OFFLINE FORENSIC ANALYSIS OF MICROSOFT®
  WINDOWS® XP PHYSICAL MEMORY

by

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September 2006

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The rise of cyber crimes combined with the recent use of computer viruses and malicious programs that reside only in volatile main memory demand further development of appropriate forensic tools. Existing forensic tools that analyze non-volatile memory are not capable of analyzing volatile memory and the few tools that are capable of detailed analysis of volatile memory are not openly available to the public. In this thesis, an open source tool is developed to analyze images of physical memory originating from the Windows XP and Windows 2003 Server operating systems. The tool, named Windows Physical Memory Offline Analyzer (WPMOA), scans the memory image and, utilizing input from the user, extracts relevant data from the various structures maintained by the Windows operating system. The WPMOA program automatically generates reports about the image and provides key information necessary for a user to perform additional manual investigation of the image beyond what is done automatically. This thesis details instructions on the preparation and use of the program, initial testing results of the program with actual physical memory images, and C language code for the program itself.
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OFFLINE FORENSIC ANALYSIS OF MICROSOFT® WINDOWS® XP PHYSICAL MEMORY

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ABSTRACT

The rise of cyber crimes combined with the recent use of computer viruses and malicious programs that reside only in volatile main memory demand further development of appropriate forensic tools. Existing forensic tools that analyze non-volatile memory are not capable of analyzing volatile memory and the few tools that are capable of detailed analysis of volatile memory are not openly available to the public. In this thesis, an open source tool is developed to analyze images of physical memory originating from the Windows XP and Windows 2003 Server operating systems. The tool, named Windows Physical Memory Offline Analyzer (WPMOA), scans the memory image and, utilizing input from the user, extracts relevant data from the various structures maintained by the Windows operating system. The WPMOA program automatically generates reports about the image and provides key information necessary for a user to perform additional manual investigation of the image beyond what is done automatically. This thesis details instructions on the preparation and use of the program, initial testing results of the program with actual physical memory images, and C language code for the program itself.
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I. INTRODUCTION

A. CYBER CRIME TODAY

No one can deny the continuing rise in the rate of computer crime with each passing year. Reading about a new computer virus or worm in the newspaper has become a common occurrence in recent history. Computer attacks such as the I Love You worm in 2000 [1], Code Red worm in 2001 [2], and Blaster worm in 2003 [3] proved the reality of this type of threat. As the technology of computer security advances, so too does the sophistication of the attacks on computers. A recent article in “Core Security Technologies” discusses a computer exploit that remains entirely in volatile memory, leaving no trace on a computer system's hard drive [4]. An example of malicious software that resides in volatile memory only is the W32.Witty.Worm worm [5]. When a malicious program is capable of residing solely in volatile memory, it will leave no evidence of itself on the compromised system [4]. Without evidence of its activity and origin, an attack can continue to wreak havoc upon businesses, government agencies, and private citizens unchecked by law enforcement agencies.

B. COMPUTER FORENSICS

The impact forensic science has had on countless criminal investigations and trials make it a crucial part of law enforcement [6]. Therefore, it is necessary to continue advancing the forensic science to meet the increasing demand of law enforcement against cyber crime. In cyber crime investigations, the crime scene can consist of one or more computers perhaps spanning one or more computer networks. A cyber criminal may affect a system locally or remotely. A local attacker may leave physical evidence at the scene such as witnesses or fingerprints in addition to electronic evidence. Via the Internet, a remote attacker can penetrate other systems connected to the Internet from anywhere in the world, leaving only electronic evidence. In either case, digital forensic evidence can be gathered from the criminal's computer, the victim's computer, or both. This digital evidence can be broadly categorized in two ways, non-volatile and volatile.

Non-volatile electronic evidence can be recovered after a system is powered down and is found on hard drives, USB flash drives, and floppy disks. It is in non-volatile memory where most of the electronic evidence originates. System logs, network logs,
malicious code, corrupted files, emails, internet browser cached files and history, and deleted files are all forensic evidence stored in non-volatile memory. Network logs may contain TCP session logs indicating the source IP address from where the attack originated. The malicious code may be analyzed to determine exactly what the attacker did to the system. Emails may contain incriminating records of criminal activity and possibly reveal accomplices. Analysis of the disk drive’s file system can lead to the recovery of deleted files, which may contain further evidence. Electronic evidence gathered from non-volatile memory can be used to determine how and when a system was infiltrated, what files were corrupted and how, and how much damage, if any, was done to the system. For the criminal’s computer, email and browser history and cache can prove the criminal’s intent, expose any accomplices, and even give further evidence of how an attack, if any, occurred [7]. However, a careful cyber criminal may have permanently erased any incriminating evidence from non-volatile memory, thereby making its recovery impossible. In the case of an infiltrated computer running malicious code, there is other evidence that can be useful.

The other type of electronic evidence is in volatile memory. Unlike data stored on hard drives, electronic evidence found in main memory disappears once power is removed from the system. Information about each running process, such as create times, exit times, open files, executing code, and child process are stored in main memory. This type of evidence is useful if a malicious program is running or another program has been corrupted on a live system. Unlike the non-volatile memory, this evidence cannot be erased from memory as long as malicious code is running. Additionally, trusted programs may be used to gather data from a live system such as open network ports, established network connections, logged on users, and list of running processes.

As with other forms of forensic evidence, special tools are necessary to analyze computer crime scenes. At present, there exist few computer forensic tools capable of performing anything other than a rudimentary analysis of non-volatile evidence gathered from running computer systems. Jorge Urrea researched and offered a method for forensically analyzing physical memory images for Linux systems. Urrea’s method combined the use of a hexadecimal editor, some Perl scripts developed by Urrea, and knowledge of the Linux kernel memory manager provided by his research. Other than
the work done by Urrea, the computer forensics field lacks the tools necessary to analyze RAM contents for forensic evidence.

The Digital Forensics Research Workshop (DFRWS) issued a challenge prior to their 2005 conference in hopes of addressing the lack of tools for analyzing physical memory for Windows 2000 systems. One of the questions posed by the challenge required finding hidden processes given a physical memory dump of a Windows 2000 system. Additionally respondents were asked to consider what other types of forensic evidence one could gather from physical memory dumps. The two winners of the challenge created their own tools to analyze the physical memory dumps, but neither of the tools has been made available to the public [8].

Inspired by the DFRWS 2005 challenge, this thesis will discuss the details involved in creating an open source C program to analyze Windows XP physical memory dumps for digital forensic evidence. To begin, the methods, tools, and challenges associated with obtaining a snapshot of physical memory will be discussed in chapter II. Once a physical memory image is obtained, its contents must be understood in order to obtain meaningful forensic information from the image. The structures maintained in physical memory will be described in chapter III. Once the contents of memory are understood, the software used to automate the analysis of the image will be covered in chapter IV and chapter V will describe how to use the Windows Physical Memory Analyzer (WPMOA) program developed for this thesis. The results from using the program to analyze actual physical memory images will be discussed in chapter VI. The final chapter will provide areas for further research on the topic of automating forensic analysis of physical memory images.
II. THE PHYSICAL MEMORY IMAGE

To analyze forensic evidence from physical memory, one must be able to extract the contents of RAM. Ideally, when a process reads from or writes to a location in its virtual address space, that address is available in physical memory for immediate use. But no system is capable of providing enough physical addresses in main memory to map to every address of each process’ virtual address space. So, when virtual memory space exceeds physical memory space, non-essential data mapped to physical memory is transferred to the system hard disk, to free physical addresses for remapping. This process is known as paging out. The data is paged to a file on the system hard disk called a swap file. On Windows systems, the swap file is named pagefile.sys and is located in the root directory of the C drive (C:\). The swap file is conceptually just an extension of physical memory to meet the capacity of virtual memory. For ease of management, main memory is divided into fixed sized chunks called pages. While a system is powered on, pages in memory are swapped to and from the swap file as new processes are created and as the existing processes run, as needed to meet the demand of the running processes. Because of the constant swapping of pages in physical memory, the total address space of virtual memory is rarely contained entirely within physical memory, nor is it ever constant.

When a forensics imaging program is used to copy the contents of physical memory to a file, that same memory will be altered by the operating system which must create data structures to manage the newly created imaging process. Furthermore, the imaging program itself will alter physical memory as it copies the data in memory to a file which typically requires a large number of data transfers between various memory resident input/output buffers. Besides affecting memory, it is possible that the program could be receiving false data from a corrupted operating system since a memory imaging program can only access physical memory through the operating system. Thus, with software tools alone, it is not possible to obtain a snapshot of physical memory unaffected by the tool used to measure it. Simply stated, the act of capturing the state of memory causes changes to the state of memory. However, it is possible to obtain a snapshot of physical memory without altering its state by using a bus mastering hardware
device connected to the system’s memory bus. The device must be connected to the system prior to intrusion, when the system is powered down, but because it communicates with physical memory through the host controller and not the operating system, the problems discussed with software acquisition of physical memory are eliminated. For those who do not have a bus mastering device to capture memory or did not have the foresight to install said device before an intrusion, snapshots of the unaltered physical memory image are not possible. An undisturbed snapshot is not necessary for forensic analysis because, as will be shown in this document, useful forensic evidence can be extracted from a physical memory image captured with the software tool dd [9].

Since there are no native tools on Windows XP to dump the contents of system memory to a file, a third-party program must be used. One such tool is George Garner’s variant of the GNU dd utility [10]. George Garner’s dd is used in a manner similar to the way in which the standard version of dd is used on Linux systems [11]. The dd program copies data in blocks from one file to another. In the case of Garner’s version, the input file is `\PhysicalMemory`, which represents the device name for physical memory in Windows. It is important to use the `noerror` option to ensure all readable blocks of data are copied from physical memory. Without the `noerror` option, the dd program will stop copying after a read error. As for the output file, it is recommended that no output file is specified in favor of piping the output of dd to netcat via the command line (see Figure 1). The netcat program sends and receives data via the host’s network connection, thus allowing the copy of physical memory to be sent directly to an external, network connected computer. This method will produce the best results for forensic analysis because it will not alter the target system’s hard disk.

Figure 1. Using dd to obtain physical memory image
After obtaining an image of Windows physical memory using George Garner’s dd program, forensic analysis can be performed on the image just as traditional forensic analysis is performed on hard disk images. The fundamental problem with analyzing physical memory structures however is that unlike disk partition images which contain well structured file systems, the layout of data in RAM must be carefully reconstructed by locating and properly parsing operating system data structures that are also resident in the RAM image. Therefore, in order to analyze physical memory and its relationship with virtual memory, the internal structures scattered throughout the RAM image must be understood first.
III. WINDOWS VIRTUAL MEMORY

The Windows operating system provides every running process with a virtual private memory space. The virtual space is an abstract representation of each process’ memory space. In reality, there is only physical memory (RAM) and it is shared among all processes on a system. All virtual address references must be translated to physical address addresses before data can actually be read or written.

![Figure 2. Layout of virtual address space](image)

A. VIRTUAL MEMORY LAYOUT

Virtual memory for Microsoft Windows XP and Windows 2003 Server on the Intel x86 architecture is the subject of this entire document and is assumed constant unless otherwise noted. Each active process on a system has its own virtual memory address space, separate from all other processes’ virtual memory address space. Within each virtual address space, there is a portion dedicated for the user application and a portion for the operating system as shown in Figure 2. The user virtual address space is for use by the application itself (e.g. Internet Explorer) and contains the application code, global variables, thread stacks, and dynamically linked library code. It spans from virtual addresses (in hexadecimal) 0x00000000 to 0xBFFFFFFF. The system address space is for use by the operating system and is accessible by all processes. The system address
space ranges from virtual addresses 0xC0000000 to 0xFFFFFFFF. It contains the necessary information for system management of the virtual memory space, including the process’ page directory and the page table entries (PTEs) used for translating virtual addresses to physical addresses in memory.

B. VIRTUAL MEMORY STRUCTURES

There are numerous structures within the process’ virtual address space and not all of them relate to the work described in this document. Therefore, the following discussion of memory structures is limited to the structures of interest in our forensic analysis of Windows physical memory. Each structure discussed is defined as a C structure in the win32structs.h file in Appendix A.

Figure 3. Structure of an EPROCESS block

1. Executive Process

The executive process (EPROCESS) block is the most important structure found in memory for forensic analysis because it is the starting point of any further investigation of that process. Figure 3 shows an abbreviated version of its structure, listing the fields of interest for forensic analysis. All EPROCESS blocks are part of a doubly linked list, which includes blocks for active processes, although it is not uncommon to encounter exited processes in the list. This phenomenon occurs when an exited process is still opened as a handle by another active process, as an exited process’
EPROCESS block is deleted only when the last handle to the process is closed. See Table 1 for a description of key EPROCESS block fields [12][13].

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kernel Process Block or Process Control Block (PCB)</td>
<td>Contains information about thread user and kernel times, process state, the pointer to the process page directory, and the pointer to the list of active threads for that process.</td>
</tr>
<tr>
<td>Process ID</td>
<td>A unique number identifying the process.</td>
</tr>
<tr>
<td>Parent Process ID</td>
<td>The process ID of the process’ parent process. Where the parent is the process that spawned the process in question.</td>
</tr>
<tr>
<td>Create and Exit times</td>
<td>Values representing the date and time the process was created and, if applicable, exited.</td>
</tr>
<tr>
<td></td>
<td>Note: The System process does not have a valid Create Time and this field is null.</td>
</tr>
<tr>
<td>Active Process Links</td>
<td>This field is a structure containing a forward and backward link that facilitates the doubly linked list of all processes.</td>
</tr>
<tr>
<td>Device Map</td>
<td>This field contains the address of the process’ object directory, which is used to resolve object names for the process.</td>
</tr>
<tr>
<td>Image File Name</td>
<td>This field contains the process’ name limited to 16 characters (e.g. explorer.exe).</td>
</tr>
<tr>
<td>Image Base Address</td>
<td>The preferred base address of the process in the user address space.</td>
</tr>
<tr>
<td>Field Name</td>
<td>Description</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Virtual Memory Information</td>
<td>This field is a pointer to the process’ Memory Manager Support structure</td>
</tr>
</tbody>
</table>

Figure 4. Handle table hierarchy

2. **Handle Table**

Each process accounts for every object it currently has open and it does so via the handle table. The process’ EPROCESS block contains a pointer to its handle table structure (see Figure 4). Within the handle table structure, there is a table code field, which contains the address of the actual handle table(s). The address in the handle code field is that of a sub handle table by default. The handle number is an index of the handle table entry for an object. Each entry in a sub handle table is represents a pointer to an opened object and a 32-bit value used to determine access control to that object. There can be up to 511 entries in one sub handle table. When more than 511 objects are opened in a process, the object manager creates a middle-level handle table, which contains pointers to a maximum of 1024 sub handle tables (see Figure 4). Additionally, one top-level handle table can be created, which contains pointers to a maximum of 1024 middle-level handle tables. A handle table's type is indicated in the least significant 3 bits of its table code field. The method is as follows: 0 indicates address is of a sub handle table, 1
indicates the address is of a middle-level handle table, and 2 indicates the address is of a top-level handle table [13].

