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Creating a Baseline of Process Activity for Memory Forensics

GIAC (GCFA) Gold Certification

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Abstract

A component of memory forensics is the examination of running processes looking for anomalies. However, this assumes that the analyst can recognize the anomalies. A frame of reference to assist the analyst is the creation of a baseline which identifies what is expected to be present in memory for a given configuration. The analyst can use the baseline as a reference to quickly filter out expected processes and to focus on what is not expected to be there. This paper covers the creation of a baseline for Windows Server 2008 R2 with several different configurations.
1. Introduction

SANS’s Advanced Forensic Analysis and Incident Response course (Lee & Tilbury, 2013) defines a process for the examination of memory to identify indicators of compromise. It is comprised of the following six steps: identify rogue processes, analyze process objects, review network artifacts, look for evidence of code injection, check for signs of rootkits, and dump suspicious processes and drivers.

While identifying rogue processes the analyst is looking at what is running, parent processes, and when they started. Should a process be there? What is the parent process and is it what is expected? Did the process start when it was supposed to?

When analyzing process objects, the analyst examines the name of the executable, the executable’s path, the command line parameters used for starting the process, and the security identifiers associated with it. Did the executable start from the directory from which it was expected? Are the command line parameters what we expected to see? Is the context in which the process is running what is expected? That is, was it run as System or was it run as a user? The analyst can also look at dynamic link libraries (DLLs) and kernel modules, which have been loaded into memory.

Next, the analyst examines the network connections that have been established and which process they are associated with. Are there any unusual network connections? Are the network connections associated with the process expected to have initiated them?

The common thread for each of the first three steps is looking for anything unusual. However, how does one know if something is unusual? Or, to turn the question around, how does one know what is expected? Searches through the literature and the web can provide some guidance, but it only provides a starting point. One solution is to establish a baseline of what is expected and use it as a reference of what to expect. Such a baseline could be used to filter out expected processes allowing the analyst to focus on the unexpected.

This paper starts out by creating a baseline from the literature, such as Windows Internals, 6th Edition Part 1 (Russinovich, Solomon & Ionescu, 2012a) and Part 2 (Russinovich, Solomon & Ionescu, 2012b), “Know your Windows Processes or Die
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Trying” (Olsen, 2014), and The Art of Memory Forensics (Ligh, Case, Levy, and Walters, 2014). It then tests the baseline against a series of Windows 2008 R2 servers in order to validate and refine the baseline.

2. Creating and Validating a Windows Server 2008 R2 Baseline

2.1. Data Collection Approach

2.1.1. Memory Acquisition

The starting point for memory analysis is the acquisition of a memory image. There are a number of tools that can be used to acquire memory; win64dd.exe from MoonSols was used for this analysis. Best practice is to capture the memory image to an external device in order to minimize the impact the capture process has on the system being analyzed. Writing the image to a disk on the system, which is the subject of the investigation, could result in important data be overwritten and lost. Given the amount of memory being captured, this could amount to gigabytes of data. For this analysis, since we are only interested in the memory image and not the disk contents, memory was collected by running win64dd.exe from the C:\tmp directory on the hard drive of the server.

2.1.2. Memory Analysis

There are a number of tools that can be used to analyze the memory image. For the purpose of this analysis, Volatility was chosen. It is an open source memory analysis framework written in Python (Volatility Wiki, 2013).

Volatility requires the memory image format be defined when executing Volatility commands, except when analyzing a Windows XP Service Pack 2 memory image (Volatility Wiki, 2013). The format used in the analysis, Win2008R2SP1x64, was determined by running the command: vol.py -f mem.img imageinfo, where mem.img was the name of the image file being analyzed. An alternative to including the image format in every Volatility commands is to set the VOLATILITY_PROFILE environment variable using the command:
export VOLATILITY_PROFILE=Win2008R2SP1x64.

2.1.3. Server Installation

Windows Server 2008 R2 was installed in VMware Workstation 9.0 with VMware Tools installed. All variations of Windows were installed from the same installation ISO disk image. The Windows Server 2008 R2 version, obtained using the command: `systeminfo | find “OS”, was 6.1.760 Service Pack 1 Build 7601. Updates to the operating system were not applied.

2.2. Establishing an Initial Baseline

As a starting point for constructing a baseline of processes in memory one needs a basic understanding of the core processes loaded by the operating system upon boot and the processes that are loaded when a user logs on. This has been documented in detail in Windows Internals, 6th Edition Part 1 (Russinovich, Solomon & Ionescu, 2012a) and Part 2 (Russinovich, Solomon & Ionescu, 2012b). A summary of the critical Windows processes can be found in the article “Know your Windows Processes or Die Trying” (Olsen, 2014), in The Art of Memory Forensics (Ligh, Case, Levy, and Walters, 2014), as well as on the SANS DFIR Digital Forensics and Incident Response Poster (Pilkington & Lee, 2014).

The first process that appears in the process list from memory is System. System is a container for kernel processes (Ligh, Case, Levy, and Walters, 2014). It has a static process ID of 4 and no parent process. System starts the session manager (`smss.exe`) (Olsen, 2014).

`Smss.exe` is the first user-mode process of the boot sequence. It is responsible for creating sessions. Two sessions are created on boot. Session 0 contains processes owned by the system and Windows services. Session 1 contains processes owned by the user. (Ligh, Case, Levy, and Walters, 2014) `Smss.exe` starts a copy of the client/server runtime subsystem (`csrss.exe`) for each session. It starts the Windows Initialization Process (`wininit.exe`) to initialize session 0 and the Windows Logon Process (`winlogon.exe`) to initialize user sessions. Each user logon has a unique session ID that is created when they log on. When creating a new session, `smss.exe` creates a child instance of itself.
which initializes the session and then exits. For this reason, the parent process ID (PPID) of `csrss.exe`, `wininit.exe`, and `winlogon.exe` do not map back to the process ID (PID) of a process in memory (Pilkington & Lee, 2014).

`Wininit.exe` performs the user-mode initialization processes that run in session 0. These include Local Security Authority (`lsass.exe`), Load Session Manager Service (`lsm.exe`), and Service Control Manager (`services.exe`). `Lsass.exe` is responsible for the local security policy. `Lsm.exe` manages terminal server sessions, calling `smss.exe` when a new session needs to be started (Olsen, 2014).

Windows, like most operating systems, has processes that are not associated with a specific interactive user. Instead, they run independent of user logons. These are services and are started by `services.exe`. Windows does not run each service as its own process. Instead, it groups services together with common characteristics into service groups. These service groups are started using a generic process called `svchost.exe`. This is why multiple `svchost.exe` can be seen running in memory. `Svchost.exe` is launched with a `-k` parameter specifying which service group to start. We will populate the initial baseline with the major service groups defined in Windows Internals Part 1 (Russinovich, Solomon & Ionescu, 2012a) listed in Table 1.

