Surveying The User Space Through User Allocations

Andrew White, Bradley Schatz, Ernest Foo
Queensland University of Technology
Brisbane Australia

DFRWS

6th August 2012

Contributions

- Framework for describing userspace memory
- Analysis of metadata sources for userspace memory
- Implementation of analysis and framework as a Volatility plugin

Cavet

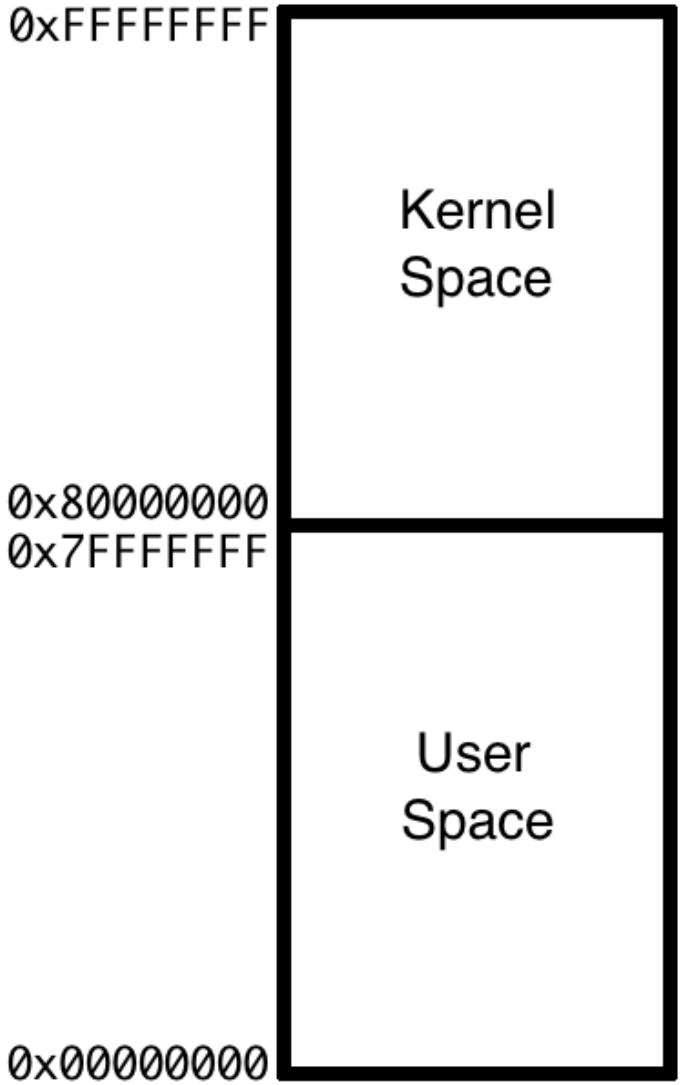
- All memory related information in this talk relates to 32-bit Windows in default configurations

Physical and Virtual Memory

- Physical memory
  - The amount of physical RAM a machine has available, eg 2GB
- Virtual memory
  - The memory address space presented to each process by the system
  - 4GB on 32-bit Windows
- Provides numerous advantages to the system, eg isolation of kernel and user space code

Kernel and User Space

- Kernel Space
  - Where code and data required by the operating system is stored
    - E.g. Processes, Sockets, Drivers
- User Space
  - Where code and data required by a process is stored
    - E.g. Threads, EXE/DLLs, Heaps



Problem

- Memory forensic research has focused on:
  - Kernel space memory
  - Recreation of live response tools
  - Locating specific data structures
- While all valuable contributions, research has mostly ignored:
  - User space memory
  - Improving how memory is explored

Motivation

- Difficult to find specific information used by a process
  - E.g. encryption keys, passwords
  - Currently would have to reverse the program or search memory with strings
- Identifying user space malware
  - Current artefact-based techniques will only last so long
  - Facilitate the development of new techniques

Related Work

- Memparser (Betz, 2005) - PEB, Loaded modules, Process Parameters
- Dolan-Gavitt (2007) - VAD Tree, File Objects
- Arasth and Debbabi (2007) - TEB, Stacks

User Allocations

- Windows memory manager tracks user space memory allocations using Virtual Address Descriptors (VADs)
- Each process has its own tree structure of VADs to store information about the memory being allocated
  - The address range, permissions, etc.
- We term each of the allocated memory ranges that a VAD describes a *user allocation*
- We use these user allocations as a framework within which to explore user space memory

