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## Research Article

**Keywords:** Fileless Malware, Intrusion Detection, Malware Analysis and Detection, Memory Forensics, Process Injection Attacks

**Posted Date:** August 23rd, 2023

**DOI:** <https://doi.org/10.21203/rs.3.rs-3252716/v1>

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**Additional Declarations:** No competing interests reported.

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# A New Approach for Detecting Process Injection Attacks Using Memory Analysis

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Received: date / Accepted: date

**Abstract** This paper introduces a new approach for examining and analyzing fileless malware artifacts in computer memory. The proposed approach offers the distinct advantage of conducting a comprehensive live analysis of memory without the need for periodic memory dumping. Once a new process arrives, log files are collected by monitoring the Event Tracing for Windows facility as well as listing the executables of the active process for violation detection. The proposed approach significantly reduces detection time and minimizes resource consumption by adopting parallel computing (programming), where the main software (Master) divides the work, organizes the process of searching for artifacts, and distributes tasks to several agents (Slaves). A dataset of 17411 malware samples is used in the assessment of the new approach. It provided satisfactory and reliable results in dealing with at least six different process injection techniques including classic DLL injection, reflective DLL injection, process hollowing, hook injection, registry modifications, and .NET DLL injection. The detection accuracy rate has reached 99.93% with a false-positive rate of 0.068%. Moreover, the accuracy was monitored in the case of launching several malwares using different process injection techniques simultaneously, and the detector was able to detect them efficiently. Also, it achieved a detection time with an average of 0.052 msec per detected malware.

**Keywords** Fileless Malware · Intrusion Detection · Malware Analysis and Detection · Memory Forensics · Process Injection Attacks

## 1 Introduction

Indications of a malware infection can be deduced from the device's impaired performance and decreased efficiency in

executing regular tasks, such as using applications or browsing the internet, as the malware excessively consumes system resources. The frequent appearance of intrusive advertisements also serves as an indicator of a malware infection. Moreover, there may be an unexplained disk space expansion, resulting in a significant loss of storage capacity [45]. Additionally, certain types of malware grant unauthorized access to the attacker, enabling them to download secondary infections onto the victim's computer, often accompanied by a noticeable surge in internet activity. A malware infection can be identified when the antivirus software suddenly ceases to function and becomes impossible to restart, indicating that the malware has directly targeted it. The inability to access files and applications on the computer is a common symptom of a ransomware infection.

Statistics [4] [5] indicate that the total number of malware of all kinds amounted to approximately 1,018 million samples by the 1st quarter of 2023, which displays the colossal rise in the total number of malware infections in recent years. Moreover, statistics show that 77% of malware in 2017 were fileless, and their rates are expected to increase dramatically by the end of 2023 [21]. Cyberattacks caused massive losses to many sectors, including business, services, and healthcare, as more than 90% of financial institutions reported being targeted by malware in 2020.

Traditional malware takes the form of deceptive (.exe) files stored on the hard disk, requiring execution to download payloads, and spread malicious code. Nowadays, attackers employ complicated disguises and obfuscation techniques to confound forensic analysis, including process injection attacks. To this end, these attacks inject malicious code into legitimate processes like svchost.exe, compromising their functionality and coercing the system to execute attacker commands. Process injection techniques enable the creation of fileless malware, residing solely in RAM without leaving traces on the hard disk [1]. Scripts, Windows Power-

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Shell, and remote attacks facilitate injecting code into legitimate processes, making such attacks resilient even if the original script is detected and removed. On the other hand, when security engineers receive suspicious activity alerts, they hope for traditional file-based malware, allowing easier tracing and identification of attack origins. Analyzing malware code aids in indicating targeted data and affected regions. In process injection attacks, attackers deceive victims by masquerading targeted processes as legitimate system processes in the task manager. While some antivirus programs detect malicious files, attackers persistently develop new methods to bypass protection protocols and firewalls [2].

Signature-based detection approach is widely used by commercial antivirus programs and firewalls to detect known malware. However, it falls short in detecting unknown malware as it requires constant updates to the signatures database [50]. Meanwhile, researchers are developing heuristic-based approaches to analyze known and unknown malware behavior. These methods often suffer from high false-positive rates and are time-consuming. In addition, reducing extracted features or API calls will significantly affect detection success rates [17], [39]. The heuristic-based approach proves effective in detecting attacks that involve direct malware files dropping into the system. Extracting API calls for process injection attack detection generates large amounts of data, making it challenging to differentiate between benign and malicious behaviors, especially when attackers create malicious libraries similar to legitimate ones.

The memory-based analysis is the present and future trend in the detection and analysis of malware due to the fact that memory is a rich source of valuable information [51]. Furthermore, Process injection attacks take place completely inside the memory as an active process without dropping the malware file on the hard drives [52]. According to Ponemon [24], process injection attacks increased by 47% in 2017, and successful attacks increased by 77%. As a result, it invokes forensic investigators to rely on memory analysis to detect this type of threat due to the difficulty of investigating elsewhere at a later time, as fileless malware takes advantage of applications (including Windows PowerShell, CMD, WScript, Etc.) that are used to launch scripts or PowerShell which contain command prompts to execute malicious commands in the memory, which antivirus programs will not detect it [14].

#### **The substantial contributions of this paper:**

1. Analyzing the distinct characteristics of fileless malware and the associated challenges in its detection.
2. Assessing the efficacy of various techniques and tools in identifying fileless malware, while highlighting their respective advantages and limitations.
3. Introducing a novel and robust investigative approach that enhances the detection of process injection attacks

by examining the memory artifacts of malware. This pioneering approach is based on a comprehensive analysis of the artifacts left behind, rather than solely focusing on the malware code.

4. Improving analysis and detection time by eliminating the need for memory dumps and instead utilizing live memory analysis and parallel computing.
5. Providing valuable insights into potential research directions for the future advancement of fileless malware detection.

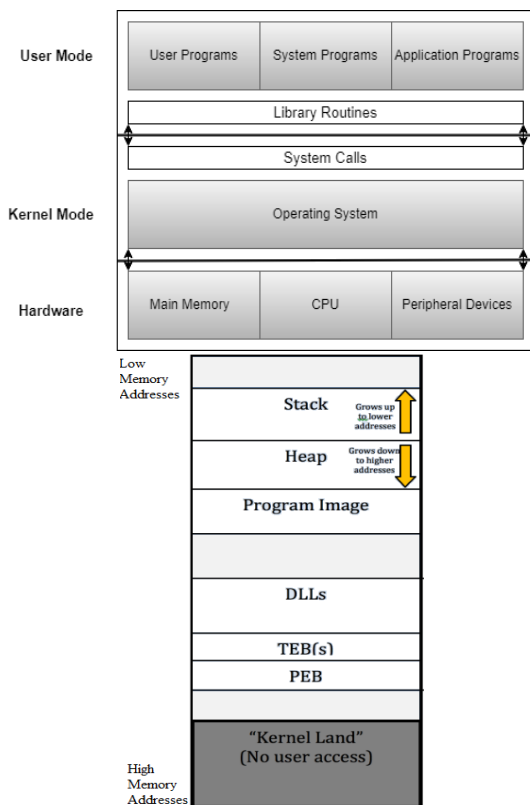
The rest of the paper is structured as follows. Section 2 clarifies the characteristics of fileless malware, memory analysis, and prevalent process injection attacks while summarizing related work. Section 3 expounds on the methodology employed in the proposed approach. Section 4 discusses the outcomes resulting from the performance analysis of the proposed approach, presenting comparisons with other works. Finally, Section 5 concludes the work and provides future directions.

## **2 Background and Related Work**

In modern operating systems, the CPU operates in two primary modes: user mode and kernel mode (also known as system mode). Kernel mode has unrestricted access to memory addresses and is commonly utilized for executing operating system functions. However, if a process crashes in this mode, it can lead to a system shutdown. On the other hand, in user mode, the CPU is unable to directly access hardware or memory. Instead, it requires special APIs to access these resources. On the other hand, user mode is where the majority of code execution takes place, and it offers recoverability and repairability in the event of interruptions, as it operates at the level of normal processes [58]. Figure 1(Top) illustrates the relationship between kernel mode and user mode, providing a visual representation of their distinct roles and privileges.

Each process is mapped into memory according to Figure 1(Bottom), and the operating system reserves the kernel region at the highest memory address for devices, paged/non-paged pool, system cache, etc., so that the user cannot access it. Any program stored in memory as a process is responsible for providing all the resources needed to run the program. Each process contains an executive process (`_EPROCESS`) that also resides in the kernel portion and contains process attributes and pointers to related data structures.

Moreover, each process in memory includes a Process Environment Block (PEB) that holds user-mode parameters specific to the active process, such as loaded modules (DLLs), the base address of the image (executable), the location of the heap, and environment variables. The PEB serves as one of the critical regions examined by the proposed approach



**Fig. 1** (Top) Kernel Mode and User Mode, (Bottom) Process Memory Layout

to detect process injection attacks. Additionally, each process consists of one or more threads that share the virtual address space and system resources assigned to the parent process but differ in priorities, exception handlers, and local storage. Similar to the PEB, each thread has a Thread Environment Block (TEB) containing context information for various Windows DLLs and the location for the exception handler list and image loader.

Dynamic Link Library (DLL) libraries/modules, also known as executable modules, occupy memory space utilized by programs for efficient code reuse and memory allocation. The Program Image section contains the *.text* section containing executable code/CPU instructions, the *.rsrc* section storing non-executable resources like icons, images, and strings, and the *.data* section holding the program's global data. Furthermore, the process employs the heap as a shared pool to store global variables, which is dynamically allocated in memory using functions like *malloc()*. The program or process manages heap memory allocation, ensuring its persistence until program termination or release <sup>1</sup>.

<sup>1</sup>

<sup>1</sup>To go deeper and read more about the memory management process, Virtual Address Descriptors (VAD)s, Handles, and PE files format, you can refer to the following references: [9], [11], [38], [53], [62].

