our approach of detecting ransomware activity only by monitoring file write API is an effective measure.

6.1.2 Usability Tests

In this section, we first answer **Q2**, how CryptoCop interprets the legitimate activities on the system by testing benign applications and observing the false-positive rate of CryptoCop. We run our experiments on a X86-32 version of Windows 7 virtual machine, with 2GB of RAM and 2 CPU cores at 1.90GHz. We set the importance value of files in temp folder and temporary internet files to *none*, since there is no user specific data in these folders.

Analysis of False Positives In the course of answering **Q2**, to measure false-positive rate, we ran Windows common applications: Chrome, 7-Zip, Dropbox, Acrobat Reader, Sticky Notes, Internet Explorer, Skype, Telegram Desktop, µTorrent, MS Word, MS Excel, GIMP, LibreOffice. We did not notice slowdown in any of the applications.

In our experiments on the hooked system, we detected that 7-Zip and µTorrent might exceed the threshold, e.g., when multiple files extracted by 7-Zip or downloaded by µTorrent. LibreOffice creates a temporary file on each save operation such that excessive number of saves causes a false positive, especially when working on a high importance file. With the rest of the applications, we performed the following tests and no false positives occurred. We browsed the Internet with Chrome for two hours and downloaded & installed 7-Zip and Dropbox. We installed Dropbox, logged in and synchronized around 3000 files with cloud. We created 3 files and updated a couple of files without any problems. We logged in a Skype account, sent/received files, and made a call. Table 6.2 demonstrates the evaluation of CryptoCop's usability against common benign applications in terms of performed operations and number of modified files.

It should be noted that the burden caused by the false positive scenarios can be mitigated by asking for user approval upon suspicious activity detection. If the user decides that the process is in fact a legitimate application, then it can continue to run.

Table 6.1: Evaluation of CryptoCop against real-world & active ransomware samples.

Family	Number of Samples (stopped / total)	`WriteFile` Statistics		
		Avg. High Importance	Avg. Low Importance	Time (ms)
Barsys	1/1	1	80	5.74
Bitman	147/149	1.18	76.46	131.13
Cerber	58/58	4	25.74	125.42
Cryakl	1/1	0	100	8.77
Crypmod	3/4	0.67	86.67	3606.04
Cryptowall	0/1	-	-	-
Cryptxxx	2/2	2.5	53	156.33
Crysis	3/3	0	100	1839.53
Dalexis	0/3	-	-	-
Deshacop	1/1	1	80	3.14
Enestaller	1/1	4	25	90.20
Enestedel	1/1	4	25	6673.11
Gamarue	2/2	1.5	70	1614.51
Gandcrab	1/1	0	100	2.64
Jaff	1/1	0	100	7.7
Lethic	4/4	1	80	4.30
Locky	42/45	3.90	26.52	366.34
Midie	1/1	1	80	708.97
Mikey	1/1	1	80	2.44
Neoreklami	1/1	0	100	11.7
Petya	2/2	5	2	16.5
Razy	6/6	2.5	52.17	4.12
Saturn	0/1	-	-	-
Scar	3/3	1.33	73.33	6.79
Scatter	2/2	4	23.5	3761.35
Shade	2/2	2.5	58	1922.88
Shiz	16/17	1.25	75	8.70
Spora	2/2	4.5	16.5	257.84
Tescrypt	4/5	1.25	75	6.27
TeslaCrypt	306/309	1.24	75.23	61.93
Tpyn	1/1	1	80	3.45
Upatre	0/7	-	-	-
Virlock	0/3	-	-	-
WannaCry	0/1	-	-	-
wowlik	1/1	5	4	10802.45
Wyhymyz	1/1	0	100	1207.86
Yakes	34/37	4.85	70.94	13.62
Zerber	49/49	4	25	172.76
Zusy	6/6	1.17	76.67	5540.31
Total:	706/736 (95.9 %)			

TABLE 6.2: `WriteFile` API call statistics of common applications and their interactions with CRYPTOCOP. *Operation* represents the functionality of the application. *WriteFile Statistics* demonstrates the number of `WriteFile` API calls during our tests: *High Protected* column displays the number of write operations on high importance files, and *Low Protected* for those with low importance. The red lines show the program activities that might exceed the threshold for high or low protected files.

Application	Operation	`WriteFile` Statistics	
		High Importance	Low Importance
Acrobat Reader	File Open	0	1
Chrome	Browsing	0	1
	Download	0	0
Dropbox	Install	1	1
	Log In	0	3
	Synchronization	0	0
	Add File	0	0
GIMP	Open & Edit File	1	0
Internet Explorer	Browsing	0	1
	Download	1	0
LibreOffice	Open a File	1	0
	Edit a File	3	0
	Ctrl+S	1	0
	Multiple Ctrl+S	5	100
Microsoft Excel	Open & Edit File	0	0
Microsoft Word	Open & Edit File	0	0
Skype	Log in	0	1
	Sent File	0	0
	Received&Save File	0	0
	Call	0	0
Sticky Notes	Installation	1	2
	Take Notes	0	0
uTorrent	Download one file	0	1
	Download multiple files	5	100
WinRAR	Compress	1	0
	Extract one file	1	0
	Extract multiple files	5	100
7zip	Compress	1	0
	Extract one file	0	1
	Extract multiple files	5	100

6.1.3 Performance Overhead

In this section, we look for the answer of **Q3**, determine the performance impact of CRYPTOCOP on the host system by measuring the overhead on calls to file write API. We run our experiments on a x86 version of Windows 7 virtual machine, with 2GB of RAM and 2 CPU cores at 1.90GHz.

In the course of answering **Q3**, we called `WriteFile` API to overwrite 1 KB, 32 KB, 1 MB and 4 MB of data inside a file which is randomly selected from a set of 100 files and measured the time taken during these operations. We limited the number of different files to a constant number to stay below the threshold limits of CryptoCop. We performed 1 million iterations of this experiment, which was observed to be sufficient enough for average time to converge/stabilize on both clean and hooked systems. CryptoCop caused the average write time to increase around `0.1ms` per call.

Table 6.3: Benchmark Results

Platform	Length of Written Data			
	1 KB	32 KB	1 MB	4 MB
Clean System	109 μs	115 μs	295 μs	4443 μs
CryptoCop	238 μs	247 μs	408 μs	4526 μs
Overhead	129 μs	132 μs	113 μs	83 μs
Relative Overhead	54 %	53 %	27 %	0.1 %

As Table 6.3 demonstrates, the time spent for CryptoCop controls is independent of the size of the buffer. Additionally, the slowdown in the write performance is due the fact that the time consumed by `WriteFile` is exceedingly short for small chunk of data and becomes comparable to time taken by CryptoCop. It can be seen that as the size of the data increases, the impact of the control becomes negligible.

We also remark that the benchmarks are performed using the prototype developed during this research and no optimization was made. It is reasonable to expect better performance results from an optimized version of CryptoCop.

Chapter 7

Discussion

In this chapter, first, we compare the state-of-the-art anti-ransomware systems in the cryptographic literature, including our system, CryptoCop. Next, we point out the potential limitations of current prototype, explain the design challenges, and discuss how CryptoCop can address them in the future.

7.1 Comparison with the Other Anti-Ransomware Systems

In Table 7.1, We present the outstanding defense solutions that were described in Section 3. *Detection Approach* denotes the operation mode of the corresponding anti-ransomware, according to the categorization given in Section 3. Note that, RWGuard is labeled as Hybrid as it unifies various approaches such as behavioral analysis, API hooking and decoy files.

