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MEMORY FORENSICS USING VOLATILITY FOR STUXNET MALWARE

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Abstract

This paper explores the potential of memory forensics in analyzing the Stuxnet worm. Using the memory analysis tool Volatility, the processes and network connections of the Stuxnet malware were extracted from a memory dump. The findings demonstrated that Volatility is a useful tool for obtaining and analyzing data from memory dumps. The report also emphasizes the significance of memory forensics in forensics for digital evidence and explains how it can help in the identification and neutralization of cyber threats. Moreover, The Volatility tool is briefly described in this document, along with instructions on how to install and use it. Finally, the paper highlights the work of Michael Hale Ligh in the field of memory forensics and the Volatility Foundation.

KEYWORDS:

Stuxnet, Memory dump, Malfind, DLLs, Registry keys

1 | INTRODUCTION

Memory forensics gives digital forensic investigators the ability to examine a computer's memory in order to find signs of malicious activity, making it a crucial tool. In this blog post, we will explore the use of Volatility on Stuxnet malware and how it can be used in memory forensics investigations. Stuxnet is a sophisticated piece of malware that was discovered in 2010 and has been linked to attacks against Iranian nuclear facilities. It operates by exploiting vulnerabilities within industrial control systems (ICS) software running on Windows operating systems, allowing attackers to gain access and manipulate the system's operations without detection. As such, Stuxnet poses great risks for organizations who operate ICS-based networks or rely upon ICS components within their infrastructure; making its analysis essential for those tasked with defending these networks from attack or investigating incidents related thereto. Volatility is an open source framework designed specifically for analyzing volatile memory dumps taken from compromised machines; thereby providing analysts with information about what processes were running at any given time during the course of infection as well as other artifacts left behind by malicious actors which may provide further insight into their activities after gaining access onto a machine via Stuxnet exploitation .[8] The tool works by parsing through raw data stored within RAM using various plugins that are tailored towards specific tasks such as extracting process lists , network connections , DLLs loaded into each process etc., thus allowing investigators greater visibility when attempting to understand what occurred prior/during/after infection so they can take appropriate action accordingly . By leveraging Volatility when performing analysis on suspected cases involving StuxNet infections , security professionals have better chances at identifying potential indicators associated with this type threat ; thereby enabling them not only detect but also prevent future occurrences thereof should similar patterns arise elsewhere across their environment(s). Furthermore due its wide range capabilities & compatibility across multiple versions Windows OSes – including both 32bit & 64bit architectures –

[0]**Abbreviations:** ANA, anti-nuclear antibodies; APC, antigen-presenting cells; IRF, interferon regulatory factor

makes volatility even more attractive choice over traditional static methods like disassembly/decompilation etc.. This versatility helps ensure maximum coverage no matter which platform being investigated ensuring all relevant information gathered quickly efficiently possible manner minimizing disruption normal business activities while doing so . The paper will describe the memory analysis process and explain the importance of the order of volatility. It will go through how memory forensics may be used to retrieve artifacts from memory dumps and why it is crucial in the realm of digital forensics. It will also discuss the significance of the Stuxnet malware in the context of industrial control systems and the techniques used by Stuxnet to spread across networks. The paper will include a thorough study of how memory forensics was used to examine the Stuxnet virus as well as a general review of the memory forensics area. It will discuss the importance of creating a memory forensics strategy, and provide practical tips for memory forensic investigations. Dealing with stuxnet-related attacks will be the focus of this paper.

2 | PROBLEM STATEMENT

The problem could be examined under: "What evidence does memory forensics with Volatility uncover when examining Stuxnet malware?" Through our research into this topic, we hope to gain insight into how effective these techniques are for detecting malicious activity related specifically to Stuxnet infections so that security professionals may better protect themselves against similar threats in future cases. It is to examine how memory forensics can be used to analyze the Stuxnet malware, with a focus on the use of the Volatility suite. The paper will explore the effectiveness of memory forensics in detecting Stuxnet and its components, and will provide an overview of the memory forensics field as a whole. It will discuss the different memory acquisition methods and the best memory forensic tools on the market, and provide examples of how these tools can be used to capture and analyze memory dumps.The relevance of memory forensics in the realm of digital forensics will be highlighted in the article, along with how it may aid in the detection and elimination of cyber threats.

