Memory Analysis of .NET and .Net Core Applications

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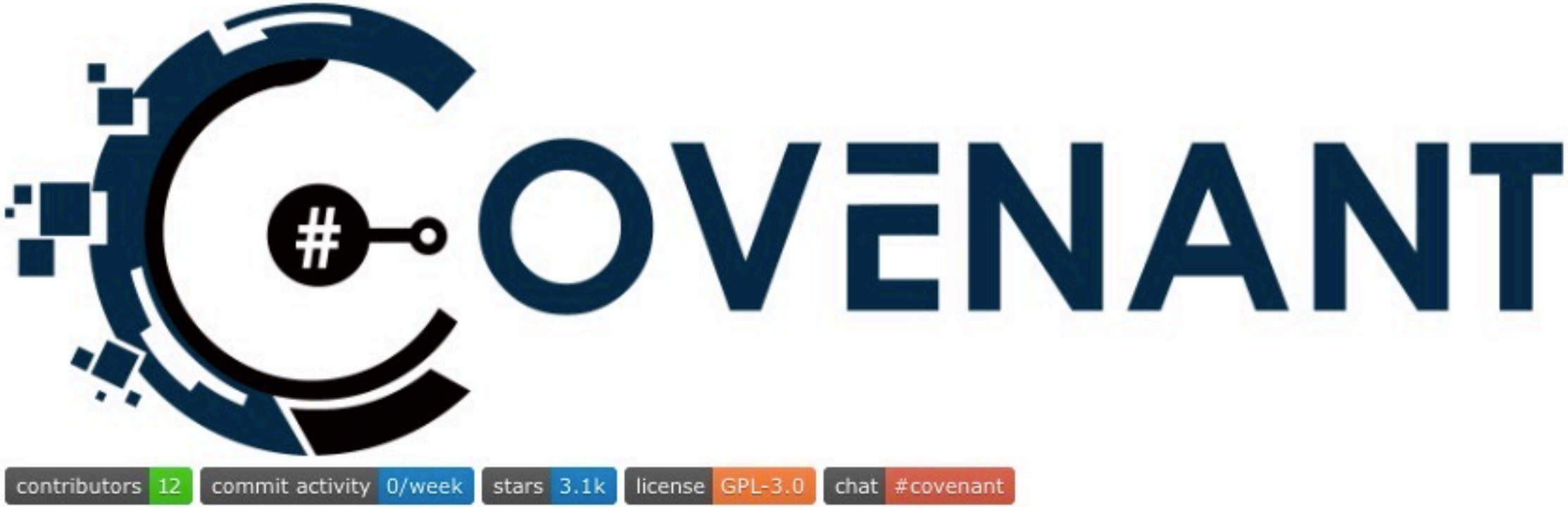
Modhuparna Manna, **Andrew Case**, Aisha Ali-Gombe, Golden G. Richard III

Motivation

- .NET-based malware is increasingly common in sophisticated, real-world attacks
- This shift occurred as Powershell became unusable in many scenarios
- .NET provides built-in support for memory-only loading, crypto routines, and full access to the Windows API
- Current memory forensic algorithms are very weak against detection of .NET-based malware

PowerShell Empire

Empire is a pure PowerShell post-exploitation agent built on cryptologically-secure communications and a flexible architecture. Empire implements the ability to run PowerShell agents without needing powershell.exe, rapidly deployable post-exploitation modules ranging from key loggers to Mimikatz, and adaptable communications to evade network detection, all wrapped up in a usability-focused framework.



Covenant is a .NET command and control framework that aims to highlight the attack surface of .NET, make the use of offensive .NET tradecraft easier, and serve as a collaborative command and control platform for red teamers.

Covenant is an ASP.NET Core, cross-platform application that includes a web-based interface that allows for multi-user collaboration.

Project Page: https://github.com/cobbr/Covenant

.NET Memory-Only Loading

Load(Byte[])

Loads the assembly with a common object file format (COFF)-based image containing an emitted assembly. The assembly is loaded into the application domain of the caller.

C# Copy

```
public static System.Reflection.Assembly Load (byte[] rawAssembly);
```

Parameters

rawAssembly Byte[]

A byte array that is a COFF-based image containing an emitted assembly.