The anti-ransomware systems can be classified into three groups according to their security function; prevention, detection, and recovery. CryptoDrop, which is an example of the *detection* group, looks for the signs of ransomware activity by monitoring the running processes, that detection occurs *during* the attack, in run-time. On the other hand, UShallNotPass is an example of *prevention* group: it stops non-whitelisted applications that access to CSPRNG APIs *before* any damage occurs to any file. In contrast, PayBreak attempts to recover files *after* the attack which makes it a member of the *recovery* group.

Based on their defense strategy, some of the anti-ransomware systems are sensitive to *obfuscation*. For instance, PayBreak is designed to hook only known APIs. Consequently, it cannot hook the cryptographic function calls if the code is obfuscated. Similarly, CfHk module of RWGuard can only hook system-provided crypto APIs, therefore cannot recognize functions from third-party crypto libraries. Other anti-ransomware systems are not sensitive to obfuscation, according to our research.

Lastly, except CryptoCop, all behavioral detection systems look for anomalies in disk I/O, such as entropy increase or file type changes, and therefore can be tricked by the next generation ransomware as we mentioned in Section 4.1. On the other hand, CryptoCop does not rely on the statistical analysis of the write buffers which enables it to be I/O oblivious. Likewise, hardware-assisted solution FlashGuard, and network-level defense systems [3] and [6] also works independently of the disk I/O.

Table 7.1: Comparison of Ransomware Defense Systems

System	Defense Approach	Protection Mechanism	Obfuscation Agnostic	I/O Oblivious
UNVEIL	Behavioral Analysis	Detection	✓	✗
CryptoDrop	Behavioral Analysis	Detection	✓	✗
ShieldFS	Behavioral Analysis	Detection	✓	✗
PayBreak	Key-escrow	Recovery	✗	✓
Redemption	Behavioral Analysis	Detection	✓	✗
UShallNotPass	Access Control	Prevention	✓	✓
DaD	Behavioral Analysis	Detection	✓	✗
RWGuard	Hybrid	Detection	✗	✗
FlashGuard	Hardware Assisted	Recovery	✓	✓
Cabaj et al. [3]	Network Level	Detection	✓	✓
Cusack et al. [6]	Network Level	Detection	✓	✓
CryptoCop	Behavioral Analysis	Detection	✓	✓

7.2 Limitations

The history of the combat with malware suggests that the ransomware mitigation is an arms race that never ends. It is possible that the ransomware authors will develop new samples that use more advanced techniques than now. In this section, we will point out and discuss the limitations of CryptoCop.

CryptoCop is designed as an early-warning system to detect cryptographic ransomware. This design decision brings up both advantages and disadvantages. On one side, CryptoCop is highly efficient in detecting ransomware with a minimal performance overhead. This makes CryptoCop a suitable defense mechanism in real-world systems. On the other hand, while our system minimizes the damage of ransomware, it does not guarantee zero data loss. However, it should be noted that even commercial anti-ransomware provide a similar protection level.

The proposed solution itself is independent of operating system; however our prototype and tests are performed on Windows 7 as malware commonly targets Windows operating system [2, 43] and the market share of Windows 7 is still one of the highest [39].

Our prototype CryptoCop, as described in Section 5.1, utilizes user-mode hooks to monitor and control another user-mode `WriteFile` API. While this approach is useful to give an easy to implement proof-of-concept, there are two issues to be addressed. First, ransomware may prevent our control by attacking to our hooks first. This is a limitation of user-mode hooking. Secondly, the ransomware may use low-level file write functions, e.g., WannaCry, that CryptoCop is not set up to control, to evade detection. This is an accepted risk that we take when implementing our research level prototype. Namely, our prototype is designed to operate in user mode as we explained in Section 5.1, therefore limited to capture only the documented user mode APIs. In particular, since `NtWriteFile` is an undocumented, low-level Windows API, our prototype cannot intercept or control `NtWriteFile` calls. However, both of these issues are purely related to the implementation choices and do not invalidate our design principles. We will develop a file system mini-filter driver to overcome these limitations in the future.

It can be possible that ransomware can create temporary files and overwrite protected files via move operation, however, we decided to leave out additional controls in order to avoid processing overhead as we didn't observe this scenario in our experiments on 736 samples. Furthermore, this family will still be detected due to write activity in non-protected folders but with increased latency.

To evade detection, ransomware can create new processes for encrypting a subset of files which would allow it to remain undetected as the Malice Score of each process would be below the security threshold. Moreover, the ransomware might fork processes with a different parent. As a result, they can not be tracked/terminated as members of the same process tree. Detection of this attack strategy requires interception of process create calls and complex bookkeeping of malice scores which is left as a future work.

The ransomware might also have advanced attack capabilities such as NotPetya which can reboot the victim's machine and load its own kernel to perform disk-level encryption. In this case, the host OS would not be up and hence CryptoCop will not be active. Therefore, such ransomware would be able to bypass the protection offered by CryptoCop. However, OS vendors recently started to take cautions to reduce this attack surface. For example, Secure Boot allows loading a kernel only if it comes from a trusted source by utilizing digital signatures. However, this technology is available only on supported hardware and OS.

Recently, with the hope of encrypting valuable data, new ransomware variants started targeting database servers. These new variants might (i) attempt to authenticate to a database and encrypt all the records; (ii) attack to vulnerable web APIs and perform SQL Injection to execute encryption commands; and (iii) encrypt the database files on the victim machine. CryptoCop will not be able to detect SQL injection attacks since they happen inside the database process, however, it can detect the direct attacks to database's files. The detection capability for this scenario heavily depends on the implementation details of the storage engine, the success rate will increase if the database maintains separate files per tables. Furthermore, following the best practices in database security might prevent the vast majority of ransomware attacks targeting databases. For instance, securing database authentication, e.g., choosing a secure password would prevent ransomware from accessing the database. Penetration tests would help system administrator fix the vulnerable APIs and prevent ransomware attacks from that surface. Likewise, managing access control to database files and processes, i.e., running database process under a separate user account [1] and granting database files' write access only to that user, would help mitigate ransomware targeting database files.

Instead of trying to encrypt the files on victim's computer, ransomware might attempt to infiltrate the important data, e.g., blueprints of a patent and trade secrets, prioritize them in reasonable amounts and transfer to a remote server. To prevent victim's access, the local copies must be deleted or overwritten. In case of deletion, CryptoCop needs to be adjusted to listen delete file API calls, however we believe ransomware would rather overwrite the data since deleted files can easily be recovered by recovery tools. In the latter case, monitoring write operations would still be an effective measure. Additionally, as the nature of this attack would involve network traffic, the defense mechanism can be enhanced with specialized tools to sniff and inspect the traffic. Developing an augmented system which works side-by-side with CryptoCop would be useful to mitigate such a new ransomware variant. Still, it should be noted that, once the important data is stolen, there would be no guarantee to prevent cyber-criminals from demanding multiple ransoms via blackmailing if the data is highly confidential/sensitive.

As an enhancement, upon ransomware detection, CryptoCop can dump the process memory and extract the keys used by ransomware in order to recover the encrypted data. However, this would not guarantee recovery of all files because old keys might have already been erased in cases where ransomware uses different keys for each file.

Finally, to increase the usability of CryptoCop, we concluded four improvements: (i) asking users approval for termination of the suspicious process, (ii) ability to identify

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[1] Making the owner of the database process a separate account might prevent ransomware from terminating that process. Consequently, the ransomware will not be able to delete the database file since the database process would be active.

trusted applications, (iii) handling Malicious Score, calculated by written unique files and their importance level, as a cache (with a suitable eviction algorithm) to avoid long-time processes exceeding the threshold over time, and (iv) excluding processes that performs only write operations without reading files which are all left for future work for the sake of simplicity. Additionally, the usability of CryptoCop should be tested under various workloads. For different user-profiles, Malice Score Computation should be switchable to different configurations. We leave the task of researching multi-user environments for future work.

