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TENTACLE:
Environment-Sensitive Malware Palpation

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http://www.ffri.jp

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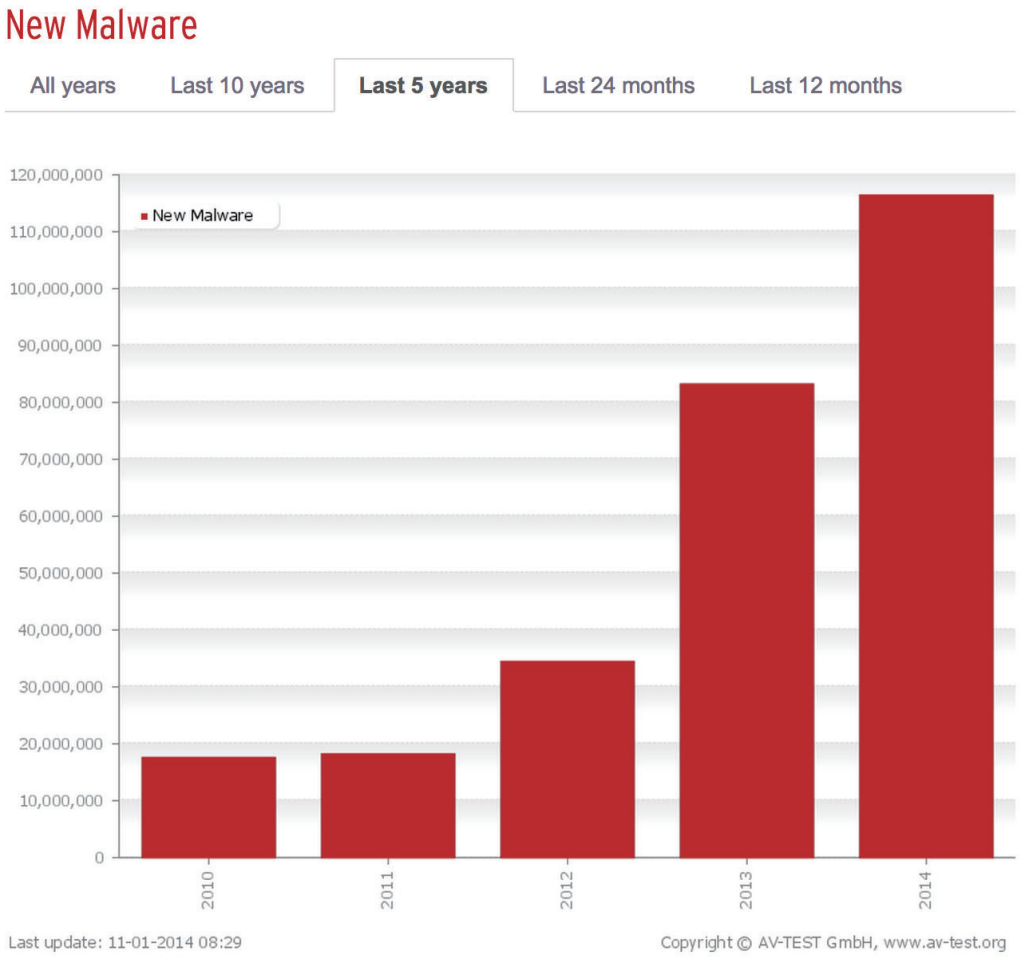
Contents

- Background/Motivation
- Taxonomy of anti-sandbox techniques
- Tentacle Design
- Implementation
- Experiments
- Conclusion

Background

- Malware explosion
  - 120,000,000/recent year
- Antivirus is dead…?



AV Test: Statistics –New Malware- (Nov. 05 2014 viewed)
http://www.av-test.org/en/statistics/malware/

We need dynamic and automated malware analysis

- “Scalability” is most important factor in information explosion era
  - Cloud
  - Bigdata
  - IoT
- Malware analysis also needs “scalable” methodology
  - Automation is justice

Obi wan said, “Use the sandbox, Luke”

- Security engineer and researcher use sandbox environment for malware analyzing

- Automated dynamic analysis technology also based on VM/application sandbox
  - Anubis(online sandbox)
  - Cuckoo Sandbox(VirtualBox base)
  - Some commercial UTM Appliance
  - Some commercial endpoint security solution

Sophisticated malware strike back

- Sophisticated malware arms many **anti-analyze** techniques
  - Naturally using targeted attacks, cyber espionage, banking malware

- We called those malware “evasive malware”

Related work

- BareCloud [Dhilung K et al., USENIX SEC'14]
  - "5,835 evasive malware out of 110,005 recent samples"
- Prevalent Characteristics in Modern Malware [Gabriel et al., BH USA '14]
  - "80% malware detect vmware using backdoor port"

What do you think?

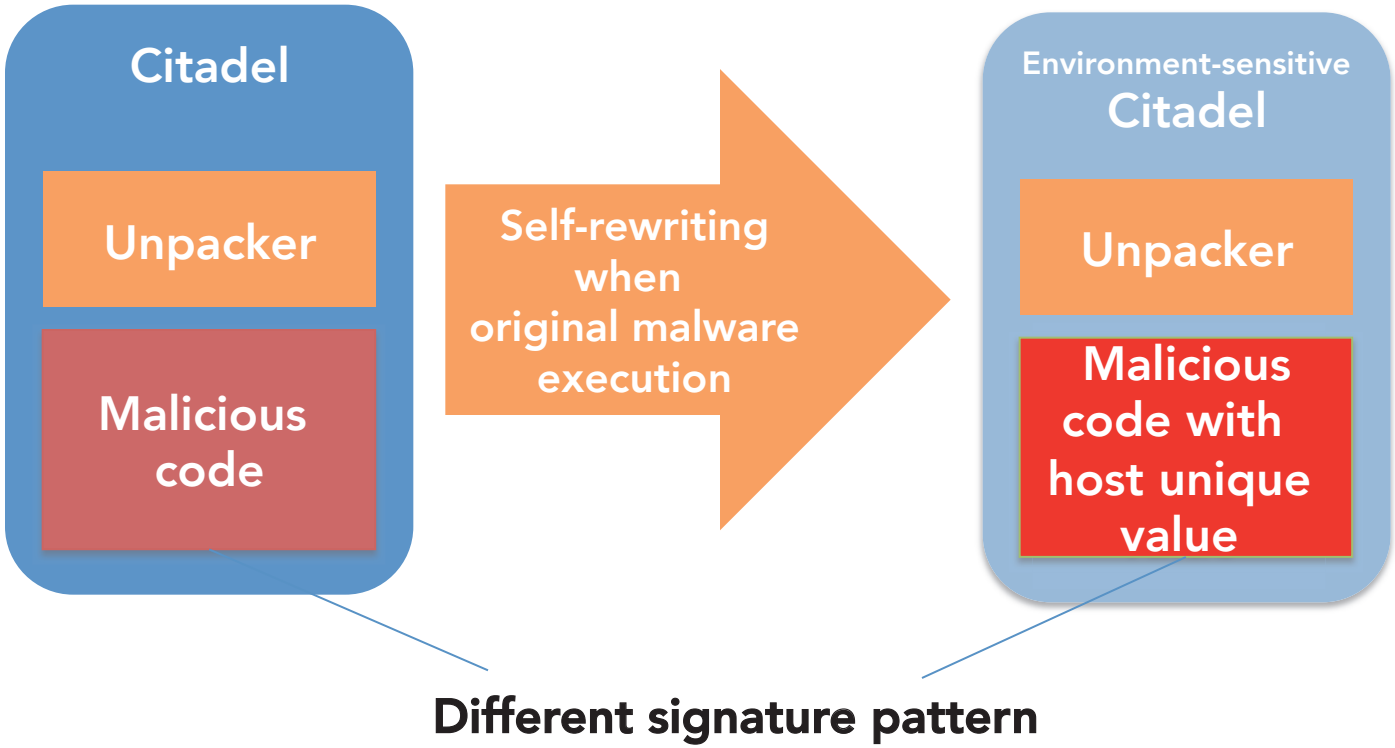
Case study: Citadel

- Some citadel detects the execution environment and do not engage in malicious behavior when the current host differs from the infected host
  - To avoid dynamic malware detection(like sandbox analysis)

