[0001] AmberAmethystDaisy -> QuartzBegonia -> LummaStealer

0x1c.zip/0001-lummastealer/

0x1c

June 21, 2024

By 0x1c in LummaStealer — Jun 21, 2024

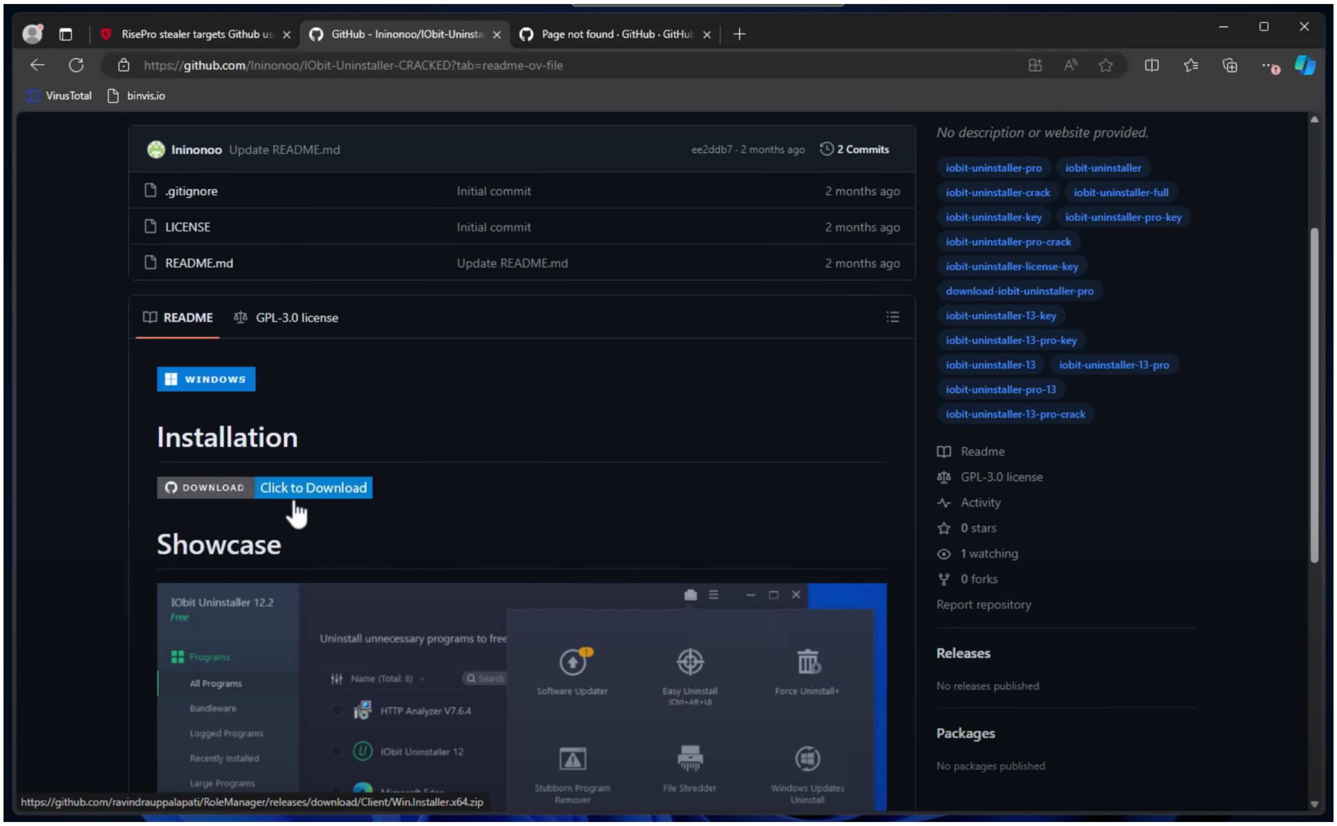
> Disclaimer: I have personally noticed a significant difficulty in finding names for many loaders, even if they have been reported on due to the overwhelming focus on the final payload within infection chains. With this in mind, I utilize a custom loader taxonomy system, with the name of the loader in open-source reporting as a secondary identifier. More information on this taxonomy system can be found here. If you happen to know the name of a loader that I report on, please let me know!

Recently, I stumbled across a video on YouTube from "The PC Security Channel", which noted that there was malware being distributed through fake cracked software on GitHub. Unfortunately, the extent of the analysis performed within the video was to check VirusTotal in order to see if the file is malicious or not.

Video: How not to Pirate: Malware in cracks on Github (youtube.com)

Although this might be good enough for most, my disappointment is *immeasurable,* and my day is nearly ruined. However, we can do the digging ourselves and get to the bottom of this!

Although the original GitHub repo that was shown within the video is now taken down, the actual download URL for the first stage seems to be hosted on another repo, as seen in the hyperlink within the video:



The URL seen in the hyperlink leads us to `https[:]//github[.]com/ravindrauppalapati/RoleManager/releases/tag/Client`, which is still up and available for download!

Stage 1 - QuartzDahlia

Also known as: Launch4j

TL;DR:

> Initial sample can be executed as a normal executable as well as a JAR

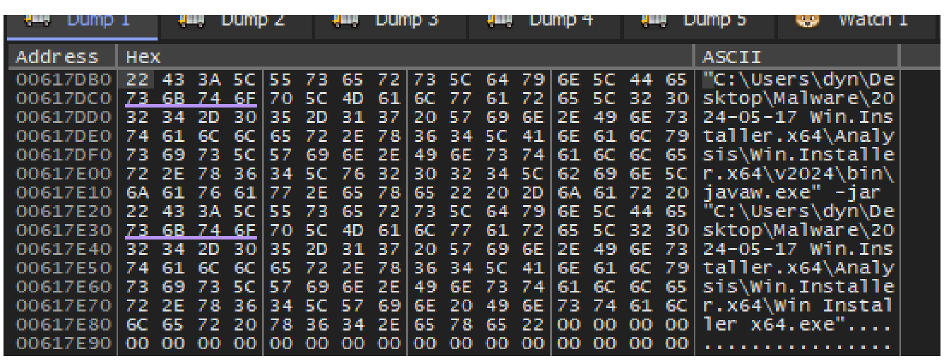
SHA-256	Filename
`8ed6a84101dfcafeac6ddbf5020312b0094576fd3f9106f7df460e1b8a7bd5e1`	`Win.Installer.x64.zip`
`94edf5396599aaa9fca9c1a6ca5d706c130ff1105f7bd1acff83aff8ad513164`	`Win Installer x64.exe`

Unpacking the ZIP archive, we can observe the following file structure:

```
│   Win Installer x64.exe
│
└───v2024
    ├───bin
    │   │   awt.dll
    │   │   glass.dll
    │   │   java.dll
    │   │   javafx_font.dll
    │   │   javafx_iio.dll
    │   │   javaw.exe
    │   │   msvcp120.dll
    │   │   msvcr100.dll
    │   │   msvcr120.dll
    │   │   net.dll
    │   │   nio.dll
    │   │   prism_d3d.dll
    │   │   sunec.dll
    │   │   sunmscapi.dll
    │   │   verify.dll
    │   │   zip.dll
    │   │
    │   └───client
    │           jvm.dll
    │
    └───lib
        │   jce.jar
        │   jfr.jar
        │   jsse.jar
        │   resources.jar
        │   rt.jar
        │
        └───ext
                jfxrt.jar
                sunec.jar
                sunjce_provider.jar
                sunmscapi.jar
```

Taking a look at the executable, it's unclear at first as to where the malicious code lies. With this in mind, I decided to load it up in x64dbg to do some quick preliminary dynamic analysis.

Stepping through a few functions, I was able to see that the malware attempts to calls its own binary with the `-jar` flag using its bundled Java runtime. It turns out that this actually a tool named *Launch4j* which allows for Java applications to be wrapped in an executable.



Since JAR files are able to be unzipped, we can go ahead and extract the contents of this executable with 7-Zip.