## 2.1 Fileless Malware Flow

The transfer methods of traditional malware and fileless malware to a user's computer are almost similar, but they diverge in terms of storage, execution, and system file access. While traditional malware typically follows a certain flow, fileless malware injects itself directly into a process, altering the execution path. Figure 2 demonstrates the disparity in the flow between traditional malware and fileless malware.

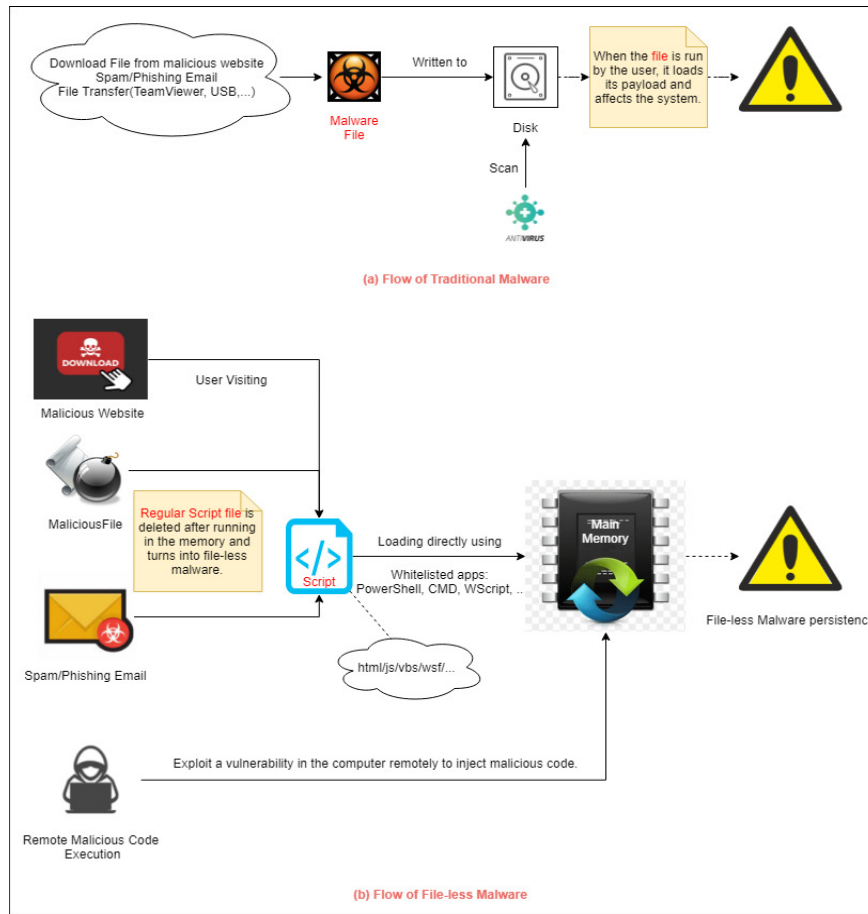
The primary distinction lies in the fact that traditional malware exists as an executable file (.exe) stored on the disk, which is activated only when the user initiates it, and hence executing its malicious actions. In contrast, process injection attacks or fileless malware exhibit the following key features:

- It does not contain any file that is dropped into the hard disk like in other types, but the malicious code is integrated into one of the system processes to appear as a legitimate process.
- It may require particular files to run in the memory (e.g., scripts, registers, shellcodes, etc.), although there is no direct file. This type of file is attractive to attackers because it can be encrypted or obfuscated to appear as a legitimate file for antivirus programs. Malware exploits whitelisted built-in applications such as Windows PowerShell, C-Script, and CMD to run these files, which contain commands to load malicious code directly into the memory.

Fileless malware is usually delivered by deceiving the victim using various social engineering methods, as shown in Figure 2. It should be noted that the attacker can exploit a vulnerability in the victim's computer to gain access and inject malicious code directly and remotely into the memory without using any file. This differs from traditional malware in that the traditional type will not do any harm unless the file on the disk is run. The malicious code can still load its payload as long as it runs inside the memory unless the computer is rebooted. For this reason, some expert attackers use the popular registry files, scheduled tasks, or Windows Management Instrumentation (WMI) to ensure that files containing the malicious code remain even after shutting down the computer.

## 2.2 Memory Analysis

Memory Analysis, a.k.a. memory forensics, is a crucial technique employed by forensic experts to investigate and identify malicious activities that may not be evident through hard drive analysis alone [3]. One of the main challenges in memory analysis is the volatile nature of memory, where data are stored temporarily and lost upon computer shutdown. To capture valuable information preceding an incident such as a



**Fig. 2** Flow of Traditional Malware vs. Fileless Malware

system crash or security breach, investigators typically create a snapshot of the computer's memory data called a memory dump. This becomes particularly significant in cases involving fileless malware, where threat data resides solely in the computer's memory, emphasizing the need for memory forensics to gain unique insights into the malware's behavior [52].

Live memory analysis involves examining the current state of memory and investigating active processes, user credentials, network information, executable files, etc. By intelligently utilizing live memory analysis to monitor suspicious activities, it becomes possible to eliminate fileless malware without the need for memory dumping, leading to improved analysis and detection time. The proposed approach primarily relies on two key factors: the arrival time of malware in memory and the specific memory regions that warrant investigation for identifying malware artifacts.

When investigating memory artifacts, one of the important things that should be considered is the memory-protection values assigned to the process executables and which give indications of suspected malicious code injection in the process. Table 1 explains the values we need to know in the investigation process.

**Table 1** Memory Protection Constants [37]

Constant/Value	
PAGE_EXECUTE '0x10'	Enables execute access to the committed region of pages. An attempt to write to the committed region results in an access violation.
PAGE_READWRITE '0x04'	Enables read-only or read/write access to the committed region of pages. If <i>Da Execution Prevention</i> is enabled, attempting to execute code in the committed region results in an access violation.
PAGE_EXECUTE_READWRITE '0x40'	Enables execute, read-only, or read/write access to the committed region of pages.
PAGE_EXECUTE_WRITECOPY '0x80'	Enables execute, read-only, or copy-on-write access to a mapped view of a file mapping object. An attempt to write to a committed copy-on-write page results in a private copy of the page being made for the process. The private page is marked as PAGE_EXECUTE_READWRITE, and the change is written to the new page.

As noticed from Table 1, every page created is assigned a memory protection value. The presence of some modules in the memory carrying the value *PAGE\_EXECUTE\_READWRITE* along with other pieces of evidence will help detect injection



processes. This will be explained in detail in the Methodology section.

### 2.3 Related Work

Process injection attacks involve injecting malicious code into active processes or creating a suspended process and injecting code into it [33]. Each process possesses its own private virtual memory space, consisting of kernel mode and user mode sections. Modifying the kernel, which impacts all system processes, is challenging and risky, as a single error can lead to a system-wide crash. Moreover, the kernel is protected and not easily modifiable. Consequently, attackers typically opt to inject malicious code into user mode, focusing on affecting the specifically targeted process. Figure 3 illustrates the prevalent techniques employed for injecting malicious code into processes.

	Shellcode Injection	Forcing A DLL To Be Loaded	Sha256
1. DLL Injection		X	07b8f25e7b536f5b6f686c12d04edc37e11347c8acd5c3f98a174723078c365
2. PE Injection	X		ce8d7590182db2e51372a4a04da0927a65b2640739f9ec01cfd6c143b1110da
3. Process Hollowing	X		ee72d803bf67df22526f50c7ab84d838efb2865c27aef1a61592b1c520d144
4. Thread Execution Hijacking	X		787cbc8a6d1bc58ea169e51e1ad029a637f22560660cc129ab8a099a745bd50e
5. Hook Injection		X	5d6ddb8458e5ab99f3e7d9a21490f4e5bc9808e18b9e20b6dc2c5b27927ba1
6. Registry Modification		X	9f10ec2786a10971eddc919a5e87a927c652e1655ddbbae72d376856d30fa27c
7. APC Injection		X	f74399cc0be275376dad23151e3d0c2e2a1c966e6db6a695a05ec1a30551c0ad
8. Shell Tray Window Injection	X		5e56a3c4d4c304ee6278df0b32afb62bd0dd01e2a9894ad007f4cc5f873ab5cf
9. Shim Injection		X	6d5048baf2c3bba85adc9ac5ff9db21c9a27d76003c4aa65f157978d7437a20
10. IAT and Inline Hooking	X	X	f827c92f8e832db3f09f47fe0dcaaf89b40c7064ab90833a1f418f2d1e75e8e

Fig. 3 Process Injection Techniques [27]

Analyzing and detecting malware is a highly complicated and delicate process. The interest in this field is continuously growing in both academia and industry. The approaches followed in detecting malware, particularly fileless malware, were divided into three main approaches: The Signature-Based approach, the Heuristic-Based approach, and the Memory Analysis approach. After reviewing the literature and extracting opinions and conclusions in detecting process injection attacks, the following points were summarized:

- The Signature-Based detection approach is the worst. Although highly accurate, it can be easily bypassed with this advanced type of attack because it relies only on signatures [39].

- The Heuristic-Based detection approach is better than its predecessor in dealing with known and unknown malware. However, it still suffers from a high rate of false-positive detections since it is not easy to distinguish between harmful and benign behaviors [12], [13], [55].
- Machine learning algorithms can be fooled by creating an amount of noise [25].
- Machine learning algorithms are only influential in detecting DLL injections and registry modifications [16], [18] [28], [43], [44].
- A Hybrid approach provides better results, but it is time-consuming as well as very complicated. Moreover, the false-positive detection rate was not improved sufficiently. It is a convenient approach to dealing with file-based malware [51].
- The Memory-Analysis approach is the optimal solution for investigating this type of attack because the memory is the container of all processes. Therefore, analyzing it greatly helps detect any malicious behavior 50.

