Integrity Validation of User Space Code

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DFRWS

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Goal

- Reduce amount of memory requiring manual analysis
- Highlight any memory that is potentially suspicious
  - e.g. malware
- Achieved by filtering out known code
Each process given its own view of memory

User Space
- Lower half of virtual memory
- 0x00000000 - 0x80000000 (2GB) on 32 bit
- Where process code and data is stored

User space memory used by the process described by the VAD Tree
Some memory is code, some memory is data
- Code must have executable permissions
  - Otherwise it will not run
- Memory permissions can be used to distinguish code and data
  - No Execute (NX) bit in Page Table Entry (PTE)
  - VAD permissions do not matter
Portable Executable (PE)
- Format used by Windows for programs and code
  - .exe, .dll, .drv etc
- Format same in memory and on disk
  - Layout is different
- Content between memory and disk not quite the same
  - Code requires updating to reflect environment
  - Relocations and imports
  - Changes not known till run time
Malware

- Common need to determine if malware is running on the system
- Numerous ways in which that malware could have been loaded
- Locating that malware can be complicated
Reducing memory requiring analysis
Example for explorer.exe on Win7
Every process on a Windows 7 system
Every process on a Windows 7 system
Proposed solution

- Build hashes of trusted code from on disk
  - e.g. a default Windows install
- Apply hashes to code in user space memory
  - Apply in a manner that takes into account imports, relocations etc.
- Remove code that passes validation from further analysis
- Reduce memory requiring analysis from whole memory image to only code that was not validated
Related Work

- Malfind [Ligh, 2009]
  - Uses VAD permissions to detect potentially injected code
  - Code capable of subverting detection exists [Keong, 2004]
- System Virginity Verifier [Rutkowska, 2005]
  - Compares contents of files on disk to contents of files in memory on a live system
  - Requires trusting contents of disk and memory simultaneously
- Walters et al. [2008]
  - Built hashes of code from on disk and applied to a memory image
  - Only able to if a page matches or not, not whether it should or should not
Building Hashes

- Parse PE files on disk
- Convert PE to virtual layout
- Normalise variable locations
  - relocations, imports, etc.
- Hash normalised page
- Output a hash, list of normalised locations and metadata for each page
- Similar to Walters et al. [2008] approach
### Sample Hashes

<table>
<thead>
<tr>
<th>Filename</th>
<th>Offset</th>
<th>Normalised Hash</th>
<th>Executable</th>
<th>To Normalise</th>
</tr>
</thead>
<tbody>
<tr>
<td>ntdll.dll</td>
<td>0</td>
<td>721652da644c8b8be9c27909f76319ca1e2c6648</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>ntdll.dll</td>
<td>32</td>
<td>0e04ac081fdd61f63a9efbf46154578da56d15cc</td>
<td>1</td>
<td>35d 4df d3a</td>
</tr>
<tr>
<td>ntdll.dll</td>
<td>45</td>
<td>d1d6e5357344dbb74957c0eec9c98cd703ab4222</td>
<td>1</td>
<td>0d2 141 190</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1bd 1e7 233</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>24e 268 289</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>33a 34f 366</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>...</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>c7c c81 c88</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>c92 c97 caf</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>cb9 cbe fa9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>fb4 fde fe8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>fed</td>
</tr>
<tr>
<td>ntdll.dll</td>
<td>5b</td>
<td>e6cc914ef3095a5a7e5f967a92a57c1c5779a806</td>
<td>1</td>
<td>fb5</td>
</tr>
</tbody>
</table>
Applying hashes

VAD Entry
0x1000000 - 0x11000000
EXECUTE_WRITECOPY
explorer.exe

Executable Allocation

Executable Page

Normalize

Normalized Page

Hash Set

Filename

Hash

Offset

Locations

Apply Hash

Result

5468697320
697320736f
6d65206669
6c6c657220
7465787420
6f6e206120

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5468697320
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6c6c657220
7465787420
6f6e206120
Applying hashes