- Showing 2 examples
  - Host-fingerprinting
  - VM/Sandbox detection

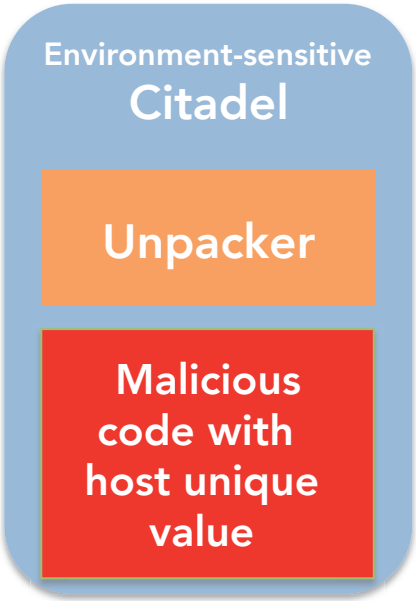
Host-fingerprinting

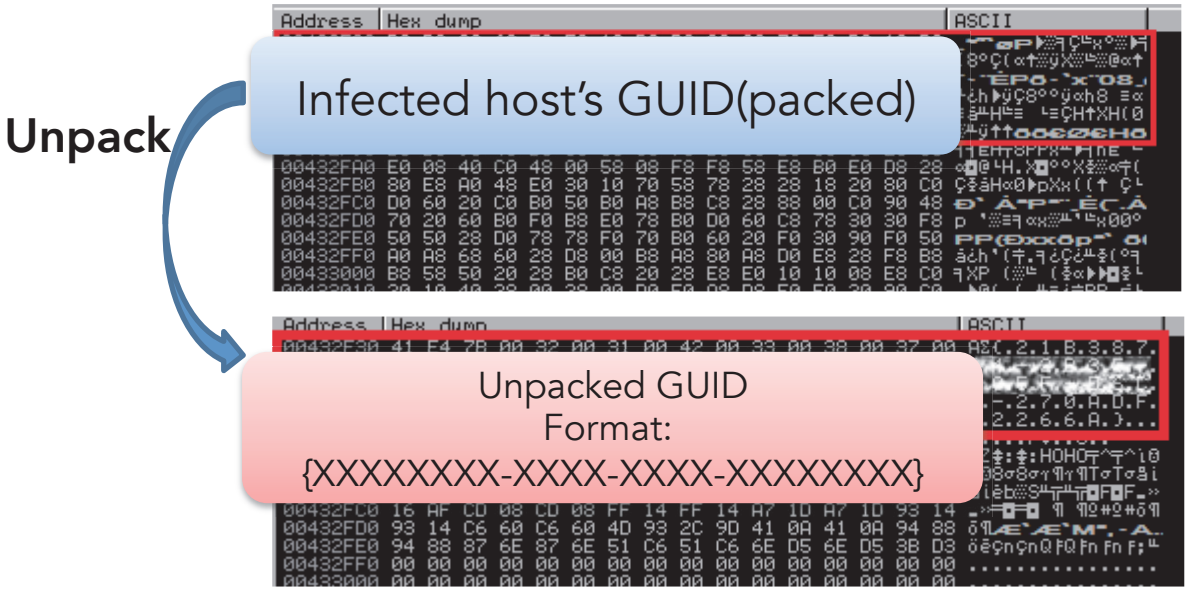
- Embedding infected host's unique value into execution binary



Host-fingerprinting(cont'd)

- Getting GUID on system drive using the GetVolumeNameForVolumeMountPoint()
- Comparing running host's GUID value and embedded infected host's value
- Process executes malicious code if GUID values are



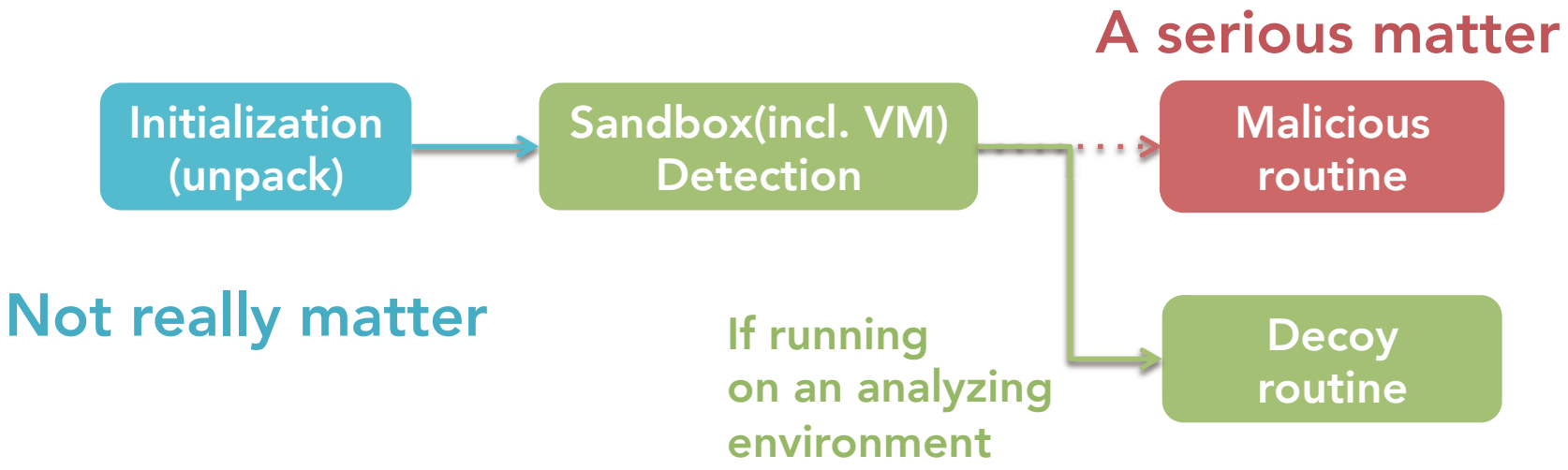


VM/Sandbox detection

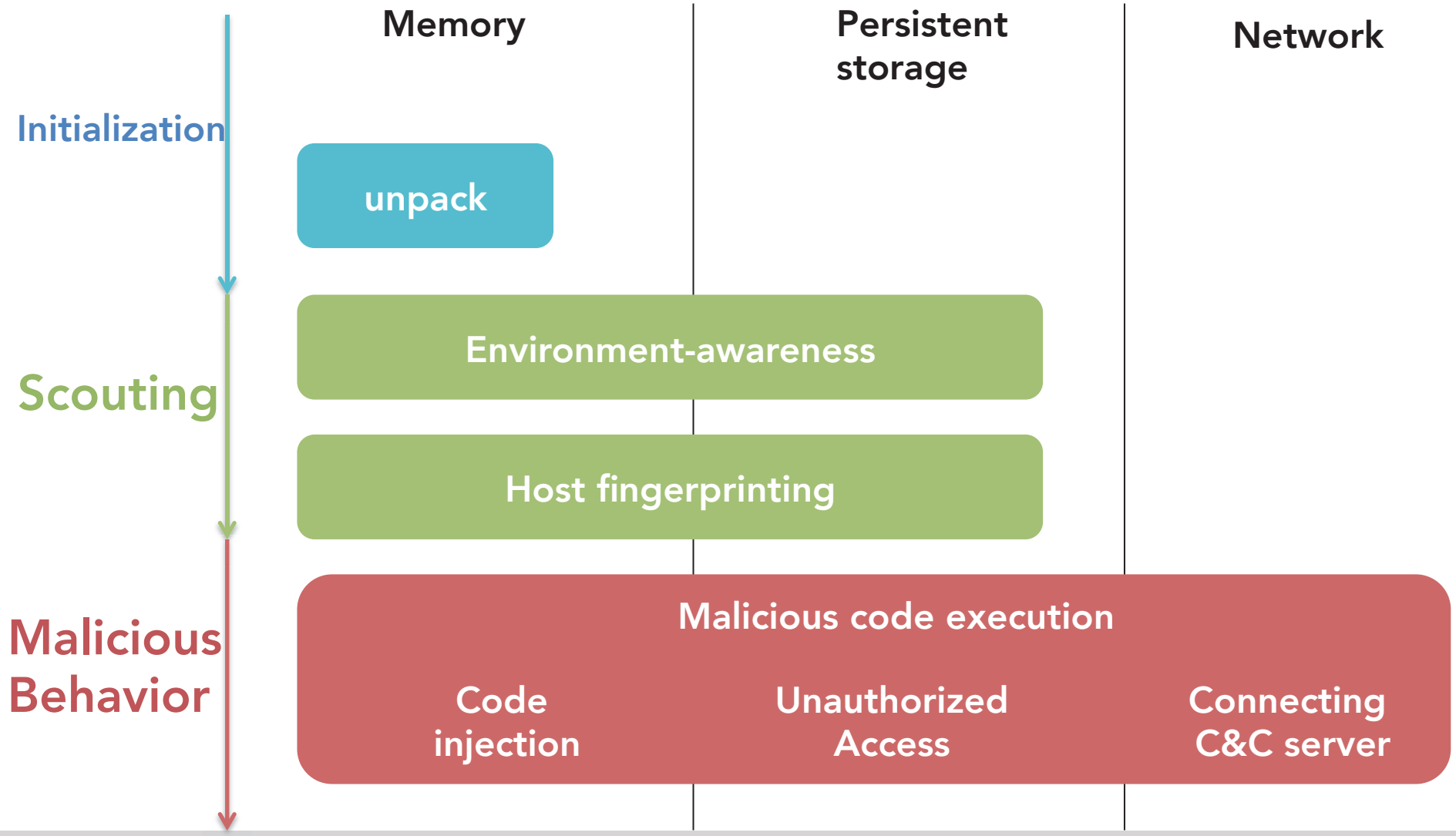
- Checking process's product name
  - like "*vmware*", "*virtualbox"
- Scanning specific files and devices
  - C:¥popupkiller.exe
  - C:¥stimulator.exe
  - C:¥TOOLS¥execute.exe
  - ¥¥.¥NPF_NdisWanIp
  - ¥¥.¥HGFS
  - ¥¥.¥vmci
  - ¥¥.¥VBoxGuest

