

Dynamic Analysis and Debugging of Binary Code for Security Applications

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The Business of Innovation

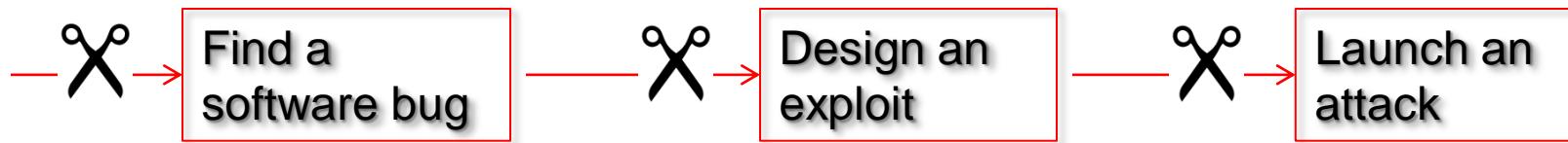


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Why bother?

The vast majority of security vulnerabilities in today's cyber systems originate from improper software implementations.



Program analysis and verification techniques are critical during this process

Why dynamic analysis?

Static program analysis is a great technique.

Analyzing the (C/C++) source code is also important.



However, in security applications, it is important to perform dynamic analysis of the binary code.

Why interactive analysis?

Security applications often require “human in the loop” analysis – they are very difficult to be fully automated.

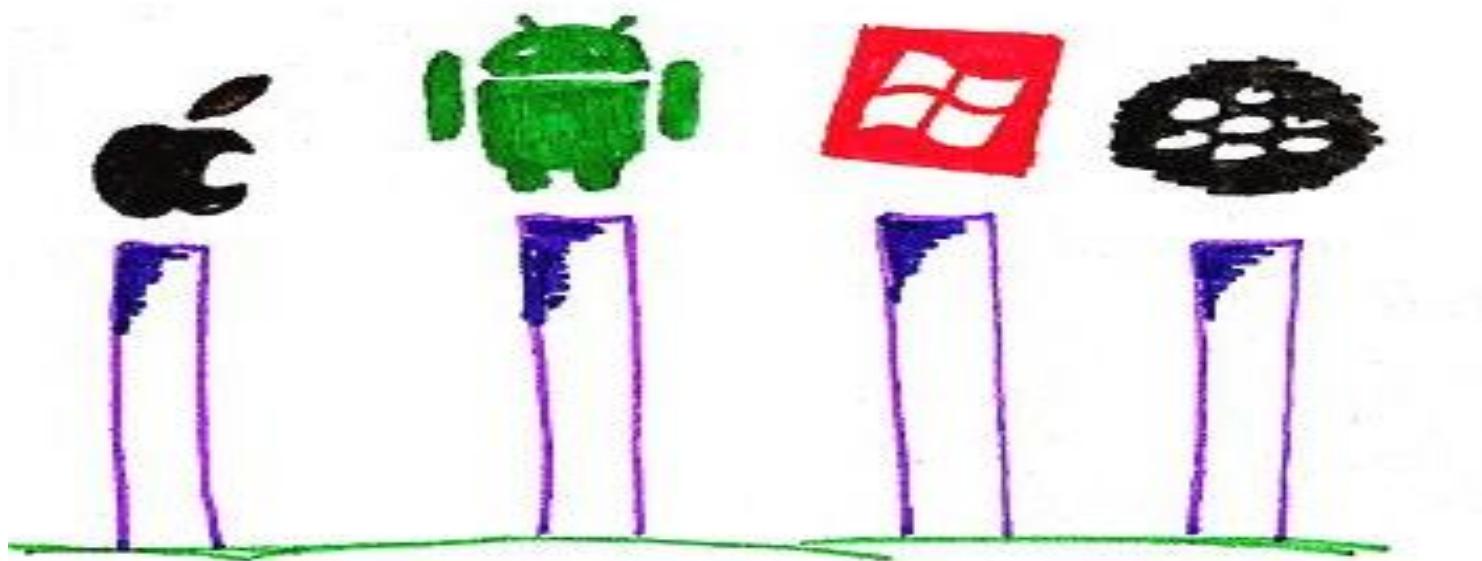


However, tools support is severely lacking.

We want to build new software tools that can be used to speed up the interactive analysis.

Why cross-platform analysis?

- **Platform-dependent** Execution Trace Generation
 - Intermediate Representation(**IR**) Translation
- **Platform-independent** Analysis
 - Reusing the algorithm and implementation

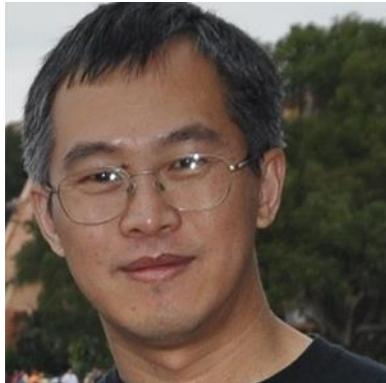


Security Problem Space

- Benign Software vs. Malware
- Binary Code vs. Source Code
- Vulnerability vs. Software Bug
- Memory Error vs. Design Error

Today, we will talk about vulnerability and exploitation analysis of memory errors in the binary code of the benign software.

The Speakers



- **Lixin (Nathan) Li**
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- **Chao Wang**
Assistant Professor
Dept. Electrical & Computer Engr.
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Where are we?



The Business of Innovation

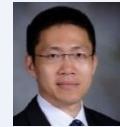


- Non-profit, \$5.2 billion annually in global R&D
- 22,000 employees in 130 locations worldwide

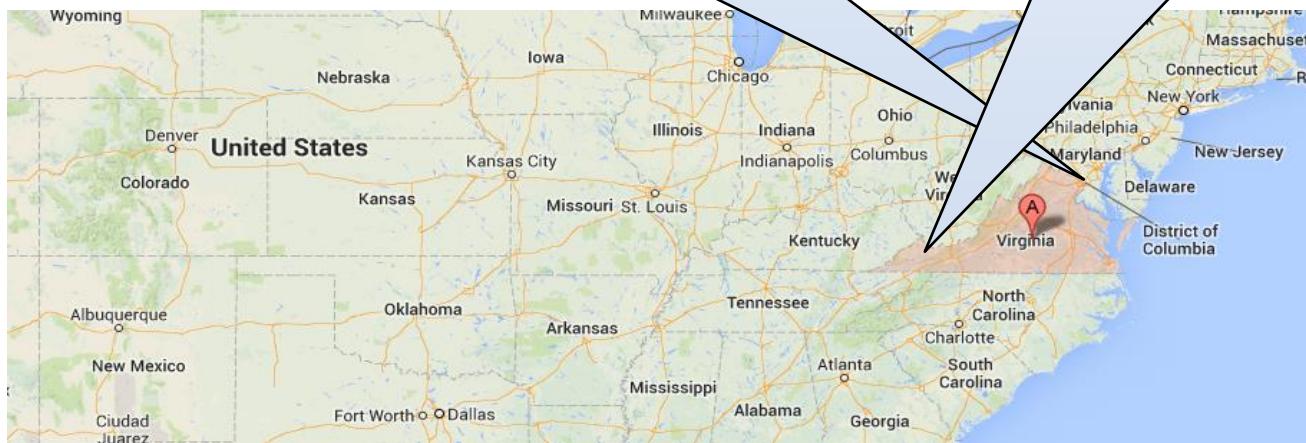


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- Land-grant university in Virginia
- 31,087 students (7,228 graduate students)



Outline of today's tutorial

- First Half (90 minutes)

- **Background**

- Dynamic analysis and symbolic analysis
 - Their success in vulnerability discovery
 - Challenges in exploitation research

- Our new security analysis tool

- Cross-platform trace generation

- Second Half (90 minutes)

- Supporting automated analysis

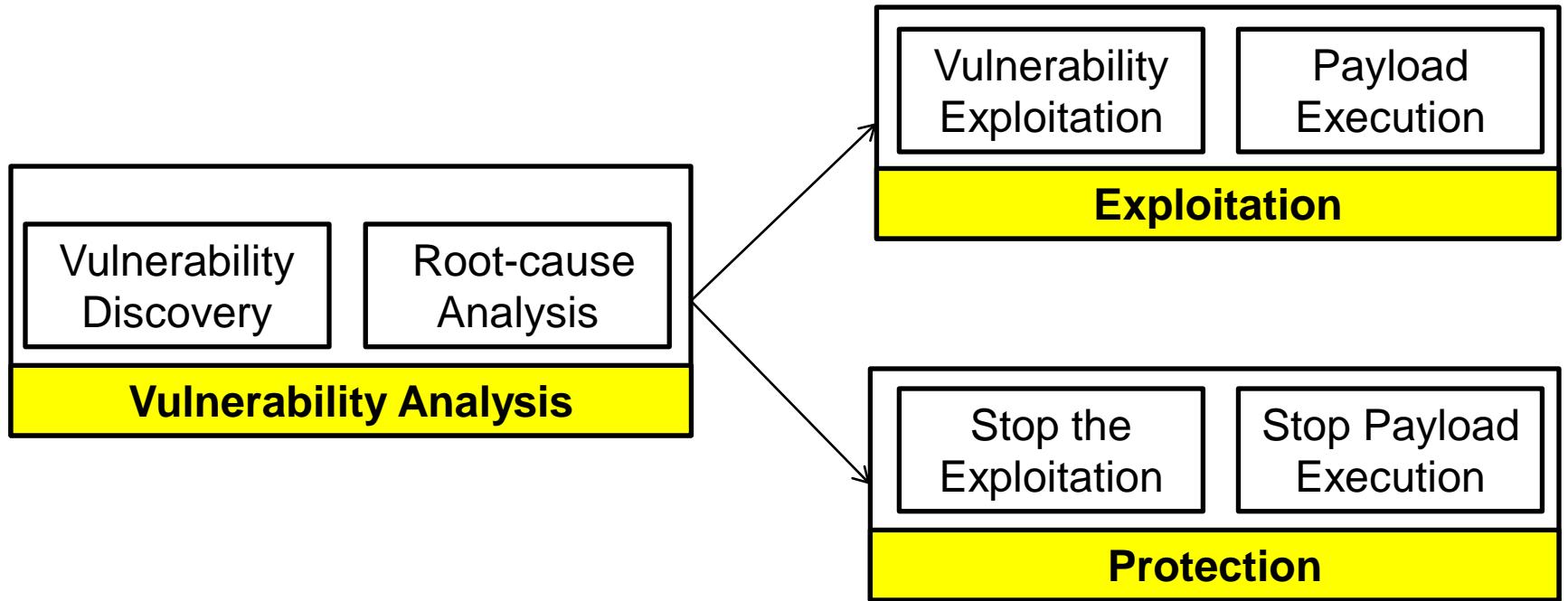
- CBASS (Cross-platform Symbolic-execution System)

- Supporting interactive analysis

- TREE (Taint-enabled Reverse Engineering Environment)

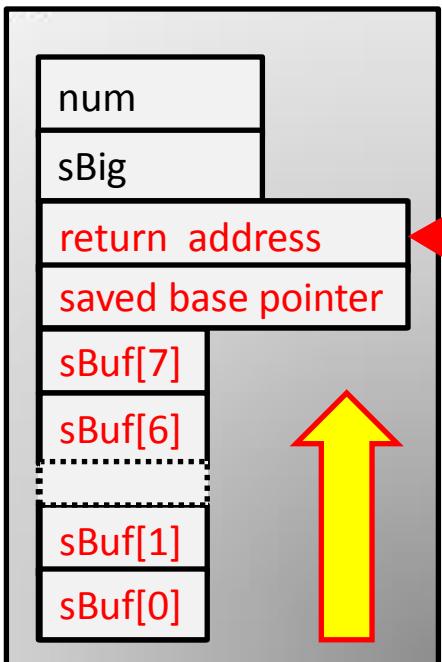
- How does TREE and CBASS Interact

Aspects of Binary Security Analysis



What is a Vulnerability?

Execution Stack



Why is it
vulnerability?

// Vulnerable Function

```
void StackOverflow(char *sBig, int num)
{
    char sBuf[8] = {0};
    .....
    for(int i=0;i<num;i++)
        //Overflow when (num>8)
    {
        sBuf[i] = sBig[i];
    }
    .....
}
```

Vulnerability Discovery

//INPUT

```
ReadFile(hFile, sBigBuf, 16, &dwBytesRead, NULL);
```

//INPUT TRANSFORMATIONS

.....

//PATH CONDITIONS

```
if(sBigBuf[0]=='b') iCount++;
if(sBigBuf[1]=='a') iCount++;
if(sBigBuf[2]=='d') iCount++;
if(sBigBuf[3]=='!') iCount++;
if(iCount==4) // bad!
```

StackOverflow (sBigBuf, dwBytesRead)

else // Good

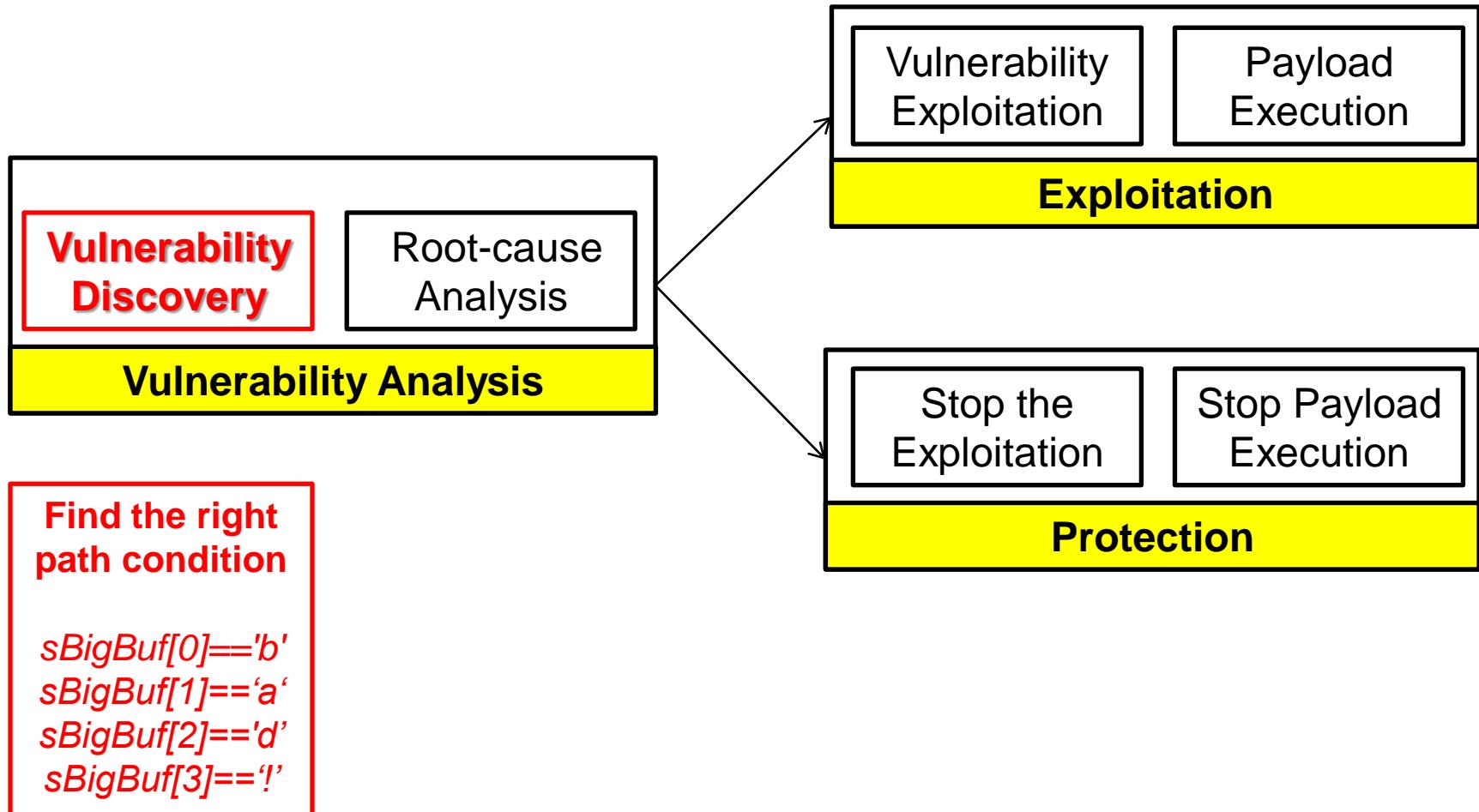
`printf("Good!");`

Is this possible?

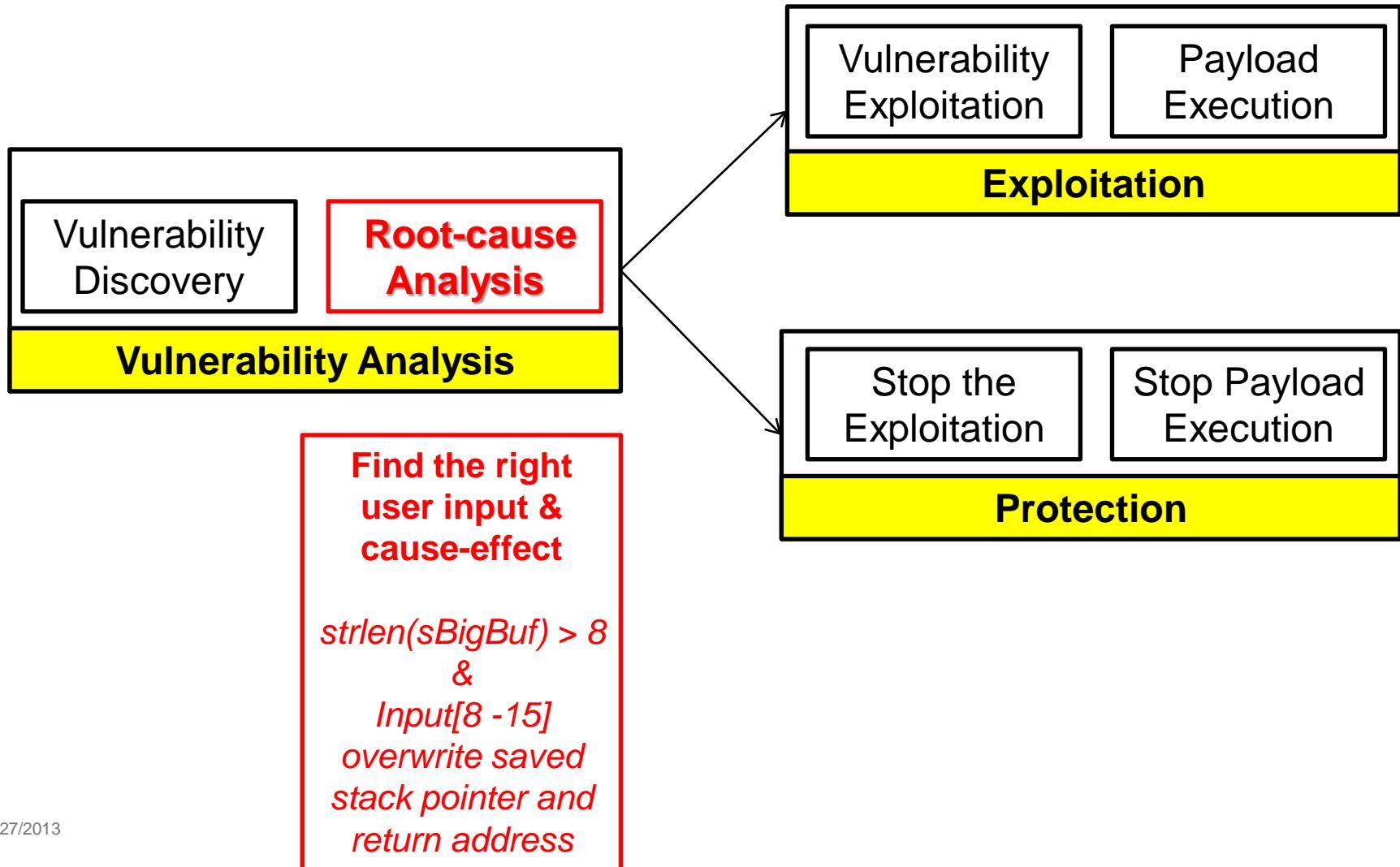
// Vulnerable Function

```
void StackOverflow(char *sBig, int num)
{
    char sBuf[8]={0};
    .....
    for(int i=0;i<num;i++)
        //Overflow when (num>8)
    {
        sBuf[i] = sBig[i];
    }
    .....
    return;
}
```