<table>
<thead>
<tr>
<th>Service Group</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local Service</td>
<td>Local Service</td>
</tr>
<tr>
<td>LocalServiceAndNoImpersonation</td>
<td>Local Service</td>
</tr>
<tr>
<td>LocalServiceNetworkRestricted</td>
<td>Local Service</td>
</tr>
<tr>
<td>LocalServiceNoNetwork</td>
<td>Local Service</td>
</tr>
<tr>
<td>LocalSystemNetworkRestricted</td>
<td>Local System</td>
</tr>
<tr>
<td>NetworkService</td>
<td>Network Service</td>
</tr>
<tr>
<td>NetworkServiceAndNoImpersonation</td>
<td>Network Service</td>
</tr>
<tr>
<td>NetworkServiceNetworkRestricted</td>
<td>Network Service</td>
</tr>
</tbody>
</table>

**Table 1: Major Service Groupings**

An initial baseline for process memory analysis can be built using this description of the Windows boot process. Table 2 summarizes the processes one would expect to find in a memory dump for session 0.
Winlogon.exe is responsible for interactive logon processes. It launches the LogonUI.exe process which manages the user logon interaction, changing of passwords, and locking and unlocking the workstation (Russinovich, Solomon & Ionescu, 2012a). Once the user successfully authenticates, the shell process, as defined in the registry value HKLM\SOFTWARE\Microsoft\Windows NT\Current Version\Winlogon\shell, is started. The default shell process is Explorer.exe. This is started by the process Userinit, which ends once explorer.exe is started. Therefore, we should not find its parent process running. If the user’s logon is via remote desktop, rather than the console, the process rdpclip.exe will also be found in memory associated with the user’s session (Ligh, Case, Levy, and Walters, 2014).

There are three states that a user session can be in: user not logged in, user logged in from console, and user logged in remotely. Table 3 lists the processes that are expected to be seen for each of these states. It constitutes the initial baseline for user logon processes. The parent process is not listed because its parent exits and so the PPID does not track back to a process in memory. Session n refers to any user session since a user session could be session 1, session 2, etc.

<table>
<thead>
<tr>
<th>Name</th>
<th>Parent Process</th>
<th>Session</th>
<th>Event</th>
<th>Owner</th>
<th>Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>-</td>
<td>0</td>
<td>Boot</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>smss.exe</td>
<td>System</td>
<td>0</td>
<td>Boot</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>csrss.exe</td>
<td>smss.exe</td>
<td>0</td>
<td>Boot</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>wininit.exe</td>
<td>smss.exe</td>
<td>0</td>
<td>Boot</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>services.exe</td>
<td>wininit.exe</td>
<td>0</td>
<td>Boot</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>lsass.exe</td>
<td>wininit.exe</td>
<td>0</td>
<td>Boot</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>lsm.exe</td>
<td>wininit.exe</td>
<td>0</td>
<td>Boot</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>svchost.exe</td>
<td>services.exe</td>
<td>0</td>
<td>Boot</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
</tbody>
</table>

Table 2: Initial Process Baseline

<table>
<thead>
<tr>
<th>Name</th>
<th>Parent Process</th>
<th>Session</th>
<th>Owner</th>
<th>Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>User not logged in</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>csrss.exe</td>
<td>n</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
<td></td>
</tr>
<tr>
<td>winlogon.exe</td>
<td>n</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
<td></td>
</tr>
<tr>
<td>LogonUI.exe</td>
<td>winlogon.exe</td>
<td>n</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>User logged in on console</th>
</tr>
</thead>
<tbody>
<tr>
<td>csrss.exe</td>
</tr>
<tr>
<td>winlogon.exe</td>
</tr>
<tr>
<td>explorer.exe</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>User logged in remotely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gordon Fraser, <a href="mailto:Gordon.fraser@ctipc.com">Gordon.fraser@ctipc.com</a></td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Name</th>
<th>Parent Process</th>
<th>Session</th>
<th>Owner</th>
<th>Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>csrss.exe</td>
<td></td>
<td>n</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>winlogon.exe</td>
<td></td>
<td>n</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>rdpclip.exe</td>
<td>services.exe</td>
<td>n</td>
<td>User</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>explorer.exe</td>
<td></td>
<td>n</td>
<td>User</td>
<td>%SystemRoot%</td>
</tr>
</tbody>
</table>

Table 3: Initial Process Baseline for logon

In addition to processes, there are three other artifacts of interest when creating a baseline for memory forensics -- dynamic link libraries, modules, and drivers. Dynamic link libraries (DLLs) contain code and resources that are shared between multiple processes. Modules are code that is loaded into the Operating System kernel. Finally, drivers are the code that allows the computer to communicate with hardware devices (Ligh, Case, Levy, and Walters, 2014). Since each of these artifacts consists of a large number of objects, the baseline will be created from the analysis of live systems rather than from literature searches.

Another set of attributes of interest to the forensic analyst is the network connections that have been opened up by processes. These can be viewed using the netscan plugin. The network connections portion of the baseline will be built by gathering data from live systems and then analyzing it.

2.3. Testing Baseline against Generic Windows Server 2008 R2

Now that we have an initial memory baseline, we can compare it against a memory image collected from a live system in order to validate and improve it. The first Windows 2008 R2 server was built using a generic standard edition installation with the server being part of a workgroup. Since this is a fresh installation from Windows media, it is assumed that it is “clean”.

2.3.1. Identify Rogue Processes

Following the memory analysis methodology, we will start with Step 1: looking for rogue processes. Since there should be no rogue process, we are really looking for processes that are not part of our initial baseline.

The output below provides a process listing using Volatility’s pslist plugin. In order to fit it on the page the cut command was used to remove some irrelevant output.

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To separate the boot process from the logon processes, there was a gap in time between them. This is evident from the start time column, seen below.

$ vol.py -f win2008r2-01-a.img pslst | cut -c 20-76,84-104
Volatility Foundation Volatility Framework 2.3.1

```
Name | PID  | PPID | Thds | Hnds  | Sess | Start
-----------------|------|------|------|-------|------|--------
System         | 4    | 0    | 76   | 460   |      | 2014-06-22 13:26:36
srss.exe       | 324  | 316  | 9    | 335   | 0    | 2014-06-22 13:26:42
srss.exe       | 376  | 368  | 10   | 189   | 1    | 2014-06-22 13:26:43
wininit.exe    | 384  | 316  | 3    | 79    | 0    | 2014-06-22 13:26:43
winlogon.exe   | 420  | 368  | 3    | 96    | 1    | 2014-06-22 13:26:43
services.exe   | 480  | 384  | 8    | 189   | 0    | 2014-06-22 13:26:44
lsass.exe      | 488  | 384  | 6    | 530   | 0    | 2014-06-22 13:26:45
lsm.exe        | 496  | 384  | 10   | 145   | 0    | 2014-06-22 13:26:45
svchost.exe    | 588  | 480  | 11   | 345   | 0    | 2014-06-22 13:26:48
svchost.exe    | 656  | 480  | 6    | 233   | 0    | 2014-06-22 13:26:49
svchost.exe    | 744  | 480  | 13   | 288   | 0    | 2014-06-22 13:26:49
svchost.exe    | 788  | 480  | 26   | 824   | 0    | 2014-06-22 13:26:49
svchost.exe    | 836  | 480  | 10   | 508   | 0    | 2014-06-22 13:26:50
svchost.exe    | 884  | 480  | 7    | 198   | 0    | 2014-06-22 13:26:51
svchost.exe    | 928  | 480  | 16   | 429   | 0    | 2014-06-22 13:26:51
svchost.exe    | 216  | 480  | 17   | 289   | 0    | 2014-06-22 13:26:53
spoolsv.exe    | 904  | 480  | 13   | 313   | 0    | 2014-06-22 13:26:54
svchost.exe    | 1040 | 480  | 3    | 46    | 0    | 2014-06-22 13:26:56
vmtoolsd.exe   | 1096 | 480  | 9    | 253   | 0    | 2014-06-22 13:26:56
TPAutoConnSvc. | 1292 | 480  | 10   | 140   | 0    | 2014-06-22 13:26:59
dllhost.exe    | 1456 | 480  | 13   | 194   | 0    | 2014-06-22 13:27:01
msdtc.exe      | 1612 | 480  | 12   | 147   | 0    | 2014-06-22 13:27:03
svchost.exe    | 1752 | 480  | 5    | 67    | 0    | 2014-06-22 13:29:01
taskhost.exe   | 1276 | 480  | 5    | 118   | 1    | 2014-06-22 13:34:03
TPAutoConnect. | 1328 | 1292 | 5    | 126   | 1    | 2014-06-22 13:34:03
conhost.exe    | 1556 | 376  | 1    | 30    | 1    | 2014-06-22 13:34:03
dwm.exe        | 1116 | 884  | 3    | 65    | 1    | 2014-06-22 13:34:03
explorer.exe   | 848  | 968  | 15   | 478   | 1    | 2014-06-22 13:34:03
vmtoolsd.exe   | 2012 | 848  | 7    | 184   | 1    | 2014-06-22 13:34:06
cmd.exe        | 332  | 848  | 1    | 20    | 1    | 2014-06-22 13:39:31
win64dd.exe    | 868  | 332  | 2    | 49    | 1    | 2014-06-22 13:52:33
```