In Table 2, the literature is summarized in terms of the approach used, and the attacks dealt with, the extracted results, and some remarks.

Works that followed the Memory-Analysis approach were at the forefront in terms of detection accuracy. Table 3 highlights some related works whose results were discussed and presented transparently and clearly according to the approach, accuracy, error rate, and false-positive rate.

### 3 Methodology

Generally, in the process injection, the legitimate process is compromised using one of the code injection techniques, through memory allocation, memory writing, forcing the process to execute something, or through a mechanism that forces the DLL to be loaded while the process starts. Using a memory forensic framework such as Volatility [57] gives valuable results in detecting injection techniques, but it will consume computer resources because it always needs to dump the memory, and besides, it may face a time hurdle, as mentioned in [54]. The new approach aimed to work on three main points: improving detection time, reducing resource consumption, and not neglecting high accuracy.

The new approach enhanced the detection of process injection attacks and reported the suspicious anomalies and heuristics by tracing the Windows events and relying on live memory analysis in a systematic way to extract and analyze artifacts that prove a violation occurred. The concept of parallel computing is used at the software level, where the main software (Master) plays the role of the organizer, breaking the large task into smaller tasks and distributing them to the other programs (Slaves).

**Table 2** Literature Summary

Reference	Detection Approach	Handled Attacks/Techniques	General Remarks
N/A	Signature-Based	N/A	It was not used to detect process injection attacks (fileless malware).
[12], [13]	Heuristic-Based	DLL Injection	<ul style="list-style-type: none"> <li>• Extract sensitive API calls.</li> <li>• Convenience in detecting file-based malware.</li> </ul>
[16], [18] [28], [43], [44]	Machine-Learning	DLL Injection, Registry Modifications	Relying on examining features (e.g., API function calls, imported DLLs, and registry activity).
[8]	Memory-Analysis	Reflective DLL Injection, Process Hollowing	<ul style="list-style-type: none"> <li>• Examine PTE for executable pages.</li> <li>• Use a forensic framework (Rekall) to analyze the extracted data.</li> </ul>
[59]	Memory-Analysis	DLL Injection	Comparing Executables and DLLs between memory and disk.
[6]	Memory-Analysis	DLL Injection, Process Hollowing	<ul style="list-style-type: none"> <li>• Identify anomalies.</li> <li>• Event timeline monitoring when using the CreateRemoteThread and LoadLibrary functions.</li> <li>• Need a forensic framework to analyze the extracted data.</li> </ul>
[15]	Memory-Analysis	DLL Injection	Bind each process to all DLLs it needs by examining IDT and EDT.
[54]	Memory-Analysis	DLL Injection, Hook Injection	A new technique for solving the timing problem based on monitoring suspicious API calls. (Trigger-Based).
[47]	Memory-Analysis	DLL Injection, Hook Injection	Incorporating static analysis and memory forensic analysis to reduce encryption and obfuscation.
[45]	Memory-Analysis	DLL Injection	Detect distributed code injection using the stack-tracking-based technique combined with a technique for finding threads that are waiting for synchronization objects.
[29]	Memory-Analysis	DLL Injection	<ul style="list-style-type: none"> <li>• Sending alerts about the presence of malware by monitoring and analyzing endpoints.</li> <li>and,</li> <li>• Involve the human interaction in the memory analysis to identify abnormal behaviors.</li> </ul>
[40], [41], [42]	Memory-Analysis	Process Hollowing	<ul style="list-style-type: none"> <li>• Parent-Child relationship.</li> <li>• Comparing PEB and VAD.</li> </ul>
[34]	Memory-Analysis	Process Hollowing	Use the fuzzy hash to calculate the process similarities in virtual memory.
[52]	Memory-Analysis	DLL Injection	Applied two use cases to prove changes in VAD and memory protections.
<b>Proposed Approach</b>	<b>Memory-Analysis</b>	<b>DLL Injection, Reflective DLL Injection, Process Hollowing, Hook Injection, Registry Modifications (AppINIT_DLLs), .NET DLL Injection</b>	<ul style="list-style-type: none"> <li>• <b>No memory dumps required. Waiting for a trigger (notification).</b></li> <li>• <b>Need not a forensic framework.</b></li> <li>• <b>Comprehensive analysis of memory artifacts (Suspicious Modules, Exports, BaseAddress, Threads, CallStack, Memory Regions, Registries, Hollowed Modules).</b></li> </ul>

**Table 3** Related Works Results

Reference	Detection Approach	Accuracy (%)	Error Rate (%)	FP Rate (%)
[12]	Heuristic	87.70	12.30	N/A
[44]	ML	96.00	4.00	0.922
[28]	ML	93.85	6.15	1.320
[47]	Memory	90.00	10.00	N/A
[6]	Memory	99.84	0.16	0.151
[29]	Memory	96.30	3.70	1.045

Data capturing is a critical investigation step, and any mistake or delay in the capture process may cause evidence to be lost. Considering that memory is one of the volatile components, we preferred to use the live memory analysis approach and combine it with the idea of using the trigger, which will be detailed later. As a result, the memory is examined as soon as the signal arrived. At the same time, there is no need to dump the memory in each analysis process, which improves the accuracy and time of detection jointly.

In addition to what is mentioned in the previous sections, most related research concentrated on analyzing the malware itself. Our new approach focused on investigating the artifacts of malicious behavior. Figure 4 is a structural diagram that lays out the main parts of the following methodology.

The dataset was extracted from several sources (explained in Section 4), reused, and compiled into a single project called Injection Tool. Furthermore, the entire project was tested before entering the memory analysis phase, as shown in Figure 4(Top). Figure 4(Bottom) shows the general idea of the proposed detection approach. In the beginning, all memory processes will be enumerated to retrieve the process ID for all processes and arranged to deal with each one separately. The importance of this critical step lies in systematically collecting details to be examined thoroughly, determining the corresponding parent process for each process, and identifying the suspicious one. The presence of a process that did not start from the parent process gives a sturdy indication of a violation.

Secondly, when the system gives a trigger to the master detector that there is a new event, including (creating process code, creating a thread, creating a file, image loading, registry operations, etc.) in the memory, the process enters the detector, and the log files are collected through monitoring Event Tracing for Windows (ETW) facility which runs at the kernel level that allows the user to trace the events of each process defined in the memory [10]. Moreover, the master detector lists all executable files for the process and operates the secondary detectors (slaves). The secondary detectors start scanning the memory for artifacts related to suspicious activities that indicate malicious code has been injected into the process. The idea behind using parallel computing is to distribute the load and reduce the consumption of computer resources since only the slave responsible for detecting the potential attack is running. Figure 5 shows the communication operation between the master detector and the slaves.

The master detector sorts the processes in the memory and lists all executable files for each process. Meanwhile, it also collects log files from tracking Windows events. Slaves start working sequentially based on a signal sent from the master detector when there is suspicious activity happens. Each one has the task of searching for artifacts related to the presence of suspicious anomalies in the place allocated for

the memory of the process that automatically holds an ID number given to it by the system, such as (Process Identifier (PID):10385). The master detector is also responsible for stopping the damage, organizing the results, and presenting the final report after receiving the response from the slaves.

#### **procedure** DETECTION

Scan the memory (live)

Enumerate all active processes

**while** New event in the memory **do**

Monitor the Event Tracing for Windows (ETW) facility

List all executable files for the process and collect log files

Run proper slave // The working principle of each slave is detailed in the methodology section