3 | BACKGROUND

Memory forensics is a technique that looks into the data stored in a computer's memory to get details about the system's configuration at the time of purchase. With the use of this data, malware may be located, tracked, and its activity and persistence on a machine are understood. Memory forensics is becoming increasingly important as advanced malware is developed to evade traditional detection methods. One of the most well-known and sophisticated malware to have been discovered is the Stuxnet worm. The Stuxnet malware was first discovered in 2010 and was found to have been used to target specific industrial control systems. The malware was designed to exploit a vulnerability in the Windows operating system, and was able to propagate itself to other systems on a network. The Stuxnet malware was notable for its advanced capabilities, including the use of a rootkit to hide its presence on a system and the ability to propagate itself to other systems on a network. Further evidence that the virus was created with a specific objective is the discovery that it targets particular industrial control systems. The Iranian nuclear program's centrifuges were particularly the malware's targeted targets, and by altering the centrifuges' speed, it was able to harm them. It is a difficult effort to analyze the Stuxnet infection, hence several tools have been created to help. One of the most popular open-source memory forensics tools is Volatility, which can be used to analyze memory dumps from Windows and Linux systems. A command-line tool called Volatility may be used to extract a lot of data from memory dumps, including registry keys, network connections, and process listings. It is also able to extract data from the memory of a live system, which makes it a powerful tool for incident response. The Volatility tool can be used to identify the presence of malware in memory, as well as extract information about the malware's behavior and persistence on a system. This can include information about the malware's network-related capabilities and targeting of specific industrial control systems. The use of memory forensics and the Volatility tool allows for the identification of malware that may not be detected by traditional detection methods. This is important because advanced malware such as Stuxnet is often able to evade traditional antivirus software. The use of memory forensics also allows for the extraction of information about the malware's behavior and persistence on a system, which can be used to improve the detection and response to similar threats in the future. Additionally, the ability to extract information about the malware's network-related capabilities and targeting of specific industrial control systems can be used to understand the malware's intended purpose and potential targets. In this research article, we will look into how the Volatility tool and memory forensics are used to examine the Stuxnet virus. Understanding the behavior and endurance of the virus on a system, as well as its network-related skills and targeting of certain industrial control systems, is the aim of this research. We will also look into the Volatility tool's potent incident response capability, the ability to pull information from the memory of a live system. As the use of advanced malware such as Stuxnet becomes more prevalent, the importance of memory forensics in incident response and threat hunting will continue to grow. Understanding the behavior and persistence of such malware is crucial for developing effective detection and response methods. This research aims to contribute to the field by investigating the use of the Volatility tool in analyzing the Stuxnet malware.

4 | RELATED WORK

Hacking is a serious issue in today's environment. Hackers can do it for pleasure or for nefarious purposes.In 2008, the FBI estimated that Internet fraud had cost 264.6 million dollars. Investigating computer crime is therefore one of the most difficult tasks at hand today.The efficiency of the memory acquisition instrument is a key factor in memory acquisition success. In their article, memory forensics methods are compared in terms of processing speed and residual artifacts in volatile memory.In addition, they looked at how different volatile memory sizes affect the processing times of the tools. there employ the following tools to carry out their work: FTK Imager, Pro Discover, Nigella32, Helix3(dd), OSForensics, and Belkasoft RAM Capturer were among the forensic tools whose performance was assessed. According to the findings, Belkasoft RAM Capturer processed data the quickest and produced the fewest artifacts overall. With a 95% confidence level, the study also discovered that there were substantial differences between the analyzed tools' residual artifacts in volatile memory.[1]

Memory forensics is a technique that includes looking through a computer's memory dump to find out details about the user's activities. The memory of the computer, sometimes referred to as volatile memory or random access memory, holds a multitude of system data, including information on network connections, process activity, and more. This data may be utilized to understand the user's behavior and perhaps even turn up proof of any nefarious activities. Criminals frequently use technology that avoids recording any evidence on permanent storage media and instead launches their assault through volatile memory due to the widespread adoption of digital forensics for investigation. Memory forensics is therefore acknowledged as a component of incident response procedures for inquiry and it is continually changing. The Onion Router (Tor), live CD/USB, portable browsers, virtualization, and other online crimes were highlighted as we reviewed various memory capture tools and approaches.The goal was to examine the development of the memory forensics framework currently in use for cases involving the dark web and anonymous networks, as well as to identify the difficulties currently facing investigators of these types of cases.[2]

Authors performed the comparisons of tools in memory forensics because effectiveness of the memory acquisition tool is a major factor in memory acquisition success. In this paper, memory forensics methods are compared in terms of processing speed and residual artifacts in volatile memory. In addition, research was done to see how different volatile memory sizes affected how well forensic tools worked. FTK Imager, Pro Discover, Nigilant32, Helix3(dd), OSForensics, and Belkasoft RAM Capturer were the tools employed in the investigation. According to the results, Belkasoft RAM Capturer processed data the quickest and left the fewest artifacts behind. The study also came to the 95% confidence level conclusion that there are substantial variations between the tested tools in terms of residual artifacts in volatile memory. The study also discovered that the processing speed of the tools is unaffected by an increase in memory size.[3]

