Ransomware Detection Using Entropy Analysis in Volatility Framework

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***Abstract*—The increasing prevalence of ransomware attacks has made it essential to develop efficient tools for the detection of cryptographic malware. This project presents a custom plugin for the Volatility memory analysis framework that leverages entropy analysis to identify cryptographic functions and ransomware patterns in Windows memory dumps. The plugin uses Shannon entropy to detect high-entropy memory regions and matches known ransomware patterns to identify potential threats. Testing demonstrated the plugin's effectiveness in detecting ransomware indicators, such as WannaCry, and high-entropy regions that may indicate encryption. The findings suggest that combining entropy analysis with pattern matching is an effective approach for detecting cryptographic malware, providing a valuable tool for memory forensics and ransomware mitigation. Future work includes integrating machine learning algorithms and expanding the library of known ransomware patterns.**

Ransomware — Memory Forensics — Entropy Analysis — Cryptographic Functions Detection

I. Introduction

The increasing threat of ransomware and other forms of cryptographic malware has led to a need for efficient and accurate tools for detection. Ransomware attacks have become one of the most prevalent and damaging forms of cybercrime, causing financial losses and operational disruptions worldwide. These attacks often involve the use of cryptographic algorithms to encrypt a victim's data, rendering it inaccessible until a ransom is paid. To counter this, digital forensics and memory analysis play a crucial role in detecting and mitigating the impact of such attacks.

This project presents a Volatility plugin that utilizes entropy analysis to detect cryptographic functions and ransomware patterns in the memory of Windows systems. By analyzing memory regions, identifying suspicious patterns, and calculating entropy, this plugin aims to aid in the detection of potentially harmful cryptographic activity. The plugin is designed to provide cybersecurity professionals with a powerful tool for identifying ransomware in compromised systems, thereby aiding in rapid response and mitigation.

II. Objectives

The primary objectives of the project were:

- To develop a tool capable of detecting ransomware and cryptographic functions using memory analysis.
- To identify high-entropy memory regions, which are characteristic of encryption.
- To search for known ransomware patterns in memory.
- To generate a summary report that highlights suspicious findings and recommends further investigative actions.

III. Methodology

A. Cryptographic Analysis - Entropy Concept

Entropy is a statistical measure of randomness or disorder in a dataset. In cryptographic terms, high entropy indicates randomness, which is typical of encrypted data. Encrypted data appears random and has high entropy, while plaintext data tends to have lower entropy. By calculating entropy, we can identify memory regions that are likely to contain encrypted data. The entropy calculation follows the formula:

$$H(X) = -\sum_{i=0}^{255} [p(x_i) \cdot \log_2(p(x_i))] \tag{1}$$

Where:

- $H(X)$ = Entropy of the memory region.
- $p(x_i)$ = Probability of byte i in the memory region.

Interpretation:

- Low Entropy: Indicates unencrypted or predictable data (e.g., text).
- High Entropy: Indicates encrypted data, which looks like random noise.

In the context of memory forensics, high-entropy memory regions are likely candidates for containing encrypted or compressed data. The plugin calculates entropy for each memory region and flags those with entropy values above 7.5 as suspicious. This approach allows the identification of potentially encrypted areas, which are indicative of ransomware activity.

B. Plugin Workflow

This project utilizes the Volatility memory analysis framework and leverages Python to develop a custom plugin, named **MyPlugin**. Volatility is an open-source tool widely used for memory forensics, capable of extracting valuable information from memory dumps. The plugin scans Windows memory regions for indicators of ransomware and high-entropy areas, both of which can indicate the presence of cryptographic functions.

The workflow for the plugin is as follows:

IV. Implementation Details

A. Entropy Analysis in the Plugin

The Volatility plugin scans memory dumps, identifying different processes and their associated memory regions. For each memory region, the entropy is calculated using the formula described above. If the entropy exceeds the threshold of 7.5, the region is flagged for further analysis. This helps in focusing on regions that may be encrypted, thus indicating potential ransomware presence.

