Lecture 19 – Finding Vulnerabilities

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Slides based on Bailey's ECE 422

Finding Vulns

- Specification testing
- Automated white box tools
- Fuzzing
- Reverse engineering

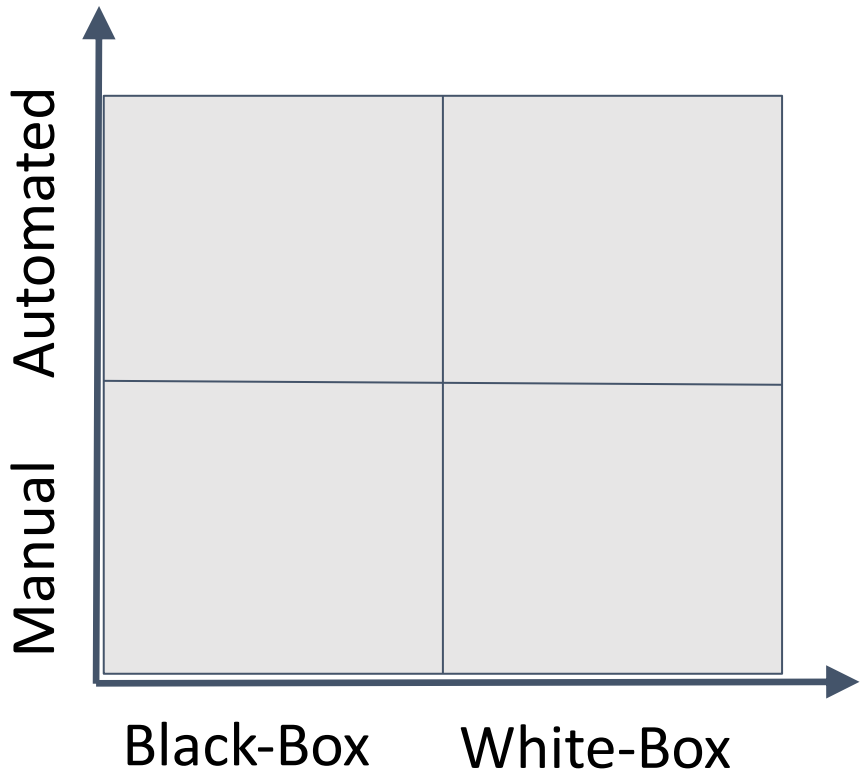
The Need for Specifications

- Testing checks whether program implementation agrees with program specification
- Without a specification, there is nothing to test!
- Testing is a form of consistency checking between implementation and specification
  - Recurring theme for software quality checking approaches
  - What if both implementation and specification are wrong?

Developer != Tester

- Developer writes implementation, tester writes specification
- Unlikely that both will independently make the same mistake
- Specifications useful even if written by developer itself
  - Much simpler than implementation
  - Specification unlikely to have same mistake as implementation

Classification of Testing Approaches



Automated vs. Manual Testing

- Automated Testing:
  - Find bugs more quickly
  - No need to write tests
  - If software changes, no need to maintain tests
- Manual Testing:
  - Efficient test suite
  - Potentially better coverage

Black-Box vs. White-Box Testing

- Black-Box Testing:
  - Can work with code that cannot be modified
  - Does not need to analyze or study code
  - Code can be in any format (managed, binary, obfuscated)
- White-Box Testing:
  - Efficient test suite
  - Potentially better coverage

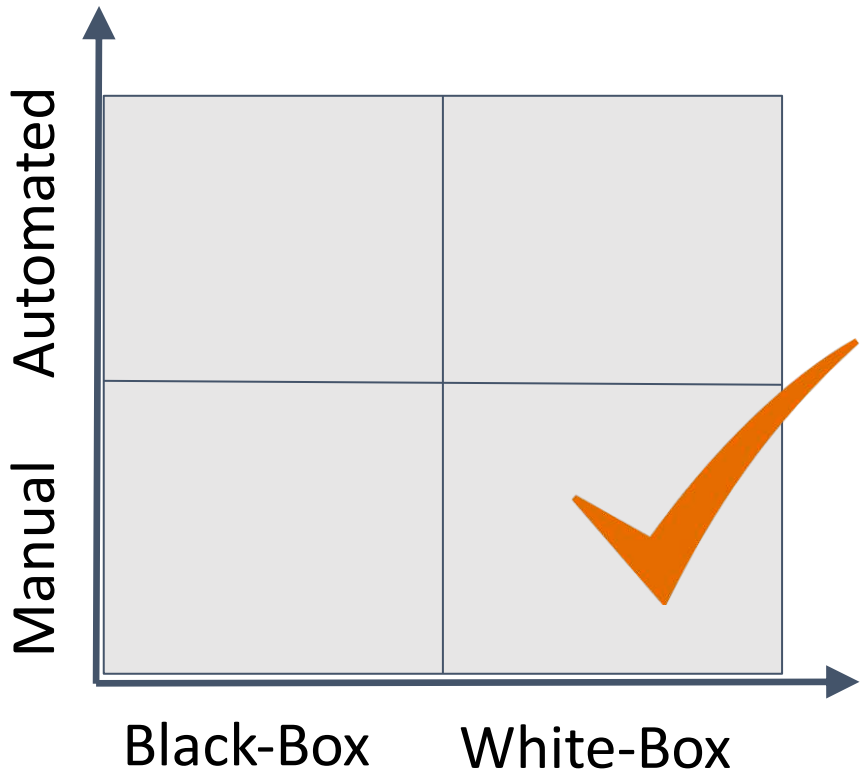
How Good Is Your Test Suite?

- How do we know that our test suite is good?
  - Too few tests: may miss bugs
  - Too many tests: costly to run, bloat and redundancy, harder to maintain
- Example: SQLite
  “As of version 3.20.0 (2017-08-01), the SQLite library consists of approximately 125.4 KSLOC of C code. (KSLOC means thousands of ‘Source Lines Of Code’ or, in other words, lines of code excluding blank lines and comments.) By comparison, the project has 730 times as much test code and test scripts - 91616.0 KSLOC.”
- Nevertheless, 18 CVEs fixed between January and June 2020

Code Coverage

- Metric to quantify extent to which a program's code is tested by a given test suite
  - Function coverage: which functions were called?
  - Statement coverage: which statements were executed?
  - Branch coverage: which branches were taken?
- Given as percentage of some aspect of the program executed in the tests
- 100% coverage rare in practice: e.g., inaccessible code
  - Often required for safety-critical applications
  - Example: SQLite has 100% branch coverage

