Extraction of Forensically Sensitive Information from Windows Physical Memory

By

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Extraction of forensically sensitive information from windows physical memory

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ABSTRACT

Forensic analysis of physical memory is gaining good attention from experts in the community especially after recent development of valuable tools and techniques. Investigators find it very helpful to seize physical memory contents and perform post-incident analysis of this potential evidence. Most of the research carried out focus on enumerating processes and threads by accessing memory resident objects. To collect case-sensitive information from the extracted memory content, the existing techniques usually rely on string matching. The most important contribution of the paper is a new technique for extracting sensitive information from physical memory. The technique is based on analyzing the call stack and the security sensitive APIs. It allows extracting sensitive information that cannot be extracted by string matching-based techniques. In addition, the paper leverages string matching to get a more reliable technique for analyzing and extracting what we called ''application/protocol fingerprints''. The proposed techniques and their implementation target the machines running under the Windows XP (SP1, SP2) operating system.

1. Introduction

The digital forensics community feels the urge to rapidly develop tools and techniques for capturing and analyzing physical memory content. This is motivated by the fact that physical memory may contain evidence that may not be found in any other source of digital evidence. The expected techniques will facilitate the investigation and analysis process and allow to reach more reliable conclusions.

There has been a good attention paid to acquisition and analysis of physical memory in the past years. However, while the acquisition techniques have acceptable degree of automation (Sarmoria and Chapin, 2005; Schatz, 2007; Carrier and Grand, 2004; Guidance Software; Suiche), analyzing the extracted memory content is usually manual, case-dependent, and relies on the investigator expertise (Zhao and Cao, 2009). In addition memory analysis techniques are limited to searching predefined strings or series of bytes.

This paper explains the importance of the information that exists in memory for forensic investigators and introduces new approaches for the extraction and analysis of this information. The contribution of the paper is mainly threefold: a) the most important one is a stack function call analysis method for extracting sensitive information, b) a systematic method for finding fingerprints of applications and protocols and using them to extract sensitive data, and c) a set of most common patterns for fingerprint analysis.

The remainder of this paper is organized as follows. Section 2 gives an overview of the related work. Section 3 provides a short background on memory management in Windows. Section 4 investigates the sensitive information inside windows memory. Section 5 is dedicated to application

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fingerprints identification and extraction. Section 6 details our approach for extracting sensitive information via call stack analysis. Finally, Section 7 concludes the paper and presents our future work.

2. Related work

There has been a good attention paid to acquisition and analysis of physical memory in the past years. For physical memory acquisition, Sarmoria and Chapin (2005) presented a runtime monitor to log read and write operations in memory-mapped files. Also the *BodySnatcher* tool (Schatz, 2007) injects an independent acquisition operating system into the potentially compromised host operating system kernel. The injected operating system takes snapshots of the host operating system memory. These two techniques rely on preparing systems before any incident happens. The method of Carrier and Grand (2004) is among the few other hardware-based memory acquisition techniques that alter memory contents as little as possible. This method uses a PCI expansion card to dump the memory content to an external device.

Various software-based tools have been recently developed for memory acquisition. We can cite *WinEn* from Guidance Software which is part of EnCase Forensic version 6.11 and above (Guidance Software). This tool produces memory images with three different levels of compression that contain headers specific to EnCase which make the image hard to understand by other analysis tools. The ManTech's Memory DD (MDD) (ManTech International Corporation) and Win32dd (Suiche) tools generate raw images of memory contents.

MemParser (Betz, 2005) is a tool that loads a Windows memory dump, generates a list of active processes, and extracts information relating to a specific process. This tool is also able to dump the memory area allocated to a specific process. KnTList (Garner and R-Mora, 2007) is a command line tool that reconstructs the virtual address space of the system process and other processes. *PTFinder* is a proof-of-concept implementation (Schuster, 2006) providing the capability of revealing hidden and terminated processes and threads. In Carvey and Kleiman (2007), a tool developed in perl script, reads a windows crash dump file, finds structures, and translates virtual addresses (and pointers) to physical offsets within the dump file itself. This tool is available in the book'd DVD toolkit of Carvey and Kleiman (2007).

In Zhao and Cao (2009), the authors have been able to extract some sensitive information from memory such as user IDs or passwords through various means such as using *hiberfil.sys* (the hibernation file that contains a memory dump when the operating system hibernates), Windows crash dump file, pagefile, and direct memory access. Although, this work proposed to look for interesting patterns in the memory that may lead to sensitive information, it did not give valuable hints on how to obtain these patterns. This method is covered in the SubSection 5.2. One important contribution of our paper is leveraging this work by explaining the process of obtaining fingerprints and how it can be automated.

Memoryze (Mandiant) and the Volatility Framework (Volatile Systems) are two other memory analysis tools that are capable of detailed analysis. While Memoryze produces its own image of the memory, Volatility performs the analysis on a variety of memory image formats such as Crash dump, Hibernate dump, and DD format. The two tools are able to list OS kernel modules, loaded DLL modules, drivers, open network sockets, and open files.

In a recently published research (Hejazi et al., 2008), S. M. Hejazi et al. paid attention to an important aspect of memory contents and proposed new methods for the extraction of executable and data files from physical memory images. Finally, A.R. Arasteh and M. Debbabi, in their paper (Arasteh and Debbabi, 2007), have paid attention to the analysis of memory stack and building a partial execution path for open processes. This has been achieved through combinational use of stack residues and process code extracted from memory contents. Section 6 of our paper augments this work by analyzing stack frames and extracting the sensitive parameters passed to functions.