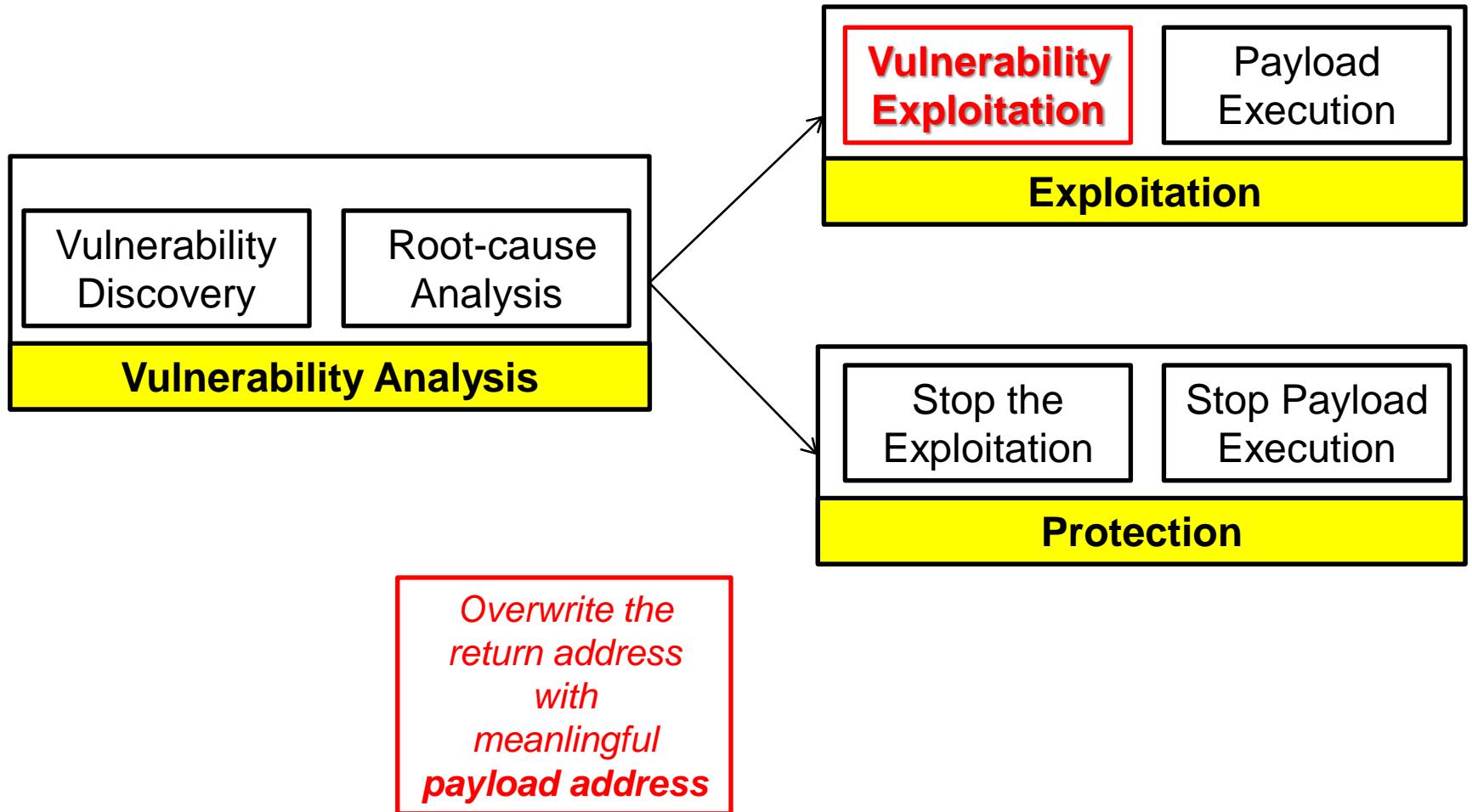
Phases of Binary Security Analysis



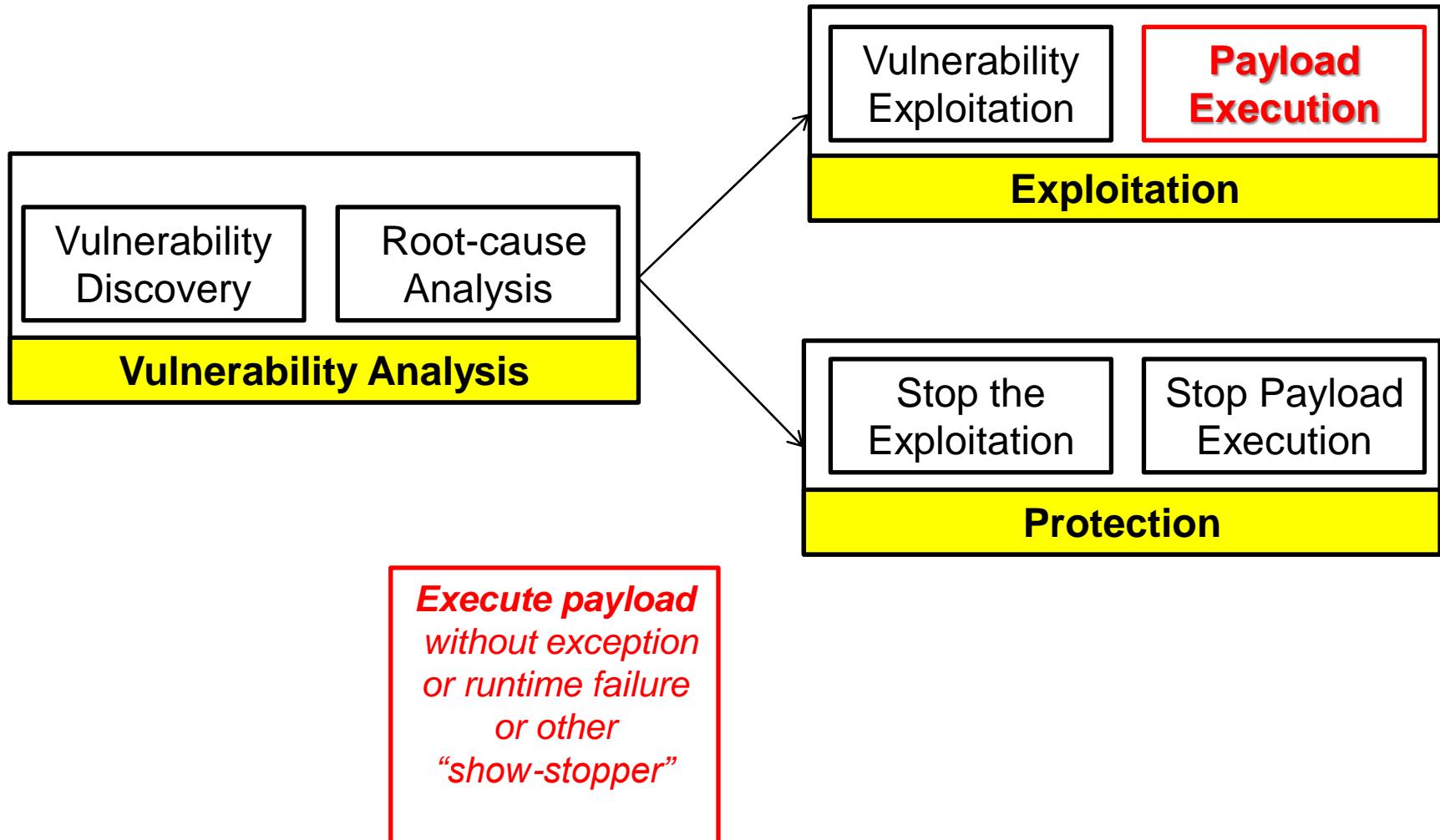
Phases of Binary Security Analysis



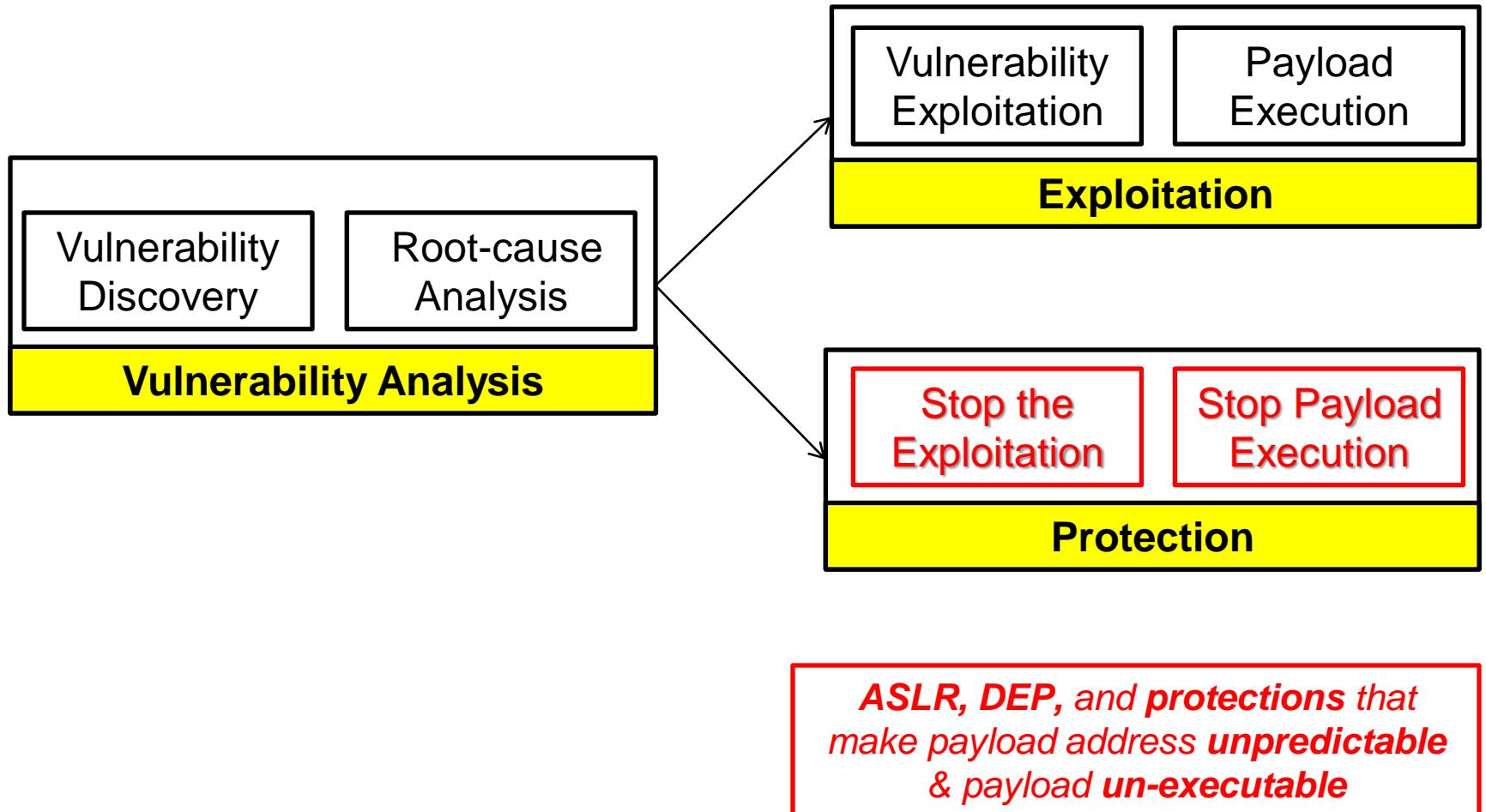
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Phases of Binary Security Analysis



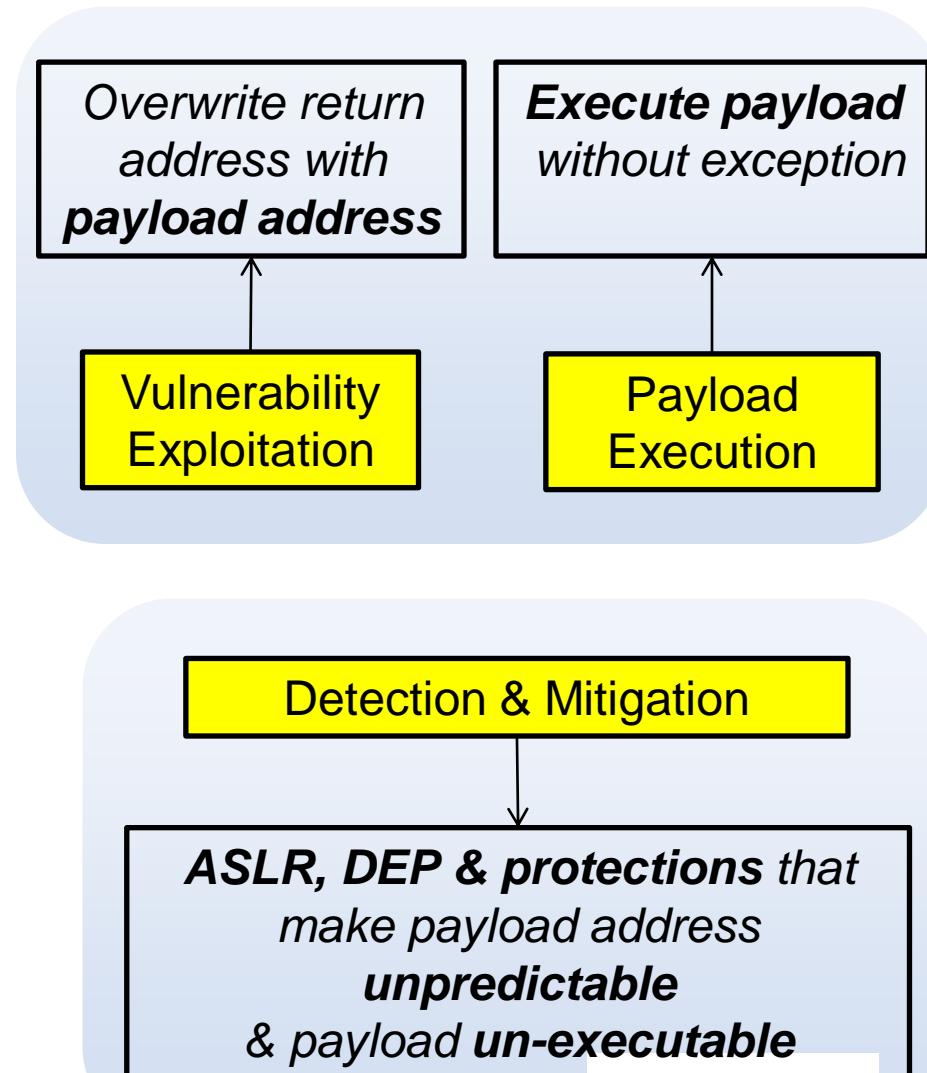
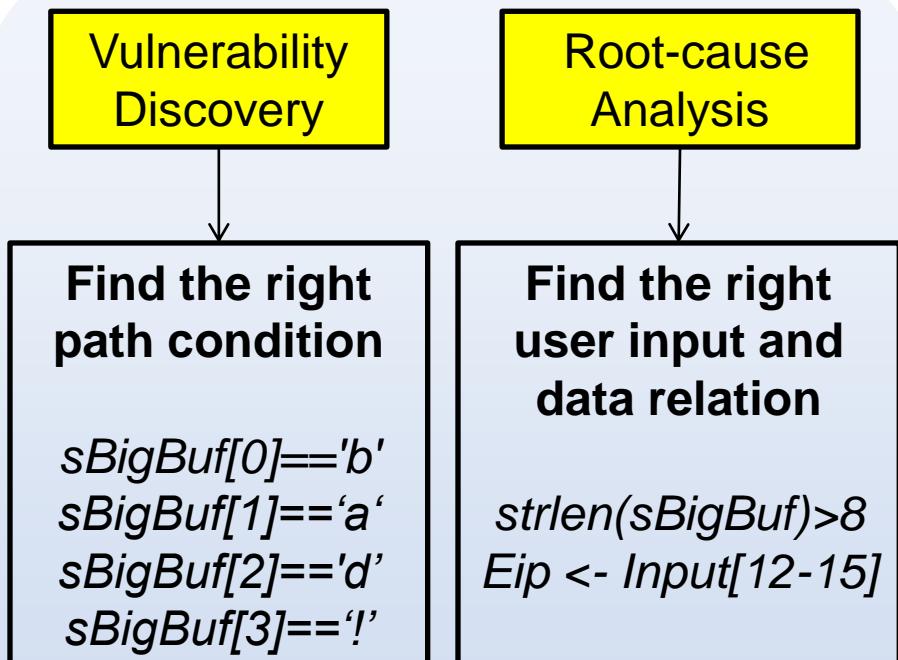
Phases of Binary Security Analysis



Aspects of Binary Security Analysis

We focus on two methods:

- dynamic taint analysis
- symbolic execution



Outline

- First Half

- Background
 - **Dynamic taint analysis and symbolic analysis**
 - Their success in vulnerability discovery
 - Challenges in exploitation research
- Our analysis platform
 - Cross-platform trace generation

- Second Half

- Supporting automated analysis
 - CBASS (Cross-platform Symbolic-execution System)
- Supporting interactive analysis
 - TREE (Taint-enabled Reverse Engineering Environment)
- How does TREE and CBASS Interact

Vulnerability is a property of the program

```
if(iCount==4) // bad!
    StackOverflow(sBigBuf,dwBytesRead)
```

```
else // Good
    printf("Good!");
```

```
void StackOverflow(char *sBig,int num)
{
    char sBuf[8]={0};
    .....
    for(int i=0;i<num;i++)
        //Overflow when num>sizeof(sBuf)
    {
        sBuf[i] = sBig[i];
    }
    .....
    return;
}
```

Doesn't change
with runtime



Dynamic Taint Analysis

Program

```
X := 8 + get_input()
```

```
Y := X + 2
```

```
Goto Y
```

Concrete Value

```
X → 0x12345678
```

```
Y → 0x1234567A
```

```
Use (Y) as address
```

Is Tainted?

```
X → {T}
```

```
X → {T} Y → {T}
```

```
Assert (Y not tainted)
```

Dynamic Taint Analysis

User input is “tainted”

Program

$X := 8 + \text{get_input}()$

$Y := X + 2$

Goto Y

Concrete Value

$X \rightarrow 0x12345678$

$Y \rightarrow 0x1234567A$

Use (Y) as address

Is Tainted?

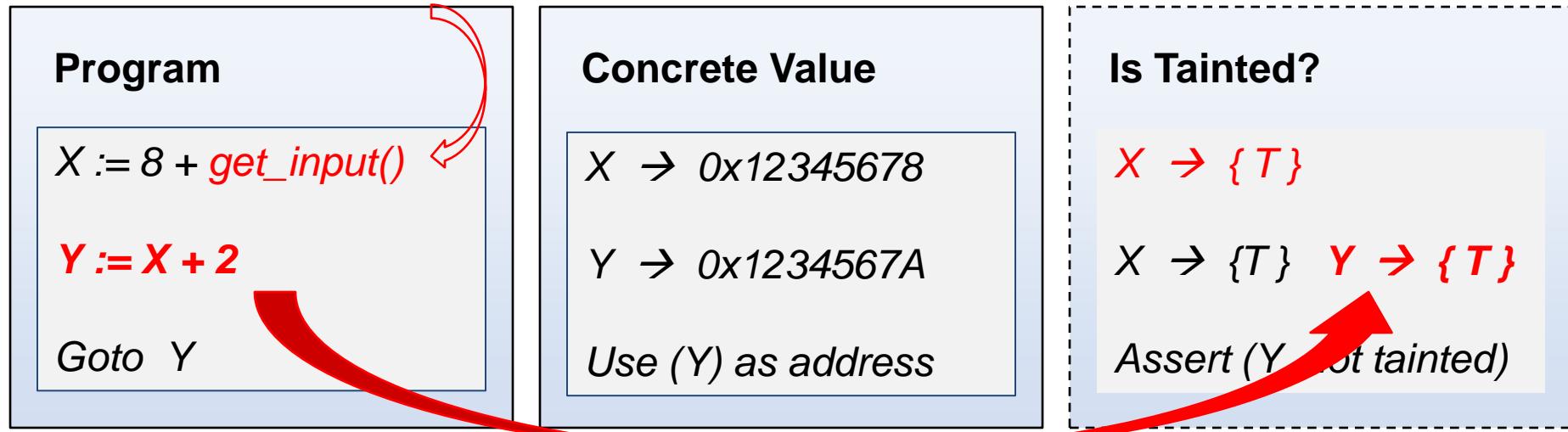
$X \rightarrow \{T\}$

$X \rightarrow \{T\} \quad Y \rightarrow \{T\}$

Assert (Y not tainted)

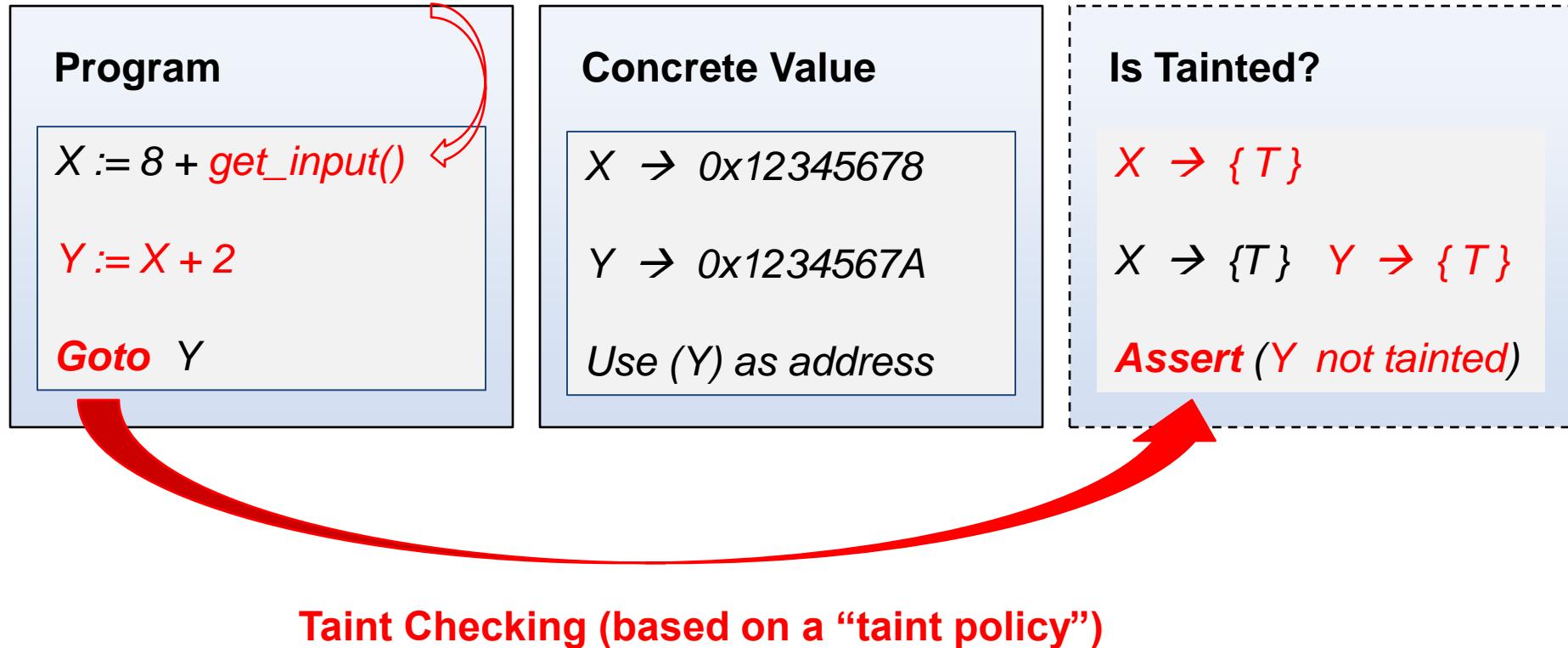
Dynamic Taint Analysis

User input is “tainted”



Dynamic Taint Analysis

User input is “tainted”

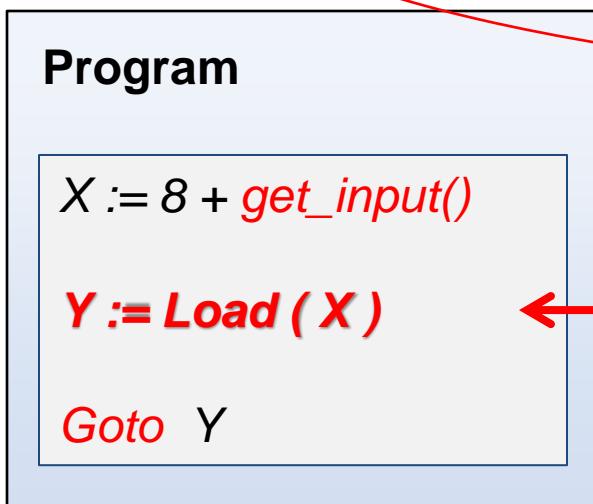


Dynamic Taint Analysis

Challenges

- Over Tainting
- Under Tainting

result of implementation choice -- taint policy



NO

YES

Should all values
derived from input be
marked as “tainted”?

Dynamic Taint Analysis

Challenges

- Over Tainting
- Under Tainting

```
num := get_input()  
...  
sBuf[i] := sBig[i]  
... (one million instructions)  
Goto return address;
```



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Symbolic Execution

Program

```
X := 8 + get_input()
```

```
If ( X - 10 == 5)
  Goto L2;
Else
  Goto L3;
```

Concrete Execution

```
X → 15
```

```
(15 - 10 == 5)
Goto L2;
```

Symbolic Execution

```
X → 8 + s
```

```
(8+s-10==5) → True
Goto L2;
(8+s-10!=5) → False
Goto L3;
```



Symbolic Execution

(path-cond, loc)

Current location
and path condition

mem-map

Current content
of the symbolic
memory

Program

$X := 8 + \text{get_input}()$

If ($X - 10 == 5$)

Goto L2;

Else

Goto L3;

```
SymbolicExec( Program P ) {
    init_state ← ⟨true, linit, M⟩;
    stack.push( init_state );
    while ( stack is not empty ) {
        ⟨pcon, l⟩ ← stack.pop();
        if ( pcon is satisfiable ) {
            for each ( event  $l \xrightarrow{\text{instr}} l'$  at location  $l$  ) {
                if ( instr is abort )
                    return ∅; //BUG_FOUND;
                else if ( instr is halt )
                     $\tau \leftarrow \text{solve}(pcon)$ ;
                     $\mathcal{T} := \mathcal{T} \cup \{\tau\}$ ;
                else if ( instr is if( $c$ ) )
                    next_state ← ⟨pcon  $\wedge c$ ,  $l'$ , M⟩;
                    stack.push( next_state );
                else if ( instr is  $v := \text{exp}$  )
                     $M' \leftarrow \text{update}(M, v, \text{exp})$ ;
                    next_state ← ⟨pcon,  $l'$ ,  $M'$ ⟩;
                    stack.push( next_state );
            }
        }
    }
    return  $\mathcal{T}$ ;
}
```

Symbolic Execution

(path-cond, loc)

(true, L0)

mem-map

x → undef

Program

X := 8 + get_input()

If (X - 10 == 5)

Goto L2;

Else

Goto L3;

L0
→

```
SymbolicExec( Program P ) {
    init_state ← ⟨ true, linit, M ⟩;
    stack.push( init_state );
    while ( stack is not empty ) {
        ⟨ pcon, l ⟩ ← stack.pop();
        if ( pcon is satisfiable ) {
            for each ( event l  $\xrightarrow{instr}$  l' at location l ) {
                if ( instr is abort )
                    return ∅; //BUG_FOUND;
                else if ( instr is halt )
                    τ ← solve (pcon);
                    T := T ∪ {τ};
                else if ( instr is if(c) )
                    next_state ← ⟨ pcon ∧ c, l', M ⟩;
                    stack.push( next_state );
                else if ( instr is v := exp )
                    M' ← update(M, v, exp);
                    next_state ← ⟨ pcon, l', M' ⟩;
                    stack.push( next_state );
            }
        }
    }
    return T;
}
```

Symbolic Execution

(path-cond, loc)

(true, L0)
(true, L1)

mem-map

X → (8+s)

Program

X := 8 + get_input()

If (X - 10 == 5)

Goto L2;

Else

Goto L3;

L1
→

```
SymbolicExec( Program P ) {
    init_state ← ⟨true, linit, M⟩;
    stack.push( init_state );
    while ( stack is not empty ) {
        ⟨pcon, l⟩ ← stack.pop();
        if ( pcon is satisfiable ) {
            for each ( event l  $\xrightarrow{instr}$  l' at location l ) {
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                    stack.push( next_state );
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                    next_state ← ⟨pcon, l', M'⟩;
                    stack.push( next_state );
            }
        }
    }
    return T;
}
```

Symbolic Execution

(path-cond, loc)

(true, L0)
($(8+s-10==5)$, L2)
($(8+s-10 \neq 5)$, L3)

mem-map

x → (8+s)

Program

$X := 8 + \text{get_input}()$

If ($X - 10 == 5$)

Goto L2;

Else

Goto L3;

L2
→

L3
→

```
SymbolicExec( Program P ) {
    init_state ← ⟨true, linit, M⟩;
    stack.push( init_state );
    while ( stack is not empty ) {
        ⟨pcon, l⟩ ← stack.pop();
        if ( pcon is satisfiable ) {
            for each ( event l  $\xrightarrow{\text{instr}}$  l' at location l ) {
                if ( instr is abort )
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                    T := T ∪ {τ};
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                    next_state ← ⟨pcon  $\wedge$  c, l', M⟩;
                    stack.push( next_state );
                else if ( instr is v := exp )
                    M' ← update(M, v, exp);
                    next_state ← ⟨pcon, l', M'⟩;
                    stack.push( next_state );
            }
        }
    }
    return T;
}
```

Symbolic Execution

(path-cond, loc)

(true, L0)

(**(8+s-10==5), L2**)

(**(8+s-10 !=5), L3**)

mem-map

x → (8+s)

Program

X := 8 + get_input()

If (X - 10 == 5)

Goto L2;

Else

Goto L3;

What input can lead to L2?