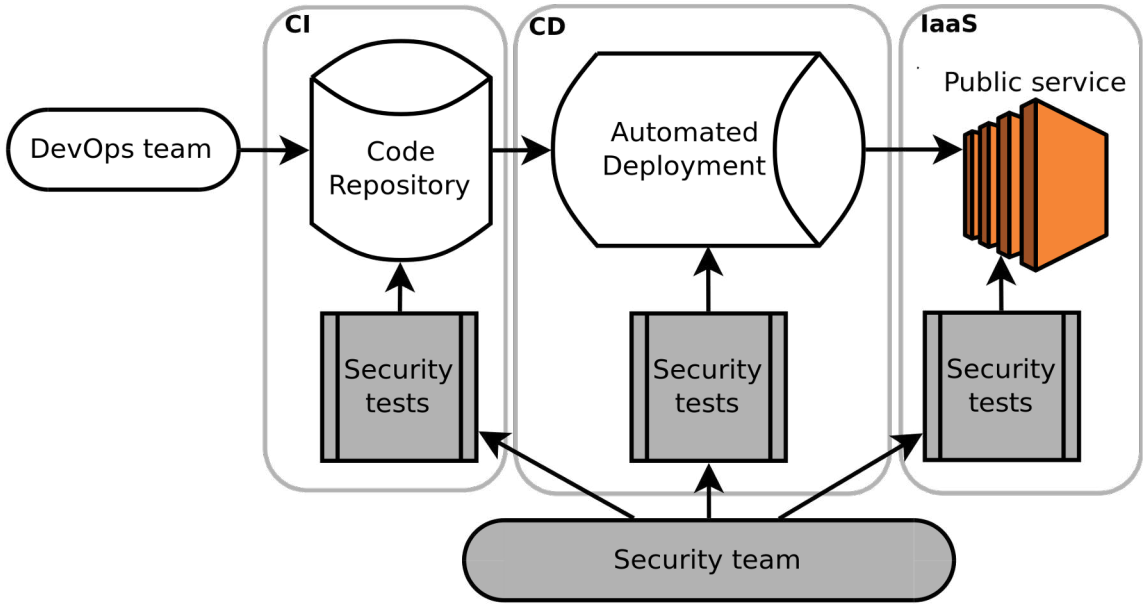
Classification of Testing Approaches

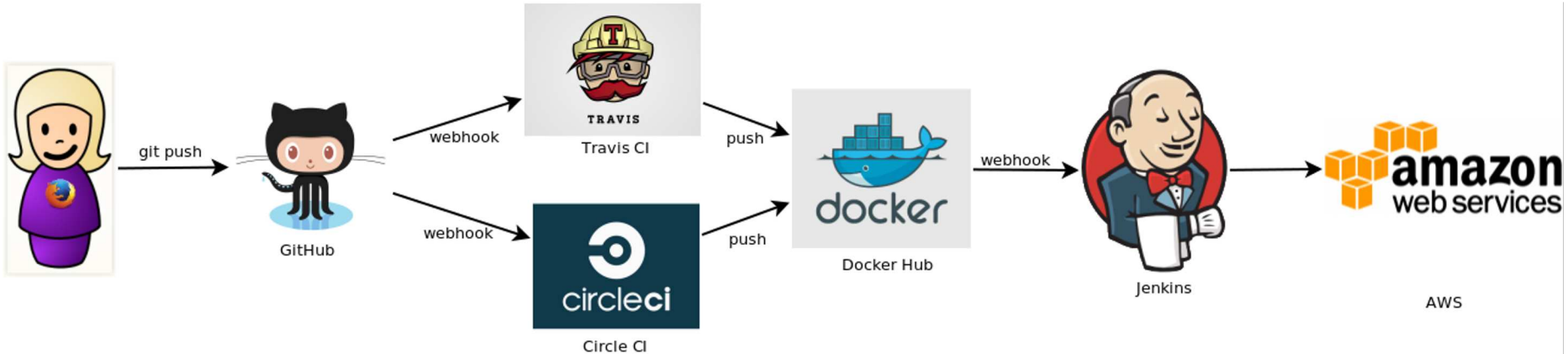


Manual white-box testing

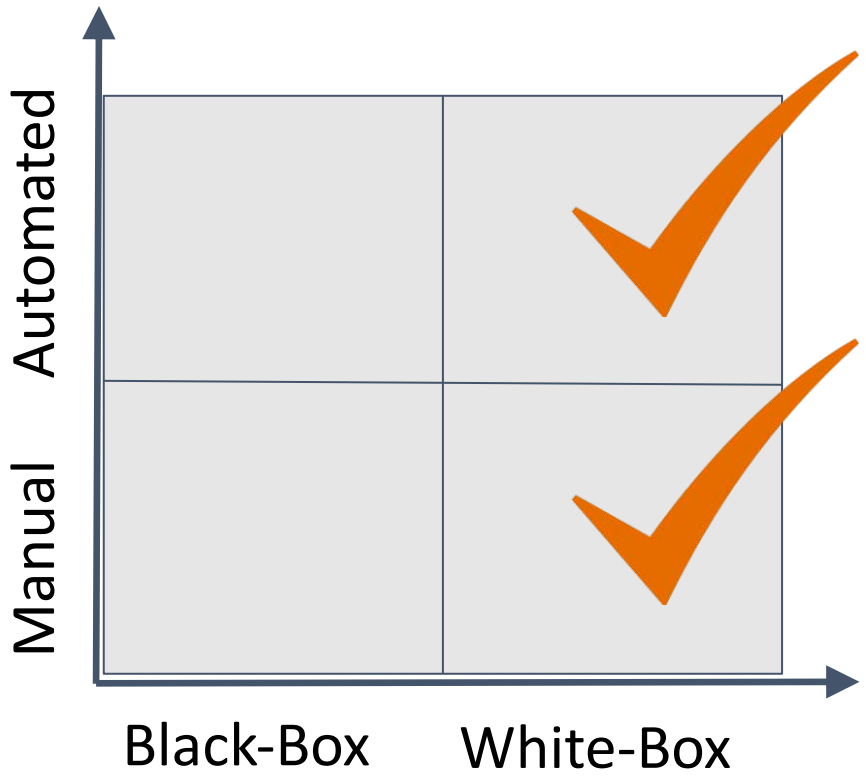
- Tests written by hand
- Full knowledge of source code/deployment/infrastructure
- Can test all parts
- Test *running* can be automated (e.g., on commits/deployment)