Citadel behavior of host/environment inconsistency

- For example:
  - Process termination
  - Running fake(or harmless) code



Citadel runtime activities



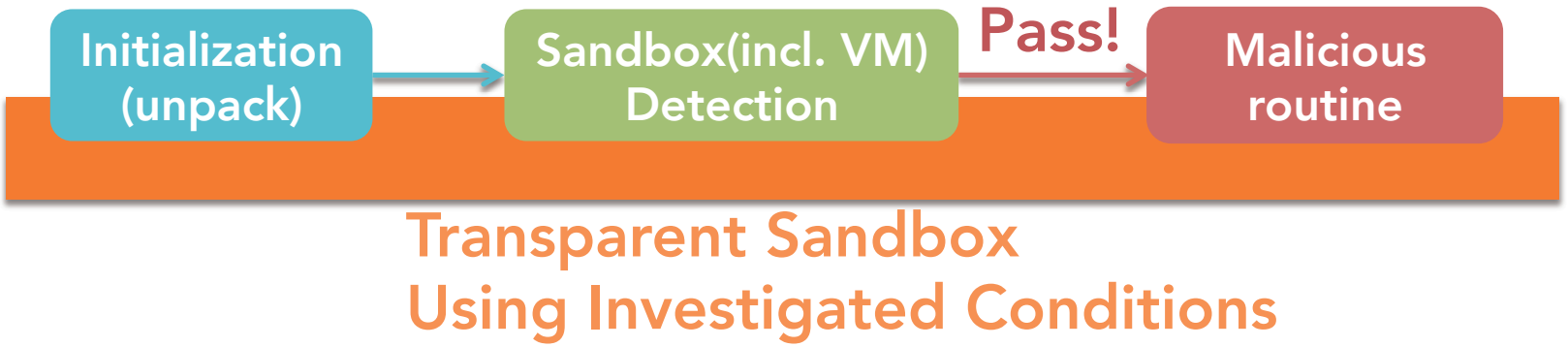
Aim of evasive malware

- Signature-based AV detection avoiding

- Anti-analyzing
  - Anti-security engineer
  - Sandbox evasion

Motivation

- An automatic investigation into a condition used by sandbox evasion
  - Faking bare-metal environment on sandboxes



Know Your Enemy

TAXONOMY OF ANTI-SANDBOX

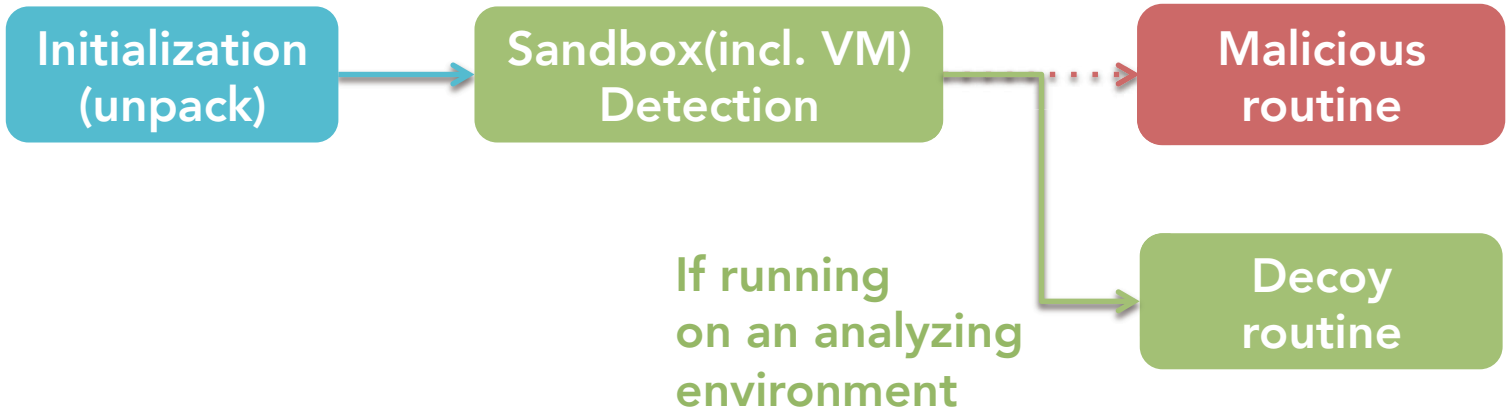
Taxonomy of anti-sandbox techniques

- Anti-sandbox maneuver
  - Environment awareness
    - Using result of sandbox detection
  - (Stalling code)
  - (User interaction checks)

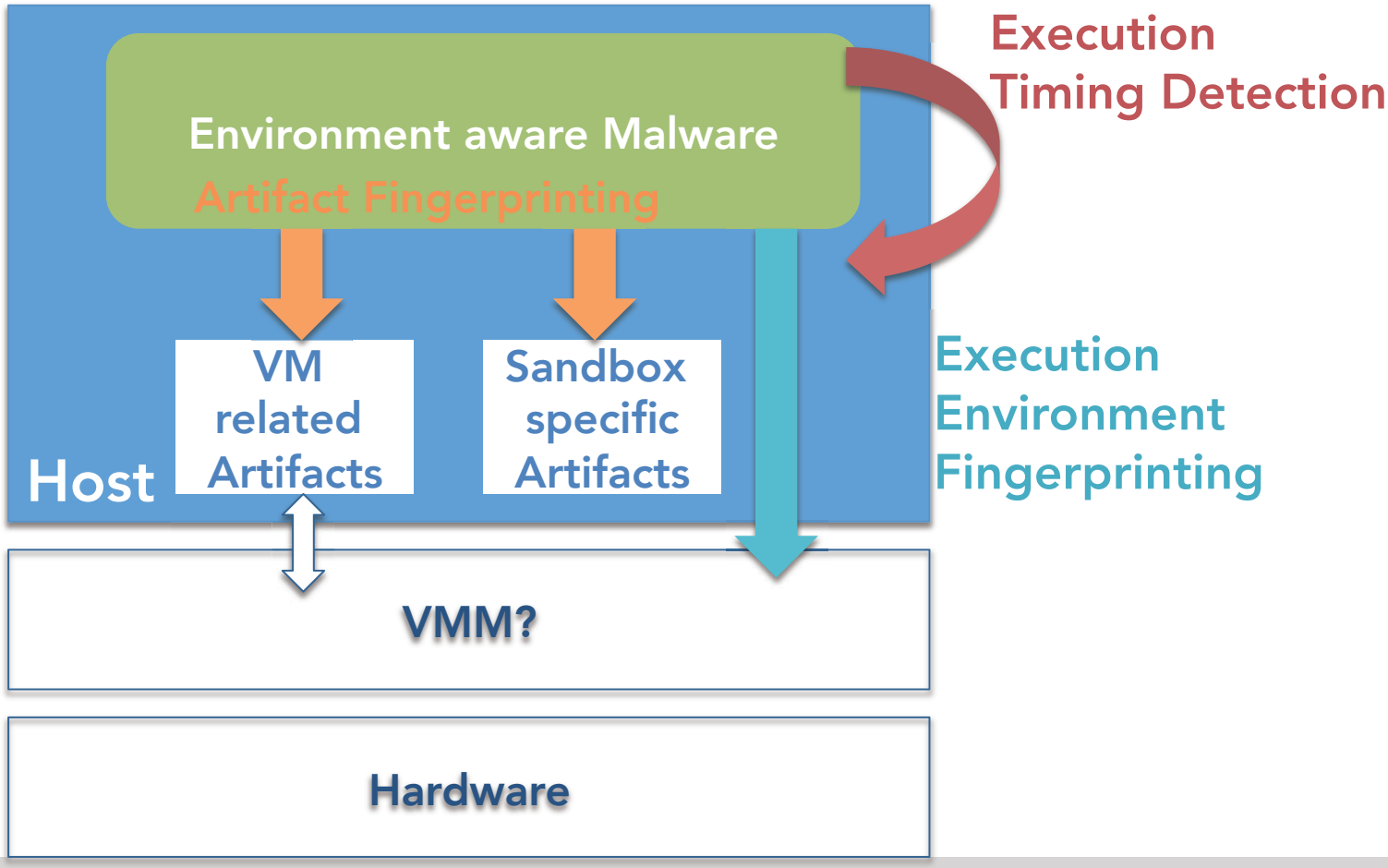
- Sandbox (debug/sandbox/vm) detection
  - Artifact fingerprinting
  - Execution environment fingerprinting
  - Execution timing detection