Bypassing AMSI

```
[Ref].Assembly.GetType('System.Management.Automation.AmsiUtils').\
    GetField('amsiInitFailed','NonPublic,Static').SetValue($null,$true)
```

- Recent Black Hat presentation on modern AMSI bypasses: https://www.blackhat.com/asia-22/briefings/schedule/#amsi-unchained-review-of-known-amsi-bypass-techniques-and-introducing-a-new-one-26120

Malicious Activity – Gathering Screenshots

CopyFromScreen(Int32, Int32, Int32, Int32, Size)

Performs a bit-block transfer of the color data, corresponding to a rectangle of pixels, from the screen to the drawing surface of the Graphics.

C# Copy

```
public void CopyFromScreen (int sourceX, int sourceY, int destinationX, int destinationY,
System.Drawing.Size blockRegionSize);
```

Malicious Activity - Microphone Recording

NAudio

NAudio is an open source .NET audio library written by Mark Heath

Malicious Activity – Keystroke Logging

```
[DllImport("user32")]
internal static extern int GetKeyboardState(byte[] pbKeyState);

[DllImport("user32.dll", SetLastError = true)]
internal static extern IntPtr SetWindowsHookEx(HookType hookType,
                                               NativeMethods.HookProc lpfn,
                                               IntPtr hMod, uint dwThreadId);

[DllImport("user32.dll")]
internal static extern IntPtr CallNextHookEx(IntPtr hhk, int nCode, IntPtr wParam, IntPtr lParam);
```

Malicious Activity - WebCamera Recording

capCreateCaptureWindowA function (vfw.h)

Article • 10/05/2021 • 2 minutes to read

The **capCreateCaptureWindow** function creates a capture window.

Syntax

C++ Copy

```
HWND VFWAPI capCreateCaptureWindowA(
  LPCSTR lpszWindowName,
  DWORD  dwStyle,
  int    x,
  int    y,
  int    nWidth,
  int    nHeight,
  HWND   hwndParent,
  int    nID
);
```

.NET Framework vs .NET Core

- .NET Framework
  - Closed source*, Windows-only implementation
  - The main version used in production environments
  - Windows-only features, such as AMSI

- .Net Core
  - Open source, cross-platform implementation
  - Supports mobile platforms and is highly scalable
  - Microsoft claims it will replace .NET Framework (unlikely)

https://www.geeksforgeeks.org/differences-between-net-core-and-net-framework/

.NET Framework vs .NET Core Analysis Differences

- .NET Framework
  - PDB files only have a few symbols
  - *NO* data structure types
  - Requires reverse engineering per version to recover the offsets

- .NET Core
  - PDB files have full symbol set and type information
  - Symbol and type information can easily be integrated into Volatility 2 and automatically integrated into Volatility 3

Runtime Memory Analysis Goals

- Recover the set of load classes
- For each class, its fields and methods
- For each field, its name and type
- For each method, its definition and code location
- Instances of each class (objects)

Domains, Assemblies, and Modules

- Each application has at least one *application domain*
  - A container (process) inside the CLR, all the .NET code and data
  - Only one allowed in .NET Core

- Each *domain* has at least one *assembly*, which is a PE (.exe or .dll) file that contains managed code and resources

- *modules* are used to track each component of an assembly
  - .NET Core only allows one module per assembly