Figure 5. Generic object structure

3. Objects

Figure 5 shows the generic structure of all objects found in memory. Every object has an object header structure. The object header stores the address of that object’s object type structure. The object type structure is common among all objects of the same type; some common examples of object types are file, process, and thread. Most objects have a body and a name, which precedes the object header, but where an object’s name is stored is ultimately dependant on its type. The object names facilitate finding objects by name and the sharing of objects between processes. If the object is not to be shared, the process’ object manager will not assign a name to it and it will be referred to by object handle only [13].
4. Executive Thread

Threads are entities within a process that represent executable code of the process. Every process created begins with a single thread, which can create other threads. Multiple threads allow a process to perform several tasks in parallel, with each thread executing a separate task. Windows represents a thread by the executive thread (ETHREAD) block stored in the physical memory. Threads are important to forensic analysis because threads are scheduled for execution by the operating system, not processes. A thread’s creation and exit times are stored in its ETHREAD block. The initial execution address for a thread is also stored in the ETHREAD block. Figure 6 shows an abbreviated ETHREAD block structure [13].

5. Process Working Set

A process’ working set is the set of virtual pages currently residing in main memory. When a thread references a virtual page that is not in the working set, a page fault occurs. The page fault triggers the memory manager to make room for the desired page by moving a resident page from main memory to the system swap file. Once space is made available, the desired virtual page is loaded into memory and the working set is updated to include the newly loaded virtual page [14].

The working set list structure contains fields for the memory manager to update the working set list easily. The addresses of the first free slot, the last entry, and last initialized entry are kept in the structure (see Figure 7). These are used by the WPMOA program to determine when to stop searching for working set addresses. The working set list entry field
contains the virtual address of the working set list entry table. In this table are the virtual addresses of every resident page of the process.

Figure 7. Working Set List structure

Each structure maintained in physical memory stores a small amount of data about the overall system. The aggregation of that data is what leads to profound information about a system. Therefore, it is essential to understand where to find and how to interpret the many structures scattered throughout physical memory in order to recover useful information. Once these structures are understood, a program can be implemented to automate the recovery of relevant forensic data from a physical memory image.
IV. SOFTWARE IMPLEMENTATION

The source code for the Windows Physical Memory Offline Analyzer (WPMOA) software is included in appendix A. The WPMOA program was developed using ANSI standard C for UNIX-based operating systems and has been successfully compiled and executed on SuSE Linux 10.0 and Mac OS X Tiger (Intel) Darwin 8.0.

A. PROGRAM OVERVIEW

The WPMOA program consists of two C source files named wpmoa.c and dissector.c and two C header files named wpmoa.h and win32structs.h. The wpmoa.h file contains all of the function prototypes, global variables, and include statements, while the win32structs.h file contains struct definitions based on those defined in the Ntddk.h file included in the Windows Driver Development Kit (DDK). Functions scanning for and manipulating the data found on the memory image are located in the dissector.c source file, while all other functions are in the wpmoa.c source file.

Figure 8. WPMOA program flow chart

Figure 8 shows the general flow of the program, which is described in words below. The program uses the user command line inputs to initialize the program global variables setting the start address of the active process list and the page size for the
physical memory image. The program then enumerates each process in the active process list by copying each EPROCESS block into a dynamically allocated array, along with the open handles and working set of each process. Once completed, the program prints the main menu and awaits user input for the next action. The user may choose to translate a virtual address to a physical address, print a report of one or all processes, or quit the program. After the chosen action is completed, the program will return to the command prompt awaiting further action until the user chooses the quit option. When quit is chosen, the program cleans up all dynamically allocated memory and closes all opened handles before exiting.

B. INITIALIZING AND MAIN MENU

There is no constant value for the address of the first EPROCESS block in the active process list; therefore, this value must be set manually via the command line arguments. The names of the physical memory image file and the output file are passed to the program via the command line arguments as well. On startup, the program scans a physical memory image, and allocates a dynamic array to hold all EPROCESS blocks found in the image. The size of the array is determined by the process_count function, which traverses the active process list, found using the address provided via the command line argument, in the physical memory image, keeping count of the number of processes traversed. The program then utilizes the enumerate_processes function, described later, which fills the allocated array with data read from the EPROCESS blocks. If the enumerate_processes function executes successfully, the interactive menu will display a command prompt preceded by a table of all processes found. There is also a help menu, showing all available options to the user (see Figure 9).

C. ENUMERATING PROCESSES

The enumerate_processes function, found in dissector.c, copies the contents of each EPROCESS block found in the active process list into an array allocated in main. Traversing the list is relatively straightforward because the virtual addresses of each
EPROCESS block did not require process specific address translation. The virtual addresses of the EPROCESS blocks differ from the physical addresses by the kernel offset of 0x80000000 and are determined by Equation 1, where VA is the virtual address and PA is the translated physical address. To determine the end of the list, the program checks the forward link of each EPROCESS block against the address of the head of the list. If the two are equal, the EPROCESS block is the last process in the list.

Equation 1

\[ PA = VA - 0x80000000 \]

Enumerating a process’ open file handles requires process specific virtual to physical address translation. The translation function, described later, enables further enumeration of a process. A process’ open file handles are found by the enumerate_handle_table function, also located in dissector.c. As mentioned in chapter II, the open file handles are kept in a hierarchy of handle tables. The enumerate_handle_table function traverses any mid-level and top-level handle tables, eventually reaching all sub handle tables. Each object pointed to by the file handles is visited and its name and type is recorded. Since each object of the same type points to a common object type structure in memory, a cache is kept of the object type names to save time wasted by repetitive disk reads visiting the same object type structure. Once the object type is known, the object’s name, if one exists, is determined based on its type. A process object’s name resides in the process object’s body, as does a file object’s name. The thread object does not have a text name; therefore, it is referred to by its unique identification number and by the process name that spawned it. All other object types, except key objects (used to access registry data), maintain their object names in the object name block, preceding the object header block. All object names are stored as Unicode, which are converted to ASCII strings and stored for later printing.

Enumerating file objects does not mean the contents of that file can be discovered as well. File objects are references to files stored on a hard drive or any other block device. If the file name is known and the system hard drive is possessed, then the file’s entire contents could be inspected for forensic evidence. However, if the system hard drive is not in possession or the process’ executable file was wiped from the hard drive,
then the process’ executable code cannot be examined. Once mapped into memory by
the operating system loader, a process’ executable file is generally not opened for I/O and
has no assigned file descriptor; therefore, in order to view the process’ executable code,
the process’ working set must be enumerated. A process’ working set is cached data
referenced by its threads. This data includes the executable code each thread is currently
referencing. The working set is arranged in a list of virtual addresses. Each address
refers to a location in memory containing at most one page of data or code. The
WPMOA program copies the working set list into an array containing both virtual
addresses and their translated physical addresses, which is then sorted based on the
virtual addresses from lowest address to highest. The list is then traversed, comparing
each address to the address before it to determine contiguous addresses. If addresses are
found to differ by the size of a page in memory (typically 4K bytes), then they are
considered contiguous, but contiguous addresses that differ in the twelve most significant
bits are put into separate files. All contiguous address ranges are then extracted to files
named after the address ranges contained in the file (e.g. 00400000h-00402000h). The
files created are placed in a directory named according to the owning process name and
unique ID number. Including the process identification number is necessary because a
program can be executed several times and be referred to by the same image name, but
each process will have a unique identification number.

Each working set item from the working set list is the size of one page. Depending on the system settings, the page size could vary from the typical 4096-byte value.
If the physical memory image page size is not 4096 bytes, then the actual size, in
bytes, must be set via the command line arguments. Additionally, each working set is a
referenced section of data from the virtual address space of the process. Therefore, when
viewing the files it is normal to see large spaces of zeroes even though there is a much
smaller space of zeroes in the file containing the original data. This is due to the
difference in the layout of an executable image on disk as defined by the Portable
Executable (PE) file specification, and the way in which that image is mapped into
memory by the operating system loader. Program file images consist of various sections
and the headers of a PE file detail the difference in size of each program section as it
exists on disk with the size of that section as it exists one mapped into memory.
D. VIRTUAL ADDRESS TRANSLATION

All pages in a process’ private address space are located by a virtual address. For the program to read locations in the physical memory image referred to within a process, that virtual address had to be translated to a physical one. The address translation begins with the virtual address to be translated. The first (most significant) 10-bits of the virtual address is an index in the process’ page directory. The page directory is found in the Kernel Process block and is referred to by its physical location. The entry in the page directory contains the valid address of a page table, if the desired page table resides in physical memory, where page tables contain addresses of page frames. The next 10-bit value of the virtual address is an index to the page table entry containing the desired page frame address. If the page is not actually in physical memory, because it has been swapped to the page file, then the page table entry will indicate this by setting the least significant bit of the page table entry and the contents of that page will not be recovered by the WPMOA program. There are a total of twelve bits in the page table entry that are used by the memory manager and are not part of the physical address (see Figure 10). The final 12-bits of the virtual address take the place of the 12-bits lost to the memory manager to form a translated 32-bit physical address [13].

E. THE REPORT

The print command of the program prints a report of data found in the physical memory image and calls the function that enumerates the process’ working set. Although there is much data found on the image, the program was designed to display only the
most relevant data found. The program generates a report, which displays the virtual address, image name, process ID, the parent process’ name, the parent process ID, time of creation, time of exit, virtual size, peak virtual size, page directory address, handle count, number of active threads, and the types and names of every open handles of every process found in the image file. The information displayed was chosen to give as much relevant forensic data to the user as possible and provide flexibility for further analysis.

The process ID numbers can be used to trace how a process was executed. For example, if a process’ parent process ID was that of cmd.exe, then that process was executed from the Windows command line. Therefore, each process in the open handle table has a number in parenthesis, which is the unique process ID of the opened process. For threads in the open handle table, the parent process of the thread is shown with the unique ID number of the thread following a semicolon.

The process creation and exit times are useful for recreating a timeline of system events. All times are shown as Coordinated Universal Time (UTC). Since the target system originated the times in the physical memory image, their accuracy depends on the accuracy of the target system’s clock. If the reported process was exited, then a time will occupy the space next to the Exited Time field, otherwise that space will indicate that no time was reported (see Figure 11).

Figure 11. WPMOA report of exited process

<table>
<thead>
<tr>
<th>Virtual Address:</th>
<th>0x09506300</th>
<th>Page Directory:</th>
<th>0x20078098</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process:</td>
<td>POWERPNT.EXE</td>
<td>Process ID:</td>
<td>2924</td>
</tr>
<tr>
<td>Virtual Size:</td>
<td>57 MB</td>
<td>Peak Virtual Size:</td>
<td>151 MB</td>
</tr>
<tr>
<td>Handle count:</td>
<td>Nonexistent</td>
<td>Number of threads:</td>
<td>0</td>
</tr>
<tr>
<td>Open Handles:</td>
<td>TYPE</td>
<td>NAME (if one exists)</td>
<td>None Found</td>
</tr>
</tbody>
</table>

For users desiring more information than the WPMOA program provides, the report gives the necessary information to do so. Specifically, the page directory address is intended to be used with the virtual address translation feature of the WPMOA program. The virtual address translation feature provides necessary functionality to
explore the physical memory image beyond the basic analysis of the WPMOA program. With it, the virtual addresses referencing every structure in RAM can be translated to physical locations in the image file. To analyze a process further, its virtual address is provided so that its location can be found in the image file. To navigate through the physical memory image, use the virtual address translator feature of the WPMOA program in conjunction with the Windows system header files. Some portions of the header files are included in the win32structs.h file (see Appendix A) used by the WPMOA program.

Figure 12. Example report of smss.exe

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0x86534900</td>
<td>0x10a5f000</td>
<td>smss.exe</td>
<td>724</td>
<td>System</td>
<td>4</td>
<td>2006-05-28 04:03:13 UTC</td>
<td>No time reported</td>
<td>3 MB</td>
<td>11 MB</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>Open Handles:</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>TYPE</td>
<td>NAME (if one exists)</td>
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<tr>
<td>Keyed Event</td>
<td>CritSecOpenMemoryEvent</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>File</td>
<td>Windows HD\WINDOWS</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Port</td>
<td>SmApiPort</td>
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</tr>
<tr>
<td>Directory</td>
<td>GLOBAL??</td>
<td></td>
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<tr>
<td>Directory</td>
<td>Sessions</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>File</td>
<td>Windows HD\WINDOWS\system32</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Symbolic Link</td>
<td>Known ullPath</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Directory</td>
<td>Known ullFile</td>
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<td></td>
</tr>
<tr>
<td>Key</td>
<td>UniqueSessionIdEvent</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Event</td>
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</tr>
<tr>
<td>Process</td>
<td>csrss.exe (700)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Process</td>
<td>winlogon.exe (824)</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process</td>
<td>svchost.exe (1052)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A sample report of the smss.exe process is shown in Figure 12. The working set information is not printed to the screen, but is printed to files labeled by the virtual address ranges each file contains. Although a small amount of information is shown in the example, more can be displayed in future versions of the software.
E.  QUITING THE PROGRAM

When the user chooses the quit option from the command prompt, the program
de-allocates all dynamically allocated memory and closes all opened file handles before
returning with a value of zero to indicate successful execution.
V. SOFTWARE USE

A. PRE-EXECUTION

Before using the Windows Physical Memory Offline Analyzer (wpmoa) program, the head of the process list must be determined manually. This is accomplished by using the grep and hexdump tools found on UNIX or UNIX-like operating systems. The necessary steps follow.