Chapter 8

Conclusion

This thesis presents a novel approach to detect and halt ransomware with low cost. The approach leverages the basic and inevitable operation of ransomware: write requests to file system. Controlling `WriteFile` API calls gives zero chance to Ransomware to modify files more than the defined threshold.

We designed and implemented a prototype of the approach, called CryptoCop. It mainly has two components: (i) Main Component intercepting `WriteFile` API calls and controlling the flow and (ii) Malice Score Computation calculating the malicious score of process.

The carefully engineered virtual test environment prevents Ransomware to detect that it is running on a virtual environment since Ransomware samples might stay inactive on a virtual environment to avoid being tested. Additionally, the experiments are aimed to be performed under as realistic conditions as possible.

In order to measure the efficiency of approach, we collected real-world Ransomware samples on the web and weed out inactive ones by leveraging the prepared test environment. Then, the active ransomware samples were run in the test environment with the help of Cuckoo.

In our experiments, CryptoCop successfully detected 706 out of 736 samples since it is oblivious to the techniques used by families but only relies on the write calls. The reason for missing some ransomware samples can be explained by implementation deficiencies: hooking technique and low level file write functions. Additionally, the result of our usability experiments show that the approach is ready for users with some additional utilities.

Since the approach works on the context of a single process and intercepts only single function call, no additional synchronization and communication costs are added, it adds a minimal effect to the system. For these reasons, our approach is effective, suitable for real-world and ready for any new versions of ransomware.

To sum up, this work proposes a solution based on the analysis of file write activity considering the fact that file write is a vital operation of ransomware. Our prototype is proven to successfully detect 96.5% of active ransomware samples. Obviously, to achieve robust and user-friendly experience in wide scale, the prototype needs more detailed work in system integration and usability. These are left as future work.