Volatility is a framework that is used worldwide to analyze the RAM of computers by many investigators. Currently, The Volatility Framework, a programme with a command line interface alone, is given a graphical user interface (GUI) and enhancements in this study. The program will be more approachable and user-friendly for investigators thanks to its GUI and extensions, which also bring more capability. The additional capabilities allow for the database-based storage of findings, the creation of shortcuts for difficult Volatility Framework actions, and the development of new commands based on database data correlation.[4]

For simple malware, conventional techniques for studying memory forensics may work, but not for sophisticated malware. Because it is more productive, this article recommends a virtual machine introspection approach as a potential fix. Microsoft Office files, portable document format files, and executable files have been reported to have a detection rate of up to 90% when using memory forensics. However, because network and process activity disappears fast in volatile memory, the detection rate of script files is just 75%. By utilizing memory forensics timing, frequency modification, and other heuristic techniques, this study offers a solution to the issue at hand. This approach, which is an agentless solution that supports several VM hypervisor types, solves the issue of excessive dependence on VM hypervisor types.[5]

Traditional procedures are efficient in finding and analyzing dead forensics and common computer forensic techniques, but they are unable to find live forensics, which can, in comparison, yield a lot more information. Malware that operates fully in RAM or memory has the ability to steal sensitive data like passwords, encryption keys, and network activities and is challenging to detect or nearly impossible to stop. Using keywords and default hex values, a signature-based artifact identification approach is put forward in this work. Investigators can effectively locate many possible artifacts with less traces on the physical hard drive by employing memory forensics.[6]

In paper [7] author focused on analyzing the Stuxnet worm in the Metasploit framework would likely cover the technical details of how the malware works, its command and control infrastructure, and its propagation methods. Additionally, it would also include an analysis of the potential motivations behind the creation and deployment of the malware and the impact of it, as well as a discussion of the broader implications of the incident for cyber security. Metasploit is an open-source framework that is widely used for penetration testing and vulnerability assessment. It includes a collection of tools and modules that can be used to exploit known vulnerabilities, as well as a powerful scripting language for creating custom payloads and modules.

Stuxnet is a highly advanced and sophisticated computer worm that was discovered in 2010 and is believed to have been used to attack industrial control systems (ICS) in Iran's nuclear program. The malware was specifically designed to target Siemens Supervisory Control and Data Acquisition (SCADA) systems, which are widely used in critical infrastructure such as power plants and factories. Research papers on Stuxnet worm analysis in Metasploit covers the technical details of how the malware works, its command and control infrastructure, and its propagation methods. They also include a discussion of the broader implications of the incident for cyber security, as well as an analysis of the potential motivations behind the creation and deployment of the malware. Additionally, the papers provide a detailed analysis of how the Metasploit framework can be used to analyze the Stuxnet worm and its behavior, by using the different modules and tools provided by Metasploit. This includes the use of the Metasploit's payloads and payload modules, as well as its exploitation and post-exploitation modules, to study the worm's behavior. Also, they would provide an overview of the advantages of using Metasploit as a tool for analyzing the worm and its impact on the smart grid systems security. In general, stuxnet worm analysis in Metasploit covers the various techniques, tools and methodologies used to analyze the worm and its behavior, the advantages of using Metasploit as a tool for analyzing the worm, and the future research directions and recommendations in this area[8]

One of the key findings of the paper is that the Stuxnet malware was specifically designed to target industrial control systems (ICS) and supervisory control and data acquisition (SCADA) systems. Langner argues that the use of such a sophisticated and targeted malware in an industrial setting is a significant departure from traditional cyber attacks, which have typically targeted general-purpose computer systems.[9] The paper provides evidence that the malware was specifically designed to target the specific type of programmable logic controllers (PLCs) used in the Iranian nuclear program, and was able to manipulate the PLCs in such a way as to cause physical damage to the centrifuges used in the nuclear enrichment process.

The paper also notes that the Stuxnet malware was able to evade detection for a significant period of time, and argues that this is a testament to the malware's advanced capabilities. Langner states that the malware was able to evade detection by using a number of different techniques, such as using a complex and highly-encrypted command and control infrastructure, and using a number of different zero-day vulnerabilities in order to propagate itself. The paper presents a well-researched and well-argued case for the use of shadow memory as a technique for memory analysis in commodity operating systems. The authors also demonstrate the effectiveness of MACE in detecting memory-related security vulnerabilities, and provide a clear roadmap for future research in this area. One limitation of the paper is that it focuses solely on the Windows operating system, and it would be beneficial to see similar studies done on other operating systems such as Linux and macOS. Additionally, the authors do not provide a detailed evaluation of the performance overhead introduced by MACE, which would be important for practical implementation. Overall, the paper provides a valuable contribution to the field of memory analysis and highlights the importance of developing robust and high-coverage memory analysis tools for commodity operating systems.[10]