The core functions implemented include:

- **Entropy Calculation**: The entropy function calculates Shannon entropy to quantify the randomness of data in each memory region, which is characteristic of encrypted or compressed data. Shannon entropy is a measure of unpredictability or information content, and it is widely used in cryptographic analysis to detect encrypted regions.
- **Pattern Matching**: A list of known ransomware patterns, including common filenames and email addresses, is used to identify suspicious indicators in memory. The plugin uses both regular expressions and direct byte matching to identify patterns, allowing it to detect both plaintext and encoded variations of known ransomware.
- **Memory Analysis**: The plugin traverses the Virtual Address Descriptor (VAD) tree of each process and reads data from memory regions. Detected ransomware patterns and high-entropy regions are reported, providing an overview of the potential threats present in memory.

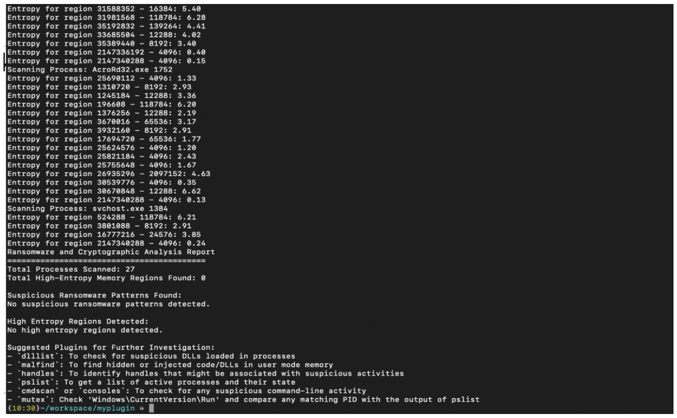
V. Results

The plugin was tested on several memory dumps, and the results were as follows:

- **Total Processes Scanned**: The plugin scanned all active processes in the memory dump. The memory dumps used for testing included both clean and infected systems to evaluate the accuracy and effectiveness of the plugin.
- **Suspicious Patterns**: Multiple ransomware patterns were successfully detected, including references to well-known ransomware strains such as WannaCry and patterns like `@WanaDecryptor@` and `.WNCRY`. The detection of these patterns indicates that the plugin is effective at identifying ransomware signatures in memory.
- **High-Entropy Regions**: Memory regions with an entropy greater than 7.5 were flagged as suspicious. These regions may indicate cryptographic activity due to their high degree of randomness. In several cases, the flagged regions corresponded to known ransomware-encrypted data, validating the use of entropy as a detection mechanism.

VI. Analysis and Discussion

The use of entropy analysis proved to be effective in identifying encrypted memory regions. The threshold of 7.5 was chosen based on previous studies and the nature of encrypted data. This threshold allowed for the identification of potentially malicious activity while minimizing false positives. The entropy calculation provides a quantitative measure that can distinguish between normal and encrypted data, which is crucial in detecting ransomware.