Assumptions

- Does the VAD Tree really describe *all* user allocations?
- The answer - not quite
  - Every process on WinXP SP3 and Win7 SP1 has one user allocation at 0x7FFE0000 not described by the VAD Tree
  - Each of these user allocations map to the same physical page
  - Contains the _KUSER_SHARED_DATA structure
- Possible that malicious code could use memory without a VAD in the same way
  - Such allocations need to be checked for when using the VAD Tree

Data versus Metadata

- Each user allocation contains data of some sort

0000	C8000000	C7010000	FFEEFFEE	02100000
0010	00000000	00FE0000	00001000	00200000
0020	00020000	00200000	09060000	FFEFFD7F
0030	02000806	00000000	00000000	00000000

- In order to understand that data, we need metadata about what that data represents

0000	C8000000 C7010000		FFEEFFEE	02100000
0010	00000000 00FE0000		00001000	00200000
0020	00020000	00200000	09060000	FFEFFD7F
0030	02000806	0000 0000	00000000 00000000	

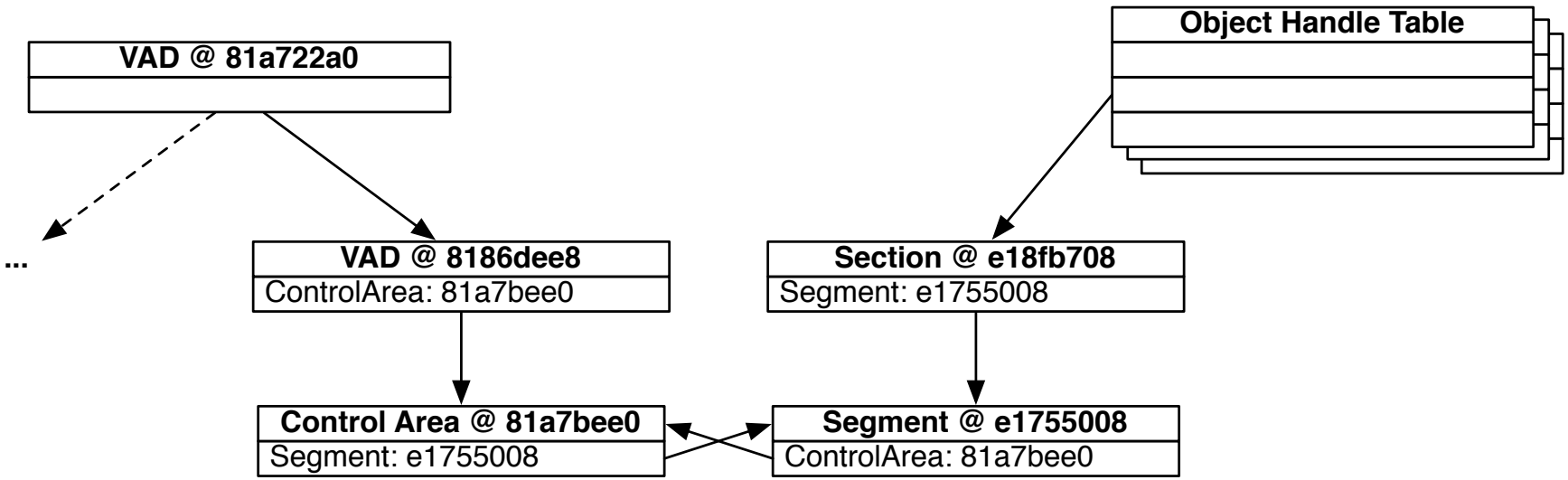
Metadata Types

- Structural
  - Describes the structure the data is stored in
  - Allows us to find specific objects
- Descriptive
  - Describes what the data represents
  - Allows us to determine the purpose of the user allocation
- While ideally we want both, sometimes we can only find one or the other
- The metadata we find can be categorized based on its origin
  - Kernel or user space

Kernel Space Metadata Sources

- VADs have two types
  - Private - Exists only in this address space
  - Mapped - Exists in multiple address spaces
  - Indicated by whether VAD references a ControlArea
- File Objects
  - Memory mapped files
- Sections
  - Represents shared memory
  - Indicates that processes are communicating in some way
  - Can be found by parsing the object manager