- Apply hashing process to every executable page in the user space of every process
- Use metadata to locate correct hash before hashing
- Categorise results
  - Verified - page matched stored hash
  - Failed - page did not match stored hash
  - Unknown - no stored hash available
  - Unverifiable - known problem Windows behaviour
<table>
<thead>
<tr>
<th>PID</th>
<th>Verified</th>
<th>Failed</th>
<th>Unverifiable</th>
<th>Unknown</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>00004</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>System</td>
</tr>
<tr>
<td>00268</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>smss.exe</td>
</tr>
<tr>
<td>00372</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>csrss.exe</td>
</tr>
<tr>
<td>00764</td>
<td>85</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>svchost.exe</td>
</tr>
<tr>
<td>01110000</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>ole32.dll executable alloc (Unverifiable)</td>
</tr>
<tr>
<td>02376</td>
<td>100</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>wmpnetwk.exe</td>
</tr>
<tr>
<td>003a0000</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>ole32.dll executable alloc (Unverifiable)</td>
</tr>
<tr>
<td>6cd00000</td>
<td>47</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>msmpge2enc.dll (Executable Data)</td>
</tr>
<tr>
<td>6ced0000</td>
<td>103</td>
<td>0</td>
<td>26</td>
<td>0</td>
<td>blackbox.dll (Unverifiable / Executable Data)</td>
</tr>
<tr>
<td>6de80000</td>
<td>165</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>drmv2clt.dll (Executable Data)</td>
</tr>
<tr>
<td>6dfa0000</td>
<td>57</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>wmdrmdev.dll (Executable Data)</td>
</tr>
</tbody>
</table>

Totals

- Allocations: 2076, 0, 7, 0
- Pages: 38788, 0, 73, 0

Unverifiable Pages Breakdown

- 59 Executable Data
- 14 Default Windows Behaviour
Complications

- Windows exhibits default behaviour that cannot be verified
  - Executable pages that are not predictable
- Windows XP - data marked executable
  - Read-Only Shared Heap
  - Desktop Heaps
  - Win32k.sys Allocation
  - Winlogon.exe Allocations
- Windows 7 - obfuscated and irregular PE loading
  - blackbox.dll
  - shell32.dll in searchindexer.exe
- Transition pages
  - Page Table Entries do not have correct permission value
  - Need to query Page Frame Number database to retrieve
  - Complicates determining if a page is executable
- See paper for more details
Potential For Subversion

- Hashing process normalises part of input
  - Can these normalised locations be modified to create malware?
- Redirect program flow to external code source
  - External code source would be detected under current approach
- Replace normalised locations with malicious code
  - Code would be broken into 4 byte chunks and interleaved with normal execution
  - Difficult to create useful behaviour in this manner
- Return Orientated Programing (ROP)
  - Technique used to bypass lack of executable permissions
  - Code only exists as stack frames (data)
  - Currently only used for single function calls, not entire programs
Implemented in two parts

- Hashbuild
  - Python script to parse a filesystem for PE files and build hashes
- Hashtest
  - Volatility plugin to apply the hashes to a memory image

Time taken to build hashes
- Clean XP install - 1.5 min
- Clean Win7 install - 3.5 min

Time taken to test hashes against an image
- XP 256MB image - 30s
- Win7 1GB image - 2min
Experimental Setup

- Tested against Windows XP SP3 and Windows 7 SP1
- Tested against malware and application dataset for each OS
- Images created with virtual machines
  - Each malware sample examined to ensure it executed correctly
## Malware Results - XP