L2

L3

```
SymbolicExec( Program P ) {  
    init_state ← ⟨true, linit, M⟩;  
    stack.push( init_state );  
    while ( stack is not empty ) {  
        ⟨pcon, l⟩ ← stack.pop();  
        if ( pcon is satisfiable ) {  
            for each ( event l  $\xrightarrow{instr}$  l' at location l ) {  
                if ( instr is abort )  
                    return ∅; //BUG_FOUND;  
                else if ( instr is halt )  
                    τ ← solve (pcon);  
                    T := T ∪ {τ};  
                else if ( instr is if(c) )  
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                    stack.push( next_state );  
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                    M' ← update(M, v, exp);  
                    next_state ← ⟨pcon, l', M'⟩;  
                    stack.push( next_state );  
            }  
        }  
    }  
    return T;  
}
```

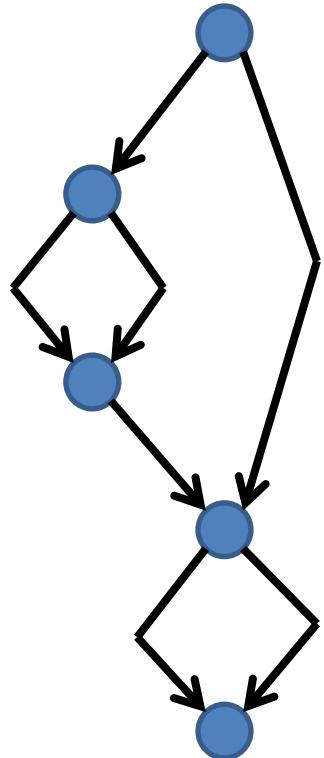
Symbolic Execution

3 branches can lead to 8 paths

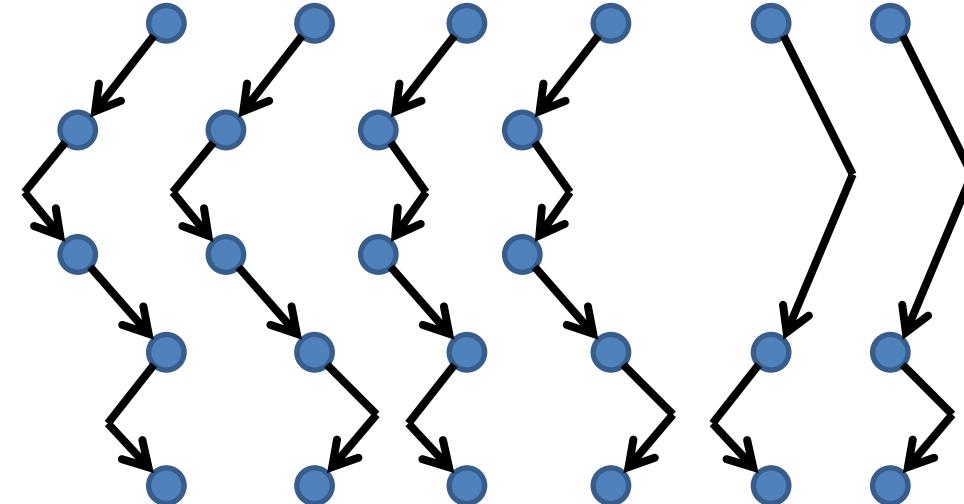
```
1: if (a<=0) res = res+1;  
2: else      res = res-1;  
    ...  
3: if (b<=0) res = res+2;  
4: else      res = res-2;  
    ...  
5: if (c<=0) res = res+3;  
6: else      res = res-3;
```

P1	P2	P3	P4	P5	P6	P7	P8
1	1	1	1	2	2	2	2
3	3	4	4	3	3	4	4
5	6	5	6	5	6	5	6

Symbolic Execution



Path explosion: the number of paths can be exponential in the number of branches



Challenges in symbolic execution

- Path Explosion → exploration strategy
- Symbolic Memory
- System/Library Calls



Over Approximation

or

Under Approximation

Y can have any value

Y has a concrete value

Program

```
X := get_input()
```

```
Y := Load (X)
```

Program

```
X := get_input()
```

```
Y := Sqrt (X)
```

Challenge in Multi-core Systems

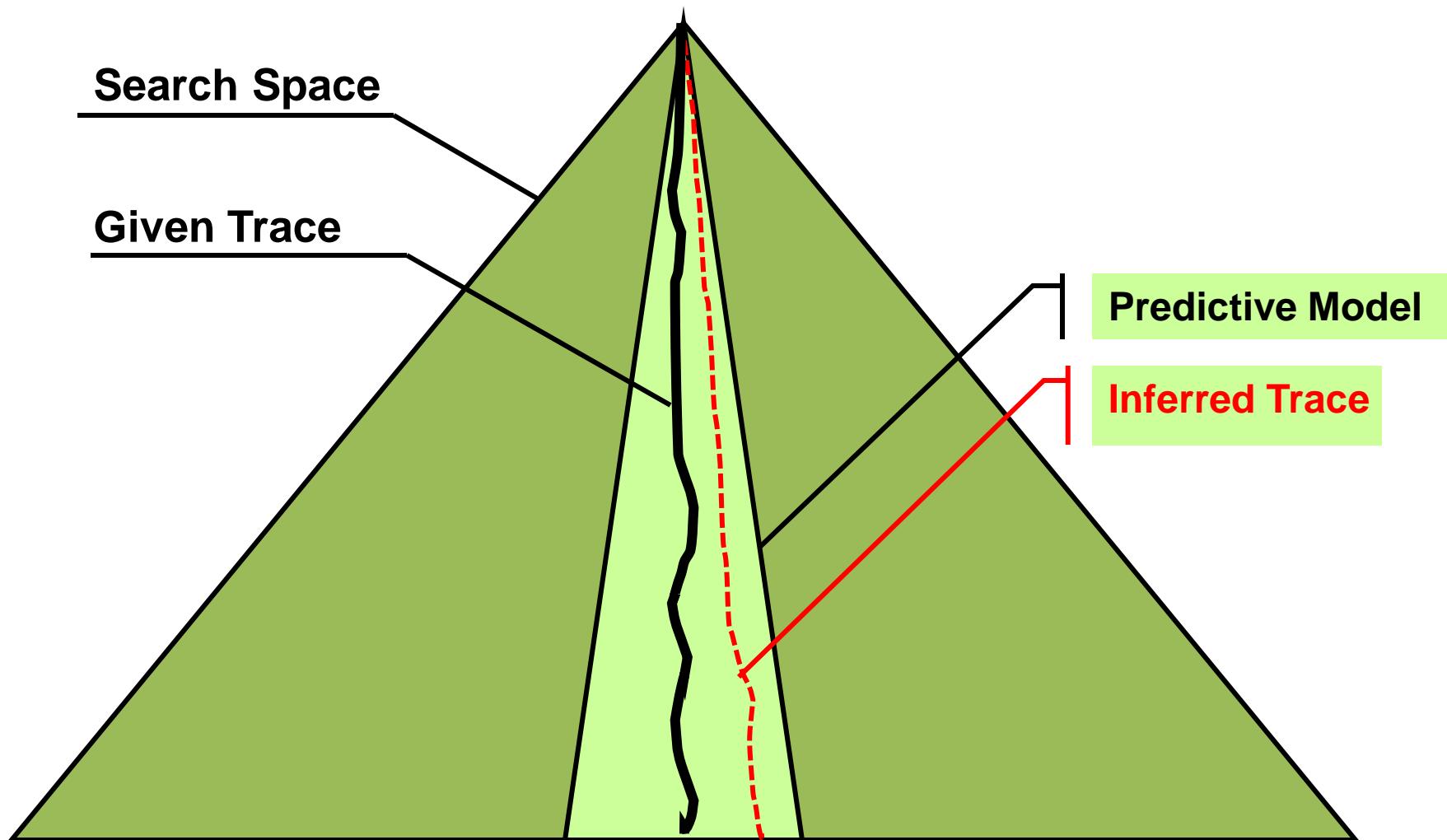
- Dynamic taint analysis
 - must model the *thread interference*
- Symbolic execution
 - must deal with the *thread interleaving explosion*, in addition to the path explosion within each thread

Symbolic Predictive Analysis

- **Statically analyzing** a logged execution trace of a multithreaded program **without re-running** the program...

Symbolic Predictive Analysis

(Rosu, Sen, et al.)



Predicting Vulnerabilities: How?

- Given run is good, but ...

Thread1

```
e1: if ( buf_index + len < BUFSIZE) {  
    ...  
e2:  memcpy(buf[buf_index], log, len);  
}
```

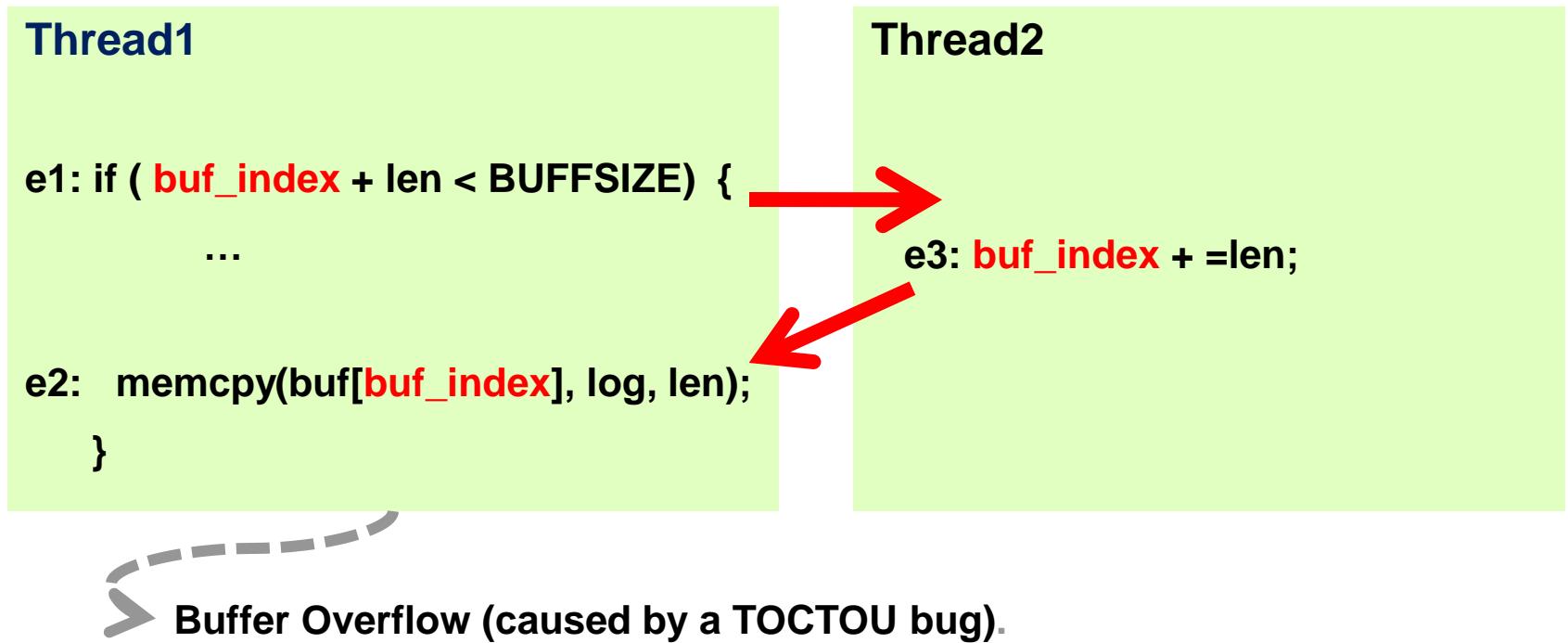
Thread2

```
e3: buf_index +=len;
```



Predicting Errors: How?

- Given run is good, but an alternative run is buggy



Outline

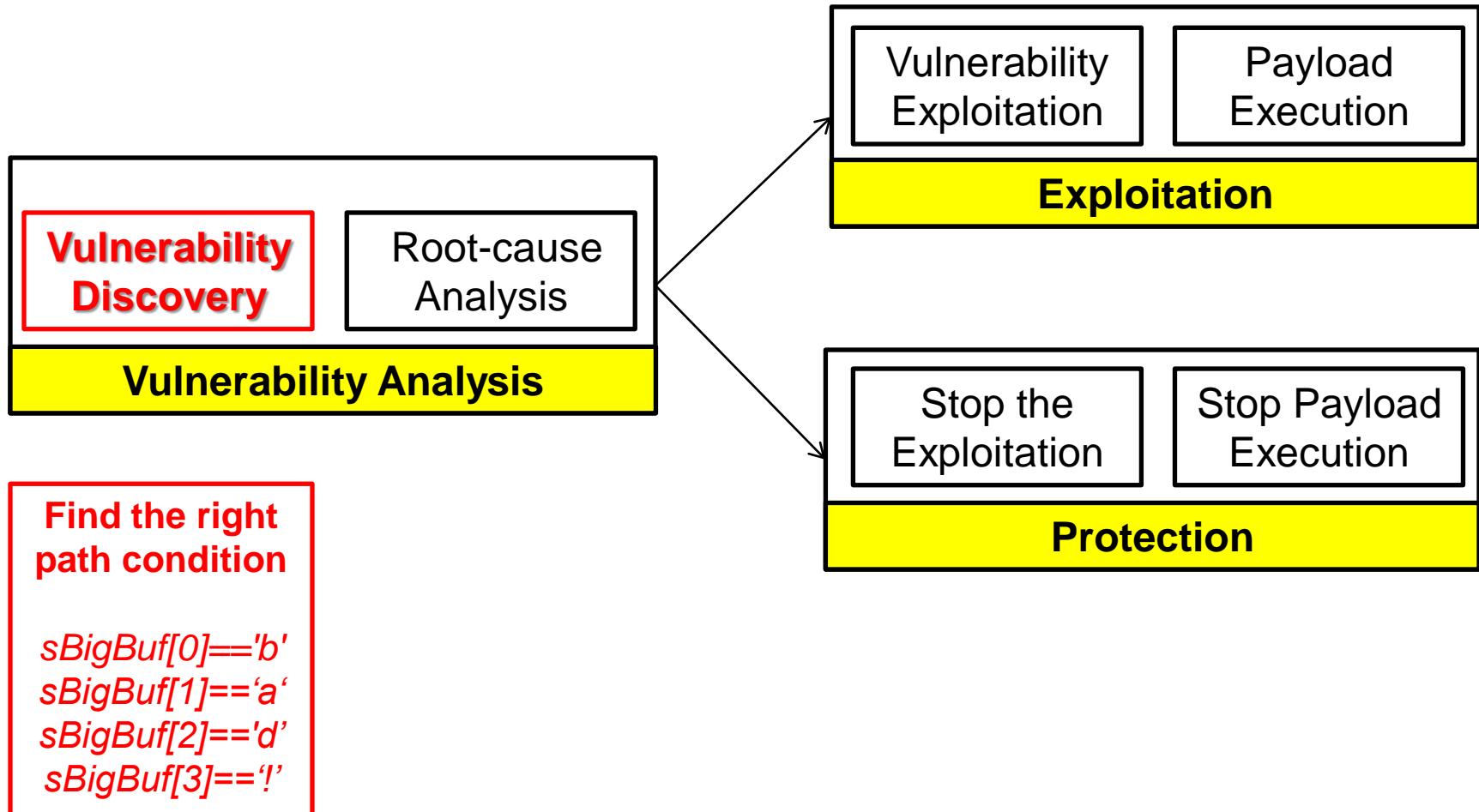
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Phases of Binary Security Analysis



How are vulnerabilities discovered in practice?

- **Black-box (Random) Fuzzing**

*“Fuzzing is a software testing technique, often automated or semi-automated, that involves providing invalid, unexpected, or random data to the inputs of a computer...
The field of fuzzing originates with Barton Miller at the University of Wisconsin in 1988”*

- Simple, easy to start, effective for low-hanging fruit
- Poor code coverage

- **Recently, white-box (symbolic execution based) Fuzzing**

- *DART, CUTE, SAGE, KLEE, Cloud9, etc.*

How are vulnerabilities discovered in practice?

- Dynamic taint analysis
 - *BitBlaze*
 - *Argos [EuroSys 2006]*
 - *DynTan [ISSTA 2007]*
 - *DTAM [FSE 2012] for multithreaded programs, etc.*

Our New Tool: Taint-enabled Reverse Engineering Environment (TREE)

Re: Taint tool

by p4r4n0id ✘ Sat Jul 27, 2013 6:46 am

Taint-enabled Reverse Engineering Environment (TREE)

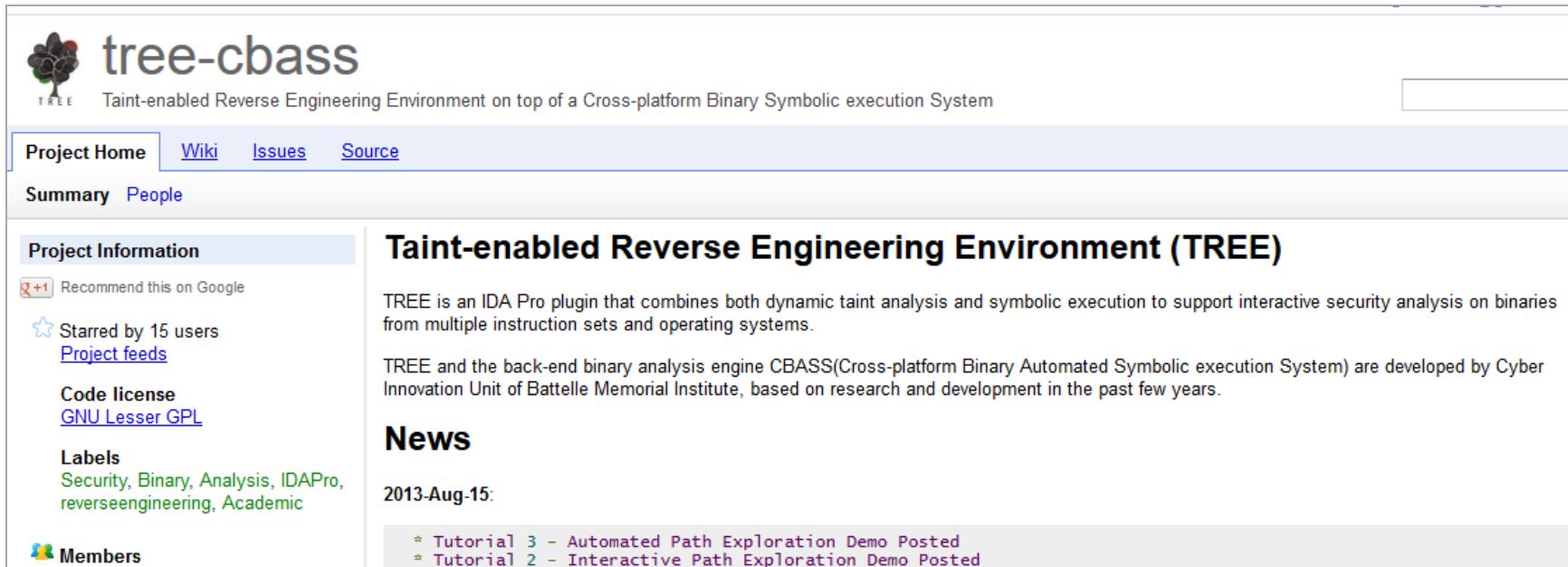
<https://code.google.com/p/tree-cbass/>

Keep Low. Move Fast. Kill First. Die Last. One Shot. One Kill. No Luck. Pure Skill.

<http://p4r4n0id.com/>

Our New Tool: Taint-enabled Reverse Engineering Environment (TREE)

<http://code.google.com/p/tree-cbass/>



The screenshot shows the Google Code page for the project "tree-cbass". The page has a header with the project logo (a stylized tree), the name "tree-cbass", and a subtitle "Taint-enabled Reverse Engineering Environment on top of a Cross-platform Binary Symbolic execution System". Below the header is a navigation bar with links for "Project Home" (which is active and highlighted in blue), "Wiki", "Issues", and "Source". Under "Project Home", there are two summary links: "Summary" and "People". On the left side, there is a sidebar with sections for "Project Information", "Recommend this on Google" (with a +1 button), "Starred by 15 users" (with a link to "Project feeds"), "Code license" (link to "GNU Lesser GPL"), "Labels" (links to "Security", "Binary", "Analysis", "IDAPro", "reverseengineering", and "Academic"), and "Members" (link to "Members"). The main content area is titled "Taint-enabled Reverse Engineering Environment (TREE)". It contains a brief description: "TREE is an IDA Pro plugin that combines both dynamic taint analysis and symbolic execution to support interactive security analysis on binaries from multiple instruction sets and operating systems." It also states: "TREE and the back-end binary analysis engine CBASS(Cross-platform Binary Automated Symbolic execution System) are developed by Cyber Innovation Unit of Battelle Memorial Institute, based on research and development in the past few years." Below this is a "News" section with a timestamp "2013-Aug-15:" followed by two purple-colored links: "* Tutorial 3 - Automated Path Exploration Demo Posted" and "* Tutorial 2 - Interactive Path Exploration Demo Posted".

Outline

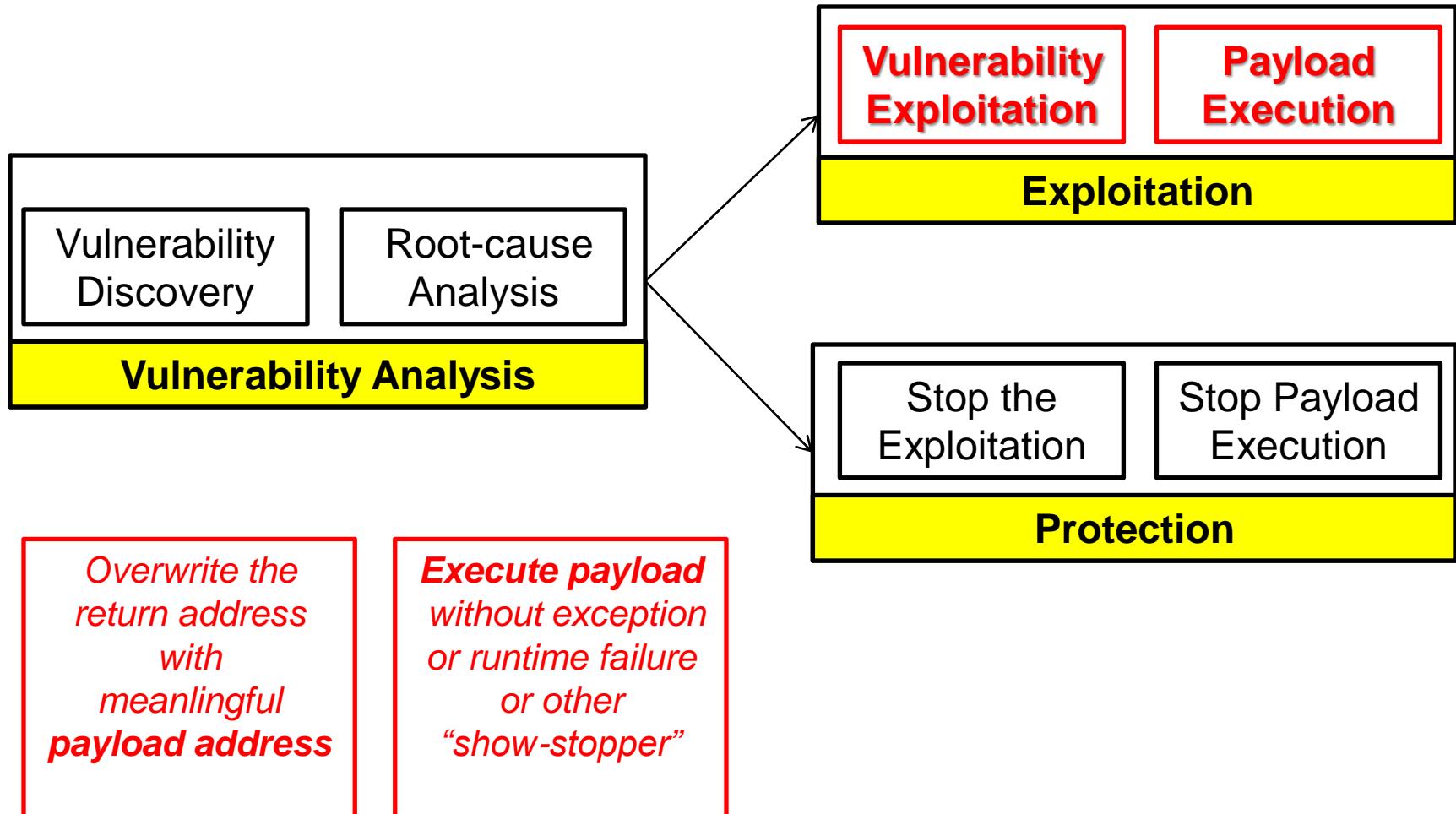
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Exploitation Analysis



Why is exploitation hard?

- Operating system has protection mechanism

- Canary



- NX (No-Execute)

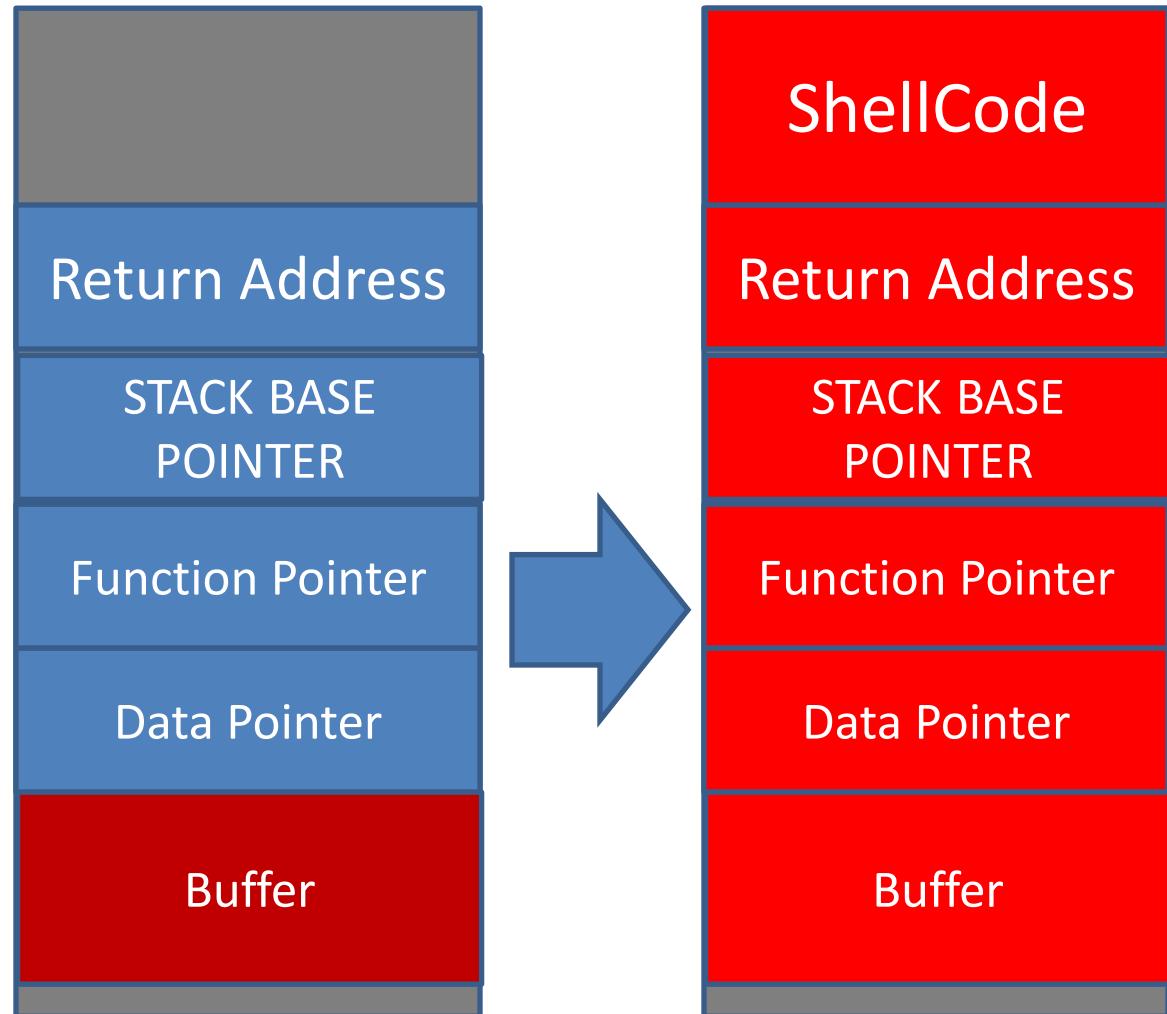


- ASLR (Address Space Layout Randomization)



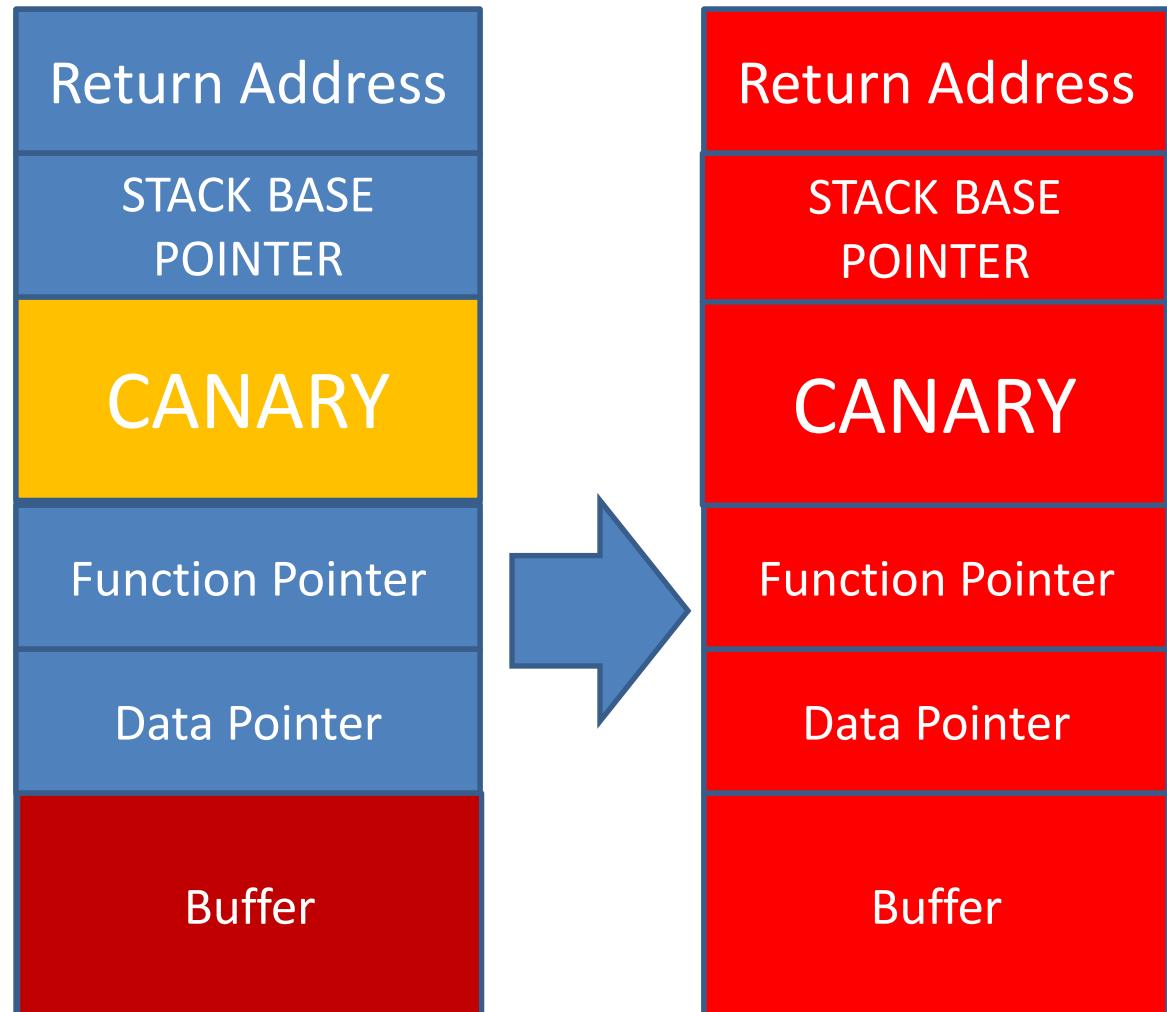
In the old days...