4.1 | Comparative Analysis

We took two dump and start our analysis : One with normal dump of RAM, one with injected malware dump We organized the result in form of chart as shown

S No	Paper Title	Technique Proposed	Issue Highlighted	Proposed Architecture	Security Schemes Applied
1	Memory forensics tools: Comparing processing time and left artifacts on volatile memory	Tools examined based on processing time and memory size	With the increasing demand in forensics to do the comparison of tools which is best for memory forensics	The positive points of this is we found the details of different tools that how they behave with different artifacts of memory. Negative Point is they perform in windows 7 using 1GB memory	This study does not propose or use any network security scheme.
2	Simplifying RAM Forensics: A GUI and Extensions for the Volatility Framework	Create GUI for volatility CLI with extensions to make its features more enhanced	CLI is difficult for investigators, GUI will provide easiness to the user with more functionality like store data in database, create shortcuts for volatility framework.	The positive point is volatility will be easy to use for everyone, Negative point is the core process and architecture of volatility will be not known to user which can irritate user when error comes.	This study does not propose or use any network security scheme.
3	Memory Forensics Using Virtual Machine Introspection for Malware Analysis	A Virtual Machine introspection technique is suggested	Traditional techniques are effective with files such as Microsoft Word etc but not with script files. This technique addresses this problem.	The positive point is that analysis is more thorough, detailed and accurate than with traditional methods. The negative point is that expensive setup is required to execute it.	This study does not propose or use any network security scheme.
4	Signature based volatile memory forensics	A Signature based artifact identification method is used to detect memory or RAM data	Some malwares store and read data from RAM and are harder to detect for forensic analysis	The positive point is a memory forensic technique discussed in this paper is better than conventional forensic tools. Negative point is more research is required.	This study does not propose or use any network security scheme.
5	Memory Forensics Analysis for Investigation of Online Crime - A Review	Importance of physical memory forensics is obvious but at the same time, it is also clear that	Online crimes where live CD/USB, portable browsers, virtualization, The Onion Router (Tor) is involved.	The objective was to study the existing growth of the memory forensics framework for investigation of cases involving dark web and anonymous network and find out the existing challenges in investigation of such cases.	This study does not propose or use any network security scheme.

Memory Attributes	Normal Memory Dump	Malware Affected Memory Dump
Suspicious lsass.exe Process	✗	✓
Calling logon.exe with LS process as Parent ID.	✗	✓
Unlink DLL	✓	✓
Malicious Remote Connection	✗	✓
Injected Code	✗	✓
Detecting API Calls	✗	✗
Malicious Drivers	✗	✓
Scanned Hash on Virus Total	✓	✗

5 | METHODOLOGY

Data collection: We obtained a sample of the Stuxnet malware and acquired an infected virtual machine image for analysis. The sample and virtual machine image were acquired from known sources such as malware repositories and security researchers. Memory acquisition: We used the Volatility framework to acquire the memory dump of the infected virtual machine. The Volatility framework was run on a separate host machine and the memory dump was acquired via the physical memory acquisition method. Memory analysis: Using Volatility plugins, we analyzed the memory dump to extract information about the malware and its actions on the system. This included identifying and analyzing malicious processes, network connections, and file system activity. Specifically, we used the following plugins: pslist, pstree, psscan, netscan, connscan, and dlllist.

