Pre-boot RAM acquisition and compression

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Why memory forensics?

• What was the user doing?
• What applications were running?
• Is the system infected with malware?
Why memory forensics?

• What was the user doing?
• What applications were running?
• Is the system infected with malware?

• Cryptokeys!
(Cold) boot attack

• Demonstrated in 2008 by Halderman et al.
  – “Lest We Remember: Cold Boot Attacks on Encryption Keys”
(Cold) boot attack

- msramdmp

- `{bios, efi}_memimage`

- Boot minimal OS?
Open challenges

• What if we want to acquire evidence from:
  – Many systems?
  – Both memory **and** disk?
  – Over the network?
  – Systems with 4G+ RAM?
Related work

- Bootable Linux CD / PXE for remote acquisition of multiple computers. (Cortjens 2014)

- Remote data acquisition on block devices in large environments. (van den Haak 2014)
Research question

“Is pre-boot compression a useful technique to reduce the destruction of data when an operating system is loaded?”
Goals

- Overwrite as little as possible
- Support >4G
- PXE & USB
- In a reasonable timeframe
Proposed solution

• Compress RAM content before starting OS

• Start Linux based OS

• Extract compressed data from RAM
Steps

• Analysis of RAM content (Shannon Entropy)

• Selection of data compression algorithm

• Development of acquisition algorithm

• Development of Proof of Concept
RAM entropy

- 12 Dump from VMs
  - 256 MiB – 8 GiB
  - Windows & Linux
  - Several roles (desktop, server, live CD)

- Shannon Entropy ($H$)
  - In bits / byte of data

- Measured over whole RAM and in blocks
  - 4 & 16 kilobyte

- Average $H$ 5.36 ($\sigma$ 1.46)
RAM entropy

Windows 7 x86 (Office usage)

Tails 1.4 with encrypted folder (photos)
Data compression algorithms

• Tested 13 algorithms
  – Some with multiple presets
  – 19 tests in total

• Focused on memory usage
  – Every byte used is written over original data
  – Measured using Valgrind with Massif

• But also duration, compression factor, theoretical worst-case scenario...
  – Tested against the RAM dumps of prev. step
Data compression algorithms

- Selected LZW for Proof of Concept
  - 3.6 seconds / GiB (compression)
  - 60% avg. space saved
  - 7.7k mem usage (4.5k code, 3.2k stack, 0 heap)
  - Worst case output up to 104% of input length
Acquisition algorithm

• Work in non-contiguous address space
• Don’t destroy more than absolutely necessary
• Make enough space to boot OS
• Protect compressed data from OS
• Provable forensic integrity
Acquisition algorithm
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Proof of Concept

- Syslinux module to compress RAM
  - Supports CD, USB stick, PXE on BIOS & UEFI
  - Compress 100 MiB / block
  - SHA256 checksum over input
  - Modifies firmware memory map to hide compressed data

- OpenWRT based OS
  - Very small & low memory footprint
  - PXE boot needs 82 MiB free memory incl. ram disk

- Python script to extract compressed data
  - Patched /dev/mem interface
Proof of Concept

• Tested with USB & PXE

• Store compressed data to NFS volume

• Decompress on different machine
  - In worst-case ~20 MiB free memory available

• Modified QEMU to fill memory with pattern
Proof of Concept

$ ./decompress.py dumps/03a78c78-dd57-436f-b81e-5e66d8e3dc49

... Memory map:

[ 0] - [ 9F7FF] OK
[ 9F800] - [ FFFFFFF] MISSING
[ 100000] - [ FFFFFFF] OK
[ 10000000] - [ 73FFFFFF] Checksum INVALID!
[ 74000000] - [ D7FFFFFF] OK
[ D8000000] - [ 13BFFFFFF] OK
[ 13C00000] - [ 19FFFFFF] OK
[ 1A000000] - [ 1FE000000] - [ 1FEF0000] - [ 1FEFF000] - [ 1FEFFFFF] OK
## Comparison with existing solutions

<table>
<thead>
<tr>
<th>Method</th>
<th>Recovered</th>
<th>Not recoverable</th>
</tr>
</thead>
<tbody>
<tr>
<td>msramdmp</td>
<td>1022.8 M</td>
<td>1.2 M</td>
</tr>
<tr>
<td></td>
<td>99.883%</td>
<td>0.117%</td>
</tr>
<tr>
<td>bios_memimage</td>
<td>1022.7 M</td>
<td>1.3 M</td>
</tr>
<tr>
<td></td>
<td>99.872%</td>
<td>0.128%</td>
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<tr>
<td>Proof of Concept</td>
<td>1019.5 M</td>
<td>4.5 M</td>
</tr>
<tr>
<td></td>
<td>99.556%</td>
<td>0.444%</td>
</tr>
<tr>
<td>OpenWRT (ref)</td>
<td>878.0 M</td>
<td>146.0 M</td>
</tr>
<tr>
<td></td>
<td>85.700%</td>
<td>14.3%</td>
</tr>
</tbody>
</table>
Conclusion

• Concept works

• Slightly increased memory usage
  - But can also be used for other evidence gathering
  - Mostly accountable to Syslinux
Future work

• Test with UEFI based systems

• Modify Syslinux
  – 64-bit or PAE support
  – Lower memory usage?

• Test more scenario’s with low amount of RAM

• More samples to predict likelihood of success
QUESTIONS?

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