Note: Detect-It-Easy also notifies us that this executable contains a ZIP archive, and we could have gone about it that way as well!


extract
v2024
Win Installer x64.e
Win.Installer.x64.z
.data
.inc
.packages
.system
.theme
action
app
behaviour
bundle
com
css
facade
font
game
javassist
javax
JPHP-INF
JPHP-INFO
META-INF
org
php
script
timer
translation
tray
App.phb
Async.phb
cURLFile.phb
Dialog.phb
driver_property_info.properties
Files.phb
isc_dpb_types.properties
isc_error_msg.properties
isc_error_sqlstates.properties
isc_tpb_mapping.properties
jfoenix-custom.fx.css
LICENSE.md
README.md
release-notes.txt
Win Installer x64.exe

Stage 2 - AmberAmethystDaisy

Also known as: D3F@ck Loader, NestoLoader

SHA-256	Filename
`515d025ba2aa1096f65c13569de283b83d86824d08ca48c1fc3bc407d4cf3266`	`MainForm.phb`

TL;DR:

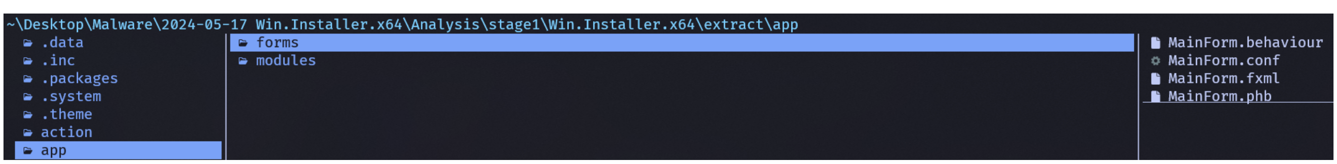
- Extracted contents of the JAR contains files with the `.phb` extension, indicative of JPHP
- The entry point for JPHP-based applications can be found within `.system/application.conf`
  - In this case, the entry point resides in `app/forms/MainForm.phb`
- Utilizing Binary Refinery and jadx, the next stage payload URL is retrieved.

A few of the extracted files have the `.phb` extension, which is indicative of JPHP, an implementation of PHP on the Java VM. For more information on triaging JPHP malware, this same malware family was recently showcased on a MalwareAnalysisForHedgehogs video.

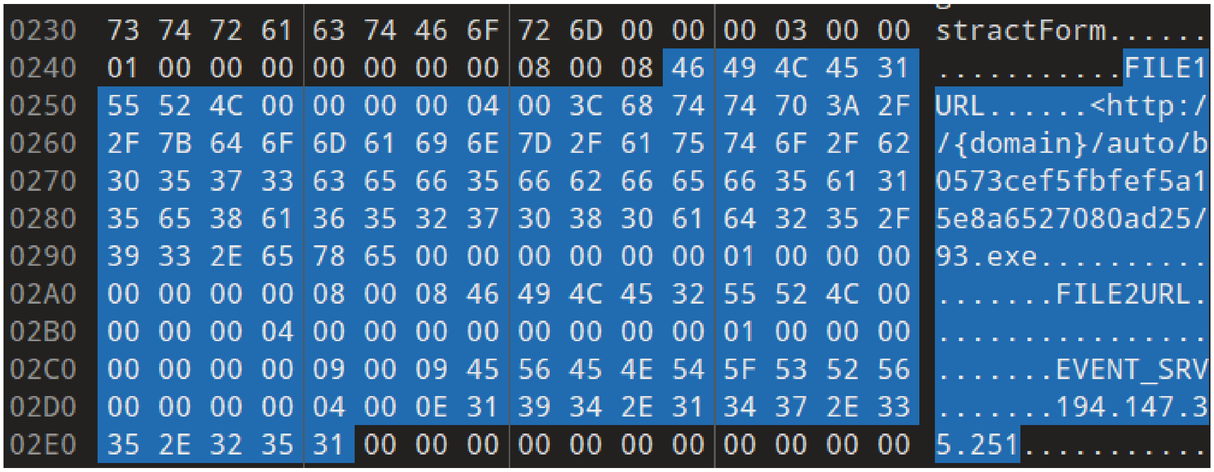
The entry point for JPHP-based applications can be found within `.system/application.conf`. The content of this file is as follows:

```
# MAIN CONFIGURATION

app.name = DarkLauncher
app.uuid = 6ccf8f8e-fb00-441b-a0f5-f3bc2fa6619b
app.version = 1

# APP
app.namespace = app
app.mainForm = MainForm
app.showMainForm = 1

app.fx.splash.autoHide = 0
```

We now know that the entry point that we are interested in would be located within the `app` folder and should be called `MainForm`. Let's go and take a look! Sure enough, a file titled `MainForm.phb` exists in the `forms` folder located within `app`.



Viewing this file with a hex editor, we can very quickly see what looks to be parts of an embedded configuration. Now we can be fairly sure that this is the file we want to be looking further into.



Although we see a C2 IP address of `194.147.35[.]251` here, this is seemingly not where the next payload is hosted. Let's dig deeper to figure out where the next payload is actually hosted.

Dealing with PHB files

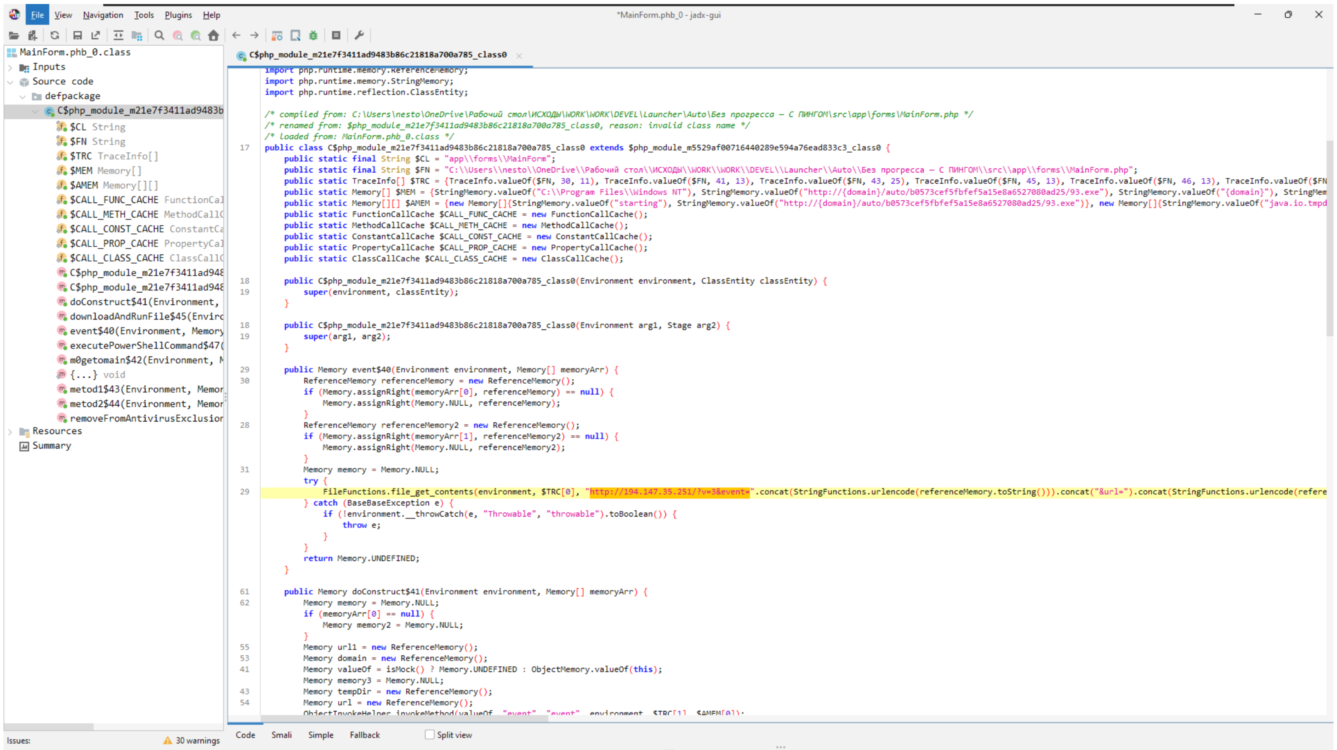
PHB files contain Java class files within them, which are denoted with a magic of `CAFEBABE`. We can utilize these magic bytes as a marker in order to extract the embedded `.class` files.