- Exploitation was easy
 - *Clobber return address on the execution stack*



When exploitation hits a “canary”

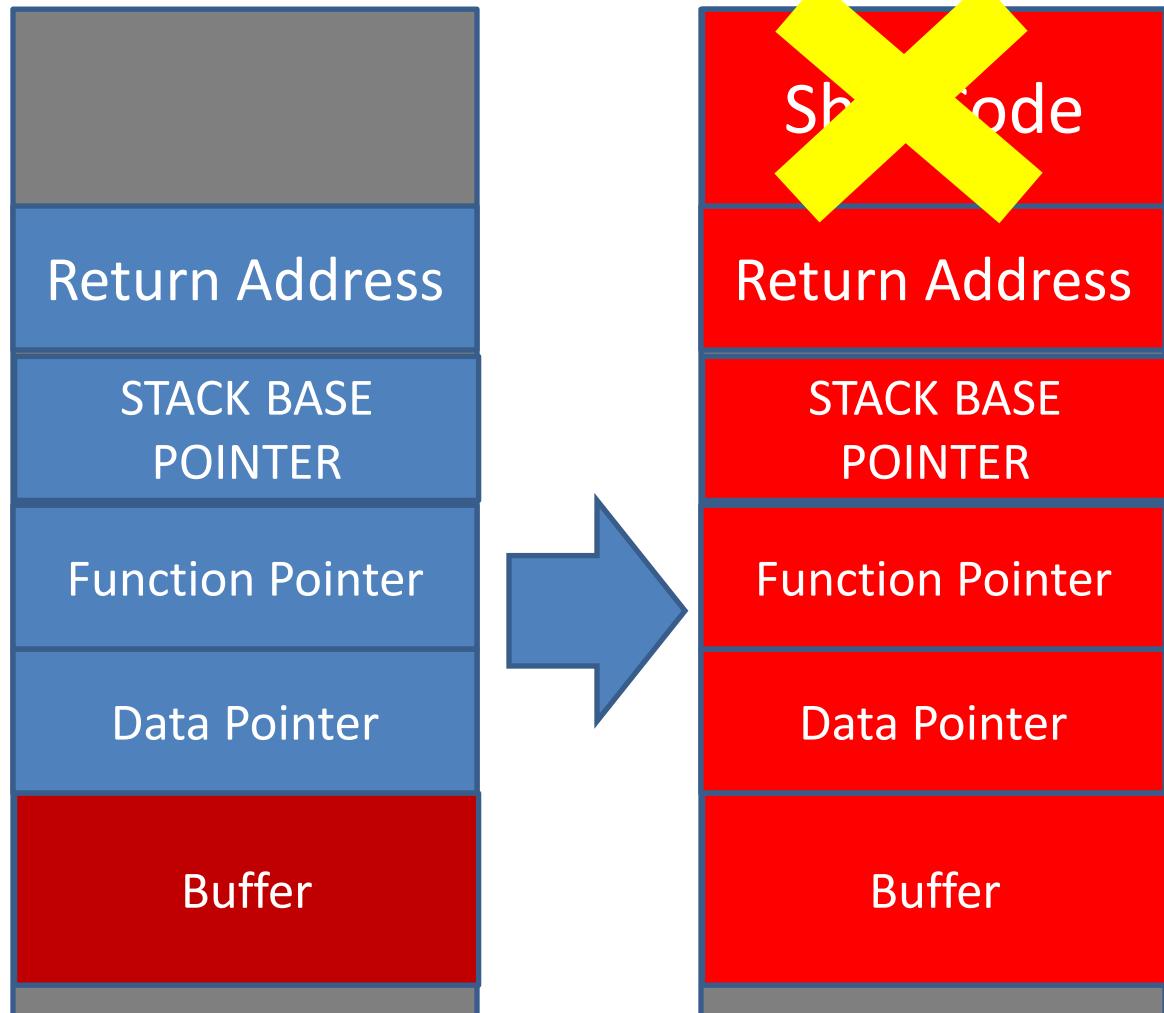
- Stack canary:
 - *Protection added at compiler time*
 - *protect return address and stack base pointer.*



When exploitation hits “NX”

NX: No-eXcute

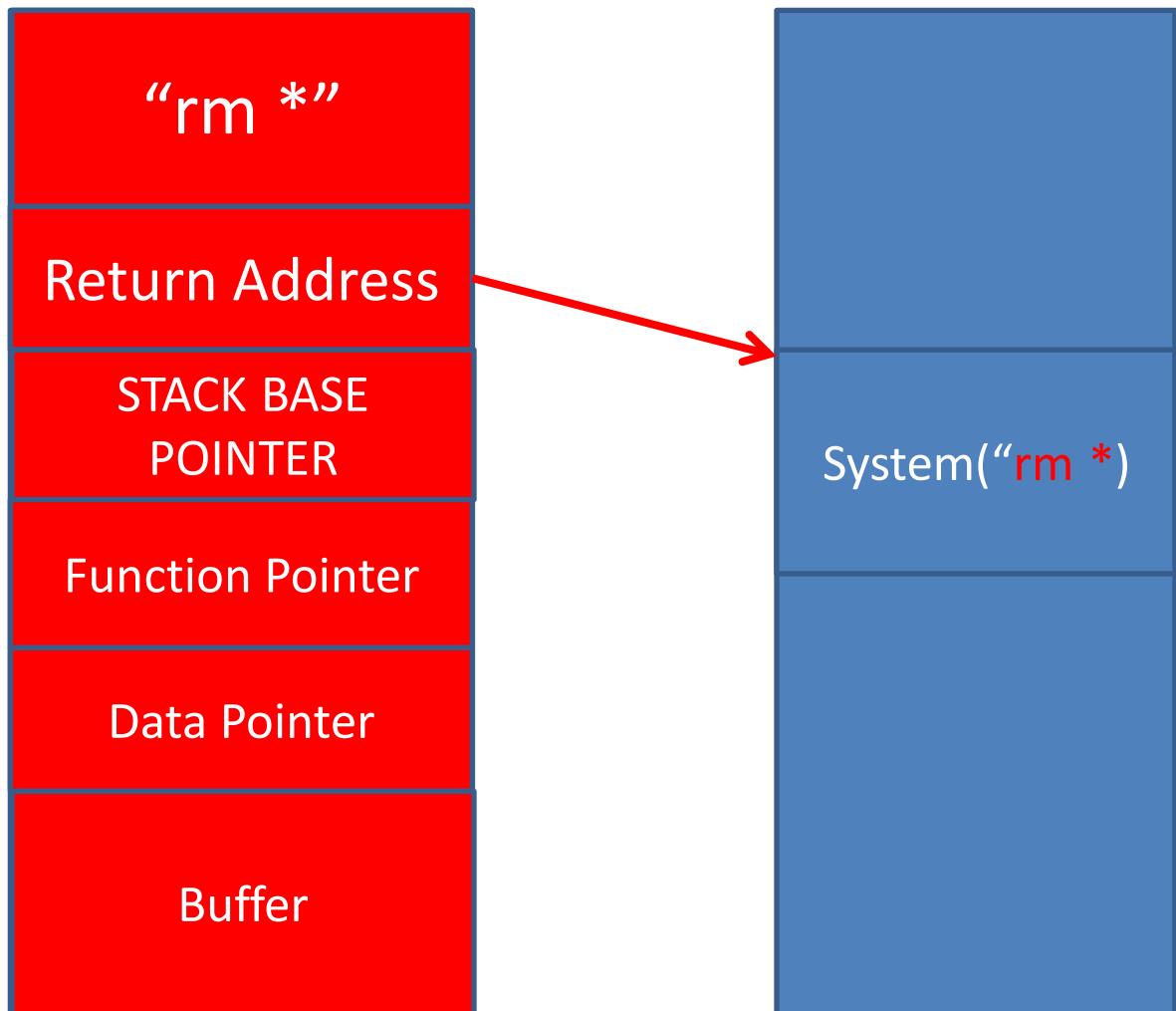
- Block Code Injection Attacks



When exploitation hits “NX”

Defeat NX

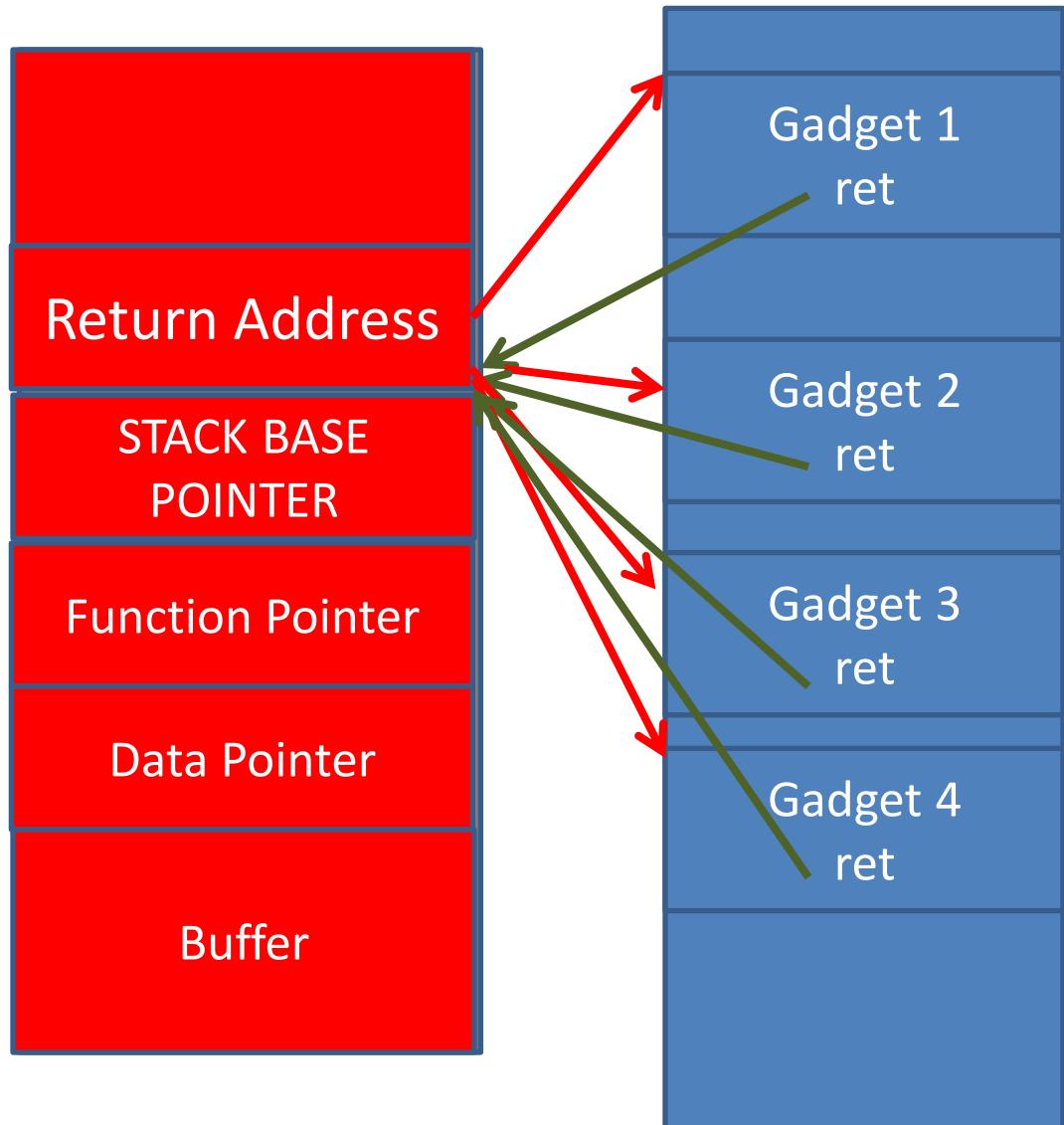
- Block Code Injection Attacks



When exploitation hits “NX”

- **Return-Oriented Programming: ROP**
 - A generalized form of “return-to-libc” attack
 - Execute existing instruction sequences, in a chained “gadgets” where each gadget ends with ret

R. Roemer, E. Buchanan, H. Shacham, and S. Savage. Return-Oriented Programming: Systems, Languages, and Applications. ACM Trans. Info. & Sys. Security 15(1):2, Mar. 2012



When exploitation hits ASLR

- *Address Space Layout Randomization: ASLR*
 - *Change program internal state*
 - *Break attacker's assumption of where the code & data is*
- *Fine-grained ASLR:*
 - *Also change the relative distance between objects*

First Boot



Second Boot

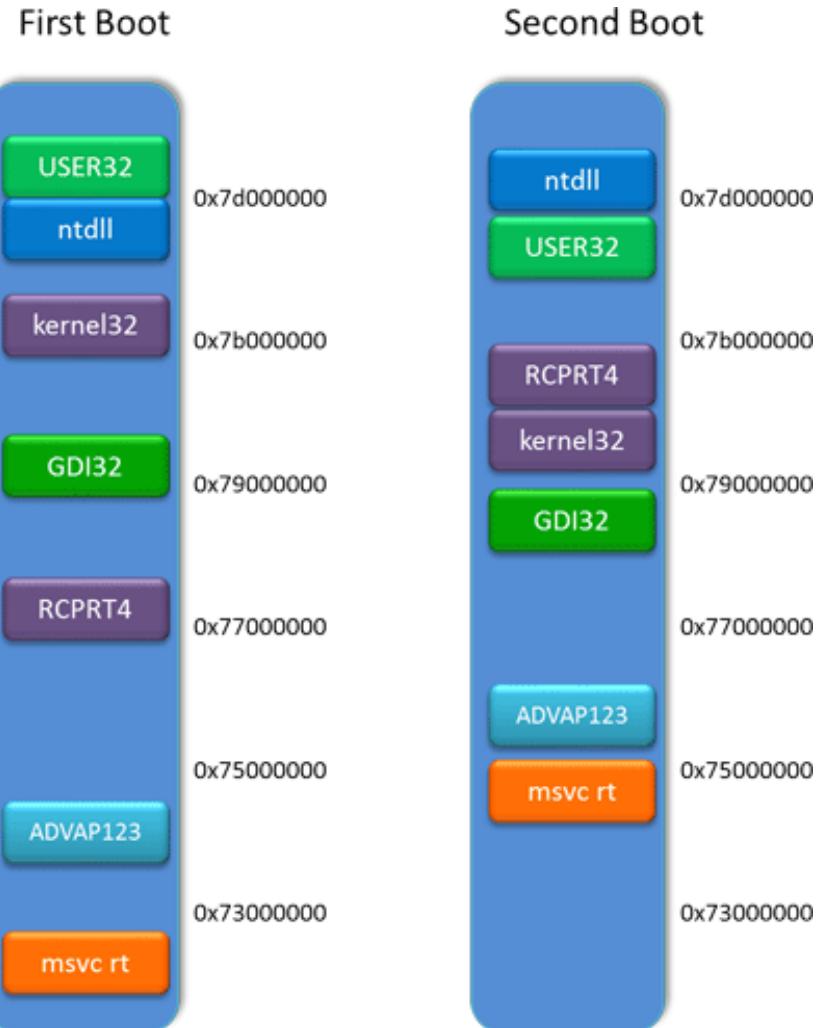


How to defeat ASLR?

- *Defeat ASLR*

- *ASLR is often for base address randomization – no change to relative distance between two objects*

Snow, Kevin Z., et al. "Just-in-time code reuse: On the effectiveness of fine-grained address space layout randomization." *IEEE Symposium on Security and Privacy*. 2013.



More info on “memory error arms race”

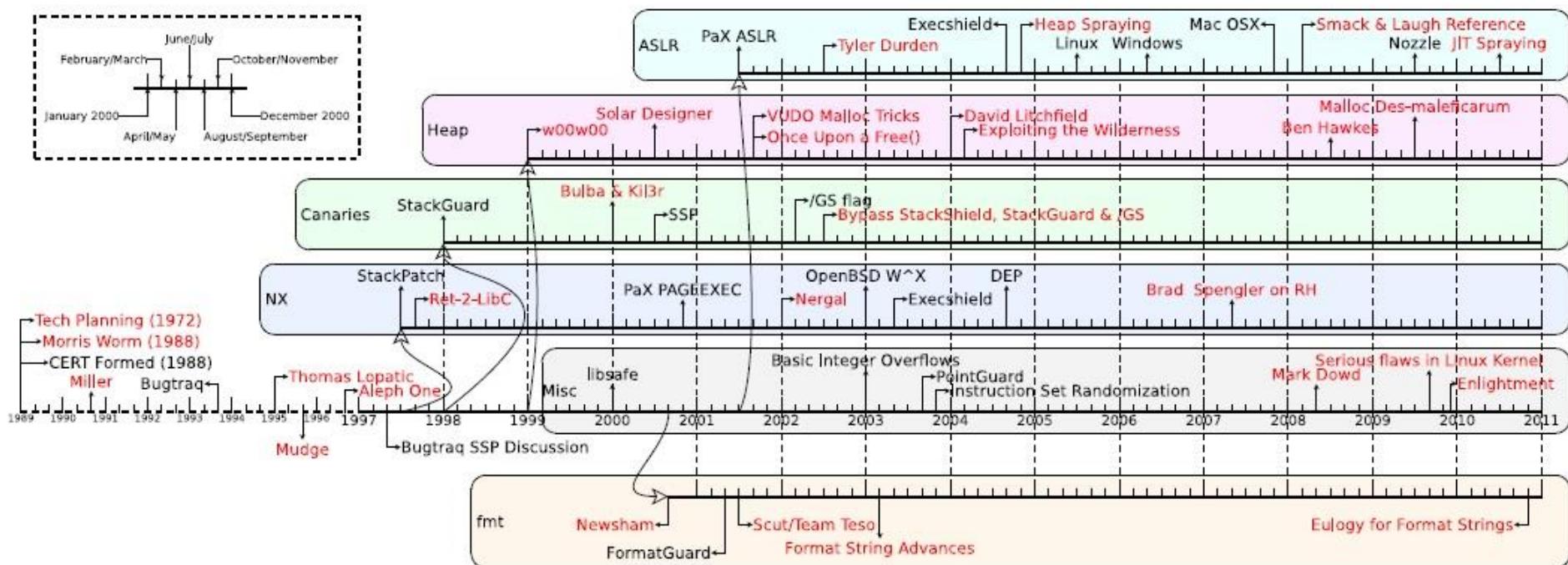


Fig. 1: General timeline

Bos, Herbert. "Memory Errors: The Past, the Present, and the Future," in RAID 2012

Outline

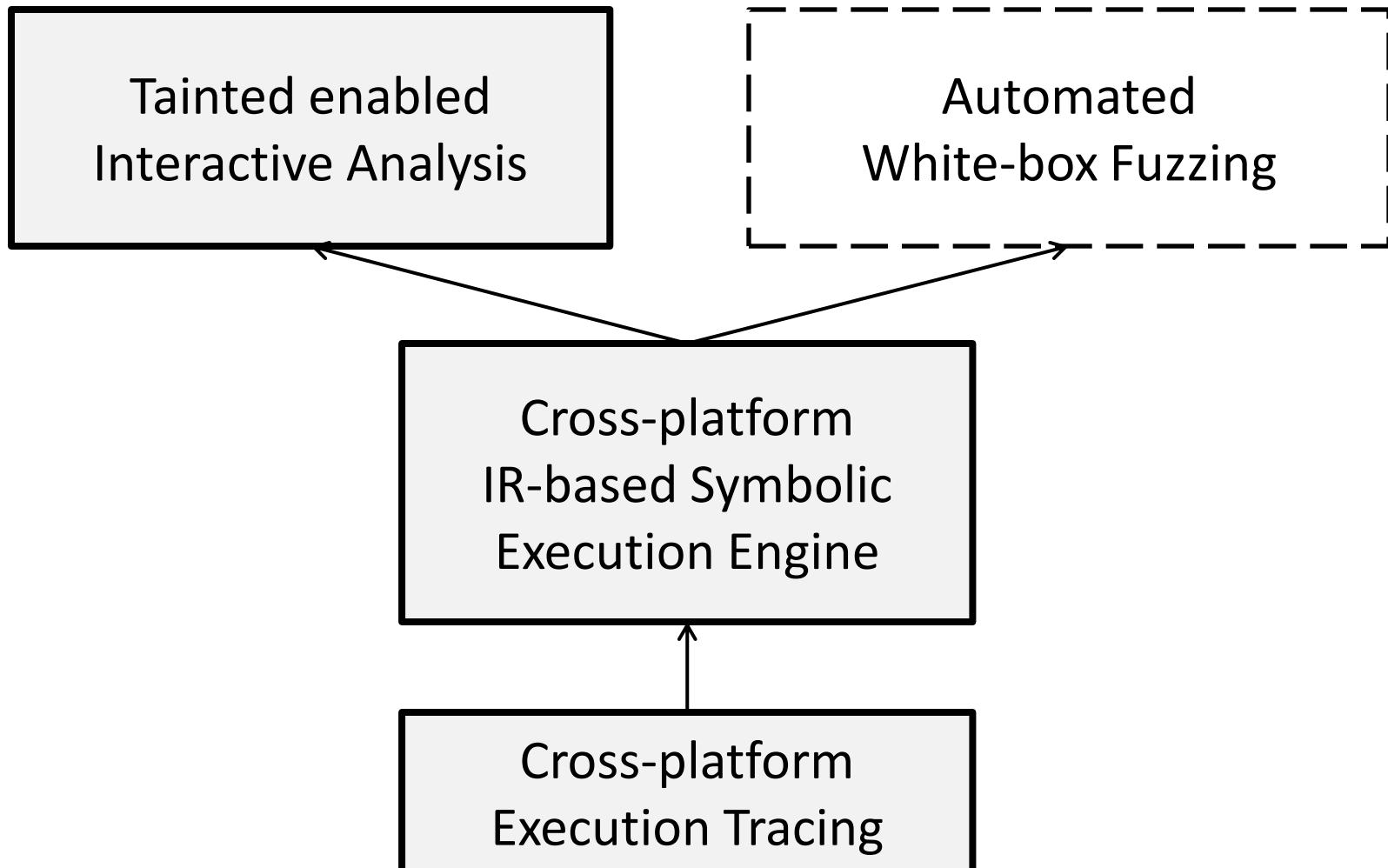
- First Half

- Background
 - Dynamic analysis and symbolic analysis
 - Their success in vulnerability discovery
 - Challenges in exploitation research
 - **Our analysis platform**
 - Cross-platform trace generation

- Second Half

- Supporting automated analysis
 - CBASS (Cross-platform Symbolic-execution System)
 - Supporting interactive analysis
 - TREE (Taint-enabled Reverse Engineering Environment)
 - How does TREE and CBASS Interact

Our goal is to support both automated and interactive analysis



Changing Computing Landscape



Diversified Platforms

Mobile
Devices



Control
Systems



Embedded
Devices

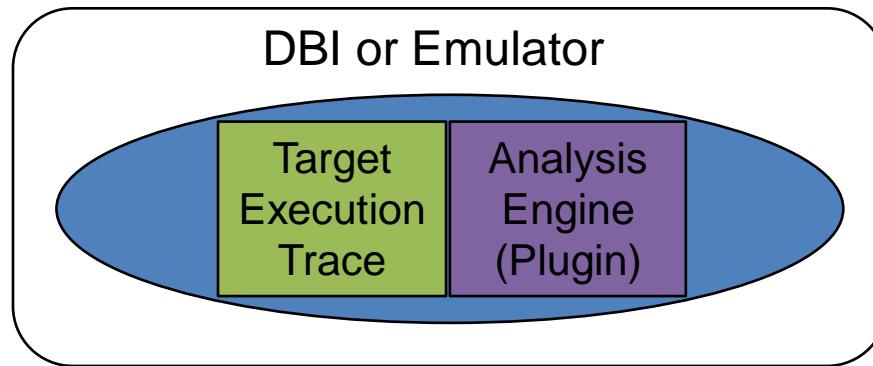


Cloud
Computing
Infrastructures



Cross-platform Analysis Problems:

- Trace analysis closely tied to trace generation and relied on instrumentation specific implementation, such as Dynamic Binary Instrumentation (DBI) or system emulator.