Environment awareness

- Checking host environments
- If malware runs decoy routine then it detects analyzer's sign
  - Malicious behavior never executed



Sandbox (debug/sandbox/vm) detection



Artifact fingerprinting

- Sandbox/VM related processes
  - Like vmware, virtualbox etc.
- Sandbox/VM environment specific files
- Sandbox/VM environment specific registry keys
- Sandbox/VM environment specific devices and its attributes
  - ex). QEMU HDD vendor name
- Sandbox/VM Specific I/O port
  - VMWare backdoor port is most famous artifact in malware

Execution environment fingerprinting

- Using virtual machine implementation specific platform value and reaction
  - CPUID instruction result
  - Redpill
    - Using LDT/GDT and IDT incongruousness
  - Interesting research here: Cardinal Pill Testing

Execution timing detection

- For example:using clock count differential
  - Traditional anti-debug technique

```
400022A2 | 60              | PUSHAD
400022A3 | 0F31            | RDTSC
400022A5 | 31C9            | XOR ECX,ECX
400022A7 | 01C1            | ADD ECX,EAX
400022A9 | 0F31            | RDTSC
400022AB | 29C8            | SUB EAX,ECX
400022AD | 3D FF0F0000     | CMP EAX,0FFF
400022B2 | 61              | POPAD
400022B3 | 0F83 11010000   | JNB 400023CA
```

Comparing two TSC differentials

Targets of today's presentation

- Anti-sandbox maneuver
  - ✓ **Environment awareness**
    - Using result of sandbox detection
  - ☐ Stalling code
  - ☐ User interaction checks
- Sandbox (debug/sandbox/vm) detection
  - ✓ **Artifact fingerprinting**
  - ✓ **Execution environment fingerprinting**
  - ☐ Execution timing detection

Automatically disarmament system for armed malware with anti-sandboxing

TENTACLE: DESIGN

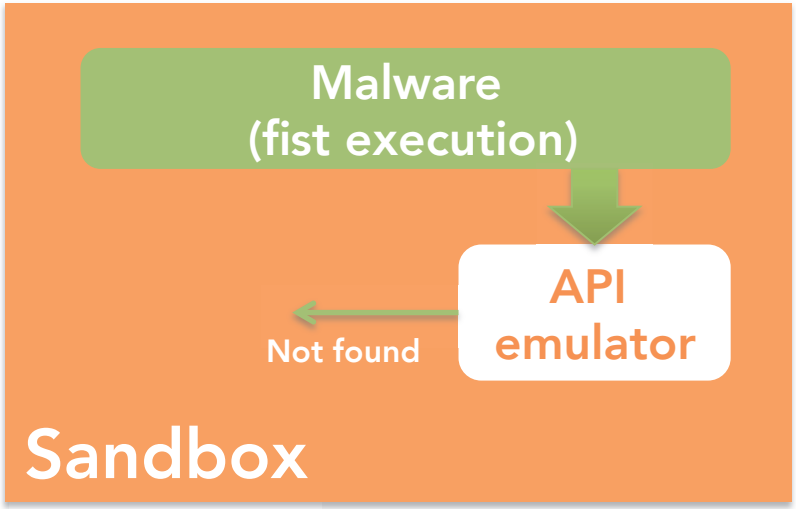
Concept: malware palpation

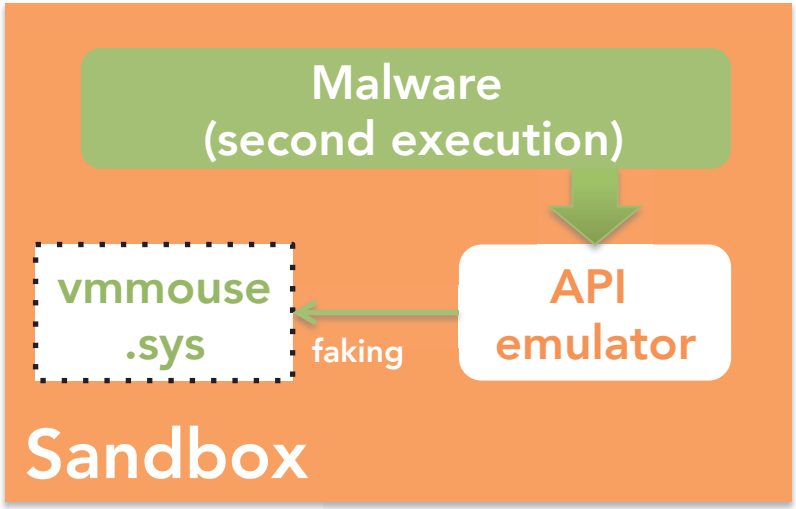
1. “Thousand form” sandbox runs malware again and again
   - Changing “virtual” artifacts exposure each execution for execution branch detection

2. Retroactive condition analysis
   - Specifying “branch condition” on unnatural process termination

Malware palpation

- Sandbox runs same malware again and again
- Sandbox fakes different sandbox-related artifacts each malware execution
  - Detecting execution difference using code execution integrity(CEI)





Code Execution Integrity(CEI)

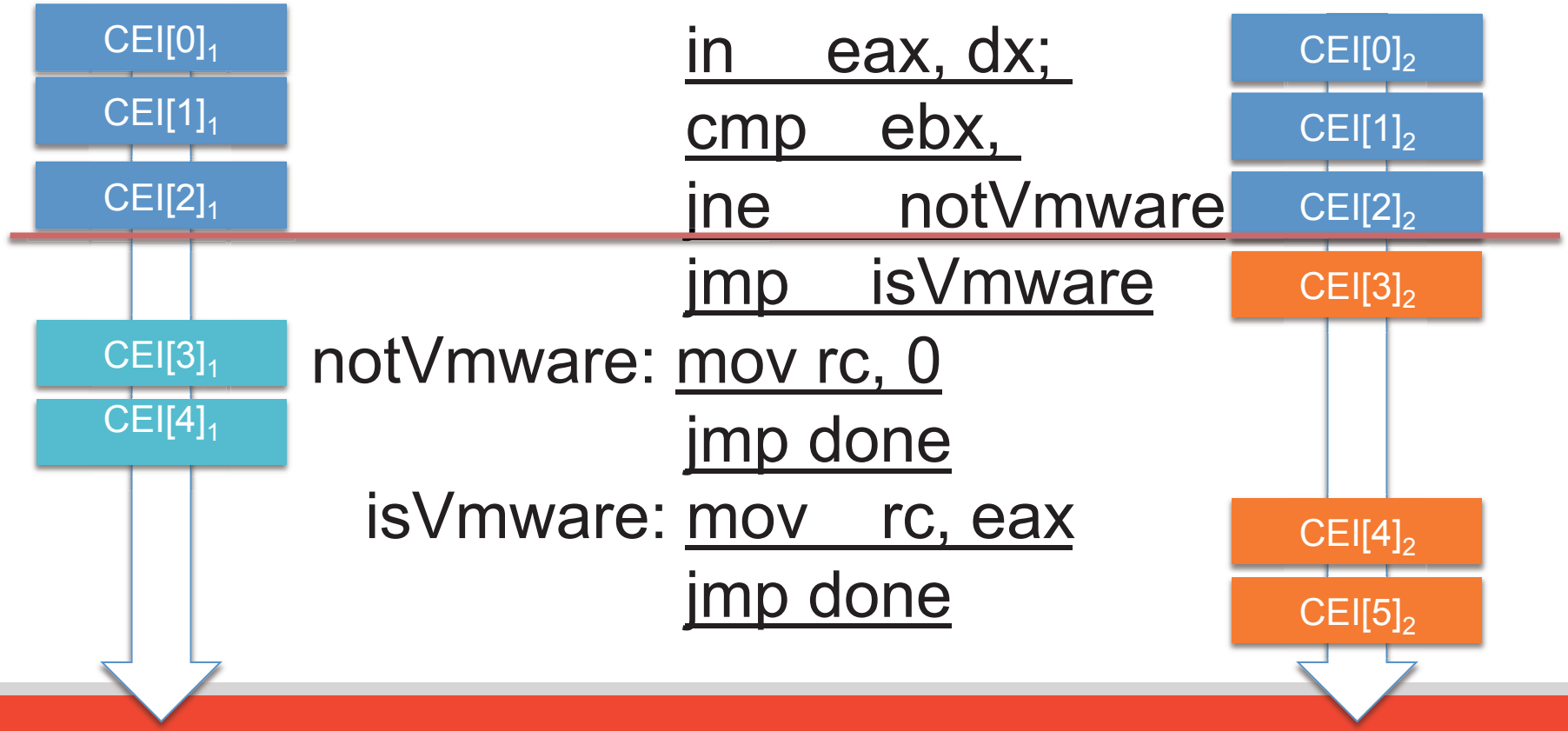
- CEI shows uniqueness of instruction execution history
  - Inspired by TPM trust chaining
- “measurement” per instruction