The bolded lines above identify those processes that are not already present in the baseline. These ones need to be examined more closely.

The servers are running on VMware Workstation, so there may be processes associated with VMware that are not part of the normal generic Windows installation. Indeed, we find three processes -- TPAutoConnSvc.exe, TPAutoConnect.exe, and vmtoolsd.exe. A clue to this association to VMware is given when examining the process information in more detail. Each of these processes is being run out of the directory C:\Program Files\VMware\VMware Tools\ as shown in the output below from the dlllist plugin.

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$ vol.py -f win2008r2-01-a.img dlllist -p 1096 | grep -B 1 -i "command line"
Volatility Foundation Volatility Framework 2.3.1
vmtoolsd.exe pid: 1096
Command line : "C:\Program Files\VMware\VMware Tools\vmtoolsd.exe"

$ vol.py -f win2008r2-01-a.img dlllist -p 1292 | grep -B 1 -i "command line"
Volatility Foundation Volatility Framework 2.3.1
TPAutoConnSvc. pid:   1292
Command line : "C:\Program Files\VMware\VMware Tools\TPAutoConnSvc.exe"

$ vol.py -f win2008r2-01-a.img dlllist -p 1328 | grep -B 1 -i "command line"
Volatility Foundation Volatility Framework 2.3.1
TPAutoConnect. pid:   1328
Command line : TPAutoConnect.exe -q -i vmware -a COM1 -F 30

The VMware Knowledge base (2014) identifies TPAutoConnect.exe and TPAutoConnSvc.exe as being started when the Virtual Printing module is installed. We can see from the pslist output that TPAutoConnSvc.exe is started by the services control manager (SCM) in session 0. TPAutoConnect.exe is started as part of the initialization of session 1 by TPAutoConnSvc.exe. The VMware tools service (vmtoolsd.exe) is installed on guest Windows operating systems (VMware, 2011). From the output of pslist, we see that there is an instance of vmtoolsd.exe running in both session 0 and session 1. Thus, these processes are added to the baseline.

Some memory artifacts are introduced by a user logon. LogonUI.exe is not present because a user is logged in. Instead, several processes associated with a successful logon are present including: taskhost.exe, conhost.exe, and dwm.exe. These processes where not part of the initial baseline. Table 4 provides a revised list of the processes that are started when a user logs on.

<table>
<thead>
<tr>
<th>Name</th>
<th>Parent Process</th>
<th>Session</th>
<th>Owner</th>
<th>Path</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>User not logged in</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>crss.exe</td>
<td></td>
<td>n</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>winlogon.exe</td>
<td></td>
<td>n</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>LogonUI.exe</td>
<td>winlogon.exe</td>
<td>n</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td><strong>User logged in on console</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>crss.exe</td>
<td></td>
<td>n</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>winlogon.exe</td>
<td></td>
<td>n</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>taskhost.exe</td>
<td>services.exe</td>
<td>n</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>TPAutoConnect.exe</td>
<td>TPAutoConnSvc.exe</td>
<td>n</td>
<td>user</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>conhost.exe</td>
<td>crss.exe</td>
<td>n</td>
<td>user</td>
<td>%SystemRoot%\System32</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Name</th>
<th>Parent Process</th>
<th>Session</th>
<th>Owner</th>
<th>Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>dwm.exe</td>
<td>svchost.exe</td>
<td>n</td>
<td>user</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>explorer.exe</td>
<td>svchost.exe</td>
<td>n</td>
<td>user</td>
<td>%SystemRoot%</td>
</tr>
<tr>
<td>vmtoolsd.exe</td>
<td>explorer.exe</td>
<td>n</td>
<td>user</td>
<td>C:\Program Files\VMware\VMware Tools\</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>User logged in remotely</td>
</tr>
<tr>
<td>csrss.exe</td>
<td></td>
<td>n</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>winlogon.exe</td>
<td>services.exe</td>
<td>n</td>
<td>Local System</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>taskhost.exe</td>
<td>TPAutoConnSvc.exe</td>
<td>n</td>
<td>user</td>
<td>C:\Program Files\VMware\VMware Tools\</td>
</tr>
<tr>
<td>TPAutoConnect.exe</td>
<td>TPAutoConnSvc.exe</td>
<td>n</td>
<td>user</td>
<td></td>
</tr>
<tr>
<td>conhost.exe</td>
<td>crsrr.exe</td>
<td>n</td>
<td>user</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>dwm.exe</td>
<td>svchost.exe</td>
<td>n</td>
<td>user</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>rdpc1ip.exe</td>
<td>services.exe</td>
<td>n</td>
<td>user</td>
<td>%SystemRoot%\System32</td>
</tr>
<tr>
<td>explorer.exe</td>
<td></td>
<td>n</td>
<td>user</td>
<td>%SystemRoot%</td>
</tr>
<tr>
<td>vmtoolsd.exe</td>
<td>explorer.exe</td>
<td>n</td>
<td>user</td>
<td>C:\Program Files\VMware\VMware Tools\</td>
</tr>
</tbody>
</table>

Table 4: Revised Process Baseline for logon

Another group of artifacts is associated with an actual memory acquisition.

Cmd.exe was run in administrative mode (PID - 332) to get a command window from which win64dd.exe (PID 868) was started to capture the memory image. When cmd.exe is run, Windows also starts up a supporting process, console host (conhost.exe - PID 1228). While these last processes are not part of the process baseline, they are taken into account when analyzing the memory image.

We also see three more processes: spoolsv.exe, dllhost.exe, and msdtc.exe, which were started by services.exe that are not part of the initial baseline. Dllhost.exe is associated with the management of Component Object Model (COM) objects (Startup Programs Database, 2014c). Msdtc.exe is the Distributed Transaction Coordinator (Startup Programs Database, 2014d). Spoolsv.exe is the spooler service and is associated with printing (Startup Programs Database, 2014e).