**end while**

Classify and organize the results

Produce the forensic report

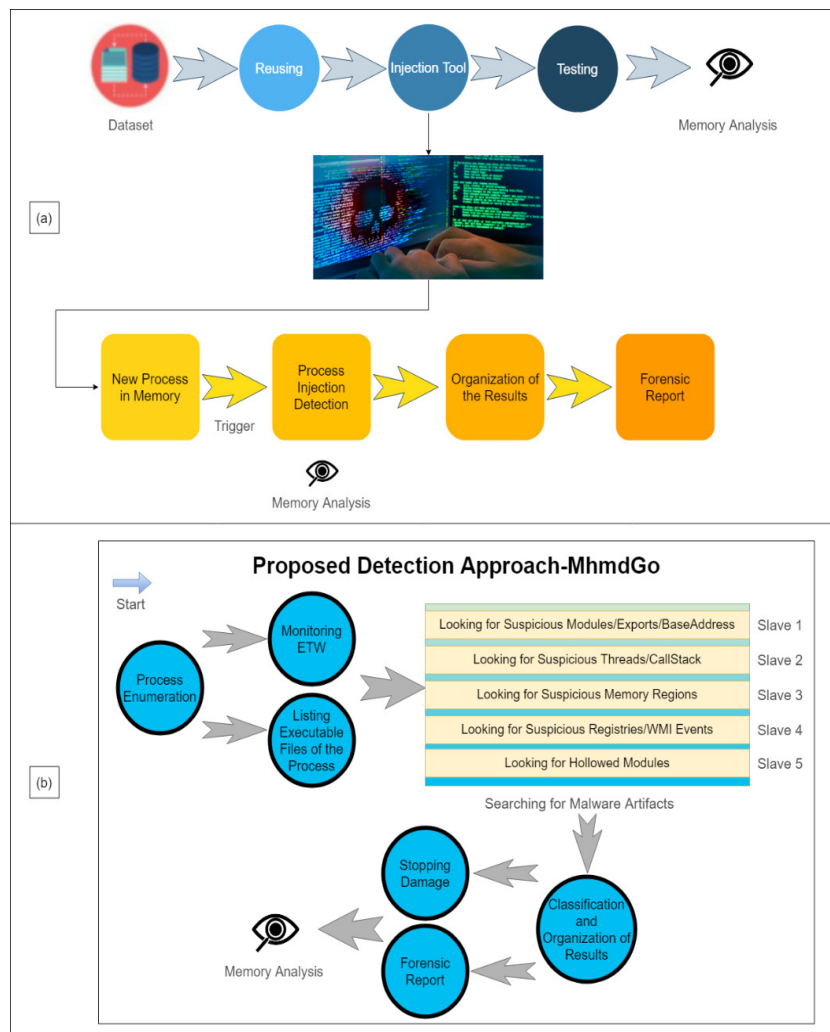
**end procedure**

### 3.1 Workflow of the Slaves

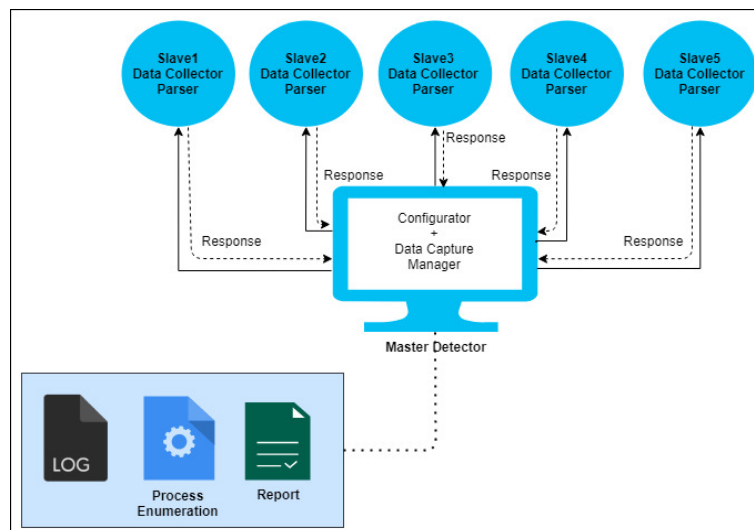
The five slaves work as follows:

1. **Slave1:** it is responsible for searching for suspicious modules in memory regions with the *PAGE\_EXECUTE\_READWRITE* memory protection flags, Read, Write, and Execute (RWX). The main module (.exe) cannot be specified with types private, not shared, or cannot be inherited by other processes, and memory protection flags, but it must always be memory-mapped, as shown in Figure 6. In other words, a memory-mapped file is a file that is physically located on the disk and has been Bit-by-Bit copied to memory at the specified location, so it is also important to monitor the base address and the full path of the module if it is from an unexpected location. This slave usually helps detect DLL injections but may identify as a good indicator that the process was hollowed. Furthermore, it looks for known bad suspicious exports/imports, such as *ReflectiveLoader()*. See Figure 7. A deeper look is taken at modules/exports, as shown in Figure 7. Unlike the remaining three, as shown in the upper right side of the figure, it is an unverified file from Windows, and the timestamp is different from the range of the rest and seems to have been created soon, as well as the difference in the form of the checksum.
2. **Slave 2:** examines memory protections for threads with RWX flags starting at the pointer of the thread base address. The process hosts a TLS callback (thread-local storage). When a new thread is created, it receives a notification like *CreateRemoteThread()* or *UserThreadStart()*. Here, the start address of the thread is checked





**Fig. 4** (Top) Top View Diagram, (Bottom) Workflow of the Proposed Approach



**Fig. 5** The relationship between master detector and slaves

The screenshot shows the 'Memory' tab of the Task Manager for the process 'notepad.exe'. The table lists memory regions with columns for Base address, Type, Size, and Protection. Two regions are circled in red:

- Normal:** Base address 0x020ba19c0000, Type Mapped, Size 641B, Protection RW.
- Suspicious:** Base address 0x020ba1f0000, Type Private, Size 1212B, Protection RW.

**Fig. 6** Mapped vs. Unmapped file

The screenshot displays the VirusShare interface with four file analysis results. The top row shows a file named 'Windows NT BASE API Client DLL' (Verified Microsoft Windows) with a 'Normal' status. The bottom row shows a file named 'Multiple Provider Router DLL' (Verified Microsoft Windows) with a 'Normal' status. The middle two rows show suspicious files: 'C:\Windows\System32\kernel32.dll' and 'C:\Windows\System32\user32.dll', both with a 'Suspicious' status. Each entry includes details like version, target machine, time stamp, image base, checksum, subsystem, and characteristics.

File	Status	Version	Target machine	Time stamp	Image base	Checksum	Subsystem	Subsystem version	Characteristics
Windows NT BASE API Client DLL (Verified Microsoft Windows)	Normal	10.0.19041.1023	AMD64	9:37:15 PM 10/14/2047	0x18000000	0x20546 (correct)	Windows CUI	10.0	Executable, DLL, Large address aware, High entropy VA, Dynamic t
C:\Windows\System32\kernel32.dll	Suspicious		AMD64	7:02:14 PM 3/16/2021	0x180000000	0x0 (real 0x2005)	Windows GUI	6.0	Executable, DLL, Large address aware, High entropy VA, Dynamic t
C:\Windows\System32\user32.dll	Suspicious		AMD64	7:40:03 AM 5/25/2069	0x180000000	0x20240 (correct)	Windows CUI	10.0	Executable, DLL, Large address aware, High entropy VA, Dynamic t
Multiple Provider Router DLL (Verified Microsoft Windows)	Normal	10.0.19041.1546	AMD64	5:09:30 PM 2/17/2048	0x180000000	0xc2287 (suspicious)	Windows CUI	10.0	Executable, DLL, Large address aware, High entropy VA, Dynamic t

### Fig. 7 Investigating suspicious exports/imports/modules

if *LoadLibrary()*, so it is a good indication that the process has been injected. Note Figure 8(Top), which shows that a new thread has been created and a start address is pointing to *LoadLibrary()*. TLS calls are the pre-entry executed subroutines, and there is a section in the PE header indicating where the TLS callback is [49]. Monitoring these calls helps in the early detection of process injections.

When a new thread is created, and it is not mapped to a location in the disk, but from type: private, this file is suspicious because it is an executable file with RWX privileges and is referred to as an unbacked executable file or floating code, so in the proposed approach we are also searching for unbacked symbols that indicate a suspicious thread has been found due to presence of malicious behavior in the process. The call stack of the suspicious thread is always unmapped, as shown in Figure 8(Bottom).

Slaves 1 and 2 play the leading role in detecting most DLL injections and hook installation attacks.

3. **Slave 3**: this slave looks for any suspicious regions in memory that contain the *PAGE\_EXECUTE\_READWRITE* memory protection RWX flags. Besides, it checks the PE files of these regions using Fuzzy PE matching, which is based on the principle of contrast with Boolean logic, which holds that the correct value of the variables is either 0 or 1, but what if the value is at the middle or near it? [63]. For example, the temperature can range between

TID	CPU	Cycles delta	Start address
15...			ntdll.dll!TPReleaseCleanupGroupMembers+0x450
6232			notepad.exe+0x23db0
188			kernel32.dll!LoadLibraryW

Stack - thread 188

14

user32.dll!DrawStateA+0x1e25

15

user32.dll!MessageBoxTimeoutW+0x1a7

16

user32.dll!MessageBoxW+0x4e

17

mreffectivpayload.dll!DllMain+0x4c

18

mreffectivpayload.dll!dllmain\_dispatch+0x8f

19

ntdll.dll!IRtActivateActivationContextUnsafeFast+0x11d

20

ntdll.dll!LdrGetProcedureAddressEx+0x2d7

21

ntdll.dll!LdrGetProcedureAddressEx+0x6a

22

ntdll.dll!RtSDispatchDv1+0xd07

23

ntdll.dll!RtGetFilePathName\_UserEx+0x231e

24

ntdll.dll!RtDooPathNameToNtPathName\_U+0xd4

25

ntdll.dll!LdrLoadDll+0xe4

26

KernelBase.dll!LoadLibraryExW+0x162

27

kernel32.dll!BaseThreadInitThunk+0x14

28

ntdll.dll!RtlUserThreadStart+0x21

Copy

Refresh

Close

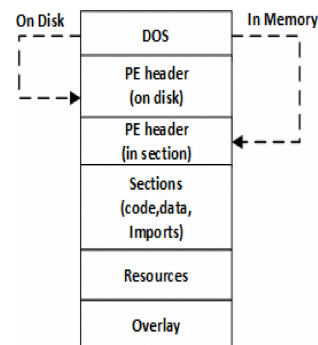
```

0  ntkrnlpa.exe!KiDeliverApc+0xb3
1  ntkrnlpa.exe!ZwYieldExecution+0x19a4
2  ntkrnlpa.exe!NtWaitForSingleObject+0x9a
3  ntkrnlpa.exe!KeReleaseInStackQueuedSpinLockFromDpc...
4  ntdll.dll!KiFastSystemCallRet (No unwind info)
5  mswsock.dll+0x5f9f (No unwind info)
6  ws2_32.dll!select+0xa7 (No unwind info)
7  0x3b05f8 (No unwind info)
8  0x9603d8 (No unwind info)
9  0x3b0519 (No unwind info)
10 kernel32.dll!GetModuleFileNameA+0x1b4 (No unwind info)

```

**Fig. 8** (Top) Investigating suspicious threads, (Bottom) Call stack of a suspicious thread

*extremely hot* with a value of 1 and *extremely cold* with a value of 0, where it can be called *warm*. This is called a decision based on partial truth. Figure 9 shows the structure of the PE File.



**Fig. 9** Portable executable (PE) file format [53]

As shown in Figure 9, a copy of the PE header is stored in a section in the memory region. In the proposed approach, slave 3 compares PE headers for suspicious memory regions that contain RWX flags with those stored on the disk. The comparison is based on the Levenshtein distance algorithm to calculate the difference between two sequences, where the distance is calculated by modifying at least a single character in terms of insertions, deletions, or substitutions that are capable of changing one word to another [64]. The slave identifies suspicious regions based on the differences between the two copies.