1. **Find the smss.exe EPROCESS block**

   The active process list maintained in physical memory begins with the System process, but because the word “System” is found in countless locations throughout memory, it is not practical to search directly for it. The next process executed at system startup is smss.exe, which is a word not commonly used throughout memory and it is a process guaranteed to be running since it is responsible for starting user sessions. Thus, to find the System EPROCESS block, the smss.exe EPROCESS block must first be found. Once the smss.exe EPROCESS block is found, the System EPROCESS block can be found by traversing the active process list backwards one link.

   To find the smss.exe EPROCESS block, use the grep command to search the image file of the physical memory for the string “smss.exe” treating the file as ASCII text, ignoring case, and reporting only the byte offset of the line containing the desired string (see Figure 13). The grep search will most likely return several addresses, so each one must be evaluated until the smss.exe executive process block is found. Examine each potential address of the physical memory image using hexdump with the display hex+ASCII and offset options (see Figure 14). Set the offset of hexdump to one of the byte offsets returned by grep. Find the string “smss.exe” and note the address where it begins. Subtract the hex offset of the process name field (0x174) from the hex address of “smss.exe.” The new address marks the beginning of the EPROCESS block and the location of the block’s type field. Verify that the first byte starting at the new address is 0x03, which indicates that the following type is of EPROCESS block type (see Figure 15). If the byte matches, then the address at which it is found is the beginning address of the smss.exe EPROCESS block.
2. Find System EPROCESS Block

Note the address located +0x08c relative to the start of the smss.exe EPROCESS block. This address marks the location of the EPROCESS block’s back link, pointing to the previous EPROCESS block in the active process list. Since the smss.exe process is always the second process executed in Windows XP, the back link pointer points to the System
process: the first process in the active process list. Since the back link actually points to the back link of the previous EPROCESS block, the address contained in the back link field must be adjusted to the starting address for the System EPROCESS block. Subtract 0x088 from the back link address to compute the virtual address of the head of the process list. The new address should be verified to be that of the System EPROCESS block to ensure that the program will function properly. Repeat the steps used to view the smss.exe EPROCESS block and look for the “System” string in the hexdump view (see Figure 16). Be sure to compute the physical address by subtracting the kernel offset of 0x80000000 from the virtual address when using hexdump.

Figure 16. hexdump view of the System EPROCESS block

3. Compile

Compile the program using the make command, if not already compiled, and the program will be ready for use.

B. EXECUTION

After successful compilation, run wpmaoa to begin the program. If the file name of the physical memory image is valid and the address of the PS_ACTIVE_PROCESS_HEAD correct, the program prints a greeting to the screen and displays the number of processes found in the image file. If the
PS_ACTIVE_PROCESS_HEAD was incorrect for the image being analyzed, then the program will appear to hang and must be interrupted or killed by the user to stop. After printing the number of process blocks found, the program displays a table associating a number with each process found followed by a command prompt (see Figure 17).

Figure 17. Welcome screen and process table

Windows Physical Memory Offline Analyzer
Use the help command for information

49 processes found in bmem.dmp

| 001 | System.exe     | 002 | one.exe      | 003 | cses.exe     | 004 | winlogon.exe |
| 005 | services.exe   | 006 | lsass.exe    | 007 | ati2evxx.exe | 008 | svchost.exe  |
| 009 | svchost.exe    | 010 | svchost.exe  | 011 | svchost.exe  | 012 | svchost.exe  |
| 013 | ccEvtMgr.exe   | 014 | spoof.exe    | 015 | scedsvr.exe  | 016 | vnetinfo.exe |
| 017 | ndn.exe        | 018 | NAPSVSC.EXE  | 019 | NPFPROTECT.EXE | 020 | NP0.EXE |
| 021 | svchost.exe    | 022 | vmware-authd.exe | 023 | vamroot.exe  | 024 | vmmact.exe  |
| 025 | SynWNL.exe     | 026 | vmmetdchp.exe | 027 | olg.exe      | 028 | ati2evxx.exe |
| 029 | explorer.exe   | 030 | StatusClient.exe | 031 | jshoch.exe   | 032 | SOUNDMAN.EXE |
| 033 | usbap.exe      | 034 | gtlash.exe   | 035 | print02.exe  | 036 | PCIEXE.exe  |
| 037 | iTunesHelper.exe | 038 | ipodService.exe | 039 | envdect.exe  | 040 | Negro.exe   |
| 041 | java.exe       | 042 | CLI.exe      | 043 | CLI.exe      | 044 | WINDDK.exe  |
| 045 | DISK.EXE       | 046 | MALWARE.exe  | 047 | cmd.exe      | 048 | dd.exe      |
| 049 | ncl.exe        |
The translate command provides virtual address translation to the user. Upon execution of the translate command, prompts for necessary information appear for the user to follow. The required information is the virtual address and page directory address, where the page directory address is provided in the printed report of the process of interest. If the virtual address maps to a valid physical address, then that address is printed to the screen and the user is returned to the command prompt.
VI. FORENSIC ANALYSIS OF PHYSICAL MEMORY DUMP

To verify the operation of the Windows Physical Memory Offline Analyzer, a test C program was run on a system running Windows XP during a live capture of the physical memory and the image was analyzed with the WPMOA program. In addition, the WPMOA program was used to analyze the physical memory images provided in the DFRWS challenge.

A. THE TEST PROGRAM

The test program was named MALWARE.exe and the source code for it is included in Appendix A. This program was intended to be very simple and not demand a lot of CPU time, but it was also desired that the program execute continually during the main memory capture. Reading input from STDIN achieved all of that with only a few lines of code. The program reads a string from STDIN and prints it to STDOUT. If the input string is “quit” then the program prints the string followed by “Hello World!” to STDOUT and then exits normally. For the test, the program was executed and left running while physical memory was captured from the target system.

B. THE FORENSIC RESULTS

Figure 18. MALWARE.exe WPMOA report

<table>
<thead>
<tr>
<th>Virtual Address: 0x063657f0</th>
<th>Image name: MALWARE.exe</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID: 3628 Parent ID: 1194</td>
<td>Created: 2006-05-28 04:25:52 UTC</td>
</tr>
<tr>
<td>Virtual Size: 6 MB</td>
<td>Exited: No time reported</td>
</tr>
<tr>
<td>Peak Virtual Size: 10 MB</td>
<td>Handle count: 8</td>
</tr>
<tr>
<td>Number of active threads: 1</td>
<td></td>
</tr>
<tr>
<td>Open Handles:</td>
<td></td>
</tr>
</tbody>
</table>

Type Name (if one exists)
File C:\\Documents and Settings\\John\\My Documents\\Visual Studio 2005\\Projects\\MALWARE\\release
WindowStation WinSta0
Event
File Windows HD\\Windows\\WinSxS\\\x86_Microsoft.VC80.CRT.ifsfb9b9cd91e30.8.0.50727.42_x-wu_0de66a0d

Port
Directory Windows
Directory KnownDlcs
KeyedEvent CrtSecOutOfMemoryEvent

The PS_ACTIVE_PROCESS_HEAD address was found in the physical memory image in accordance with the instructions from Chapter IV and the WPMOA program was compiled successfully. The forensic report of MALWARE.exe was found and
printed to a file (see Figure 18). The created time correlated to the time that is was executed and the exit time does not exist because the program had not been exited. The MALWARE process reported a file handle to the directory `\Windows\HD\Documents and Settings\John\My Documents\Visual Studio 2005\Projects\MALWARE\release`, which was the base directory of MALWARE.exe. From the report, it is known that the MALWARE program was executed at 04:25 GMT on May 28, 2006 and was still running at the time of the capture. In this example, the MALWARE.exe file was executed from the system hard drive, but if it were run from a removable drive, the report would indicate that. In a test where MALWARE.exe was executed from a floppy disk, the WPMOA report reflected the new base directory of the program (see Figure 19). This information would indicate where the malicious code was executed from, which may reveal how the malicious code was transferred to the attacked system. In the report shown in Figure 19, an investigator would have learned that the source of the attack was a floppy disk and that the intruder had physical access to the floppy drive.