Digest[i] = SHA1(fetched CPU instruction + Digest[i-1])

mov	$0x616b6157, %eax	0xb857616b61	d[0] = SHA1(0xb857616b61)
push	%ebx	0x53	d[1] = SHA1(d[0] + 0x53)
push	%eax	0x50	d[2] = SHA1(d[1] + 0x50)
mov	$4, %edx	0xba04000000	d[3] = SHA1(d[2]
mov	$1, %ebx	0xbb01000000	+0xba04000000)
			...

Execution branch detection

- Using execution step count and code execution integrity(CEI) value



Retroactive condition analysis

- Sandbox retroactive from termination to terminated reason API and arguments when suspicious termination
  - Only a few steps executions
  - To terminate before network activities

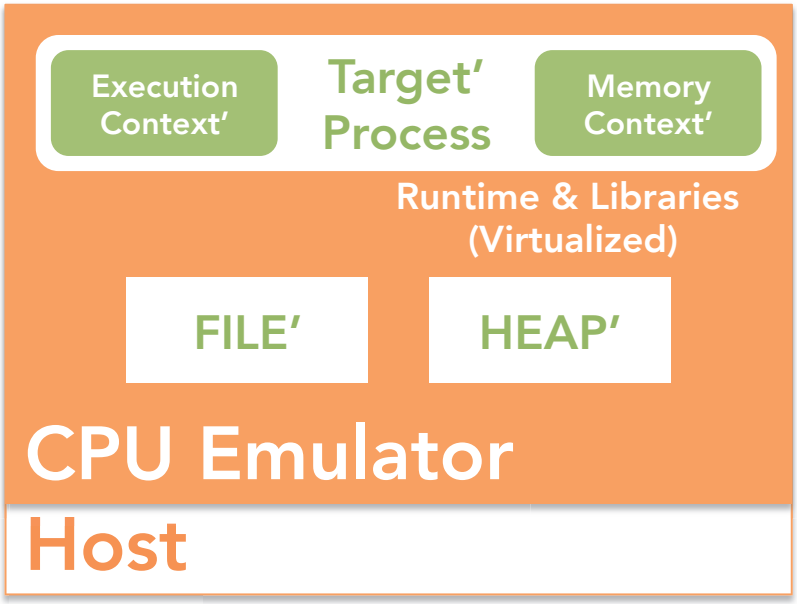
```
sub esp, 1024
mov ebx, esp
push 400h
push ebx
push 0h
call GetModuleFileNameA
lea eax, MyPath
push eax
push ebx
call lstrcmpA
test eax, eax
push 0h
lea eax, MsgCaption
push eax
jz _ok
lea eax, NGMsgText
push eax
push 0h
call MessageBoxA
invoke ExitProcess, NULL
_ok:    lea eax, OKMsgText
```