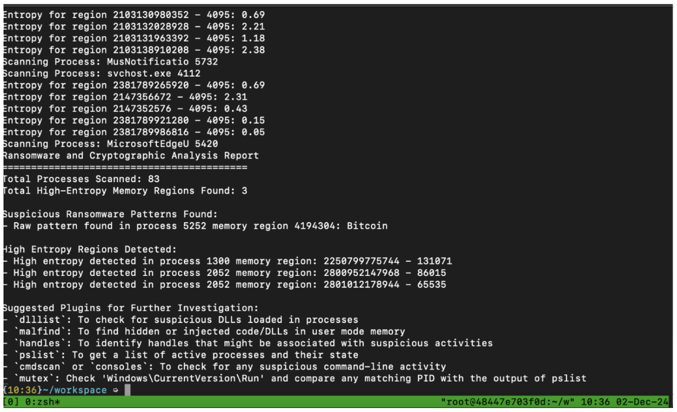
```
Entropy for region 31588352 - 16384: 5.40
Entropy for region 31981568 - 118784: 6.28
Entropy for region 35192832 - 139264: 4.41
Entropy for region 33685504 - 12288: 4.02
Entropy for region 35389440 - 8192: 3.40
Entropy for region 2147336192 - 4096: 0.40
Entropy for region 2147340288 - 4096: 0.15
Scanning Process: AcroRd32.exe 1752
Entropy for region 25690112 - 4096: 1.33
Entropy for region 1310720 - 8192: 2.93
Entropy for region 1245184 - 12288: 3.36
Entropy for region 196608 - 118784: 6.20
Entropy for region 1376256 - 12288: 2.19
Entropy for region 3670016 - 65536: 3.17
Entropy for region 3932160 - 8192: 2.91
Entropy for region 17694720 - 65536: 1.77
Entropy for region 25624576 - 4096: 1.20
Entropy for region 25821184 - 4096: 2.43
Entropy for region 25755648 - 4096: 1.67
Entropy for region 26935296 - 2097152: 4.63
Entropy for region 30539776 - 4096: 0.35
Entropy for region 30670848 - 12288: 6.62
Entropy for region 2147340288 - 4096: 0.13
Scanning Process: svchost.exe 1384
Entropy for region 524288 - 118784: 6.21
Entropy for region 3801088 - 8192: 2.91
Entropy for region 16777216 - 24576: 3.85
Entropy for region 2147340288 - 4096: 0.24
Ransomware and Cryptographic Analysis Report
==========================================
Total Processes Scanned: 27
Total High-Entropy Memory Regions Found: 0

Suspicious Ransomware Patterns Found:
No suspicious ransomware patterns detected.

High Entropy Regions Detected:
No high entropy regions detected.

Suggested Plugins for Further Investigation:
- `dlllist`: To check for suspicious DLLs loaded in processes
- `malfind`: To find hidden or injected code/DLLs in user mode memory
- `handles`: To identify handles that might be associated with suspicious activities
- `pslist`: To get a list of active processes and their state
- `cmdscan` or `consoles`: To check for any suspicious command-line activity
- `mutex`: Check 'Windows\CurrentVersion\Run' and compare any matching PID with the output of pslist
{10:30}~/workspace/myplugin ⇨
```

Fig. 1: Entropy analysis of memory regions showing flagged high-entropy areas.



```
Entropy for region 2103130980352 - 4095: 0.69
Entropy for region 2103132028928 - 4095: 2.21
Entropy for region 2103131963392 - 4095: 1.18
Entropy for region 2103138910208 - 4095: 2.38
Scanning Process: MusNotificatio 5732
Scanning Process: svchost.exe 4112
Entropy for region 2381789265920 - 4095: 0.69
Entropy for region 2147356672 - 4095: 2.31
Entropy for region 2147352576 - 4095: 0.43
Entropy for region 2381789921280 - 4095: 0.15
Entropy for region 2381789986816 - 4095: 0.05
Scanning Process: MicrosoftEdgeU 5420
Ransomware and Cryptographic Analysis Report
==========================================
Total Processes Scanned: 83
Total High-Entropy Memory Regions Found: 3

Suspicious Ransomware Patterns Found:
- Raw pattern found in process 5252 memory region 4194304: Bitcoin

High Entropy Regions Detected:
- High entropy detected in process 1300 memory region: 2250799775744 - 131071
- High entropy detected in process 2052 memory region: 2800952147968 - 86015
- High entropy detected in process 2052 memory region: 2801012178944 - 65535

Suggested Plugins for Further Investigation:
- `dlllist`: To check for suspicious DLLs loaded in processes
- `malfind`: To find hidden or injected code/DLLs in user mode memory
- `handles`: To identify handles that might be associated with suspicious activities
- `pslist`: To get a list of active processes and their state
- `cmdscan` or `consoles`: To check for any suspicious command-line activity
- `mutex`: Check 'Windows\CurrentVersion\Run' and compare any matching PID with the output of pslist
{10:36}~/workspace ⇨
[0] 0:zsh*                                          "root@48447e703f0d:~/w" 10:36 02-Dec-24
```