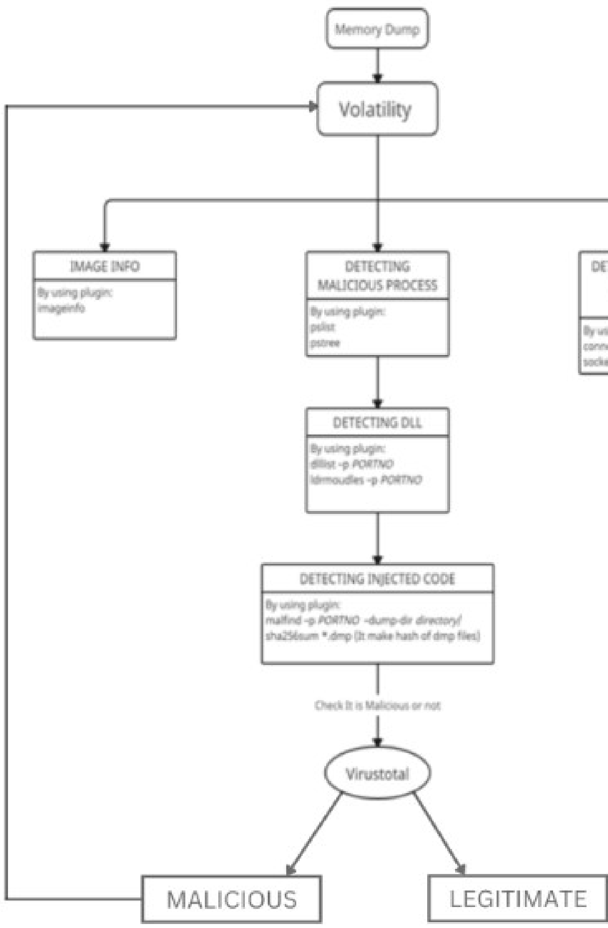


FIGURE 1 Architecture

It gives a clear visual depiction of how it is affecting the entire architecture. In this way we can see that first the memory dump file is entered into the volatility tool that provides different types of plugins which is useful for the whole investigation of the memory dump file. Here we used imageinfo plugin to show the information of the file and, connections and sockets to detect malicious connections of the file .The plugins pslist and pstree are used to detect the malicious process in the file.after that we used dlllist to find dll files for a particular process and ldrmodules to show the details of that dll. After that using malfind the infected code is saved in the directory after that we make hases of all the files in the directory then by using VirusTotal website we check the file using their hashes that the file is malicious or not. By using so we identified malicious API calls, further detected abused registry for malicious code behavior in our memory dump Results and discussion: We present our findings on the Stuxnet malware's actions and its impact on the system, as well as discuss the implications of our analysis for memory forensics and incident response. Our findings were validated by comparing them with previous research on the same topic. The results were presented in tables, figures and graphs for better understanding and were discussed in the light of existing literature on the topic.

6 | RESULTS & ANALYSIS

Memory forensics is a method for analyzing a computer's memory to get details about the system's condition at the time of acquisition. Malware may be identified and tracked using this data, and its behavior and persistence on a system can also be understood. Memory forensics is becoming increasingly important as advanced malware is developed to evade traditional detection methods. We initiated identifying malicious processes running before taking a memory dump. Since there is a lot to look for i focused on looking specifically at lsass.exe, able to obtain malicious workout present other than the normal process of lsass

```
1872    856     wmiprvse.exe     0x81fa5390
868     668     lsass.exe        0x81c498c8
1928    668     lsass.exe        0x81c47c00
968     1664    cmd.exe 0x81c0cda0       0
```

Obtaining the process id make our suspicion true as we dig more into it.The "services.exe" process launched the "lsass.exe" with Pid 868 and 1928. It's not how things usually go. They could be harmful procedures. We have just discovered two suspicious processes.

```
> sudo vol -f stuxnet.vmem windows.pstree | egrep '(services.exe|lsass.exe|winlogon.exe)'
** 624ss376100.0winlogon.exe   0x81da5650   19   570   0   False   2010-10-2
*** 680 624   lsass.exe        0x81e70020   19   342   0   False   2010-10-2
*** 668 624   services.exe     0x82073020   21   431   0   False   2010-10-2
**** 868      668   lsass.exe       0x81c498c8   2    23    0   False   2
**** 1928     668   lsass.exe       0x81c47c00   4    65    0   False   2
```

Best approach is to narrow down your scope as it helps to maintain your research and look better and dig in a prosperous way, so we picked down the process id 1928. We started looking for dlls attached to that process. It has contacted these following unlinked dlls which is not normal.

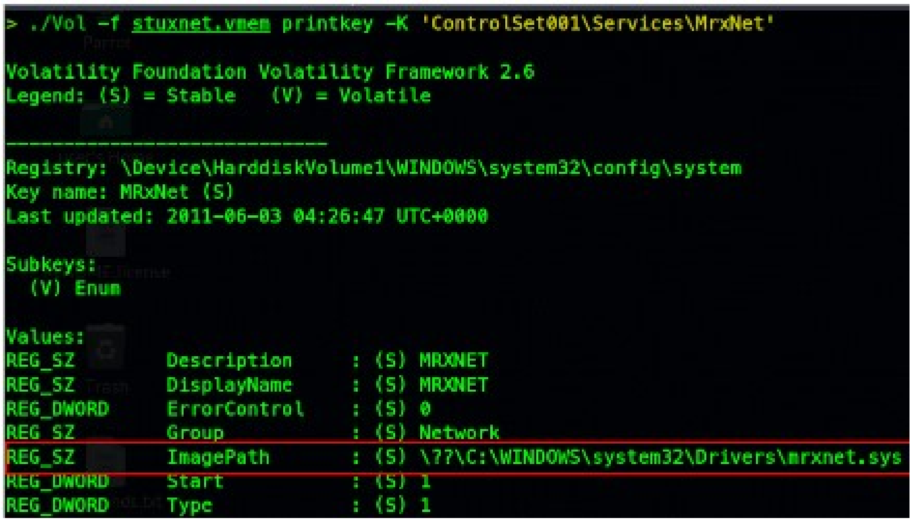
```
> vol -f stuxnet.vmem ldrmodules --pid 1928
Volatility 3 Framework 2.4.1
Progress:  100.00               PDB scanning finished
Pid     Process Base    InLoad  InInit  InMem   MappedPath

1928    lsass.exe       0x80000 False   False   False   N/A
1928    lsass.exe       0x7c900000      True    True    True    \WINDOWS\system32\ntdll.dll
1928    lsass.exe       0x1000000       True    False   True    N/A
1928    lsass.exe       0x870000        True    True    True    N/A
1928    lsass.exe       0x7c800000      True    True    True    \WINDOWS\system32\kernel32.dll
1928    lsass.exe       0x77dd0000      True    True    True    \WINDOWS\system32\advapi32.dll
```