Test Driven Security





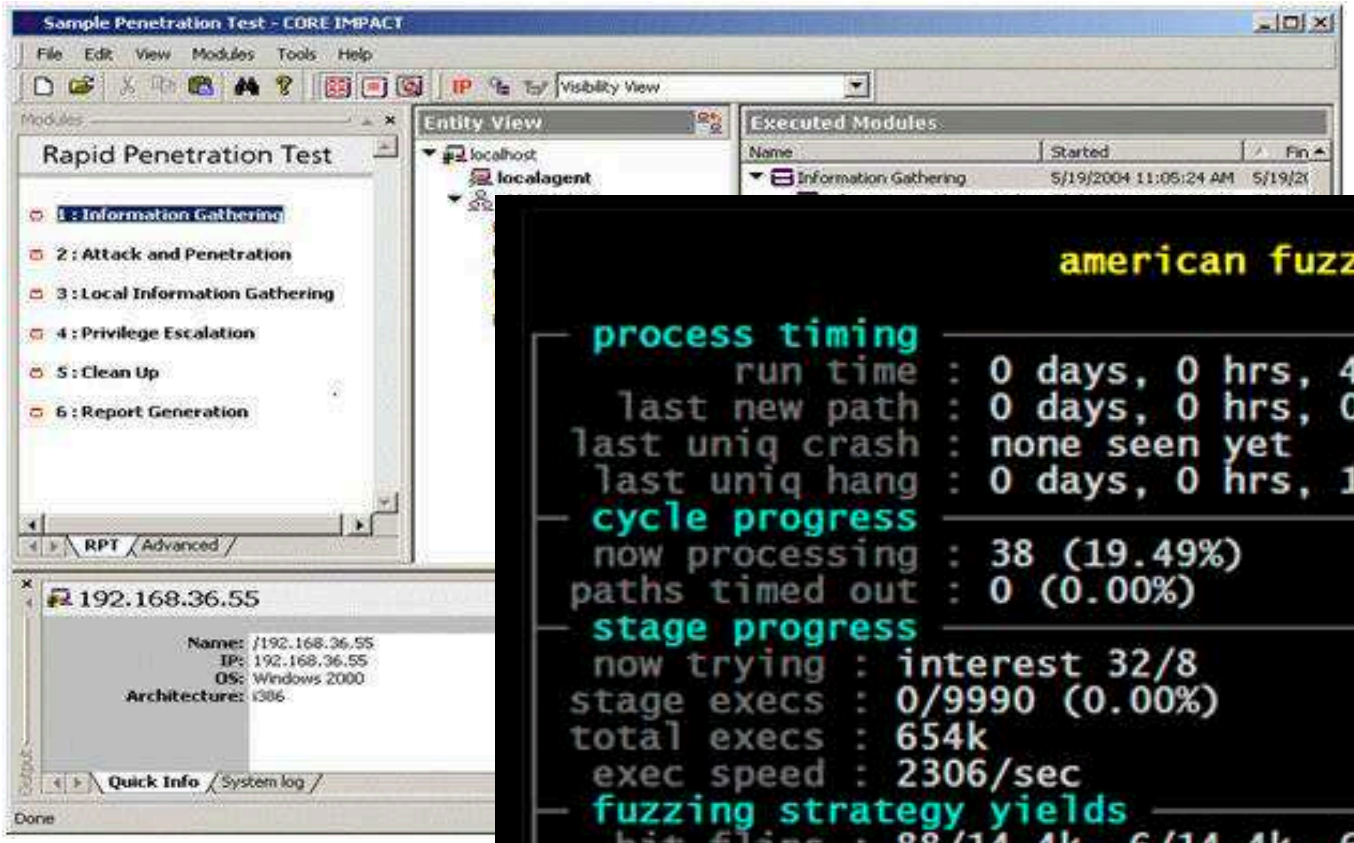
Classification of Testing Approaches

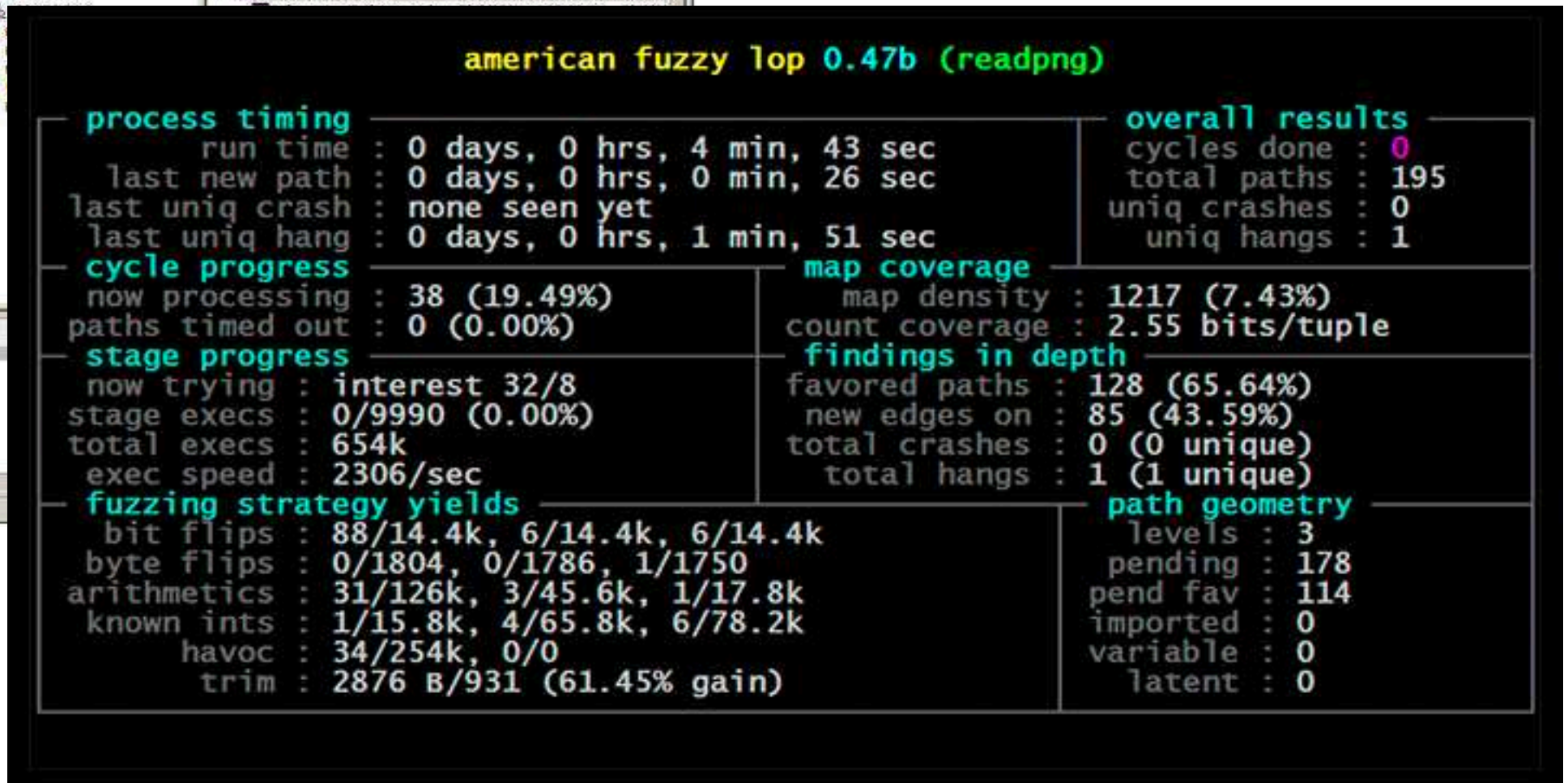


Automated white-box testing

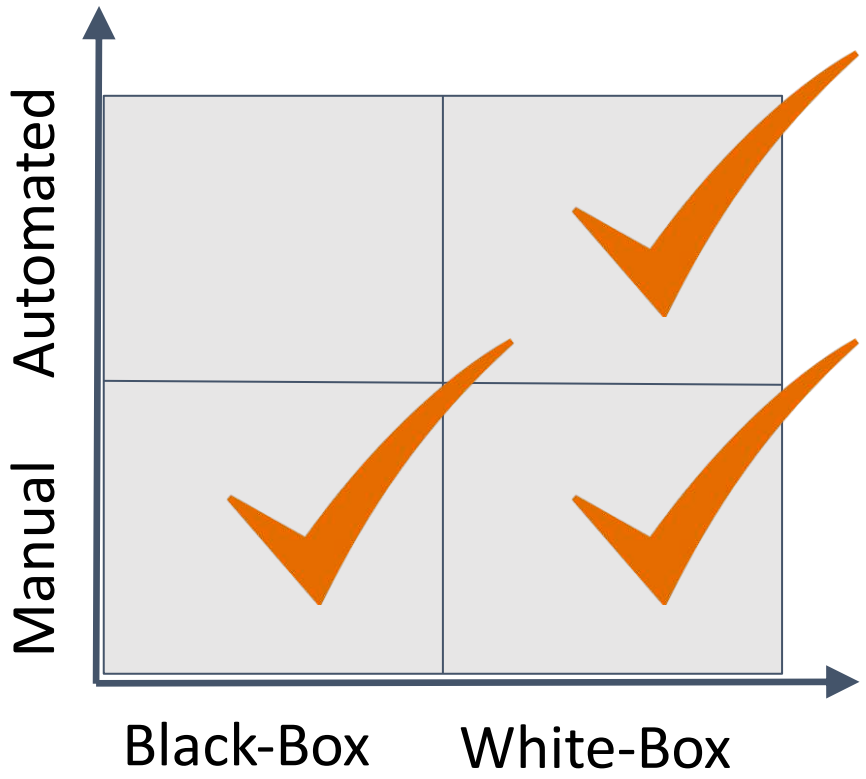
- Tests created automatically/dynamically
- Godefroid et al. “Automated Whitebox Fuzz Testing”
  - Record trace of program on well-formed inputs
  - Symbolic execution to capture constraints on input
  - Negate a constraint, use a constraint solver to derive new input, run on that input
- American fuzzy lop
  - Compile-time instrumentation
  - Genetic algorithms guided by the instrumentation
- Tools exist