Mapping a Section to a VAD



User Space Metadata Sources

- Process Environment Block (PEB)
  - Allows the location of numerous data structures
  - Heaps, Code Pages, Activation Contexts, Shim Data, etc.
- Thread Environment Block (TEB)
  - Stacks, Threads
- Heaps
  - Some heap structures occupy their own user allocation
  - Heap Segments, Heap Virtual Allocations

Using Metadata

- Link metadata to its relevant user allocation
  - Reveals content or purpose of the allocation
- The metadata allows us to narrow the search range for data of interest
  - E.g. user data
    - Search only data storage user allocations, eg heaps, stacks, files
    - Can safely ignore code and default process user allocations, e.g. EXE/DLLs, activation contexts, code pages

Implementation

- Implemented analysis of metadata sources as a Volatility plugin
- Userspace.py
  - Links user allocations with related metadata
  - Allows content or purpose of user allocation to be known
  - Tested on WinXP SP3 x86 and Win7 SP1 x86
- Created two versions for evaluation purposes
  - Existing.py - Only metadata previous research could identify
  - Userspace.py - Metadata our research additionally identifies

malloc.exe on WinXP SP3 - Existing.py

Start	End	Used	Size	Permission	Type	Description
00010000	00010fff	00001000	00001000	READWRITE	Private	
00020000	00020fff	00001000	00001000	READWRITE	Private	Parameters
00030000	0012ffff	00002000	00100000	READWRITE	Private	Stack (Thread 1)
00130000	00132fff	00002000	00003000	READONLY	Mapped	
00140000	0023ffff	00004000	00100000	READWRITE	Private	
00240000	0024ffff	00003000	00010000	READWRITE	Private	
00250000	0025ffff	00002000	00010000	READWRITE	Mapped	
00260000	00275fff	00005000	00016000	READONLY	Mapped	\WINDOWS\system32\unicode.nls
00280000	002c0fff	00001000	00041000	READONLY	Mapped	\WINDOWS\system32\locale.nls
002d0000	00310fff	00000000	00041000	READONLY	Mapped	\WINDOWS\system32\sortkey.nls
00320000	00325fff	00004000	00006000	READONLY	Mapped	\WINDOWS\system32\sorttbls.nls
00330000	0033ffff	00005000	00010000	READWRITE	Private	
00340000	00342fff	00002000	00003000	READONLY	Mapped	\WINDOWS\system32\ctype.nls
00350000	003d0fff	00081000	00081000	READWRITE	Private	
00400000	0040efff	0000e000	0000f000	EXECUTE_WRITECOPY	Mapped	\Documents and Settings\xp\malloc.exe
7c800000	7c8f5fff	0002b000	000f6000	EXECUTE_WRITECOPY	Mapped	\WINDOWS\system32\kernel32.dll
7c900000	7c9b1fff	0002f000	000b2000	EXECUTE_WRITECOPY	Mapped	\WINDOWS\system32\ntdll.dll
7f6f0000	7f7effff	00002000	00100000	EXECUTE_READ	Mapped	
7ffb0000	7ffd3fff	00005000	00024000	READONLY	Mapped	
7ffd7000	7ffd7fff	00001000	00001000	READWRITE	Private	PEB
7ffdf000	7ffdffff	00001000	00001000	READWRITE	Private	TEB (Thread 1)