2.3.2. Analyze Process Objects

Step 2 in the memory analysis methodology is to examine process objects. We will use several Volatility plugins to do this starting with the dlllist plugin. Since it is
very verbose, we ran the command limiting its output to one process, `smss.exe`, which has a PID of 232. The output of this command provides information about the command used to initiate the process as well as the DLLs associated with the process, as seen below.

$ vol.py -f win2008r2-01-a.img -p 232 dlllist
Volatility Foundation Volatility Framework 2.3.1
************************************************************************
smss.exe pid: 232
Command line : \SystemRoot\System32\smss.exe

Base Size LoadCount Path
------------------ -------------- -------------- ------------------
0x0000000047a50000 0x20000 0xffff \SystemRoot\System32\smss.exe
0x0000000077120000 0x1a9000 0xffff C:\Windows\SYSTEM32\ntdll.dll

Since what we are interested in are the names of the process, the process ID, and the command line used to start the process, we can use grep to create an abbreviated output from the `dlllist` plugin that only prints out the lines with the PID and the command line, as seen below.

$ vol.py -f win2008r2-01-a.img dlllist | grep -B 1 -i "command line"
Volatility Foundation Volatility Framework 2.3.1
smss.exe pid: 232
--
csrss.exe pid: 324
Command line : %SystemRoot%\system32\csrss.exe ObjectDirectory=\Windows
SharedSection=1024,20480,768 Windows=On SubSystemType=Windows
ServerDll=basesrv,1 ServerDll=winrv:UserServerDllInitialization,3
ServerDll=winrv:ConServerDllInitialization,2 ServerDll=sxssrv,4
ProfileControl=Off MaxRequestThreads=16
--
csrss.exe pid: 376
Command line : %SystemRoot%\system32\csrss.exe ObjectDirectory=\Windows
SharedSection=1024,20480,768 Windows=On SubSystemType=Windows
ServerDll=basesrv,1 ServerDll=winrv:UserServerDllInitialization,3
ServerDll=winrv:ConServerDllInitialization,2 ServerDll=sxssrv,4
ProfileControl=Off MaxRequestThreads=16
--
wininit.exe pid: 384
Command line : wininit.exe
--
winlogon.exe pid: 420
Command line : winlogon.exe
--
services.exe pid: 480
Command line : C:\Windows\system32\services.exe
--
lsass.exe pid: 488
Command line : C:\Windows\system32\lsass.exe
--
lsm.exe pid: 496
Command line : C:\Windows\system32\lsm.exe
--

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svchost.exe pid:  588  
Command line : C:\Windows\system32\svchost.exe -k DcomLaunch

svchost.exe pid:  656  
Command line : C:\Windows\system32\svchost.exe -k RPCSS

svchost.exe pid:  744  
Command line : C:\Windows\system32\svchost.exe -k LocalServiceNetworkRestricted

svchost.exe pid:  788  
Command line : C:\Windows\system32\svchost.exe -k netsvcs

svchost.exe pid:  836  
Command line : C:\Windows\system32\svchost.exe -k LocalService

svchost.exe pid:  884  
Command line : C:\Windows\system32\svchost.exe -k LocalSystemNetworkRestricted

svchost.exe pid:  928  
Command line : C:\Windows\system32\svchost.exe -k NetworkService

svchost.exe pid:  216  
Command line : C:\Windows\system32\svchost.exe -k LocalServiceNoNetwork

spoolsv.exe pid:  904  
Command line : C:\Windows\System32\spoolsv.exe

svchost.exe pid:  1040  
Command line : C:\Windows\system32\svchost.exe -k regsvc

vmtoolsd.exe pid:  1096  
Command line : "C:\Program Files\VMware\VMware Tools\vmtoolsd.exe"

TPAutoConnSvc. pid:  1292  
Command line : "C:\Program Files\VMware\VMware Tools\TPAutoConnSvc.exe"

dllhost.exe pid:  1456  
Command line : C:\Windows\system32\dllhost.exe /Processid:{02D4B3F1-FD88-11D1-960D-00805FC79235}

msdtc.exe pid:  1612  
Command line : C:\Windows\System32\msdtc.exe

svchost.exe pid:  1752  
Command line : C:\Windows\system32\svchost.exe -k LocalServiceAndNoImpersonation

taskhost.exe pid:  1276  
Command line : "taskhost.exe"

TPAutoConnect. pid:  1328  
Command line : TPAutoConnect.exe -q -i vmware -a COM1 -F 30

crosh.exe pid:  1556  
Command line : \??\C:\Windows\system32\crosh.exe

dwm.exe pid:  1116  
Command line : "C:\Windows\system32\Dwm.exe"

explorer.exe pid:  848  
Command line : C:\Windows\Explorer.EXE

vmtoolsd.exe pid:  2012  

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Command line: "C:\Program Files\VMware\VMware Tools\vmtoolsd.exe" -n vmusr --
cmd.exe pid: 332
Command line: "C:\Windows\system32\cmd.exe" --
conhost.exe pid: 1228
Command line: \??\C:\Windows\system32\conhost.exe --
win64dd.exe pid: 868
Command line: win64dd /f win2008r2-01-a.img

We compare the output of the dlllist plugin to our baseline to validate the commands used to start processes and to identify the service groups started by services.exe. In doing so, we quickly identify three service groups: DcomLaunch, RPCSS, and regsvc; all of which are not in the baseline and need to be added.

The process analysis step includes checking to make sure the process is running under the expected account. This information is available using the getsid Volatility plugin. The example below shows the output for one process with a PID of 488.

$ vol.py -f win2008r2-01-a.img -p 488 getsids
Volatility Foundation Volatility Framework 2.3.1
lsass.exe (488): S-1-5-18 (Local System)
lsass.exe (488): S-1-5-32-544 (Administrators)
lsass.exe (488): S-1-1-0 (Everyone)
lsass.exe (488): S-1-5-11 (Authenticated Users)
lsass.exe (488): S-1-16-16384 (System Mandatory Level)

The volatility output can be shortened using the uniq command as shown below. Here is a list of each process and the account it runs under. This technique of using uniq is not perfect. A few duplicate lines show up for System, but it still simplifies the analysis process.

$ vol.py -f win2008r2-01-a.img getsids | uniq -w 18
Volatility Foundation Volatility Framework 2.3.1
System (4): S-1-5-18 (Local System)
System (4): S-1-1-0 (Everyone)
System (4): S-1-5-11 (Authenticated Users)
System (4): S-1-16-16384 (System Mandatory Level)
smss.exe (232): S-1-5-18 (Local System)
cssr.exe (324): S-1-5-18 (Local System)
cssr.exe (376): S-1-5-18 (Local System)
wininit.exe (384): S-1-5-18 (Local System)
winlogon.exe (420): S-1-5-18 (Local System)
services.exe (480): S-1-5-18 (Local System)
lsass.exe (488): S-1-5-18 (Local System)
lsass.exe (488): S-1-5-18 (Local System)
lsass.exe (488): S-1-5-18 (Local System)
svchost.exe (588): S-1-5-18 (Local System)
svchost.exe (656): S-1-5-20 (NT Authority)
svchost.exe (744): S-1-5-19 (NT Authority)
svchost.exe (788): S-1-5-18 (Local System)
svchost.exe (836): S-1-5-19 (NT Authority)
svchost.exe (884): S-1-5-18 (Local System)

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One item of note concerning the above output is that two SIDs are listed by Volatility as NT Authority. A better translation, more in line with the literature, is S-1-5-19 translates to Local Service and S-1-5-20 translates to Network Service (Microsoft Knowledge Base, 2013a). The SIDs with the long list of numbers ending in “-1000” are associated with a user. Thus, processes such as taskhost.exe, cmd.exe, and win64dd.exe are running in the user’s context.