I set up the following Binary Refinery pipeline to extract the 2 class files from `app/forms/MainForm.phb`:

```
ef MainForm.phb | resplit h:CAFEBABE [ \
        | pop \
        | ccp h:CAFEBABE \
        | dump extracted_class_{index}.class \
]
```

Unit	Name	Definition
`ef`	Emit File	Places a file into the pipeline
`resplit`	Regular Expression Split	Splits the data in the pipeline by the supplied regular expression
`pop`	Pop	Removes a chunk from the frame (and stores it in a meta variable) - Used here to remove the first chunk in the pipeline, which contains data before the first `CAFEBABE` header
`ccp`	ConCat Prepend	Concatenates a value to the beginning of each chunk
`dump`	Dump	Dumps the data stored in each chunk to disk

Using jadx, we can decompile the recovered Java class files in order to get a better idea as to what the malicious code does.



Looking through the code, we come across 2 base64 encoded strings which decode to URLs. We can set up the following Binary Refinery pipeline to extract, defang, and print these indicators:

```
ef MainForm.phb | carve b64 [ \
    | b64 \
    | xtp url \
    | defang \
    | cfmt "{}\n" \
]
https[:]//pastebin[.]com/raw/md5jVrEB
https[:]//t[.]me/+JBdY0q1mUogwZWMy
```

Unit	Name	Definition
`ef`	Emit File	Places a file into the pipeline
`carve`	Carve	Extracts pieces of the pipeline that matches a given format - in this case, base64
`b64`	Base64	Base64 decodes each chunk in the pipeline
`xtp`	eXtracT Pattern	Extracts indicators from the data within the pipeline by a given pattern
`defang`	Defang	Defangs indicators within the pipeline
`cfmt`	Convert to ForMaT	Transforms each chunk in the pipeline by applying a string format operation

The Pastebin URL holds a paste that contains the IP address `78.47.105[.]28`, which is where the next payload is hosted. We can now reconstruct the true URL of the next-stage payload: `http[:]//78.47.105[.]28/auto/b0573cef5fbfef5a15e8a6527080ad25/93.exe`

Stage 3 - QuartzBegonia

Also known as: N/A

SHA-256	Filename
`5b751d8100bbc6e4c106b4ef38f664fb031c86f919c3e2db59a36c70c57f54e0`	`93.exe`

The third-stage payload in this infection chain is a loader written in C++. Loading the sample in Binary Ninja quickly reveals a large amount of non-code data, which is very likely the encrypted payload.

Within the main function, we can see that a thread would be created, which would execute a function which I've named `thread_start_addr` (`0x401750`) with an argument - a pointer to a function I've named `mal::thread_main` (`0x41d7b0`).

```
0041d9d0  int32_t mal::run_mal_main_thread()

0041d9d0  {
0041d9d3      FreeConsole();
0041d9db      DWORD* thread_main_ptr = operator new(4);
0041d9e5      if (thread_main_ptr == 0)
0041d9e5      {
0041d9ef          thread_main_ptr = nullptr;
0041d9e5      }
0041d9e5      else
0041d9e5      {
0041d9e7          *(uint32_t*)thread_main_ptr = mal::thread_main;
0041d9e5      }
0041da02      int32_t* thread_addr;
0041da02      uintptr_t tid = _beginthreadex(nullptr, 0, thread_start_addr, thread_main_ptr, 0, &thread_addr);
```

When called, the function `thread_start_addr` executes the function at the address that was passed-in as an argument:

```
00401750  uint32_t thread_start_addr(void* main_func_ptr)

00401750  {
00401755      *(uint32_t*)main_func_ptr();
00401759      __Cnd_do_broadcast_at_thread_exit();
0040175e      int32_t var_8 = 4;
00401761      operator new(main_func_ptr);
0040176c      return 0;
00401750  }
```

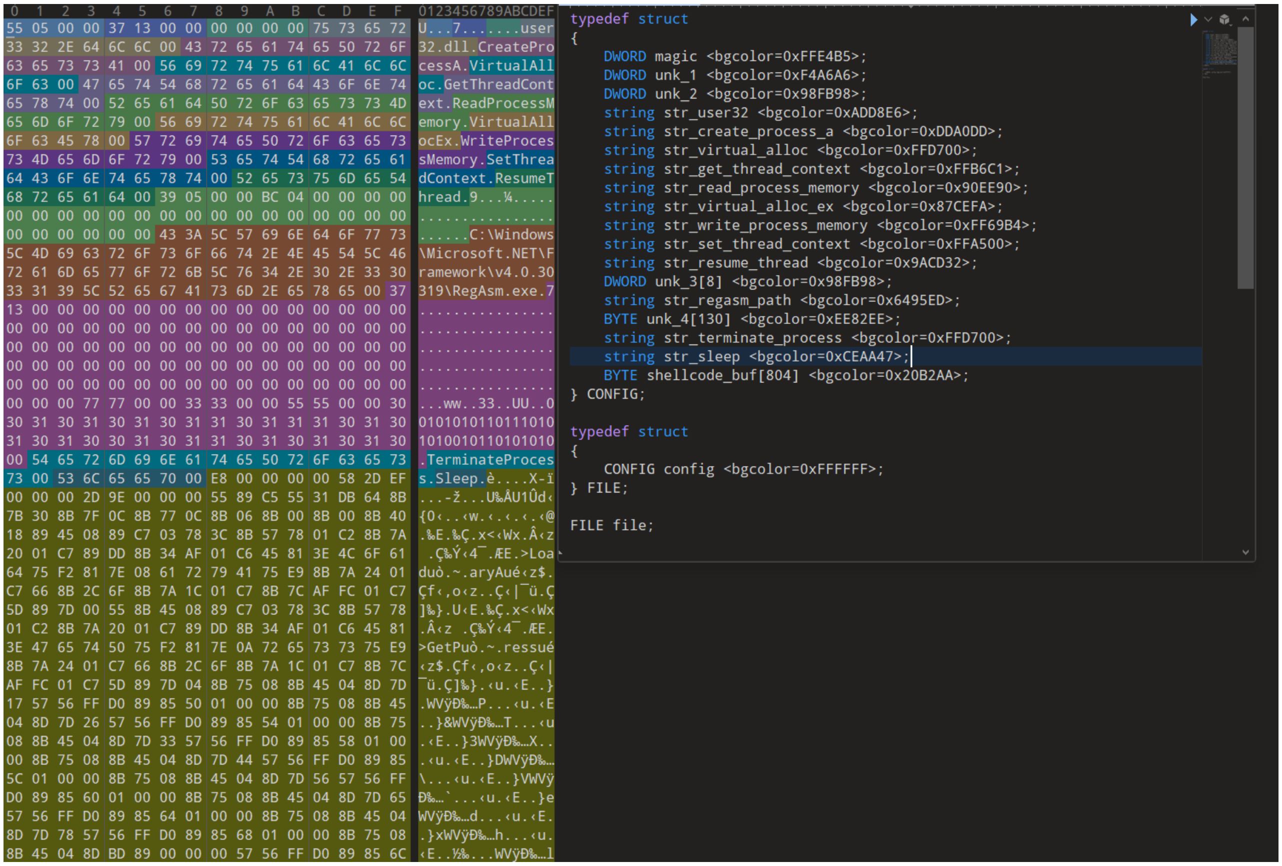
Diving into the `mal::thread_main` function, we come across an encrypted buffer and its corresponding decryption loop:

```
int32_t mal::thread_main()

0041d8f4        do
0041d8f4        {
0041d88c            enc_buf[counter] = ((enc_buf[counter] ^ 0x73) - 0x15);
0041d89e            if (((int8_t)(((char*)val_edx - ptr_unk_1) >> 2)) < 0x4ac)
0041d89e            {
0041d8a0                int32_t cur_idx = w_idx;
0041d8a6                if (val_edx == edx)
0041d8a6                {
0041d8bd                    sub_4012f0(&ptr_unk, val_edx, &cur_idx);
0041d8c2                    edx = var_2c;
0041d8c6                    val_edx = val_edx_1;
0041d8ca                    ptr_unk_1 = ptr_unk;
0041d8a6                }
0041d8a6                else
0041d8a6                {
0041d8a8                    *(uint32_t*)val_edx = w_idx;
0041d8aa                    val_edx = &val_edx[1];
0041d8ad                    val_edx_1 = val_edx;
0041d8a6                }
0041d89e            }
0041d8d4            w_idx += 2;
0041d8e7            enc_buf[counter] = ((((((((enc_buf[counter] - 0x57) ^ 0x74) + 0x4e) ^ 0x70) - 0x65) ^ 0x22) - 0x73) ^ 0x2a);
0041d8ed            counter += 1;
0041d8f4        } while (w_idx < 0x958);
```