3. Windows memory and stack map

Windows operating system uses the virtual memory concept to manage the system memory. In this context, the set of all the virtual addresses that are available to a process is called its virtual address space (Microsoft Corporation, 2005). This virtual address space is divided into two ranges: user space and system space. User space is the range of addresses that user-mode processes, processes specific data and user-mode DLL files are mapped into. System space, a.k.a., kernel space is the range of addresses in which the operating system resides and is only accessible to kernel-mode code. This restriction provides a security level preventing process threads from reading/writing data from/to the memory space not belonging to them.

Almost all the implementations of virtual memory, divide the virtual address space into blocks of adjacent virtual addresses, called *pages*. These pages can be either active, and hence reside in the physical memory, or inactive and maybe stored (paged) to the disk. In modern programming, dynamic memory allocation enables programs to allocate memory space at runtime (Deitel and Deitel, 2007). One method of dynamic memory allocation is memory pool allocation. Windows, as well as many other operating systems, provide pools of paged and non-paged memory that can be allocated to processes. A pool memory is a memory space, not necessarily contiguous, that is available to processes and their threads. Another method of allocating dynamic memory is stack allocation in which data is added and removed in a Last-In-First-Out manner. The kernel stack is a limited memory space holding local variables of functions and parameters passed to them.

4. Sensitive information in memory

Memory is like a game table for all running applications and processes. To be part of the game, data should be brought to this table. This data includes, but is not limited to, executable code of the processes, data files accessed by processes, URLs accessed via a web browser, usernames, and passwords. The

data resident in memory can be classified into the following categories:

1) Metadata
2) Files
3) Sensitive data
4) Case irrelevant data

Metadata is the data that explains or clarifies other data. Examples of metadata existing in memory include the number and names of running and terminated processes, start and end time (if the process has ended) for each process, names of the files they had accessed, and the DLL files they had used for the course of execution. Metadata can be very important from forensic point of view and may yield conclusive evidence.

Files are of great significance when conducting an investigation. Files contain valuable information such as images and other sensitive data. We have classified files into two categories; *executable files* and *data files*. Finding pieces of log files or documents can be extremely helpful since they may contain reliable evidence.

By *sensitive data* we mean pieces of data such as usernames, passwords, encryption keys, or URLs that have been used by users during their interaction with the machine under investigation. In many cases, these pieces of information are not parts of files and are passed as parameters to functions inside processes' code. Regardless of the adopted parameters passing mechanism, parameters are stored in memory locations before being used by the application. In many cases these memory locations will not be overwritten after use. Finding these kinds of data in memory can help the investigator to reach the right person, right time, or right physical location.

In any investigative case, there are some data that seem to be *irrelevant* to the case. Irrelevant data include pieces of data that do not hold any clues about what an investigator is searching for such as operating system specific data, or data that fall outside of times of interest (Beebe and Clark, 2007; Cohen, 2006). By vast increases in volume of memory modules and complexity of the applications, the volume of irrelevant data also increases. In addition, sensitivity of investigation time in forensic cases adds importance to eliminating irrelevant data from analysis.

When investigating and analyzing the memory, finding possible correlation between gathered evidence can add credibility to conclusions or even refute assumptions. Thus, detailed and precise information obtained from memory can be very important when analyzing the correlation between evidence. For instance, a deleted record in a log file can be acquired from memory as a part of an extracted log file. Likewise, metadata acquired from process information can be used to reject a manipulated log file. On the other hand, assume that a suspect has entered a username and a password in a Secure Socket Layer (SSL) enabled web page. This information can be extracted from memory and afterwards be used for analyzing other collected evidence.

To find and extract sensitive information from memory we offer two main approaches that can be used. Forthcoming sections provide details of these methods.

5. Application/protocol fingerprint analysis

This section introduces our approach for Application/Protocol fingerprint analysis. The first subsection explains the conventional string search method and the second subsection describes our fingerprint analysis approach.

5.1. *Search for pre-known strings*

In many cases, when investigators are looking for data related to a specific subject such as a person's name, address, or friends, they know what they are looking for in memory. For example finding a specific name or memory address can be accomplished by searching for *ASCII* or *Unicode* strings in the memory dump using applications such as WinHex (X-Ways Software Technology, 2009) which facilitates string and binary search in a binary file. Fig. 1 shows how an investigator may end up a Yahoo account username when searching for a pre-known last name. The main advantages of this method are easiness and availability of tools and in some cases, accuracy and relativeness of results. Existence of unknown sensitive data in the memory is the main important limitation of this method. Indeed, in many cases, there are names, addresses, user IDs, and strings that are not present in the list the investigator is looking for while they are present in the memory dump and are of paramount importance for the investigative case.