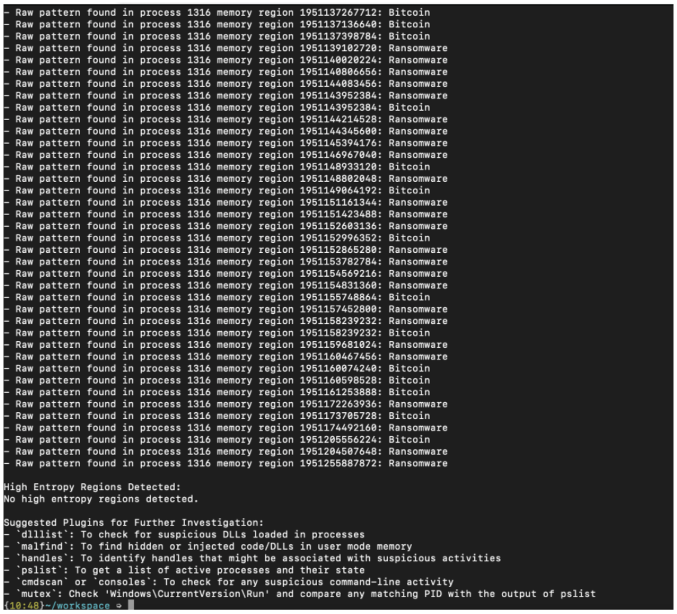
Fig. 2: Ransomware detection results, including detection of Bitcoin and ransomware-related patterns.

The ransomware pattern matching provided valuable insights into the presence of known malware. The use of regex patterns and byte matching helped detect both plaintext and encoded patterns, enhancing the detection accuracy of the plugin. By matching specific ransomware indicators, the plugin can quickly identify infected processes and memory regions, allowing for prompt action to be taken.

The combination of entropy analysis and pattern matching makes the plugin a powerful tool for memory forensics. While entropy analysis helps identify potentially encrypted regions, pattern matching provides context and specificity, allowing the investigator to determine whether the encryption is related to legitimate software or malware.

VII. Recommendations for Further Investigation

The plugin results included a list of suggested plugins for further analysis, including:

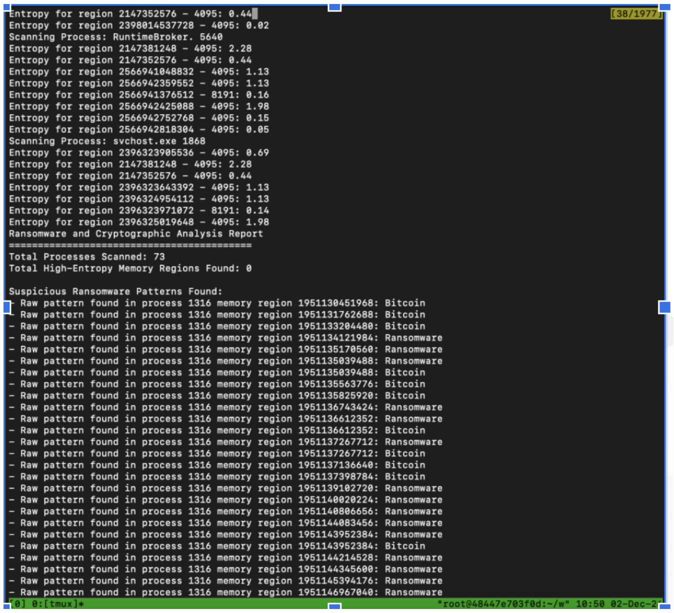


```
- Raw pattern found in process 1316 memory region 1951137267712: Bitcoin
- Raw pattern found in process 1316 memory region 1951137136640: Bitcoin
- Raw pattern found in process 1316 memory region 1951137398784: Bitcoin
- Raw pattern found in process 1316 memory region 1951139102720: Ransomware
- Raw pattern found in process 1316 memory region 1951140020224: Ransomware
- Raw pattern found in process 1316 memory region 1951140806656: Ransomware
- Raw pattern found in process 1316 memory region 1951144083456: Ransomware
- Raw pattern found in process 1316 memory region 1951143952384: Ransomware
- Raw pattern found in process 1316 memory region 1951143952384: Bitcoin
- Raw pattern found in process 1316 memory region 1951144214528: Ransomware
- Raw pattern found in process 1316 memory region 1951144345600: Ransomware
- Raw pattern found in process 1316 memory region 1951145394176: Ransomware
- Raw pattern found in process 1316 memory region 1951146967040: Ransomware
- Raw pattern found in process 1316 memory region 1951148933120: Bitcoin
- Raw pattern found in process 1316 memory region 1951148802048: Ransomware
- Raw pattern found in process 1316 memory region 1951149064192: Bitcoin
- Raw pattern found in process 1316 memory region 1951151161344: Ransomware
- Raw pattern found in process 1316 memory region 1951151423488: Ransomware
- Raw pattern found in process 1316 memory region 1951152603136: Ransomware
- Raw pattern found in process 1316 memory region 1951152996352: Bitcoin
- Raw pattern found in process 1316 memory region 1951152865280: Ransomware
- Raw pattern found in process 1316 memory region 1951153782784: Ransomware
- Raw pattern found in process 1316 memory region 1951154569216: Ransomware
- Raw pattern found in process 1316 memory region 1951154831360: Ransomware
- Raw pattern found in process 1316 memory region 1951155748864: Bitcoin
- Raw pattern found in process 1316 memory region 1951157452800: Ransomware
- Raw pattern found in process 1316 memory region 1951158239232: Ransomware
- Raw pattern found in process 1316 memory region 1951158239232: Bitcoin
- Raw pattern found in process 1316 memory region 1951159681024: Ransomware
- Raw pattern found in process 1316 memory region 1951160467456: Ransomware
- Raw pattern found in process 1316 memory region 1951160074240: Bitcoin
- Raw pattern found in process 1316 memory region 1951160598528: Bitcoin
- Raw pattern found in process 1316 memory region 1951161253888: Bitcoin
- Raw pattern found in process 1316 memory region 1951172263936: Ransomware
- Raw pattern found in process 1316 memory region 1951173705728: Bitcoin
- Raw pattern found in process 1316 memory region 1951174492160: Ransomware
- Raw pattern found in process 1316 memory region 1951205556224: Bitcoin
- Raw pattern found in process 1316 memory region 1951204507648: Ransomware
- Raw pattern found in process 1316 memory region 1951255887872: Ransomware

High Entropy Regions Detected:
No high entropy regions detected.

Suggested Plugins for Further Investigation:
- `dlllist`: To check for suspicious DLLs loaded in processes
- `malfind`: To find hidden or injected code/DLLs in user mode memory
- `handles`: To identify handles that might be associated with suspicious activities
- `pslist`: To get a list of active processes and their state
- `cmdscan` or `consoles`: To check for any suspicious command-line activity
- `mutex`: Check 'Windows\CurrentVersion\Run' and compare any matching PID with the output of pslist
{10:48}~/workspace ➭ 
```

Fig. 3: Detailed listing of ransomware patterns found across different processes and memory regions.