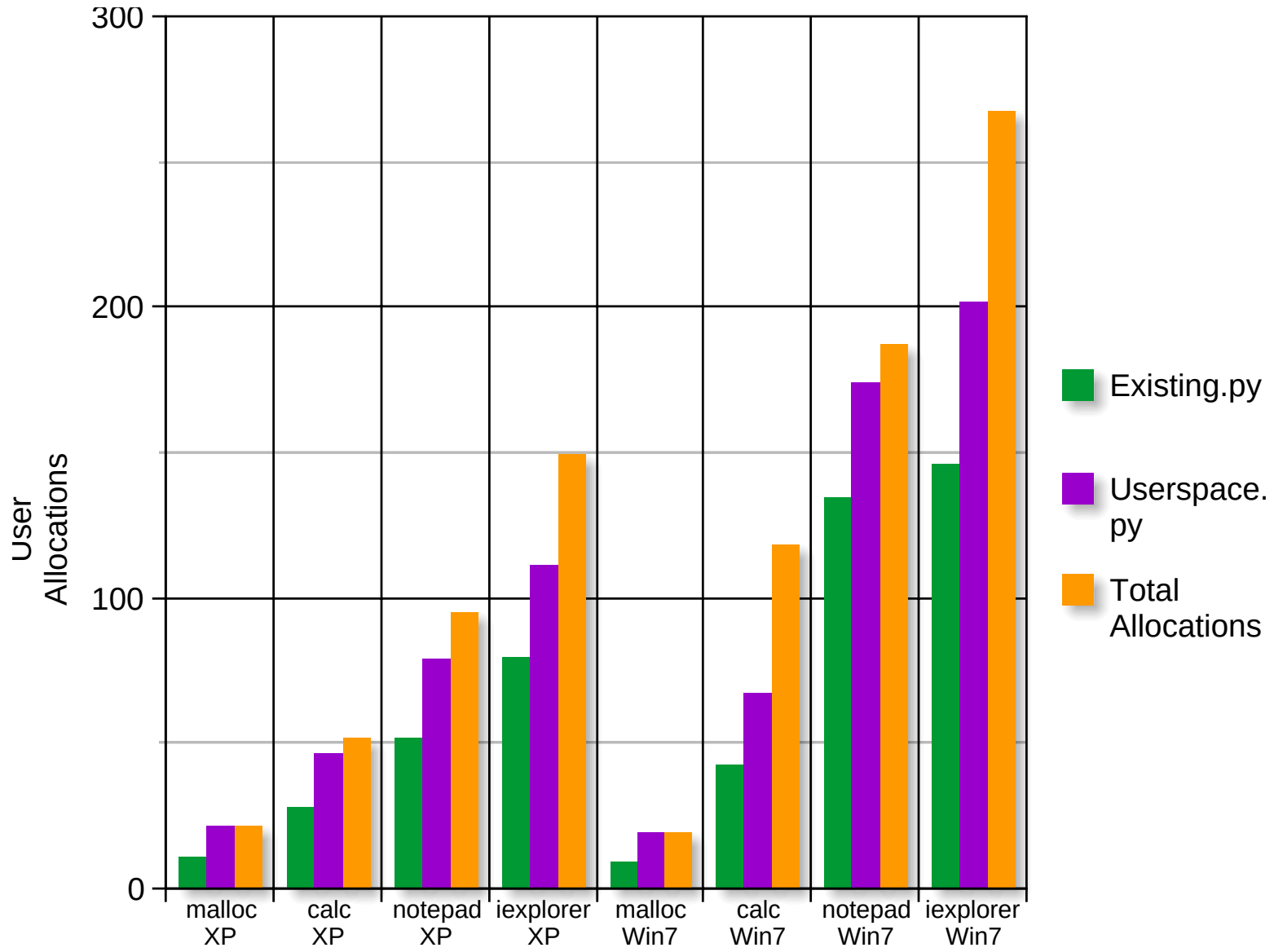
malloc.exe on WinXP SP3 - Userspace.py

Start	End	Used	Size	Permission	Type	Description
00010000	00010fff	00001000	00001000	READWRITE	Private	Environment
00020000	00020fff	00001000	00001000	READWRITE	Private	Parameters
00030000	0012ffff	00002000	00100000	READWRITE	Private	Stack (Thread 1)
00130000	00132fff	00002000	00003000	READONLY	Mapped	SystemDefaultActivationContextData Section - PID 00584, Name ''
00140000	0023ffff	00004000	00100000	READWRITE	Private	Heap 0
00240000	0024ffff	00003000	00010000	READWRITE	Private	Heap 1
00250000	0025ffff	00002000	00010000	READWRITE	Mapped	Heap 2
00260000	00275fff	00005000	00016000	READONLY	Mapped	\WINDOWS\system32\unicode.nls Section - PID 00584, Name 'NlsSectionUnicode'
00280000	002c0fff	00001000	00041000	READONLY	Mapped	\WINDOWS\system32\locale.nls Section - PID 00584, Name 'NlsSectionLocale'
002d0000	00310fff	00000000	00041000	READONLY	Mapped	\WINDOWS\system32\sortkey.nls Section - PID 00584, Name 'NlsSectionSortkey'
00320000	00325fff	00004000	00006000	READONLY	Mapped	\WINDOWS\system32\sorttbls.nls Section - PID 00584, Name 'NlsSectionSortTbls'
00330000	0033ffff	00005000	00010000	READWRITE	Private	Heap 3
00340000	00342fff	00002000	00003000	READONLY	Mapped	\WINDOWS\system32\ctype.nls Section - PID 00584, Name 'NlsSectionCType'
00350000	003d0fff	00081000	00081000	READWRITE	Private	Virtual Alloc of Heap 3
00400000	0040efff	0000e000	0000f000	EXECUTE_WRITECOPY	Mapped	\Documents and Settings\xp\malloc.exe
7c800000	7c8f5fff	0002b000	000f6000	EXECUTE_WRITECOPY	Mapped	\WINDOWS\system32\kernel32.dll
7c900000	7c9b1fff	0002f000	000b2000	EXECUTE_WRITECOPY	Mapped	\WINDOWS\system32\ntdll.dll
7f6f0000	7f7effff	00002000	00100000	EXECUTE_READ	Mapped	Shared Heap Section - PID 00584, Name ''
7ffb0000	7ffd3fff	00005000	00024000	READONLY	Mapped	Code Page
7ffd7000	7ffd7fff	00001000	00001000	READWRITE	Private	PEB
7ffdf000	7ffdffff	00001000	00001000	READWRITE	Private	TEB (Thread 1)