Automated white-box testing tools





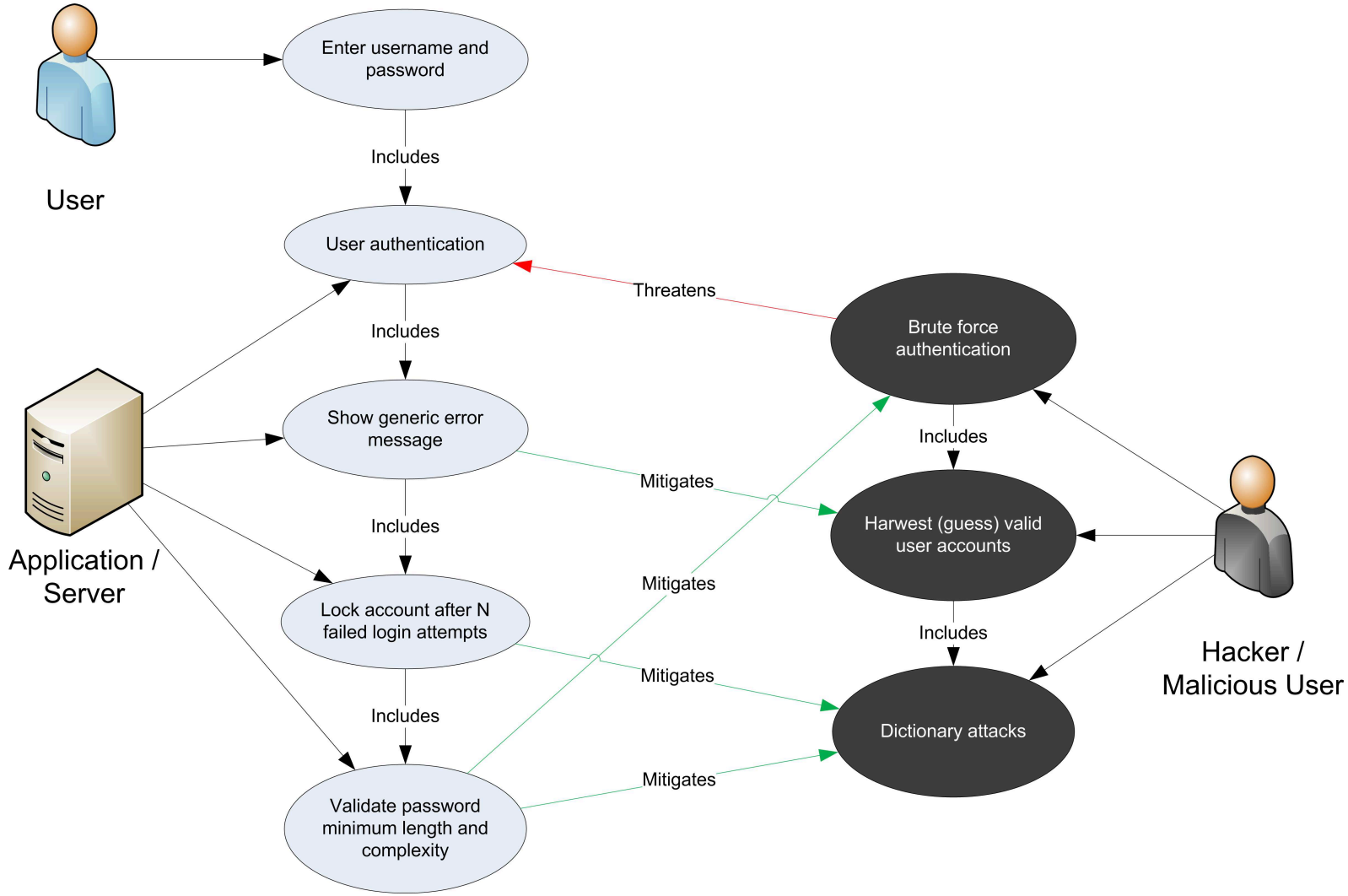
Classification of Testing Approaches



Manual black-box testing

- Tester interacts with the system in a black-box fashion
- Crafts ill-formed inputs, tests them, and records how the system reacts

Web Pen Testing Simple Example



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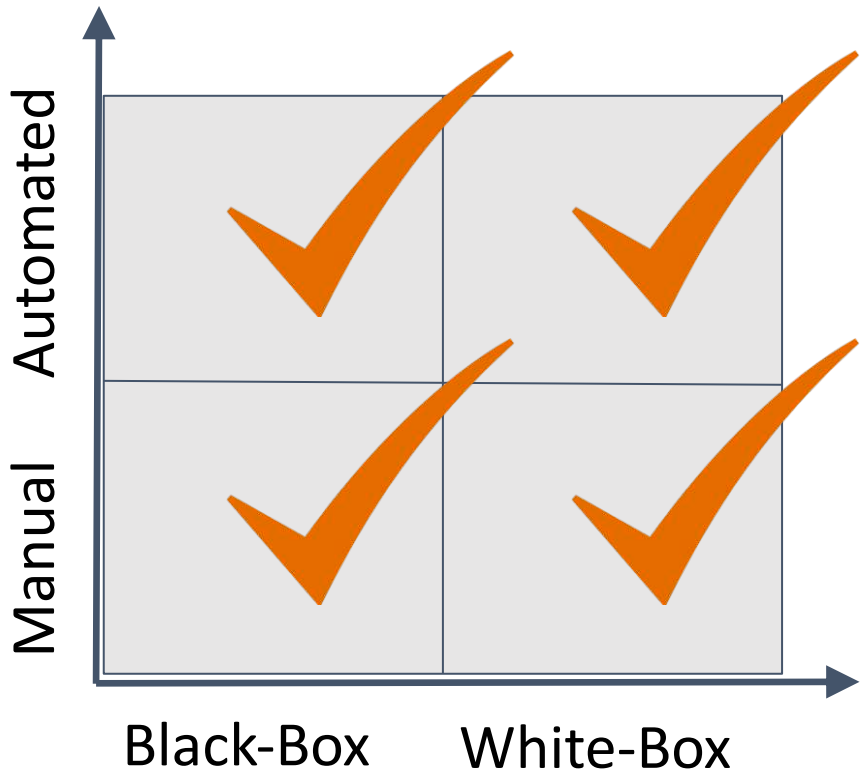


Automated black-box testing

- Fuzzing components
  - Test case generation
  - Application execution
  - Exception detection and logging

Test Case Generation

- Random Fuzzing
- “Dumb” (mutation-based) Fuzzing
  - Mutate an existing input
- “Smart” (generation-based) Fuzzing
  - Generate an input based on a model (grammar)

Mutation Fuzzer

- Charlie Miller's "5 lines of Python" fuzzer
- Found bugs in PDF and PowerPoint readers

```
numwrites=random.randrange(
                    math.ceil((float(len(buf)) / FuzzFactor)))+1
for j in range(numwrites):
   rbyte = random.randrange(256)
   rn = random.randrange(len(buf))
   buf[rn] = "%c"%(rbyte);
```

Reverse Engineering

- Reverse Engineering (RE) -- process of discovering the technological principles of a [insert noun] through analysis of its structure, function, and operation.
- The development cycle ... backwards

Why Reverse Engineer?