As expected, different services started using svchost have different SIDs based on the requirements of the service group. Moreover, processes associated with the logged on user are associated with a user SID.

Another memory artifact to analyze is the DLLs. A complete list of DLLs generated by the dlllist plugin is rather lengthy. As seen earlier, it also includes other information in addition to the DLLs. We can take advantage of the fact that each line listing a DLL begins with a “0x” and produce output from the dlllist plugin which only lists the DLLs. The following command lists those lines containing a DLL and then counts them. In all, 1,411 DLLs were identified.

```
$ vol.py -f win2008r2-01-a.img dlllist | grep "^0x" | cut -c 20-37,57- | wc -l
1411
```

By examining the list of DLLs, it becomes clear very quickly that there are many duplicates which exist because many different processes use the same DLL. By sorting the list and then only displaying unique lines and ignoring case, we can trim the list down.
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For our baseline, rather than creating a table listing 370 items, we created a file that can then be compared to the output of the same command run against another memory image to look for DLLs not listed in the baseline. The file should be reviewed to make sure that there are no entries that do not belong. One entry, win64dd.exe, should be removed since it was introduced as part of the memory capture process. The command used to create the DLL baseline is:

```bash
$ vol.py -f win2008r2-01-a.img dlllist | grep "^0x" | cut -c 20-37,57- | sort | uniq -i > dll-baseline-01.lst
```

Similarly, Volatility provides a plugin to list kernel modules in memory called `modules`. Reviewing the output reveals 147 modules in memory. A similar approach was used to create a module baseline as shown below.

```bash
$ vol.py -f win2008r2-01-a.img modules | cut -c 20-40,60- | grep "0x" | sort | uniq -i > module-baseline-01.lst
```

The file should be reviewed to make sure that there are no entries that do not belong. Win64dd.sys was removed since it is an artifact of the memory capture process.

2.3.3. Review Network Artifacts

Starting with Windows Vista and Windows Server 2008 Microsoft changed the dynamic port range assignment from 1025 through 5000 to 49152 through 65535, as per the IANA recommendation (Microsoft Knowledge Base, 2013c). The Volatility `netscan` plugin provides a list of open ports and which process owns it. In the case of each
s\texttt{vchost.exe} instance, further analysis needs to be done to determine which service group owns it. For example, consider the following:

\begin{verbatim}
Volatility Foundation Volatility Framework 2.3.1
Proto  Local Address        Foreign Addr  Pid     Owner
TCPv4  0.0.0.0:49156        0.0.0.0:0     480     services.exe
TCPv6 ::::49156             ::::0         480     services.exe
TCPv4  0.0.0.0:445          0.0.0.0:0     4       System
TCPv6 ::::445               ::::0         4       System
TCPv4  0.0.0.0:47001        0.0.0.0:0     4       System
TCPv6 ::::7001              ::::0         4       System
TCPv4  0.0.0.0:49153        0.0.0.0:0     744     svchost.exe
TCPv6 ::::9153              ::::0         744     svchost.exe
TCPv4  0.0.0.0:49154        0.0.0.0:0     788     svchost.exe
TCPv6 ::::9154              ::::0         788     svchost.exe
TCPv4  0.0.0.0:49152        0.0.0.0:0     384     wininit.exe
TCPv6 ::::9152              ::::0         384     wininit.exe
TCPv4  0.0.0.0:49155        0.0.0.0:0     488     lsass.exe
TCPv6 ::::9155              ::::0         488     lsass.exe
TCPv4  0.0.0.0:49154        0.0.0.0:0     788     svchost.exe
TCPv6 ::::9154              ::::0         788     svchost.exe
UDPv4  0.0.0.0:5355         *:*          928     svchost.exe
UDPv4  0.0.0.0:0            *:*          928     svchost.exe
UDPv6 ::::0                 *:*          928     svchost.exe
UDPv4  0.0.0.0:123          *:*         836     svchost.exe
UDPv6 ::::123               *:*         836     svchost.exe
UDPv4  0.0.0.0:123          *:*         836     svchost.exe
UDPv4  0.0.0.0:0            *:*         836     svchost.exe
UDPv6 ::::0                 *:*         836     svchost.exe
UDPv4  0.0.0.0:0            *:*         836     svchost.exe
UDPv4  192.168.139.129:137 *:*         4       System
UDPv4  0.0.0.0:5355         *:*         928     svchost.exe
UDPv6 ::::5355             *:*         928     svchost.exe
\end{verbatim}

Table 5 provides a list of ports opened by Windows Server 2008 R2 as identified by the \texttt{netscan} plugin. This list establishes the initial baseline and includes some services that an organization might disable for security reasons including Server Message Block (SMB) and NETBIOS.

<table>
<thead>
<tr>
<th>Port</th>
<th>Protocol</th>
<th>Service/Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>123</td>
<td>udp</td>
<td>svchost.exe (LocalService)</td>
</tr>
<tr>
<td>135</td>
<td>tcp</td>
<td>RPCSS</td>
</tr>
<tr>
<td>137</td>
<td>udp</td>
<td>System</td>
</tr>
<tr>
<td>138</td>
<td>tcp</td>
<td>System</td>
</tr>
<tr>
<td>139</td>
<td>tcp</td>
<td>System</td>
</tr>
<tr>
<td>445</td>
<td>tcp</td>
<td>System</td>
</tr>
</tbody>
</table>

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Table 5: Initial Baseline of open ports

<table>
<thead>
<tr>
<th>PID</th>
<th>Protocol</th>
<th>Process Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5355</td>
<td>udp</td>
<td>svchost.exe (NetworkService)</td>
<td>Local Link Multicast Name Resolution (LLMNR)</td>
</tr>
<tr>
<td>47001</td>
<td>tcp</td>
<td>System</td>
<td>Windows Remote Management listener (WINRM)</td>
</tr>
<tr>
<td>49152</td>
<td>tcp</td>
<td>wininit.exe</td>
<td></td>
</tr>
<tr>
<td>49153</td>
<td>tcp</td>
<td>svchost.exe (LocalServiceNetworkRestricted)</td>
<td></td>
</tr>
<tr>
<td>49154</td>
<td>tcp</td>
<td>svchost.exe (NetworkService)</td>
<td></td>
</tr>
<tr>
<td>49155</td>
<td>tcp</td>
<td>lsass.exe</td>
<td></td>
</tr>
<tr>
<td>49156</td>
<td>tcp</td>
<td>services.exe</td>
<td></td>
</tr>
</tbody>
</table>

2.4. Testing the Baseline against a Domain Attached Windows Server 2008 R2

We repeat the process again using the new revised baseline against another system to further validate and refine it. The second Windows Server 2008 R2 server for testing the baseline against was built using the same configuration as the first with the exception that it was attached to a domain and remote logon was enabled to see what differences exist as a result. In this image two users have logged into the server, one remotely, using Microsoft Terminal Server Connection (mstsc) and one via the console. The memory image was created by the remote user.