Re-implementing this decryption loop in Python, we can recover the content of the encrypted buffer:

```
dec_buf = bytearray()
for b in enc_buf:
    first_dec = (b ^ 0x73) - 0x15
    second_dec = ((((((((first_dec - 0x57) ^ 0x74) + 0x4e) ^ 0x70) - 0x65) ^ 0x22) - 0x73) ^ 0x2a) %
256
    dec_buf.append(second_dec)

>> dec_buf
bytearray(b'U\x05\x00\x007\x13\x00\x00\x00\x00\x00\x00user32.dll\x00CreateProcessA\x00VirtualAlloc\x0
0GetThreadContext\x00ReadProcessMemory\x00VirtualAllocEx\x00WriteProcessMemory\x00SetThreadContext\x0
0ResumeThread\x009\x05\x00\x00\xbc\x04\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x0
0\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00C:\\Windows\\Microsoft.NET\\Framework\\v4.0.30319\\RegAsm.ex
e\x007\x13\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x0
0\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\x00\x00\
x00\x00\x00\x00\x00\x00\x00\x00\x00ww\x00\x0033\x00\x00UU\x00\x0000101010110111010101001011010101 0\x0
0TerminateProcess\x00Sleep\x00\xe8\x00\x00\x00\x00X-\xef\x00\x00\x00-
\x9e\x00\x00\x00U\x89\xc5U1\xdbd\x8b{0\x8b\x7f\x0c\x8bw\x0c\x8b\x06\x8b\x00\x8b\x00\x8b@\x18\x89E\x08
\x89\xc7\x03x<\x8bWx\x01\xc2\x8bz
\x01\xc7\x89\xdd\x8b4\xaf\x01\xc6E\x81>Loadu\xf2\x81~\x08aryAu\xe9\x8bz$\x01\xc7f\x8b,o\x8bz\x1c\x01\
xc7\x8b|\xaf\xfc\x01\xc7]\x89}\x00U\x8bE\x08\x89\xc7\x03x<\x8bWx\x01\xc2\x8bz
\x01\xc7\x89\xdd\x8b4\xaf\x01\xc6E\x81>GetPu\xf2\x81~\nressu\xe9\x8bz$\x01\xc7f\x8b,o\x8bz\x1c\x01\xc
7\x8b|\xaf\xfc\x01\xc7]\x89}\x04\x8bu\x08\x8bE\x04\x8d}\x17WV\xff\xd0\x89\x85P\x01\x00\x00\x8bu\x08\x
8bE\x04\x8d}&WV\xff\xd0\x89\x85T\x01\x00\x00\x8bu\x08\x8bE\x04\x8d}3WV\xff\xd0\x89\x85X\x01\x00\x00\x
8bu\x08\x8bE\x04\x8d}DWV\xff\xd0\x89\x85\\\x01\x00\x00\x8bu\x08\x8bE\x04\x8d}VWV\xff\xd0\x89\x85`\x01
\x00\x00\x8bu\x08\x8bE\x04\x8d}eWV\xff\xd0\x89\x85d\x01\x00\x00\x8bu\x08\x8bE\x04\x8d}xWV\xff\xd0\x89
\x85h\x01\x00\x00\x8bu\x08\x8bE\x04\x8d\xbd\x89\x00\x00\x00WV\xff\xd0\x89\x85l\x01\x00\x00\x8b\x85P\x
01\x00\x00\x8d\x95\xef\x00\x00\x00R\x8d\xb5\xff\x00\x00\x00Vj\x00j\x00j\x04j\x00j\x00j\x00j\x00\x8d\x
bd\xb6\x00\x00\x00W\xff\xd0\x8b\x85T\x01\x00\x00j\x04h\x00\x10\x00\x00j\x04j\x00\xff\xd0\x89\xc6\x89\
xb5K\x01\x00\x00\xc7\x06\x07\x00\x01\x00\x8b\x85X\x01\x00\x00V\x8b\x95\xf3\x00\x00\x00R\xff\xd0\x8b\x
85\\\x01\x00\x00j\x00j\x04\x8d\xbdC\x01\x00\x00W\x8b\x96\xa4\x00\x00\x00\x83\xc2\x08R\x8b\x95\xef\x00
\x00\x00R\xff\xd0\x8b\x85`\x01\x00\x00j@h\x000\x00\x00\x89\xe2\x8bR\x10\x8bZ<\x01\xda\x83\xc2\x04\x8b
JLQ\x8bJ0Q\x8b\x8d\xef\x00\x00\x00Q\xff\xd0\x85\xc0u
\x8bE\x04\x8d\x95q\x01\x00\x00R\x8bU\x08R\xff\xd0j\x00\x8b\x95\xef\x00\x00\x00R\xff\xd0\xe91\xff\xff\
xff\x89\xc1\x89\x8dG\x01\x00\x00\x8b\x85d\x01\x00\x00\x89\xe2\x8bR\x08\x8bZ<\x01\xdaRj\x00\x83\xc2\x0
4\x89\xd7)\xda\x83\xea\x04\x8b_PSRQ\x8b\x9d\xef\x00\x00\x00S\xff\xd0Z1\xff1\xc0f\x8bz\x06\x81\xc2\xf8
\x00\x00\x001\xdbf9\xfbt=f\xb8(\x00Rf\xf7\xe3Z\x01\xc2PRj\x00\x8bB\x10P\x89\xe0\x8b@\x18\x03B\x14P\x8
bB\x0c\x03\x85G\x01\x00\x00P\x8b\x85\xef\x00\x00\x00P\x8b\x85d\x01\x00\x00\xff\xd0ZX)\xc2fC\xeb\xbej\
x00j\x04\x89\xe0\x8b@\x10\x8bX<\x01\xd8\x83\xc0\x18\x8dX\x1cS\x8b\x9dK\x01\x00\x00\x81\xc3\xa4\x00\x0
0\x00\x8b\x1b\x83\xc3\x08S\x8b\x9d\xef\x00\x00\x00S\x8b\x85d\x01\x00\x00\xff\xd0\x8b\x9dK\x01\x00\x00
\x81\xc3\xb0\x00\x00\x00\x89\xe7\x8b\x7f\x08\x8bG<\x01\xc7\x83\xc7\x18\x83\xc7\x10\x8b?
\x03\xbdG\x01\x00\x00\x89;\x8b\x85h\x01\x00\x00\x8b\x9dK\x01\x00\x00S\x8b\x9d\xf3\x00\x00\x00S\xff\xd
0\x8b\x9d\xf3\x00\x00\x00S\x8b\x85l\x01\x00\x00\xff\xd0]\xc3')
```

However, this is *very ugly*, so I created a *colorful and pretty* template for the decrypted data within 010Editor in order to make better sense of it visually. Now we can see that the data is mostly a few function names and a shellcode buffer used in order to inject the final payload into `RegAsm.exe`.

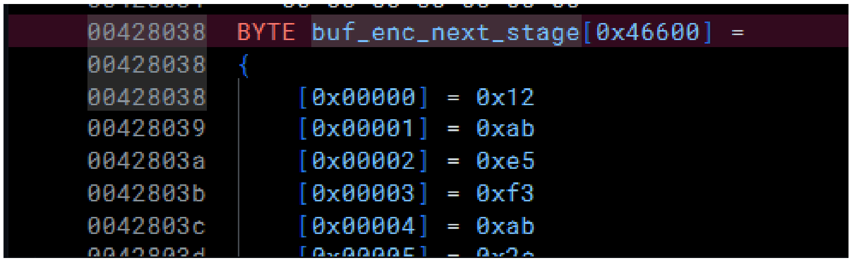


DiamondDaffodil shellcode seen in buffer decrypted within *QuartzBegonia*

One thing that I tend to do when triaging loaders is to find the beginning of what is likely the encrypted content of the payload in order to find functions that cross-reference these buffers. I was able to locate a very large buffer (`0x46600` bytes long) at `0x428038`, as well as a smaller buffer (`0x31` bytes long) at `0x428000`.

A function located at `0x41d4d0` references both of these buffers and taking a look at the function—my suspicions of these buffers being the next-stage payload and its corresponding decryption key were confirmed.