- Malware analysis
- Vulnerability or exploit research
- Check for copyright/patent violations
- Interoperability (e.g., understanding a file/protocol format)
- Copy protection removal

Legality

- Gray Area (a common theme)
- Usually breaches the EULA contract of software
- Additionally -- DMCA law governs reversing in U.S.
  - “may circumvent a technological measure ... solely for the purpose of enabling interoperability of an independently created computer program”

Two Techniques

- Static Code Analysis (structure)
  - Disassemblers
- Dynamic Code Analysis (operation)
  - Tracing / Hooking
  - Debuggers
- Combination of the two works best in my experience

Disassembly

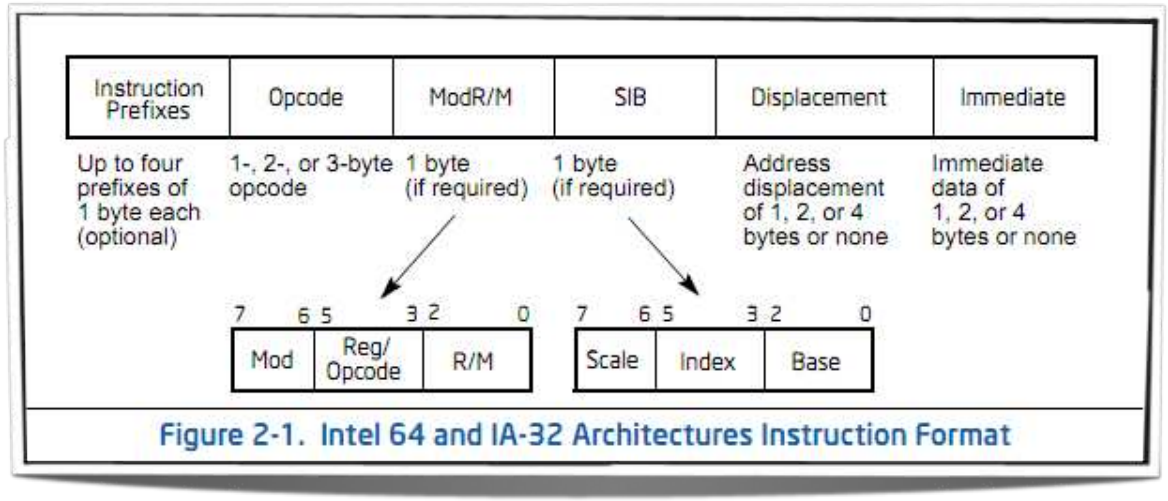
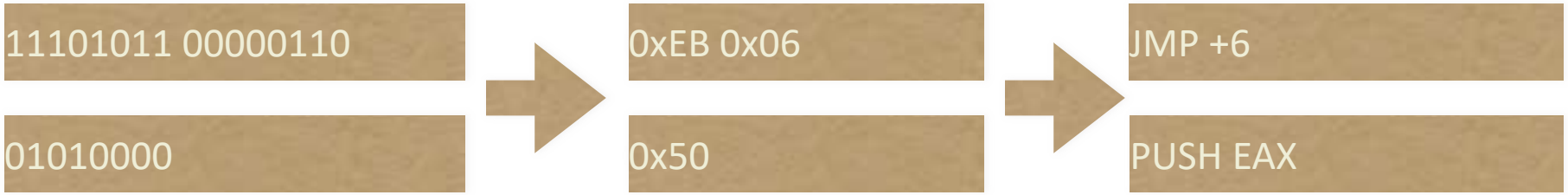


Figure 2-1. Intel 64 and IA-32 Architectures Instruction Format

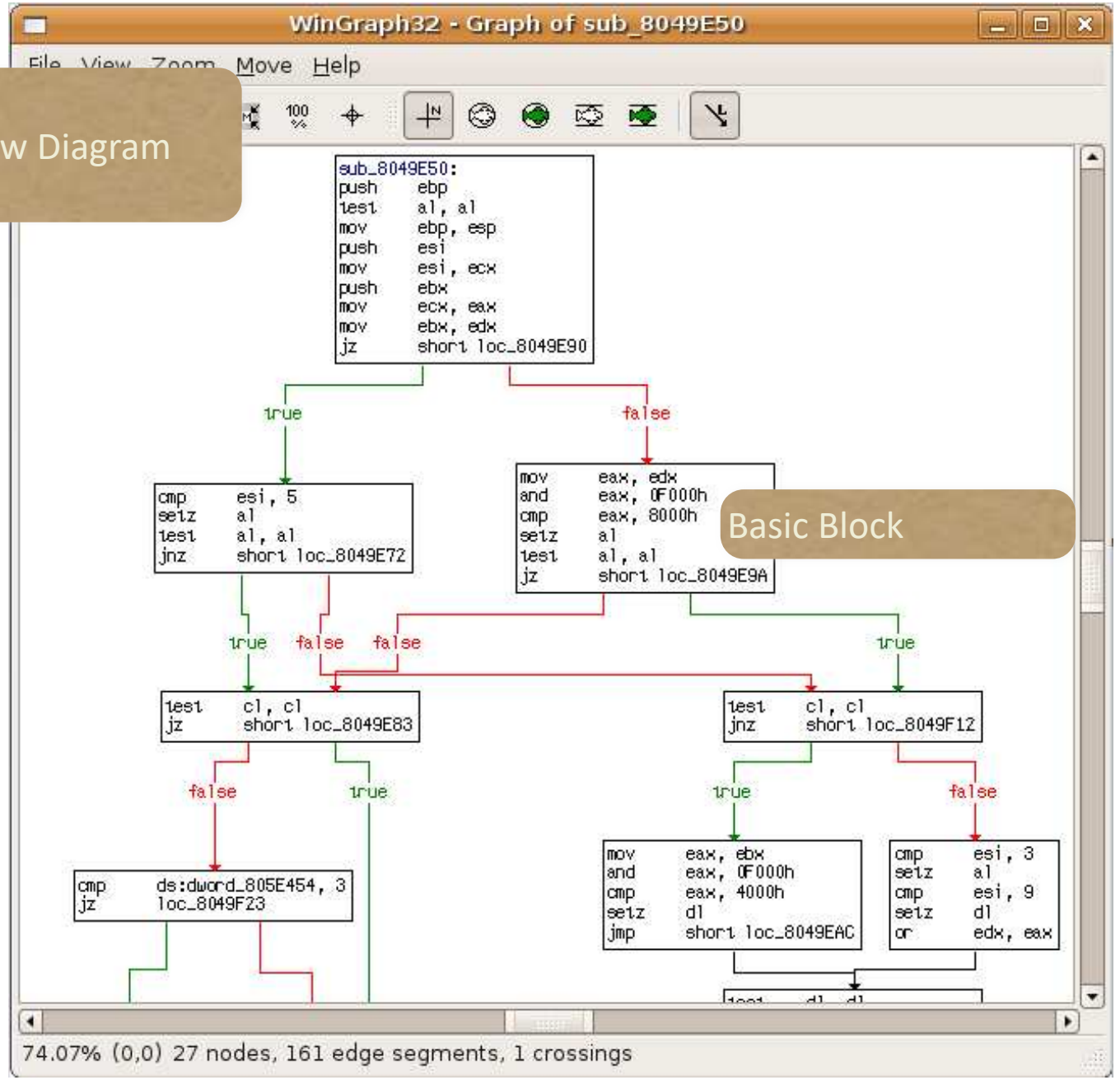


Bits

Hex Bytes

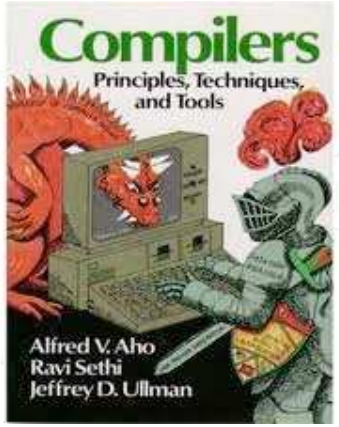
Instructions (human-readable)