5.2. *Search for fingerprints*

While processing sensitive input data, application functions usually use constants that at some point of time are brought to memory. We call these constants that precede or succeed sensitive information "*fingerprints*". Fingerprints, being string constants or series of non-string bytes may have constant distances from sensitive pieces of information in memory. In order to shed some light on this concept, consider the piece of code below:

```
if (encrypted){
   dlg.SetPasswordMode(true);
   if (dlg.ShowModal() != wxID_OK)
    return false;
   if (! Send(_T("password" + dlg.GetValue())))
    return false;
   if (GetReply(reply) != success)
    return false;

}
```

This code is a part of FileZilla (Filezilla, 2008) project code (can be found in optionspage_connection_sftp.cpp, filezilla 3.2.0). Line 6 shows that the string "password" concatenated with another string value (seems to be a password received from a dialog box) is passed to a function as a parameter. When this value is about to be processed, it should exists somewhere in the memory. Assuming that the user has entered the string "my_secret" in the dialog box, the string "password my_secret" can be found in the memory. It is obvious that the string

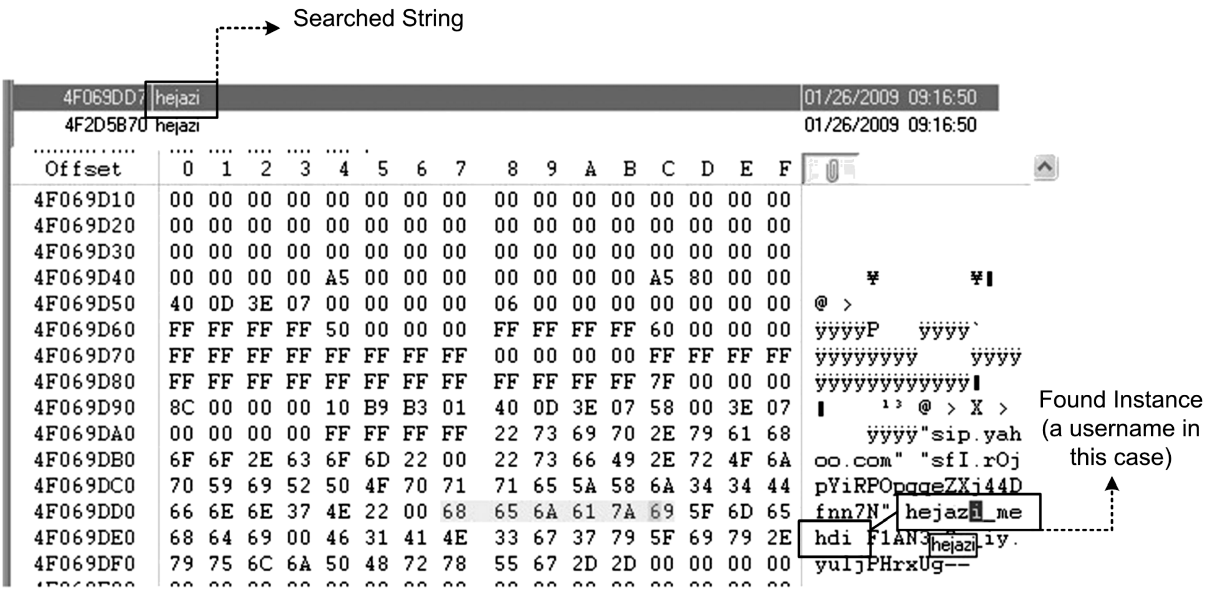

Fig. 1 – Sensitive information found while searching for strings in memory contents.

"password" can be considered as a prefix of actual values of passwords presented by this piece of code.

In order to help investigators, we have identified a set of common applications that deal with sensitive information and classified them into several categories. By examining the source code or the compiled code of the applications (in case the application is not open source or we do not have access to the source code) we looked for the portions of the code dealing with sensitive information. We also used disassembler applications such as IDA Pro (Hex Rays, 2009) and PE.Explorer (Heaventools Software, 2009) to analyze the compiled code. When traced, we examined the code for possible existing strings (or sequence of bytes) that precede or succeed sensitive information. Since there are a limited number of commonly used applications in these categories, we could build a set of these *fingerprints*. This set contains fingerprints used in applications such as FTP clients, SSH/Telnet clients, messengers, and web browsers. Table 1 demonstrates some fingerprints present in our set of patterns.

6. Call stack analysis

In this section, we explain our method for investigating memory stack to extract forensically sensitive information. Firstly, we explain some background information and after shedding light on building blocks of this work, we present our approach.

6.1. *Call stack and stack frames*

A call stack is a (Last-In First-Out) structure used by the operating system to store information about the active subroutines of each program. This structure is also known as execution stack, control stack, or simply stack. The stack is used to: pass arguments from a *caller* subroutine to a *called* subroutine, store local variables of subroutines and store the address to which the control of the program should be transferred after a subroutine finishes (*return address*). Stacks are usually allocated to each thread of process execution, thus each thread has its own stack.

A *stack frame* is the block of information stored on the call stack as a result of a subroutine call. A stack frame, in general, contains all the information required to save and restore the state of a procedure. These frames, each associated with one procedure call, contains arguments (parameters) passed to the function, local variables and the return address. Physically, a function's stack frame is the chunk of memory between the addresses contained in the ESP register (the stack pointer) and the EBP register (the frame pointer or base pointer in Intel terminology). The most important registers that interfere in call instructions are the following:

- EIP: Instruction Pointer holds the address of the instruction, which will be executed by the CPU.
- EBP: Base Pointer or also known as frame pointer is used to allow access to function arguments and local variables in the stack frame.
- ESP: Stack Pointer always points to the top of the stack that is the last element used on the stack.