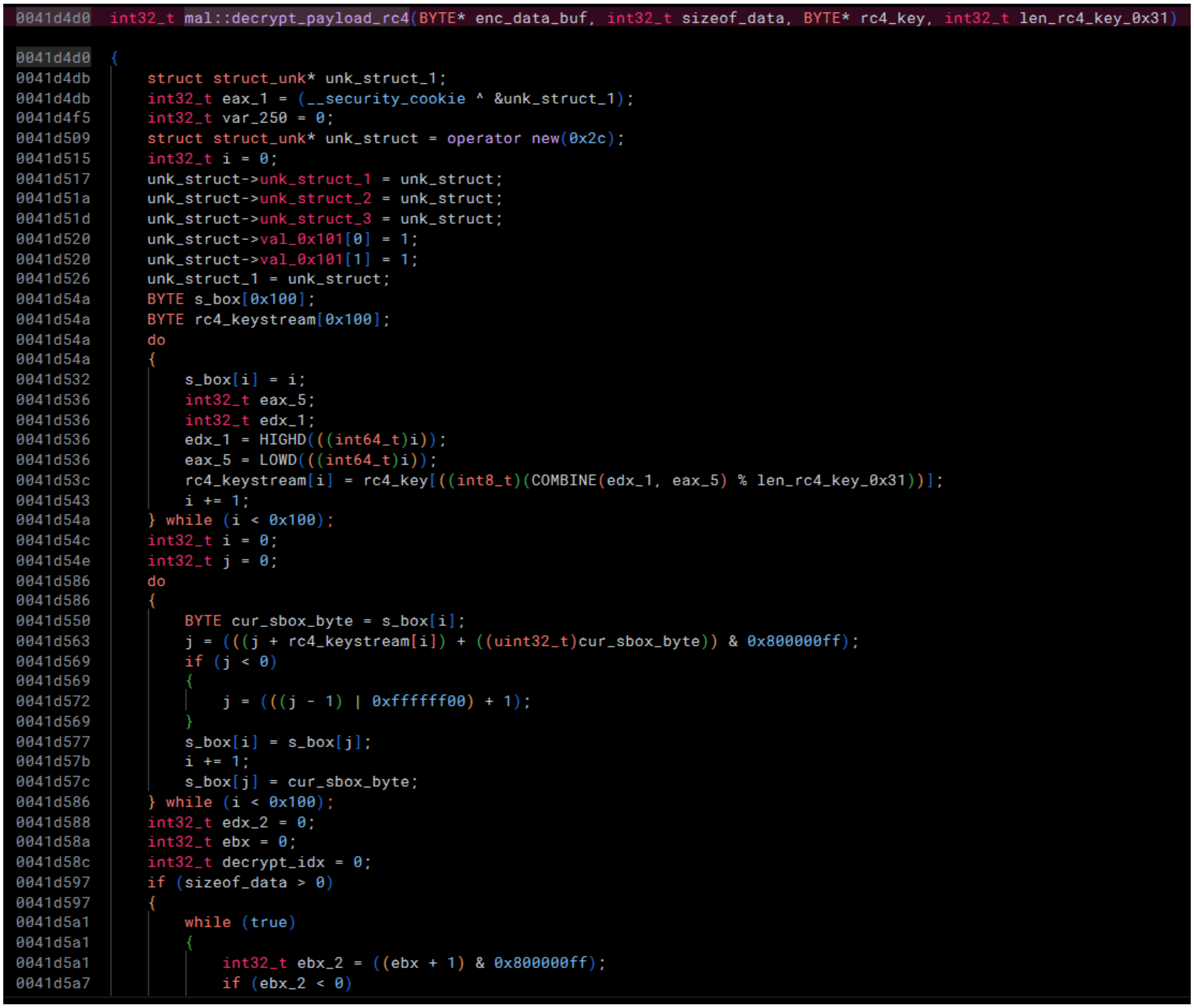
```
PE ▾   Linear ▾   Pseudo C ▾

    0x428000 .data {0x428000-0x47093c} Writable data

    .data section started  {0x428000-0x47093c}
    00428000  BYTE rc4_key[0x31] =
    00428000  {
    00428000      [0x00] = 0x22
    00428001      [0x01] = 0xa4
    00428002      [0x02] = 0x3b
    00428003      [0x03] = 0x87
    00428004      [0x04] = 0xdf
    00428005      [0x05] = 0x1e
    00428006      [0x06] = 0xde
    00428007      [0x07] = 0xe2
    00428008      [0x08] = 0x94
    00428009      [0x09] = 0xde
    0042800a      [0x0a] = 0xcd
    0042800b      [0x0b] = 0x10
    0042800c      [0x0c] = 0xf5
    0042800d      [0x0d] = 0xe8
    0042800e      [0x0e] = 0x5c
    0042800f      [0x0f] = 0x46
    00428010      [0x10] = 0x8f
    00428011      [0x11] = 0xcc
    00428012      [0x12] = 0xf9
    00428013      [0x13] = 0xfd
    00428014      [0x14] = 0xda
    00428015      [0x15] = 0x2e
    00428016      [0x16] = 0x48
    00428017      [0x17] = 0x84
    00428018      [0x18] = 0x17
    00428019      [0x19] = 0x17
    0042801a      [0x1a] = 0x96
    0042801b      [0x1b] = 0x5a
    0042801c      [0x1c] = 0xbe
    0042801d      [0x1d] = 0xdc
    0042801e      [0x1e] = 0xd6
    0042801f      [0x1f] = 0x1c
    00428020      [0x20] = 0xe4
    00428021      [0x21] = 0xdb
    00428022      [0x22] = 0xe9
    00428023      [0x23] = 0xf3
    00428024      [0x24] = 0xe0
    00428025      [0x25] = 0xc9
    00428026      [0x26] = 0xca
    00428027      [0x27] = 0x66
    00428028      [0x28] = 0xfc
    00428029      [0x29] = 0xea
    0042802a      [0x2a] = 0x73
    0042802b      [0x2b] = 0x76
    0042802c      [0x2c] = 0x2a
    0042802d      [0x2d] = 0x5b
    0042802e      [0x2e] = 0xe
    0042802f      [0x2f] = 0x5c
    00428030      [0x30] = 0x53
    00428031  }

    00428031     00 00 00 00 00 00 00
```



```
00428038  BYTE buf_enc_next_stage[0x46600] =
00428038  {
00428038      [0x00000] = 0x12
00428039      [0x00001] = 0xab
0042803a      [0x00002] = 0xe5
0042803b      [0x00003] = 0xf3
0042803c      [0x00004] = 0xab
```

Key and encrypted content of the final payload, located within the `.data` segment

Taking a look at the function located at `0x41d4d0`, we can see telltale signs of the RC4 encryption algorithm:



```
0041d4d0  int32_t mal::decrypt_payload_rc4(BYTE* enc_data_buf, int32_t sizeof_data, BYTE* rc4_key, int32_t len_rc4_key_0x31)

0041d4d0  {
0041d4db      struct struct_unk* unk_struct_1;
0041d4db      int32_t eax_1 = (__security_cookie ^ &unk_struct_1);
0041d4f5      int32_t var_250 = 0;
0041d509      struct struct_unk* unk_struct = operator new(0x2c);
0041d515      int32_t i = 0;
0041d517      unk_struct->unk_struct_1 = unk_struct;
0041d51a      unk_struct->unk_struct_2 = unk_struct;
0041d51d      unk_struct->unk_struct_3 = unk_struct;
0041d520      unk_struct->val_0x101[0] = 1;
0041d520      unk_struct->val_0x101[1] = 1;
0041d526      unk_struct_1 = unk_struct;
0041d54a      BYTE s_box[0x100];
0041d54a      BYTE rc4_keystream[0x100];
0041d54a      do
0041d54a      {
0041d532          s_box[i] = i;
0041d536          int32_t eax_5;
0041d536          int32_t edx_1;
0041d536          edx_1 = HIGHD(((int64_t)i));
0041d536          eax_5 = LOWD(((int64_t)i));
0041d53c          rc4_keystream[i] = rc4_key[((int8_t)(COMBINE(edx_1, eax_5) % len_rc4_key_0x31))];
0041d543          i += 1;
0041d54a      } while (i < 0x100);
0041d54c      int32_t i = 0;
0041d54e      int32_t j = 0;
0041d586      do
0041d586      {
0041d550          BYTE cur_sbox_byte = s_box[i];
0041d563          j = (((j + rc4_keystream[i]) + ((uint32_t)cur_sbox_byte)) & 0x800000ff);
0041d569          if (j < 0)
0041d569          {
0041d572              j = (((j - 1) | 0xffffff00) + 1);
0041d569          }
0041d577          s_box[i] = s_box[j];
0041d57b          i += 1;
0041d57c          s_box[j] = cur_sbox_byte;
0041d586      } while (i < 0x100);
0041d588      int32_t edx_2 = 0;
0041d58a      int32_t ebx = 0;
0041d58c      int32_t decrypt_idx = 0;
0041d597      if (sizeof_data > 0)
0041d597      {
0041d5a1          while (true)
0041d5a1          {
0041d5a1              int32_t ebx_2 = ((ebx + 1) & 0x800000ff);
0041d5a7              if (ebx_2 < 0)
```