Control Flow Diagram



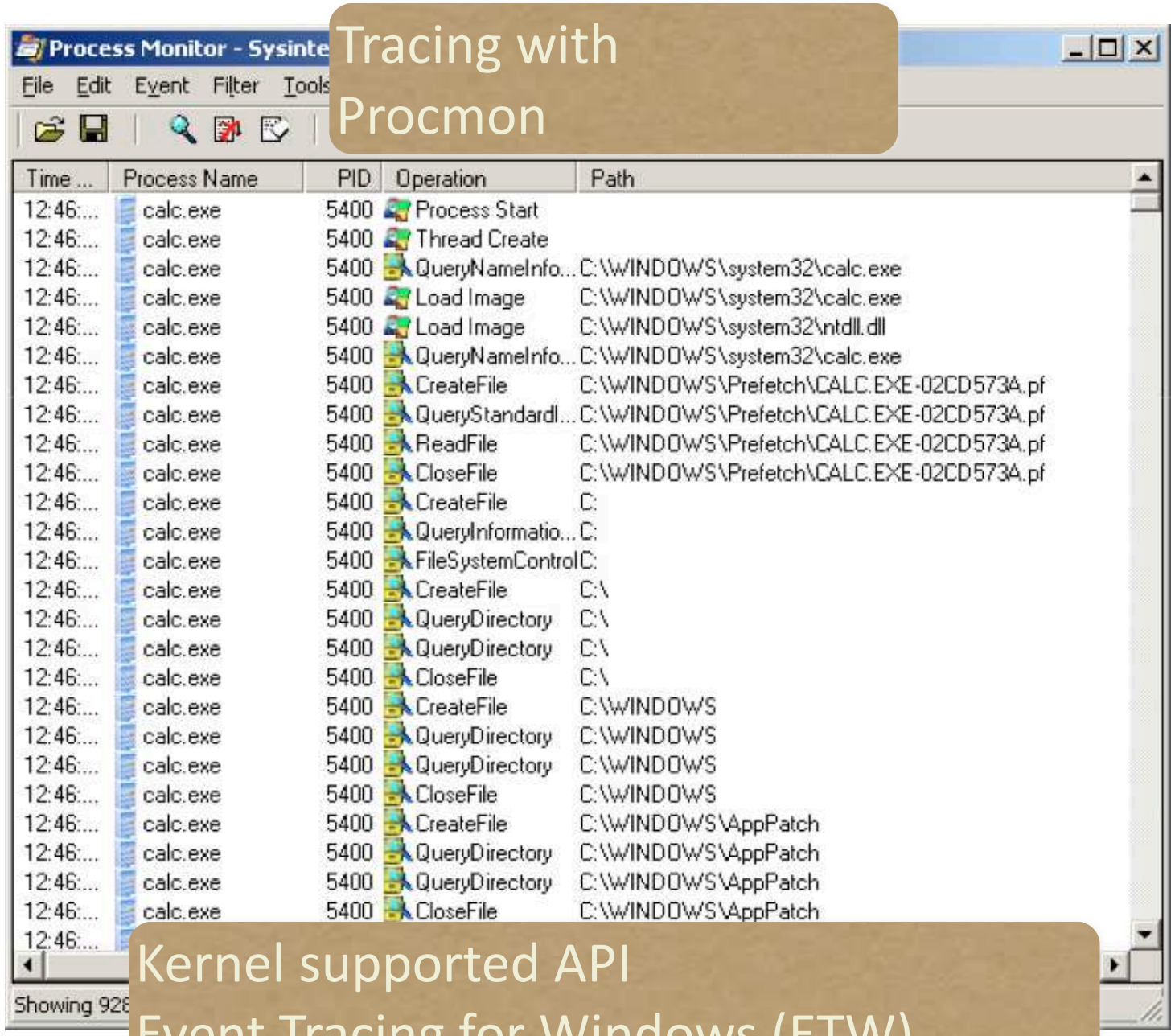
Difficulties

- Imperfect disassembly
- Benign Optimizations
  - Constant folding
  - Dead code elimination
  - Inline expansion
  - Loop unrolling
  - etc...
- Intentional Obfuscation
  - Packing
  - No-op instructions