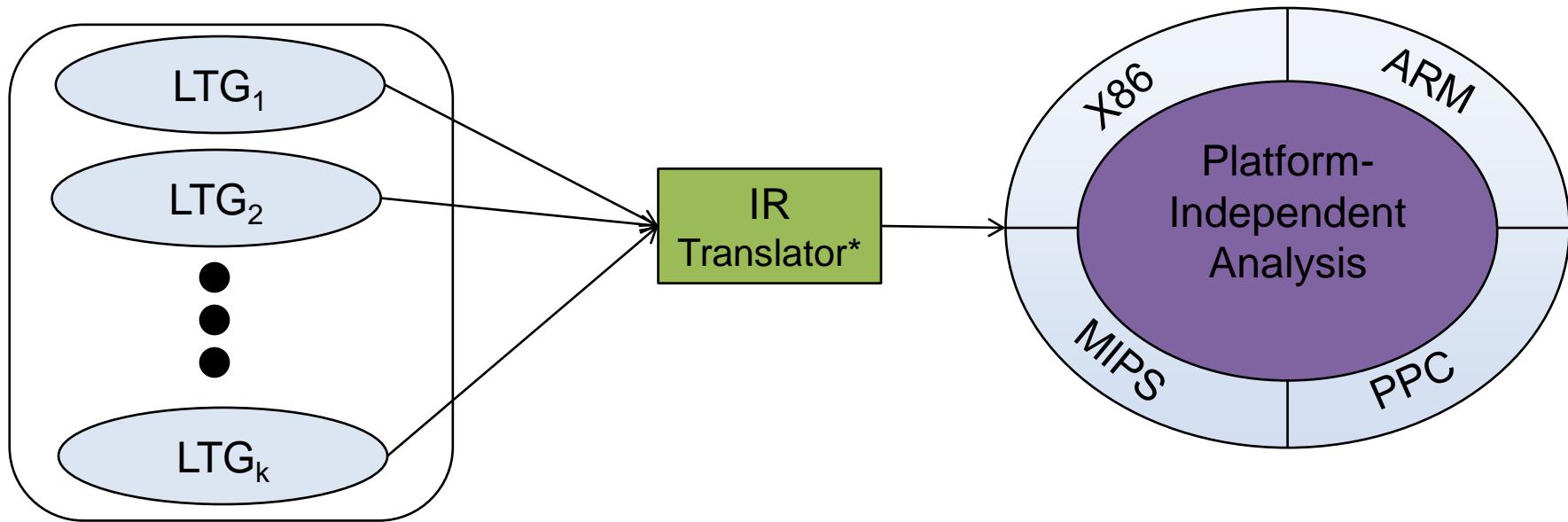
Comparisons of Popular DBI Tools:

Tool	Tool Runs On	Target ISA
PIN	Windows/Linux	X86/64 Windows/Linux
Dynamorio	Windows/Linux	X86/64 Windows/Linux
Valgrind	Linux/Android/Mac	X86/64, ARM, PPC32/64, MIPS

Our Approach:

Separate Trace Generation from Trace Analysis with Intermediate Representation

- **Platform-dependent** Light-weight Trace Generation (LTG)
- Intermediate Representation(**IR**) Translation
- **Platform-independent** Analysis Engine
- Analysis Algorithm and Implementation Reuse



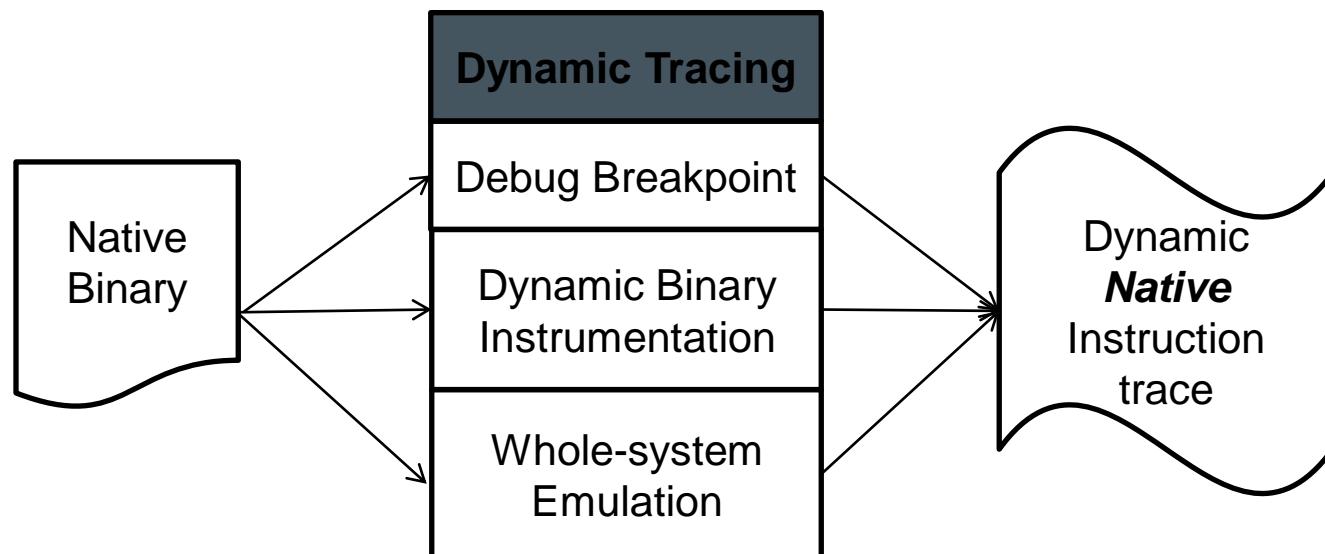
Multiple-platform Trace Generation

Trace Generation

- Dynamic Binary Instrumentation
 - Process based
 - Just-in-time binary translation
 - PIN, DynamoRIO, Valgrind
- Whole System Emulation
 - System based
 - Just-in-time binary translation
 - QEMU
- Debug Breakpoint
 - Both process(user mode) and system(kernel)
 - Universal and accessible on real devices

Light-weight Trace Generation:

- Target-dependent
- Capture basic program state using platform-specific instrumentation framework
- Support interactive tracing

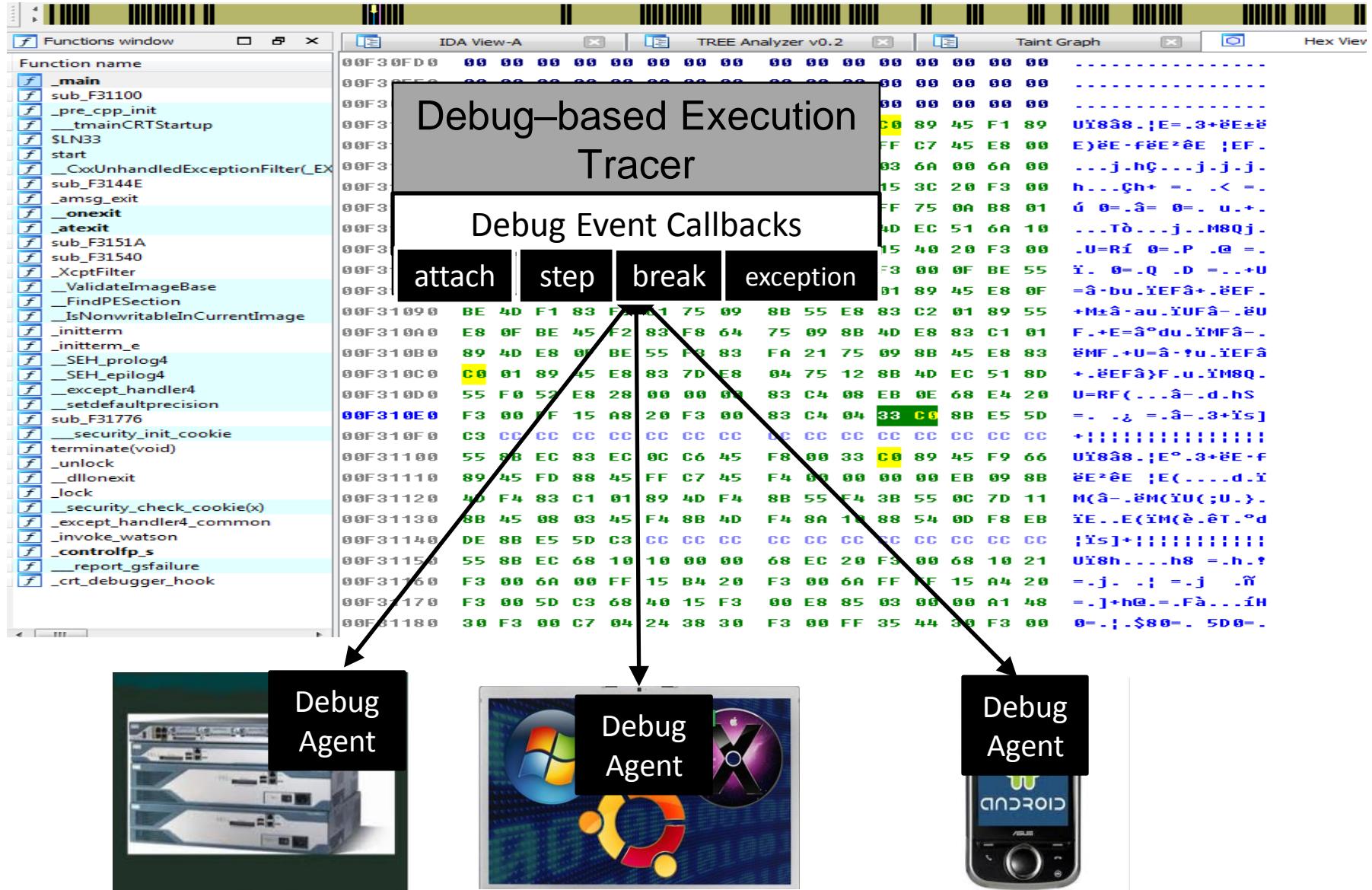


Our Debug Tracer Runs as IDA-Pro Plug-in

- **Why IDA Pro?** It is the most popular *reverse engineering tool* with cross-platform debugging support

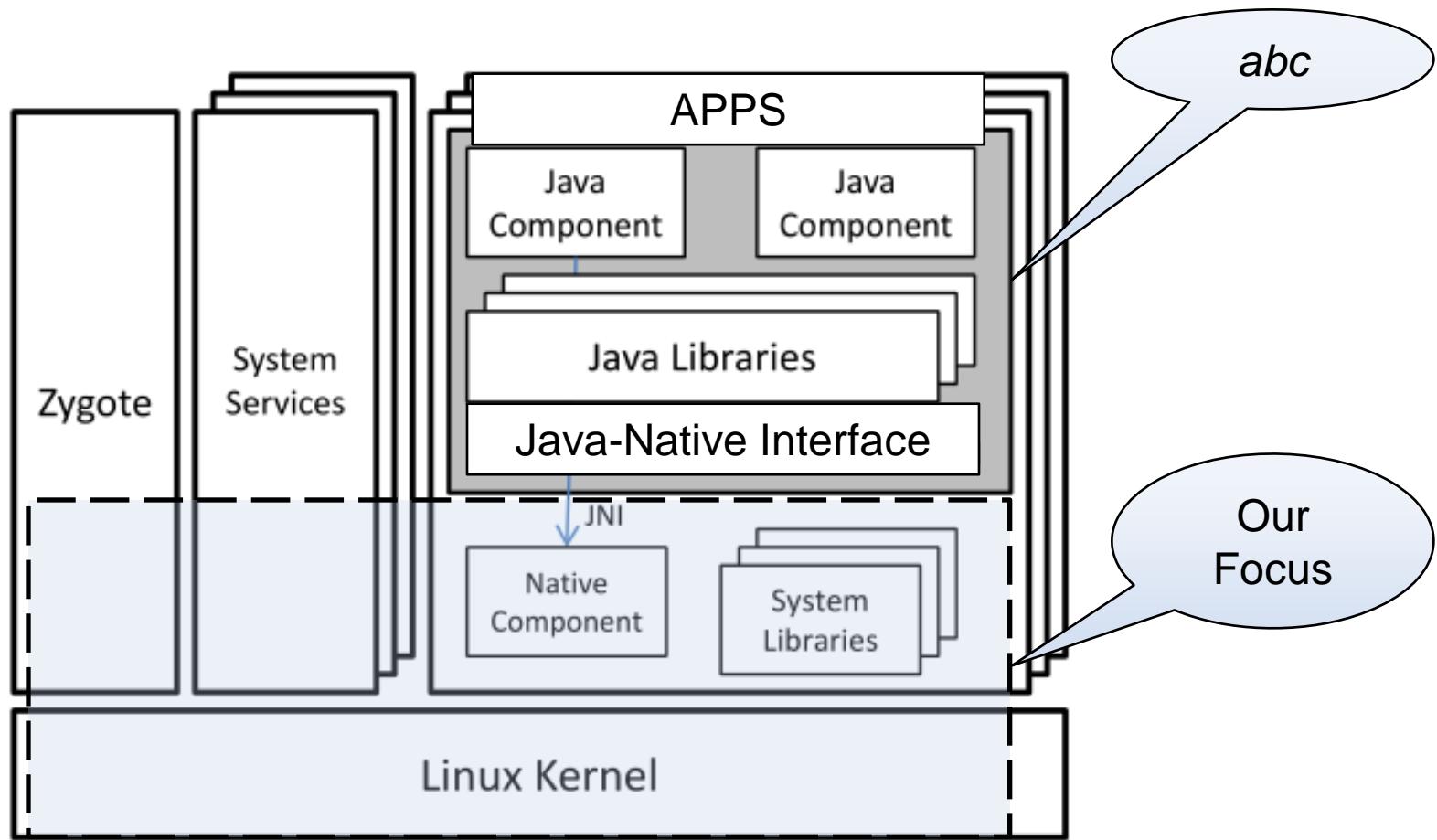
	IDA runs on: Windows	IDA runs on: Linux	IDA runs on: Mac OS X	Additional Notes
				
Target Platform: Windows 32/64-bit	Local/Remote	Remote	Remote	On 64-bit Windows platforms, remote only.
Target Platform: Linux 32/64-bit	Remote	Local/Remote	Remote	On 64-bit Linux platforms, remote only.
Target Platform: OS X 32/64-bit	Remote	Remote	Local/Remote	On 64-bit Mac OS X platforms, remote only.
Target Platform: iPhone				Remote / / Discontinued in IDA v5.6
Target Platform: Bochs				Bochs Emulator Bochs Emulator Bochs Emulator
Target Platform: GDB Server				GDB Server GDB Server GDB Server 
Target Platform: WinDBG 32/64-bit				Remote / / Both user-mode and kernel-mode debugging are available. 64-bit debugging is supported too. See help懵懵

Our Debug Execution Tracer



Multiple-platform Tracing on Android Demo

Android Architecture



Android Tracing Setup



Trace Generation on Android-based Device



Trace Zip code in zlib.so

Key Step: Create an APP to trigger the compression/decompression activity

The screenshot shows the Android Tracing tool interface. On the left, there is a code editor window titled "android_tracing_1" containing Java code for decompression. On the right, there is a timeline or trace viewer window.

```
android_tracing_1
    while (!deflater.finished()) {
        int byteCount = deflater.deflate(buf);
        baos.write(buf, 0, byteCount);
    }
    deflater.end();

    byte[] compressedBytes = baos.toByteArray();

    System.out.println("Here is the compressed data...");
    mEdit.setText(compressedBytes.toString());

    return compressedBytes;
}

private void decompress(byte[] compressedBytes, int decompressedByteCount) throws UnsupportedEncodingException
{
   Inflater inflater = new Inflater();
    inflater.setInput(compressedBytes, 0, compressedBytes.length);
    byte[] decompressedBytes = new byte[decompressedByteCount];

    try {
        if (inflater.inflate(decompressedBytes) != decompressedByteCount) {
            throw new AssertionError();
        }
        System.out.println("Here is the decompressed data...");
        // Decode the bytes into a String
        String outputString = new String(decompressedBytes, 0, decompressedByteCount, "UTF-8");
        mEdit.setText(outputString);
    } catch (DataFormatException e) {
        // TODO Auto-generated catch block
        e.printStackTrace();
    } catch (AssertionError e) {
        // TODO Auto-generated catch block
        e.printStackTrace();
    }

    inflater.end();
}
```

A large green text overlay "Decompression Routine" is positioned in the center-right area of the slide, partially covering the timeline window.

Trace Zip code in zlib.so (cont)

Key Step: Launch Debug Agent on the Device

```
c:\ Command Prompt - adb shell
Microsoft Windows [Version 6.1.7601]
Copyright <c> 2009 Microsoft Corporation. All rights reserved.

C:\Users\xing>adb devices
List of devices attached
3730FB394FD100EC          device

C:\Users\xing>adb shell
root@android:/ # cd /data/local
cd /data/local
root@android:/data/local # ls -la
ls -la
-rwxr-xr-x root      root      572920 2013-03-06 11:04 android_server
drwxrwx--x shell      shell      2013-09-05 10:27 tmp
-rwxr-xr-x root      root      77352 2013-07-24 21:08 toolbox
root@android:/data/local # ./android_server
./android_server
IDA Android 32-bit remote debug server(ST) v1.15. Hex-Rays <c> 2004-2013
Listening on port #23946...
```

Launch android_server

Trace Zip code in zlib.so (cont)

Key Step: Select the tracing mode and parameters

Configurable Parameters

Interactive Mode

Application: libz.so

Path: libz.so

Arguments:

Remote PIN

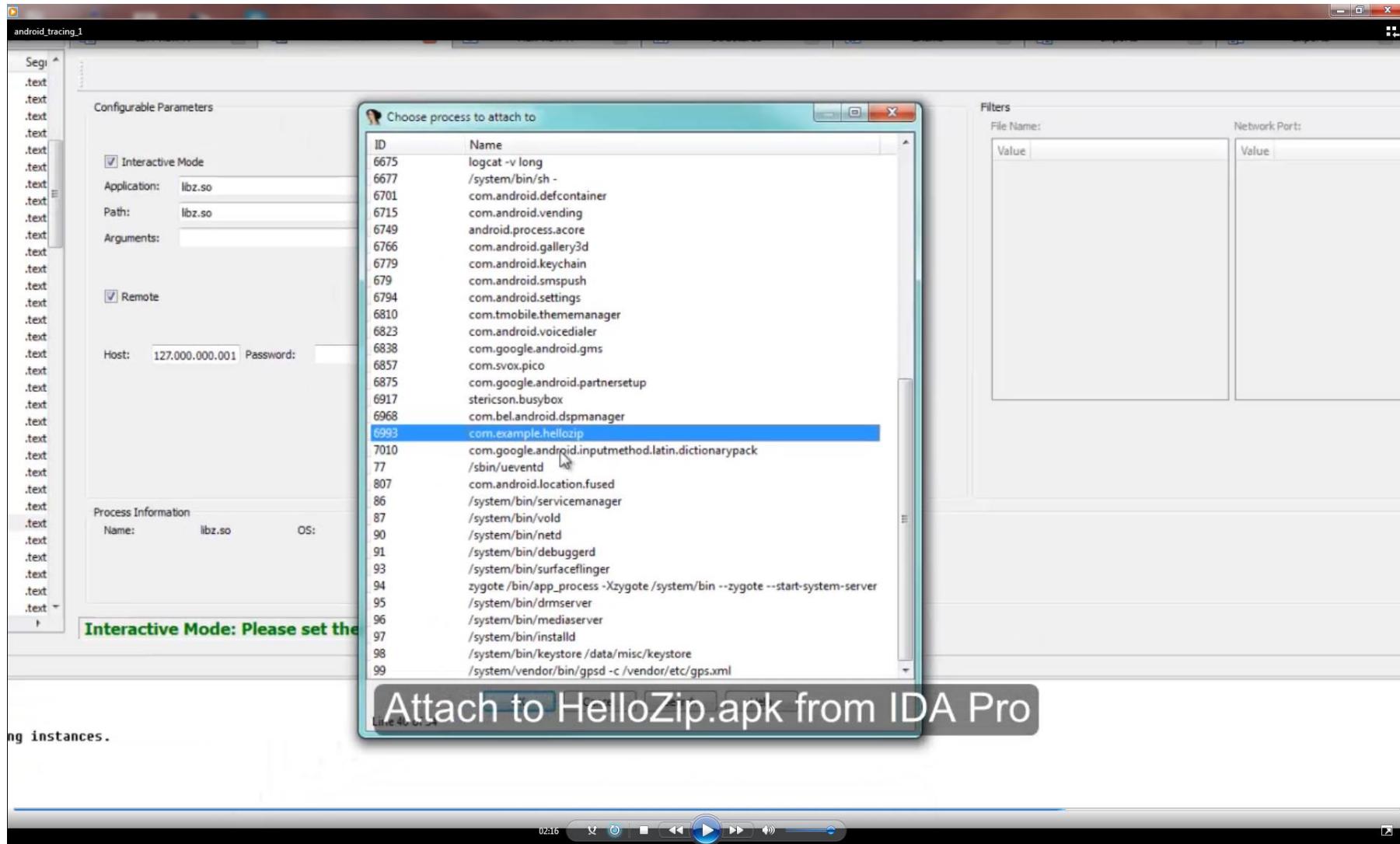
Host: 127.000.000.001 Password: Port 23946

Process Information

Name:	libz.so	OS:	linux ARM Bit
-------	---------	-----	---------------

Trace Zip code in zlib.so (cont)

Key Step: Attach tracer to the right process



Trace Zip code in zlib.so (cont)

Key step: Collect program states from callback

```
1 E 0x40037208 4 f04f2de9 R0=0x4d5d8048, R1=0x4, R2=0x2000, R3=0x4014c228, R4=0x4025
2 E 0x4003720c 4 005050e2 R0=0x4d5d8048, R1=0x4, R2=0x2000, R3=0x4014c228, R4=0x4025
3 E 0x40037210 4 e88b9fe5 R0=0x4d5d8048, R1=0x4, R2=0x2000, R3=0x4014c228, R4=0x4025
4 E 0x40037214 4 1cd04de2 R0=0x4d5d8048, R1=0x4, R2=0x2000, R3=0x4014c228, R4=0x4025
5 E 0x40037218 4 0160a0e1 R0=0x4d5d8048, R1=0x4, R2=0x2000, R3=0x4014c228, R4=0x4025
6 E 0x4003721c 4 08808fe0 R0=0x4d5d8048, R1=0x4, R2=0x2000, R3=0x4014c228, R4=0x4025
7 E 0x40037220 4 e801000a R0=0x4d5d8048, R1=0x4, R2=0x2000, R3=0x4014c228, R4=0x4025
8 E 0x40037224 4 1c4095e5 R0=0x4d5d8048, R1=0x4, R2=0x2000, R3=0x4014c228, R4=0x4025
9 E 0x40037228 4 013074e2 R0=0x4d5d8048, R1=0x4, R2=0x2000, R3=0x4014c228, R4=0x4d5d
10 E 0x4003722c 4 0030a033 R0=0x4d5d8048, R1=0x4, R2=0x2000, R3=0xb2a33ff9, R4=0x4d5d
11 E 0x40037230 4 050051e3 R0=0x4d5d8048, R1=0x4, R2=0x2000, R3=0x0, R4=0x4d5cc008, E
12 E 0x40037234 4 013083c3 R0=0x4d5d8048, R1=0x4, R2=0x2000, R3=0x0, R4=0x4d5cc008, E
13 E 0x40037238 4 000053e3 R0=0x4d5d8048, R1=0x4, R2=0x2000, R3=0x0, R4=0x4d5cc008, E
14 E 0x4003723c 4 e101001a R0=0x4d5d8048, R1=0x4, R2=0x2000, R3=0x0, R4=0x4d5cc008, E
```

Demo

Android Trace Generation Demo

Halftime

Outline

- First Half

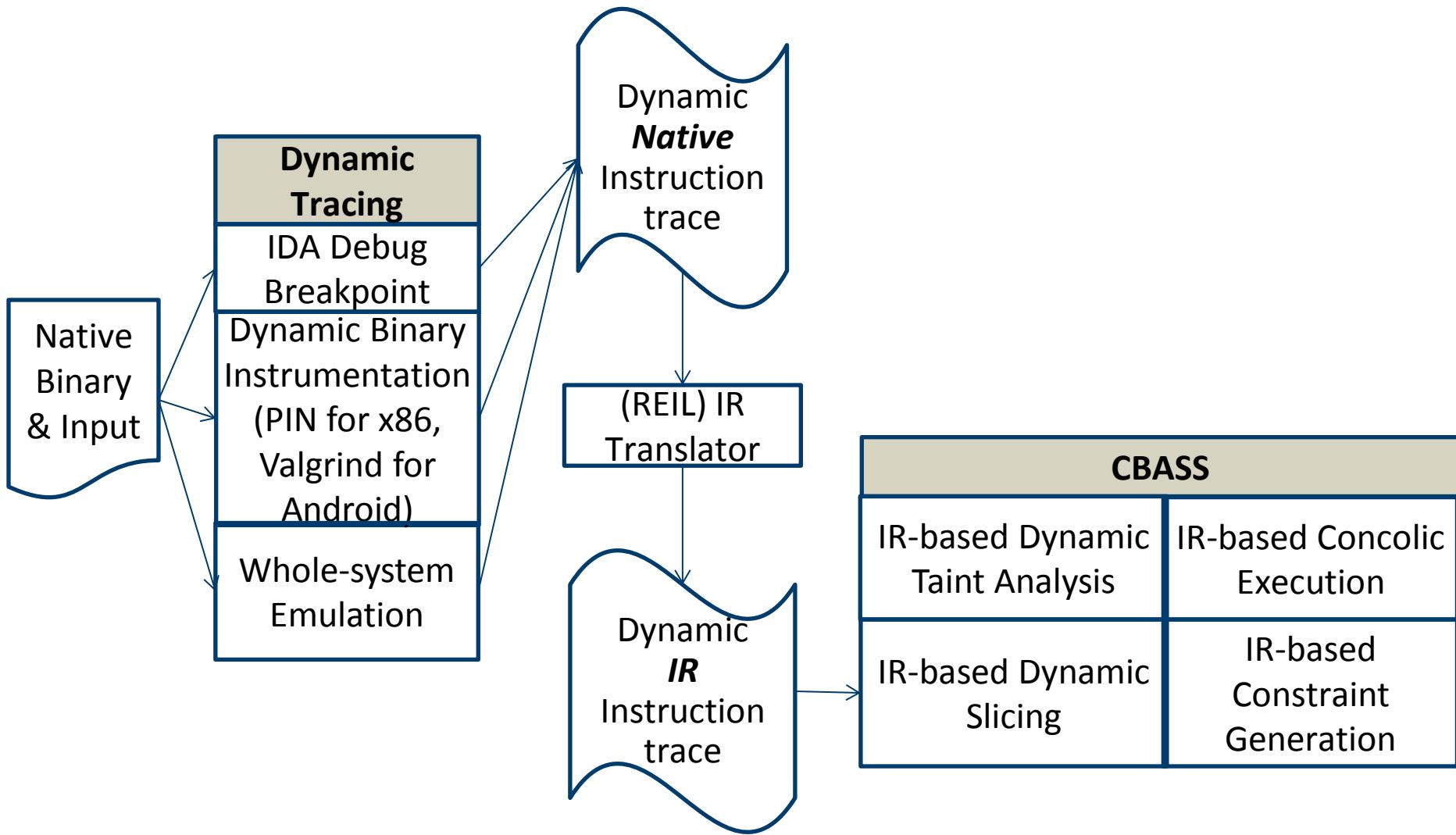
- Background
 - Dynamic analysis and symbolic analysis
 - Their success in vulnerability discovery
 - Challenges in exploitation research
 - Our analysis platform
 - Cross-platform trace generation