know thyself

TENTACLE: IMPLEMENTATION

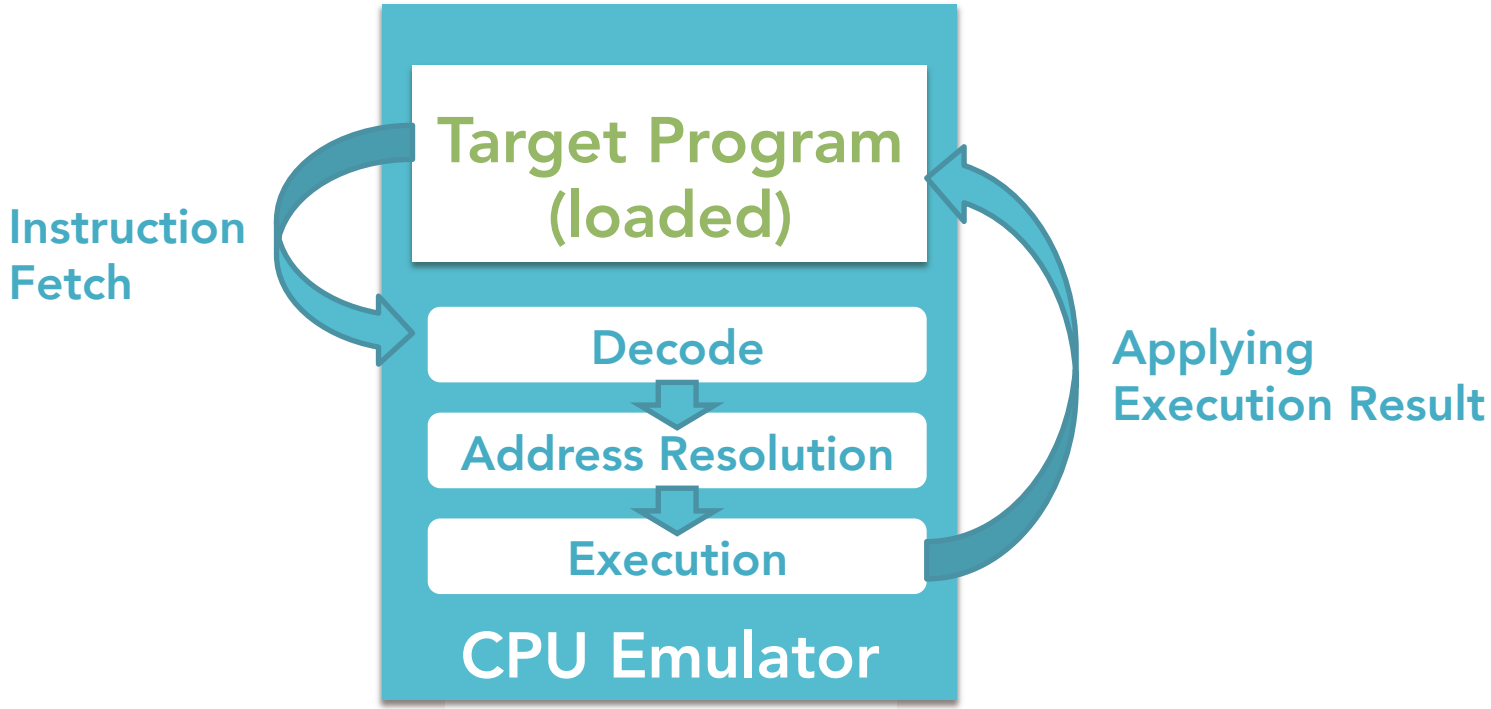
Tentacle implementation overview

- Tentacle based on IA-32 CPU emulator

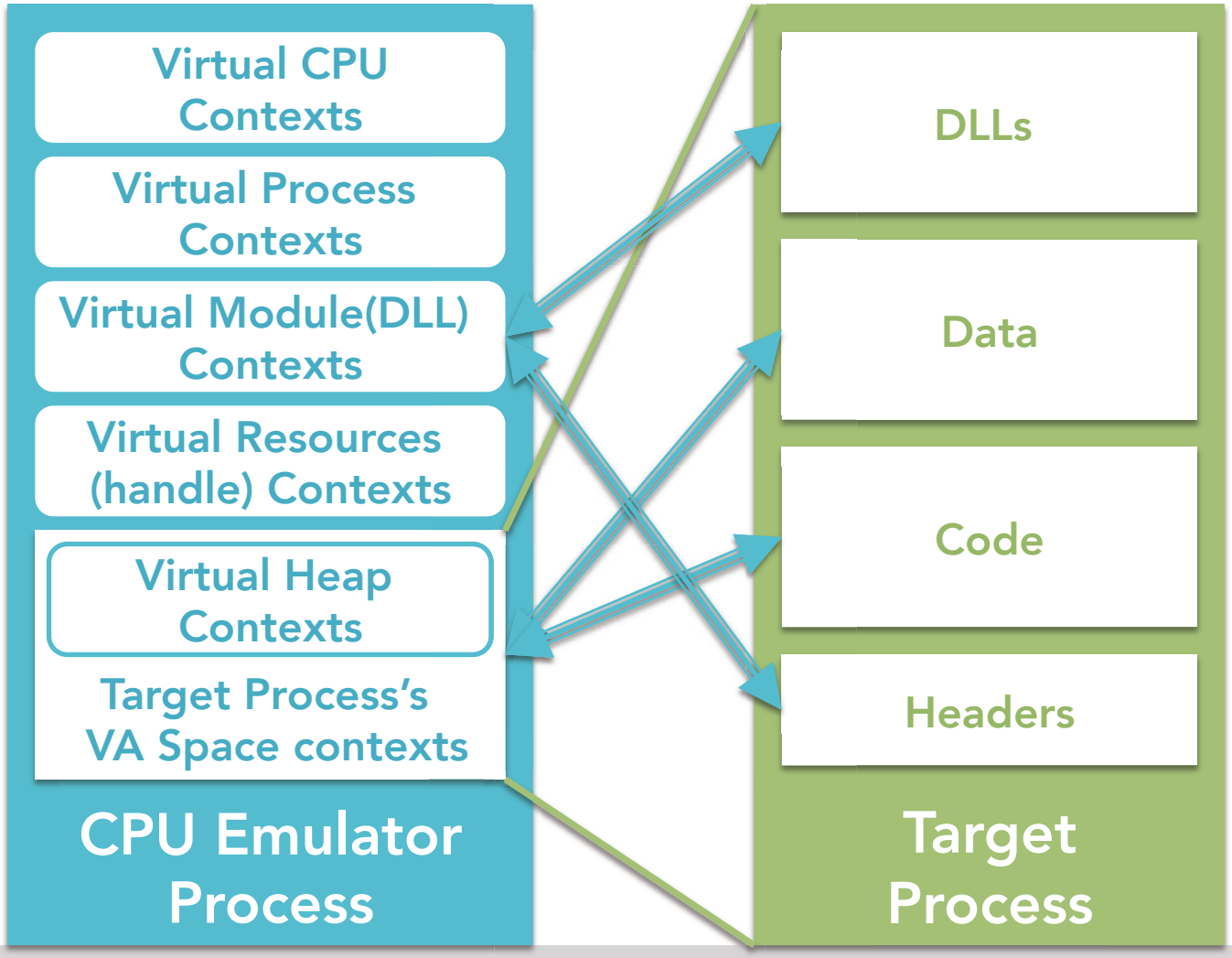


IA-32 CPU emulator-based sandbox

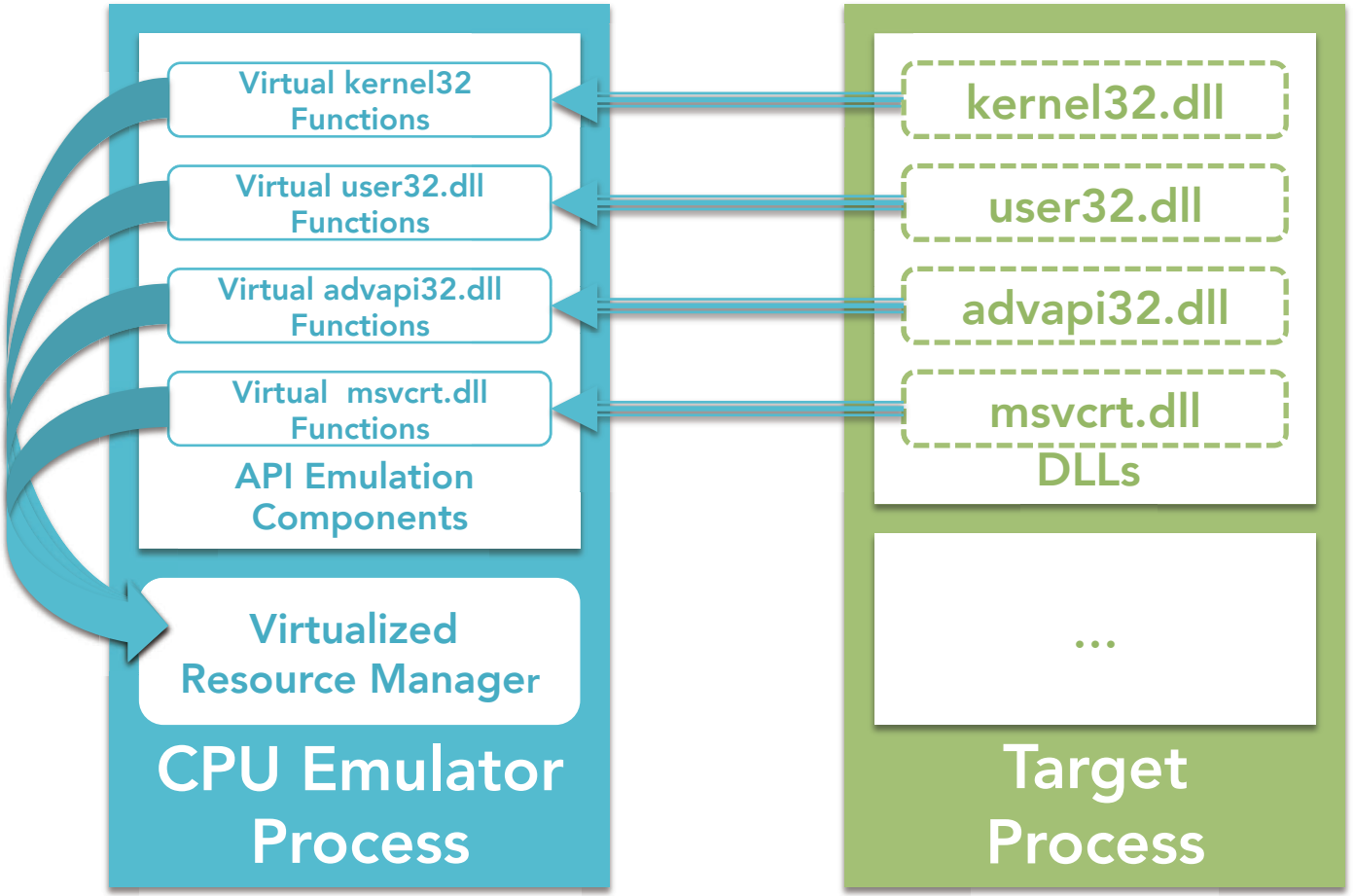
- We have already CPU Emulator-based sandbox for win32 execution (in-house use)
  - Like IDA Bochs PE operation mode



IA-32 CPU Emulator: Virtual contexts



IA-32 CPU Emulator: API emulation



Limitations

- The original CPU emulator supports a limited API
- The original CPU emulator supports a limited CPU instruction

Tentacle implementation details

- Nyarlathotep “Thousand Form” Sandbox
  - Camouflaging sandbox/vm related artifact existence
  - Execution branch detection using CEI
- Retroactive condition analysis
- ***Necronomicon***
  - Execution logging framework

Necronomicon

- Necrnomicon logs instruction per execution
  - Tracing specific API call and its arguments for Retroactive condition analysis
    - lstrcmp, GetModuleFileName, GetVolumeNameForVolumeMountPoint…
- Code execution integrity calculation per execution
  - For execution branch detection

Nyarlathotep "Thousand Form" Sandbox

- For example, VMWare related artifacts
  - backdoor port
  - vm-related files (2 files)
  - registry entries (1 entry)
- Sandbox fake "in" instruction result for backdoor port check
- Files and registry entry virtualization used by sandbox's own virtual resource manager

Experiments

- Disarmament #01: Artifact fingerprinting sample
- Disarmament #02: Comparing Disk GUID value sample
- Disarmament #03: Comparing executable file path sample