5. **Slave 5:** several found artifacts can be inferred that a process hollowing technique was used. This slave is doing the following:

- The legitimate process has a real system parent process, but the parent of the suspicious process is compromised. Figure 12 shows the difference between the two, as it appears in the *Parent* field for the suspicious process *non-existent process*. This slave searches for processes that do not have a parent process, more precisely, processes that do not start from the corresponding parent process that is terminated.

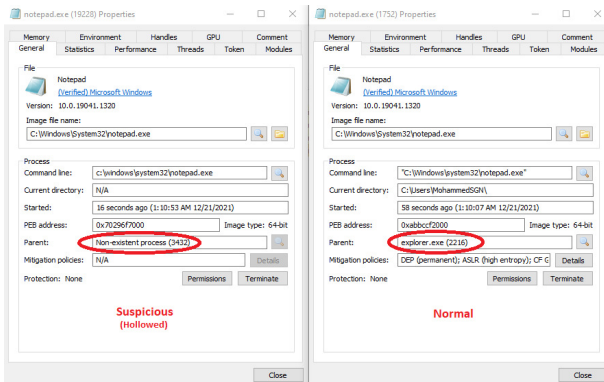


Fig. 12 Normal vs. Hollowed process

- Compares the differences between PEB (which is located in a process memory and contains the base address "Entry point" and full path of the executable file) and VAD (which is a data structure located in the kernel and holds information about allocating virtual address space for the process as well as the start & end address, initial protections, and the executable file path if was loaded). The difference in their values confirms that the process has been hollowed. Also, it compares code size and linker version.
- Checks the `CREATE_SUSPENDED` flag since the process hollowing technique relies on creating a new process in a suspended mode. It acts as a container for the malicious code and is then stored in the designated memory location after unmapped the legitimate process. If it is found that the *CreationProcess* Flag holds the value (0x00000004), then this is an indication of the intent to use the process hollowing technique [26]. This indicator is not strong enough because the suspended mode after hollowing the process is stopped by calling *ResumeThread()*, which removes the flag's value. However, it is not bad to monitor it constantly.

Note that Slave 1 can help detect process hollowing by searching suspicious memory protections. More clearly, if the process's VAD has memory protection `PAGE_EXECUTE_READWRITE` with RWX flags, this

is an indication that the process has been injected because it is expected that the loaded executable has memory protection `PAGE_EXECUTE_WRITECOPY`.

### 3.2 Classification Results

Each slave responds to the master detector after they have finished examining the artifacts of the suspicious activities that they are looking for with one of the two following responses:

- **First case, not suspicious:** Nothing was found. For example, suppose the process has not been injected with any malicious code, has not been hollowed out, or has already been injected, but the slave responsible for searching in the specified region could not detect the suspicious behavior. At the same time, the presence of suspicious threads or modules is being investigated; indeed, the responsible slave will reply that it did not find anything.
- **Second case, suspicious:** Assuming that the process was injected using create remote thread technique. Slave 2, which is responsible for searching for suspicious threads, will return the result to the master detector with investigation data proving it. Note that more than one slave can work in parallel to detect more than one type of injection.

Finally, the master detector collects and organizes the data and displays the final forensic report containing all the findings. The retrieved information includes suspicious process identifier PID, full path, number of threads, suspicious thread identifier (TID), discovered modules, base address, abnormal user permissions, integrity levels, Thread base priority, code size, unique thread token, Privileges, Logon Session/Type, and other investigation information related to the detected activity.

## 4 Results and Evaluation

This section discusses the results of experiments to evaluate the performance of the proposed approach in detecting process injection attacks. For this purpose, it provides an overview of the testing platform, dataset sources, and criteria used in the evaluation process.

### 4.1 Testing Environment Set-up

The virtualized environment provides various options for the computer user. It helps information systems administrators install updates and upgrades in a specific computer region without interfering with working on other programs that may be on a different operating system. It is also essential for software developers to easily write their programs



and navigate between the environments [32]. In the event of a failure, the operating system on which it is installed is treated as a program that can be repaired or reloaded by another alternative system quickly without the need to create an image of the hard disk [61]. This technology assisted in accomplishing many things efficiently and smoothly.

A safe and isolated virtual environment was prepared using VMware Workstation 15.5.1 Pro [56] to perform real-world process injection experiments, execute the proposed detection approach, and evaluate the findings. Table 4 presents the prepared virtual machine configurations.

The reason behind testing Windows 10 was that it is the most used among computer users. Moreover, several types of process injection attacks only target Windows operating systems [6]. Two separate projects were created using Microsoft Visual Studio 2019 to perform the injections and simulate the proposed approach. Furthermore, the dataset of the process injection attacks was extracted from several sources, reused, and organized under the "Injection Tool" project. Besides, the proposed approach was implemented in the "Detection Tool" project. For this purpose, the C/C++ was mainly used, and the C# in .NET DLL injection. More details in Appendix 7.

The ProcessHacker 2 program, which helps capture live images of the memory, was used to monitor the memory, list the running processes, compare the status of the legitimate and injected process executables (before, during, and after injection) with the results of the proposed approach, and record all required information.

The fantastic tool GitHub Copilot was used to build some code blocks to implement the proposed detection approach. This tool has been trained using artificial intelligence to help developers write their code quickly. It offers a wealth of examples, solutions, and suggestions in the form of individual lines and whole functions. It also converts comments into code. Besides, it does Autofill for repetitive code, and it helps a lot in testing the code. The tool was used as a good helper in constructing and implementing the proposed approach.

#### 4.1.1 Dataset Sources

In order to evaluate the proposed approach performance, the dataset was carefully selected from several trustworthy sources due to the difficulty of extracting them from a single source, given that each injection tactic is a separate complete project.

- For Classic DLL Injection, Reflective DLL Injection, Hook Injection, and Process Hollowing techniques. The experiments were conducted on the datasets that were extracted respectively from projects [7], [30], [23].

- Also, for Reflective DLL Injection, was extracted from the source [20], as he is the father and first developer of this technique.
- For attacks using (AppINIT\_DLLs, and .NET DLL Injection) injection techniques. The source was the Specialized Group (Red Teaming [48]) & [46].

## 4.2 Experiments and Discussion

This section exhibits the results of experiments conducted on the proposed approach compared to related works.

### 4.2.1 Evaluation Metrics

To assess the efficiency of the proposed approach in comparison with related work, the set of evaluation metrics listed in Table 5 was used:

$$Accuracy = \frac{Number\ of\ detected\ attacks}{Total\ number\ of\ attacks} * 100\% \quad (1)$$

$$Error = 1 - Accuracy \quad (2)$$

$$FPR = \frac{Number\ of\ falsed\ detected\ attacks}{Number\ of\ detected\ attacks} * 100\% \quad (3)$$

### 4.2.2 Scenarios and Assumptions

For the purposes of conducting injection experiments, the Notepad process located in the path `C:\Windows\notepad.exe` was used. It was assumed that the attacker already had a *meterpreter shell* on the victim's system and tried injecting the notepad system process using different injection techniques. The number of attacks was gradually increased to measure the performance of the proposed approach. Also, the virtual environment used was safe, well-checked, and not targeted by any attacks, and the VAD region was entirely emptied, which reduced the percentage of false positives.

It should be noted that the attacker's primary goal in using process injection techniques is to facilitate the launch of the malware payload in order to escalate the privileges and perform malicious activities such as evasion and data theft through one of the system processes. Processes other than Notepad can be injected (e.g., `lsass.exe`, `calc.exe`, `werfault.exe`, `svchost.exe`, `regsvr32.exe`, etc.).

For each type of attack, the memory was analyzed through several scenarios before injection, during DLL execution, after DLL termination, and after the injection process was terminated as follows:

- No injections.
- Injection on a single process using one technique.
- Injection on a single process using more than one technique simultaneously.
- Injection on multiple processes using one technique.
- Injection on multiple processes using more than one technique.



**Table 4** Virtual Environment Configurations

Operating System	Windows 10 Enterprise, version 20H2(10.0.19042.0) [36]
OS Type	64-bit Operating System
OS Architecture	x64-based processor
Processor	Intel(R) Core (TM) i5 – 3230M CPU @2.60GHz
Disk Space	40.00GB
Physical Memory (RAM)	4.00GB
Number of Cores	4
Number of Threads	8
Tools	Visual Studio 2019, ProcessHacker 2 [35], GitHub Copilot [22]

**Table 5** Evaluation Metrics

Metrics	Description
Number of handled techniques	Denotes the number of techniques that can be identified in their early stages.
Accuracy	It is calculated using equations (1), (2), and (3).
Time	Indicates the actual time spent to detect the injection in the process from notifying the trigger until printing the results.
Resources consumption	Denotes the amount of computer resource consumption during the analysis process.
Automated extracted records(artifacts)	The obtained forensic information as a result of the memory analysis and its importance in detecting the attack.

### 4.2.3 Results and Discussion

#### 1. Number of Handled Techniques:

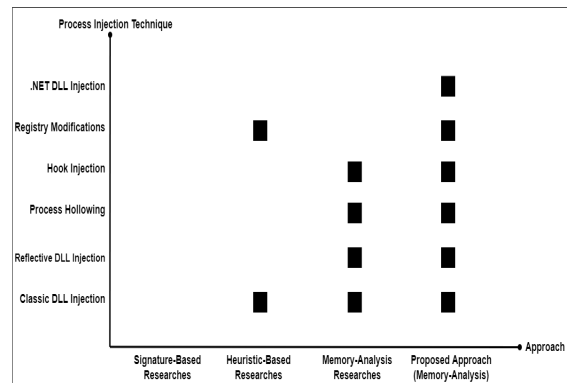
The proposed approach achieved satisfactory results in detecting process injection attacks compared to other works. Regarding the number of techniques that can be detected in their early stages, the approach has successfully dealt with six different techniques: Classic DLL Injection, Reflective DLL Injection, Process Hollowing, Hook Injection, Registry Modification (AppINIT\_DLLs), and .NET DLL Injection. It is expected to help detect more techniques with more work.