Figure 19. MALWARE.exe WPMOA report showing removable drive

```
Virtual Address: 0x85796dd0  Image name: MALWARE.exe
ID: 1056 Parent ID: 602 Created: 2006-05-28 09:03:27 UTC
Virtual Size: 6 MB Exit: No time reported
Peak Virtual Size: 6 MB Page Directory: 0x3ef83000
Handle count: 3 Number of threads: 1
Open Handles:
  Type            Name(if one exists)
  KeypadEvent    CritSecOut0fMemoryEvent
  Directory      KnownEills
  File           Driver\Vf\vfpdisk
  Directory      Windows
  Port
  File           Windows HD:\\WIND\\WS\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\"
range is kept application and dynamically linked library machine code, thread stacks, and global variables. The file expected to contain the application machine code was the one named 00400000h-00405000h. The 00400000h-00405000h was compared with the MALWARE.exe file. This comparison revealed that the first 1024 bytes were identical between the two files. Because the working set pages represent sections of data referenced by threads, there are large spaces of zeroes in the 00400000h-00405000h file, where there are none in the original MALWARE.exe file. At the 4096-byte offset, the size of a page in the tested system, the 00400000h-00405000h file is identical to the next section in the MALWARE.exe for 2048 bytes. The final section of the executable file is loaded into the working set of the MALWARE.exe process similarly to the manners of the first two sections.

Figure 20. WPMOA dd.exe report

<table>
<thead>
<tr>
<th>Virtual Address:</th>
<th>0x657e6000</th>
<th>Image name: dd.exe</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID:</td>
<td>2996</td>
<td>Parent ID: 152</td>
</tr>
<tr>
<td>Packed Virtual Size:</td>
<td>14 MB</td>
<td>Exit: No time reported</td>
</tr>
<tr>
<td>Page Directory:</td>
<td>0x20f00000</td>
<td>Page Directory: 0x20f00000</td>
</tr>
<tr>
<td>Handle count:</td>
<td>1</td>
<td>Number of threads: 1</td>
</tr>
<tr>
<td>Open Handles:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>File</td>
<td>Windows H:\Documents and Settings\John</td>
<td></td>
</tr>
<tr>
<td>Mutant</td>
<td>DDWinMutex</td>
<td></td>
</tr>
</tbody>
</table>

The results from the MALWARE.exe test were ideal because all of the executable code was recovered from the process’ working set. A larger program will not likely yield in such ideal results as obtained from the MALWARE test. Using the WPMOA program to generate a report on George Garner’s dd.exe program demonstrates this issue. The printed report does indicate data that correlates with facts pertaining to its use for copying physical memory (see Figure 20).

In addition to the report generated by the WPMOA program, the working set files were created. It is in the working set files where the discrepancies exist. Comparing the dd.exe executable file with the 00411000h-004f1000h file generated by the WPMOA program does not give the same results as the MALWARE test. Not all of the sections of
dd.exe were part of the working set at the time of the physical memory capture and must have been swapped to the system swap file.

C. RESULTS FROM DFRWS CHALLENGE

The WPMOA program was unable to analyze the physical memory images provided by the DFRWS 2005 challenge because the images were obtained from a Windows 2000 system. Windows 2000 differs from Windows XP and Windows 2003 Server enough to prevent forensic analysis by the WPMOA program. When executed, the program appears to hang and does not reach the interactive menu.
Future work for this topic includes expanding the forensic analysis of Windows virtual memory to the system swap file. Non-resident virtual pages are stored to the system swap file located on the system hard disk to create free space in main memory. With the program developed for this report, only resident pages in main memory are analyzed for forensic evidence. An executable file being executed by a process is loaded into memory by sections. If the file is very large or the working set is very small, some sections of the file may be copied to the swap file and removed from main memory. The WPMOA program would only be able to extract the resident pages containing the file content and the complete original file may not be recovered. This problem would be eliminated by combining both the physical memory image with the system swap file. Their combination yields a complete view of the virtual address space for all processes running on the system.

The current manual process of locating the head of the active process list in the memory image may intimidate users inexperienced with hexdump and grep commands. Future work could be done to automate this process to relieve the burden from the user. The instructions for manually locating the address could be translated to machine language for the computer to carry out. As 1 GB RAM capacities is not uncommon in many modern computers, the automation should be efficient to minimize the time required to locate the address in question.

Unfortunately, the results of this work could not verify the findings of the DFRWS challenge because the tool developed does not support RAM images for Windows 2000 systems. Future work could expand the compatibility of the WPMOA program to be able to analyze physical memory images obtained from Windows 2000 systems. The work could then be verified against the findings posted on the DRFWS 2005 challenge website in Ref.8.

Another area of research would be integrating the WPMOA program functionality into another forensics tool, such as Autopsy. It would be convenient to have the
functionality of Autopsy include to the ability to analyze physical memory images in addition to analysis of file systems already supported.
APPENDIX A. WPMOAH

 tuần t*(k**t) + s*(t**s) - t + s

Name: Windows Physical Memory Offline Analyzer
File: wpmoa.h
Version: 1.0
Author: John Schultz

Description: Console Program which enumerates the processes running on a Windows PC. The program reads an offline copy of the physical memory for all the information gathered about the running processes.

#include<stdlib.h>
#include<stdio.h>
#include<string.h>
#include<strings.h>
#include<ctype.h>
#include<unistd.h>
#include<time.h>
#include"win32structs.h"

/*kernel offset of 0x80000000 set for WinXP & Win2K3 Server*/
#define KERNEL_OFFSET 0x80000000
/*value set on case by case basis see chapter IV for instructions*/
#define PS_ACTIVE_PROCESS_HEAD 0x867c6660 /* 0x81bccbd0 */
/*PAGESIZE set to the pagesize of system RAM image was taken from 4096 bytes is typical*/
#define PAGESIZE 4096

void print_report(struct EPROCESS *[], int, FILE * restrict);
void win_time(long long, char[]);
void unicode_to_ascii(char *, unsigned short);
int process_count(FILE * restrict);
int enumerate_processes(FILE * restrict, struct EPROCESS **);
long virtual_to_physical(long, long, FILE * restrict);
void *enumerate_handle_table(FILE * restrict, struct EPROCESS *);
int enumerate_workingsetlist(FILE * restrict, struct EPROCESS *);
int longcmp(const void *, const void *);
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APPENDIX B. WIN32STRUCTS.H

ibraries://sys/cdefs.h>
#define __WIN32STRUCTS_H
BEGIN_DECLS
/* Each struct is defined based on that given by the Windows(R) Kernel Debugger with few exceptions, which are noted*/
struct _unnamed {
    /* +0x000 */ long double var01;
    /* +0x00a */ long double var02;
    /* +0x014 */ long double var03;
    /* +0x01e */ long double var04;
};

struct LIST_ENTRY {
    /* +0x000 */ void *Flink;
    /* +0x004 */ void *Blink;
};

struct UNICODE_STRING {
    /* 0x000 */ unsigned short  Length;
    /* 0x002 */ unsigned short  MaximumLength;
    /* 0x004 */ unsigned short *Buffer;
};

struct STRING {
    /* 0x000 */ unsigned short Length;
    /* 0x002 */ unsigned short MaximumLength;
    /* 0x004 */ char          *Buffer;
};

struct DISPATCHER_HEADER {
    /* +0x000 */ unsigned char     Type;
    /* +0x001 */ unsigned char     Absolute;
    /* +0x002 */ unsigned char     Size;
    /* +0x003 */ unsigned char     Inserted;
    /* +0x004 */ unsigned long     SignalState;
    /* +0x008 */ struct LIST_ENTRY WaitList;
};
struct KEVENT {
    /* +0x000 */ struct DISPATCHER_HEADER Header;
};

struct KDEVICE_QUEUE {
    /* +0x000 */ short              Type;
    /* +0x002 */ short              Size;
    /* +0x004 */ struct LIST_ENTRY  DeviceListHead;
    /* +0x00c */ unsigned long      Lock;
    /* +0x010 */ unsigned char      Busy;
};

struct KDPC {
    /* +0x000 */ short             Type;
    /* +0x002 */ unsigned char     Number;
    /* +0x003 */ unsigned char     Importance;
    /* +0x004 */ struct LIST_ENTRY DpcListEntry;
    /* +0x00c */ void             *DeferredRoutine;
    /* +0x010 */ void             *DeferredContext;
    /* +0x014 */ void             *SystemArgument1;
    /* +0x018 */ void             *SystemArgument2;
    /* +0x01c */ unsigned long    *Lock;
};

struct MMWSLE_HASH {
    /* +0x000 */ void         *Key;
    /* +0x004 */ unsigned long Index;
};

struct MMSUPPORT_FLAGS {
    /* +0x000 */ int Sessionspace : 1;
    /* +0x000 */ int BeingTrimmed : 1;
    /* +0x000 */ int SessionLoader : 1;
    /* +0x000 */ int TrimHard : 1;
    /* +0x000 */ int WorkingSetHard : 1;
    /* +0x000 */ int AddressSpaceBeingDeleted : 1;
    /* +0x000 */ int Available : 10;
    /* +0x000 */ int AllowWorkingSetAdjustment : 8;
    /* +0x000 */ int MemoryPriority : 8;
};

struct MMWSL {
    /* +0x000 */ unsigned long         Quota;
    /* +0x004 */ unsigned long         FirstFree;
    /* +0x008 */ unsigned long         FirstDynamic;
    /* +0x00c */ unsigned long         LastEntry;
    /* +0x010 */ unsigned long         NextSlot;
    /* +0x014 */ void                 *Wsle; /*points to MMWSLE*/
    /* +0x018 */ unsigned long         LastInitializedWsle;
    /* +0x01c */ unsigned long         NonDirectCount;
    /* +0x020 */ struct MMWSLE_HASH    *HashTable;
    /* +0x024 */ unsigned long         HashTableSize;
    /* +0x028 */ unsigned long         NumberOfCommittedPageTables;
    /* +0x02c */ void                 *HashTableStart;
    /* +0x030 */ void                 *HighestPermittedHashAddress;
struct MMSUPPORT {
    /* +0x000 */ long long LastTrimTime;
    /* +0x008 */ struct MMSUPPORT_FLAGS Flags;
    /* +0x00c */ unsigned long PageFaultCount;
    /* +0x010 */ unsigned long PeakWorkingSetSize;
    /* +0x014 */ unsigned long WorkingSetSize;
    /* +0x018 */ unsigned long MinimumWorkingSetSize;
    /* +0x01c */ unsigned long MaximumWorkingSetSize;
    /* +0x020 */ struct MMWSL *VmWorkingSetList;
    /* +0x024 */ struct LIST_ENTRY WorkingSetExpansionLinks;
    /* +0x02c */ unsigned long Claim;
    /* +0x030 */ unsigned long NextEstimationSlot;
    /* +0x034 */ unsigned long NextAgingSlot;
    /* +0x038 */ unsigned long EstimatedAvailable;
    /* +0x03c */ unsigned long GrowthSinceLastEstimate;
};

struct FAST_MUTEX {
    /* +0x000 */ long Count;
    /* +0x004 */ void *Owner;
    /* +0x008 */ unsigned long Contention;
    /* +0x00c */ struct DISPATCHER_HEADER Event;
    /* +0x01c */ unsigned long OldIrql;
};

struct CURDIR {
    /* 0x000 */ struct UNICODE_STRING DosPath;
    /* 0x008 */ void *Handle;
};

struct PEB_LDR_DATA {
    /* 0x000 */ unsigned long Length;
    /* 0x004 */ unsigned char Initialized;
    /* 0x008 */ void *SsHandle;
    /* 0x00c */ struct LIST_ENTRY InLoadOrderModuleList;
    /* 0x014 */ struct LIST_ENTRY InMemoryOrderModuleList;
    /* 0x01c */ struct LIST_ENTRY InInitializationOrderModuleList;
    /* 0x024 */ void *EntryInProgress;
};

struct KSEMAPHORE {
    /* +0x000 */ struct DISPATCHER_HEADER Header;
    /* +0x010 */ long Limit;
};

struct KGDTENTRY {
    /* +0x000 */ unsigned short LimitLow;
    /* +0x002 */ unsigned short BaseLow;
    /* +0x004 */ unsigned long HighWord;
};
struct KIDTENTRY {
    /* +0x000 */ unsigned short Offset;
    /* +0x002 */ unsigned short Selector;
    /* +0x004 */ unsigned short Access;
    /* +0x006 */ unsigned short ExtendedOffset;
};

struct HANDLE_TABLE {
    /* +0x000 */ unsigned long TableCode;
    /* +0x004 */ struct EPROCESS *QuotaProcess;
    /* +0x008 */ void *UniqueProcessID;
    /* +0x00c */ unsigned long HandleTableLock[4];
    /* +0x01c */ struct LIST_ENTRY HandleTableList;
    /* +0x02c */ unsigned long HANDLECONTENTIONEVENT HandleContentionEvent;
    /* +0x030 */ void *DebugInfo;
    /* +0x034 */ long ExtraInfoPages;
    /* +0x038 */ unsigned long FirstFree;
    /* +0x03c */ unsigned long LastFree;
    /* +0x040 */ unsigned long NextHandleNeedingPool;
    /* +0x044 */ long HandleCount;
    /* +0x048 */ unsigned long Flags;
};

struct OWNER_ENTRY {
    /* +0x000 */ unsigned long OwnerThread;
    /* +0x004 */ long OwnerCount;
    /* +0x004 */ unsigned long TableSize;
};

struct OBJECT_TYPE_INITIALIZER {
    /* +0x000 */ unsigned short Length;
    /* +0x002 */ unsigned char UseDefaultObject;
    /* +0x003 */ unsigned char CaseInsensitive;
    /* +0x004 */ unsigned long InvalidAttributes;
    /* +0x008 */ void *GenericMapping;
    /* +0x018 */ unsigned long ValidAccessMask;
    /* +0x01c */ unsigned char SecurityRequired;
    /* +0x01d */ unsigned char MaintainHandleCount;
    /* +0x01e */ unsigned char MaintainTypeList;
    /* +0x020 */ void *PoolType;
    /* +0x024 */ unsigned long DefaultPagedPoolCharge;
    /* +0x028 */ unsigned long DefaultNonPagedPoolCharge;
    /* +0x02c */ void *DumpProcedure;
    /* +0x030 */ void *OpenProcedure;
    /* +0x034 */ void *CloseProcedure;
    /* +0x038 */ void *DeleteProcedure;
    /* +0x03c */ void *ParseProcedure;
    /* +0x040 */ void *SecurityProcedure;
    /* +0x044 */ void *QueryNameProcedure;
    /* +0x048 */ void *OkayToCloseProcedure;
};