<table>
<thead>
<tr>
<th>Malware</th>
<th>Executable Pages</th>
<th>Pages Failed</th>
<th>Pages Verified</th>
<th>Executable PE Data</th>
<th>Unverifiable Allocations</th>
<th>Unknown Allocations</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Sample</td>
<td>18701</td>
<td>0</td>
<td>100.00%</td>
<td>0</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Cridex.B</td>
<td>18808</td>
<td>38</td>
<td>99.80%</td>
<td>0</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>Cridex.E</td>
<td>16964</td>
<td>28</td>
<td>99.83%</td>
<td>0</td>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td>Dexter</td>
<td>37506</td>
<td>0</td>
<td>100.00%</td>
<td>0</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>NGRBot</td>
<td>19700</td>
<td>332</td>
<td>98.31%</td>
<td>0</td>
<td>25</td>
<td>44</td>
</tr>
<tr>
<td>Shylock</td>
<td>19583</td>
<td>30</td>
<td>99.85%</td>
<td>0</td>
<td>25</td>
<td>7</td>
</tr>
<tr>
<td>Spyeye</td>
<td>18564</td>
<td>107</td>
<td>99.42%</td>
<td>0</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>TDL3</td>
<td>19719</td>
<td>14</td>
<td>99.93%</td>
<td>0</td>
<td>25</td>
<td>49</td>
</tr>
<tr>
<td>TDL4</td>
<td>19911</td>
<td>14</td>
<td>99.93%</td>
<td>0</td>
<td>25</td>
<td>52</td>
</tr>
<tr>
<td>Vobfus</td>
<td>18322</td>
<td>0</td>
<td>100.00%</td>
<td>0</td>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td>ZeroAccess</td>
<td>19644</td>
<td>0</td>
<td>100.00%</td>
<td>0</td>
<td>25</td>
<td>10</td>
</tr>
</tbody>
</table>
## Application Results - Win 7

<table>
<thead>
<tr>
<th>Program</th>
<th>Executable Pages</th>
<th>Pages Failed</th>
<th>Pages Verified</th>
<th>Executable PE Data</th>
<th>Unverifiable Allocations</th>
<th>Unknown Allocations</th>
</tr>
</thead>
<tbody>
<tr>
<td>7zip</td>
<td>583</td>
<td>0</td>
<td>100.00%</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Adobe Reader</td>
<td>3478</td>
<td>42</td>
<td>98.79%</td>
<td>0</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>Chrome</td>
<td>10867</td>
<td>9</td>
<td>99.92%</td>
<td>32</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Excel</td>
<td>2419</td>
<td>6</td>
<td>99.75%</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Firefox</td>
<td>4480</td>
<td>5</td>
<td>99.89%</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Google Talk</td>
<td>2951</td>
<td>0</td>
<td>100.00%</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Internet Explorer</td>
<td>3794</td>
<td>27</td>
<td>99.29%</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>iTunes</td>
<td>5991</td>
<td>0</td>
<td>100.00%</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Notepad++</td>
<td>1651</td>
<td>0</td>
<td>100.00%</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Outlook</td>
<td>6981</td>
<td>11</td>
<td>99.84%</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Pidgin</td>
<td>2720</td>
<td>0</td>
<td>100.00%</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Powerpoint</td>
<td>3558</td>
<td>2023</td>
<td>43.14%</td>
<td>972</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Skype</td>
<td>7320</td>
<td>4216</td>
<td>42.40%</td>
<td>262</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Thunderbird</td>
<td>4247</td>
<td>5</td>
<td>99.88%</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>VLC</td>
<td>2073</td>
<td>0</td>
<td>100.00%</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Winamp</td>
<td>3810</td>
<td>0</td>
<td>100.00%</td>
<td>0</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>Windows Media Player</td>
<td>3160</td>
<td>1</td>
<td>99.97%</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Winrar</td>
<td>1457</td>
<td>0</td>
<td>100.00%</td>
<td>11</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Wordpad</td>
<td>1545</td>
<td>0</td>
<td>100.00%</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Word</td>
<td>3403</td>
<td>9</td>
<td>99.74%</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>
Results

- Introduction of malware detected in all samples
  - Each introduced unknown allocations
  - Some changed existing pages
- Detected unknown code not found using Malfind
  - Executable pages in non-executable allocations
- Significant reduction in memory requiring analysis
  - $\sim 39,000$ pages down to $\sim 75$ on default Windows 7 system
Limitations

- Many applications introduced noise into this process
  - Some applications introduced unknown allocations
  - Packed application performance poor
- Does not take into account interpreted / JIT code
Conclusion

- Approach for validating the integrity of code in user space memory
  - Allows the reduction of memory requiring manual analysis
- Analysis of default Windows behaviour
- Implementation as a Volatility plugin
Future Work

- Other Windows versions
  - x64 / ARM
  - Vista and 8
- Kernel memory
  - Conversion of techniques for kernel memory
- Alternative hash building methods
  - Memory based or virtual machine based approaches
Questions

- Code
  - https://github.com/a-white/
- Questions?