Table 1 – Some fingerprints and their corresponding applications.

	Application	Fingerprint
1	Yahoo Web Mail	*passwd*
2	Yahoo Web Mail	*login*
3	Horde Web Mail	*imapuser* =
4	Horde Web Mail	*pass* =
5	WinSCP	*password 00 00 00 08*[a]
6	Yahoo Messenger	*buddies* = (*[b]

a A string followed by hexadecimal values.
b List of friends present in Yahoo messenger.

6.2. Function parameters extraction

Functions inside a program, process its inputs and many times pass their variables as inputs between each other. Some of the inputs passed to functions in a program are just indexes or local variables, which are not of forensic interest, but others can indicate names, dates, e-mail addresses, web site addresses, usernames or passwords. In the following subsections, we show how we can use information present on call stack of each process and the executable image of that process to track sensitive function calls and find arguments passed to these functions.

6.2.1. Parameter extraction methodology

In order to extract functions' parameters, we will analyze the stack of a process (or more precisely, a stack of an execution thread) to find out which functions have been called and afterwards, if they are dealing with sensitive data, we will try to locate and extract the arguments passed to them. These arguments are usually stored in the process space and can be accessed using their virtual addresses, which are in turn, stored on the stack. For this purpose, we have to analyze the signature of the designated functions and based on the number and type of their arguments, look for them (pointers to arguments or the arguments themselves) on the stack.

Windows is based on a layered architecture that prevents user applications from accessing sensitive system components. In this architecture, applications transfer the execution to DLL files in order to be able to communicate with executive services in kernel mode and finally to hardware. There are numerous programs that deal with forensically important and sensitive data, such as web browsers, FTP clients and many more. On the other hand, there are a limited number of DLL files that handle requests of these programs. Therefore, as Fig. 2 explains, it is reasonable that instead of digging into all applications, we focus on those DLL files that handle sensitive requests.

When an executable or a DLL calls a function in another DLL, a call instruction in the program will be executed. Suppose an FTP client application wants to establish a connection to an FTP server. This program takes the username, password, the address of the FTP server, and other sensitive information as inputs. Then it stores this information in different locations in process address space and passes them as arguments to functions inside application's code. According to the layered architecture of Windows, application's functions at the end, call some functions in different DLL files and arguments are passed to these newly called functions as well. Therefore, if the function FTPConnect(user, pass, uri) in the FTP client application calls the function connect(s: TSocket; var name: TSockAddr; namelen: Integer) in WSOCK32.DLL, then the structure of the stack for that thread of execution would look like Fig. 3.

This way, we can use DLL files as bottlenecks and look for important function calls in specific DLLs that can be found on the stack. Our approach is based on the following steps:

1) Locating the stack memory associated with each thread.
2) Locating stack frames for each function call on the stack.
3) Understanding the function that has been called.
4) Reconstructing the Import Address Table (IAT) of the process image.
5) Comparing each called function with the list of forensically sensitive functions.
6) Extracting the parameters that are present in the stack.

The rest of this section is dedicated to explain each of the above steps.

6.2.2. Locating the stack of each thread

As described in Section 3, Windows uses internal data structures to manage memory operations and objects in the memory. To reach threads and their stacks we start with the important *EPROCESS* block. The *EPROCESS* block, contains a *KPROCESS* structure, also known as PCB (Process Control Block), a kernel structure that contains information about scheduling of process threads. The *KPROCESS* block, under the name of "*ThreadListHead*" maintains the starting address of an array (*LIST_ENTRY*) at the offset 0x050. Each entry of this array, in turn, keeps the starting address of *KTHREAD* structures, each of which represents a thread of execution for the

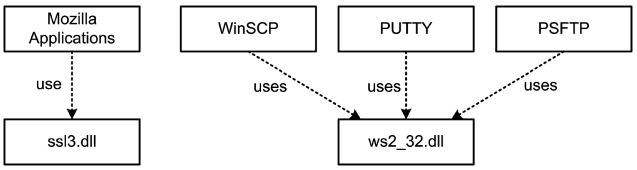

Fig. 2 – Many applications use common DLLs.

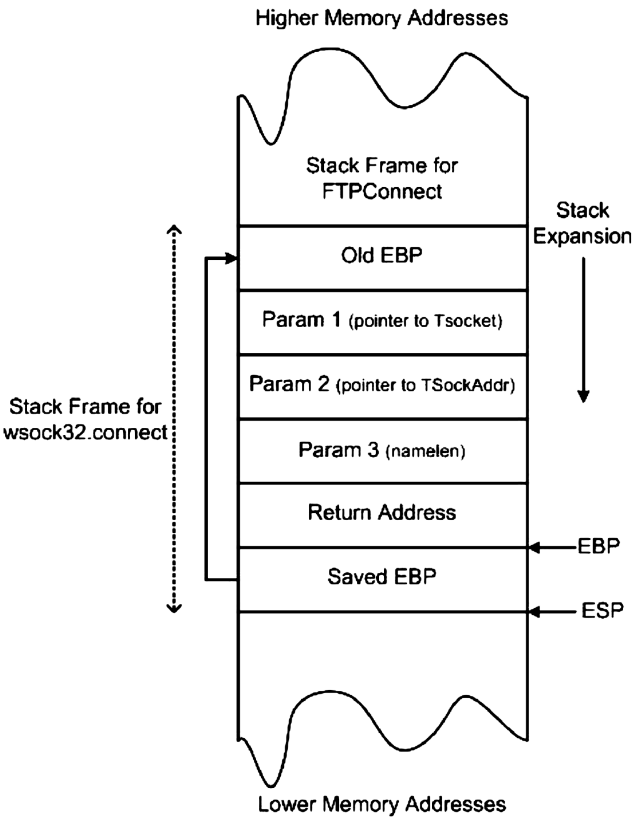

Fig. 3 – Stack structure during function calls.