struct ERESOURCE {
    /* +0x000 */ struct LIST_ENTRY SystemResourcesList;
    /* +0x008 */ struct OWNER_ENTRY *OwnerTable;
    /* +0x00c */ short ActiveCount;
    /* +0x00e */ unsigned short Flag;
struct SEGMENT {
    /* +0x000 */ struct CONTROL_AREA *ControlArea;
    /* +0x004 */ unsigned long TotalNumberOfPtes;
    /* +0x008 */ unsigned long NonExtendedPtes;
    /* +0x00c */ unsigned longWritableUserReferences;
    /* +0x010 */ unsigned long SizeOfSegment;
    /* +0x018 */ long SegmentPteTemplate;
    /* +0x01c */ unsigned long NumberOfCommittedPages;
    /* +0x020 */ /* struct MMEXTEND_INFO */ void *ExtendInfo;
    /* +0x024 */ void *SystemImageBase;
    /* +0x028 */ void *BasedAddress;
    /* +0x02c */ long u1;
    /* +0x030 */ long u2;
    /* +0x034 */ long *PrototypePte;
    /* +0x038 */ long ThePtes[1];
};

struct CONTROL_AREA {
    /* +0x000 */ struct SEGMENT *Segment;
    /* +0x004 */ struct LIST_ENTRY DereferenceList;
    /* +0x00c */ unsigned long NumberOfSectionReferences;
    /* +0x010 */ unsigned long NumberOfPfnReferences;
    /* +0x014 */ unsigned long NumberOfMappedViews;
    /* +0x018 */ unsigned short NumberOfSubsections;
    /* +0x01a */ unsigned short FlushInProgressCount;
    /* +0x01c */ unsigned long NumberOfUserReferences;
    /* +0x020 */ long unnamed;
    /* +0x024 */ struct FILE_OBJECT *FilePointer;
    /* +0x028 */ /* struct EVENT_COUNTER */ void *WaitingForDeletion;
    /* +0x02c */ unsigned short ModifiedWriteCount;
    /* +0x030 */ unsigned short NumberOfSystemCacheViews;
};

struct SUBSECTION {
    /* +0x000 */ struct CONTROL_AREA *ControlArea;
    /* +0x004 */ long unnamed;
    /* +0x008 */ unsigned long StartingSector;
    /* +0x00c */ unsigned longNumberOfFullSectors;
    /* +0x010 */ /* struct MMPTE */ void *SubsectionBase;
    /* +0x014 */ unsigned long UnusedPtes;
    /* +0x018 */ unsigned long PtesInSubsection;
    /* +0x01c */ struct SUBSECTION *NextSubsection;
};

struct SEGMENT_OBJECT {
    /* +0x000 */ void *BaseAddress;
};
/* +0x004 */ unsigned long TotalNumberOfPtes;
/* +0x008 */ long long SizeOfSegment;
/* +0x010 */ unsigned long NonExtendedPtes;
/* +0x014 */ unsigned long ImageCommitment;
/* +0x018 */ struct CONTROL_AREA *ControlArea;
/* +0x01c */ struct SUBSECTION *Subsection;
/* +0x020 */ /*struct LARGE_CONTROL_AREA*/void *LargeControlArea;
/* +0x024 */ /*struct MMSECTION_FLAGS*/ void *MmSectionFlags;
/* +0x028 */ /*struct MMSUBSECTION_FLAGS*/ void *MmSubSectionFlags;
};

struct SECTION_OBJECT_POINTERS {
  /* +0x000 */ void *DataSectionObject;
  /* +0x004 */ void *SharedCacheMap;
  /* +0x008 */ void *ImageSectionObject;
};

struct SECTION_OBJECT {
  /* +0x000 */ void *StartingVa;
  /* +0x004 */ void *EndingVa;
  /* +0x008 */ void *Parent;
  /* +0x00c */ void *LeftChild;
  /* +0x010 */ void *RightChild;
  /* +0x014 */ struct SEGMENT_OBJECT *Segment;
};

struct OBJECT_TYPE {
  /* +0x000 */ struct ERESOURCE Mutex;
  /* +0x038 */ struct LIST_ENTRY TypeList;
  /* +0x040 */ struct UNICODE_STRING Name;
  /* +0x048 */ void *DefaultObject;
  /* +0x04c */ unsigned long Index;
  /* +0x050 */ unsigned long TotalNumberOfObjects;
  /* +0x054 */ unsigned long TotalNumberOfHandles;
  /* +0x058 */ unsigned long HighWaterNumberOfObjects;
  /* +0x05c */ unsigned long HighWaterNumberOfHandles;
  /* +0x060 */ struct OBJECT_TYPE_INITIALIZER TypeInfo;
  /* +0x0ac */ unsigned long Key;
  /* +0x0b0 */ struct ERESOURCE ObjectLocks[4];
};

struct OBJECT_HEADER {
  /* +0x000 */ long PointerCount;
  /* +0x004 */ long HandleCount;
  /* +0x008 */ void *NextToFree;
  /* +0x00c */ struct OBJECT_TYPE *Type;
  /* +0x00d */ unsigned char NameInfoOffset;
  /* +0x00d */ unsigned char HandleInfoOffset;
  /* +0x00e */ unsigned char QuotaInfoOffset;
  /* +0x00f */ unsigned char Flags;
  /* +0x010 */ /* struct OBJECT_CREATE_INFORMATION *ObjectCreateInfo;
  /* +0x014 */ void *QuotaBlockCharged;
  /* +0x018 */ void *SecurityDescriptor;
};
struct VPB {
    /* +0x000 */ short                        Type;
    /* +0x002 */ short                        Size;
    /* +0x004 */ unsigned short               Flags;
    /* +0x006 */ unsigned short               VolumeLabelLength;
    /* +0x008 */ struct DEVICE_OBJECT        *DeviceObject;
    /* +0x00c */ struct DEVICE_OBJECT        *RealDevice;
    /* +0x010 */ unsigned long                SerialNumber;
    /* +0x014 */ unsigned long                ReferenceCount;
    /* +0x018 */ unsigned short               VolumeLabel[32];
    /*Unicode name*/
};

struct DEVICE_OBJECT {
    /* +0x000 */ short                        Type;
    /* +0x002 */ unsigned short               Size;
    /* +0x004 */ long                        ReferenceCount;
    /* +0x008 */ struct DRIVER_OBJECT    *DriverObject;
    /* +0x00c */ struct DEVICE_OBJECT    *NextDevice;
    /* +0x010 */ struct DEVICE_OBJECT    *AttachedDevice;
    /* +0x014 */ /* struct IRP */ void             *CurrentIrp;
    /* +0x018 */ /* struct IO_TIMER */ void        *Timer;
    /* +0x01c */ unsigned long                Flags;
    /* +0x020 */ unsigned long                Characteristics;
    /* +0x024 */ struct VPB              *Vpb;
    /* +0x028 */ void                    *DeviceExtension;
    /* +0x02c */ unsigned long                DeviceType;
    /* +0x030 */ char                     StackSize;
    /* +0x034 */ struct _unnamed          Queue;
    /* +0x038 */ unsigned long                AlignmentRequirement;
    /* +0x060 */ struct KDEVICE_QUEUE     DeviceQueue;
    /* +0x074 */ struct KDPC              Dpc;
    /* +0x094 */ unsigned long                ActiveThreadCount;
    /* +0x098 */ void                    *SecurityDescriptor;
    /* +0x09c */ struct KEVENT            DeviceLock;
    /* +0x0ae */ unsigned short           SectorSize;
    /* +0x0b0 */ /* struct DEVOBJ_EXTENSION */ void *DeviceObjectExtension;
    /* +0x0b4 */ void                    *Reserved;
};

struct DRIVER_OBJECT {
    /* +0x000 */ short                    Type;
    /* +0x002 */ short                    Size;
    /* +0x004 */ struct DEVICE_OBJECT    *DeviceObject;
    /* +0x008 */ unsigned long            Flags;
    /* +0x00c */ void                    *DriverStart;
    /* +0x010 */ unsigned long            DriverSize;
    /* +0x014 */ void                    *DriverSection;
    /* +0x018 */ void                    *DriverExtension;
    /* +0x01c */ struct UNICODE_STRING    DriverName;
    /* +0x024 */ struct UNICODE_STRING   *HardwareDatabase;
    /* +0x02c */ void                    *FastIoDispatch;
    /* +0x030 */ void                    *DriverInit;
    /* +0x034 */ void                    *DriverUnload;
/* +0x038 */ void                    *MajorFunction[28];
}

struct FILE_OBJECT {
    /* +0x000 */ short                           Type;
    /* +0x002 */ short                           Size;
    /* +0x004 */ struct DEVICE_OBJECT           *DeviceObject;
    /* +0x008 */ struct VPB                    *Vpb;
    /* +0x00c */ void                           *FsContext;
    /* +0x010 */ void                           *FsContext2;
    /* +0x014 */ struct SECTION_OBJECT_POINTERS *SectionObjectPointer;
    /* +0x018 */ void                           *PrivateCacheMap;
    /* +0x01c */ long                           FinalStatus;
    /* +0x020 */ struct FILE_OBJECT            *RelatedFileObject;
    /* +0x024 */ unsigned char                   LockOperation;
    /* +0x025 */ unsigned char                   DeletePending;
    /* +0x026 */ unsigned char                   ReadAccess;
    /* +0x027 */ unsigned char                   WriteAccess;
    /* +0x028 */ unsigned char                   DeleteAccess;
    /* +0x029 */ unsigned char                   SharedRead;
    /* +0x02a */ unsigned char                   SharedWrite;
    /* +0x02b */ unsigned char                   SharedDelete;
    /* +0x02c */ unsigned long                   Flags;
    /* +0x030 */ struct UNICODE_STRING           FileName;
    /* +0x038 */ long long                       CurrentByteOffset;
    /* +0x040 */ unsigned long                   Waiters;
    /* +0x044 */ unsigned long                   Busy;
    /* +0x048 */ void                           *LastLock;
    /* +0x04c */ struct KEVENT                   Lock;
    /* +0x05c */ struct KEVENT                   Event;
    /* +0x06c */ /* struct IO_COMPLETION_CONTEXT */ void *CompletionContext;
}*CompletionContext;
}

struct EX_PUSH_LOCK {
    /* +0x000 */ int           Waiting : 1; //LSB
    /* +0x000 */ int           Exclusive : 1;
    /* +0x000 */ int           Shared : 30;
    /* +0x000 */ unsigned long  Value;
    /* +0x000 */ void         *Ptr;
};

struct OBJECT_DIRECTORY_ENTRY {
    /* +0x000 */ struct OBJECT_DIRECTORY_ENTRY *ChainLink;
    /* +0x004 */ void                           *Object;
};

struct OBJECT_DIRECTORY {
    /* +0x000 */ struct OBJECT_DIRECTORY_ENTRY *HashBuckets[37];
    /* +0x094 */ struct EX_PUSH_LOCK                 Lock;
    /* +0x098 */ struct DEVICE_MAP                  *DeviceMap;
    /* +0x09c */ unsigned long                      SessionId;
    /* +0x0a0 */ unsigned short                     Reserved;
    /* +0x0a2 */ unsigned short                     SymbolicLinkUsageCount;
};

struct DEVICE_MAP {

/* +0x000 */ struct OBJECT_DIRECTORY *DosDevicesDirectory;
/* +0x004 */ struct OBJECT_DIRECTORY
    *GlobalDosDevicesDirectory;
/* +0x008 */ unsigned long ReferenceCount;
/* +0x00c */ unsigned long DriveMap;
/* +0x010 */ unsigned char DriveType[32];
};

struct RTL_DRIVE_LETTER_CURDIR {
/* +0x000 */ unsigned short Flags;
/* +0x002 */ unsigned short Length;
/* +0x004 */ unsigned long TimeStamp;
/* +0x008 */ struct STRING DosPath;
};

struct RTL_USER_PROCESS_PARAMETERS {
/* +0x000 */ unsigned long MaximumLength;
/* +0x004 */ unsigned long Length;
/* +0x008 */ unsigned long Flags;
/* +0x00c */ unsigned long DebugFlags;
/* +0x010 */ void *ConsoleHandle;
/* +0x014 */ unsigned long ConsoleFlags;
/* +0x018 */ void *StandardInput;
/* +0x01c */ void *StandardOutput;
/* +0x020 */ void *StandardError;
/* +0x024 */ struct CURDIR CurrentDirectory;
/* +0x030 */ struct UNICODE_STRING DllPath;
/* +0x038 */ struct UNICODE_STRING ImagePathName;
/* +0x040 */ struct UNICODE_STRING CommandLine;
/* +0x048 */ void *Environment;
/* +0x04c */ unsigned long StartingX;
/* +0x050 */ unsigned long StartingY;
/* +0x054 */ unsigned long CountX;
/* +0x058 */ unsigned long CountY;
/* +0x05c */ unsigned long CountCharsX;
/* +0x060 */ unsigned long CountCharsY;
/* +0x064 */ unsigned long FillAttribute;
/* +0x068 */ unsigned long WindowFlags;
/* +0x06c */ unsigned long ShowWindowFlags;
/* +0x070 */ struct UNICODE_STRING WindowTitle;
/* +0x078 */ struct UNICODE_STRING DesktopInfo;
/* +0x080 */ struct UNICODE_STRING ShellInfo;
/* +0x088 */ struct UNICODE_STRING RuntimeData;
/* +0x090 */ struct RTL_DRIVE_LETTER_CURDIR CurrentDirectores[32];
};

struct PEB {
/* +0x000 */ unsigned char InheritedAddressSpace;
/* +0x001 */ unsigned char ReadImageFileExecOptions;
/* +0x002 */ unsigned char BeingDebugged;
/* +0x003 */ unsigned char SpareBool;
/* +0x004 */ void *Mutant;
/* +0x008 */ void *ImageBaseAddress;
/* +0x00c */ struct PEB_LDR_DATA *Ldr;
/* +0x010 */ struct RTL_USER_PROCESS_PARAMETERS *ProcessParameters;
/* +0x014 */ void *SubSystemData;
/* +0x018 */ void *ProcessHeap;
}
/* +0x01c */ struct RTL_CRITICAL_SECTION *FastPebLock;
/* +0x020 */ void                *FastPebLockRoutine;
/* +0x024 */ void                *FastPebUnlockRoutine;
/* +0x028 */ unsigned long        EnvironmentUpdateCount;
/* +0x02c */ void                *KernelCallbackTable;
/* +0x030 */ unsigned long        SystemReserved[1];
/* +0x034 */ unsigned long        AtlThunkSList;
/* +0x038 */ struct PEB_FREE_BLOCK *FreeList;
/* +0x03c */ unsigned long        TlsExpansionCounter;
/* +0x040 */ void                *TlsBitmap;
/* +0x044 */ unsigned long        TlsBitmapBits[2];
/* +0x04c */ void                *readOnlySharedMemoryBase;
/* +0x050 */ void                *readOnlySharedMemoryHeap;
/* +0x054 */ void                **readOnlyStaticServerData;
/* +0x058 */ void                *AnsiCodePageData;
/* +0x05c */ void                *OemCodePageData;
/* +0x060 */ void                *UnicodeCaseTableData;
/* +0x064 */ unsigned long        NumberOfProcessors;
/* +0x068 */ unsigned long        NtGlobalFlag;
/* +0x070 */ long long            CriticalSectionTimeout;
/* +0x078 */ unsigned long        HeapSegmentReserve;
/* +0x07c */ unsigned long        HeapSegmentCommit;
/* +0x080 */ unsigned long        HeapDeCommitTotalFreeThreshold;
/* +0x084 */ unsigned long        HeapDeCommitFreeBlockThreshold;
/* +0x088 */ unsigned long        NumberOfHeaps;
/* +0x08c */ unsigned long        MaximumNumberOfHeaps;
/* +0x090 */ void                **ProcessHeaps;
/* +0x094 */ void                *GdiSharedHandleTable;
/* +0x098 */ void                *ProcessStarterHelper;
/* +0x09c */ unsigned long        GdiDCAttributeList;
/* +0x0a0 */ void                *LoaderLock;
/* +0x0a4 */ unsigned long        OSMajorVersion;
/* +0x0a8 */ unsigned long        OSMajorVersion;
/* +0x0ac */ unsigned short      *OSBuildNumber;
/* +0x0ae */ unsigned short      *OSCSVersion;
/* +0x0b0 */ unsigned long        OSPlatformId;
/* +0x0b4 */ unsigned long        ImageSubsystem;
/* +0x0b8 */ unsigned long        ImageSubsystemMajorVersion;
/* +0x0bc */ unsigned long        ImageSubsystemMinorVersion;
/* +0x0c0 */ unsigned long        ImageProcessAffinityMask;
/* +0x0c4 */ unsigned long        GdiHandleBuffer[34];
/* +0x14c */ void                *PostProcessInitRoutine;
/* +0x150 */ void                *TlsExpansionBitmap;
/* +0x154 */ unsigned long        TlsExpansionBitmapBits[32];
/* +0x158 */ unsigned long        SessionId;