- Second Half

- **Supporting automated analysis**
 - CBASS (Cross-platform Symbolic-execution System)
 - Supporting interactive analysis
 - TREE (Taint-enabled Reverse Engineering Environment)
 - How does TREE and CBASS Interact

Architecture (ISA) Independent Concrete-Symbolic (Concolic) Execution

Cross-platform Tracing and IR-based Symbolic Execution Engine



Intermediate Representation

- Prerequisite:
 - Binary code stripped of symbols
- Requirements for IR:
 - Translators are already available for popular ISAs:
 - X86, ARM, PowerPC and MIPS
 - Representation is simple and low level
 - Easy mapping from native to IR instructions
 - Can leverage program state from native trace
 - The semantics of IR instructions amenable to symbolic analysis
- REIL (Reverse Engineering Intermediate Language)
 - http://www.zynamics.com/binnavi/manual/html/reil_language.htm

Reverse Engineering Intermediate Language (REIL) Instruction Set

Category	REIL Instruction	Semantics
Arithmetic	ADD s1, s2, d	$d = s1 + s2$
	SUB s1, s2, d	$d = s1 - s2$
	MUL s1, s2, d	$d = s1 * s2$
	DIV s1, s2, d	$d = s1 / s2$
	MOD s1, s2, d	$d = s1 \bmod s2$
	BSH s1, s2, d	if $s2 > 0$ $d = s1 * 2^{s2}$ else $d = s1 / 2^{-s2}$
Bitwise	AND s1, s2, d	$d = s1 \& s2$
	OR s1, s2, d	$d = s1 s2$
	XOR s1, s2, d	$d = s1 \text{ xor } s2$
Logical	BISZ s1, ℓ , d	if $s1 = 0$, $d = 1$ else $d = 0$
	JCC s1, ℓ , d	iff $s1 \neq 0$, set eip = d
Transfer	LDM s1, ℓ , d	$d = \text{mem}[s1]$
	STM s1, ℓ , d	$\text{mem}[d] = s1$
	STR s1, ℓ , d	$d = s1$
Other	NOP, ℓ , ℓ , ℓ	No op
	UNDEF ℓ , ℓ , d	Undefined instruction
	UNKN ℓ , ℓ , ℓ	Unknown instruction

Benefits of REIL: The Easy Mapping from Native Instructions to REIL IR

Original Native Address -> Shift 1 Byte to the Left + Offset -> REIL IR Address

REIL IR Address -> Shift 1 Byte to the Right -> Original Native Address

Native Instruction (x86)	REIL IR Instruction
00401073 movsx edx, byte ss:[eb 10]	40107300: add [DWORD FFFFFFF0, DWORD ebp, QWORD t0] 40107301: and [QWORD t0, DWORD FFFFFFFF, DWORD t1] 40107302: ldm [DWORD t1, EMPTY , BYTE t2] 40107303: xor [BYTE t2, BYTE 0x80, BYTE t3] 40107304: sub [BYTE t3, BYTE 0x80, DWORD t4] 40107305: and [DWORD t4, BYTE FFFFFFFF, BYTE t5] 40107306: str [DWORD t5, EMPTY , DWORD edx]

Benefits of REIL: (cont)

REIL makes native instruction side effects explicit

X86 Sub instruction semantics

Operation:

DEST <- DEST – SRC;

Description (from Intel Manual)

This instruction subtracts the second operand (source operand) from the first operand (destination operand) and stores the result in the destination operand. The destination operand can be a register or a memory location; the source operand can be an immediate, register, or memory location. (However, two memory operands cannot be used in one instruction.) When an immediate value is used as an operand, it is sign-extended to the length of the destination operand format.

The SUB instruction does not distinguish between signed or unsigned operands. Instead, the processor evaluates the result for both data types and sets the OF and CF flags to indicate a borrow in the signed or unsigned result, respectively. The SF flag indicates the sign of the signed result.

Native Instruction: sub esi, ss:[esp+12]

Translated to the following REIL IRs:

```
add [DWORD 12, DWORD esp, QWORD t0]
and [QWORD t0, DWORD 4294967295, DWORD t1]
ldm [DWORD t1, EMPTY , DWORD t2]
and [DWORD esi, DWORD 2147483648, DWORD t3]
and [DWORD t2, DWORD 2147483648, DWORD t4]
sub [DWORD esi, DWORD t2, QWORD t5]
and [QWORD t5, QWORD 2147483648, DWORD t6]
bsh [DWORD t6, DWORD -31, BYTE SF]
xor [DWORD t3, DWORD t4, DWORD t7]
xor [DWORD t3, DWORD t6, DWORD t8]
and [DWORD t7, DWORD t8, DWORD t9]
bsh [DWORD t9, DWORD -31, BYTE OF]
and [QWORD t5, QWORD 4294967296, QWORD t10]
bsh [QWORD t10, QWORD -32, BYTE CF]
and [QWORD t5, QWORD 4294967295, DWORD t11]
bisz [DWORD t11, EMPTY , BYTE ZF]
str [DWORD t11, EMPTY , DWORD esi]
```

Benefits of REIL: (cont)

REIL IR can enable static analysis on complex native instructions

MOVS/MOVSB/MOVSW/MOVSD—Move Data from String to String

REP/REPE/REPZ/REPNE/REPNZ—Repeat String Operation Prefix:

Operation

IF AddressSize = 16

THEN

 use CX for CountReg;

ELSE (* AddressSize = 32 *)

 use ECX for CountReg;

FI;

WHILE CountReg <> 0

DO

 service pending interrupts (if any);

 execute associated string instruction;

 CountReg <- CountReg – 1;

 IF CountReg = 0

 THEN exit WHILE loop

 FI;

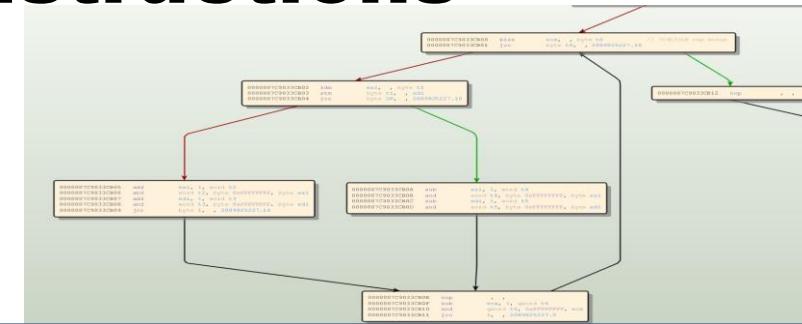
 IF (repeat prefix is REPZ or REPE) AND (ZF=0)

 OR (repeat prefix is REPNZ or REPNE) AND (ZF=1)

 THEN exit WHILE loop

 FI;

OD;



Native Instruction: 7c9033cb rep movsb IRs:

7C9033CB00: bisz [DWORD ecx, EMPTY , BYTE t0]

7C9033CB01: jcc [BYTE t0, EMPTY , ADDRESS 7C9033CB12]

7C9033CB02: ldm [DWORD esi, EMPTY , BYTE t1]

7C9033CB03: stm [BYTE t1, EMPTY , DWORD edi]

7C9033CB04: jcc [BYTE DF, EMPTY , ADDRESS 7C9033CB10]

7C9033CB05: add [DWORD esi, DWORD 1, WORD t2]

7C9033CB06: and [WORD t2, BYTE 4294967295, BYTE esi]

7C9033CB07: add [DWORD edi, DWORD 1, WORD t3]

7C9033CB08: and [WORD t3, BYTE 4294967295, BYTE edi]

7C9033CB09: jcc [BYTE 1, EMPTY , ADDRESS 7C9033CB0E]

7C9033CB0A: sub [DWORD esi, DWORD 1, WORD t4]

7C9033CB0B: and [WORD t4, BYTE 4294967295, BYTE esi]

7C9033CB0C: sub [DWORD edi, DWORD 1, WORD t5]

7C9033CB0D: and [WORD t5, BYTE 4294967295, BYTE edi]

7C9033CB0E: nop [EMPTY , EMPTY , EMPTY]

7C9033CB0F: sub [DWORD ecx, DWORD 1, QWORD t6]

7C9033CB10: and [QWORD t6, DWORD 4294967295, DWORD ecx]

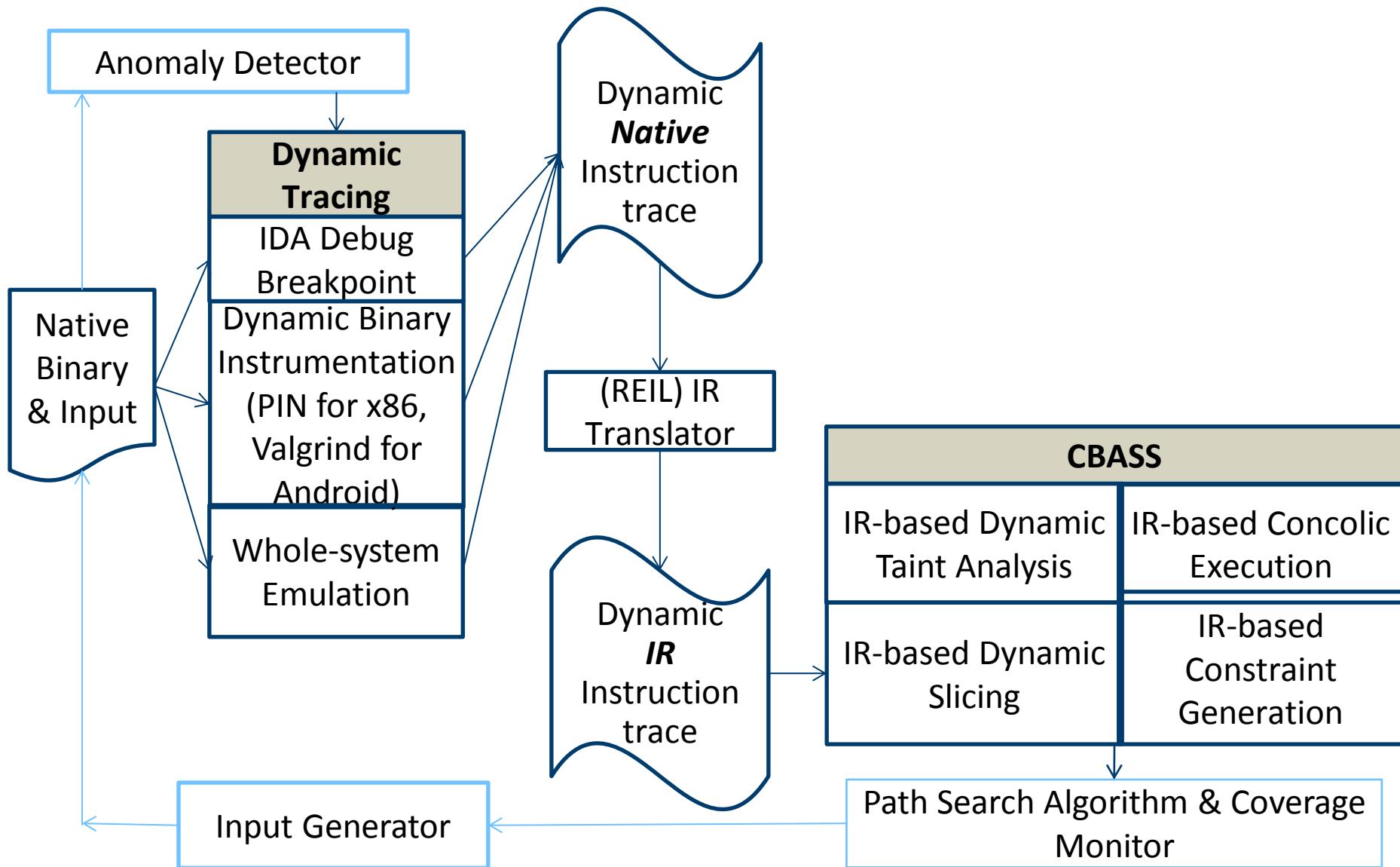
7C9033CB11: jcc [DWORD 1, EMPTY , ADDRESS 7C9033CB00]

7C9033CB12: nop [EMPTY , EMPTY , EMPTY]

Concolic Execution on REIL IR Using SMT Operations

Native Instructions	REIL Instructions	Symbolic Execution, with $\text{ebp} = 0x12ff84$ and $\text{mem}[12ff74] = \text{INPUT}$
00401073 movsx edx, byte ss:[ebp-10]	40107300: add [DWORD FFFFFFF0, DWORD ebp, QWORD t0]	$t0 = 0x12ff84 + 0xffffffff0 = 10012ff74$
	40107301: and [QWORD t0, DWORD FFFFFFFF, DWORD t1]	$t1 = t0 \text{ and } 0xffffffff = 0x12ff74$
	40107302: ldm [DWORD t1, EMPTY, BYTE t2]	$t2 = \text{mem}[t1] = \text{INPUT_VAR}[8]$
	40107303: xor [BYTE t2, BYTE 0x80, BYTE t3]	$t3 = \text{INPUT_VAR}[8] \text{ xor } 0x80$
	40107304: sub [BYTE t3, BYTE 0x80, DWORD t4]	$t4 = (\text{INPUT_VAR}[8] \text{ xor } 0x80) - 0x80$
	40107305: and [DWORD t4, BYTE FFFFFFFF, BYTE t5]	$t5 = (((\text{INPUT_VAR}[8] \text{ xor } 0x80) - 0x80) \text{ and } 0xffffffff)$
00401077 cmp edx, 0x62	40107700: and [DWORD edx, DWORD 0x80000000, DWORD t0]	$t0 = (((\text{INPUT_VAR}[8] \text{ xor } 0x80) - 0x80) \text{ and } 0xffffffff) \text{ and } 0x80000000$
	40107701: and [DWORD 98, DWORD 0x80000000, DWORD t1]	$t1 = 98 \text{ and } 0x80000000 = 98$
	40107702: sub [DWORD edx, DWORD 98, QWORD t2]	$t2 = (((\text{INPUT_VAR}[8] \text{ xor } 0x80) - 0x80) \text{ and } 0xffffffff) - 98$
	Ignore irrelevant temps
	4010770B: and [QWORD t2, QWORD FFFFFFFF, DWORD t8]	$t8 = (((((\text{INPUT_VAR}[8] \text{ xor } 0x80) - 0x80) \text{ and } 0xffffffff) - 98) \text{ and } 0xffffffff)$
	4010770C: bisz [DWORD t8, EMPTY, BYTE ZF]	$ZF = \text{ite}(t8 == 0, 1, 0)$
0040107a jnz loc_40108e	40107A00: bisz [BYTE ZF, EMPTY, BYTE t0]	$t0 = \text{ite}(ZF == 0, 1, 0)$
	40107A01: jcc [BYTE t0, EMPTY, DWORD 0x40108e]	$eip = \text{ite}(t0 == 1, 0x40108e, 0x40107c)$

Integrate Automated and Interactive Analysis System around CBASS



CBASS Supports Automated Symbolic Path Exploration (White-box Fuzzing)

cbass_automated_fuzz

Steps:

1. Generate IDB file with IDA Pro
2. Import IDB file into BinNavi
3. Generate a 'good' trace with Pin
4. Find the 'bad' path with CBASS

Finding the 'bad' path

```
graph TD; b((b?)) -- F --> a1((a?)); b -- T --> a2((a?)); a1 -- F --> d1((d?)); a1 -- T --> d2((d?)); d1 -- F --> l1((l?)); d1 -- T --> l2((l?)); d2 -- F --> l3((l?)); d2 -- T --> l4((l?)); d3 -- F --> l5((l?)); d3 -- T --> l6((l?)); d4 -- F --> l7((l?)); d4 -- T --> l8((l?)); l1 --> good[good]; l2 --> bad[bad?]
```

03:16

Key Steps of Automated Symbolic Path Exploration (White-box Fuzzing)

Symbolize concrete input

Find all path conditions

And their prefixes

```
Symbolic execution on trace file .\badcondov_good.pin...
Concrete input received at 0x12ff6c for 16 bytes:goodbetterbest?!
0: Current branch condition is False:
52:ITE[8]
  0:NE[32]
    58:ITE[32]
      0:NE[64]
        58:BU_AND[64]
          EXTRACT[0, 63]
          0:SUB[64]
          SX[64]
        52:BU_AND[32]
          EXTRACT[0, 31]
          0:SUB[32]
          SX[32]
        57:BU_XOR[8]
        57:INPUT_VAR[8]: IN_0x12ff6c_0x0_SEQ0
        128
4294967168
4294967295
98
  0
    0:_CONST[32]: 0x1
    BU_CONST[32]: 0x0
    BU_CONST[8]: 0x1
    _CONST[8]: 0x0

1: Current branch condition is False:
62:ITE[8]
  0:NE[32]
    61:ITE[32]
      0:NE[64]
        61:BU_AND[64]
          EXTRACT[0, 63]
          0:SUB[64]
          SX[64]
        60:BU_AND[32]
          EXTRACT[0, 31]
          0:SUB[32]
          SX[32]
        60:BU_XOR[8]
        60:INPUT_VAR[8]: IN_0x12ff6c_0x1_SEQ0
        128
4294967168
4294967295
```

Key Steps of Automated Symbolic Path Exploration (White-box Fuzzing)

3

Path Conditions:

(path_condition0.smt2==False)->(path_condition1.smt2==False)->(path_condition2.smt2==True)->(path_condition3.smt2==True)

Solve constraints and get new input assignments:

((_IN_0x12ff6c_0x2_SEQ0 #x64))
((_IN_0x12ff6c_0x3_SEQ0 #x21))

Search paths and solve their path conditions for required inputs

4

Path Conditions:

(path_condition0.smt2==False)->(path_condition1.smt2==True)->(path_condition2.smt2==False)->(path_condition3.smt2==False)

16 path conditions solved

Solve constraints and get new input assignments:

Automated White-box Fuzzing with CBASS

Demo

Outline

- First Half

- Background
 - Dynamic analysis and symbolic analysis
 - Their success in vulnerability discovery
 - Challenges in exploitation research
 - Our analysis platform
 - Cross-platform trace generation

- Second Half

- Supporting automated analysis
 - CBASS (Cross-platform Symbolic-execution System)
 - **Supporting interactive analysis**
 - TREE (Taint-enabled Reverse Engineering Environment)
 - How does TREE and CBASS Interact

Gaps between Research and Analysis

Snapshot of A Popular Security Forum

The screenshot shows the top navigation bar of a phpBB forum. On the left is the phpBB logo with the tagline "creating communities". To its right is the forum's name, "KernelMode.info", followed by the subtitle "A forum for kernel-mode exploration." Below the header is a breadcrumb navigation bar showing the path: "Board index < Forums < Tools/Software".

Taint tool

[POSTREPLY ↵](#)



Search this topic...

[Search](#)

Taint tool

by **p4r4n0id** » Sat Jul 07, 2012 8:13 am

Hi Guys,

Do you know any good windows tainting tools?

Thx,

p4r4n0id

Keep Low. Move Fast. Kill First. Die Last. One Shot. One Kill. No Luck. Pure Skill.
<http://p4r4n0id.com/>

Status Quo: advanced analysis tools are not available to engineers

Re: Taint tool

by [kareldjag/michk](#) » Sun Jul 08, 2012 2:24 pm

hi

Unfortunately most tools available are for Linux or Mac; others are Private.

You can find an overview of these tools in this .pdf paper

<http://code.google.com/p/tanalysis/downloads/list>

rgds

Security? Yeah But Well: <http://www.ouaismaisbon.ch/>)

Re: Taint tool

by [Cr4sh](#) » Sun Jul 08, 2012 7:42 pm

Unfotunately, powerful and friendly (for integration with the 3-rd party code analysis software) taint analysis tools are not available for public

Few weeks ago I tried to contact with the autors of dytan framework (to ask for binaries or source code), but got no answer.

Last edited by [Cr4sh](#) on Sun Jul 08, 2012 7:46 pm, edited 1 time in total.

<http://blog.cr4.sh/>

Real World Demands TREE:

Re: Taint tool

by p4r4n0id × Sat Jul 27, 2013 6:46 am

Taint-enabled Reverse Engineering Environment (TREE)

<https://code.google.com/p/tree-cbass/>

Keep Low. Move Fast. Kill First. Die Last. One Shot. One Kill. No Luck. Pure Skill.

<http://p4r4n0id.com/>

Interactive Binary Analysis

- Automated binary analyses useful for certain tasks (e.g., finding crashes)
- Many binary analyses can't be automated
- Expert experience and heuristics are still **key** to binary analyses

Interactive Analysis – A Reverse Engineer’s Workflow

- A reverse engineer’s work is an incremental and iterative process, rather than a straight one
- “An Exploratory Study of Software Reverse Engineering in a Security Context”
 - Binary analysis is at the heart of the project
 - Most of the reverse engineering work is performed using IDA Pro
 - Challenges include complexity and the need to track different levels of details

An Interactive Analysis Process

- Step 1:

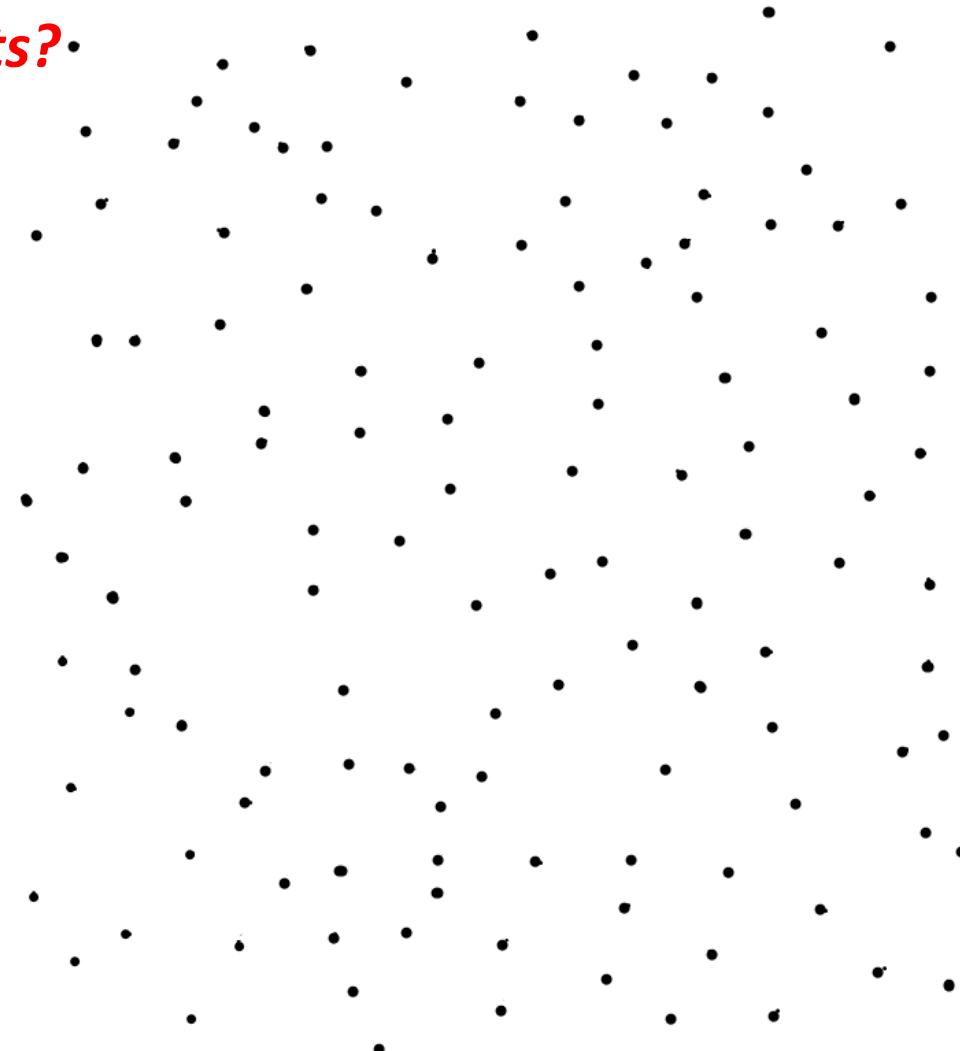
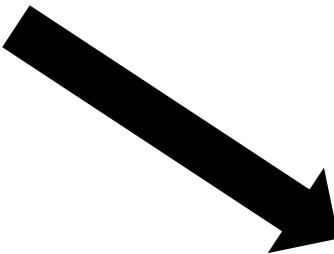
Start from unknown: not sure what you are looking for and what you will find
- Step 2:

What -if: make a series of hypothesis, prove or disprove them
- Step 3:

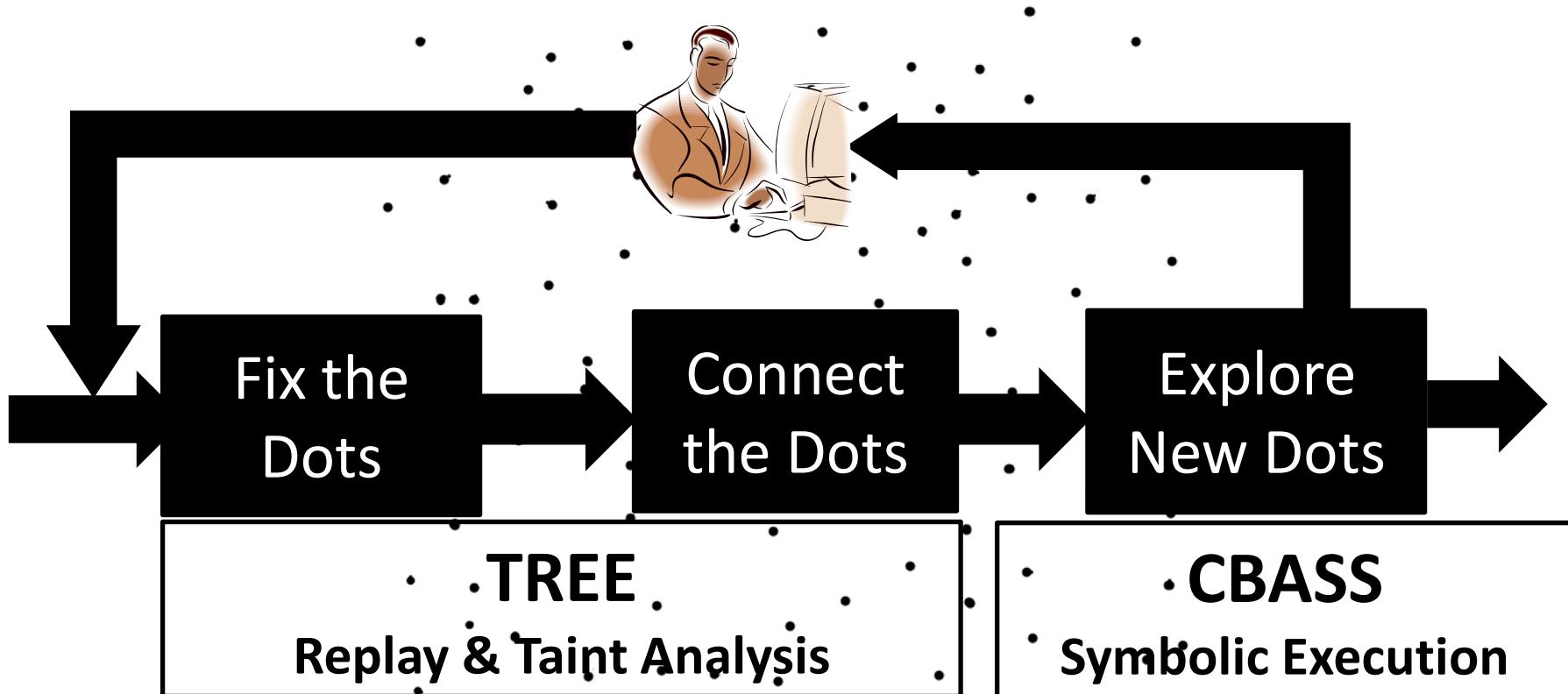
Create new hypothesis based on what you have found, if Satisfied or Exhausted Quit
Else go back to Step 2

Interactive Analysis is Like Connecting Dots

What's in the dots?