Appendix A

Report of a Bitman Sample

```
1552118376437 [ATTACHED]
1552118382715 [HIGH]  [MALICIOUSSCORE] 20 C:\Users\meltem\Documents\recover_file_skkwbbmcc.txt
1552118382840 [LOW]  [MALICIOUSSCORE] 21 C:\$Recycle.Bin\S-1-5-21-786200809-895886964-1289355992-1000\$IIOTCDF.pdf
1552118382871 [LOW]  [MALICIOUSSCORE] 22 C:\$Recycle.Bin\S-1-5-21-786200809-895886964-1289355992-1000\$IJYDCL4.pdf
1552118382887 [LOW]  [MALICIOUSSCORE] 23 C:\$Recycle.Bin\S-1-5-21-786200809-895886964-1289355992-1000\$IRBQ7F1.pdf
1552118382903 [LOW]  [MALICIOUSSCORE] 24 C:\$Recycle.Bin\S-1-5-21-786200809-895886964-1289355992-1000\$IU9LOXK.pdf
1552118382918 [LOW]  [MALICIOUSSCORE] 25 C:\$Recycle.Bin\S-1-5-21-786200809-895886964-1289355992-1000\$RIOTCDF.pdf
1552118382950 [LOW]  [MALICIOUSSCORE] 26 C:\$Recycle.Bin\S-1-5-21-786200809-895886964-1289355992-1000\$RJYDCL4.pdf
1552118383168 [LOW]  [MALICIOUSSCORE] 27 C:\$Recycle.Bin\S-1-5-21-786200809-895886964-1289355992-1000\$RRBQ7F1.pdf
1552118383528 [LOW]  [MALICIOUSSCORE] 28 C:\$Recycle.Bin\S-1-5-21-786200809-895886964-1289355992-1000\$RU9LOXK.pdf
1552118383871 [LOW]  [MALICIOUSSCORE] 29 C:\$Recycle.Bin\S-1-5-21-786200809-895886964-1289355992-1000\help_recover_instructions+rkd.png
1552118383918 [LOW]  [MALICIOUSSCORE] 30 C:\$Recycle.Bin\S-1-5-21-786200809-895886964-1289355992-1000\help_recover_instructions+rkd.txt
1552118383934 [LOW]  [MALICIOUSSCORE] 31 C:\$Recycle.Bin\S-1-5-21-786200809-895886964-1289355992-1000\help_recover_instructions+rkd.html
1552118383981 [LOW]  [MALICIOUSSCORE] 32 C:\$Recycle.Bin\help_recover_instructions+rkd.png
1552118384075 [LOW]  [MALICIOUSSCORE] 33 C:\$Recycle.Bin\help_recover_instructions+rkd.txt
1552118384075 [LOW]  [MALICIOUSSCORE] 34 C:\$Recycle.Bin\help_recover_instructions+rkd.html
1552118384153 [LOW]  [MALICIOUSSCORE] 35 C:\Users\help_recover_instructions+rkd.png
1552118384184 [LOW]  [MALICIOUSSCORE] 36 C:\Users\help_recover_instructions+rkd.txt
1552118384200 [LOW]  [MALICIOUSSCORE] 37 C:\Users\help_recover_instructions+rkd.html
1552118384200 [LOW]  [MALICIOUSSCORE] 38 C:\eula.1028.txt
1552118384231 [LOW]  [MALICIOUSSCORE] 39 C:\eula.1031.txt
1552118384262 [LOW]  [MALICIOUSSCORE] 40 C:\eula.1033.txt
1552118384262 [LOW]  [MALICIOUSSCORE] 41 C:\eula.1036.txt
1552118384285 [LOW]  [MALICIOUSSCORE] 42 C:\eula.1040.txt
1552118384305 [LOW]  [MALICIOUSSCORE] 43 C:\eula.1041.txt
1552118384305 [LOW]  [MALICIOUSSCORE] 44 C:\eula.1042.txt
1552118384321 [LOW]  [MALICIOUSSCORE] 45 C:\eula.2052.txt
1552118384321 [LOW]  [MALICIOUSSCORE] 46 C:\eula.3082.txt
1552118384383 [LOW]  [MALICIOUSSCORE] 47 C:\PerfLogs\Admin\help_recover_instructions+rkd.png
1552118384399 [LOW]  [MALICIOUSSCORE] 48 C:\PerfLogs\Admin\help_recover_instructions+rkd.txt
1552118384399 [LOW]  [MALICIOUSSCORE] 49 C:\PerfLogs\Admin\help_recover_instructions+rkd.html
1552118384461 [LOW]  [MALICIOUSSCORE] 50 C:\PerfLogs\help_recover_instructions+rkd.png
1552118384493 [LOW]  [MALICIOUSSCORE] 51 C:\PerfLogs\help_recover_instructions+rkd.txt
1552118384493 [LOW]  [MALICIOUSSCORE] 52 C:\PerfLogs\help_recover_instructions+rkd.html
1552118384539 [LOW]  [MALICIOUSSCORE] 53 C:\Python27\DLLs\help_recover_instructions+rkd.png
1552118384571 [LOW]  [MALICIOUSSCORE] 54 C:\Python27\DLLs\help_recover_instructions+rkd.txt
1552118384571 [LOW]  [MALICIOUSSCORE] 55 C:\Python27\DLLs\help_recover_instructions+rkd.html
1552118384633 [LOW]  [MALICIOUSSCORE] 56 C:\Python27\Doc\help_recover_instructions+rkd.png
1552118384664 [LOW]  [MALICIOUSSCORE] 57 C:\Python27\Doc\help_recover_instructions+rkd.txt
1552118384664 [LOW]  [MALICIOUSSCORE] 58 C:\Python27\Doc\help_recover_instructions+rkd.html
1552118384727 [LOW]  [MALICIOUSSCORE] 59 C:\Python27\include\help_recover_instructions+rkd.png
1552118384743 [LOW]  [MALICIOUSSCORE] 60 C:\Python27\include\help_recover_instructions+rkd.txt
1552118384758 [LOW]  [MALICIOUSSCORE] 61 C:\Python27\include\help_recover_instructions+rkd.html
1552118384758 [LOW]  [MALICIOUSSCORE] 62 C:\Python27\Lib\abc.py
1552118384805 [LOW]  [MALICIOUSSCORE] 63 C:\Python27\Lib\aifc.py
1552118384868 [LOW]  [MALICIOUSSCORE] 64 C:\Python27\Lib\antigravity.py
1552118384868 [LOW]  [MALICIOUSSCORE] 65 C:\Python27\Lib\anydbm.py
1552118384883 [LOW]  [MALICIOUSSCORE] 66 C:\Python27\Lib\argparse.py
1552118384914 [LOW]  [MALICIOUSSCORE] 67 C:\Python27\Lib\ast.py
1552118384946 [LOW]  [MALICIOUSSCORE] 68 C:\Python27\Lib\asynchat.py
1552118384977 [LOW]  [MALICIOUSSCORE] 69 C:\Python27\Lib\asyncore.py
```

```
1552118384993 [LOW]  [MALICIOUSSCORE] 70 C:\Python27\Lib\atexit.py
1552118385008 [LOW]  [MALICIOUSSCORE] 71 C:\Python27\Lib\audiodev.py
1552118385039 [LOW]  [MALICIOUSSCORE] 72 C:\Python27\Lib\base64.py
1552118385071 [LOW]  [MALICIOUSSCORE] 73 C:\Python27\Lib\BaseHTTPServer.py
1552118385071 [LOW]  [MALICIOUSSCORE] 74 C:\Python27\Lib\Bastion.py
1552118385086 [LOW]  [MALICIOUSSCORE] 75 C:\Python27\Lib\bdb.py
1552118385102 [LOW]  [MALICIOUSSCORE] 76 C:\Python27\Lib\binhex.py
1552118385133 [LOW]  [MALICIOUSSCORE] 77 C:\Python27\Lib\bisect.py
1552118385149 [LOW]  [MALICIOUSSCORE] 78 C:\Python27\Lib\bsddb\db.py
1552118385164 [LOW]  [MALICIOUSSCORE] 79 C:\Python27\Lib\bsddb\dbobj.py
1552118385180 [LOW]  [MALICIOUSSCORE] 80 C:\Python27\Lib\bsddb\dbrecio.py
1552118385180 [LOW]  [MALICIOUSSCORE] 81 C:\Python27\Lib\bsddb\dbshelve.py
1552118385211 [LOW]  [MALICIOUSSCORE] 82 C:\Python27\Lib\bsddb\dbtables.py
1552118385227 [LOW]  [MALICIOUSSCORE] 83 C:\Python27\Lib\bsddb\dbutils.py
1552118385227 [LOW]  [MALICIOUSSCORE] 84 C:\Python27\Lib\bsddb\test\test_all.py
1552118385243 [LOW]  [MALICIOUSSCORE] 85 C:\Python27\Lib\bsddb\test\test_associate.py
1552118385258 [LOW]  [MALICIOUSSCORE] 86 C:\Python27\Lib\bsddb\test\test_basics.py
1552118385274 [LOW]  [MALICIOUSSCORE] 87 C:\Python27\Lib\bsddb\test\test_compare.py
1552118385321 [LOW]  [MALICIOUSSCORE] 88 C:\Python27\Lib\bsddb\test\test_compat.py
1552118385336 [LOW]  [MALICIOUSSCORE] 89 C:\Python27\Lib\bsddb\test\test_cursor_pget_bug.py
1552118385352 [LOW]  [MALICIOUSSCORE] 90 C:\Python27\Lib\bsddb\test\test_db.py
1552118385352 [LOW]  [MALICIOUSSCORE] 91 C:\Python27\Lib\bsddb\test\test_dbenv.py
1552118385368 [LOW]  [MALICIOUSSCORE] 92 C:\Python27\Lib\bsddb\test\test_dbobj.py
1552118385368 [LOW]  [MALICIOUSSCORE] 93 C:\Python27\Lib\bsddb\test\test_dbshelve.py
1552118385399 [LOW]  [MALICIOUSSCORE] 94 C:\Python27\Lib\bsddb\test\test_dbtables.py
1552118385414 [LOW]  [MALICIOUSSCORE] 95 C:\Python27\Lib\bsddb\test\test_distributed_transactions.py
1552118385414 [LOW]  [MALICIOUSSCORE] 96 C:\Python27\Lib\bsddb\test\test_early_close.py
1552118385430 [LOW]  [MALICIOUSSCORE] 97 C:\Python27\Lib\bsddb\test\test_fileid.py
1552118385446 [LOW]  [MALICIOUSSCORE] 98 C:\Python27\Lib\bsddb\test\test_get_none.py
1552118385446 [LOW]  [MALICIOUSSCORE] 99 C:\Python27\Lib\bsddb\test\test_join.py
1552118385461 [LOW]  [MALICIOUSSCORE] 100 C:\Python27\Lib\bsddb\test\test_lock.py
1552118385461 [MAXWRITE_EXCEEDED]
1552118385461 [EXIT_PROCESS]
1552118385461 [PARENT PROCESS SEARCH] nthfrgd.exe:3176
1552118385461 Parent: 2616 Child: 3176
1552118385461 2616 Open Process Failed. Return empty as name. Error Code:87
1552118385461 [PARENT PROCESS SEARCH] :2616
1552118385461 Parent not exist  : 2616
1552118385477 2616 Open Process Failed. Return empty as name. Error Code:87
1552118385477 [KILL PROCESS TREE] :2616  KILLER PROCESS:3176
1552118385477 [KILL PROCESS TREE] nthfrgd.exe:3176  KILLER PROCESS:3176
1552118385477 [KILL PROCESS] 2616
1552118385477 [KILL MAIN]
```

Appendix B

Active Ransomware Samples

Table B.1 lists the active ransomware samples which forms the ground truth set used in the experiments. Family names are determined by AVClass tool [37], as we described in Section 5.4.1.

Table B.1: Ground Truth Data Set.