struct HARDWARE_PTE {
    /* +0x000 */ int Valid : 1; //LSB
    /* +0x000 */ int Write : 1;
    /* +0x000 */ int Owner : 1;
    /* +0x000 */ int WriteThrough : 1;
    /* +0x000 */ int CacheDisable : 1;
    /* +0x000 */ int Accessed : 1;
    /* +0x000 */ int Dirty : 1;
    /* +0x000 */ int LargePage : 1;
    /* +0x000 */ int Global : 1;
    /* +0x000 */ int CopyOnWrite : 1;
    /* +0x000 */ int Prototype : 1;
    /* +0x000 */ int Reserved : 1;
    /* +0x000 */ int PageFrameNumber : 20;
};

struct KPROCESS {
    /* +0x000 */ struct DISPATCHER_HEADER Header;
    /* +0x010 */ struct LIST_ENTRY ProfileListHead;
    /* +0x018 */ unsigned long DirectoryTableBase[2];
    /* +0x020 */ struct KGDTENTRY LdtDescriptor;
    /* +0x028 */ struct KIDTENTRY Int21Descriptor;
    /* +0x030 */ unsigned short IopmOffset;
    /* +0x032 */ unsigned char Iopl;
    /* +0x033 */ unsigned char Unused;
    /* +0x034 */ unsigned long ActiveProcessors;
    /* +0x038 */ unsigned long KernelTime;
    /* +0x03c */ unsigned long UserTime;
    /* +0x040 */ struct LIST_ENTRY ReadyListHead;
    /* +0x048 */ void *SwapListEntry;
    /* +0x04c */ void *VdmTrapcHandler;
    /* +0x050 */ struct LIST_ENTRY ThreadListHead;
    /* +0x058 */ unsigned long ProcessLock;
    /* +0x05c */ unsigned long Affinity;
    /* +0x060 */ unsigned short StackCount;
    /* +0x062 */ char BasePriority;
    /* +0x063 */ char ThreadQuantum;
    /* +0x064 */ unsigned char AutoAlignment;
    /* +0x065 */ unsigned char State;
    /* +0x066 */ unsigned char ThreadSeed;
    /* +0x067 */ unsigned char DisableBoost;
    /* +0x068 */ unsigned char PowerState;
    /* +0x069 */ unsigned char DisableQuantum;
    /* +0x06a */ unsigned char IdealNode;
    /* +0x06b */ KEXECUTE_OPTIONS Flags; /*
    /* +0x06b */ unsigned char ExecuteOptions;
};

struct EPROCESS {
    /* +0x000 */ struct KPROCESS Pcb;
    /* +0x06c */ unsigned long ProcessLock;
    /* +0x070 */ unsigned long long CreateTime;
    /* +0x078 */ unsigned long long ExitTime;
    /* +0x080 */ unsigned long RunDownProtect;
    /* +0x084 */ void *UniqueProcessId;
    /* +0x088 */ struct LIST_ENTRY ActiveProcessLinks;
    /* +0x090 */ unsigned long QuotaUsage[3];
};
/* +0x09c */ unsigned long QuotaPeak[3];
/* +0x0a8 */ unsigned long CommitCharge;
/* +0x0ac */ unsigned long PeakVirtualSize;
/* +0x0b0 */ unsigned long VirtualSize;
/* +0x0b4 */ struct LIST_ENTRY SessionProcessLinks;
/* +0x0bc */ void *DebugPort;
/* +0x0c0 */ void *ExceptionPort;
/* +0x0c4 */ struct HANDLE_TABLE *ObjectTable;
/* +0x0c8 */ unsigned long Token;
/* +0x0cc */ struct FAST_MUTEX WorkingSetLock;
/* +0x0ec */ unsigned long WorkingSetPage;
/* +0x0f0 */ struct FAST_MUTEX AddressCreationLock;
/* +0x110 */ unsigned long HyperSpaceLock;
/* +0x114 */ struct ETHREAD *ForkInProgress;
/* +0x118 */ unsigned long HardwareTrigger;
/* +0x11c */ void *VadRoot;
/* +0x120 */ void *VadHint;
/* +0x124 */ void *CloneRoot;
/* +0x128 */ unsigned long NumberOfPrivatePages;
/* +0x12c */ unsigned long NumberOfLockedPages;
/* +0x130 */ void *Win32Process;
/* +0x134 */ void *Job; /*Points to EJOB*/
/* +0x138 */ void *SectionObject;
/* +0x13c */ void *SectionBaseAddress;
/* +0x140 */ void *QuotaBlock; /*points to EPROCESS_QUOTA_BLOCK*/
/* +0x144 */ void *WorkingSetWatch; /*points to PAGEFAULT_HISTORY*/
/* +0x148 */ void *Win32WindowStation;
/* +0x14c */ void *InheritedFromUniqueProcessId;
/* +0x150 */ void *LdtInformation;
/* +0x154 */ void *VadFreeHint;
/* +0x158 */ void *VdmObjects;
/* +0x15c */ struct DEVICE_MAP *DeviceMap;
/* +0x160 */ struct LIST_ENTRY PhysicalVadList;
/* +0x164 */ struct HARDWARE_PTE PageDirectoryPte;
/* +0x168 */ struct LIST_ENTRY Filler;
/* +0x170 */ void *Session;
/* +0x174 */ char ImageFileName[16];
/* +0x184 */ struct LIST_ENTRY JobLinks;
/* +0x18c */ void *LockedPagesList;
/* +0x190 */ struct LIST_ENTRY ThreadListHead;
/* +0x198 */ void *SecurityPort;
/* +0x19c */ void *PaeTop;
/* +0x1a0 */ unsigned long ActiveThreads;
/* +0x1a4 */ unsigned long GrantedAccess;
/* +0x1a8 */ unsigned long DefaultHardErrorProcessing;
/* +0x1ac */ long LastThreadExitStatus;
/* +0x1b0 */ struct PEB *Peb;
/* +0x1b4 */ unsigned long PrefetchTrace;
/* +0x1b8 */ unsigned long ReadOperationCount;
/* +0x1c0 */ unsigned long WriteOperationCount;
/* +0x1c4 */ unsigned long OtherOperationCount;
/* +0x1d0 */ unsigned long ReadTransferCount;
/* +0x1d4 */ unsigned long WriteTransferCount;
/* +0x1e0 */ unsigned long OtherTransferCount;
/* +0x1e4 */ unsigned long CommitChargeLimit;
/* +0x1ec */ unsigned long CommitChargePeak;
/* +0x1f0 */ void *AweInfo;
/* +0x1f4 */ unsigned long SeAuditProcessCreationInfo;
/* +0x1f8 */ struct MMSUPPORT Vm;
/* +0x238 */ unsigned long LastFaultCount;
/* +0x23c */ unsigned long ModifiedPageCount;
/* +0x240 */ unsigned long NumberOfVads;
/* +0x244 */ unsigned long JobStatus;
/* +0x248 */ unsigned long Flags;
/* +0x24c */ long ExitStatus;
/* +0x250 */ unsigned short NextPageColor;
/* +0x252 */ unsigned char SubSystemMinorVersion;
/* +0x253 */ unsigned char SubSystemMajorVersion;
/* +0x254 */ unsigned short SubSystemVersion;
/* +0x256 */ unsigned char PriorityClass;
/* +0x257 */ unsigned char WorkingSetAcquiredUnsafe;
/* +0x258 */ unsigned long Cookie;
};

struct CLIENT_ID {
    /* +0x000 */ void *UniqueProcess;
    /* +0x004 */ void *UniqueThread;
};

struct KAPC_STATE {
    /* +0x000 */ struct LIST_ENTRY ApcListHead[2];
    /* +0x010 */ struct KPROCESS *Process;
    /* +0x014 */ unsigned char KernelApcInProgress;
    /* +0x015 */ unsigned char KernelApcPending;
    /* +0x016 */ unsigned char UserApcPending;
    /* +0x017 */ unsigned char Trailer;
};

struct KQUEUE {
    /* +0x000 */ struct DISPATCHER_HEADER Header;
    /* +0x010 */ struct LIST_ENTRY EntryListHead;
    /* +0x018 */ unsigned long CurrentCount;
    /* +0x01c */ unsigned long MaximumCount;
    /* +0x020 */ struct LIST_ENTRY ThreadListHead;
};

struct KTIMER {
    /* +0x000 */ struct DISPATCHER_HEADER Header;
    /* +0x010 */ unsigned long long DueTime;
    /* +0x018 */ struct LIST_ENTRY TimerListEntry;
    /* +0x020 */ struct KDPC *Dpc;
    /* +0x024 */ long Period;
};

struct KAPC {
    /* +0x000 */ short Type;
    /* +0x002 */ short Size;
    /* +0x004 */ unsigned long Spare0;
    /* +0x008 */ struct KTHREAD *Thread;
    /* +0x00c */ struct LIST_ENTRY ApcListEntry;
    /* +0x014 */ void *KernelRoutine;
    /* +0x018 */ void *RundownRoutine;
    /* +0x01c */ void *NormalRoutine;
    /* +0x020 */ void *NormalContext;
}
/* +0x024 */ void                    *SystemArgument1;
/* +0x028 */ void                    *SystemArgument2;
/* +0x02c */ char                     ApcStateIndex;
/* +0x02d */ char                     ApcMode;
/* +0x02e */ unsigned char            Inserted;
/* +0x02f */ char                     Trailer;
};

struct KWAIT_BLOCK {
  struct LIST_ENTRY   WaitListEntry;
  struct KTHREAD     *Thread;
  void               *Object;
  struct KWAIT_BLOCK *NextWaitBlock;
  unsigned short      WaitKey;
  unsigned short      WaitType;
};

struct KTHREAD {
  struct DISPATCHER_HEADER  Header;
  struct LIST_ENTRY         MutantListHead;
  void                     *InitialStack;
  void                     *StackLimit;
  void                     *Teb;
  void                     *TlsArray;
  void                     *KernelStack;
  unsigned char             DebugActive;
  unsigned char             State;
  unsigned char             Alerted[2];
  unsigned char             IoPl;
  unsigned char             NpxState;
  char                      Saturation;
  char                      Priority;
  struct KAPC_STATE         ApcState;
  unsigned long             ContextSwitches;
  char                      IdleSwapBlock;
  char                      Alerted;
  struct KWAIT_BLOCK       *WaitBlockList;
  struct LIST_ENTRY         WaitListEntry;
  unsigned long             WaitTime;
  unsigned char             WaitIrql;
  char                      WaitMode;
  char                      WaitReason;
  struct KWAIT_BLOCK       *WaitBlockList;
  unsigned long             WaitListEntry;
  unsigned long             WaitTime;
  char                      BasePriority;
  char                      DecrementCount;
  char                      PriorityDecrement;
  char                      Quantum;
  struct KWAIT_BLOCK        WaitBlock[4];
  *LegoData;
  unsigned long             KernelApcDisable;
  unsigned long             UserAffinity;
  unsigned char             SystemAffinityActive;
  unsigned char             PowerState;
  unsigned char             NpxIrql1;
  unsigned char             InitialNode;
  *ServiceTable;
}
struct KQUEUE {
  struct KQUEUE *Queue;
  unsigned long ApcQueueLock;
  struct KTIMER Timer;
  struct LIST_ENTRY QueueListEntry;
  unsigned long SoftAffinity;
  unsigned long Affinity;
  unsigned char Preempted;
  unsigned char ProcessReadyQueue;
  unsigned char KernelStackResident;
  unsigned char NextProcessor;
  void *CallbackStack;
  void *Win32Thread;
  struct KAPC_STATE *ApcStatePointer[2];
  char PreviousMode;
  unsigned char EnableStackSwap;
  unsigned char LargeStack;
  unsigned char ResourceIndex;
  unsigned long KernelTime;
  unsigned long UserTime;
  struct KAPC_STATE SavedApcState;
  unsigned char Alertable;
  unsigned char ApcStateIndex;
  unsigned char ApcQueueable;
  unsigned char AutoAlignment;
  void *StackBase;
  struct KAPC SuspendApc;
  struct KSEMAPHORE SuspendSemaphore;
  struct LIST_ENTRY ThreadListEntry;
  long long CreateTime;
  long long ExitTime;
  long ExitStatus;
  struct LIST_ENTRY PostBlockList;
  void *TerminationPort;
  struct LIST_ENTRY ActiveTimerListHead;
  struct CLIENT_ID Cid;
  void *LpcReplySemaphore;
  void *LpcReplyMessage;
  void *ImpersonationInfo;
  void *IrplList;
  struct LIST_ENTRY TopLevelIrp;
  struct LIST_ENTRY DeviceToVerify;
  struct LIST_ENTRY ThreadsProcess;
  void *StartAddress;
  void *Win32StartAddress;
  struct LIST_ENTRY ThreadListEntry;
}

struct ETHREAD {
  struct KTHREAD Tcb;
  long long CreateTime;
  long long ExitTime;
  long ExitStatus;
  struct LIST_ENTRY PostBlockList;
  void *TerminationPort;
  struct LIST_ENTRY ActiveTimerListLock;
  struct LIST_ENTRY ActiveTimerListHead;
  struct CLIENT_ID Cid;
  struct KSEMAPHORE LpcReplySemaphore;
  void *LpcReplyMessage;
  void *ImpersonationInfo;
  void *IrplList;
  struct LIST_ENTRY TopLevelIrp;
  void *DeviceToVerify;
  void *ThreadsProcess;
  void *StartAddress;
  void *Win32StartAddress;
  struct LIST_ENTRY ThreadListEntry;
  long long RundownProtect;
/* +0x238 */ unsigned long        ThreadLock;
/* +0x23c */ unsigned long        LpcReplyMessageId;
/* +0x240 */ unsigned long        ReadClusterSize;
/* +0x244 */ unsigned long        GrantedAccess;
/* +0x248 */ unsigned long        CrossThreadFlags;
/* +0x24c */ unsigned long        SameThreadPasssiveFlags;
/* +0x250 */ unsigned long        SameThreadApcFlags;
/* +0x254 */ unsigned char        ForwardClusterOnly;
/* +0x255 */ unsigned char        DisablePageFaultClustering;
};

__END_DECLS

#endif

#endif

@endef
APPENDIX C.  WPMOA.C

Name: Windows Physical Memory Offline Analyzer  
File: wpmoa.c  
Version: 1.0  
Author: John Schultz  

Description: Contains main as well as functions for running the user interactive menus. Contains conversion functions for various data reported by the dissector program.

#include"wpmoa.h"

Main opens the required i/o files and controls the main menu commands. When the program is quit, main closes all opened i/o files and returns 0.

int main( int argc, char **argv ) {
    FILE * restrict imgFile = NULL;  
    char command[64];  
    char *action;  
    char argstr[32];  
    long address = 0;  
    int argint = 0;  
    int argint2 = 0;  
    int numofProcs = 0;  
    char outfile[32] = "STDOUT";
    const char welcomescreen[] =  
        "Windows Physical Memory Offline Analyzer\n"  
        "Use the help command for information\n";
    const char helpmenu[] =  
        "Commands are caseinsensitive\n"  
        "HELP - prints this menu\n"  
        "PRINT ALL|1-999 - prints information about a process\n"  
        "QUIT - exits program\n"  
        "TRANSLATE - translate a virtual address to physical address\n";
    const char usage[] =  
        "Usage: wpmoa [-f file] image\n";

    /*Open the image file, specified by last argument desired to be analyzed*/
    imgFile = fopen(argv[argc-1],"r");  
    if( imgFile == NULL )
        imgFile = fopen(argv[argc-1],"r");  
    if ( imgFile == NULL )
        puts(usage);
        exit(-1);
}
fprintf(stderr,"Error: Could not open %s!\nTry another?\n",argstr);

for( int n=1;n<argc-1;n++ ) {
    if( strcmp(argv[n],"-f") == 0 ) {
        if( strlen(argv[n+1]) > 32 ) {
            fprintf(stderr,"Error: File name too long. Cannot exceed 32 chars. Exiting...\n");
            return -1;
        }
        strncpy(outfile,argv[n+1],sizeof(outfile));
        output = fopen(outfile, "w");
        if( output == NULL ) {
            fprintf(stderr,"Error: Could not open \'%s\'! Exiting...
",outfile);
            return -1;
        }
    }
}

/*Print the welcome screen*/
system("clear");
puts(welcomescreen);

/*search the input file containing RAM image for EPROCESS blocks and report how many were found*/
numofProcs = process_count(imgFile);
printf("%i processes found in %s\n\n",numofProcs,argv[argc-1]);
struct EPROCESS *procSet[numofProcs];
enumerate_processes(imgFile,procSet);

/*user interaction loop - print command line prompt for the user to enter commands*/
while( 1 ) {
    for( int k=0;k<numofProcs;k++) {
        printf("[%i] %-16s ",k+1,procSet[k]->ImageFileName);
        if( (k+1)%4 == 0 )
            puts(""");
    }
    puts("\n");
    printf("> ");