2.4.1. Identify Rogue Processes

Our analysis starts by running the *pslist* plugin to get a listing of processes so we can identify rogue processes. Consider the following:

```
$ vol.py -f win2008r2-03-s1.img pslist | cut -c 20-53,70-76,84-114

Volatility Foundation Volatility Framework 2.3.1
Name                  PID     PPID   Sess Start
----------------------------------------------------
System                4        0       2014-07-28 01:26:59 UTC+0000
smss.exe              224      4       2014-07-28 01:26:59 UTC+0000
csrss.exe             316      308     2014-07-28 01:27:04 UTC+0000
wininit.exe           368      308     2014-07-28 01:27:04 UTC+0000
services.exe          472      368     2014-07-28 01:27:05 UTC+0000
lsass.exe             480      368     2014-07-28 01:27:05 UTC+0000
lsm.exe               488      368     2014-07-28 01:27:05 UTC+0000
svchost.exe           584      472     2014-07-28 01:27:10 UTC+0000
svchost.exe           660      472     2014-07-28 01:27:11 UTC+0000
svchost.exe           740      472     2014-07-28 01:27:11 UTC+0000
svchost.exe           796      472     2014-07-28 01:27:11 UTC+0000
svchost.exe           848      472     2014-07-28 01:27:12 UTC+0000
svchost.exe           888      472     2014-07-28 01:27:12 UTC+0000
svchost.exe           932      472     2014-07-28 01:27:13 UTC+0000
svchost.exe           236      472     2014-07-28 01:27:14 UTC+0000
```
Two new processes appear in session 0 -- spssvc.exe and TrustedInstall -- both of which were started by services.exe. Spssvc.exe is Microsoft’s software protection service and is associated with managing digital licenses for Windows and Microsoft applications (Startup Programs Database, 2014a). TrustedInstaller.exe is the Windows Modules Installer and is associated with Windows Updates (Startup Programs Database, 2014b). These processes may not have shown up in our initial baseline because it was created soon after system boot, while they were started later.

In examining the two user sessions 1 and 2, we see that they are consistent with the baseline.

2.4.2. Analyze Process Objects

Once again, we start the analysis of the process objects by running the dlllist plugin.

```sh
$ vol.py -f win2008r2-03-s1.img dlllist | grep -B 1 -i "command line"
Volatility Foundation Volatility Framework 2.3.1
smss.exe pid:     224
Command line : \SystemRoot\System32\smss.exe
```

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---
csrss.exe pid: 316
Command line: %SystemRoot%\system32\csrss.exe ObjectDirectory=\Windows
SharedSection=1024,20480,768 Windows=On SubSystemType=Windows
ServerDll=basessorv,1 ServerDll=winsrv:UserServerDllInitialization,3
ServerDll=winsrv:ConServerDllInitialization,2 ServerDll=sxssrv,4
ProfileControl=Off MaxRequestThreads=16
---
wininit.exe pid: 368
Command line: wininit.exe
---
services.exe pid: 472
Command line: C:\Windows\system32\services.exe
---
lsass.exe pid: 480
Command line: C:\Windows\system32\lsass.exe
---
lsm.exe pid: 488
Command line: C:\Windows\system32\lsm.exe
---
svchost.exe pid: 584
Command line: C:\Windows\system32\svchost.exe -k DcomLaunch
---
svchost.exe pid: 660
Command line: C:\Windows\system32\svchost.exe -k RPCSS
---
svchost.exe pid: 740
Command line: C:\Windows\system32\svchost.exe -k LocalServiceNetworkRestricted
---
svchost.exe pid: 796
Command line: C:\Windows\system32\svchost.exe -k netsvcs
---
svchost.exe pid: 848
Command line: C:\Windows\system32\svchost.exe -k LocalService
---
svchost.exe pid: 888
Command line: C:\Windows\system32\svchost.exe -k LocalSystemNetworkRestricted
---
svchost.exe pid: 932
Command line: C:\Windows\system32\svchost.exe -k NetworkService
---
svchost.exe pid: 236
Command line: C:\Windows\system32\svchost.exe -k LocalServiceNoNetwork
---
spoolsv.exe pid: 324
Command line: C:\Windows\System32\spoolsv.exe
---
svchost.exe pid: 1092
Command line: C:\Windows\system32\svchost.exe -k regsvc
---
vmtoolsd.exe pid: 1148
Command line: "C:\Program Files\VMware\VMware Tools\vmtoolsd.exe"
---
svchost.exe pid: 1412
Command line: C:\Windows\System32\svchost.exe -k termsvcs
---
svchost.exe pid: 1472
Command line: C:\Windows\system32\svchost.exe -k NetworkServiceNetworkRestricted
---
TPAutoConnSvc. pid: 1508
Command line: "C:\Program Files\VMware\VMware Tools\TPAutoConnSvc.exe"
---

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dllhost.exe pid:   1776
Command line : C:\Windows\system32\dllhost.exe /Processid:{02D4B3F1-FD88-11D1-960D-00805FC79235}
--
msdtc.exe pid:   1896
Command line : C:\Windows\System32\msdtc.exe
--
svchost.exe pid:   1204
Command line : C:\Windows\system32\svchost.exe -k
LocalServiceAndNoImpersonation
--
spssvc.exe pid:   1068
Command line : C:\Windows\system32\spssvc.exe
--
TrustedInstall pid:   252
Command line : C:\Windows\servicing\TrustedInstaller.exe
--
csrss.exe pid:   3020
Command line : %SystemRoot%\system32\csrss.exe ObjectDirectory=\Windows
SharedSection=1024,20480,768 Windows=On SubSystemType=Windows
ServerDll=basesrv,1 ServerDll=winsrv:UserServerDllInitialization,3
ServerDll=winsrv:ConServerDllInitialization,2 ServerDll=sxssrv,4
ProfileControl=Off MaxRequestThreads=16
--
winlogon.exe pid:   2896
Command line : winlogon.exe
--
taskhost.exe pid:   1264
Command line : "taskhost.exe"
--
dwm.exe pid:   2328
Command line : "C:\Windows\system32\Dwm.exe"
--
explorer.exe pid:   1284
Command line : C:\Windows\Explorer.EXE
--
vmtoolsd.exe pid:   1556
Command line : "C:\Program Files\VMware\VMware Tools\vmtoolsd.exe" -n vmusr
--
TPAutoConnect.p pid:   2712
Command line : TPAutoConnect.exe -q -i vmware -a COM1 -F 30
--
conhost.exe pid:   2856
Command line : \??\C:\Windows\system32\conhost.exe
--
csrss.exe pid:   2232
Command line : %SystemRoot%\system32\csrss.exe ObjectDirectory=\Windows
SharedSection=1024,20480,768 Windows=On SubSystemType=Windows
ServerDll=basesrv,1 ServerDll=winsrv:UserServerDllInitialization,3
ServerDll=winsrv:ConServerDllInitialization,2 ServerDll=sxssrv,4
ProfileControl=Off MaxRequestThreads=16
--
winlogon.exe pid:   2124
Command line : winlogon.exe
--
taskhost.exe pid:   2116
Command line : "taskhost.exe"
--
rdpclip.exe pid:   2108
Command line : rdpclip
--
dwm.exe pid:   2088
Command line : "C:\Windows\system32\Dwm.exe"
Two new services appear in the memory image: termsvcs and service group NetworkServiceNetworkRestricted. These would be expected upon having enabling remote desktop. All of the other processes are in our baseline and the paths for the executables are correct.