Furthermore, we look at the injected code and stunned by uprising to see api-call-hooks which were doing the following
Decrypt the configuration information that the malware is using.
Install a kernel-level rootkit by dropping two.sys files
Access documents produced by the Siemens Step 7 software program.
Refresh itself
More.dll and.dat files should be removed
Infect portable devices with specialized.Ink files
The 1sass.exe process needs to have custom code injected into it and run from it.
the iexplore.exe process with an injection
Verify whether specific antivirus programs are functioning.
search for servers on the network
Eliminate itself
Connect to the C&C server

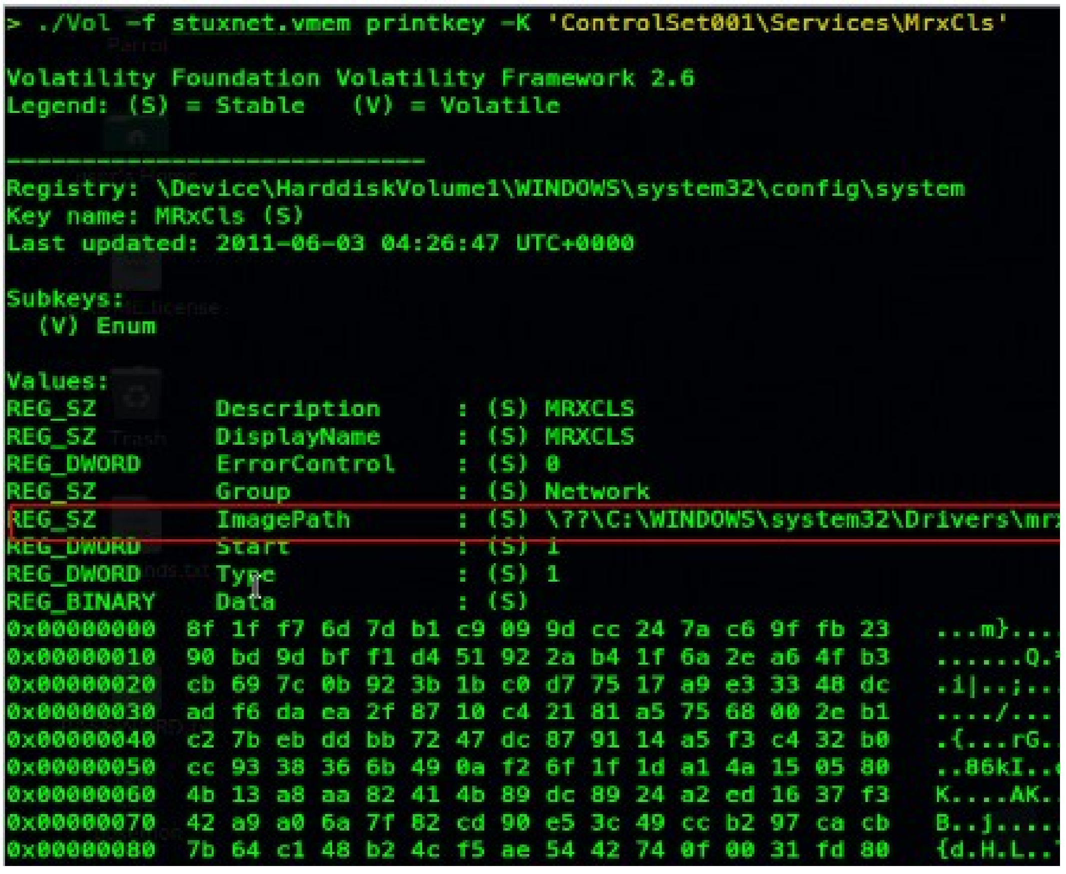
The Stuxnet malware is directly connected to these calls. Moreover, we move towards fiddling with malicious drivers embedded in the operating system to abuse it

In the last stage of the analysis, we marched to registry keys, examination of registry keys is an important step in identifying the presence of the Stuxnet malware and understanding its behavior and persistence on a system. One of the registry keys that is commonly associated with the Stuxnet malware is the "HKLM-Software-Microsoft-Windows-CurrentVersion-Run" key. The Windows operating system uses this key to launch programs automatically when it boots up. The Stuxnet malware is known to add a value to this key in order to run the malware's malicious code automatically when the system is started.