    fgets(command,sizeof(command),stdin);
    action = strtok(command," \n");
    if( action == NULL )
        continue;
    else if( strncasecmp(action,"quit",1) == 0 ) {
        system("clear");
        break;
    }
    else if( strncasecmp(action,"help",1) == 0 )
        puts(helpmenu);
    else if( strncasecmp(action,"print",1) == 0 ) {
        action = strtok(NULL," \n");
        if( action == NULL )

56
continue;
strncpy(argstr,action,sizeof(argstr));
if( strcmpeq(argstr,"all") == 0 ) {
    for( int k=0;k<numofProcs;k++ )
        print_report(procSet,k,output);
    printf("All processes added to %s\n\n",outfile);
    continue;
}
argint = atoi(argstr);
if( argint <= numofProcs && argint > 0 ) {
    print_report(procSet,argint-1,output);
    printf("%s process added to %s\n\n",procSet[argint-1]->ImageFileName,outfile);
    if( enumerate_workingsetlist(imgFile,procSet[argint-1]) < 0) {
        puts("Working Set Files could not be created.");
    } else
        puts("Working Set File created successfully.");
} else if( strncasecmp(action,"translate",1) == 0 ) {
    printf("Virtual Address? (in hex) ");
    scanf("%x",&argint);
    printf("Page Directory? (in hex) ");
    scanf("%x",&argint2);
    address = virtual_to_physical(argint,argint2,imgFile);
    if( address != -1 )
        printf("Virtual address %#1.8x maps to physical address
%#1.8lx\n\n",argint,address);
    else
        printf("Virtual address %#1.8x does not map to a valid physical
address\n\n",argint);
} else if( strncasecmp(action,"translate",1) == 0 ) {
    sleep(3);
    system("clear");
    puts(welcomescreen);
}
/*clean up dynamic memory*/
for(int y=0;y<numofProcs;y++) {
    free(procSet[y]);
}
fclose(output);
fclose(imgFile);
return 0;
}

/****************************************************************************************************
 Prints a report of information found in the physical memory image which
 would be useful for forensic analysis
*****************************************************************************************************/
void print_report(struct EPROCESS *eprocess[], int i, FILE * restrict out) {
    const char * restrict format =
        "\nVirtual Address: 0x%1.8x  Image name: %21s\n"
        "ID: %8lu  Parent ID: %8lu  Created: %24s\n"
Virtual Size: %8lu MB  Exited: %25s

"Peak Virtual Size: %8lu MB  Page Directory: %1.8lx

"Handle count: %20s  Number of threads: %8lu

"Open Handles:
Type Name(if one exists)
%s
;

unsigned long eprocessAddress;
char handleCount[16];
char created[32];
char exited[32];
char notfoundmsg[] = "None Found";
char *handles = NULL;

/*if the current eprocess block is the first in the list, then there
is no other process in the array that points to this, so it must be
explicitly set*/
if( strncmp(eprocess[i]->ImageFileName,"System",6) == 0 )
  eprocessAddress = PS_ACTIVE_PROCESS_HEAD;
else
  eprocessAddress = (long)eprocess[i-1]->ActiveProcessLinks.Flink-0x88;

/*if the object table was not resident in physical memory, then this
fact is relayed to the user by printing Does Not Exist as the number of
handles opened by the process*/
if( eprocess[i]->ObjectTable == NULL ) {
  strncpy(handleCount,"Nonexistent",sizeof(handleCount));
} else {
  snprintf(handleCount,sizeof(handleCount),
"%lu",eprocess[i]->ObjectTable->HandleCount);
}

/*convert the times the the process was created and exited*/
win_time(eprocess[i]->CreateTime,created);
win_time(eprocess[i]->ExitTime,exited);

/*format the handle list for printing*/
if( eprocess[i]->ObjectTable == NULL )
  handles = notfoundmsg;
else
  handles = eprocess[i]->ObjectTable->DebugInfo;

/*print out the physical memory information to output user
specified*/
fprintf(out,format,
  eprocessAddress,
  eprocess[i]->ImageFileName,
  eprocess[i]->UniqueProcessId,
  eprocess[i]->InheritedFromUniqueProcessId,
  created,
  eprocess[i]->VirtualSize/1048576,
  exited,
  eprocess[i]->PeakVirtualSize/1048576,
  eprocess[i]->Pcb.DirectoryTableBase[0],
  handleCount,
  eprocess[i]->ActiveThreads,
handles);

fflush(NULL);

return;
}

/**********************************************************************
Translates virtual address to a valid physical address, if the virtual
address is mapped to a physical address.
**********************************************************************/
long virtual_to_physical(long ptr32, long pageDirBase, FILE * restrict
in) {
    if( (ptr32 & 0xf0000000) == 0x80000000 ){
        return ptr32 - KERNEL_OFFSET;
    }

    unsigned long pageDirectoryIndex = ptr32 & 0xffc00000;
    pageDirectoryIndex = pageDirectoryIndex >> 22;
    unsigned long pageTableIndex = ptr32 & 0x003ff000;
    pageTableIndex = pageTableIndex >> 12;
    unsigned long byteIndex = ptr32 & 0x00000fff;

    ptr32 = pageDirBase + pageDirectoryIndex * 4;
    fseek(in,ptr32,0);
    fread(&ptr32,4,1,in);

    if( (ptr32 & 0x00000001) != 1 ) {
        return -1;
    }

    ptr32 = (ptr32 & 0xfffff000) + pageTableIndex * 4;
    fseek(in,ptr32,0);
    fread(&ptr32,4,1,in);

    if( (ptr32 & 0x00000001) != 1 ) {
        return -1;
    }

    ptr32 = (ptr32 & 0xfffff000) + byteIndex;
    return ptr32;
}

/**********************************************************************
Convert the Windows time format to Unix format and convert the Unix
time to GMT with the existing Linux Time library functions.
Unix    epoch is 1970-01-01 00:00:00 resolution is seconds
Windows epoch is 1601-01-01 00:00:00 resolution is 100ns
**********************************************************************/
void win_time(long long winTime, char date[] ) {
    long unixTime = 0;

/*convert by subtracting the difference in time between Windows and
Unix epochs*/
unixTime = (winTime/1e7) - 11644473600;
/*if the time is zero or negative (as a result of the conversion for
example) then make the time zero and make it so the printout displays
that the time is "No time reported" This applies to both the create
time of System and the exit times of processes that have not exited
yet*/
if( unixTime <= 0 ) {
    unixTime = 0;
    strncpy(date,"No time reported",32);
} /*format the time and copy it into the date buffer for later
printing*/
else
    strftime(date,32,"%Y-%m-%d %H:%M:%S %Z",gmtime(&unixTime));

return;

/**********************************************************************
convert unicode string to ascii string and put it in tempString
**********************************************************************/
void unicode_to_ascii(char *string, unsigned short length) {
    if( length <= 0 )
        return;
    char *tempString = malloc(length/2);
    for(int m=0;m<length;m+=2) {
        memcpy(tempString+m/2,string+m,1);
    }
    memset(string,0,length);
    memcpy(string,tempString,length/2);
    free(tempString);
    return;
}

/**********************************************************************
Compares 2 4-byte numbers for greater than, less than, or equal to
condition
**********************************************************************/
int longcmp( const void *n1, const void *n2 ) {
    unsigned long a = *(unsigned long *)n1;
    unsigned long b = *(unsigned long *)n2;

    return (a < b) ? -1 : ((a == b) ? 0 : 1);
}
APPENDIX D. DISSECTOR.C

/******************************************************************************
Name: Windows Physical Memory Offline Analyzer
File: dissector.c
Version: 1.0
Author: John Schultz

Description: Houses all the functions that dissect the Windows physical memory layout and structures. Interprets the raw data into human readable information.
******************************************************************************/

#include"wpmoa.h"

#define TOTAL_TYPES 32

/*Cache the type names to avoid unnecessary file seeks and reads*/
typedef struct {
  long address;
  char name[16];
} typename;

typename typenameset[TOTAL_TYPES];
int typeCount = 0;

/******************************************************************************
Follows the active process list pointers through memory, keeping a count of how many processes exist
******************************************************************************/
int process_count(FILE * restrict in) {
  struct EPROCESS *dummyProcList;
  int count = 0;

  /*A dummy process list is used to traverse the active process list, counting the total number of processes that will be enumerated*/
  dummyProcList = malloc(sizeof(struct EPROCESS));

  fseek(in,PS_ACTIVE_PROCESS_HEAD-KERNEL_OFFSET,SEEK_SET);
  fread(dummyProcList,sizeof(struct EPROCESS),1,in);

  /*The active process list is traversed, meanwhile keeping count of how many processes will be enumerated*/
  while( 1 ) {
    if( count != 0 ) {
      fseek(in,(long)(dummyProcList->ActiveProcessLinks.Flink-KERNEL_OFFSET-0x88),SEEK_SET);
      fread(dummyProcList,sizeof(struct EPROCESS),1,in);
      if( (unsigned long)(dummyProcList->ActiveProcessLinks.Flink-0x88) == PS_ACTIVE_PROCESS_HEAD )
        break;
    }
    count++;
  }
/* clean up the dummy list */
free(dummyProcList);
return count;
}

/***************************************************************
Given the pointer to the first process in the active process list, this
function follows the list of active processes, reading and storing each
executive process block into memory (the heap).
***************************************************************
int enumerate_processes(FILE * restrict in, struct EPROCESS **processList) {
    /*create a new array of pointers to EPROCESS blocks that will exactly
    provide enough space for the processes to be enumerated in the
    following while loop*/
    processList[0] = malloc(sizeof(struct EPROCESS));

    /*read the System process block into the array*/
    fseek(in,PS_ACTIVE_PROCESS_HEAD-KERNEL_OFFSET,SEEK_SET);
    fread(processList[0],sizeof(struct EPROCESS),1,in);

    /*read and store all the executive process blocks from the RAM image
    file into
    memory*/
    int n = 0;
    while( 1 ) {
        if( n != 0 ) {
            fseek(in,(long)(processList[n-1]->ActiveProcessLinks.Flink-
            KERNEL_OFFSET-0x88),SEEK_SET);
            fread(processList[n],sizeof(struct EPROCESS),1,in);
            if( (unsigned long)(processList[n]->ActiveProcessLinks.Flink-
            0x88) ==
                PS_ACTIVE_PROCESS_HEAD )
                break;
        }

        /* enumerate the process block's handle table */
        processList[n]->ObjectTable =
        enumerate_handle_table(in,processList[n]);

        n++;
        processList[n] = malloc(sizeof(struct EPROCESS));
    }

    free(processList[n]);

    /*return number of processes found*/
    return 0;
}

/***************************************************************
Enumerate the Object Table containing a process block's opened file
handle info
Returns the pointer to dynamic memory containing the HANDLE_TABLE
structure or
void *enumerate_handle_table(FILE * restrict in, struct EPROCESS *eprocess) {
    long marker = 0;
    long subhandles[1024];
    long *subhandlePtr = subhandles;
    long currentObject = 0;
    long midhandles = 0;
    long pageDir = eprocess->Pcb.DirectoryTableBase[0];
    int numofHandles = 0;
    int typeID = 0;
    unsigned short length = 0;
    char *objNames = NULL;
    char readbuffer[PAGESIZE];
    char volName[32];
    struct OBJECT_HEADER *objectHdr = NULL;
    struct OBJECT_TYPE *objectType = NULL;
    struct FILE_OBJECT *fileObj = NULL;
    struct DEVICE_OBJECT *deviceObj = NULL;
    struct DRIVER_OBJECT *driverObj = NULL;
    struct VPB *vpbObj = NULL;
    struct ETHREAD *ethread = NULL;

    /*set marker variable to the physical address of the process Object Table*/
    marker = virtual_to_physical((long)eprocess->ObjectTable,pageDir,in);

    /*if the object table is not resident in physical memory, set it to point to NULL if it is resident, follow the link to the handle tables. Despite the name of the HandleTable field, it does not point to the actual table of handles. The TableCode field does. If the TableCode field ends in 0x0, then that address is the virtual address of the subhandle table for that process. If the field ends in 0x1, then that address points to a mid-level handle table. The mid-level handle table contains addresses of subhandle tables (up to a page of unique entries, equates to 1024 entries with typical page size of 4096 bytes)* /
    if( marker > 0 ) {
        fseek(in,marker,SEEK_SET);
        eprocess->ObjectTable = malloc(sizeof(struct HANDLE_TABLE));
        fread(eprocess->ObjectTable,sizeof(struct HANDLE_TABLE),1,in);

        marker = eprocess->ObjectTable->TableCode;

        if( (marker & 0x03) == 0 ) {
            subhandles[0] = virtual_to_physical((marker & 0xfffffffff) ,pageDir,in);
        }
        /*when the TableCode field indicates that there are more than one subhandle table, store the subhandle table addresses in the array called subhandles*/
        else if( (marker & 0x03) == 1 ) {
            midhandles = virtual_to_physical((marker & 0xffffffff) ,pageDir,in);
            marker = midhandles;
            int r = 0;
            while( r < 511 ) {
                subhandles[r] = virtual_to_physical((marker & 0xfffffffff) ,pageDir,in);
                marker = subhandles[r] + 1;
                r++;
            }
            /*if the object table indicates that there are more than one subhandle table, store the subhandle table addresses in the array called subhandles*/
        }
    }

    return NULL;
}
fseek(in,marker,SEEK_SET);
fwrite(subhandlePtr,4,1,in);
if( subhandles[r] == 0 )
    break;
subhandles[r] = virtual_to_physical((subhandles[r] & 0xffffffff8),pageDir,in);
    marker+=4;
    r++;
    subhandlePtr = &subhandles[r];
}