Covenant Memory Only Assemblies

```
public static GenericObjectResult AssemblyExecute(byte[] AssemblyBytes,
                                                   String TypeName = "",
                                                   String MethodName = "Execute",
                                                   Object[] Parameters = default(Object[]))
{
      Reflect.Assembly assembly = Load(AssemblyBytes);
      Type type = TypeName == "" ? assembly.GetTypes()[0] : assembly.GetType(TypeName);
      Reflect.MethodInfo method = MethodName == "" ? type.GetMethods()[0] :
                                                     type.GetMethod(MethodName);
      var results = method.Invoke(null, Parameters);
      return new GenericObjectResult(results);
}
```

```
$ python vol.py  -f data.lime --profile=Win10x64_19041 dotnet_memory_only -D output
Volatility Foundation Volatility Framework 2.6
Module                            Base                 Result
--------------------------------- -------------------- ------
aulqzbzo.3pq                      0x000001b149eb0000 OK: aulqzbzo.3pq.0x1b149eb0000.dmp
qxle4kw3.jad                      0x000001b149ed0000 OK: qxle4kw3.jad.0x1b149ed0000.dmp
td554lhy.s2d                      0x000001b149ee0000 OK: td554lhy.s2d.0x1b149ee0000.dmp
CSPHZsvIYrVNQAEdUqkPnzbwhnhK      0x000001b14a040000 OK: CSPHZsvIYrVNQAEdUqkPnzbwhnhK.0x1b14a040000.dmp

$ file *
CSPHZsvIYrVNQAEdUqkPnzbwhnhK.0x1b14a040000.dmp: PE32 executable (DLL) (console) Intel 80386 Mono/.Net assembly
aulqzbzo.3pq.0x1b149eb0000.dmp:                 PE32 executable (GUI) Intel 80386 Mono/.Net assembly
qxle4kw3.jad.0x1b149ed0000.dmp:                 PE32 executable (DLL) (console) Intel 80386 Mono/.Net assembly
td554lhy.s2d.0x1b149ee0000.dmp:                 PE32 executable (DLL) (console) Intel 80386 Mono/.Net assembly
```

Recovering Loaded Classes

- Each *module* has a a *MethodTable* that holds the information on contained classes, each of which is represented by the *EEClass* type

- ”Querying” the in-memory metadata database leads to recovery of the name and namespace of a class

```
$ python vol.py  -f data.lime --profile=Win10x64_19041 dotnet_classes
Volatility Foundation Volatility Framework 2.6
Class Address      Class Name
------------------ ----------
0x00007ffc64827950 System.AppContext
0x00007ffc64765d10 System.Array
0x00007ffc64892758 System.CLRConfig
<snip>
```

Recovering Fields

- Each class stores a list where each element is a field
- Fields have a *name, type,* and *offset*

```
$ python vol.py  -f data.lime --profile=Win10x64_19041 dotnet_fields
Volatility Foundation Volatility Framework 2.6
Module       Class        Field        Type
------------ ------------ ------------ ----
td554lhy.s2d <Module>     <INVALID>    System.Reflection.Assembly
```

Recovering Methods – NDirect (native)

```
[DllImport("user32")]
internal static extern int GetKeyboardState(byte[] pbKeyState);

[DllImport("user32.dll", SetLastError = true)]
internal static extern IntPtr SetWindowsHookEx(HookType hookType,
                                               NativeMethods.HookProc lpfn,
                                               IntPtr hMod, uint dwThreadId);

[DllImport("user32.dll")]
internal static extern IntPtr CallNextHookEx(IntPtr hhk, int nCode, IntPtr wParam, IntPtr lParam);
```

```
$ python vol.py  -f data.lime --profile=Win10x64_19041 dotnet_ndirect_methods
Volatility Foundation Volatility Framework 2.6
Module       Class        DLL          Method
------------ ------------ ------------ ------------------------
ohydkf5n.ceo Keylogger    kernel32.dll GetModuleHandle
ohydkf5n.ceo Keylogger    user32.dll   CallNextHookEx
ohydkf5n.ceo Keylogger    user32.dll   GetForegroundWindow
ohydkf5n.ceo Keylogger    user32.dll   GetWindowText
ohydkf5n.ceo Keylogger    user32.dll   SetWindowsHookEx
ohydkf5n.ceo Keylogger    user32.dll   UnhookWindowsHookEx
```

Recovering Methods – .NET (IL)

- Methods written in .NET are not JIT'd until they are called
- We only analyze these functions as otherwise they have no x86 or x86-64 code present
- The code is statically analyzed for calls to suspicious functions

```
$ python vol.py  -f data.lime --profile=Win10x64_19041 dotnet_il_methods
Volatility Foundation Volatility Framework 2.6
Module Function  Called Function
------ --------  ---------------
Form1  jgi6MuZBI System.Drawing.Graphics.FromImage
```

Conclusions & Future Work

- Modern DFIR requires memory forensics to be effective and complete
- Our research effort has provided a strong set of support to routine integration of .NET analysis into memory forensics workflows
- Automation of type extraction needed for fully automated workflows

Questions? Comments?

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- Social Media
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- 2022 Volatility Plugin Contest now open!
  https://volatility-labs.blogspot.com/2022/07/the-10th-annual-volatility-plugin-contest.html