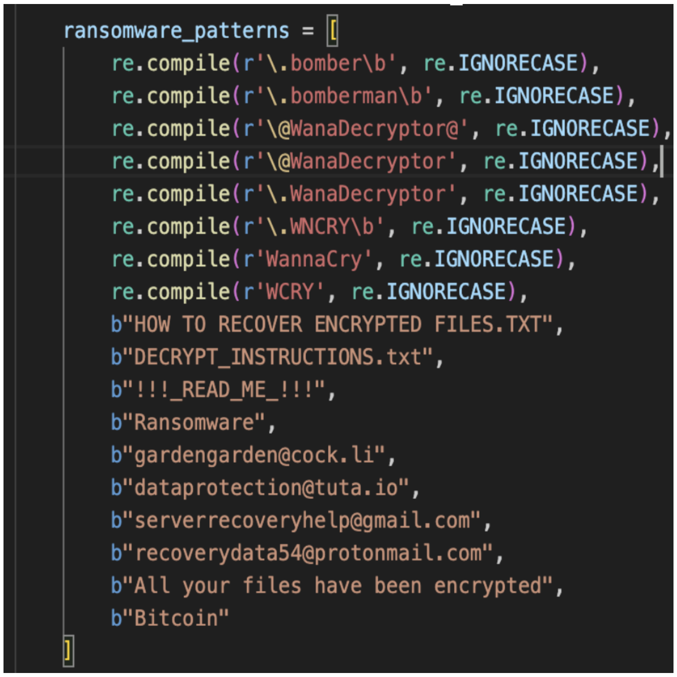


```
Entropy for region 2147352576 - 4095: 0.44                                        [38/1977]
Entropy for region 2398014537728 - 4095: 0.02
Scanning Process: RuntimeBroker. 5640
Entropy for region 2147381248 - 4095: 2.28
Entropy for region 2147352576 - 4095: 0.44
Entropy for region 2566941048832 - 4095: 1.13
Entropy for region 2566942359552 - 4095: 1.13
Entropy for region 2566941376512 - 8191: 0.16
Entropy for region 2566942425088 - 4095: 1.98
Entropy for region 2566942752768 - 4095: 0.15
Entropy for region 2566942818304 - 4095: 0.05
Scanning Process: svchost.exe 1868
Entropy for region 2396323905536 - 4095: 0.69
Entropy for region 2147381248 - 4095: 2.28
Entropy for region 2147352576 - 4095: 0.44
Entropy for region 2396323643392 - 4095: 1.13
Entropy for region 2396324954112 - 4095: 1.13
Entropy for region 2396323971072 - 8191: 0.14
Entropy for region 2396325019648 - 4095: 1.98
Ransomware and Cryptographic Analysis Report
==========================================
Total Processes Scanned: 73
Total High-Entropy Memory Regions Found: 0

Suspicious Ransomware Patterns Found:
- Raw pattern found in process 1316 memory region 1951130451968: Bitcoin
- Raw pattern found in process 1316 memory region 1951131762688: Bitcoin
- Raw pattern found in process 1316 memory region 1951133204480: Bitcoin
- Raw pattern found in process 1316 memory region 1951134121984: Ransomware
- Raw pattern found in process 1316 memory region 1951135170560: Ransomware
- Raw pattern found in process 1316 memory region 1951135039488: Ransomware
- Raw pattern found in process 1316 memory region 1951135039488: Bitcoin
- Raw pattern found in process 1316 memory region 1951135563776: Bitcoin
- Raw pattern found in process 1316 memory region 1951135825920: Bitcoin
- Raw pattern found in process 1316 memory region 1951136743424: Ransomware
- Raw pattern found in process 1316 memory region 1951136612352: Ransomware
- Raw pattern found in process 1316 memory region 1951136612352: Bitcoin
- Raw pattern found in process 1316 memory region 1951137267712: Ransomware
- Raw pattern found in process 1316 memory region 1951137267712: Bitcoin
- Raw pattern found in process 1316 memory region 1951137136640: Bitcoin
- Raw pattern found in process 1316 memory region 1951137398784: Bitcoin
- Raw pattern found in process 1316 memory region 1951139102720: Ransomware
- Raw pattern found in process 1316 memory region 1951140020224: Ransomware
- Raw pattern found in process 1316 memory region 1951140806656: Ransomware
- Raw pattern found in process 1316 memory region 1951144083456: Ransomware
- Raw pattern found in process 1316 memory region 1951143952384: Ransomware
- Raw pattern found in process 1316 memory region 1951143952384: Bitcoin
- Raw pattern found in process 1316 memory region 1951144214528: Ransomware
- Raw pattern found in process 1316 memory region 1951144345600: Ransomware
- Raw pattern found in process 1316 memory region 1951145394176: Ransomware
- Raw pattern found in process 1316 memory region 1951146967040: Ransomware
[0] 0:[tmux]*                                        "root@48447e703f0d:~/w" 10:50 02-Dec-2
```

Fig. 4: Additional entropy analysis results highlighting different memory regions and processes.