Running the getsids plugin provides the account under which the processes are running. Termsvcs and service group NetworkServiceNetworkRestricted are running under network service. All other processes are running under the expected accounts.

```bash
$ vol.py -f win2008r2-03-s1.img getsids | uniq -w 18
Volatility Foundation Volatility Framework 2.3.1
System (4): S-1-5-18 (Local System)
System (4): S-1-5-0 (Everyone)
System (4): S-1-5-11 (Authenticated Users)
System (4): S-1-16-16384 (System Mandatory Level)
smss.exe (224): S-1-5-18 (Local System)
csrss.exe (316): S-1-5-18 (Local System)
wininit.exe (368): S-1-5-18 (Local System)
services.exe (472): S-1-5-18 (Local System)
lsass.exe (480): S-1-5-18 (Local System)
lsm.exe (488): S-1-5-18 (Local System)
svchost.exe (584): S-1-5-18 (Local System)
svchost.exe (660): S-1-5-20 (NT Authority)
svchost.exe (740): S-1-5-19 (NT Authority)
svchost.exe (796): S-1-5-18 (Local System)
svchost.exe (848): S-1-5-19 (NT Authority)
svchost.exe (888): S-1-5-18 (Local System)
svchost.exe (932): S-1-5-20 (NT Authority)
svchost.exe (236): S-1-5-19 (NT Authority)
spoolsv.exe (324): S-1-5-18 (Local System)
svchost.exe (1092): S-1-5-19 (NT Authority)
vmtoolsd.exe (1148): S-1-5-18 (Local System)
svchost.exe (1412): S-1-5-20 (NT Authority)
svchost.exe (1472): S-1-5-20 (NT Authority)
TPAutoConnSvc. (1508): S-1-5-18 (Local System)
```
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Following the same process for analyzing DLLs in our second image, we identify
1990 instances. Again, this number can be reduced significantly by sorting and removing
duplicates thus reducing the population of interest to 397.

$ vol.py -f win2008r2-03-s1.img dlllist | grep "^0x" | cut -c 20-37,57- | wc -l
Volatility Foundation Volatility Framework 2.3.1
1990

$ vol.py -f win2008r2-03-s1.img dlllist | grep "^0x" | cut -c 20-37,57- | sort |
uniq -i | wc -l
Volatility Foundation Volatility Framework 2.3.1
397

Next we create a file containing the 397 DLLs in the same format as our DLL
baseline file. As a double check, the number of lines was counted using wc.

$ vol.py -f win2008r2-03-s1.img dlllist | grep "^0x" | cut -c 20-37,57- | sort |
uniq -i > dll-03.lst
Volatility Foundation Volatility Framework 2.3.1
$ cat dll-03.lst | wc -l
397

By applying the baseline against the DLL list, we can reduce the population of
DLLs to review to 37. This is a significant improvement over reviewing 1990.

$ cat dll-03.lst dll-baseline-01.lst dll-baseline-01.lst | sort | uniq -iu | wc -l

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In our analysis, we took advantage of several properties of the *uniq* command to perform the comparison. The `-i` parameter was used to ignore case. The `-u` parameter directed *uniq* to only print lines that are unique. To ensure the uniqueness was only due to the contents of the *dll-03.lst* file, the baseline file was added twice.

In reviewing the 37 DLLs, they look reasonable. Only one entry, *win64dd.exe*, should be removed as it was introduced by the memory capture process. Since they come from a clean image, a new baseline for DLLs can be created by merging the two lists.

```bash
$ cat dll-03.lst dll-baseline-01.lst | sort | uniq -i | wc -l
406
$ cat dll-03.lst dll-baseline-01.lst | sort | uniq -i > dll-baseline-02.lst
$ cat dll-baseline-02.lst | wc -l
406
```

In checking the module count for the domain attached memory image, 153 modules were found. Following the same process as with the DLLs, we quickly narrow down the modules not in the baseline to 7. This provides a much more manageable number of modules to investigate.

```bash
$ vol.py -f win2008r2-03-s1.img modules | cut -c 20-40,60- | grep "0x" | sort | uniq -i | wc -l
153
$ vol.py -f win2008r2-03-s1.img modules | cut -c 20-40,60- | grep "0x" | sort | uniq -i > module-03.lst
Volatility Foundation Volatility Framework 2.3.1
$ cat module-03.lst | wc -l
153
$ cat module-03.lst module-base-01.lst module-base-01.lst | sort | uniq -iu | wc -l
7
```

The modules, which were not in our baseline, are shown below. *Win64dd.sys* is an artifact of the memory capture process and does not belong in the baseline, as shown below. The other modules do.

```bash
$ cat module-03.lst module-base-01.lst module-base-01.lst | sort | uniq -iu
RDPDD.dll 0x48000 \SystemRoot\System32\RDPDD.dll
rdpdr.sys 0x2e000 \SystemRoot\System32\drivers\rdpdr.sys
RDPWD.SYS 0x39000 \SystemRoot\System32\Drivers\RDPWD.SYS
spsys.sys 0x71000 \SystemRoot\system32\drivers\spsys.sys
tdtcp.sys 0xb000 \SystemRoot\system32\drivers\tdtcp.sys
tssecsrv.sys 0xf000
\SystemRoot\System32\DRIVERS\tssecsrv.sys
win64dd.sys 0x11000 \??\C:\temp\windd\win64dd.sys
```

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### 2.4.3. Review Network Artifacts

Analysis of the network artifacts begins by running the *netscan* plugin.

```
$ vol.py -f win2008r2-03-s1.img netscan | cut -c 12-18,21-40,50-63,86-112 | sort | uniq -w 20
```