/*allocate memory for a name for each open file handle of the
process*/
numofHandles = eprocess->ObjectTable->HandleCount;
objNames = calloc(numofHandles,128);

/*traverse a subhandle table, then move to the next subhandle table
in the mid-level handle table until all open handles/objects have been
discovered*/
table = 0; int count = 0; int handle = 0;
while( count < numofHandles && subhandles != 0 ) {
    while( count < numofHandles && handle < 511 ) {
        /*clear the file read buffer before each use*/
        memset(readbuffer,0,sizeof(readbuffer));
        /*set the marker to the address of the object to be examined*/
        fseek(in,subhandles[table]+handle*8+8,SEEK_SET);
        fread(&marker,4,1,in);

        /*if the object's address is null (meaning this spot is a free
handle), do not count this handle and move on to the next position in
the subhandle table*/
        if( marker == 0 ) {
            handle++;
            continue;
        }

        /*translate the address from virtual to physical*/
        marker = virtual_to_physical((marker & 0xffffffff8),pageDir,in);

        /*if the physical address is not mapped then count the object and
move on to the next handle in the subhandle table*/
        if( marker == -1 ) {
            count++;
            handle++;
            continue;
        }

        /*the file location of the object pointed to by the current
subhandle position is saved for use later in determining the object's
name*/
        currentObject = marker;
    }
}

64
/* allocate and read data into memory for the object header. use the object header to determine the address of the information about the object's type */
objectHdr = malloc(sizeof(struct OBJECT_HEADER));
fseek(in,marker,SEEK_SET);
fread(objectHdr,sizeof(struct OBJECT_HEADER),1,in);
marker = (long)objectHdr->Type;

/* check the object type address cache for the read type address */
for( typeID=0;typeID<TOTAL_TYPES;typeID++ ) {
    if( marker == typenameset[typeID].address && marker != 0 ) {
        strncpy(readbuffer,typenameset[typeID].name,16);
        objNames = strncat(objNames,readbuffer,16);
        break;
    }
}
/* if the type was not already in the cache, then add it */
if( typeID == TOTAL_TYPES ) {
    /* first add the address of the object type structure */
    typenameset[typeCount].address = marker;
    /* convert the virtual address to physical */
    marker = virtual_to_physical(marker,pageDir,in);
    /* if virtual address not mapped, then ignore the object type */
    if( marker == -1 ) {
        free(objectHdr);
        count++;
        handle++;
        continue;
    }
    /* copy the object type into dynamic memory */
    objectType = malloc(sizeof(struct OBJECT_TYPE));
    fseek(in,marker,SEEK_SET);
    fread(objectType,(sizeof(struct OBJECT_TYPE)),1,in);
    /* fetch the unicode name by its address */
    marker = (long)objectType->Name.Buffer;
    marker = virtual_to_physical(marker,pageDir,in);
    if( marker == -1 ) {
        count++;
        handle++;
        free(objectHdr);
        free(objectType);
        continue;
    }
    /* read length of unicode name */
    length = objectType->Name.Length;
    /* if name has a length greater than 64, then it is deemed invalid and ignored */
    if( length > 64 || length <= 0 ) {
        handle++;
        count++;
        free(objectHdr);
        free(objectType);
        continue;
    }
fseek(in, marker, SEEK_SET);
fread(readbuffer, 1, length, in);

/*convert unicode to ascii and copy it into the cache*/
unicode_to_ascii(readbuffer, length);

strcpy(typeNamesSet[typeCount].name, readbuffer, 16);
typeCount++;

objNames = strncat(objNames, readbuffer, length/2);

free(objectType);
}

/*copy the object type name into the list of opened objects of
the current process*/
objNames = strncat(objNames, "\t", 1);

/*If the object type is a process, then fetch the process name
from the object body and add it to the list of opened objects*/
if ( strncmp(readbuffer, "Process", 7 ) == 0 ) {
    fseek(in, currentObject+0x18c, SEEK_SET);
fread(readbuffer, 16, 1, in);
readbuffer[16] = '\0';
objNames = strncat(objNames, "\t", 1);
objNames = strncat(objNames, readbuffer, 16);
objNames = strncat(objNames, "(" , 1 );
    fseek(in, currentObject+0x9c, SEEK_SET);
    fread(&marker, 1, 4, in);
sprintf(readbuffer, "%lu", marker);
objNames = strncat(objNames, readbuffer, 5);
objNames = strncat(objNames, ")", 1);
}

/*If the object type is thread, then fetch the thread's process
name and ID as well as the thread's unique ID number and add it all to
the list of opened objects*/
else if( strncmp(readbuffer, "Thread", 6 ) == 0 ) {
    ethread = malloc(sizeof(struct ETHREAD));
    fseek(in, currentObject+0x18, SEEK_SET);
fread(ethread, sizeof(struct ETHREAD), 1, in);
    marker = (long)ethread->ThreadsProcess;
    marker = virtual_to_physical(marker, pageDir, in);
    fseek(in, marker+0x174, SEEK_SET);
fread(readbuffer, 16, 1, in);
    readbuffer[16] = '\0';
    objNames = strncat(objNames, "\t", 1);
    objNames = strncat(objNames, readbuffer, 16);
    objNames = strncat(objNames, "\", 1);
    snprintf(readbuffer, 5, "%li", (long)ethread->Cid.UniqueProcess);
    objNames = strncat(objNames, readbuffer, 5);
    objNames = strncat(objNames, ");", 2);
    snprintf(readbuffer, 5, "%li", (long)ethread->Cid.UniqueThread);
    objNames = strncat(objNames, readbuffer, 5);
    free(ethread);
}

/*If the object type is File, then fetch the name, if one exists,
from the object body and add it to the list of opened objects*/
else if( strncmp(readbuffer, "File", 4 ) == 0 ) {
    fileObj = malloc(sizeof(struct FILE_OBJECT));
    fseek(in, currentObject+0x18, SEEK_SET);
fread(fileObj,sizeof(struct FILE_OBJECT),1,in);
length = fileObj->FileName.Length;
if( length <= 2 ) {
    marker = (long)fileObj->DeviceObject;
    marker = virtual_to_physical(marker,pageDir,in);
    if( marker != -1 ) {
        deviceObj = malloc(sizeof(struct DEVICE_OBJECT));
        fseek(in,marker,SEEK_SET);
        fread(deviceObj,sizeof(struct DEVICE_OBJECT),1,in);
        marker = (long)deviceObj->DriverObject;
        marker = virtual_to_physical(marker,pageDir,in);
        if( marker != -1 ) {
            driverObj = malloc(sizeof(struct DRIVER_OBJECT));
            fseek(in,marker,SEEK_SET);
            fread(driverObj,sizeof(struct DRIVER_OBJECT),1,in);
            length = driverObj->DriverName.Length;
            marker = (long)driverObj->DriverName.Buffer;
            marker = virtual_to_physical(marker,pageDir,in);
            fseek(in,marker,SEEK_SET);
            fread(readbuffer,1,length,in);
            unicode_to_ascii(readbuffer,length);
            objNames = strncat(objNames,readbuffer,length/2);
            free(deviceObj);
            free(driverObj);
        }
    }
}
/*if the name length of the file is less than 512, then it is
demed valid and will be added to the list of opened objects*/
else if(length < 512) {
    marker = (long)fileObj->Vpb;
    marker = virtual_to_physical(marker,pageDir,in);
    if( marker != -1 ) {
        vpbObj = malloc(sizeof(struct VPB));
        fseek(in,marker,SEEK_SET);
        fread(vpbObj,sizeof(struct VPB),1,in);
        memcpy(volName,vpbObj->VolumeLabel,32);
        free(vpbObj);
        unicode_to_ascii(volName,32);
        objNames = strncat(objNames,volName,16);
        marker = (long)fileObj->FileName.Buffer;
        marker = virtual_to_physical(marker,pageDir,in);
        fseek(in,marker,SEEK_SET);
        fread(readbuffer,1,length,in);
        unicode_to_ascii(readbuffer,length);
        objNames = strncat(objNames,readbuffer,length/2);
    }
}
free(fileObj);
else {
    if (strlen(readbuffer) < 8)
        objNames = strncat(objNames, "\t", 1);
    fseek(in, currentObject-0xc, SEEK_SET);
    fread(&length, 2, 1, in);
    fseek(in, currentObject-0x8, SEEK_SET);
    fread(&marker, 4, 1, in);
    marker = virtual_to_physical(marker, pageDir, in);
    if (marker != -1 && length > 0 && length < 2048) {
        memset(readbuffer, 0, sizeof(readbuffer));
        fseek(in, marker, SEEK_SET);
        fread(readbuffer, 1, length, in);
        unicode_to_ascii(readbuffer, length);
        objNames = strncat(objNames, readbuffer, length/2);
    }
}
objNames = strncat(objNames, "\n", 1);
free(objectHdr);
handle++;
count++;
}
table++;
handle = 0;
eprocess->ObjectTable->DebugInfo = objNames;
} else
    eprocess->ObjectTable = NULL;
return eprocess->ObjectTable;
}

/**************************************************************************
Function enumerates a process' working set and creates files with the contents of the working set pages in memory.
***************************************************************************/
int enumerate_workingsetlist(FILE * restrict in, struct EPROCESS *eprocess) {
    char pname[24];
    char processID[8];
    char vaddress[24];
    char fname[56];
    char fname2[64];
    char directory[24] = "mkdir ";
    char deldir[24] = "rm -rf ";
    int i = 0;
    long marker = 0;
    long pageDir = 0;
    long pid = 0;
    unsigned int n = 0;
    unsigned int wsIndex = 0;
    unsigned int wsSize = 0;
    unsigned int wsCount = 0;
    unsigned long wsEnd = 0;
    unsigned long buffer[1024];
    unsigned long *wsList = NULL;
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unsigned long start = 0;
FILE *fd = NULL;
struct MMWSL *wsl = NULL;

t = eprocess->Pcb.DirectoryTableBase[0];
wsSize = eprocess->Vm.WorkingSetSize;
wsList = malloc(wsSize*4);

/*find address of the workingsetlist structure*/
marker = (long)eprocess->Vm.VmWorkingSetList;
marker = virtual_to_physical(marker,pageDir,in);
if( marker < 0 )
    return -1;

/*read the contents of the workingsetlist structure into dynamic
memory*/
wsl = malloc(sizeof(struct MMWSL));
fseek(in,marker,SEEK_SET);
fwrite(wsl,1,sizeof(struct MMWSL),in);

wsEnd = wsl->LastInitializedWsle;

marker = (long)wsl->Wsle;
marker = virtual_to_physical(marker,pageDir,in);
if( marker < 0 ) {
    free(wsl);
    return -1;
}

fseek(in,marker,SEEK_SET);

memset(wsList,0,sizeof(wsList));
wsCount = 0;
while( wsCount < wsSize && wsIndex < wsEnd ) {
    i = -1;
    fread(buffer,4,sizeof(buffer)/4,in);
    while( wsCount < wsSize && i < 1024 ) {
        i++; wsIndex++;
        if( virtual_to_physical(buffer[i],pageDir,in) < 0 )
            continue;

        wsList[wsCount] = (buffer[i] & 0xffffffff);
        wsCount++;
    }
    fseek(in,4096,SEEK_CUR);
}

/*sort the list of virtual addresses in the working set from low to
high order*/
qsort(wsList,wsCount,4,longcmp);

/*Pool together consecutive memory locations and create files from
the data in those areas */

pid = (long)eprocess->UniqueProcessId;
snprintf(processID,sizeof(processID),"\x5f%lu",pid);
strncpy(pname,e_process->ImageFileName,sizeof(pname));
strncat(pname,processID,sizeof(pname));
strncat(directory,pname,sizeof(directory)-strlen(directory));
if( fopen(pname,"r") != NULL ) {
    strncat(deldir,pname,sizeof(deldir)-strlen(deldir));
    system(deldir);
}
  system(directory);

n = 1;

puts("Creating Working Set Files, Please Wait");

while( n < wsCount ) {

    if( wsList[n] - wsList[n-1] == 0x1000 ) {  
        if( start == 0 )  
            start = wsList[n-1];
        snprintf(vaddress,11,"/%1.8lxh",start);
        strncpy(fname,pname,sizeof(fname));
        strncat(fname,vaddress,sizeof(fname)-strlen(fname));
        fd = fopen(fname,"w");
        memcpy(buffer,\x41\x42\x43\x44",4);
        if( fd == NULL )
            return -1;
        while( ( wsList[n] & 0xfff00000) == (start & 0xfff00000) ) {
            marker = virtual_to_physical(wsList[n-1],pageDir,in);
            fseek(in,marker,SEEK_SET);
            fread(buffer,1,sizeof(buffer),in);
            fwrite(buffer,1,sizeof(buffer),fd);
            n++;
        }
        strncpy(fname2,fname,sizeof(fname2));
        strncat(fname2,\-",1);
        snprintf(vaddress,10,"/%1.8lxh",wsList[n-1]+4096);
        strncat(fname2,vaddress,sizeof(fname2)-strlen(fname2));
        rename(fname,fname2);
        fclose(fd);
        start = 0;
        if( memcmp(buffer,\x41\x42\x43\x44",4) == 0 )
            n++;
    } else
        n++;
}
free(wsl);
return 0;
APPENDIX E.  MALWARE.C

// MALWARE.cpp : Defines the entry point for the console application.
//
#include "stdafx.h"

int _tmain(int argc, _TCHAR* argv[])
{
    char string[32];

    while( 1 ) {
        scanf_s("%s",string);
        printf("%s\n",string);
        if( strcmp(string,"quit") == 0 )
            break;
    }
    puts("Hello World!");
    return 0;
}
LIST OF REFERENCES

1. Michelle Finley. “Now That Was a Nasty Worm.” Internet:
2. Robert Lemos. ““Code Red” worm claims 12,000 servers,” Internet:
3. “MSBlast echoes across the Net.” Internet: news.com.com/2009-1002_3-
   2, Oct. 20, 2005 [Apr. 24, 2006].
5. Eric Chien. “W32.Witty.Worm” Internet:
   securityresponse.symantec.com/avcenter/venc/data/w32.witty.worm.html, Mar. 22,
   2004 [Apr. 24, 2006].
6. Michael G. Noblett, Mark M. Pollitt, and Lawrence A. Presley. “Recovering and
   Examining Computer Forensic Evidence.” Forensic Science Communications, Vol. 2,
7. Chris Prosise, Kevin Mandia, and Matt Pepe. Incident Response and Computer
8. “DRFWS 2005 Forensic Challenge.” Internet:
9. Brian D. Carrier and Joe Grand. “A Hardware-Based Memory Acquisition Procedure
10. George M. Garner. “Forensic Acquisition Tools.” Internet:
11. GNU Coreutils Manual. Internet:
    http://www.gnu.org/software/coreutils/manual/html_mono/coreutils.html#Basic-
    operations [Jun. 29, 2006].
12. “DLLs, Processes, and Threads.” MSDN Library. Internet:
    msdn.microsoft.com/library/default.asp?url=/library/en-

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