Our Tools are Designed to Help Interactive Analysis



Tainted-enabled Reverse Engineering Environment *Cross-platform Binary Automated Symbolic execution System*

Our Tools Support

Fixing the Dots (TREE)

Fix the Dots

- Reverse engineers don't like moving dots
- Why do the dots move?
 - Concurrency (multi-thread/multi-core) brings non-deterministic behavior
- Even for deterministic behavior, reverse engineer needs to analyze the internals repeatedly
 - ASLR guarantees nothing internally will be the same

Fix the Dots

- How does TREE work?
 - Generates the trace at runtime
 - Replays it offline
- TREE trace
 - Captures program state = {Instruction, Thread, Register, Memory}
 - Fully automated generation
- TREE can collect traces from multiple platforms
 - Windows/Linux/Mac OS User/Kernel and real devices (Android/ARM, Cisco routers/MIPS, PowePC)

TREE Taint-based Replay vs. Debug-based Replay

- Debug-replay lets **you connect the dots**
 - Single step, stop at function boundary, Breakpoint
- TREE replay **connects dots for you**
 - Deterministic replay with taint-point break

Our Tools Support

Connecting the Dots (TREE)

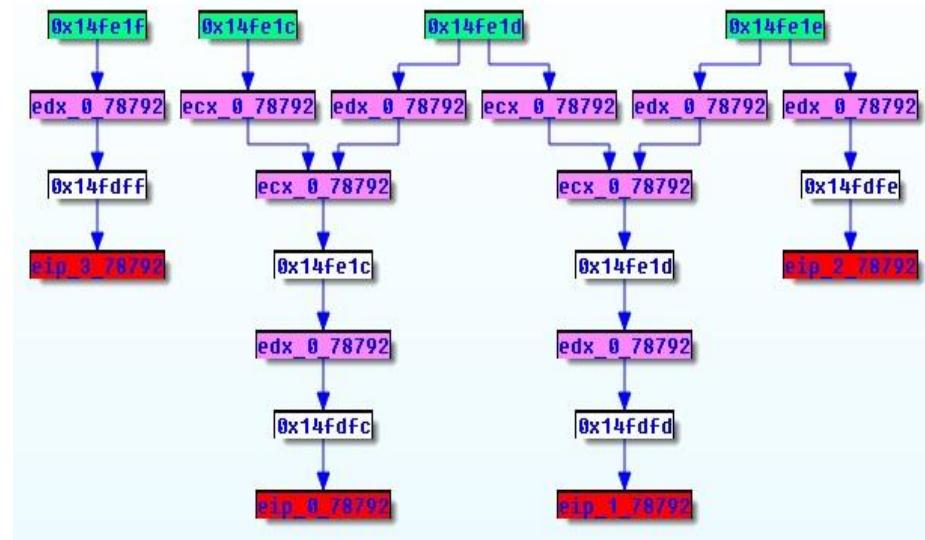
Why connecting the dots?

- Vulnerability root cause needs to determine *precisely* what original, like input, byte (s) impact security target(s) later, and how
- A little enhanced running example:

```
//INPUT
DWORD dwBytesRead;
ReadFile(hFile, sBigBuf, 16, &dwBytesRead, NULL);

//INPUT TRANSFORMATION
for(int i=0; i< (dwBytesRead-2); i++)
    sBigBuf[i] +=sBigBuf[i+1];

//PATH CONDITION
If(sBigBuf[0]==‘b’)
//Vulnerable Function
StackOverflow(sBigBuf,dwBytesRead);
```



Connecting Dots is Hard

- Basic elements are complex in real programs
 - Code size can be thousands (++) of lines
 - Inputs can come from many places
 - Transformations can be lengthy
 - Paths grow exponentially
- Basic elements are likely separated by millions of instructions, spatially and temporally
- Multiple protections built in

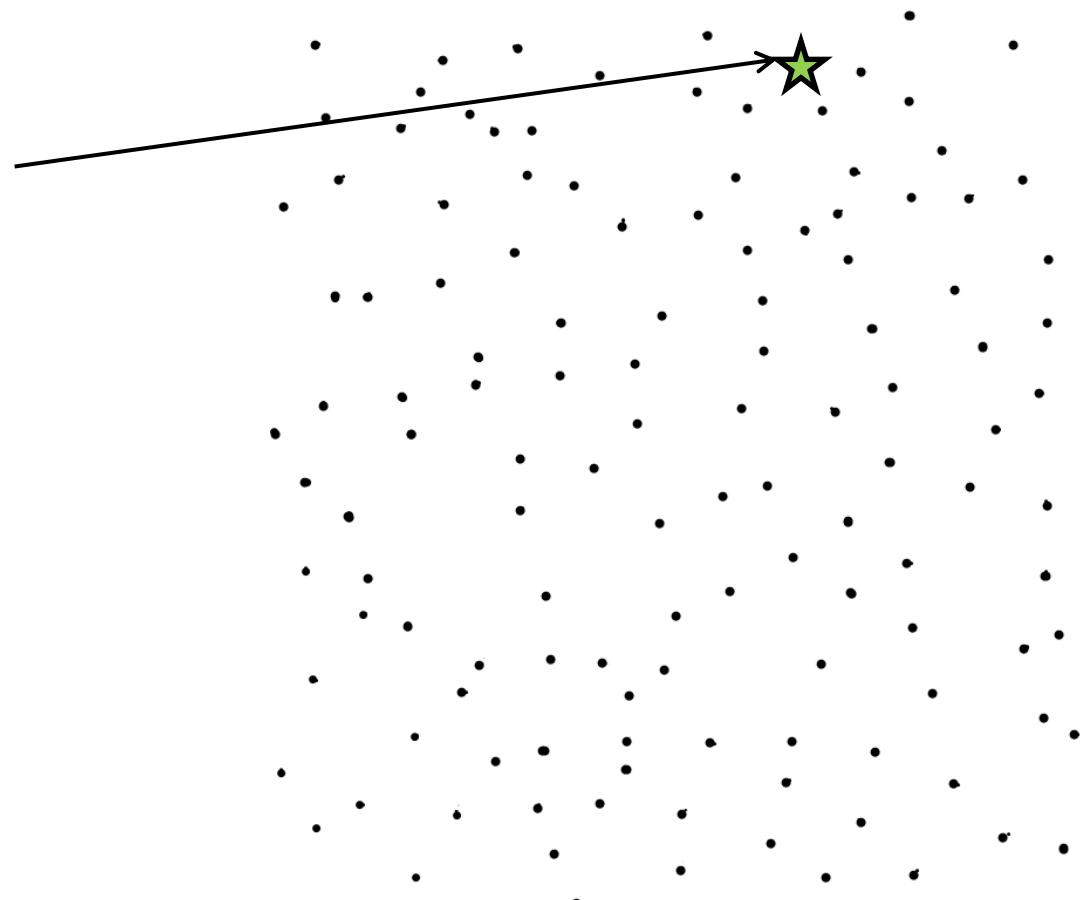
Techniques Help Connect the Dots

- Dynamic Taint Analysis
 - Basic Definitions
 - Taint source
 - Taint Sink:
 - Taint Policy:
- Taint-based Dynamic Slicing
 - Taint focused on data
 - Slicing focused on relevant instructions and sequences

Connect the Dots

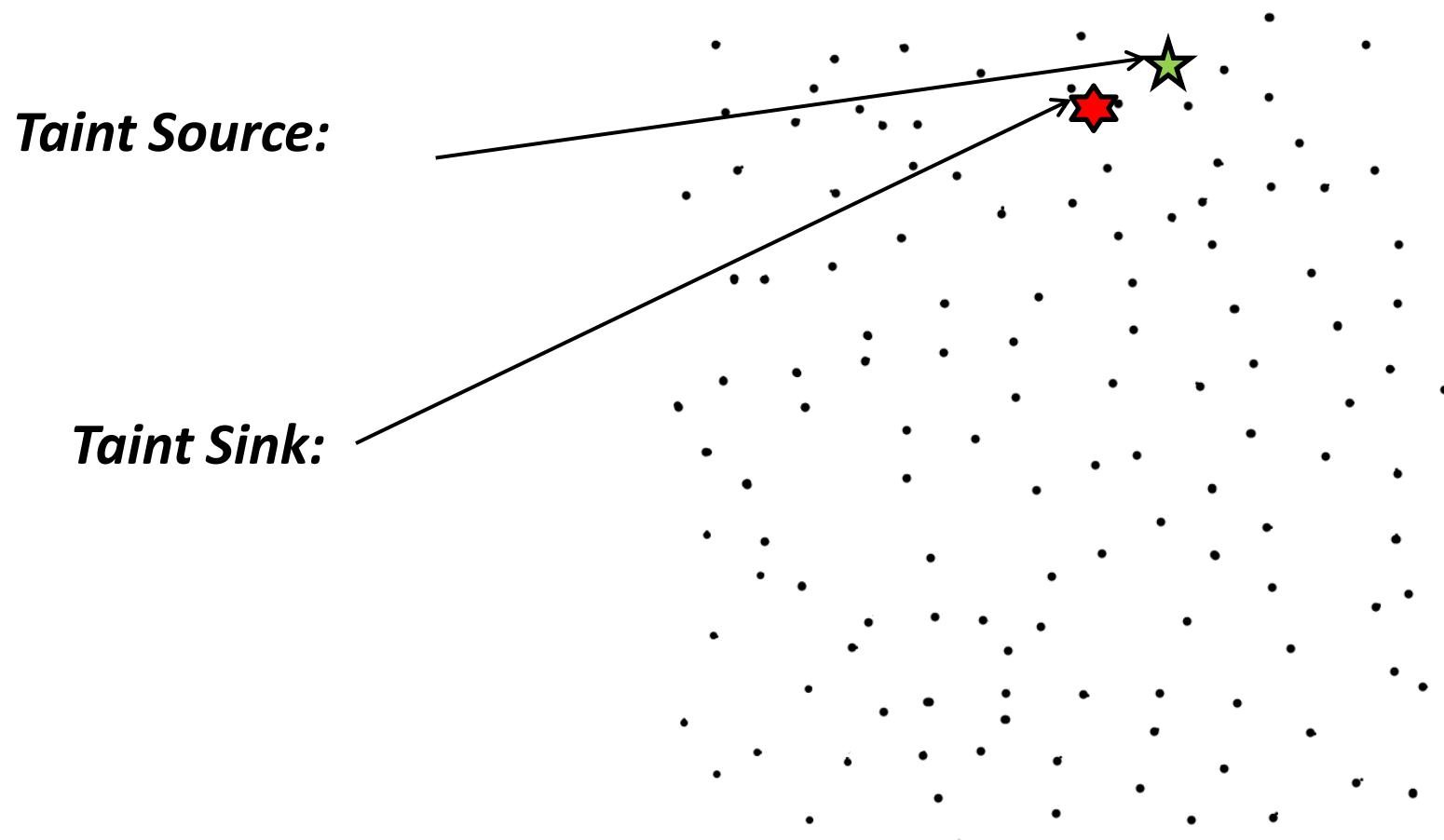
- TREE connects dots -- using taint analysis

Taint Source:



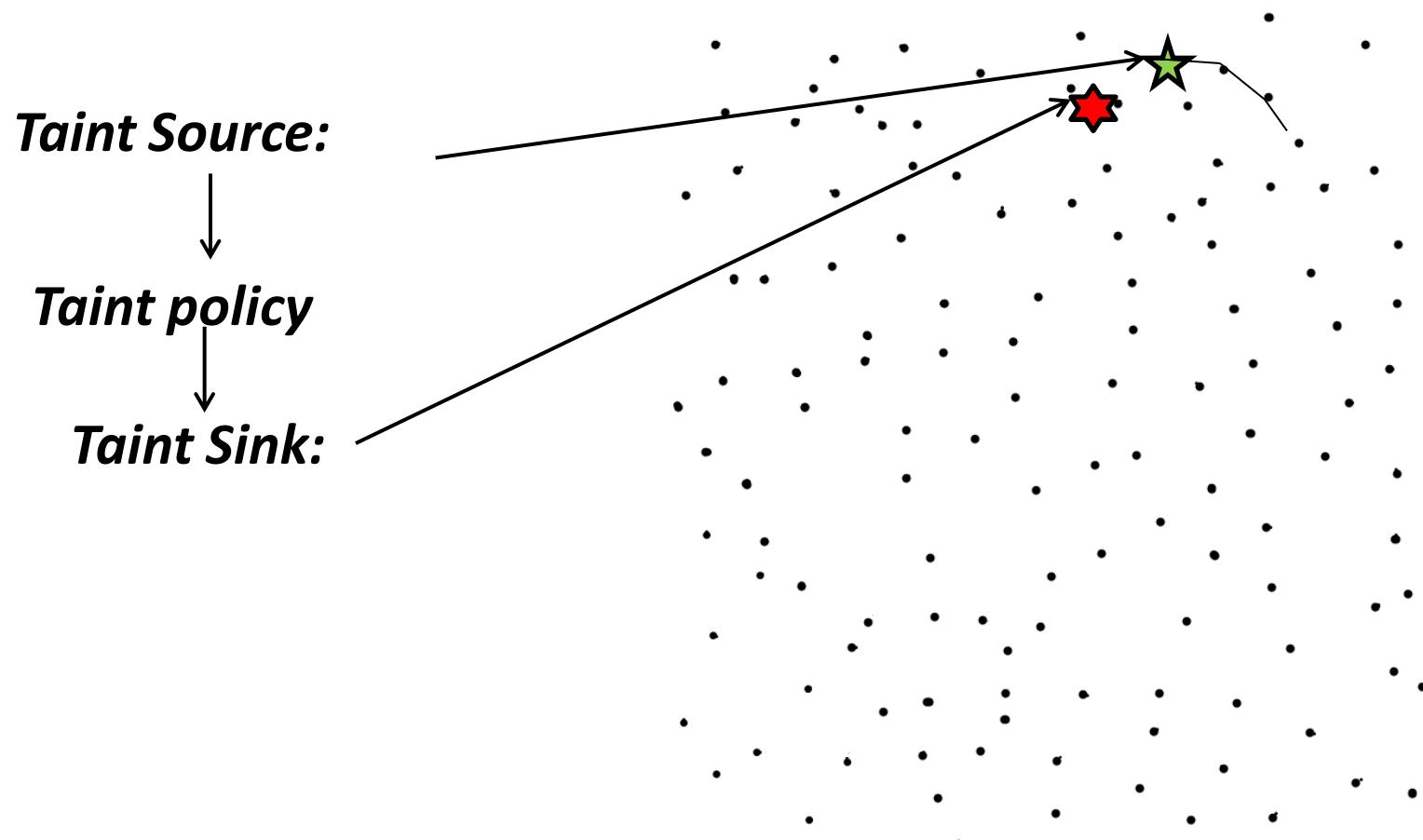
Connect the Dots

- TREE connects dots -- using taint analysis



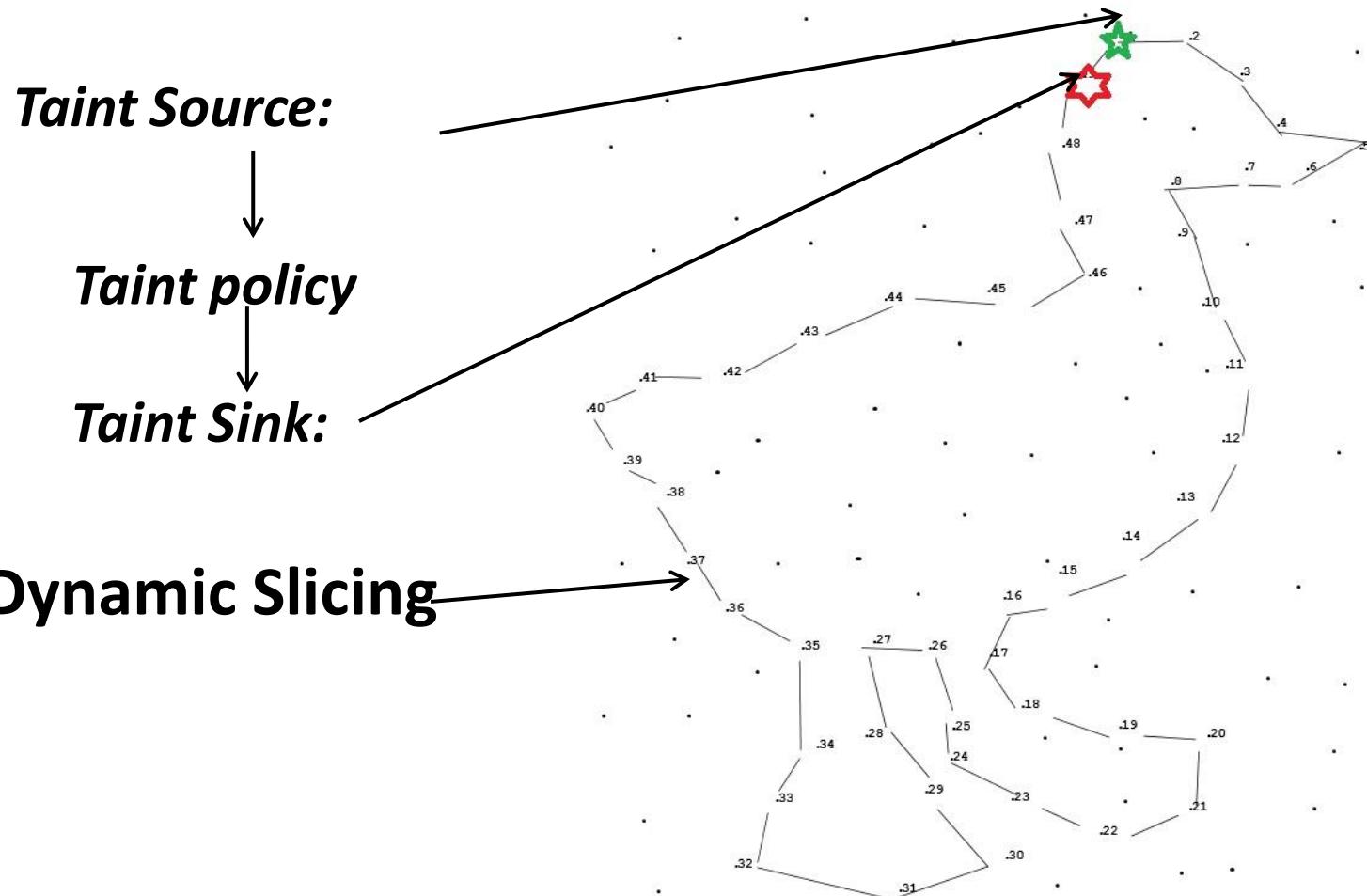
Connect the Dots

- TREE connects dots -- using taint analysis



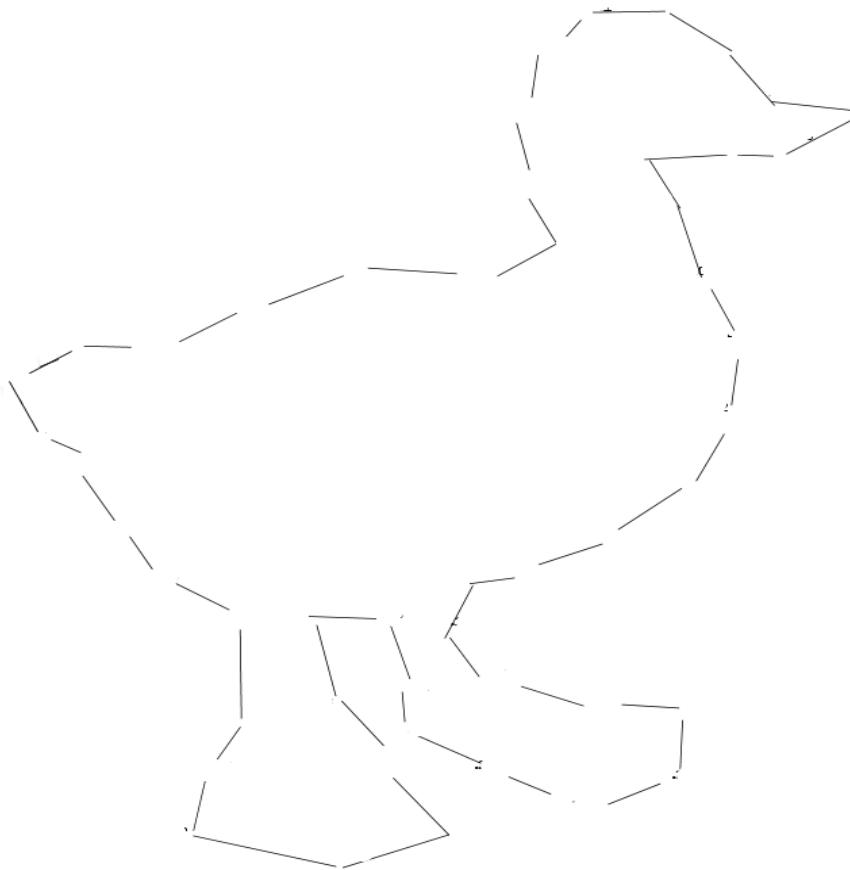
Connect the Dots

- TREE connects dots -- using taint analysis



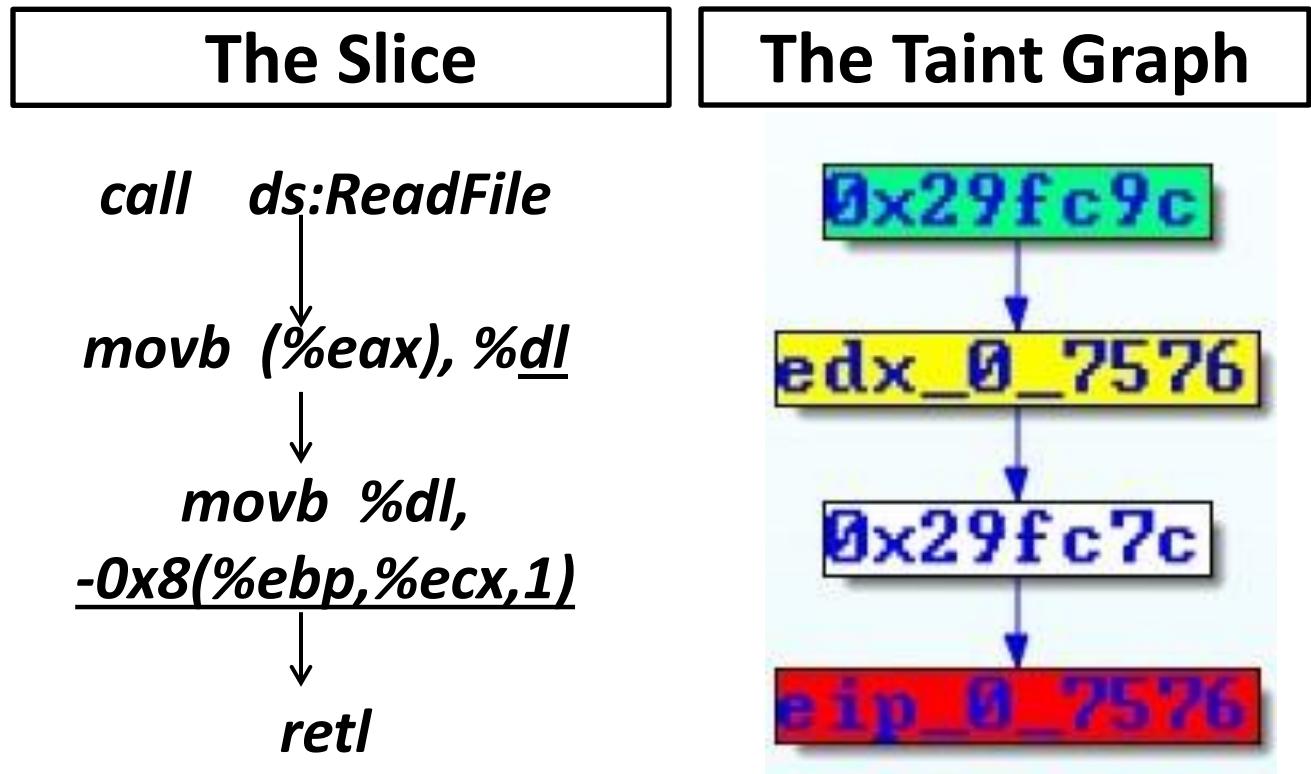
Find the Dots and Slice that Matter

In practice, most dots don't matter –
eliminate them quickly to focus on what
matters