Disarmament #01: Artifact fingerprinting sample

```
int _tmain(int argc, _TCHAR* argv[])
{
        int count = 0;
        delay();
        if ( sbdetect_vmware_backdoor_port() > 0){
                printf("VMWare backdoor port detected.  I am on the virtual.");
        }
        if ( sbdetect_vmware_sysf01() == 0 ){
                printf("vmmouse.sys detected. I am on the virtual.\n");
                exit(1);
        }
        if ( sbdetect_vmware_sysf02() == 0 ){
                printf("vmmouse.sys detected. I am on the virtual.\n");
                exit(1);
        }
        if ( sbdetect_vmware_reg01() == 0 ){
                printf("RegKey: \"SOFTWARE\\VMware, Inc.\\VMware Tools\"
detected. I am on the virtual.\n");
                exit(1);
        }
        //Malicious behavior
        printf("malicious behavior\n”);
        return 0;
}
```

sbdetect_vmware_backdoor_port()

```
int sbdetect_vmware_backdoor_port(void)
{
    int rc = 0;
    __try
    {
        __asm
        {
            mov    eax, 'VMXh'
            mov    ebx, 0;
            mov    ecx, 0xA
            mov    edx, 'VX'  // port
            in     eax, dx; // read port
            cmp    ebx, 'VMXh' // Vmware echo 'VMXh'
            jne      notVmware
            jmp    isVmware
            notVmware:
            mov rc, 0
            jmp done
            isVmware:
            mov    rc, eax
            done:
        }
    }
    __except(EXCEPTION_EXECUTE_HANDLER)
    {
        rc = 0;
    }

    return rc;
}
```

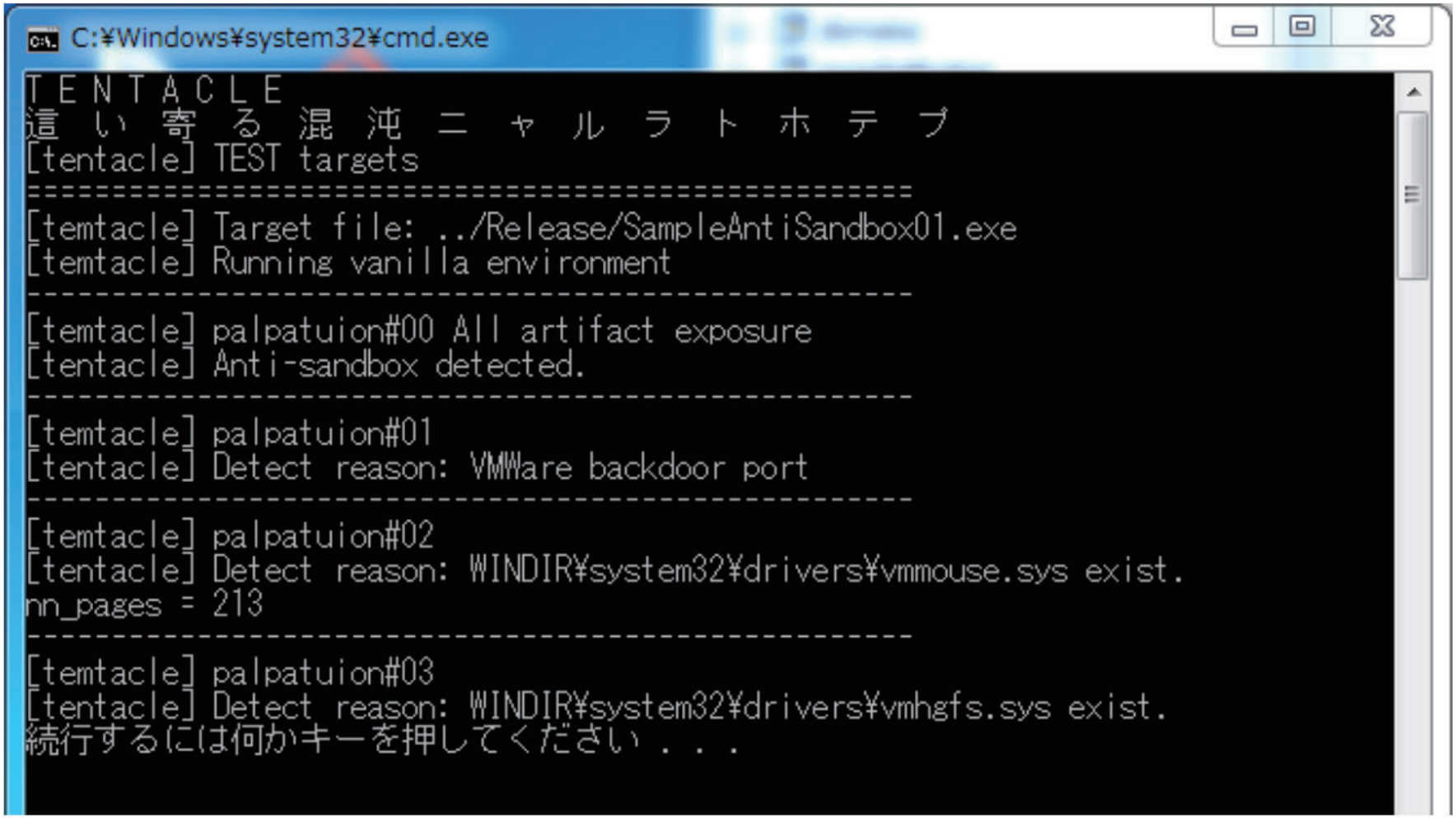
sbdetect_vmware_sysf01()

```
//
// Detect proven: Windows 7 32bit
// Not detected:  Windows 7 64bit
//
int sbdetect_vmware_sysf01() {
    DWORD ret;
            TCHAR target[255] = "%WINDIR%\\system32\\drivers\\vmmouse.sys";
            ret = GetFileAttributes(target);
    if( ret != INVALID_FILE_ATTRIBUTES ){
        return 0;
    }
            else{
        return 1;
    }
}
```

sbdetect_vmware_sysf02()

```
//
// Detect proven: Windows 7 32bit
// Not detected:  Windows 7 64bit
//
int sbdetect_vmware_sysf02() {
    DWORD ret;
            TCHAR target[255] = "%WINDIR%\\system32\\drivers\\vmhgfs.sys";
            ret = GetFileAttributes(target);
    if( ret != INVALID_FILE_ATTRIBUTES ){
        return 0;
    }
            else{
        return 1;
    }
}
```