#	SHA256 Digest	Family
1.	afe7d0ce397a44c9740cc1a8e3434bb2858d4ab1f5ee85ad17d61952e72e58bc	barys
2.	000a77953565d43520dacf7446baef17252718d06fc8770727ee6aacb245db8a	bitman
3.	00b56667d794895fe8342f4d616e303cea222b88d2af8f0042b8e264a759e975	bitman
4.	0a68cf3e31426966aee7d9c76d52df906d7e1fa3380a78e3cde3b56b930f7680	bitman
5.	0af44523884f1b6c6d033fbb13fe7383a007219b57b1a1afc9bd44b84b4d6d52	bitman
6.	0afd142d30bb173793438ccfd427624532cc681b27806f0b5e1c3d8777aeaf97	bitman
7.	0b89cae095d2375b6781a33ef28a858e26cb13e4545e2f4e017803d9efa7648c	bitman
8.	0ba325cbaeefed253e6dc0ff2b7ae4e578f8f7b348f4e451499323104f9b3d69	bitman
9.	0bf5a007fe8c1a4f68b16d99febb5d30f4562cb175cdc4ae7747fc5d6b3cc36d	bitman
10.	0c7d0ad0454b780997f5d6856cf87920e9fe667634bd8ccab53177d5f32de5a2	bitman
11.	0cd8fa6de1e03962d36497690edda81c6a9e033c0f7e93121af60f2aef0c0be9	bitman
12.	0ce6dfaf77e59c2a01d4aa15ce4387d65e968a97ea6322c573e5b04e204bd293	bitman
13.	0d38539d70a1957602d9a6e40bd30702c724d648a4dba5fe985027a38ad7c4cf	bitman
14.	0d82b1678d9a7b935c375c3a76e26e77c8d78751ed7db72d21be6bb790d8d1d0	bitman
15.	0db239807f0de42d485dd30ac02de02dd844b6984688aa65ba578c7cd9f02b96	bitman
16.	0dc773242fe5ccb38e382b52f2182d9833e3cc4d299dd4a5ff2c83e054bc82ac	bitman
17.	0e8e6a467e2f65f767a4d5a811bcafd4db0a6aee0436d19c7cda9f9184d7dcab	bitman
18.	0edbf805708a74d4eb4b1d53d044a48825a1ba4eba1d1334d57c6fb3cd3969b3	bitman
19.	0ee0da5dd380639c256b0cc97a7b7773d8a5881d0b30608f73fcd81cf6b271c6	bitman
20.	0f03877e986a07a5f8d5340e45c499e72226707876076fc8e6dddc1d26e21094	bitman
21.	0f5a259f8bd9ae4be2c73894a287cbac9db737b182ee9e694282aaf1fa9af1fe	bitman
22.	0fc7f6584fcfd7af6b7296ed32d006429f777b6673c654172a0c84ba2111950a	bitman
23.	0fd0a87376a2ddd4709d53d9f91dcb8ddddb36b14e9fe688093455ed7f240280	bitman
24.	0fdb9c04debec09ed53f34accfba6e087e9dbe00279a3ed92004e90649d9def5	bitman
25.	a027e30ff931dd1235d991ee1ae72d72b3e7e78c9f708920b31c1b9fbb9dbf11	bitman
26.	a07b496d7a40ebafd3dbe348305d363eaa60e1ba17e67888969b458b4feef565	bitman
27.	a098e8ba6601472a2b3e5f25c397e06be410c7db6e39ad14766eae09a9322c77	bitman
28.	a0acbd92cd619324daa2121c15c3291bdee7dd785f9f09d0fdcb6ace49072f22	bitman
29.	a0b21558804bf306650fe6a44104423fd55488585b99703af47530723b64f3af	bitman
30.	a0b9b6cfafe5dd2f124d5cb345a2198c8739fa18b733e1044f0c38c5d15a5390	bitman
31.	a0fa488fac8ff118dee224fb4c6a7d5fce7c5ddfcfcd20f736fe91289ae408a0	bitman
32.	a10886568925ae74c6afc92e9dba804d3f48692445eb0c022c1888dcc9e8ee26	bitman
33.	a1c5387082247bd24188b0e3912e55a766e573d5651502022543f7292278963b	bitman
34.	a1ca8bed01129c81c7b383cd5b1aea7d907ffd6e5c3337e7bbad2b613f921966	bitman
35.	a1fb8fde3db83d201fe65bbd8c2e046cb9e03e5a7b791a071529a8e8d7213e8d	bitman
36.	a20a0f9939017a46c5c99cf38143c009cbef5685f0ac8d5063bb709e1ffed7d1	bitman
37.	a2569ded9fecf87eaeebff6da06b9ad723a23979e8e6c233a13cc5e2ef6f7270	bitman
38.	a2877426e8a8910e386d99a37b9f390cd0192ff3a48bd205bae9043127874211	bitman

39.	a2b2c46b99d8f6eeb1478c7df8ffcd89829f3bd166ac2c533857e53b0075e05f	bitman
40.	a34da806daf10d4ea434062371c4dca4ad91278440971baec3453bc4d05603d6	bitman
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42.	a3baf5ad1f16fab147d8fe60b78af535fa7c3b95debf20c0fc9b77f4d4e4e874	bitman
43.	a3fecd9da4eb3e4b8c35fff66b4771888580900aaad2ba6e56b4fb174f83f44c	bitman
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209.	0f6b28ee75b58be8c8d4cb73f6752c42a063ee28a9dae1420c4c97ff65647a7b	cryakl
210.	0a9806946cb29ff0e95cc97e4693e5d527b987d653b965440541f29bf033e2e7	crypmod
211.	ab8098ed6fbdd6a5a33ee58279229d9cb76d67141afce64fb6dff63f73bfd88d	crypmod
212.	ad7cbf50e45ebc58aae9897851073bd3fa058e5685a63f78d300bac391929cc2	crypmod
213.	b9f3838c1cca2c5913e6c9ebc05f4f9fb65d6429c3bb2fba75f00dcc86ff6ef3	crypmod
214.	ae977eae68b7afe3acb760d853bc92ddeb9e75fe3bc926087f7c8f88ae6a0d36	cryptowall
215.	0e9bedc57f97bb2c7119ad4713b03fc9b10df09202fb7a237b610aec4687b736	cryptxxx
216.	b2bcfc4c5d1d60f7ea4298d32dcfff303f4db4b1ba89a8b6d24b7ccfe883e45a	cryptxxx
217.	a0c0f18d1c867c486dc5f9f68efb5488c16a63e7322db27afd9cbb496fab08c3	crysis
218.	ab9e0812b05d0f9a32affdf352a8d85e85b110d27ed8fe685931e706a1aa88c1	crysis
219.	b67083fbdf8880345b5e7eabb9bc257607958b2c61c2f6b70f158c5d10603653	crysis
220.	ab29528a67b660eaf1201ef51f5e5bbb818c2cfffb042bdef1270e43bcf1994a	dalexis
221.	b212ccea8a8579b9ed90782990b16ffa56299bec43f761e677cb649387aa4032	dalexis
222.	b8ce751d638af73b4feac31623b7f373ee6eaed6a8a0002215cbc69a020a8eab	dalexis
223.	c22dafebb84c22df623546a3e72886612a697a499ab10260af7267ecd37ade68	deshacop
224.	c20c6e9fda42e4bf453c839c874c6e1ca38f5dd2af41b3c4286c09e5fc34ad12	enestaller
225.	ab4db017e1e09c4f284a2f10a052a9282bb81043de9fa523d814e6e78f6515c6	enestedel
226.	a9cd68be689ab5f695e2f710f2e13fc54b779b15cabd5a7df306ddd87e6a2d28	gamarue
227.	baddad2764055fac7d717ca688777991f173c5cce7c23413aa71e63a16f85c57	gamarue
228.	b828059c7af40bf42c036a16e4c8c3f11eea6607beaec93f42a01ab53a8c5f33	gandcrab
229.	b55d23b9df8ffe5678234a2ebc473afb3024015c2a79dfef33a1824d08396139	jaff
230.	a84fc1196fbcbfccd726faab9eda5f562269708194bf1c3e54c15dcec82adec2	lethic
231.	b149ac6820820cc1fc8c722519b554daaf2c1cec4274d2224fbfd938dfed7ffc	lethic
232.	b35671a0da9261e972e668d2b13cfe654d935eed7ec9a258e1ea80069cea2fe4	lethic
233.	b52dfd9851c8d9e73cf644e019f09c73b4b8b965703933403d68e7c38cfe9bdc	lethic
234.	00ed72ffa97f75e1f4d1769e25f94614dbf3fe2a468361b3511a7c0b10ba9038	locky
235.	0c96311fbd6dcd5af7dfa4875fc72beda0c9e1c7470ec8d0cb54041201f94708	locky
236.	0d80447ad564ffd0c40cc71213787f823de1b058dc1aa856aa67f438dd51d537	locky
237.	0d8ab1be84c9ce7d3b167b344cbe5d7572448f7f07f01c7c4ef7ed5c8b68ec98	locky
238.	0ddc0f51f16a49c6ea129b63eecbd2001ddcaac050f595fca5eede491f7a7693	locky
239.	0e18826a91eab4f024c91d5c2b3da7b825747d2cb53829e13da98a3848d883fd	locky
240.	0f75c08edc81483acae170972d3f24dea05149295773badc126a61961525c251	locky
241.	0f9ca5c555ddf4b5b29573ea1a513a69555afcfd0b1d3fa8f441bc6991bce543	locky
242.	0fd0d74780af9c9c15ea53bb7dfe8bd1f7bd097bdfcd5140a4a9f9e78b7ff79b	locky
243.	a1596136fe5f12521e5ee1bc05429459453ff8cc8a12bf35f23738ef1c0ce8eb	locky
244.	a2b37fd7fbdb708041f257c1004ad0200937817bbec3f54f3ee67865163c6658	locky
245.	a2f39c1650e4f237741dddcb49e1ddcdd1d5d7b7ac1dfc007049e5051bf2a3c9	locky
246.	a512406a4a94325a618cb0a3d68393bca6c714024c612f0074529e4bb5ad8071	locky
247.	a6669aee7aa34ca73e776e8df5083c2934cabb11463a72702658829689252cf6	locky
248.	a8b7cda73fc3e8078aeca585af9dd748b11f70603e91957b1ef1fec260e5842c	locky
249.	a9c72c30ffb007e04926f77ba204fc73c7f72693e9afb4cd152b4986497a5000	locky
250.	acaf8469aad50639040886d6f5fc9681930351a233f1e3db0f9f833033ecd8f4	locky
251.	ad2daaeefe92766ad11745aa3910b127bde4428ae631748b50c3a9066fe135ff	locky
252.	ad40440bb8b4e443c9537675af5b7f588c4289b9cd37f21a91cf2d2110cf8f74	locky
253.	ad4940d5b842b9c8008fd5ce35145c8e4a6465d5e80774ca203d136496ff51c0	locky
254.	adcc6eded5dfdd7a5d79dd7a9c2294b41aec2f173c09d3096a7516d49c02c86f	locky
255.	adf749ad3ddb0bd7a67e4ca0ec549a44b6fd22d525a839101085b1111d669c28	locky
256.	af3568e48341b40d5006a12a11971344577110afdc42a0d8b53f62453b0b389b	locky
257.	af7797bf0df65314f3173e06b114b0498ee0d76c35a243376d1bc1efc4a01347	locky
258.	b01a05fb7e4d26ed9f760fd08658024a4265302997b6e8456a606d042e6fd13d	locky
259.	b1282ad8fcc12f9457fd9344e6dea01dd14edac7c0627482255bc9878c17d6b6	locky
260.	b2444acebcb63697fc73c6ff0b462a176e277d6ed7fa127f28c203853bcd4d03	locky