Tip: Seeing two loops and the number `256 (0x100)` is often indicative of the RC4 encryption algorithm

With this information, I set up a Binary Refinery pipeline to decrypt the final payload:

```
ef 93.exe | \
        vsnip 0x428038:0x46600 | \
        rc4
h:22a43b87df1edee294decd10f5e85c468fccf9fdda2e48841717965abedcd61ce4dbe9f3e0c9ca66fcea73762a5b0e5c53
| \
        dump stage4.bin
```

Unit	Name	Definition

Unit	Name	Definition
`ef`	Emit File	Places a file into the pipeline
`vsnip`	Virtual Snip	Snips (extracts) data from PE/ELF/MACHO files based on virtual offset
`rc4`	RC4	RC4 decrypts the data in the pipeline, given a key
`dump`	Dump	Dumps the data stored in each chunk to disk

Stage 4 - LummaStealer

Also known as: LummaC2 Stealer

SHA-256	Filename
`0cf55c7e1a19a0631b0248fb0e699bbec1d321240208f2862e37f6c9e75894e7`	N/A

Loading the *LummaStealer* sample in Binary Ninja, we see the following function:

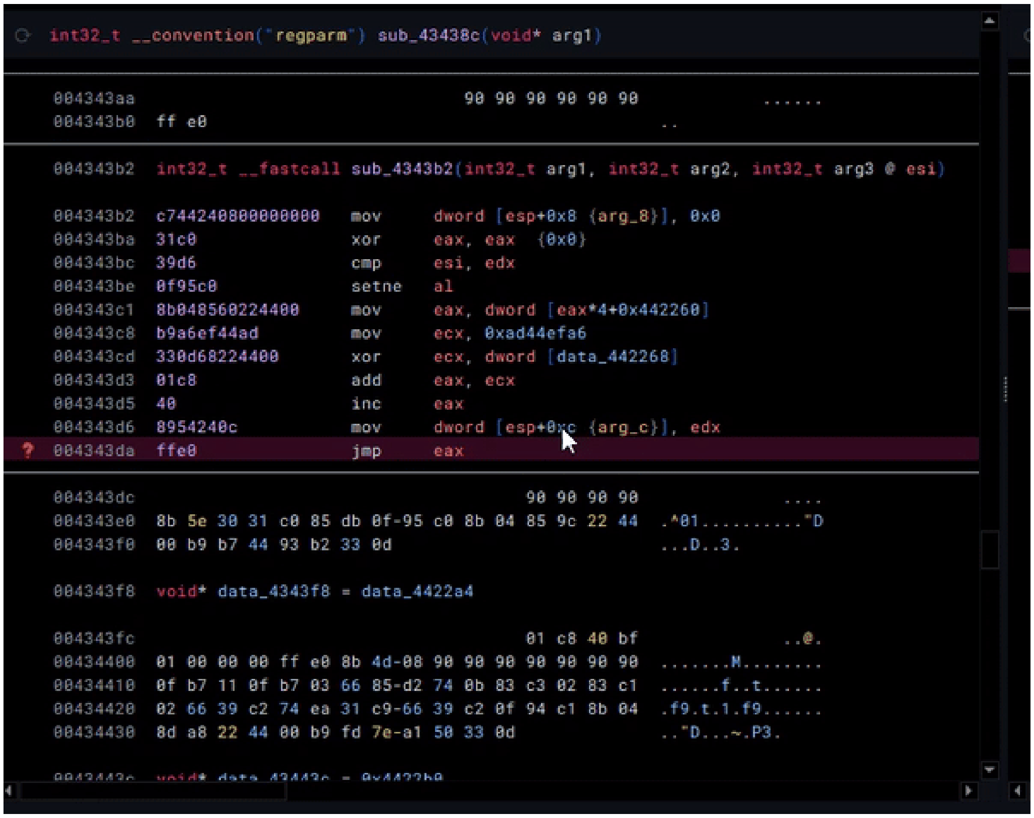
```
? 00408ba0  void _start() __noreturn
   This function has unresolved stack usage. View graph of stack usage to resolve.

  00408bad      if ((sub_432130() & 1) != 0)
  00408bba          if ((sub_42d6b0() & 1) != 0)
  00408bd0              HANDLE var_104_1 = GetStdHandle(nStdHandle: STD_INPUT_HANDLE)
  00408bf5              void var_100
  00408bf5              if ((sub_409f50(sub_408c20(&var_100, "eleet or leetspeak, is a system of modified spellings used prima…")) & 1) != 0)
  00408bf9                  sub_40ff70()
  00408c02          sub_4341b0()
  00408c12      ExitProcess(uExitCode: 0)
  00408c12      noreturn
```

Taking a look at the function `sub_432130`, we immediately come across a problem:

```
  00432130  int32_t sub_432130()

? 00432154      jump(data_440fe8 + (0x8070d626 ^ data_440fec) + 1)
```

Opaque Predicates

Here, we have an example of an obfuscation technique called *Opaque Predicates*. The jumps to the next section of code are obfuscated by making their destination the result of a mathematical operation. Typically, we would deal with these via patching, which is possible (this is not at the same place in code, but is an example of this technique):



However, I was recently informed by Xusheng from the Binary Ninja / Vector35 team (huge shoutouts to the team!) of a better way to tackle this:

By default, Binary Ninja believes that the value defined at `data_440fe8` and `data_440fec` can be modified by the program. Although this may be true, we know that this is likely not the case. With this in mind, if we convert the types—which are by default `void*`—to `const int32_t`, Binary Ninja can do its magic (dataflow analysis) in order to solve the opaque predicate for us!

```
00432130  int32_t sub_432130()

00432154      jump(data_440fe8 + (0x8070d626 ^ data_440fec) + 1)


00432156  int32_t sub_432156(void* arg1 @ esi)

00432161      int32_t var_30
00432161      __builtin_memcpy(dest: &var_30, src: "\x14\x85\x10\x8b\xee\x89\xe4\x8f\xe2\x8d\xde\x
00432183      int32_t s_1
00432183      __builtin_memset(s: &s_1, c: 0, n: 0x17)
004321ad      *(arg1 + 8) = 0
004321ba      if (*(arg1 + 8) u<= 0x2a)
004321de          do
004321d2              *(&var_30 + *(arg1 + 8)) = (((*(arg1 + 8)).b + 0x15) ^ *(&var_30 + *(arg1 +
004321d5              *(arg1 + 8) += 1
004321de          while (*(arg1 + 8) u< 0x2b)
004321e1      int32_t eax = sub_434300(&var_30)
004321e9      data_443e24 = eax
00432215      int32_t var_34_1 = eax
00432220      int32_t var_60
00432220      int32_t* var_64 = &var_60
00432227      void var_268
00432227      *(arg1 + 0x20) = &var_268
0043222a      int32_t* var_26c = &var_60
```

Just like that, we can save our precious reverse-engineering time (and sanity...)! I originally was manually patching a whole bunch of these, and let me tell you—it was *miserable*.