On the other hand, the Signature-Based approach did not report any research working on detecting this type of attack but rather file-based malware. Research results using the Heuristic-Based approach indicated its ability to detect some types of DLL injection attacks by extracting sensitive API calls. Moreover, machine learning research helped detect registry modifications.

Works that relied on memory analysis took turns detecting a higher number of process injection techniques. For example, [8] and [6] focused on DLL injection and process hollowing, while [47] on DLL Injection and Hook Installation, and others focused on one type, such as [29] on DLL Injection and [34] on process hollowing. What distinguished the proposed approach was that it focused on a greater number of techniques. Figure 13 illustrates the comparison.

#### 2. Accuracy and Time:

The detection accuracy of the proposed approach was fixed at 99.93% after testing 17411 malware samples using the different techniques discussed, and the average detection time was approximately 0.052 msec/attack. The

**Fig. 13** Comparison of the number of detected techniques

experiment was repeated 30 times in order to verify the results, and the average was calculated. Table 6 displays the final results of the experiments.

The plugins that were developed and tested in many related works using the popular open-source memory forensics framework *Volatility* were also tested on the same dataset, the number of attacks, scenarios, and conditions (FindDLLInj [6], Malfind [57] [52], Threadmap [?], and Hollowfind [41]). The proposed approach achieved the highest detection accuracy rate among them, in addition to the process injection techniques it can deal with. Tables 7 and 8 and Figure 14 shows the results of the comparison.

The experiment was also performed 30 times, and the average was calculated in order to have a fair comparison with the mentioned plugins in terms of accuracy and detection time.

**Table 6** Results of Experiments

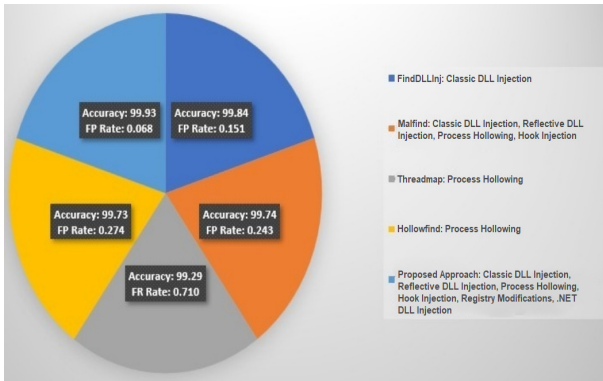
Number of Malware Samples	Number of Detected Malware	Accuracy (%)	Average Detection Time (msec)	Average Detection Time/Malware (msec)
1	1	100.0	0.73	0.730
10	10	100.0	1.14	0.114
50	50	100.0	2.91	0.058
100	100	100.0	5.30	0.053
500	500	100.0	26.18	0.052
750	750	100.0	38.49	0.051
1000	999	99.90	52.10	0.052
5000	4996	99.92	260.27	0.052
10000	9993	99.93	520.09	0.052
$\Sigma$ 17411	17399	99.93	910.74	0.052

**Table 7** Process injection techniques that can be handled compared with Volatility Plugins

Reference	Process Injection Techniques
FindDLLInj	Classic DLL Injection
Malfind	Classic DLL Injection, Reflective DLL Injection, Process Hollowing, Hook Injection
Threadmap	Process Hollowing
Hollowfind	Process Hollowing
Proposed Approach	Classic DLL Injection, Reflective DLL Injection, Process Hollowing, Hook Injection, Registry Modifications, .NET DLL Injection

**Table 8** Comparison of detection accuracy with Volatility Plugins

Reference	Accuracy (%)	Error Rate (%)	FP Rate (%)
FindDLLInj	99.84	0.16	0.151
Malfind	99.74	0.26	0.243
Threadmap	99.29	0.71	0.710
Hollowfind	99.73	0.27	0.274
Proposed Approach	99.93	0.07	0.068

**Fig. 14** A Comparison chart of detection accuracy with Volatility Plugins

As mentioned earlier, the works that followed the memory analysis approach fulfilled a high detection accuracy in general compared to their counterparts. The proposed approach greatly reduced the false-positive detection rate, as shown in Table 8.

Fortunately, the comprehensive proposed approach endured a modest false-positive rate of 0.068%. Sometimes it identified the Injection Tool used in the experiments as

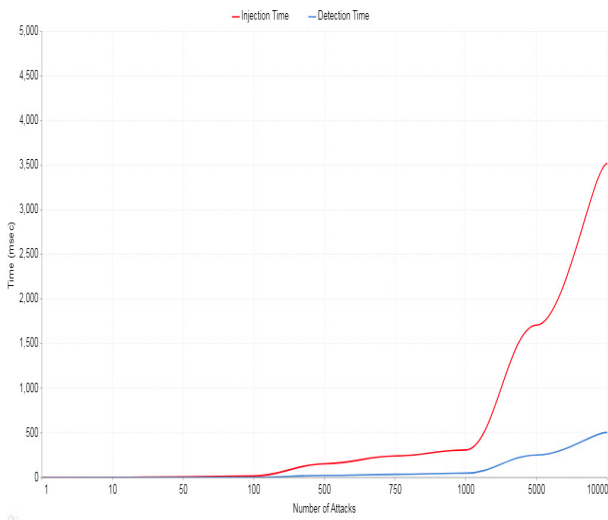
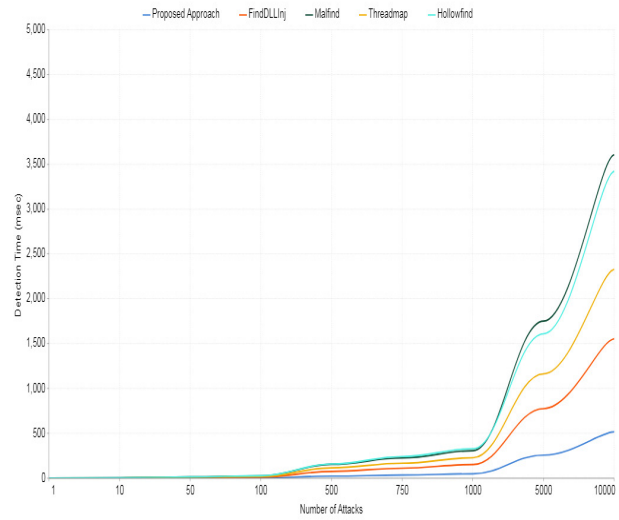
a threat, and this can be considered a reasonable thing because the project contains instructions to build and compile the malicious code. False-positive results may be encountered due to protected applications or some behaviorally erratic security programs that behave similarly to attacks to improve their detection, but this may make the detection of real threats more difficult.

We will endeavor to reduce it to as close to zero as possible in the future. Besides, the performance was monitored when attacks were executed using more than one technique simultaneously, and a successful detection rate of 99.91% was achieved.

The approach enhanced the detection and reduced the remediation time because it did not require a memory dump while not affecting the accuracy. Meanwhile, it was easy to implement and did not need a complex infrastructure. Table 9 and Figure 15 show the relationship between the injection time and detection time under the optimal conditions for the number of executed attacks. It can be noticed that the injection timeline had a gap in the form of an increase after the number of attacks exceeded 1000, but the detection line was not affected, as it kept increasing almost steadily. This means that the ap-

**Table 9** Relation between injection time and detection time (Optimal conditions)

Number of Malware Samples	Injection Time (msec)	Detection Time (msec)
1	1.01	0.68
10	2.94	1.13
50	11.07	2.82
100	20.91	5.18
500	157.14	25.98
750	244.62	38.09
1000	312.05	51.44
5000	1711.42	255.02
10000	3522.23	509.37

**Fig. 15** Comparison between detection time and injection time**Fig. 16** Comparison of detection time with Volatility Plugins

proach's performance was not affected by the increased number of attacks.

By monitoring the detection time on the same dataset used to test the performance of the proposed approach compared to Volatility plugins, it achieved a very short detection time compared to its counterparts. The difference can be seen in Table 10 and Figure 16.

Figure 16 shows a clear superiority of the proposed approach in terms of detection time. It fulfilled the best average detection time when the number of carried out attacks passed 10,000 with a stable increase in proportion to the increase in the number of attacks. Also, a sudden and unexplained increase in detection time for the Malfind plugin can be seen after increasing the number of attacks to more than 2000.

In the memory analysis, dumping memory is cumbersome and requires a lot of time, but many researchers such as [45] and [54] developed solutions that were slightly similar to the proposed approach, where they monitored some activities in the system. When suspicious behavior was noticed, the memory was dumped, and the resulting image was analyzed. Also, one of the suggested

solutions is to dump the memory every 30 seconds. As mentioned earlier, malware may execute and be cleaned up in a very short time.

The proposed approach addressed this dilemma in two ways. First, by monitoring the ETW to identify any suspicious behavior and adopting the parallel computing principle, which eliminates the need to dump the memory every period, thus, helping to enhance detection time and reduce resource consumption. As mentioned in section 3, each slave is responsible for searching for specific artifacts inside the memory. Table 11 binds each slave and the attacks it helped detect.

As seen from Table 11, most types of attacks were detected by more than one slave, and each slave contributed to the detection of more than one attack, which helped improve the accuracy and time of detection significantly.