current process. *KTHREAD*, is the kernel representation of a thread that contains information about thread scheduling. The main interesting fields of this structure are the following:

- *StackLimit* at offset 0x01c,
- *KernelStack* at offset 0x028 and
- *StackBase* at offset 0x168

These information provide the maximum size of the stack, current value of the *stack pointer*, and the starting address of the stack expansion respectively. By knowing these values and translating them to physical addresses, we can reach the area in the memory image that corresponds to each stack. In this approach, we would not limit the area of searching to the space between the *StackBase* and the *Stack Pointer*, because there might be some inactive stack frames below the address that *Stack Pointer* points to (stack residues). These stack frames, represent previous function calls (those functions that have returned). Therefore we will do our experiments on the whole memory space between the *StackBase* and the *StackLimit*. Fig. 4 shows stacks of different processes' threads inside the process address space. After locating each stack, we start to parse its content.

6.2.3. *Locating the stack frame of each function call*

To investigate the stack frame of each called function, we have to identify the boundaries of each stack frame. As stated above in this section, when a function is called, the return address for the called function is saved on the stack. This return address is actually the address of the instruction which comes right after the *call* instruction. In other words, if the address of the *call* instruction is n, and the length of the *call* instruction is l, then the return address will be: $retAddress = n + l$. Based on this fact, we will read each 4 bytes on the stack and assume that what is read, is a return address (*retAddress*). If this assumption is true, then at l bytes before this address (inside the code segment) we should find a *call* instruction, where l is the length of a *call* instruction. Hence, if what we find at address $retAddress - l$ is a *call* instruction, then our first assumption is true, and what we had read from the stack would be a return address. Fig. 4 demonstrates how stack frames can be associated with function calls inside the code and therefore distinguished.

6.2.4. *Finding out the target function of a function call*

Since we are trying to find forensically important function calls, we will focus on functions imported from common *Application Programming Interfaces* (API) rather than functions that are specific to an application. For instance, while analyzing the stack of Internet Explorer process, we prefer to look for functions imported and called from Secure Socket Layer (SSL)/Transport Layer Security (TLS) APIs instead of those functions inside Microsoft Internet Explorer that directly implement SSL API. Each imported DLL function is mapped to a physical address in the memory. To find a return address, we reach a *call* instruction in the code of the executable. By looking deeper at a call instruction we will see that this instruction is always followed by the address of the called module. This address can be in different modes of addressing depending on the type of the call instruction. This address can be an immediate value, a general-purpose register, or a memory location. Since *Near Call* instructions are calls to procedures within the current code segment, and we are looking for calls to imported procedure (which are definitely not in the current segment) we will only look for *Far Call* instructions. By finding the address of the called procedure (immediate value or memory location) we will locate the function which corresponds to the current stack frame.

6.2.5. *Reconstructing the import address table (IAT) of the process image*

While processing information about each process, we will make a list of imported functions for each imported DLL file declared by the process. This information can be obtained from Import Address Table (IAT) which is simply a lookup table used when the application calls a Windows API function. IAT stores memory locations of the corresponding library functions. By traversing this table, we can find all the Windows API functions that are imported by this process and can be possibly used during the course of execution of the process. Fig. 5 shows the name of imported DLL file ADVAPI32.dll and names of the functions in this DLL file that are imported by a process (ftp.exe) inside a memory image.

6.2.6. *Comparing called functions with sensitive functions*

As explained earlier in this section, not all the called functions carry sensitive information. For example, the *WSACleanup* function imported from *ws2_32.dll* (Windows Socket 2 API) calls the Winsock 2 DLL (24), a functionality that does not provide us with direct forensically important information. On the contrary, the *getaddrinfo* function, from the same DLL file, provides protocol-independent translation from an ANSI host name to an address, which can give us sensitive information such as a host name. Thus, in order to filter called functions based on their sensitivity, we have to prepare a list of API functions that are more important for investigators. To achieve this, we studied common APIs that may process forensically sensitive information such as:

- OpenSLL, SSL/TLS APIs
- Network Security Services (NSS) (25)
- Microsoft Networking and Windows Security APIs (including Windows socket API)
- Microsoft CryptoAPI (Cryptography application programming interface)

Table 2 presents examples of functions that we have been looking for during our experiments. We have also traced some functions such as *WriteFile* which writes data to the specified file or input/output (I/O) device and is exported from *kernel32.dll*. Although *kernel32.dll* is not a part of security or networking APIs and is widely used by different applications, *WriteFile* is used to write sensitive information to a socket (a specific type of I/O device).