261.	b428e5d84776ac342681ab069cdcf0585b62868a6407345b508f2c459f870a71	locky
262.	b4b7ed56b9243880006e6d0ec2429831332d0ad4d71baae2add373768945c630	locky
263.	b4ffc48d7ce966631d1a7eba54f91047c979f53211ce077f528068adb2140cf2	locky
264.	b5064979527714bbbd0558f1ede2a47072374c36e0e946ce1855eaafa2112b7c	locky
265.	b609d78e860248f3631a7093b64ee0abbe90768be4de122bbf579d127426b49d	locky
266.	b694bd9859ad8707b0326ffec045c30699514d0b0eafe374bd125baabfc1c38c	locky
267.	b88f7b654cf46aa20a610cb0aa280ca80f6d5128fd079cf719a151969943fc04	locky
268.	b99b4c7847b3a31454d4a2a2caa29e40924e2279b6cb65c900d261c37525bdd0	locky
269.	bb2073c2575f6e253b63a1ffc99ada1ee60278504eae0c8e73ce273cb93cb516	locky
270.	bcf6d56f585b61ad22094e7c893d12d733ed7623d56c53de97bffe43041c5814	locky
271.	bd6f0b5056e3a831337d1092342a207bd15f76706d5eaf1bfe6c80991eec196f	locky
272.	be6143f0d5db62a2ce51e5c85b207632979e50098163588b2f8ba3acf6e7b67a	locky
273.	bfe1bead58ca164501b619a93a93a91dcd25f147615e181ebfd68f7eac64ba13	locky
274.	c11b9d1ba0badcc063eb6e60894b7f4f0932e4f73d037f05e06c80d72833b328	locky
275.	c1245b403a345b76a5f4aa82ec336842b2355977055c80cfd2417d8184af6eed	locky
276.	c127b95c9d4710e862ca8b477928b78b43bcfb6655c27462a7c644daac1e3c30	locky
277.	c2e56510866a6e038ac723a3e5a2ac66b14f407b91886077727f622f561164e3	locky
278.	c35f705df9e475305c0984b05991d444450809c35dd1d96106bb8e7128b9082f	locky
279.	a1ce492b077c0d0cf6fa362b57e7f6b3b9d1ab7ad60541a12e9eeaa7708b9af1	midie
280.	aa8768bd3e213219bf17a0e0d2411f5a2f6ad1e60ca55c489b72e27166c49f01	mikey
281.	b6144a20dc6b4656551494d6fee1450abcbf6c4e30badf5765dd64a254495e27	neoreklami
282.	b86e5f28c965802604464067a73560b16a710f6df599e156a5aa23e2054b6295	petya
283.	b8fe3a953887aa22b4b3d1d9870474cd54ace319ad678fe1cfbe860bb0e5ac9a	petya
284.	0b70b21bb62f9b9dbcde8da791b84623afec45ae566b4a0acfa53fc4b861324d	razy
285.	a4204086b787f92fa432c800df7751e5a2f64d5b7c5df6be39c21779ee5b2747	razy
286.	ad1a191331e87832455c4ac315af8d01788c5d43c00ea26f80c54f6145d790a5	razy
287.	af29893ffe76fb286d51655327dadae5f9f20e5dcf4aaa6a5e4f555b91c5ff73	razy
288.	b124a1b33d3b2349c389ce3ab77603dd39b03023290bad9ae9ce6e5975767727	razy
289.	bb37f3f511683bb363e6fe62a2e83fc74b447646e1697d9ac2cec3e7cfacf984	razy
290.	b3040fe60ac44083ef54e0c5414135dcec3d8282f7e1662e03d24cc18e258a9c	saturn
291.	b70cd75e503a74f3197429f1562c23c92bdbbe8d803ff5963ddfc25f29652174	scar
292.	b7c9e8a46426aa8a56e8a9f6d7e8b7db497f533f38c281e45dffe0737f1e557d	scar
293.	bb96b88b03cb4f54c3749e6ac9eb54785438e04023f38a93ee7b2f908b7446ab	scar
294.	a01e5f9bd86868992024f55146e1412b593b610d330d6a200b2748d3aa3cb457	scatter
295.	aefe62e7705678d90d5b11927a8cbd4a04fa32971b4df6e36cb8199b59bf13e2	scatter
296.	aac56d25685a1b8536dd5efeff9fbd8845da20693affb33acd67724ae998a6c3	shade
297.	bd4d300f37b230e7c7578bf453d96a15553b88868fe13d4ec2d94bfce4eea567	shade
298.	0b2cd15983e7475d8a27023cb5687a1343d4d963e2ffcaa6538d9337ed4efa1d	shiz
299.	0c2519955f1bb8c552b66e6bcab181f6d593db2d5f1e679d5fd55e0dfdfeb762	shiz
300.	0f770775248a08598e59110eb9ab2630ad935bc0df2c2c643d3211c3abf9123d	shiz
301.	0f7d43fe5b8d69752f0c83ef5aca116dd7f0beff0273634518c84bc7d4a37a3c	shiz
302.	a0870dfdaeb889d4285f4bba81fe5bd4fc76bcd0ceb3925d39c65298da5e4bda	shiz
303.	a12fc5685d9a09ea492a75a0764c61b9d84aeb4b923bde62b9eb96608ab205fb	shiz
304.	a2b189b19c37fa23798ff1689c076f0743d8e63587d397041409cace20c87829	shiz
305.	a69d02fe52333fee24b5d1f8aef92da8877c8cfb9f32f7b7117b7ffa9db37c8b	shiz
306.	a8a5577bbaac9aace0bbfc6d7f57926a171cb2d5d112d6066ac9ea9e1f9a6811	shiz
307.	ad71b68f7b8e2a7ea94354cd0733c7fc1aa29aff9364175f48823f5dbc2b72e6	shiz
308.	b2c335fd2b43230fd8bef4858365fb18daf1054c2fbbc648ac97ed2a6f1bb27b	shiz
309.	b3fdeeacfae9268f213940605f119e8e196287e8ab81850636cee9111aa2cc61	shiz
310.	b4d6af0d624dd46851de333604316dbf55f9c36e6cabc11bdb2ff5c201e19ba4	shiz
311.	b50a5eca4c159d3e2a1a81b73384407238710bf5556c86282b4e90c20b22667d	shiz
312.	bd3c8f5228ec773432faf4be5c8481673479a603882bea8b3e816df1367a5482	shiz
313.	c1df72723a7b8ffe360f8d6290fbed493674e54783f885acc2d3129a704d838d	shiz
314.	c33c22542dbc59aa66b3346b8921086d95ad4ce0daf6fe3905605ce02337f43a	shiz
315.	0fa6afcf6e176443f40a957d536390b16863490e7ebbd67d56ad9a64ab089fe5	spora
316.	bba5c1b169c80cd519c00b35fa4a0bbf209bc7f763a10c240613df6f44349339	spora
317.	0ade3100d2afd6d9623834b2c99d36f2b14c0fa154f43f72989b5b6ba6fe3326	tescrypt
318.	a1db671d73239ec6d62eaf48c6128daf78c2d2ee5f9d54c4752f6c1b64eafc42	tescrypt
319.	a4156e684f4335d4663e6d685c78e2a6fb8374a6e1f38f3ed970a9c5ce1b0211	tescrypt
320.	b55bfa22d913d54bfcf39a749ce829a7804c709b12821fd7fa1df3dd65975f0a	tescrypt
321.	c10ddff904d11d0f4ae719afa2ba37fae00bca01deaad5c8237536441f39af90	tescrypt
322.	00d340cfd9c80206b0d282187ec15d8f93164cc1f8e65809038ac4d74b3ba0df	teslacrypt
323.	0a0adf21ee7edeadec0d6d93944e4c01504d53cfdbf466fea3479cf5878d812f	teslacrypt
324.	0a47655d725a5a91dc401b51a67e69ba8c85cbe7ceb2200d7496d5bf5aa58f97	teslacrypt
325.	0a5b115a930ea47f8d37e4c6a936dd4713bc3df0b401091c404b0d95caa4a7ae	teslacrypt
326.	0a605935da8dd95b37190e8a083b8357ef035e4850d335609ace78d2cc93ffe4	teslacrypt
327.	0a630522fccc4341ce0ea4b21dc490a2f32bb8f89504758480e03cec55962863	teslacrypt
328.	0a63be6f6c13d275a14b734111b8c13baaf06e6108ce8c4cc0a4407f6ff5d18f	teslacrypt
329.	0a6c9afaea8b59b99364a50ef5391f54b3deeab9dc8c8aac40c9b2b3c5f681fe	teslacrypt
330.	0aeca2acc2be0622753e2762f00955d74123530a0f0fc2e2f721a3dcbeab5542	teslacrypt
331.	0b0827ad2ce8b61329d1ff84ec763b151e49c83312a78c4ef46909a33068d765	teslacrypt
332.	0b17c081060be4975e1fc41f929b27c30077b471da401aef273ebb96631f1e96	teslacrypt
333.	0b2227232b786974f45d9cef9fd49ff20f581e301f2ac6406ac620de30f1285c	teslacrypt
334.	0b531bc4f0f4ea0913f6ec2fa01873e2efdca85c86c72d5e8614f18b5107c027	teslacrypt