### 3. The Forensic Report:

The produced forensic report contains valuable detailed forensic information about suspicious behavior detected inside the memory to locate the threat and prevent its impact. The report includes the suspicious process name, PID, process path, suspicious module, thread, etc. Tables

**Table 10** Comparison of detection time (msec) with Volatility Plugins

Number of Malware Samples	FindDLLInj	Malfind	Threadmap	Hollowfind	Proposed Approach
1	2.12	4.28	3.21	4.76	0.73
10	4.01	8.17	6.02	8.52	1.14
50	8.87	17.14	13.26	17.35	2.91
100	14.93	28.97	22.11	30.80	5.30
500	79.02	157.66	117.99	161.71	26.18
750	114.51	228.51	170.41	244.09	38.49
1000	155.60	309.92	231.41	331.82	52.10
5000	778.92	1754.51	1166.75	1613.04	260.27
10000	1556.11	3607.44	2329.07	3423.05	520.09

**Table 11** Slaves' responsibilities in the detected techniques

Slave Number	Process Injection Techniques
1	Classic DLL Injection, Reflective DLL Injection, Hook Injection
2	Classic DLL Injection, Reflective DLL Injection, .NET DLL Injection
3	Classic DLL Injection, Reflective (Shellcode) DLL Injection, .NET DLL Injection
4	Classic DLL Injection, Registry Modifications (Persistence)
5	Process Hollowing

12 and 13 present an example of two forensic reports resulting from the investigation process.

As shown in Tables 12 and 13. The proposed approach sought to produce a forensic report containing detailed information about the location of the threat in the memory, its effect, its type, and the escalated privileges. Figures 17, 18, 19, and 20 are examples of the forensic reports generated by (FindDLLInj, Malfind, Threadmap, Hollowfind) Volatility tool plugins.

Name	Explanation
Pid	6108
Description	Suspicious process notepad.exe
ImageFileName	notepad.exe
DLL	c:\users\jeuser\desktop\injectallthethings-master\x64\release\dlmain.dll
DllLoadTime	2018-06-04 14:23:27 (UTC+0000)
TimeDifference from previously loaded Dll in sec	113
ThreadPid	6108
ThreadTid	5304
ThreadLoadTime	2018-06-04 14:23:27 UTC+0000
ThreadExitTime	
ThreadHandlePid	5248

**Fig. 17** Example of FindDLLInj forensic report [6]

## 5 Conclusion and Future Work

This work covered process injection attacks based on file-less malware. The differences between them and traditional malware are flow methods and consequences. Reviewing the literature concluded that memory analysis is the optimal approach for analyzing and detecting these types of attacks considering that the malicious code is executed en-

```

root@kali:~/share/volatility# python vol.py -f /media/sf_Shared/KALI/WSEdge - Win18_preview-aaa27c2-onrepNew.vmem --profile=Win18x64_14393
malfind -p 7284
Volatility Foundation Volatility Framework 2.6
Process: notepad.exe Pid: 7284 Address: 0x7f6f3b70000
Vad Tag: Vad5 Protection: PAGE_EXECUTE_READWRITE
Flags: PrivateMemory: 1, Protection: 6

0x7f6f3b70000 4d 5a 90 00 03 00 00 04 00 00 ff ff 00 00 KZL.....
0x7f6f3b70010 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....@.....
0x7f6f3b70020 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....
0x7f6f3b70030 00 00 00 00 00 00 00 00 00 00 00 00 00 00 .....

0xf3b70000 4d DEC EBP
0xf3b70001 5a POP EDI
0xf3b70002 90 NOP
0xf3b70003 0003 ADD [EBX], AL
0xf3b70004 0000 ADD [EAX], AL
0xf3b70005 0000 ADD [EAX-EAX], AL
0xf3b70006 0000 ADD [EAX], AL
0xf3b70007 ff DB BXT
0xf3b70008 ff00 INC DWORD [EAX]
0xf3b70009 0000000000000000 ADD [EAX+0x0], BH
0xf3b7000a 0000 ADD [EAX], AL
0xf3b7000b 004000 ADD [EAX+0x0], AL
0xf3b7000c 0000 ADD [EAX], AL
0xf3b7000d 0000 ADD [EAX], AL
0xf3b7000e 0000 ADD [EAX], AL
0xf3b7000f 0000 ADD [EAX], AL
0xf3b70010 0000 ADD [EAX], AL
0xf3b70011 0000 ADD [EAX], AL
0xf3b70012 0000 ADD [EAX], AL
0xf3b70013 0000 ADD [EAX], AL
0xf3b70014 0000 ADD [EAX], AL
0xf3b70015 0000 ADD [EAX], AL
0xf3b70016 0000 ADD [EAX], AL
0xf3b70017 004000 ADD [EAX+0x0], AL
0xf3b70018 0000 ADD [EAX], AL
0xf3b70019 0000 ADD [EAX], AL
0xf3b7001a 0000 ADD [EAX], AL
0xf3b7001b 0000 ADD [EAX], AL
0xf3b7001c 0000 ADD [EAX], AL
0xf3b7001d 0000 ADD [EAX], AL
0xf3b7001e 0000 ADD [EAX], AL
0xf3b7001f 0000 ADD [EAX], AL
0xf3b70020 0000 ADD [EAX], AL
0xf3b70021 0000 ADD [EAX], AL
0xf3b70022 0000 ADD [EAX], AL
0xf3b70023 0000 ADD [EAX], AL
0xf3b70024 0000 ADD [EAX], AL
0xf3b70025 0000 ADD [EAX], AL
0xf3b70026 0000 ADD [EAX], AL
0xf3b70027 0000 ADD [EAX], AL
0xf3b70028 0000 ADD [EAX], AL
0xf3b70029 0000 ADD [EAX], AL
0xf3b7002a 0000 ADD [EAX], AL
0xf3b7002b 0000 ADD [EAX], AL
0xf3b7002c 0000 ADD [EAX], AL
0xf3b7002d 0000 ADD [EAX], AL
0xf3b7002e 0000 ADD [EAX], AL
0xf3b7002f 0000 ADD [EAX], AL
0xf3b70030 0000 ADD [EAX], AL
0xf3b70031 0000 ADD [EAX], AL
0xf3b70032 0000 ADD [EAX], AL
0xf3b70033 0000 ADD [EAX], AL
0xf3b70034 0000 ADD [EAX], AL
0xf3b70035 0000 ADD [EAX], AL
0xf3b70036 0000 ADD [EAX], AL
0xf3b70037 0000 ADD [EAX], AL
0xf3b70038 0000 ADD [EAX], AL
0xf3b70039 0000 ADD [EAX], AL
0xf3b7003a 0000 OR [EAX], AL
0xf3b7003b 0001 OR [EAX], AL
0xf3b7003c 0000 ADD [EAX], AL
0xf3b7003d 0000 ADD [EAX], AL

```

**Fig. 18** Example of Malfind forensic report

```

root@kali:~/share/volatility# python vol.py -f /media/sf_Shared/KALI/WSEdge - Win18_preview-aaa27c2-onrepNew.vmem --profile=Win18x64_14393
threadmap
Volatility Foundation Volatility Framework 2.6

Thread Map Information:

Traceback (most recent call last):
  File "vol.py", line 192, in <module>
    main()
  File "vol.py", line 183, in main
    command.execute()
  File "/usr/lib/python2.7/dist-packages/volatility/commands.py", line 147, in execute
    func(outfd, data)
  File "/usr/lib/python2.7/dist-packages/volatility/plugins/threadmap.py", line 537, in render_text
    suspicious_thread_in_process in data:
  File "/usr/lib/python2.7/dist-packages/volatility/plugins/threadmap.py", line 498, in calculate
    if vad.u.VadFlags.VadType.v != IMAGE_FILE_TYPE:
  File "/usr/lib/python2.7/dist-packages/volatility/obj.py", line 751, in _getattr__
    return self.mgetattr()
  File "/usr/lib/python2.7/dist-packages/volatility/obj.py", line 733, in m
    raise AttributeError("Struct (%s) has no member (%s).format(self.obj_name, attr))
AttributeError: Struct _MMWAD has no member u

```

**Fig. 19** Example of Threadmap forensic report

**Table 12** Example of Classic DLL Injection detection report

Data Name	Value
Process ID	6332
Process Name	Notepad.exe
Process Path	C:\windows\system32\notepad.exe
Process Command Line	"C:\windows\system32\notepad.exe"
Process Number of Threads	3
Suspicious Module Name	createremotethread.dll
Suspicious Module Path	C:\Users\MohammedSGN\Desktop\...\createremotethread.dll
Suspicious Thread ID	11772
Suspicious Thread Priority	0
Suspicious Thread Base Address	0x000002AA59860037
Suspicious Memory Protection	PAGE_EXECUTE_READWRITE
Suspicious Memory Alloc. Protection	PAGE_EXECUTE_READWRITE
Suspicious Memory State	MEM_COMMIT
Suspicious Memory Type	MEM_PRIVATE
TOKEN_USER.User-Sid	DESKTOP-B90A38T\MohammedSGN
Attributes	0x00000000
TOKEN_OWNER.Owner-Sid	DESKTOP-B90A38T\MohammedSGN
TOKEN_PRIMARY_GROUP...	DESKTOP-B90A38T\MohammedSGN
TOKEN_TYPE	Token Primary
...	...
Number of Detected Attacks	1
Detection Time	0.738 seconds

**Table 13** Example of Process Hollowing detection report

Data Name	Value
Process ID	11964
Process Name	Notepad.exe
Process Path	C:\windows\system32\notepad.exe
Process Command Line	"C:\windows\system32\notepad.exe"
Process Number of Threads	1
Suspicious Module Name	processhollowing.exe
Suspicious Module Path	C:\Users\MohammedSGN\Desktop\...\processhollowing.exe
Image Size on Disk	0x00000000000038100
Image Size on Memory	0x0000000000001D000
Headers Size on Disk	0x0000000000000600
Headers Size on Memory	0x0000000000000600
DLL Characteristics on Disk	0x000000000000D280
DLL Characteristics on Memory	0x00000000000008280
Imports Size on Disk	0x000000000000001E
Imports Size on Memory	0x0000000000000012
Sections Size on Disk	0x0000000000000010
Sections Size on Memory	0x0000000000000010
Number of Detected Attacks	1
Detection Time	0.987 seconds

```

root@kali:~/share/volatility# python vol.py -f "/media/sf_Shared/KALI/MSEdge - Win10_preview-eaaa27c2-onreplNew.vmem" --profile=Win10x64_14393
hollowfind
Volatility Foundation Volatility Framework 2.6
Traceback (most recent call last):
  File "vol.py", line 192, in <module>
    main()
  File "vol.py", line 183, in main
    command.execute()
  File "/usr/lib/python2.7/dist-packages/volatility/commands.py", line 147, in execute
    func(outfd, data)
  File "/usr/lib/python2.7/dist-packages/volatility/plugins/hollowfind.py", line 286, in render_text
    for (hol_proc_peb_info, hol_proc_vad_info, hol_pid, hol_type, similar_procs, parent_proc_info) in data:
  File "/usr/lib/python2.7/dist-packages/volatility/plugins/hollowfind.py", line 179, in calculate
    self.update_proc_peb_info(pdata)
  File "/usr/lib/python2.7/dist-packages/volatility/plugins/hollowfind.py", line 50, in update_proc_peb_info
    self.proc_peb_info.extend((str(proc_cmd_line),
UnboundLocalError: local variable 'proc_cmd_line' referenced before assignment

```

**Fig. 20** Example of Hollowfind forensic report

tirely through an active process in the memory. Works that adopted the memory analysis approach fulfilled better results in terms of detection accuracy and false-positive detection rate compared to those that depended on the Signature-Based approach or Heuristic-Based approach.