6.2.7. *Extracting parameters*

Except very small-size parameters, most of the parameters (including strings) are passed to functions as pointers to memory locations where the actual values of the parameters

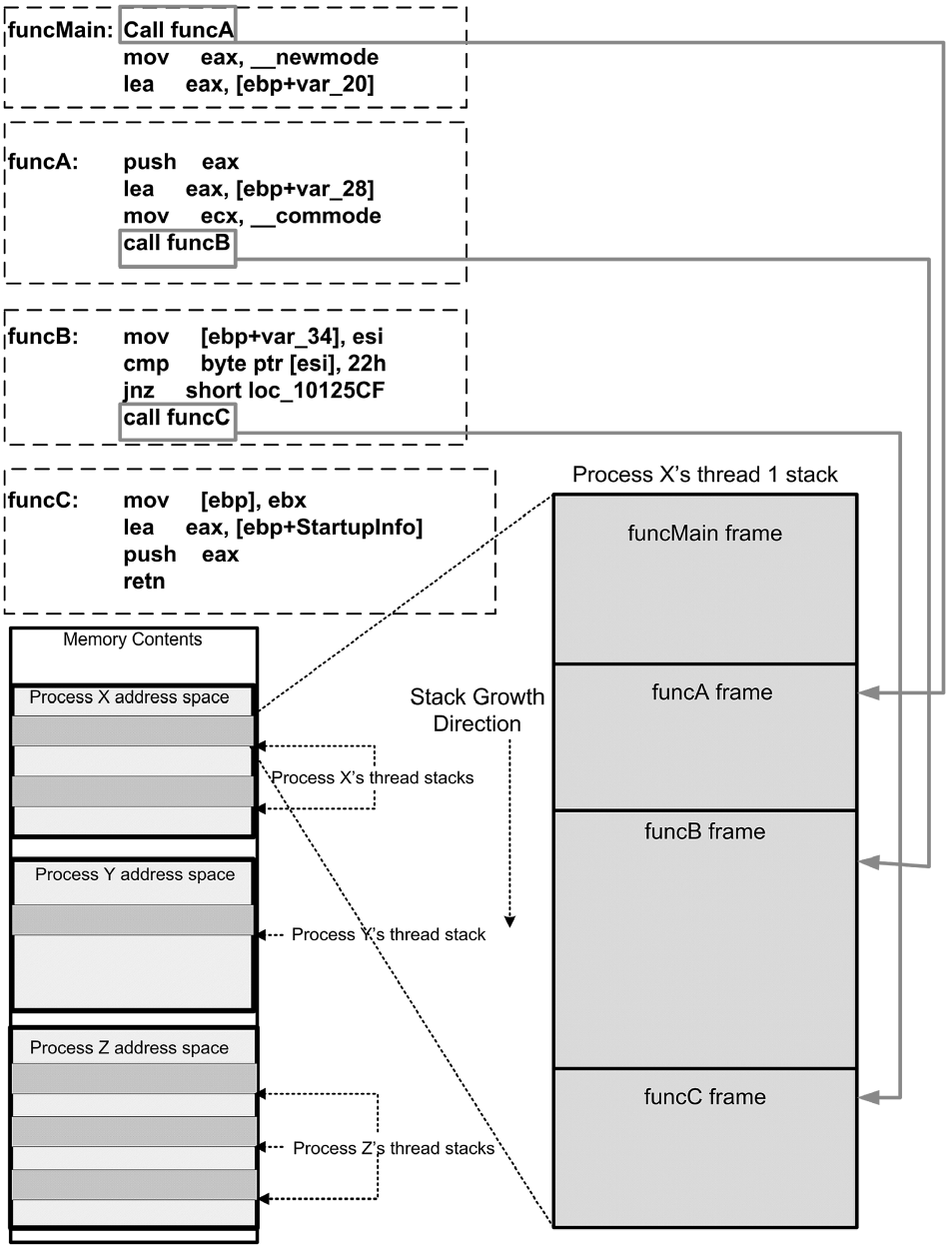

Fig. 4 – Finding thread stacks and the corresponding stack frames.

reside. These pointers are stored on the stack (as a part of the call stack frame). The order of the parameters in the stack frame is the same as the order of the parameters passed to the function. Thus, in order to locate a parameter in the memory, we have to extract the pointer to that parameter from the stack frame and follow that pointer to reach the desired memory location. Now we need to know how many bytes to read and how to interpret the read bytes. Should we read 4 bytes and interpret them as an integer number or should we read 16 bytes and interpret them as a 16-character string? In order to solve this issue along with the issue of the order of the parameters, we have to know the signature of the function that we are investigating: The number, type, and order of the parameters. This is what the stack analysis module expects from the user.