7ffe0000	7ffe0fff	00001000	00001000	N/A	N/A	User Shared Data

Plugin Comparison

- Compared results of existing.py and userspace.py on a number of processes
  - malloc.exe - extremely simple C program that allocates memory
  - calc.exe, notepad.exe, iexplorer.exe - standard Windows applications
  - For Windows programs, default OS versions were used
  - All programs run through basic usage scenarios
- Averaged results across multiple runs on different VMs with different memory configurations
- Compared to average number of user allocations from each process
  - Determined from analysis of VAD Tree and completeness scan

Allocations explained by existing.py and userspace.py



Limitations

- In general, the more complex the application, the lower the percentage of user allocations that were explained
- Two possible explanations
  - Metadata for unexplained allocations does not exist
  - Metadata for unexplained allocations exist in an unexaminated source of metadata

Conclusion

- Framework for analysis of user space memory
- Analysis of user space memory metadata sources
- Implementation as a Volatilty plugin
- Facilitate future analysis of user space memory

Future Work

- Increase the granularity of analysis
  - Physical -> Virtual -> Allocations -> Objects
  - Object identification
  - Use new information to improve malware detection
- Resistance of metadata to malicious modification
- 64-bit / Windows 8 support

Questions?

- Code available at `http://github.com/a-white/`
- Slides available at `http://tinyurl.com/dfrws-a-white`
- Questions?

Bibliography

- Arasteh AR, Debbabi M. Forensic memory analysis: From stack and code to execution history. Digital Investigation 2007;4(S1):114-25.
- Betz C. MemParser. `http://www.dfrws.org/2005/challenge/memparser.shtml`; 2005.
- Dolan-Gavitt B. The VAD tree: A process-eye view of physical memory. Digital Investigation 2007;4(S1):62-4.

More sample output [1/3]