Disarmament #01

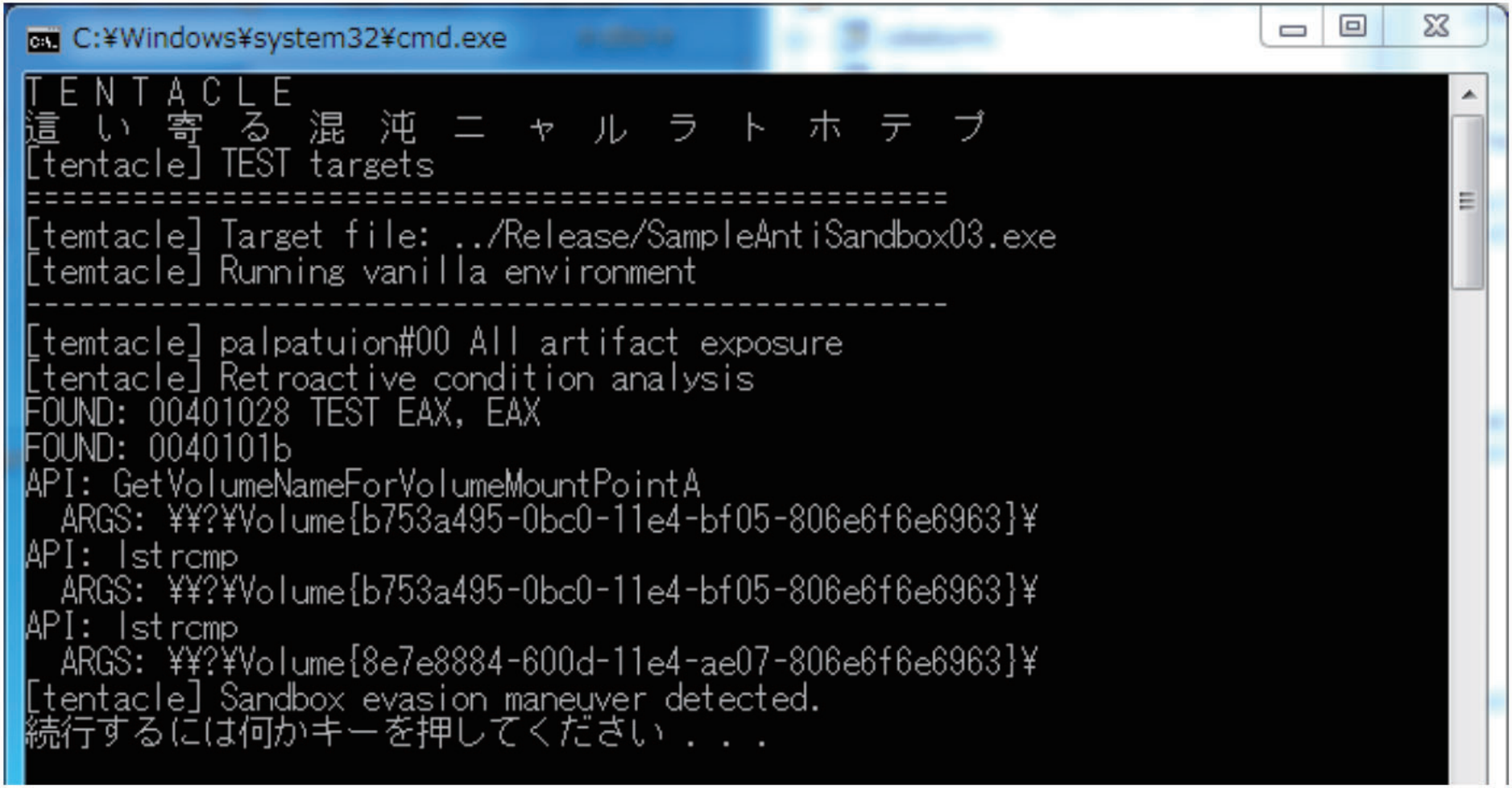


Disarmament #02: Comparing Disk GUID value sample

```
.386
.model flat,stdcall
option casemap:none
include \masm32\include\windows.inc
include \masm32\include\kernel32.inc
includelib \masm32\lib\kernel32.lib
include \masm32\include\user32.inc
includelib \masm32\lib\user32.lib
.data
        DriveC     db "C:\", 0
        VolumeC    db "\\?\Volume{8e7e8884-600d-11e4-
ae07-806e6f6e6963}\", 0
        MsgCaption db "MESSAGE", 0
        OKMsgText  db "Normal Message", 0
        NGMsgText  db "Detect Message", 0
.code
```

```
start:
        sub esp, 1024
        mov ebx, esp
        sub esp, 4
        mov eax, esp
        push eax
        push ebx
        lea eax, DriveC
        push eax
        call GetVolumeNameForVolumeMountPointA
        lea eax, VolumeC
        push eax
        push ebx
        call lstrcmpA
        test eax, eax
        push 0h
        lea eax, MsgCaption
        push eax
        jz _ok
        lea eax, NGMsgText
        push eax
        push 0h
        call MessageBoxA
        invoke ExitProcess, NULL
_ok:
        lea eax, OKMsgText
        push eax
        push 0h
        call MessageBoxA
        invoke ExitProcess, NULL
end start
```

Disarmament #02



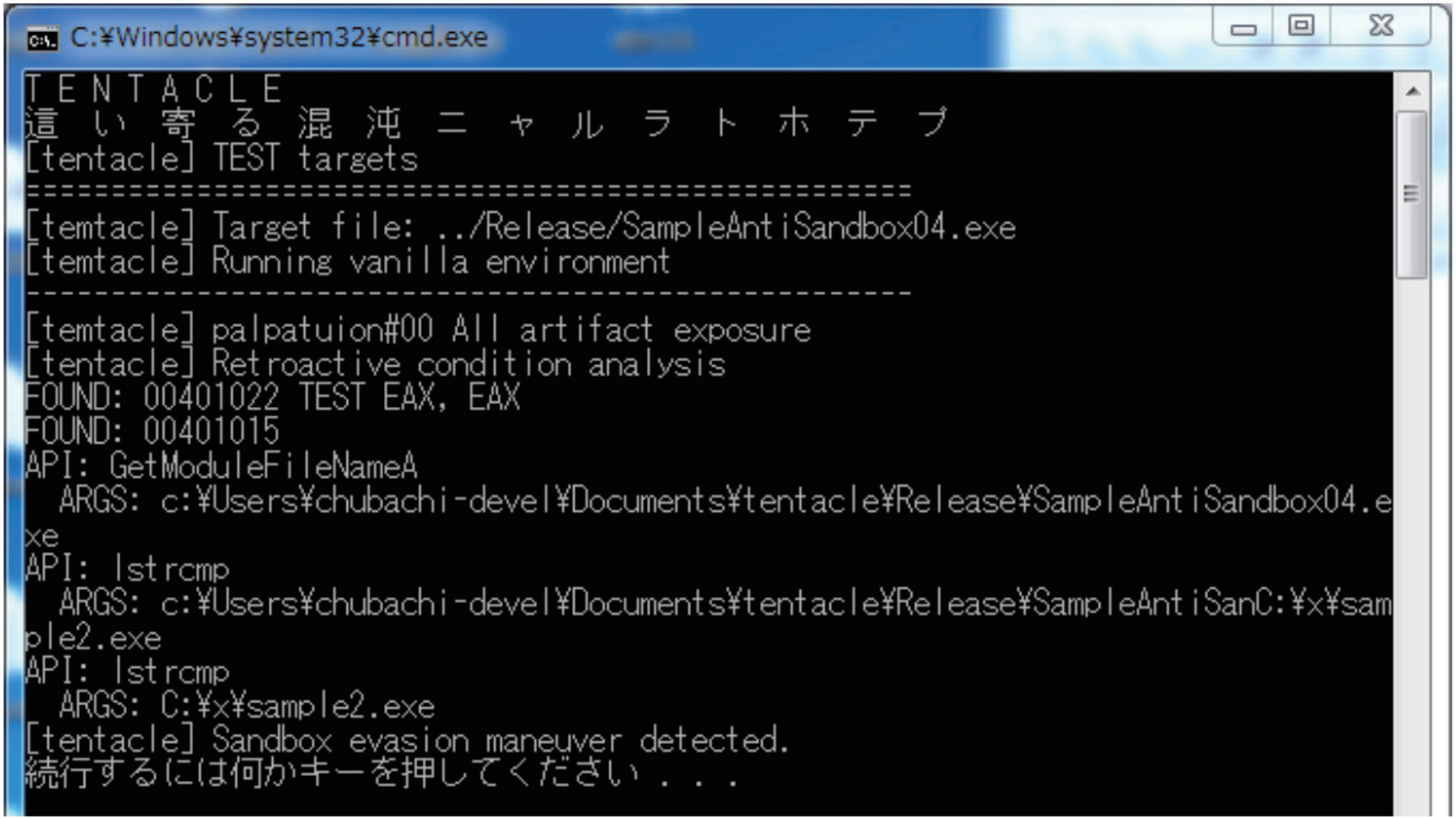
Disarmament #03 Comparing executable file path sample

```
.386
.model flat,stdcall
option casemap:none
include \masm32\include\windows.inc
include \masm32\include\kernel32.inc
includelib \masm32\lib\kernel32.lib
include \masm32\include\user32.inc
includelib \masm32\lib\user32.lib
.data

        MyPath     db "C:\x\sample2.exe", 0
        MsgCaption db "MESSAGE", 0
        OKMsgText  db "Normal Message", 0
        NGMsgText  db "Detect Message", 0

.code
start   sub esp, 1024
        mov ebx, esp
        push 400h
        push ebx
        push 0h
        call GetModuleFileNameA
        lea eax, MyPath
        push eax
        push ebx
        call lstrcmpA
        test eax, eax
        push 0h
        lea eax, MsgCaption
        push eax
        jz _ok
        lea eax, NGMsgText
        push eax
        push 0h
        call MessageBoxA
        invoke ExitProcess, NULL
_ok:    lea eax, OKMsgText
        push eax
        push 0h
        call MessageBoxA
        invoke ExitProcess, NULL
end start
```

Disarmament #03



Future work

- Improving anti-sandbox detection
  - Stalling code detection and evasion
- Improving sandbox quality

Conclusions

- This is proof of concept of automatically disarmament system for armed malware with anti-sandboxing with CPU emulator-based sandbox

- We introduced anti-sandbox taxonomy

"Know thy self, know thy enemy. A thousand battles, a thousand victories."- Sun Tzu

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Thank you !

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