6.2.8. *Case study*

Using the explained method, we have been able to identify and extract sensitive information from a memory image that cannot be accessed using the other analysis methods. We have implemented this method as a part of our memory analysis plug-in which in turn is a part of our Digital Forensics Framework. The mentioned plug-in, takes a DD-style (Manual page for dd command, 2009) image of the memory and starts analyzing it. After initial parsing of kernel data structures, it performs the stack analysis searching for forensically sensitive pieces of information. The investigator can add signatures of custom functions to search for in XML format and the tool will report found function calls and their sensitive extracted parameters in XML format as well. For instance, we extracted an FTP account username that was used during an FTP

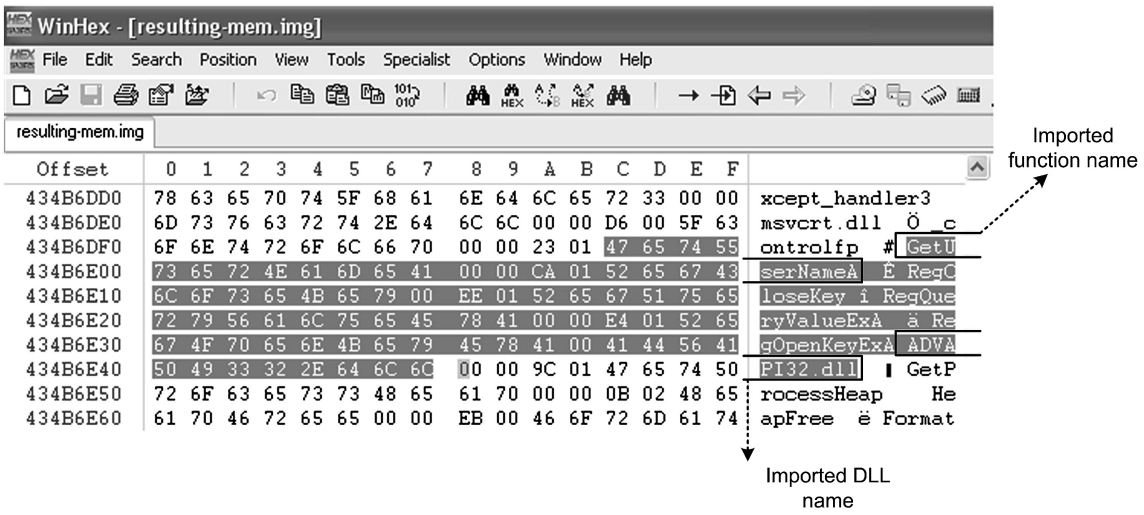

Fig. 5 – An imported DLL file and one of it's functions in the memory image.

session. The FTP client used in this example is Microsoft FTP client, available in machines running Windows operating systems. The login credentials used by this program are not cached or saved and are just sent to the server using a connection socket. This is an interesting case were stack analysis method comes to help the investigator. To pinpoint the transmitted sensitive information, we:

1) found the process ftp.exe on the list of processes that were running at the time of imaging,
2) enumerated all DLL files imported by this process and all imported functions,
3) located the stack for thread(s) of execution,
4) examined addresses on the stack(s) to find return addresses (to locate the stack frames),

Table 2 – Functions from various APIs that may carry forensically sensitive information.

	Function	API	Function description
1	SSL_CIPHER_description	*SSL/Ciphers*	Returns a textual description of the cipher used into the buffer *buf* of length *len* provided
2	SSL_CTX_check_private_key	*SSL/Protocols*	Verifies that the private key agrees with the corresponding public key in the certificate that is associated with a specific context (CTX) structure
3	SSL_check_private_key	*SSL/Connections*	Verifies that the private key agrees with the corresponding public key in the certificate that is associated with the Secure Sockets Layer (SSL) structure
4	FindFirstUrlCacheEntry	*WinINet(Windows Internet)*	Begins the enumeration of the Internet cache
5	FtpCommand	*WinINet(Windows Internet)*	Sends commands directly to an FTP server
6	GetAddressByName	*Windows Sockets 2 (Winsock)*	Queries a namespace, or a set of default namespaces, to retrieve network address information for a specified network service
7	gethostbyaddr	*Windows Sockets 2 (Winsock)*	Retrieves the host information corresponding to a network address
8	send	*Windows Sockets 2 (Winsock)*	Sends data on a connected socket
9	BluetoothAuthenticateDevice	*Wireless Networking/Bluetooth*	Sends an authentication request to a remote Bluetooth device