Start	End	Used	Size	Permission	Type	Description
00010000	0001ffff	00001000	00010000	READWRITE	Mapped	Heap 1
00020000	00022fff	00003000	00003000	WRITECOPY	Mapped	\Windows\System32\en-US\notepad.exe.mui
00030000	00033fff	00004000	00004000	READONLY	Mapped	SystemDefaultActivationContextData Section - PID 00356, Name ‘’
00040000	00041fff	00002000	00002000	READONLY	Mapped	ActivationContextData Section - PID 00356, Name ‘’
00050000	00050fff	00001000	00001000	READWRITE	Private	pContextData
00060000	00060fff	00001000	00001000	READWRITE	Private	(GDI Data)
00070000	00070fff	00001000	00001000	READWRITE	Private	(GDI Data)
00080000	00080fff	00001000	00001000	READWRITE	Mapped	Section - PID 00308, Name ‘windows_shell_global_
00090000	00091fff	00002000	00002000	READONLY	Mapped	Section - PID 00356, Name ‘’
000c0000	001bffff	00027000	00100000	READWRITE	Private	Heap 0 (GDI Data)
001d0000	0020ffff	00003000	00040000	READWRITE	Private	Stack of Thread 0
00210000	00276fff	00030000	00067000	READONLY	Mapped	\Windows\System32\locale.nls
00280000	00347fff	00005000	000c8000	READONLY	Mapped	
00390000	0039ffff	00001000	00010000	READWRITE	Private	Heap 3
003a0000	0041ffff	00001000	00080000	READWRITE	Private	
00440000	0044ffff	00003000	00010000	READWRITE	Private	Heap 2
00450000	00550fff	0000b000	00101000	READONLY	Private	GdiSharedHandleTable
00560000	0063efff	00053000	000df000	READONLY	Mapped	Section - PID 00308, Name ‘’
00700000	0073ffff	00010000	00040000	READWRITE	Private	Heap 4
00830000	0086ffff	00014000	00040000	READWRITE	Private	Heap 5
00870000	00b3efff	0001f000	002cf000	READONLY	Mapped	\Windows\Globalization\Sorting\SortDefault.nls
00c00000	00c2ffff	0000f000	00030000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\notepad.exe
00c30000	0182ffff	0000e000	00c00000	READONLY	Mapped	
01830000	0215ffff	0003e000	00930000	READONLY	Mapped	\Windows\Fonts\StaticCache.dat Section - PID 00308, Name ‘’

More sample output [2/3]

Start	End	Used	Size	Permission	Type	Description
72e00000	72e50fff	00013000	00051000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\winspool.drv
73a00000	73a12fff	00009000	00013000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\dwmapi.dll
73d30000	73d6ffff	0001c000	00040000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\uxtheme.dll
73eb0000	7404dfff	0003c000	0019e000	EXECUTE_WRITECOPY	Mapped	\Windows\winsxs\x86_microsoft.windows.common-[..
74420000	74428fff	00007000	00009000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\version.dll
74e70000	74e7bfff	00008000	0000c000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\cryptbase.dll
74fd0000	75019fff	0001d000	0004a000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\KernelBase.dll
75220000	752bcfff	00043000	0009d000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\usp10.dll
752c0000	7536bfff	0001c000	000ac000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\msvcrt.dll
75370000	754cbfff	00019000	0015c000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\ole32.dll
754d0000	7551dfff	00015000	0004e000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\gdi32.dll
75520000	75576fff	00010000	00057000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\shlwapi.dll
758f0000	75990fff	00013000	000a1000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\rpcrt4.dll
75a00000	75ad3fff	00029000	000d4000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\kernel32.dll
75ae0000	75b6efff	0000b000	0008f000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\oleaut32.dll
75b70000	767b9fff	00017000	00c4a000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\shell32.dll
767c0000	76888fff	00028000	000c9000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\user32.dll
76a90000	76b0afff	00008000	0007b000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\comdlg32.dll
76cb0000	76d4ffff	00011000	000a0000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\advapi32.dll
76d50000	76d59fff	00007000	0000a000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\lpk.dll
76d60000	76d7efff	0000a000	0001f000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\imm32.dll
76dd0000	76f0bfff	0005d000	0013c000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\ntdll.dll
76f10000	76f28fff	00008000	00019000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\sechost.dll
76f30000	76ffbfff	00025000	000cc000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\msctf.dll
77010000	77010fff	00001000	00001000	EXECUTE_WRITECOPY	Mapped	\Windows\System32\apisetschema.dll

More sample output [3/3]

```
Start    End      Used     Size     Permission       Type     Description
-------- -------- -------- -------- ---------------- -------- ---------------------------------------------
7f6f0000 7f7effff 00005000 00100000 READONLY         Mapped   Heap 6 (Shared)
                                                               Section - PID 00356, Name 'SharedSection'
7ffb0000 7ffd2fff 00013000 00023000 READONLY         Mapped   Code Page
7ffd4000 7ffd4fff 00001000 00001000 READWRITE        Private  PEB
7ffdf000 7ffdffff 00001000 00001000 READWRITE        Private  TEB (Thread 0)
7ffe0000 7ffe0fff 00001000 00001000 N/A              N/A      KSHARED_USER_DATA

Unreferenced Pages
Start    Size
```

Figure: *Userspace.py* running against *notepad.exe* on Windows 7.