However, going through the code a little more, we hit yet another roadblock:

```
004321f1      int32_t eax = sub_434300(&var_c0)
004321fb      data_443e24 = eax
00432339      int32_t eax_1
00432339      eax_1.b = eax == 0
00432353      jump((0x5059d3bb ^ data_441004) + (&data_440ffc)[eax_1] + 1)
```

In this case, the value `data_440ffc` holds the address of 2 possible values used in order to calculate the destination. If we take a look at `data_440ffc`, right now, it is only showing up as a `void*`:

```
00440fe4  void* data_440fe4 = 0x4844fa
00440fe8  int32_t const data_440fe8 = 0x4845b9
00440fec  int32_t const data_440fec = 0x7f8a0a7d
00440ff0  void* data_440ff0 = 0x4845b9
00440ff4  int32_t const data_440ff4 = 0x4846d9
00440ff8  int32_t const data_440ff8 = -0x5f34365b
00440ffc  void* data_440ffc = 0x4846f9
00441000  void* data_441000 = 0x485236
00441004  int32_t data_441004 = -0x505cf020
```

Let's go ahead and change this to a `const int32_t[2]` in order to correctly reflect its type.

```
00440ffc  int32_t const data_440ffc[0x2] =
00440ffc  {
00440ffc      [0x0] =  0x004846f9
00441000      [0x1] =  0x00485236
00441004  }
```

Now, if we change the type of `data_441004` to `const int32_t`, we can now see that the variable named `data_440ffc` has automatically been changed to `jump_table_440ffc`:

```
00440ffc  int32_t const jump_table_440ffc[0x2] =
00440ffc  {
00440ffc      [0x0] =  0x004846f9
00441000      [0x1] =  0x00485236
00441004  }
00441004  uint32_t data_441004 = 0xafa30fe0
```

Going back to our function, we now see that the dataflow analysis has taken care of the opaque predicate! (and left two more of them in its wake...)

```
   004321f1    int32_t eax = sub_434300(&var_c0)
   004321fb    data_443e24 = eax
   00432339    int32_t eax_1
   00432339    eax_1.b = eax == 0
?  00432368    if (eax_1 == 0)
   00432368        jump(data_441014 + (0x7855065a ^ data_441018) + 1)
?  00432eb0    if (eax_1 == 1)
   00432eb0        jump(data_441504 + (0x67d326c7 ^ data_44150c) + 1)
```

We'll have to go and do this a *whole bunch of times*, but it is still much better than calculating the location of the jump and patching it all manually (by a long shot).

After patching up the functions called by the main method, we have a much cleaner look at the binary. Let's move our focus over to the function located at `0x409f50`.

API Hash Resolution

```
uint32_t __convention("regparm") sub_409f50(int32_t arg1)
This function has unresolved stack usage. View graph of stack usage to resolve.

00409f5e    int32_t var_3c = arg1
00409f5f    int32_t* ebx = &var_3c
00409f61    int32_t var_40 = arg1
00409f62    int32_t* var_30 = &var_40
00409f65    int32_t var_44 = arg1
00409f66    int32_t* esi = &var_44
00409f68    int32_t var_48 = arg1
00409f69    int32_t* var_1c = &var_48
00409f6c    int32_t var_4c = arg1
00409f6d    int32_t* edi = &var_4c
00409f6f    int32_t var_50 = arg1
00409f70    int32_t* var_34 = &var_50
00409f79    void var_150
00409f79    void* var_18 = &var_150
00409f82    void var_350
00409f82    void* var_14 = &var_350
00409fa2    data_44318c = sub_434a60(data_4431bc, 0xcb63c52c)
00409fc2    data_443190 = sub_434a60(data_4431bc, 0x58ae9742)
00409fe2    data_443194 = sub_434a60(data_4431bc, 0x681c6d55)
0040a002    data_443198 = sub_434a60(data_4431bc, 0xd5d0b043)
0040a022    data_44319c = sub_434a60(data_4431bc, 0xe9023384)
0040a046    data_4431a0 = sub_434a60(data_4431bc, 0x12c6785a)
0040a066    data_4431a4 = sub_434a60(data_4431bc, 0xd80a5fbf)
0040a086    data_4431a8 = sub_434a60(data_4431bc, 0x8a9fb04a)
0040a0a6    data_4431ac = sub_434a60(data_4431bc, 0x996d52fb)
0040a0c6    data_4431b0 = sub_434a60(data_4431bc, 0x15efbf48)
0040a0e6    data_4431b4 = sub_434a60(data_4431bc, 0x5062dfe3)
0040a10a    data_4431b8 = sub_434a60(data_4431bc, 0xbd732396)
0040a118    *var_30 = 0x4388c4
0040a120    var_44 = 0x4388c4
```

Here, we come across a case of *API Hash Resolution*. The function `sub_434a60` is used to take a module (`data_4431bc`, which is a pointer to the base address of `WinHttp.dll`) and a corresponding hash in order to resolve a function for further use.

I won't showcase `sub_434a60` here, as it goes out of scope for this post—but this function essentially goes through the exports of `WinHttp.dll`, hashes all the function names, and returns a pointer to the function matching the provided hash.

I was able to deduce that this copy of *LummaStealer* is utilizing a hashing algorithm, namely `FNV-1a` with a modified offset. I went ahead and added this modified hashing algorithm to the *hashdb* project.

Now that the modified hashing algorithm has been deployed within *hashdb*, we can go ahead and simply utilize the *hashdb* plugin within Binary Ninja to find the names of the APIs used:

```
00409fa2    WinHttpOpen = mal::resolve_func_by_hash(module_WinHttp, WinHttpOpen);
00409fc2    WinHttpConnect = mal::resolve_func_by_hash(module_WinHttp, WinHttpConnect);
00409fe2    WinHttpOpenRequest = mal::resolve_func_by_hash(module_WinHttp, WinHttpOpenRequest);
0040a002    WinHttpCrackUrl = mal::resolve_func_by_hash(module_WinHttp, WinHttpCrackUrl);
0040a022    WinHttpSetTimeouts = mal::resolve_func_by_hash(module_WinHttp, WinHttpSetTimeouts);
0040a046    WinHttpAddRequestHeaders = mal::resolve_func_by_hash(module_WinHttp, WinHttpAddRequestHeaders);
0040a066    WinHttpSendRequest = mal::resolve_func_by_hash(module_WinHttp, WinHttpSendRequest);
0040a086    WinHttpRecieveResponse = mal::resolve_func_by_hash(module_WinHttp, WinHttpReceiveResponse);
0040a0a6    WinHttpQueryDataAvaliable = mal::resolve_func_by_hash(module_WinHttp, WinHttpQueryDataAvailable);
0040a0c6    WinHttpReadData = mal::resolve_func_by_hash(module_WinHttp, WinHttpReadData);
0040a0e6    WinHttpWriteData = mal::resolve_func_by_hash(module_WinHttp, WinHttpWriteData);
0040a10a    WinHttpCloseHandle = mal::resolve_func_by_hash(module_WinHttp, WinHttpCloseHandle);
```

Decrypting C2 Addresses

Now that we have both the opaque predicates and API hash resolution out of the way, let's try to find the C2 addresses for *LummaStealer*.

Within the function that resolves the `WinHttp` functions, we see a variable being assigned to a list of pointers. If we investigate this further, we see that the list of pointers contains what looks to be base64 encoded strings. However, if we try to base64 decode the strings, we do not end up with readable text. Let's dig deeper to see how these strings are decrypted!

```
004388c4  char const* enc_c2_addrs[0x9] =
004388c4  {
004388c4      [0x0] = 0x439200 {"o1/IUhkqhz/fHLzuOmol51GcSbB872oxMzf7zImhOBLQPqE+alP0S7px2ZdfH1aN…"}
004388c8      [0x1] = 0x43917f {"o1/IUhkqhz/fHLzuOmol51GcSbB872oxMzf7zImhOBLUNrs3dEv0TLZq2YZbGEiI…"}
004388cc      [0x2] = 0x4390fe {"o1/IUhkqhz/fHLzuOmol51GcSbB872oxMzf7zImhOBLAMKQ9a0zyU7ptyY9WH0KL…"}
004388d0      [0x3] = 0x43907d {"o1/IUhkqhz/fHLzuOmol51GcSbB872oxMzf7zImhOBLROqQ3b0vpS6lz1Y1fBkCU…"}
004388d4      [0x4] = 0x438ffc {"o1/IUhkqhz/fHLzuOmol51GcSbB872oxMzf7zImhOBLHOrw3el7oTbt1z41PGVaC…"}
004388d8      [0x5] = 0x438f7b {"o1/IUhkqhz/fHLzuOmol51GcSbB872oxMzf7zImhOBLGO70gfFnzSrFy1YBdCVeG…"}
004388dc      [0x6] = 0x438efa {"o1/IUhkqhz/fHLzuOmol51GcSbB872oxMzf7zImhOBLTMKcgfFziUbZy24hPGUCI…"}
004388e0      [0x7] = 0x438e79 {"o1/IUhkqhz/fHLzuOmol51GcSbB872oxMzf7zImhOBLXKro5fFPyUbN114tWE0qB…"}
004388e4      [0x8] = 0x438df8 {"o1/IUhkqhz/fHLzuOmol51GcSbB872oxMzf7zImhOBLCLLs9ekPmS7Zz0oFRD0rJ…"}
004388e8  }
004388e8  data_4388e8:
```