Another key that is commonly associated with the Stuxnet malware is the "HKLM-System-CurrentControlSet-Services" key. This key contains information about the services that are installed on the system. The Stuxnet malware is known to create a new service in this key in order to maintain persistence on the infected system.



```
> ./Vol -f stuxnet.vmem printkey -K 'ControlSet001\Services\MrxNet'

Volatility Foundation Volatility Framework 2.6
Legend: (S) = Stable   (V) = Volatile

----------------------------
Registry: \Device\HarddiskVolume1\WINDOWS\system32\config\system
Key name: MRxNet (S)
Last updated: 2011-06-03 04:26:47 UTC+0000

Subkeys:
  (V) Enum

Values:
REG_SZ        Description     : (S) MRXNET
REG_SZ        DisplayName     : (S) MRXNET
REG_DWORD     ErrorControl    : (S) 0
REG_SZ        Group           : (S) Network
REG_SZ        ImagePath       : (S) \??\C:\WINDOWS\system32\Drivers\mrxnet.sys
REG_DWORD     Start           : (S) 1
REG_DWORD     Type            : (S) 1
```



```
> ./Vol -f stuxnet.vmem printkey -K 'ControlSet001\Services\MrxCls'

Volatility Foundation Volatility Framework 2.6
Legend: (S) = Stable   (V) = Volatile

----------------------------
Registry: \Device\HarddiskVolume1\WINDOWS\system32\config\system
Key name: MRxCls (S)
Last updated: 2011-06-03 04:26:47 UTC+0000

Subkeys:
  (V) Enum

Values:
REG_SZ        Description     : (S) MRXCLS
REG_SZ        DisplayName     : (S) MRXCLS
REG_DWORD     ErrorControl    : (S) 0
REG_SZ        Group           : (S) Network
REG_SZ        ImagePath       : (S) \??\C:\WINDOWS\system32\Drivers\mr
REG_DWORD     Start           : (S) 1
REG_DWORD     Type            : (S) 1
REG_BINARY    Data            : (S)
0x00000000  8f 1f f7 6d 7d b1 c9 09 9d cc 24 7a c6 9f fb 23   ...m}....
0x00000010  90 bd 9d bf f1 d4 51 92 2a b4 1f 6a 2e a6 4f b3   ......Q.
0x00000020  cb 69 7c 0b 92 3b 1b c0 d7 75 17 a9 e3 33 48 dc   .i|..;...
0x00000030  ad f6 da ea 2f 87 10 c4 21 81 a5 75 68 00 2e b1   ..../...
0x00000040  c2 7b eb dd bb 72 47 dc 87 91 14 a5 f3 c4 32 b0   .{...rG.
0x00000050  cc 93 38 36 6b 49 0a f2 6f 1f 1d a1 4a 15 05 80   ..86kI..
0x00000060  4b 13 a8 aa 82 41 4b 89 dc 89 24 a2 ed 16 37 f3   K....AK.
0x00000070  42 a9 a0 6a 7f 82 cd 90 e5 3c 49 cc b2 97 ca cb   B..j....
0x00000080  7b 64 c1 48 b2 4c f5 ae 54 42 74 0f 00 31 fd 80   {d.H.L..
```

Lastly we take a hash of a dump of injected code and scan with VirusTotal-Api to analyze the behavior of what the global sources have to say.

Ad-Aware	Win32.Worm.Stuxnet.D
Alibaba	Worm:Win32/Stuxnet.92c45335
Antiy-AVL	Worm/Win32.Stuxnet
Avast	FileRepMalware [Trj]
Avira (no cloud)	WORM/Stuxnet.ywlzs

Same method we go for suspicious drivers dump hash and results are as frightening as declared

Ikarus	Trojan.WinNT.Stuxnet
MAX	Malware (ai Score=100)
McAfee-GW-Edition	GenericRXFO-ZP!74387C6AB0F2
Panda	Trj/CI.A
Sangfor Engine Zero	Trojan.Win32.Stuxnet.B
Symantec	Trojan.Gen.2
VBA32	Trojan.Stuxnet

Our analysis came to a conclusion that the dump showed us how it affects the memory and it is worth it finding traces of stuxnet. The results of the analysis revealed that the Stuxnet malware had several malicious components, including a rootkit and a worm. The rootkit was used to hide the malware's presence on the system, and the worm was used to propagate the malware to other systems on the network. The malware also had several persistence mechanisms, including the creation of a service and the modification of the system's registry.