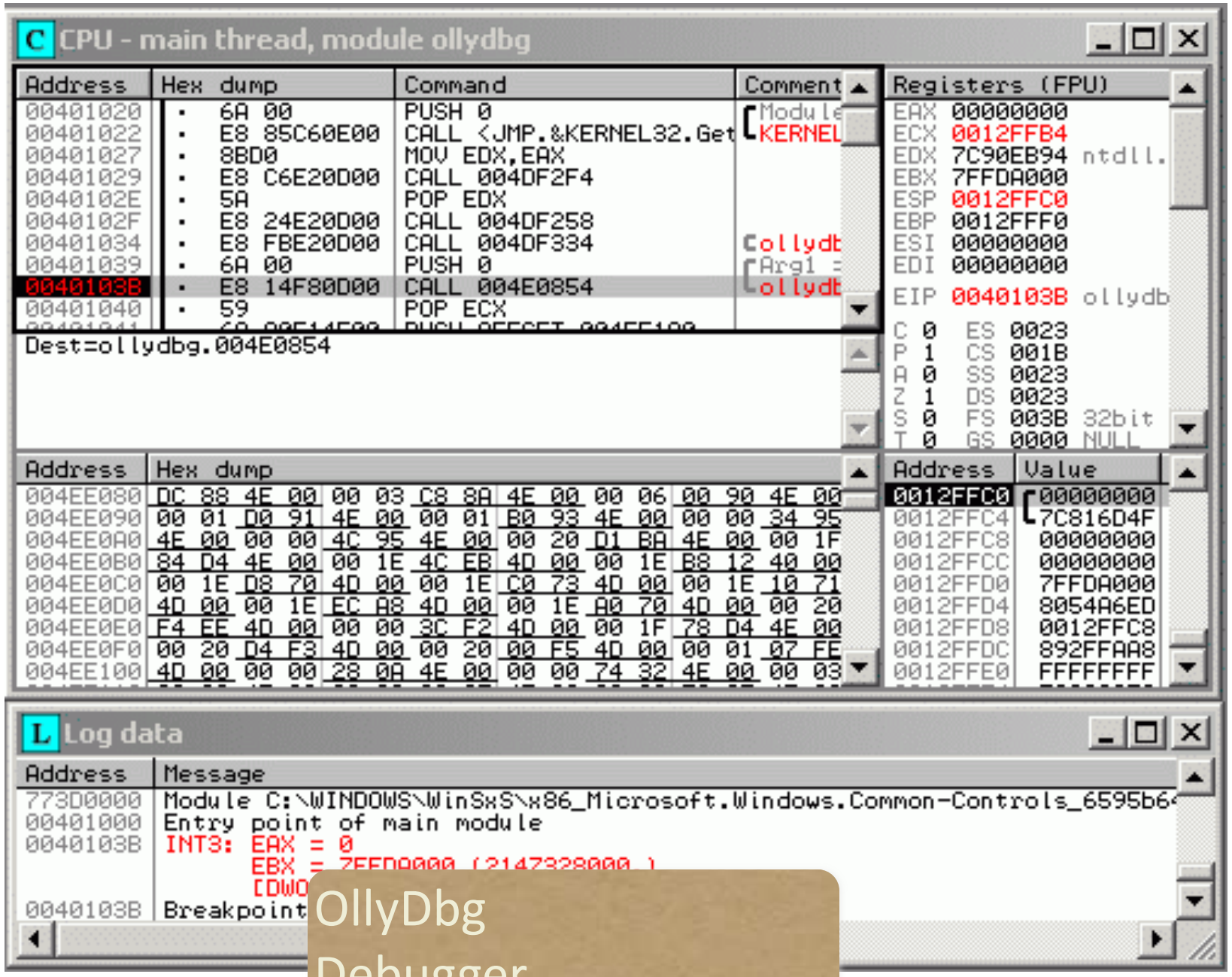
Dynamic Analysis

- A couple techniques available:
  - Tracing / Hooking
  - Debugging


Process Monitor - Sysinte
File Edit Event Filter Tools
Time ... Process Name PID Operation Path
12:46:... calc.exe 5400 Process Start
12:46:... calc.exe 5400 Thread Create
12:46:... calc.exe 5400 QueryNameInfo... C:\WINDOWS\system32\calc.exe
12:46:... calc.exe 5400 Load Image C:\WINDOWS\system32\calc.exe
12:46:... calc.exe 5400 Load Image C:\WINDOWS\system32\ntdll.dll
12:46:... calc.exe 5400 QueryNameInfo... C:\WINDOWS\system32\calc.exe
12:46:... calc.exe 5400 CreateFile C:\WINDOWS\Prefetch\CALC.EXE-02CD573A.pf
12:46:... calc.exe 5400 QueryStandardI... C:\WINDOWS\Prefetch\CALC.EXE-02CD573A.pf
12:46:... calc.exe 5400 ReadFile C:\WINDOWS\Prefetch\CALC.EXE-02CD573A.pf
12:46:... calc.exe 5400 CloseFile C:\WINDOWS\Prefetch\CALC.EXE-02CD573A.pf
12:46:... calc.exe 5400 CreateFile C:
12:46:... calc.exe 5400 QueryInformatio... C:
12:46:... calc.exe 5400 FileSystemControl C:
12:46:... calc.exe 5400 CreateFile C:\
12:46:... calc.exe 5400 QueryDirectory C:\
12:46:... calc.exe 5400 QueryDirectory C:\
12:46:... calc.exe 5400 CloseFile C:\
12:46:... calc.exe 5400 CreateFile C:\WINDOWS
12:46:... calc.exe 5400 QueryDirectory C:\WINDOWS
12:46:... calc.exe 5400 QueryDirectory C:\WINDOWS
12:46:... calc.exe 5400 CloseFile C:\WINDOWS
12:46:... calc.exe 5400 CreateFile C:\WINDOWS\AppPatch
12:46:... calc.exe 5400 QueryDirectory C:\WINDOWS\AppPatch
12:46:... calc.exe 5400 QueryDirectory C:\WINDOWS\AppPatch
12:46:... calc.exe 5400 CloseFile C:\WINDOWS\AppPatch
Showing 926
Tracing with Procmon
Kernel supported API
Event Tracing for Windows (ETW)

Debugger Features

- Trace every instruction a program executes -- single step
- Or, let program execute normally until an exception
- At every step or exception, can observe / modify:
  - Instructions, stack, heap, and register set
- May inject exceptions at arbitrary code locations
- INT 3 instruction generates a breakpoint exception


CPU - main thread, module ollydbg
Address Hex dump Command Comment
00401020 · 6A 00 PUSH 0
00401022 · E8 85C60E00 CALL <JMP.&KERNEL32.Get
00401027 · 8BD0 MOV EDX,EAX
00401029 · E8 C6E20D00 CALL 004DF2F4
0040102E · 5A POP EDX
0040102F · E8 24E20D00 CALL 004DF258
00401034 · E8 FBE20D00 CALL 004DF334
00401039 · 6A 00 PUSH 0
0040103B · E8 14F80D00 CALL 004E0854
00401040 · 59 POP ECX
Dest=ollydbg.004E0854
Registers (FPU)
EAX 00000000
ECX 0012FFB4
EDX 7C90EB94 ntdll.
EBX 7FFDA000
ESP 0012FFC0
EBP 0012FFF0
ESI 00000000
EDI 00000000
EIP 0040103B ollydb
C 0 ES 0023
P 1 CS 001B
A 0 SS 0023
Z 1 DS 0023
S 0 FS 003B 32bit
T 0 GS 0000 NULL
Address Hex dump
004EE080 DC 88 4E 00 00 03 C8 8A 4E 00 00 06 00 90 4E 00
004EE090 00 01 D0 91 4E 00 00 01 B0 93 4E 00 00 00 34 95
004EE0A0 4E 00 00 00 4C 95 4E 00 00 20 D1 BA 4E 00 00 1F
004EE0B0 84 D4 4E 00 00 1E 4C EB 4D 00 00 1E B8 12 40 00
004EE0C0 00 1E D8 70 4D 00 00 1E C0 73 4D 00 00 1E 10 71
004EE0D0 4D 00 00 1E EC A8 4D 00 00 1E A0 70 4D 00 00 20
004EE0E0 F4 EE 4D 00 00 00 3C F2 4D 00 00 1F 78 D4 4E 00
004EE0F0 00 20 D4 F3 4D 00 00 20 00 F5 4D 00 00 01 07 FE
004EE100 4D 00 00 00 28 0A 4E 00 00 00 74 32 4E 00 00 03
Address Value
0012FFC0 00000000
0012FFC4 7C816D4F
0012FFC8 00000000
0012FFCC 00000000
0012FFD0 7FFDA000
0012FFD4 8054A6ED
0012FFD8 0012FFC8
0012FFDC 892FFAA8
0012FFE0 FFFFFFFF
Log data
Address Message
773D0000 Module C:\WINDOWS\WinSxS\x86_Microsoft.Windows.Common-Controls_6595b6
00401000 Entry point of main module
0040103B INT3: EAX = 0
EBX = 7FFDA000 (2147328000.)
0040103B Breakpoint
OllyDbg
Debugger

Debugging Benefits

- Sometimes easier to just see what code does
- Unpacking
  - just let the code unpack itself and debug as normal
- Most debuggers have in-built disassemblers anyway
- Can always combine static and dynamic analysis

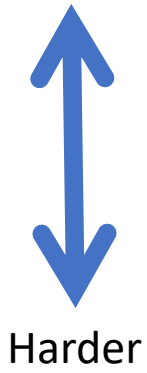
Difficulties

- We are now executing potentially malicous code
  - use an isolated virtual machine
- Anti-Debugging
  - detect debugger and [exit | crash | modify behavior]
  - IsDebuggerPresent(), INT3 scanning, timing, VM-detection, pop ss trick, etc., etc., etc.
  - Anti-Anti-Debugging can be tedious