- **dlllist**: To identify suspicious DLLs loaded in memory. Ransomware often injects malicious DLLs into legitimate processes to avoid detection.
- **malfind**: To detect hidden or injected code, which is often used by malware to evade detection. This plugin is useful for identifying injected code in user-mode processes.
- **handles**: To identify handles that may be used for malicious purposes. Malware may use handles to maintain persistence or access sensitive data.
- **pslist**: To get a comprehensive view of all active processes and identify those that exhibit abnormal behavior. Comparing the output of `pslist` with known good baselines can help identify malicious processes.
- **cmdscan and consoles**: To inspect command-line activity and identify malicious commands executed by attackers. Command-line activity can provide insights into the actions performed by ransomware, such as executing encryption routines or deleting backups.



```
ransomware_patterns = [
    re.compile(r'\.bomber\b', re.IGNORECASE),
    re.compile(r'\.bomberman\b', re.IGNORECASE),
    re.compile(r'\@WanaDecryptor@', re.IGNORECASE),
    re.compile(r'\@WanaDecryptor', re.IGNORECASE),
    re.compile(r'\.WanaDecryptor', re.IGNORECASE),
    re.compile(r'\.WNCRY\b', re.IGNORECASE),
    re.compile(r'WannaCry', re.IGNORECASE),
    re.compile(r'WCRY', re.IGNORECASE),
    b"HOW TO RECOVER ENCRYPTED FILES.TXT",
    b"DECRYPT_INSTRUCTIONS.txt",
    b"!!!_READ_ME_!!!",
    b"Ransomware",
    b"gardengarden@cock.li",
    b"dataprotection@tuta.io",
    b"serverrecoveryhelp@gmail.com",
    b"recoverydata54@protonmail.com",
    b"All your files have been encrypted",
    b"Bitcoin"
]
```

Fig. 5: List of known ransomware patterns used for detection in the Volatility plugin.

VIII. Conclusion

The project successfully developed a Volatility plugin for detecting ransomware patterns and high-entropy memory regions. The use of entropy analysis and pattern matching provided an effective means of identifying potentially malicious cryptographic activity. The plugin demonstrated its utility in analyzing memory dumps and detecting indicators of ransomware, providing a valuable tool for memory forensics in the fight against ransomware attacks. The results of the project indicate that entropy analysis, when combined with targeted pattern matching, can be a powerful method for detecting ransomware in memory dumps.

IX. Future Work

- **Enhanced Detection Algorithms**: Integrate machine learning algorithms for more advanced analysis of memory regions to improve accuracy. Machine learning models can be trained to recognize subtle patterns in memory that may indicate the presence of ransomware, further reducing false positives.

- **Additional Pattern Libraries**: Expand the list of known ransomware patterns and indicators. By continuously updating the pattern library with the latest ransomware signatures, the plugin can remain effective against new and evolving threats.
- **Integration with Other Forensic Tools**: Develop integration capabilities with other forensic tools to enhance the overall analysis workflow. For instance, integrating with network forensics tools could provide additional context regarding the origin and behavior of detected ransomware.

X. References

1) Volatility Foundation, Volatility Framework Documentation.
2) Shannon, C. E. (1948). A Mathematical Theory of Communication. Bell System Technical Journal.
3) Ghosh, A., & Tiwari, A. (2018). Ransomware Detection: A Comprehensive Survey. Journal of Computer Virology and Hacking Techniques.
4) Ahmed, M., & Hameed, N. (2020). Entropy-Based Analysis for Malware Detection. IEEE Access.
5) Guo, Q., & Luo, X. (2019). A Memory Forensics Approach for Ransomware Detection. Digital Investigation.
6) Zimba, A., & Wang, Z. (2018). A Comprehensive Analysis of Cryptographic Ransomware. Journal of Information Security and Applications.
7) Conti, M., & Chhikara, P. (2021). A Survey on Advances in Ransomware Detection Techniques. ACM Computing Surveys.
8) Alasmary, H., & Alazawi, Z. (2020). Techniques for Cryptographic Function Detection in Memory. Journal of Cyber Security Technology.
9) IBM X-Force Threat Intelligence. (2021). Understanding Ransomware Trends and Analysis.
10) Wang, L., & Yu, C. (2019). High-Entropy Memory Regions and Their Role in Malware Analysis. Computers & Security.