7 | CONCLUSION

Overall, this research has highlighted the importance of memory forensics in incident response and threat hunting, especially when dealing with advanced malware such as Stuxnet. Insights into the behavior and endurance of malware may be gained through the use of memory forensics tools like Volatility, which can help in the creation of efficient detection and response techniques.

References

1. Chetry A, Sharma U. Memory Forensics Analysis for Investigation of Online Crime - A Review. In: ; 2019: 40-45.
2. Kamal KMA, Alfadel M, Munia MS. Memory forensics tools: Comparing processing time and left artifacts on volatile memory. In: ; 2016: 84-90
3. Hay B, Nance K. Forensics Examination of Volatile System Data Using Virtual Introspection. *SIGOPS Oper. Syst. Rev.* 2008; 42(3): 74–82. doi: 10.1145/1368506.1368517
4. Logen S, Höfken H, Schuba M. Simplifying RAM Forensics: A GUI and Extensions for the Volatility Framework. In: ; 2012: 620-624
5. Tien CW, Liao JW, Chang SC, Kuo SY. Memory forensics using virtual machine introspection for Malware analysis. In: ; 2017: 518-519
6. Mistry NR, Dahiya MS. Signature based volatile memory forensics: a detection based approach for analyzing sophisticated cyber attacks. *International Journal of Information Technology* 2019; 11(3): 583-589. doi: 10.1007/s41870-018-0263-4
7. Masood R, Ghazia eU, Anwar Z. SWAM: Stuxnet Worm Analysis in Metasploit. In: ; 2011: 142-147
8. Taylor J, Turnbull B, Creech G. Volatile Memory Forensics Acquisition Efficacy: A Comparative Study Towards Analysing Firmware-Based Rootkits. In: ARES 2018. Association for Computing Machinery; 2018; New York, NY, USA
9. Langner R. Stuxnet: Dissecting a Cyberwarfare Weapon. *IEEE Security Privacy* 2011; 9(3): 49-51. doi: 10.1109/MSP.2011.67
10. Feng Q, Prakash A, Yin H, Lin Z. MACE: High-Coverage and Robust Memory Analysis for Commodity Operating Systems. In: ACSAC '14. Association for Computing Machinery; 2014; New York, NY, USA: 196–205
11. Lashkari AH, Li B, Carrier TL, Kaur G. VolMemLyzer: Volatile Memory Analyzer for Malware Classification using Feature Engineering. In: ; 2021: 1-8
12. Yu J, Huang Q, Yian C. DroidScreening: a practical framework for real-world Android malware analysis. *Security and Communication Networks* 2016; 9(11): 1435–1449.
13. Murthaja M, Sahayanathan B, Munasinghe A, Uthayakumar D, Rupasinghe L, Senarathne A. An Automated Tool for Memory Forensics. In: ; 2019: 1-6
14. Henderson K, Eliassi-Rad T, Faloutsos C, et al. Metric Forensics: A Multi-Level Approach for Mining Volatile Graphs. In: KDD '10. Association for Computing Machinery; 2010; New York, NY, USA: 163–172
15. Kazim A, Almaeeni F, Ali SA, Iqbal F, Al-Hussaeni K. Memory Forensics: Recovering Chat Messages and Encryption Master Key. In: ; 2019: 58-64

16. Austin RD. Digital Forensics on the Cheap: Teaching Forensics Using Open Source Tools. In: InfoSecCD ’07. Association for Computing Machinery; 2007; New York, NY, USA

17. Hegarty R, Haggerty J. SlackStick: Signature-Based File Identification for Live Digital Forensics Examinations. In: ; 2015: 24-29

18. Poore J, Flores JC, Atkison T. Evolution of Digital Forensics in Virtualization by Using Virtual Machine Introspection. In: ACMSE ’13. Association for Computing Machinery; 2013; New York, NY, USA

19. Lee JT, Choi HK, Kim KJ. Gathering and Storage Technique Implementation of Volatility Memory Data for Real-Forensic. In: ; 2009: 1076-1079

20. Mohamed H, Koroniotis N, Moustafa N. Digital Forensics Based on Federated Learning in IoT Environment. In: ACSW ’23. Association for Computing Machinery; 2023; New York, NY, USA: 92–101

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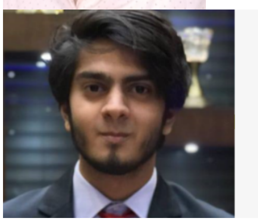

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