Volatility Foundation Volatility Framework 2.3.1

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<tr>
<th>Proto</th>
<th>Local Address</th>
<th>Foreign Addr</th>
<th>Pid</th>
<th>Owner</th>
</tr>
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<td>0.0.0.0:135</td>
<td>0.0.0.0:0</td>
<td>660</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>TCPv4</td>
<td>0.0.0.0:445</td>
<td>0.0.0.0:0</td>
<td>4</td>
<td>System</td>
</tr>
<tr>
<td>TCPv4</td>
<td>0.0.0.0:49152</td>
<td>0.0.0.0:0</td>
<td>368</td>
<td>wininit.exe</td>
</tr>
<tr>
<td>TCPv4</td>
<td>0.0.0.0:49153</td>
<td>0.0.0.0:0</td>
<td>740</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>TCPv4</td>
<td>0.0.0.0:49154</td>
<td>0.0.0.0:0</td>
<td>796</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>TCPv4</td>
<td>0.0.0.0:49173</td>
<td>0.0.0.0:0</td>
<td>472</td>
<td>services.exe</td>
</tr>
<tr>
<td>TCPv4</td>
<td>0.0.0.0:49174</td>
<td>0.0.0.0:0</td>
<td>1472</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>TCPv4</td>
<td>0.0.0.0:49178</td>
<td>0.0.0.0:0</td>
<td>480</td>
<td>lsass.exe</td>
</tr>
<tr>
<td>TCPv4</td>
<td>192.168.139.102:135</td>
<td>18d9:ef0d:80:ffff:0 CLOSED</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>TCPv6</td>
<td>::::135</td>
<td>::::0</td>
<td>660</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>TCPv6</td>
<td>::::3389</td>
<td>::::0</td>
<td>1412</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>TCPv6</td>
<td>::::445</td>
<td>::::0</td>
<td>4</td>
<td>System</td>
</tr>
<tr>
<td>TCPv6</td>
<td>::::49152</td>
<td>::::0</td>
<td>368</td>
<td>wininit.exe</td>
</tr>
<tr>
<td>TCPv6</td>
<td>::::49153</td>
<td>::::0</td>
<td>740</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>TCPv6</td>
<td>::::49154</td>
<td>::::0</td>
<td>796</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>TCPv6</td>
<td>::::49173</td>
<td>::::0</td>
<td>472</td>
<td>services.exe</td>
</tr>
<tr>
<td>TCPv6</td>
<td>::::49174</td>
<td>::::0</td>
<td>1472</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>TCPv6</td>
<td>::::49178</td>
<td>::::0</td>
<td>480</td>
<td>lsass.exe</td>
</tr>
<tr>
<td>UDPv4</td>
<td>0.0.0.0:0</td>
<td><em>:</em></td>
<td>1472</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>UDPv4</td>
<td>0.0.0.0:123</td>
<td><em>:</em></td>
<td>848</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>UDPv4</td>
<td>0.0.0.0:4500</td>
<td><em>:</em></td>
<td>796</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>UDPv4</td>
<td>0.0.0.0:500</td>
<td><em>:</em></td>
<td>796</td>
<td>svchost.exe</td>
</tr>
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<td>UDPv4</td>
<td>0.0.0.0:5355</td>
<td><em>:</em></td>
<td>932</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>UDPv4</td>
<td>127.0.0.1:57762</td>
<td><em>:</em></td>
<td>480</td>
<td>lsass.exe</td>
</tr>
<tr>
<td>UDPv4</td>
<td>127.0.0.1:65282</td>
<td><em>:</em></td>
<td>796</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>UDPv4</td>
<td>192.168.139.102:137</td>
<td><em>:</em></td>
<td>4 System</td>
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</tr>
<tr>
<td>UDPv6</td>
<td>::::0</td>
<td><em>:</em></td>
<td>1472</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>UDPv6</td>
<td>::::123</td>
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<td>svchost.exe</td>
</tr>
<tr>
<td>UDPv6</td>
<td>::::4500</td>
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<td>svchost.exe</td>
</tr>
<tr>
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<td>::::500</td>
<td><em>:</em></td>
<td>796</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>UDPv6</td>
<td>::::5355</td>
<td><em>:</em></td>
<td>932</td>
<td>svchost.exe</td>
</tr>
</tbody>
</table>

Based on the output from *netscan* and comparing it with the baseline, the ports can be divided into three categories -- general ports, ports used when the server is not domain attached, and ports used when a server is domain attached. These are summarized in Table 6. Additional work would need to be done to validate this list with additional configurations including an IIS server, domain controller, and SQL server.
<table>
<thead>
<tr>
<th>Port</th>
<th>Protocol</th>
<th>Service/Process</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>123</td>
<td>udp</td>
<td>svchost.exe (LocalService)</td>
<td>Windows Time Services</td>
</tr>
<tr>
<td>135</td>
<td>tcp</td>
<td>RPCSS</td>
<td>Terminal Services</td>
</tr>
<tr>
<td>137</td>
<td>udp</td>
<td>System</td>
<td>NETBIOS Name Resolution</td>
</tr>
<tr>
<td>138</td>
<td>tcp</td>
<td>System</td>
<td>NETBIOS Datagram Service</td>
</tr>
<tr>
<td>139</td>
<td>tcp</td>
<td>System</td>
<td>NETBIOS Session Service</td>
</tr>
<tr>
<td>445</td>
<td>tcp</td>
<td>System</td>
<td>SMB</td>
</tr>
<tr>
<td>3389</td>
<td>tcp</td>
<td>terminal services</td>
<td></td>
</tr>
<tr>
<td>5355</td>
<td>udp</td>
<td>svchost.exe (NetworkService)</td>
<td>Local Link Multicast Name Resolution (LLMNR)</td>
</tr>
<tr>
<td>47001</td>
<td>tcp</td>
<td>System</td>
<td>Windows Remote Management listener (WINRM)</td>
</tr>
<tr>
<td>49152</td>
<td>tcp</td>
<td>wininit.exe</td>
<td></td>
</tr>
<tr>
<td>49153</td>
<td>tcp</td>
<td>svchost.exe (LocalServiceNetworkRestricted)</td>
<td></td>
</tr>
<tr>
<td>49154</td>
<td>tcp</td>
<td>svchost.exe (NetworkService)</td>
<td></td>
</tr>
</tbody>
</table>

Server Not domain Attached

<table>
<thead>
<tr>
<th>Port</th>
<th>Protocol</th>
<th>Service/Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>49155</td>
<td>tcp</td>
<td>lsass.exe</td>
</tr>
<tr>
<td>49156</td>
<td>tcp</td>
<td>services.exe</td>
</tr>
</tbody>
</table>

Server Domain Attached

<table>
<thead>
<tr>
<th>Port</th>
<th>Protocol</th>
<th>Service/Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>49173</td>
<td>tcp</td>
<td>services.exe</td>
</tr>
<tr>
<td>49174</td>
<td>tcp</td>
<td>svchost.exe (NetworkServiceNetworkRestricted)</td>
</tr>
<tr>
<td>49178</td>
<td>tcp</td>
<td>lsass.exe</td>
</tr>
<tr>
<td>4500</td>
<td>udp</td>
<td>netsvcs</td>
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<tr>
<td>500</td>
<td>udp</td>
<td>netsvcs</td>
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<td>57762</td>
<td>udp</td>
<td>lsass.exe</td>
</tr>
<tr>
<td>65282</td>
<td>udp</td>
<td>netsvcs</td>
</tr>
</tbody>
</table>

Table 6: Revised Baseline of open ports

Caution must be exercised when using the network ports in the baseline. When looking at ports in the dynamic port range a different dynamic port might be assigned in a different server configuration, if another process already is using the port.

### 3. Conclusion

This paper laid out a process for building a baseline for memory analysis. The baseline documented here is only a start. More work would have to be done to validate and build upon it using additional different Windows Server 2008 R2 configurations. A
similar process could be used to build baselines for Windows 7, Windows 8, and Windows Server 2012.

The value of a baseline was demonstrated during the process of building and testing one. The baseline, by documenting the expected processes, allowed us to quickly identify processes that were not in the baseline but should have been. We could just as easily have used the baseline against the memory image of a compromised system to identify the unexpected. In looking at the processes in the process and DLL lists, we were able to quickly focus on a few processes out of dozens. The value of using a baseline was even more dramatic when we reduced the list of DLLs to examine from 1990 to 37 and the list of kernel modules from 153 to 7.

A generic baseline can be helpful for general analysis of memory images from multiple sources. For an organization, a baseline tailored to their standard configurations could save considerable time in analysis. In our baseline, we saw the effects of the baseline on artifacts introduced by our implementing the servers under VMware workstation. Other artifacts could be expected for an organization’s standard configurations like anti-virus software. Thus, establishing a baseline could save the analyst considerable time.

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4. References


Creating a Baseline of Process Activity for Memory Forensics

Gordon Fraser, Gordon.fraser@ctipc.com


## Upcoming SANS Forensics Training

<table>
<thead>
<tr>
<th>Event</th>
<th>Location</th>
<th>Dates</th>
<th>Organiser</th>
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