The proposed approach introduced new methods to perform a comprehensive live analysis of memory artifacts and generate evidence of the presence of malicious code without dumping the memory. Moreover, the new approach helped reduce resource consumption and significantly decreased detection and remediation time by adopting the parallel com-



puting principle. The performance of the proposed approach was tested and assessed on a reliable dataset, and the results were compared with related works according to the appropriate evaluation metrics. The new approach achieved the highest successful detection rate of 99.93% and the lowest false-positive detection rate of 0.068%.

Definitely, the threats cannot be stopped forever, but their effects can be greatly reduced with continuous solutions development. This research is a starting point to develop new methods to detect a greater number of process injection attacks by searching for the artifacts left by malware instead of analyzing malware itself while ensuring detection accuracy and reducing the false-positive detection rate as much as possible. Also, it is important to implement and test the proposed approach on other operating systems such as Linux, Mac, and mobile operating systems, taking into consideration the different technologies, memory layout, privileges, etc. It would also be interesting to consider semi-fileless malware that generates unreadable registry keys using non-ASCII characters that contain obfuscated malicious code, where the malicious code is stored on the disk as registry keys, but at the same time does not take the traditional form of malware.

## 6 Declarations

- No funds, grants, or other support was received for the submitted work.
- The authors have no relevant financial or non-financial interests to disclose.
- The authors assert that there is no potential conflicts of interest.
- The datasets analyzed during the current study are available in the Github, Red Teaming, and MITRE repositories, and are explicitly cited in 4.1.1.
- The code developed to implement the new approach can be requested from the corresponding author upon reasonable request.

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## 7 Main Tools

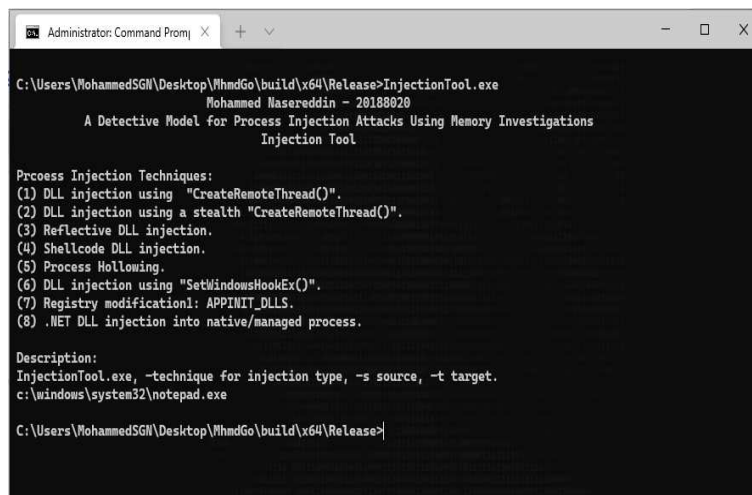
Three main tools were programmed as follows: The first is an integrated project called "Injection Tool" for process in-

jection attacks, where each injection technique is a complete project with sequential steps and lines of code extracted from its sources.

Secondly, the "Automated Injection Tool" was developed to implement a larger number of attacks at the same time, in addition to implementing more than one type of attack at the

same time. It works the same as the Manual Injection Tool but with more options.

Third, C/C++ was used to develop the "Automated Detection Tool," which enumerates the processes and organizes the work of the slaves used in detection.



```

Administrator: Command Promj
C:\Users\MohammedSGN\Desktop\MhmdGo\build\x64\Release>InjectionTool.exe
Mohammed Nasereddin - 20180820
A Detective Model for Process Injection Attacks Using Memory Investigations
Injection Tool

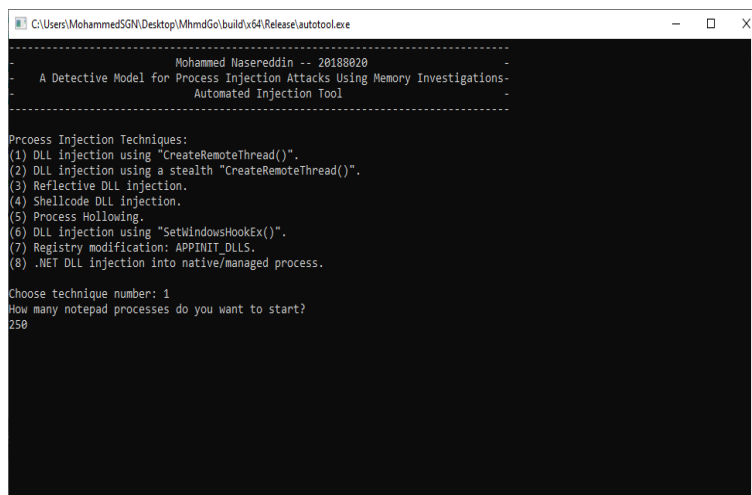
Process Injection Techniques:
(1) DLL injection using "CreateRemoteThread()".
(2) DLL injection using a stealth "CreateRemoteThread()".
(3) Reflective DLL injection.
(4) Shellcode DLL injection.
(5) Process Hollowing.
(6) DLL injection using "SetWindowsHookEx()".
(7) Registry modification: APPINIT_DLLS.
(8) .NET DLL injection into native/managed process.

Description:
InjectionTool.exe, -technique for injection type, -s source, -t target.
c:\windows\system32\notepad.exe

C:\Users\MohammedSGN\Desktop\MhmdGo\build\x64\Release>

```

Fig. 21 Manual Injection Tool



```

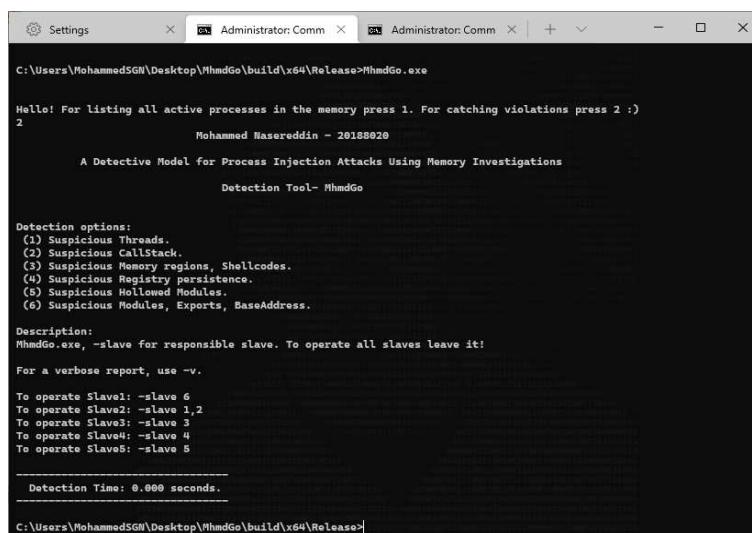
C:\Users\MohammedSGN\Desktop\MhmdGo\build\x64\Release>autotool.exe
Mohammed Nasereddin -- 20180820
A Detective Model for Process Injection Attacks Using Memory Investigations-
Automated Injection Tool

Process Injection Techniques:
(1) DLL injection using "CreateRemoteThread()".
(2) DLL injection using a stealth "CreateRemoteThread()".
(3) Reflective DLL injection.
(4) Shellcode DLL injection.
(5) Process Hollowing.
(6) DLL injection using "SetWindowsHookEx()".
(7) Registry modification: APPINIT_DLLS.
(8) .NET DLL injection into native/managed process.

Choose technique number: 1
How many notepad processes do you want to start?
250

```

Fig. 22 Automated Injection Tool



```

Settings Administrator: Comm Administrator: Comm
C:\Users\MohammedSGN\Desktop\MhmdGo\build\x64\Release>MhmdGo.exe

Hello! For listing all active processes in the memory press 1. For catching violations press 2 :)
2
Mohammed Nasereddin - 20180820
A Detective Model for Process Injection Attacks Using Memory Investigations
Detection Tool- MhmdGo

Detection options:
(1) Suspicious Threads.
(2) Suspicious Callstack.
(3) Suspicious Memory regions, Shellcodes.
(4) Suspicious Registry persistence.
(5) Suspicious Hollowed Modules.
(6) Suspicious Modules, Exports, BaseAddress.

Description:
MhmdGo.exe, -slave for responsible slave. To operate all slaves leave it!
For a verbose report, use -v.

To operate Slave1: -slave 6
To operate Slave2: -slave 1,2
To operate Slave3: -slave 3
To operate Slave4: -slave 4
To operate Slave5: -slave 8

Detection Time: 0.000 seconds.

C:\Users\MohammedSGN\Desktop\MhmdGo\build\x64\Release>

```

Fig. 23 Automated Detection Tool