335.	0b5b3ffaca1402eaf6efc8bb7b1f89b0745c6e32d9eee0dd83a2d7025401cf89	teslacrypt
336.	0b907a6a20511ce40020ce2601d25546ee844c29ca84416a6e18260159e561b9	teslacrypt
337.	0b94f23319dc90c567f55b3a6751d3df5c31c3a715fd9df9f9c886db77d89043	teslacrypt
338.	0b9715dba8554cf431eba283cc182a5f286b5b8a10a83bbafbbf0b266bde836a	teslacrypt
339.	0bba827860c9c3624b69c2611675170c78e3a64f44a775fe8e0a3775ff994022	teslacrypt
340.	0bbf03be24dc308e84ed73035601d5d145f280e5c340c21eee57354b46092d7d	teslacrypt
341.	0bd92e51f473e1320353640fa26a9a543ee71a68b689aa54ec9df5b18e005188	teslacrypt
342.	0be94e1cfe8deb7bb41301aae644cb8a2b5898f4bc50f13eff1b3ca45e8a47d0	teslacrypt
343.	0bf3cfe6be4ab21533046a289b2f4aedd5d1e4c48ed9a2a0d008821db4988cd8	teslacrypt
344.	0c00b8186de77029f7717c745e5e2afe39007598c72dafe06b35d0827ba2323c	teslacrypt
345.	0c06ef68a001fb8d9d255f6c352086b60fc5f26a44b1acf72717c3b2020e56f5	teslacrypt
346.	0c25208d0eb1a45fa8692677ba7322cc42109afd8bdbb9fc4b5d9f24adba99f8	teslacrypt
347.	0c5991cd96c09101b6f9e0830237a82f892a6ebf80312695db08d6bfdf187fb9	teslacrypt
348.	0c64eba4607b9fc93957fc1d55dd330b9d4a4608eb3703209d8914d06159ca13	teslacrypt
349.	0c6adfe2e692dcbb051d58643ba1e6b5f3d5488386708ba97acd4911e525a51e	teslacrypt
350.	0c747830dee54a4d9a50b96e44a3ee9172457e801d954f77ba65a6d6461ffb3b	teslacrypt
351.	0c9e122f5674c5b6e556b5df501557248dfef05c1de0d7c6abd5866240e2fa12	teslacrypt
352.	0cb03a83b88b62025f2f77b1788e69c10e685c54002486b487b0b24ae98ec631	teslacrypt
353.	0cb6692d0f8a8bd856f58f1c24cc1aff43607d61e9650fa5593b2e04fdb7a6fe	teslacrypt
354.	0ccbdb60f44a3af9b6b8781092d04067ee19bf64971a74a20e17c44536d0fc9b	teslacrypt
355.	0cd3f52c0471a21692f3bafde0d292a942a80e1954ae169a4df7b074cb92c2be	teslacrypt
356.	0cdd42ed61452e28c50bba66619dff45ce170238b4e22542c267bca514edf2ee	teslacrypt
357.	0d2a045bba1da9bc7ca16797aad362962a19efbfb75f809054bdab13d9f3c356	teslacrypt
358.	0d30b68435df2954d0d2358bf5c955bbd2a0693401cb291742d7dd57df434f14	teslacrypt
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361.	0eab309a8088b5fe8982c97f43ee717e02fef4968f5787a1f7108d793aaa1d94	teslacrypt
362.	0eb05e3a678920b8d1770a036a98bf283931a5a02e9d3ae893149a36a533ae06	teslacrypt
363.	0ee41942ca5fac9f1e8525cbf5d53479ca8f2ee6a51e394ba8f047bdb919c944	teslacrypt
364.	0eefa8bca3e42d2edf5745c4274c51cf42457932467a614544274c8bca255d81	teslacrypt
365.	0f08244193e78cfb3b373694f3def175bff3e94a1d72716f435f58e3331a942d	teslacrypt
366.	0f2fc2bec5577aefc2bd2ae7fbe2439abf1538f1d508c862537da017d265cf98	teslacrypt
367.	0f395855da1758e4bad73afe400564384ebc01093578bd8270e16dd461ff4407	teslacrypt
368.	0f6e778618fd182e8f9e707ce88e6dd89c1fd7ab14f4bed56a425eb824d9e9fc	teslacrypt
369.	0f79ed97257e4b84c1e0de8ff0187544dd2fb22909df4fc776ccfd379dd007a6	teslacrypt
370.	0f9ae792f0344dd086241ecddfe63bdaf7224f2e89bdfbf2182775ae0c344142	teslacrypt
371.	0fe65bae092b7e50ee2a43b786bdf089df91bed8e9fcd8ee5ae44a3522aa4127	teslacrypt
372.	0fe970c1d7f98fcb5096c31cb6173e208a252526a3cea3ed4b520a47d32d8f0e	teslacrypt
373.	a056cd494b445b135bba72c42f2ba18a801e9e657d564c4f23c3972e87502317	teslacrypt
374.	a0658ddc1bc3d40abaa88e4611cfddb43c17cf4da70648c1c11f9ff5797c42c4	teslacrypt
375.	a07a769d70eb06d7650e681b375c1c8d75866452a7a5b3da1fb20311a68e7f81	teslacrypt
376.	a082b3171dfb990cdd22cfa3c0a084fd0b0226d207e35392a9575b5b3de0fde7	teslacrypt
377.	a091406768073fc305aaef7fe7c9e349469ec8584117bb405438a1cda4048039	teslacrypt
378.	a0ab8b0f923a42f755f443047007a8a9e7b71eefea5853efef2d02b3211d9d9e	teslacrypt
379.	a0b10c500c105768092721a1d428c9a1b80359a6e92e9420359a05f8ff6bcf73	teslacrypt
380.	a0d0b84db349123d08c2fab691df5bb5d6b3e0a44372e75beb9bcb0e663ecb96	teslacrypt
381.	a0fa20d58b554eb73dd036bcd9e12827024821e2c8cf1f38f24b64081c96c3f8	teslacrypt
382.	a12e2c7675613cc83546fc0dfdee1acab5168bbfdc35bccb874ab9c195feef4e	teslacrypt
383.	a15f64453da067a1ab584479276fe9b63f8c6771b98db0454799f96862873646	teslacrypt
384.	a1692c6ed1469a510a8d8007f3388b63a10bce006173a15e9c129b33f16e0e28	teslacrypt
385.	a1a1e42dec95b6bc1fdcd9a95a098cb9305d83634d24a4d589dcfbc30fe2cd60	teslacrypt
386.	a1b44e55276545d3e54e8323198cb54dfbcbdf20e0459729bdd34860ac68dfc2	teslacrypt
387.	a1e6f7205dc9b76d1fc28657accc758f848426b8ada4ce2df3e9272aaa38b09d	teslacrypt
388.	a1ea14c9e82d2169f4960d30b32334029f8f44cbb5e3a52b98c447ea4d5b81fc	teslacrypt
389.	a22d2683d79d83335cd43142fa1dbf53c5ad5d3eb17b02b61c175cd93b56b6cb	teslacrypt
390.	a28da4394c228bd37ea27d5922fd0131e4b6ea911657925c93c62b6ab0b352bd	teslacrypt
391.	a2981d4fd4facd7bccd02ffd4be44267156eed0e3f56f4365c22383dbc7515a3	teslacrypt
392.	a29d1bbec6a7890eb521c3d1e28274980545ee98cbe3895bd40f81259e6d11c2	teslacrypt
393.	a2dc35392fcddcb4a3b422d2b94062557330467d5deeef23c0fda4c62fbcbfb1	teslacrypt
394.	a311cb236d6f917e17dd0962e4b4b1d4f5a5186a19134f8fa708408e8411a3f8	teslacrypt
395.	a37db1598db38aaee321d0765e683612e5c49b1ab72bab74d47ead4e116dd84c	teslacrypt
396.	a3878e4b411e4eee88c977d3bba364d63cdf5a6efd210986b76c96f478a9c0c4	teslacrypt
397.	a3ad2144cd9867e3e8e89e46b4a04cb96d9afbe368c9016a8dc22d7e9ed09bad	teslacrypt
398.	a3c4672e2aaef1b443636317c4e2e3f90a428daa05a0b6a58fd594529c7f62dd	teslacrypt
399.	a4030fd0a699e66d5a9176fd12ed86a8d762209240bc369ee77533782030dc78	teslacrypt
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407.	a592775e88939808c3dea0241933cef9a9280b2f58612dbea640e60d1985d79f	teslacrypt
408.	a5a2f64d60d24aac8e5b9021263fe0951788fe34204d07e2732038ec00954276	teslacrypt