Encrypted *LummaStealer* C2 addresses

In this case, it seems that each string is passed in as the first argument to a function at `0x00409cb0`.

```
0040a160        *(uint32_t*)current_encrypted_c2 = **(uint32_t**)_enc_c2_addrs;
0040a16a        char* decrypted_c2 = c2_struct.field_18;
0040a171        mal::w_decrypt(*(uint32_t*)current_encrypted_c2, decrypted_c2);
```

Let's take a further look at that function:

```
00409cb0  int32_t mal::w_decrypt(char* current_c2_addr, uint8_t* output_passedin)

00409cb0  {
00409cc4      uint32_t len_enc_c2 = strlen(current_c2_addr);
00409cdc      uint32_t len_b64_decoded_expected = len_decoded_buf(current_c2_addr, len_enc_c2);
00409cf8      uint8_t* output = output_passedin;
00409cfc      int32_t len_b64_decoded = mal::b64decode(current_c2_addr, len_enc_c2, output);
00409d0d      int32_t success;
00409d0d      int32_t result;
00409d0d      if (len_b64_decoded != len_b64_decoded_expected)
00409d0d      {
00409dd4          success = 0;
00409d0d      }
```

At the beginning, we see that the length of the current encrypted C2 address is being calculated, alongside a call to a function at `0x00409e10` which calculates the length of the blob, if you were to base64 decode it. This is followed by a function that actually base64 decodes the data.

Continuing through the function, we see the following code:

```
00409d0d        else
00409d0d        {
00409d3c            void var_28;
00409d3c            __builtin_memcpy(&var_28, output_passedin, 8);
00409d4c            int32_t __saved_esi;
00409d4c            __builtin_memcpy(&__saved_esi, &output_passedin[0x20], 0);
00409d51            int32_t len_c2_result = 0;
00409d61            while (true)
00409d61            {
00409d61                int32_t finished;
00409d61                finished = len_c2_result < (len_b64_decoded - 0x20);
00409d66                if ((finished & 1) == 0)
00409d66                {
00409d66                    break;
00409d66                }
00409d74                uint32_t current_char = ((uint32_t)output_passedin[(0x20 + len_c2_result)]);
00409d7f                uint32_t ecx_5 = ((uint32_t)*(uint8_t*)(&var_28 + (len_c2_result & 0x1f)));
00409d9e                output_passedin[len_c2_result] = (current_char - (((int8_t)((ecx_5 & ((current_char ^ ecx_5) ^ 0xffffffff)) << 1)) - ecx_5));
00409db0                len_c2_result = (0 - ((0 - len_c2_result) - 1));
00409d61            }
00409dbe            output_passedin[(len_b64_decoded - 0x20)] = 0;
00409dc6            result = (len_b64_decoded - 0x20);
00409dca            success = 1;
00409d0d        }
00409de9        if (success == 0)
00409de9        {
00409deb            result = 0;
00409df3            int32_t var_3c = 1;
00409de9        }
00409e0a        return result;
00409cb0    }
```

This code takes the first `32 (0x20)` bytes of the decoded blob as a key and XORs the rest of the data with it. The resulting output is a C2 address for *LummaStealer*!

With this in mind, I set up the following Binary Refinery pipeline in order to decrypt the *LummaStealer* C2 addresses:

```
ef stage4.bin \
| vsnip 0x438df8:0x451 \
| carve b64 -n 5 [ \
        | b64 \
        | push [ \
                | snip :32 \
                | pop key \
        ] \
        | snip 32: \
        | xor var:key \
        | defang \
        | cfmt "{}\n" \
]
```

```
associationokeo[.]shop
turkeyunlikelyofw[.]shop
pooreveningfuseor[.]pw
edurestunningcrackyow[.]fun
detectordiscusser[.]shop
relevantvoicelesskw[.]shop
colorfulequalugliess[.]shop
wisemassiveharmonious[.]shop
sailsystemeyeusjw[.]shop
```

Unit	Name	Definition

Unit	Name	Definition
`ef`	Emit File	Places a file into the pipeline
`vsnip`	Virtual Snip	Snips (extracts) data from PE/ELF/MACHO files based on virtual offset
`carve`	Carve	Extracts pieces of the pipeline that matches a given format—in this case, base64 with a minimum length of 5 characters
`b64`	Base64	Base64 decodes each chunk in the pipeline
`push`	Push	Temporarily sets aside the current chunk of data and replaces it with a new chunk. This is useful if you want to perform operations on a piece of data while keeping the original data intact for later use. Think of this as a way to create a copy of the data in order to do some work on the data, before restoring the original data.
`snip`	Snip	On the copy of the data, retrieves (snips) the first 32 bytes, which is the XOR key
`pop`	Pop	Places the modified copy of the data into a meta-variable. Meta-variables can be later utilized with the `var` keyword
`snip`	Snip	On the original data, retrieves (snips) everything after the first 32 bytes, which is the encrypted C2 address
`xor`	XOR	Performs an exclusive-or operation on the data within the chunk with the popped key
`defang`	Defang	Defangs indicators within the pipeline
`cfmt`	Convert to ForMaT	Transforms each chunk in the pipeline by applying a string format operation

And now, we can happily say that we *actually* know what this infection chain is, how it works, and we've successfully retrieved the final payload and its C2 addresses. Thanks for reading! 💖

Indicators of Compromise:

IoC	Description
`https[:]//github[.]com/ravindrauppalapati/RoleManager/releases/tag/Client`	Sample Download URL
`8ed6a84101dfcafeac6ddbf5020312b0094576fd3f9106f7df460e1b8a7bd5e1`	Sample ZIP
`94edf5396599aaa9fca9c1a6ca5d706c130ff1105f7bd1acff83aff8ad513164`	*QuartzDahlia* EXE
`515d025ba2aa1096f65c13569de283b83d86824d08ca48c1fc3bc407d4cf3266`	*AmberAmethystDaisy* PHB
`194.147.35[.]251`	*AmberAmethystDaisy* Event Server
`https[:]//pastebin[.]com/raw/md5jVrEB`	*AmberAmethystDaisy* Dead-Drop

IoC	Description
`https[:]//t[.]me/+JBdY0q1mUogwZWMy`	*AmberAmethystDaisy* Telegram
`http[:]//78.47.105[.]28/auto/b0573cef5fbfef5a15e8a6527080ad25/93.exe`	*QuartzBegonia* Download URL
`5b751d8100bbc6e4c106b4ef38f664fb031c86f919c3e2db59a36c70c57f54e0`	*QuartzBegonia* EXE
`0cf55c7e1a19a0631b0248fb0e699bbec1d321240208f2862e37f6c9e75894e7`	*DiamondDaffodil* Shellcode
`d6a40534d8a76509605e67ead55ef3506050c7df86701db13443d091c7a4bce2`	*LummaStealer* EXE
`associationokeo[.]shop`	*LummaStealer* C2
`turkeyunlikelyofw[.]shop`	*LummaStealer* C2
`pooreveningfuseor[.]pw`	*LummaStealer* C2
`edurestunningcrackyow[.]fun`	*LummaStealer* C2
`detectordiscusser[.]shop`	*LummaStealer* C2
`relevantvoicelesskw[.]shop`	*LummaStealer* C2
`colorfulequalugliess[.]shop`	*LummaStealer* C2
`wisemassiveharmonious[.]shop`	*LummaStealer* C2
`sailsystemeyeusjw[.]shop`	*LummaStealer* C2

P.S - Huge thanks to my friend donaldduck8 for proofreading this post, be sure to check out his blog at https://sinkhole.dev