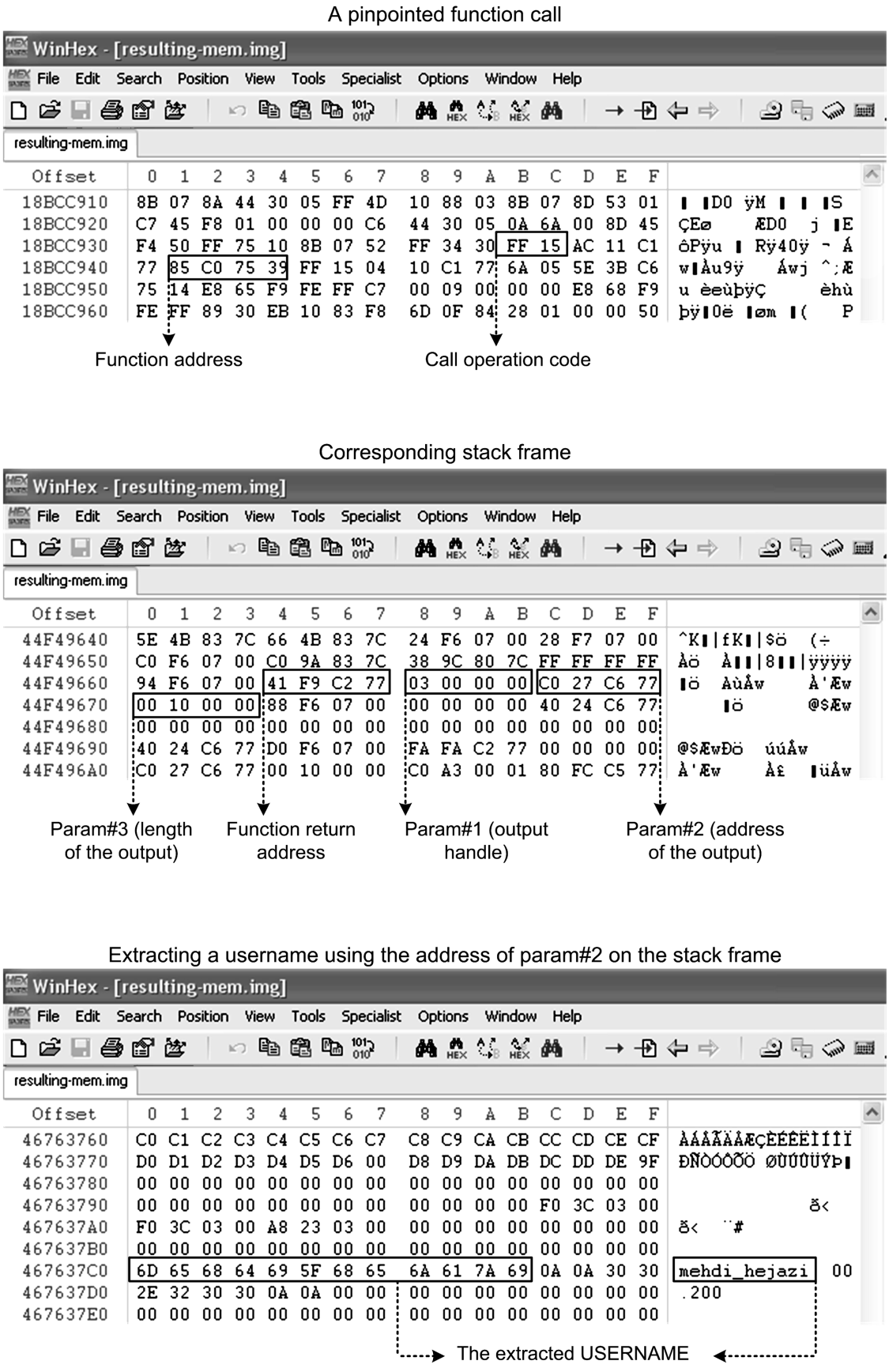

Fig. 6 – Extracting an account username from memory using the stack analysis method.

5) checked function calls on the stack against imported functions from DLLs (from step 2),
6) found the function WriteFile imported from KERNEL32.dll (this function writes a buffer of characters to a general file, which is a socket in this case),
7) located addresses of the WriteFile parameters (according to its signature) and finally,
8) extracted the **username** (second parameter to WriteFile function).

Our developed toolkit produces an XML file in order to present its findings in terms of processes, their loaded DLL modules, sensitive functions called in each modules (present on the stack), and extracted (if any) parameters. In order to clarify, Fig. 6 displays and summarizes the result of the above steps.

There are two issues that should be mentioned here:

1) All the address values pointed to in the screenshots, are presenting virtual addresses that during the analysis have been translated to physical addresses in order to locate new values in memory image.
2) Due to the fast changes made to stack frames on a stack (because of numerous function calls), we cannot make sure that the stack frame of a certain function call can be found on the stack. This is why in the example above, we have been able to identify an account username, but not the corresponding password.

6.2.9. *Limitations*

There are some issues that add to the difficulty of this method. Some of these limitations are the following:

- Many applications do their internal processing (including encryption password processing, etc) inside the application code and do not directly call the available API. So in some cases, only those low-level and common functions are called from APIs (such as WriteFile function, explained in Section 6.2.1). These calls are repeated many times for various purposes and do not always lead to sensitive information.
- In some applications (such as PuTTY (Putty: A free telnet/ssh client, 2009)) in order to consider security of the users and prevent attacks, sensitive information such as SSH2 client's passwords are completely removed from memory contents right after they are used (by setting memory bytes used to hold the password to zero) (Public Advisory, 2008).
- In cases that we want to analyze closed source applications, to find the flow of sensitive data such as inputs, we need to analyze the assembly code of the program and sometimes use assembly debuggers such as IDA Pro (Hex Rays, 2009). Consequently, the process of tracing sensitive information path and finding functions that handle these data becomes more cumbersome.

7. Conclusion

Due to pertinent and accurate information that can be carved from memory contents, memory analysis has become an important part of forensic analysis. In many cases, evidence found by analyzing physical memory cannot be found in any other sources. In addition, these evidence can respond to key questions about the incident such as who, when, how, and where. In this paper, we introduced new methods for extracting forensically sensitive information such as usernames, passwords, visited URLs, and encryption keys from physical memory. The first method leverages string matching to get a more reliable technique for analyzing and extracting what we called ''application/protocol fingerprints''. These fingerprints are string constants or series of non-string bytes that may have constant distances from sensitive pieces of information in memory. The second method, which is the most important, is based on analyzing the call stack and the security sensitive APIs. It allows extracting sensitive information that cannot be extracted by string matching-based techniques.

In the future, we will investigate more APIs for fingerprint analysis and render the process as automatic as possible. As for stack analysis we are planning to perform more empirical experiments, investigate more APIs, and leverage the method to applications code.

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