409.	a5d04667c3927b12a8f9f8b6af3697eecd85aa92e8560a4ba72ee71174097a0e	teslacrypt
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639.	ab10ac6549a773a1159223aa46aca4f3c3a9415cd1cc9ced3a206ec22e671579	virlock
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719.	bd0d0db1bddc1ddfc9aa38611ed4d94976dcbdd18ef4b15bf8f3ad323bcfae1b	zerber
720.	be86d51ddc52ec55e30a170bfde4584655d5f3a9ac56688c7c49b99352e7842d	zerber
721.	bf60c5fd440899d8b99c209db47a9f39a7ca31d0bed7c831b1c5f23f533abdde	zerber
722.	c01ead04d9a4aabeca56feba7905b64e7a6c2b924cbfe38ac25806143cf668a5	zerber
723.	c03a4a0412a9c8c50f73c0f4020fa035456830dd676cdcc7ac2d0214d324f109	zerber
724.	c0a91edf65cbaddb99c2d9dda1210b62d0f0895edf49dc44eb1618e9f81ee1c3	zerber
725.	c0ed6360a5176ecc284953e231c0c1b262b429e0d74836bdb0de5166f7be981f	zerber
726.	c123b58199f6b92951d27387040cad294f7ab457fdddd529760925414827ea89	zerber
727.	c1448598e2afcbd8adda5d6e3f24a8609552cad4ad9a25849b56cc534cabcc9e	zerber
728.	c1fcab4d6d19cc97f30e8cd0d8c7fa8ed6fe206f8160082a1b22594a86362067	zerber
729.	c2e7ccd6077c043ba722b3ee141c95cc10dd506ce26ac18be29c8ef8ac26971a	zerber
730.	c320a7c9282551177083af0fefdcb47ceb3e721a665314eea759099de82bf89d	zerber
731.	a261d7a919495ac349c125dadf89cc557352a7d2feedf3898fa5e320c4c75efa	zusy
732.	a6496f696b3792fffb4cf1b009b6ce76a39a3f410cd2692b71a55474746c4368	zusy
733.	b00ce6a6107f0ace12878c3636fd42494bc387ba494f87c094c3597eb1dd4943	zusy
734.	b9fbc8deb897ea739ae10986e0c16714d5468e7b960ca4a1c93fadd39fb54486	zusy
735.	ba99ac9b25cf0b78872b502cc1ae43df86cce96ff2a22c378ff17d7c03497b99	zusy
736.	c10eeb0df592f972d478bd4f5de86a092df17060837e516503fa964d837287c0	zusy

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