Commonality of evasion

- Detect evidence of monitoring systems
  - Fingerprint a machine/look for fingerprints
- Hide real malicious intent if necessary
  - IF VM_PRESENT() or DEBUGGER_PRESENT()
    - Terminate() *// hide real intent*
  - ELSE
    - Malicious_Behavior() *//real intent*

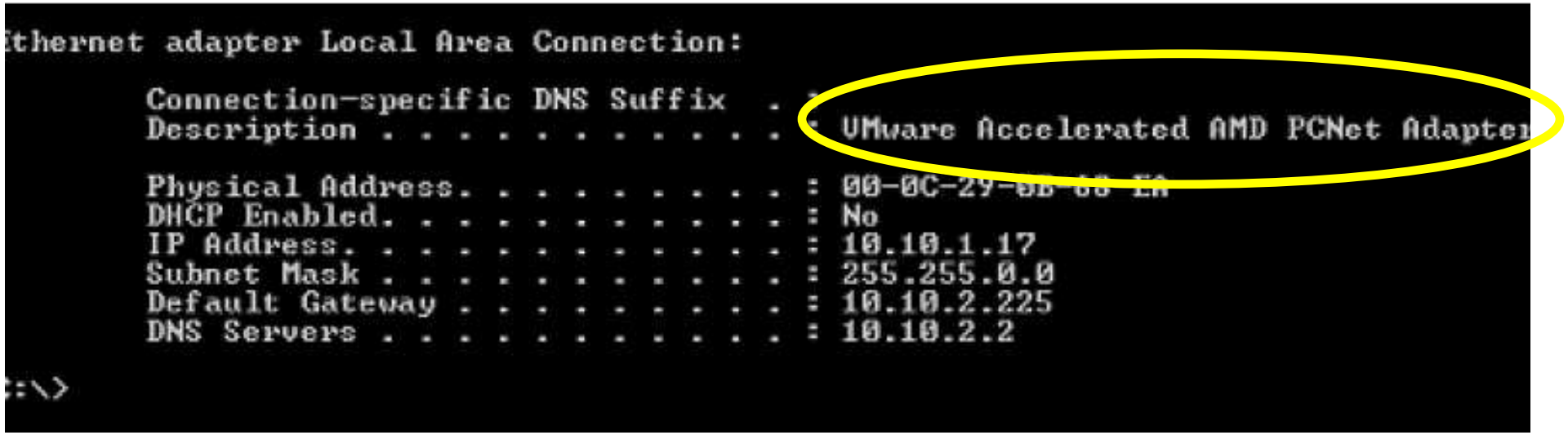
Taxonomy of malware evasion



Layer of abstraction	Examples
Application	Installation, execution
Hardware	Device name, drivers
Environment	Memory and execution artifacts
Behavior	Timing

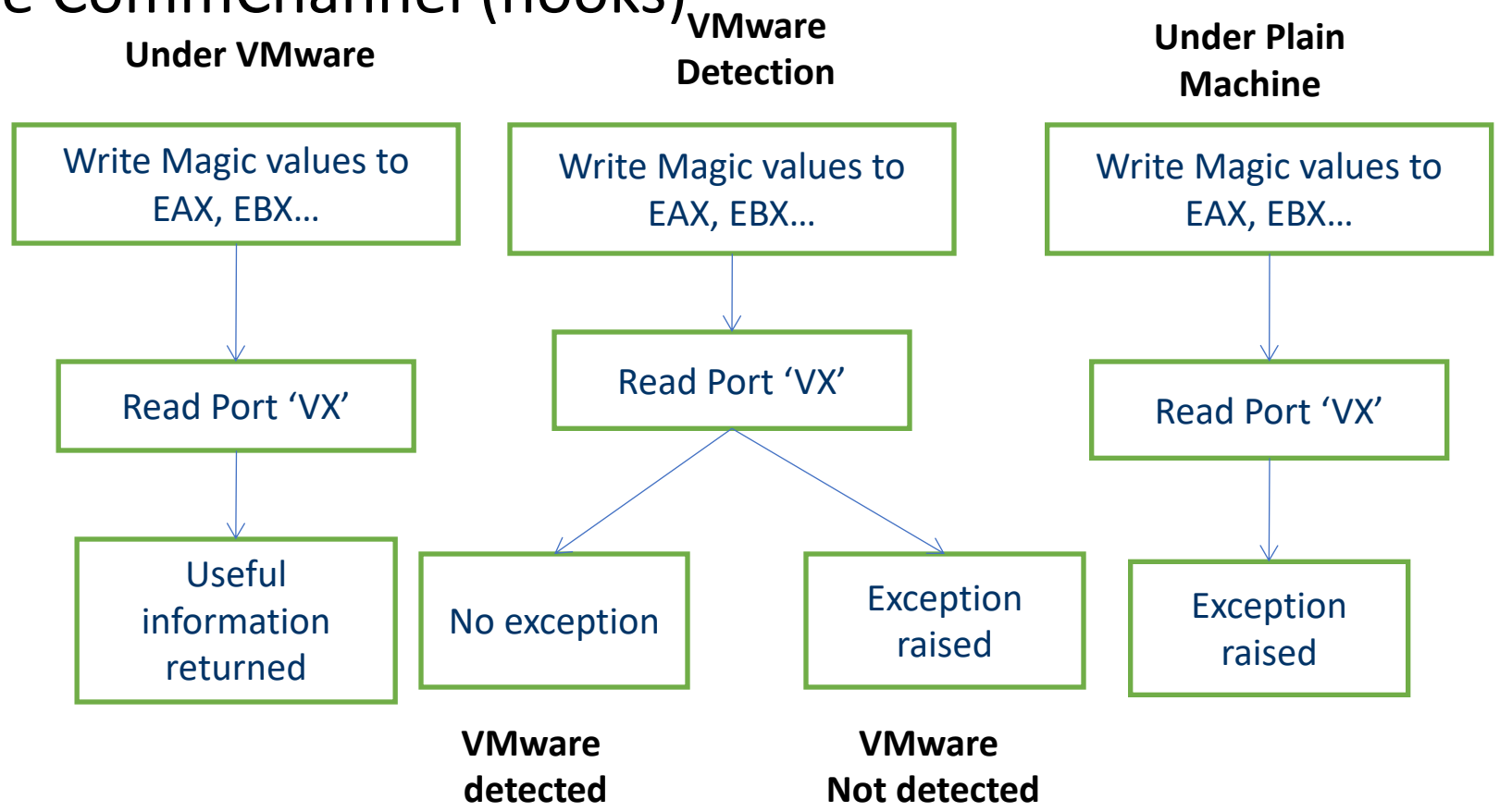
Example 1

- Device driver strings
  - Network cards



Example 2

- VMWare CommChannel (hooks)



VMware detection code

```
MOV     EAX, 0x564D5868   ; 'VMXh'
MOV     EBX, 0            ; Any value but not the MAGIC VALUE
MOV     ECX, 0x0A         ; Get VMWare version
MOV     EDX, 0x5658       ; 'VX' (port number)
IN      EAX, DX           ; Read port
CMP     EBX, 0x564D5868   ; Is there a reply from VMWare? 'VMXh'
```

https://www.aldeid.com/wiki/VMXh-Magic-Value

Prevalence of evasion

- ***40%*** of malware samples exhibit fewer malicious events with debugger attached
- ***4.0%*** exhibit fewer malicious events under VMware execution