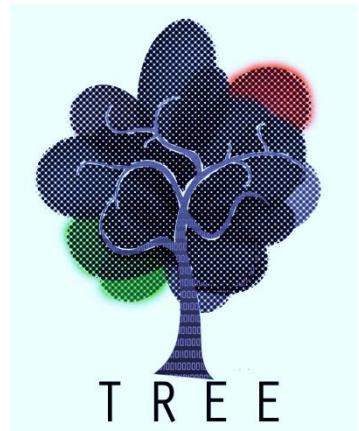
Connecting Dots in Running Example

Taint Source:
(Input)
↓
Taint policy
(Data)
↓
Taint Sink: eip



What You Connect is What You Get

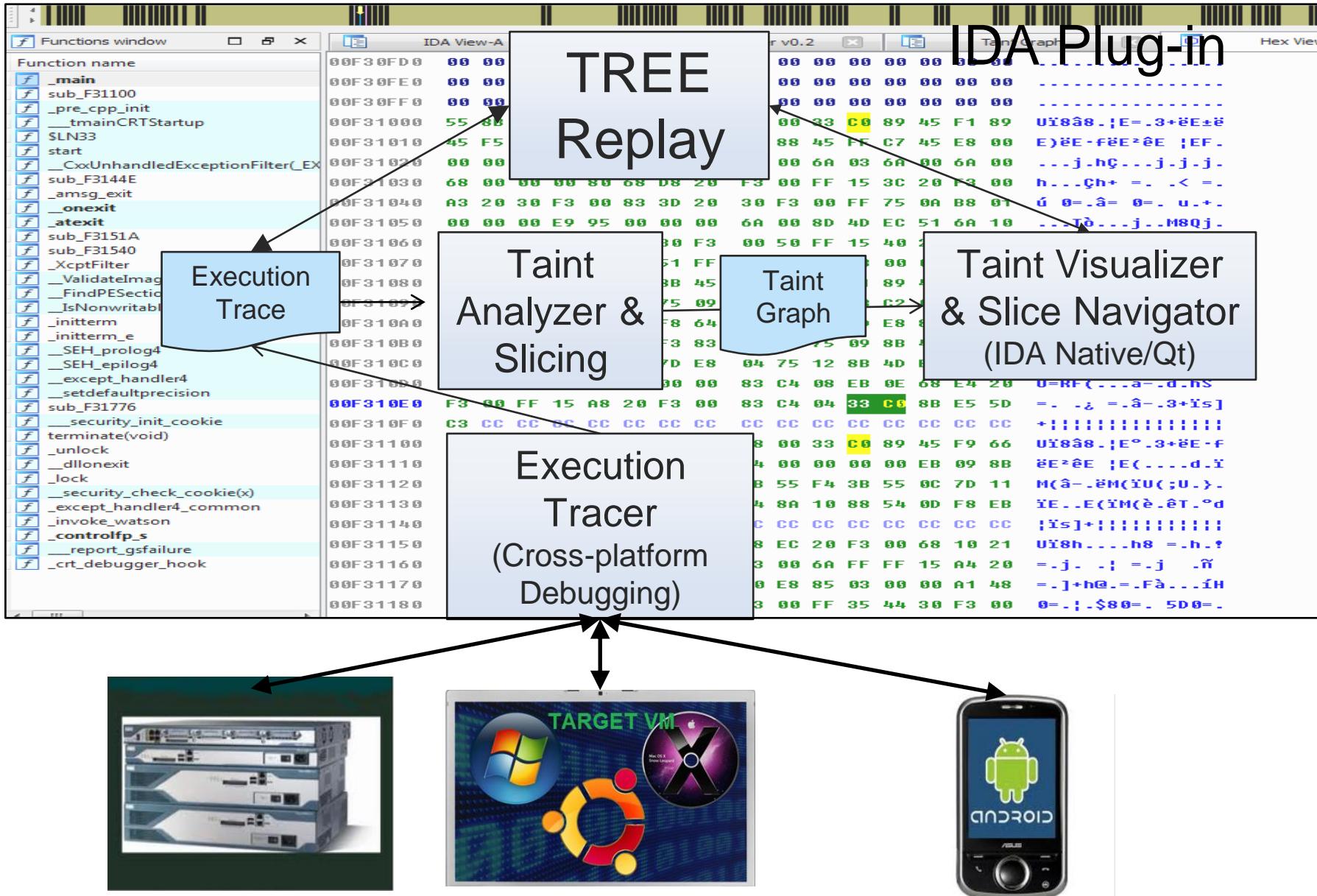
- **ABCD** – Connect Dots in different ways
 - Address dependency
 - Branch conditions
 - Counter (Loop)
 - Data dependency
- Each dependency (taint policy) has different security implications



TREE

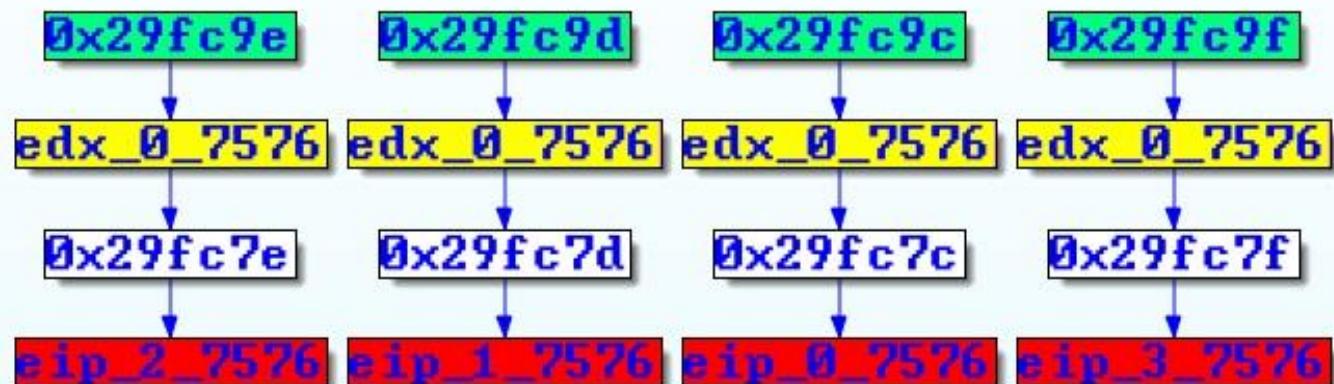
***TAINT-ENABLED
REVERSE ENGINEERING ENVIRONMENT***

TREE Key Components



TREE: The Front-end of Our Interactive Analysis System

Taint
Graph



TREE: The Front-end of Our Interactive Analysis System

Taint
Table

UUID	Type	Name	Start Sequence	End Sequence	Formation Instr	Child C	Child D
60	register	eip_3_14876	0x11c		retl		52
59	register	eip_2_14876	0x11c		retl		50
58	register	eip_1_14876	0x11c		retl		48
57	register	eip_0_14876	0x11c		retl		46
52	memory	0x38f79b	0x112		movb %dl, -...		51
51	register	edx_0_14876	0x111	0x117	movb (%eax), %dl		16
50	memory	0x38f79a	0x106		movb %dl, -...		49
49	register	edx_0_14876	0x105	0x10b	movb (%eax)...		15
48	memory	0x38f799	0xfa		movb %dl, -...		47
47	register	edx_0_14876	0xf9	0xff	movb (%eax)...		14
46	memory	0x38f798	0xee		movb %dl, -0x8(%ebp, %...		45
45	register	edx_0_14876	0xed	0xf3	movb (%eax), %dl		13
16	input	0x38f7bb	0x0		0x12f106a		

TREE: The Front-end of Our Interactive Analysis System

Execution Trace Table

Instruction Address	Disassembly		Registers	Memory Access
270 0x12f1130	mov	eax, [ebp+arg_0]	eax=0x38f7ba ebp=0x38f794	R 4 0x38f79c
271 0x12f1133	add	eax, [ebp+var_C]	eax=0x38f7ac ebp=0x38f794 eflags=0x287	R 4 0x38f788
272 0x12f1136	mov	ecx, [ebp+var_C]	ebp=0x38f794 ecx=0xf	R 4 0x38f788
273 0x12f1139	mov	dl, [eax]	eax=0x38f7bb dl=0xf	R 1 0x38f7bb
274 0x12f113b	mov	[ebp+ecx+var_8], dl	dl=0x68 ebp=0x38f794 ecx=0xf	W 1 0x38f79b
275 0x12f113f	jmp	short loc_12F111F	eip=0x12f113f	
276 0x12f111f	mov	ecx, [ebp+var_C]	ebp=0x38f794 ecx=0xf	R 4 0x38f788
277 0x12f1122	add	ecx, 1	eflags=0x216 ecx=0xf	
278 0x12f1125	mov	[ebp+var_C], ecx	ebp=0x38f794 ecx=0x10	W 4 0x38f788

TREE: The Front-end of Our Interactive Analysis System

Stack View	Register View	Memory View
0038F758	0C 3F 7D 77 2C 85 4A 74 84 03 2F 0	
0038F768	00 00 00 00 F0 53 7D 77 5C F7 38 0	
0038F778	F0 F7 38 00 23 41 87 77 B4 4D 0F 0	
0038F788	0C 3F 7D 77 70 10 2F 01 5C 00 00 0	
0038F798	10 00 00 00 A8 F7 38 00 00 00 00 0	
0038F7A8	10 00 00 00 62 61 64 21 62 65 74 7	
0038F7B8	73 74 74 68 00 F8 38 00 E1 12 2F 0	
0038F7C8	A0 1B 45 00 38 20 45 00 40 EA 7A 7	
0038F7D8	00 00 00 00 00 E0 FD 7E 00 00 00 0	
0038F7E8	D0 F7 38 00 B2 3E 7E 4A 3C F8 38 0	

UNKNOWN|0038F798: Stack[00003A1C]:0038F798

◀ III ▶

Register/stack/
memory
Views

TREE: The Front-end of Our Interactive Analysis System

Replay is focal point of user interaction

The screenshot displays the TREE interface, which includes several panes:

- Top Bar:** Contains checkboxes for "Replayer" and "Taint Analysis", along with various icons for file operations.
- Taint Graph:** A central pane showing a flowchart of tainted data. It starts with four memory locations at the top: `0x38f7ba`, `0x38f7b9`, `0x38f7b8`, and `0x38f7bb`. Arrows point from each of these to a corresponding `edx_0_14876` register below. These registers then point to four memory locations: `0x38f79a`, `0x38f799`, `0x38f798`, and `0x38f79b`. Finally, arrows point from these memory locations to four `eip_x_14876` registers at the bottom.
- Table View:** A table on the right side listing taint information. The columns are: UUID, Type, Name, Start Sequence, End Sequence, Information Instr, Child C, and Child D. The table shows multiple rows of data, with the 48th row highlighted in blue.
- Assembly View:** A bottom-left pane showing assembly code with addresses from `0038F758` to `0038F7E8`. The 274th instruction is highlighted in blue.
- Memory View:** A bottom-right pane showing memory dump details for the highlighted instruction at address `0x12f113b`.

Tree Demo

Using TREE to Analyze a Crash

Outline

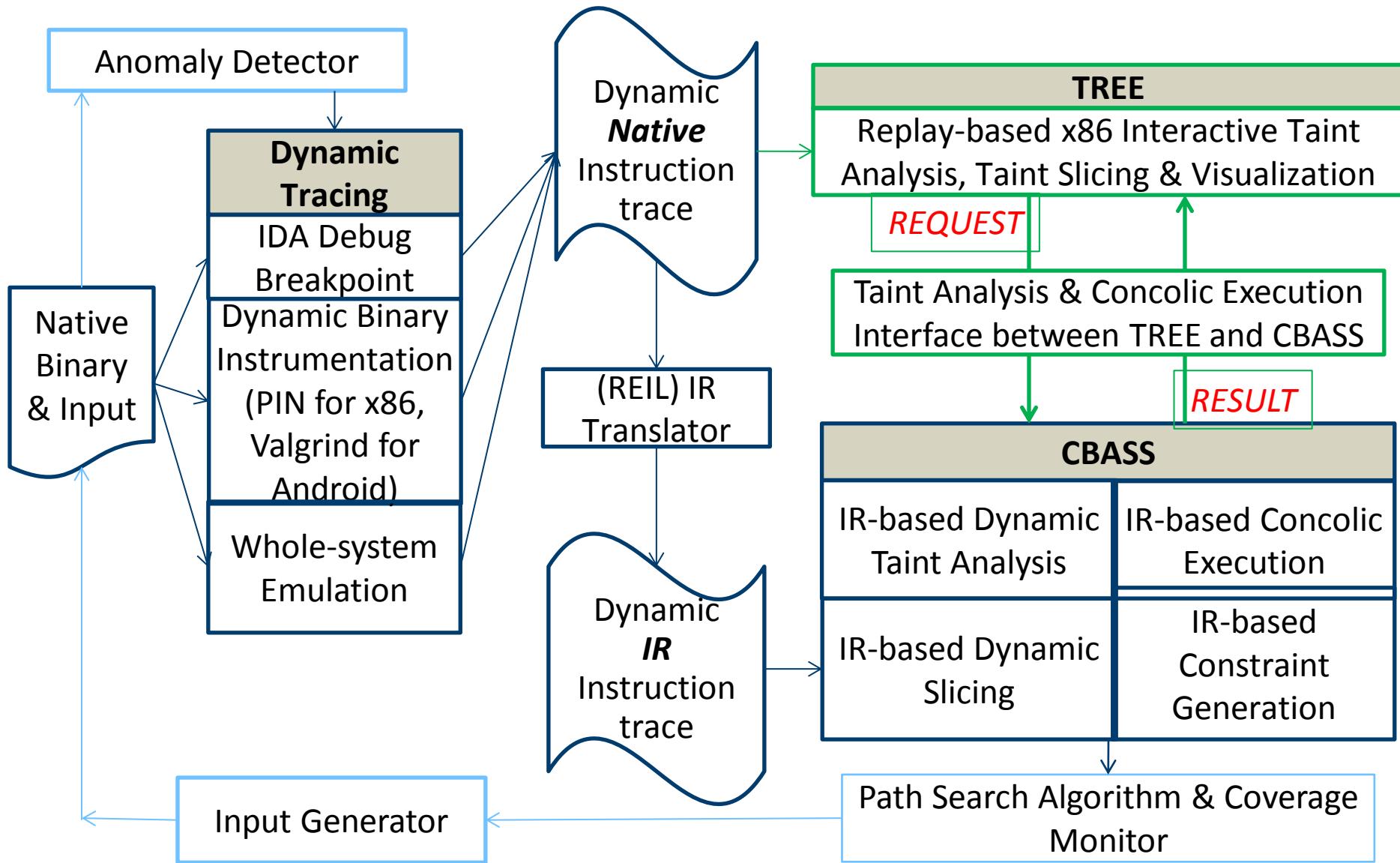
- First Half

- Background
 - Dynamic analysis and symbolic analysis
 - Their success in vulnerability discovery
 - Challenges in exploitation research
- Our analysis platform
 - Cross-platform trace generation

- Second Half

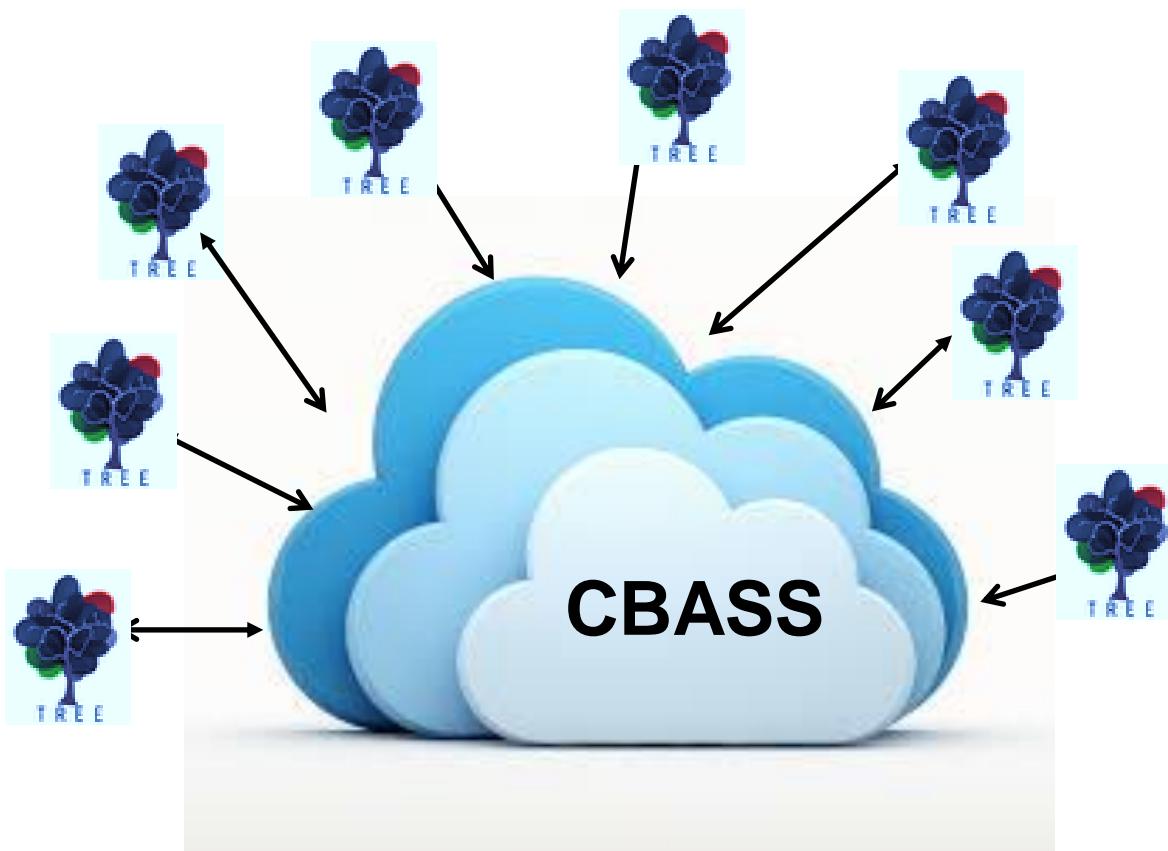
- Supporting automated analysis
 - CBASS (Cross-platform Symbolic-execution System)
- Supporting interactive analysis
 - TREE (Taint-enabled Reverse Engineering Environment)
- **How does TREE and CBASS Interact**

Integrate Automated and Interactive Analysis System around CBASS

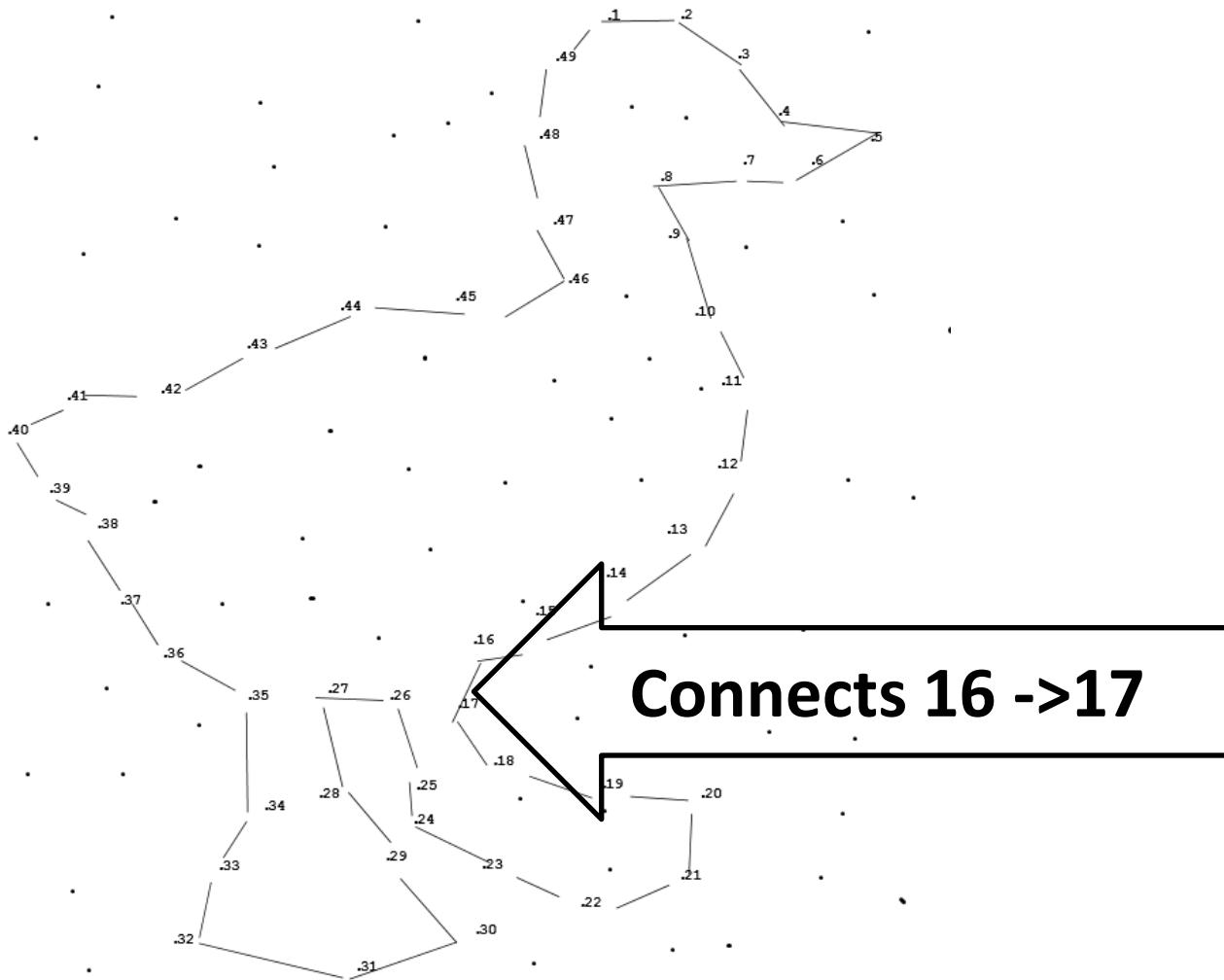


TREE and CBASS in the Future:

- Users use TREE to access service
- CBASS runs in parallel and can be deployed in Cloud

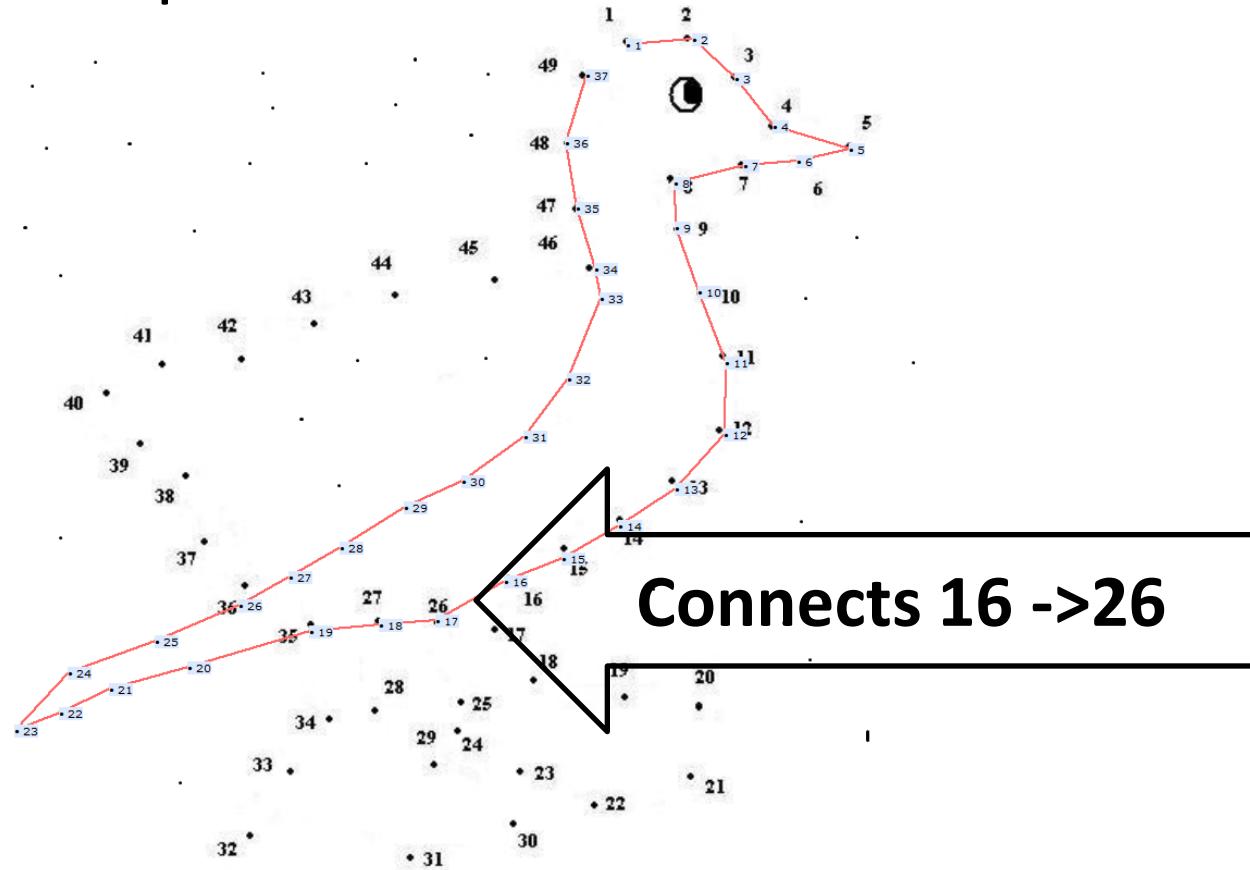


A Key Branch Point for a Duck



The Path for a ...

- Reverse engineers don't just connect dots; they want to explore new dots:



Explore New Dots

- How do you force the program to take a different path to lead to “bad!”?

```
//INPUT  
ReadFile(hFile, sBigBuf, 16, &dwBytesRead, NULL);  
.....  
//PATH CONDITION  
if(sBigBuf[0]=='b') iCount++;  
if(sBigBuf[1]=='a') iCount++;  
if(sBigBuf[2]=='d') iCount++;  
if(sBigBuf[3]=='!') iCount++;  
if(iCount==4) // "bad!" path  
    StackOverflow(sBigBuf,dwBytesRead) ?  
Else // "Good" path  
    printf("Good!");
```

Explore New Dots

- User wants execution to take different path at a branch point Y – what input will make that happen?

User:

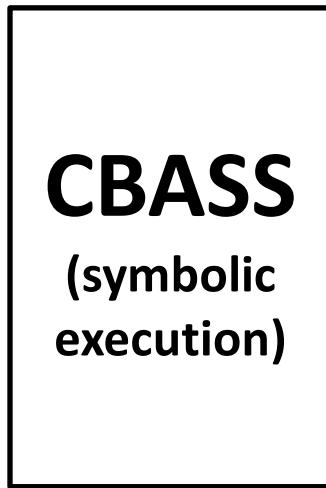
*How to execute
different path
at branch Y?*

TREE: Input
[0] must be 'b'

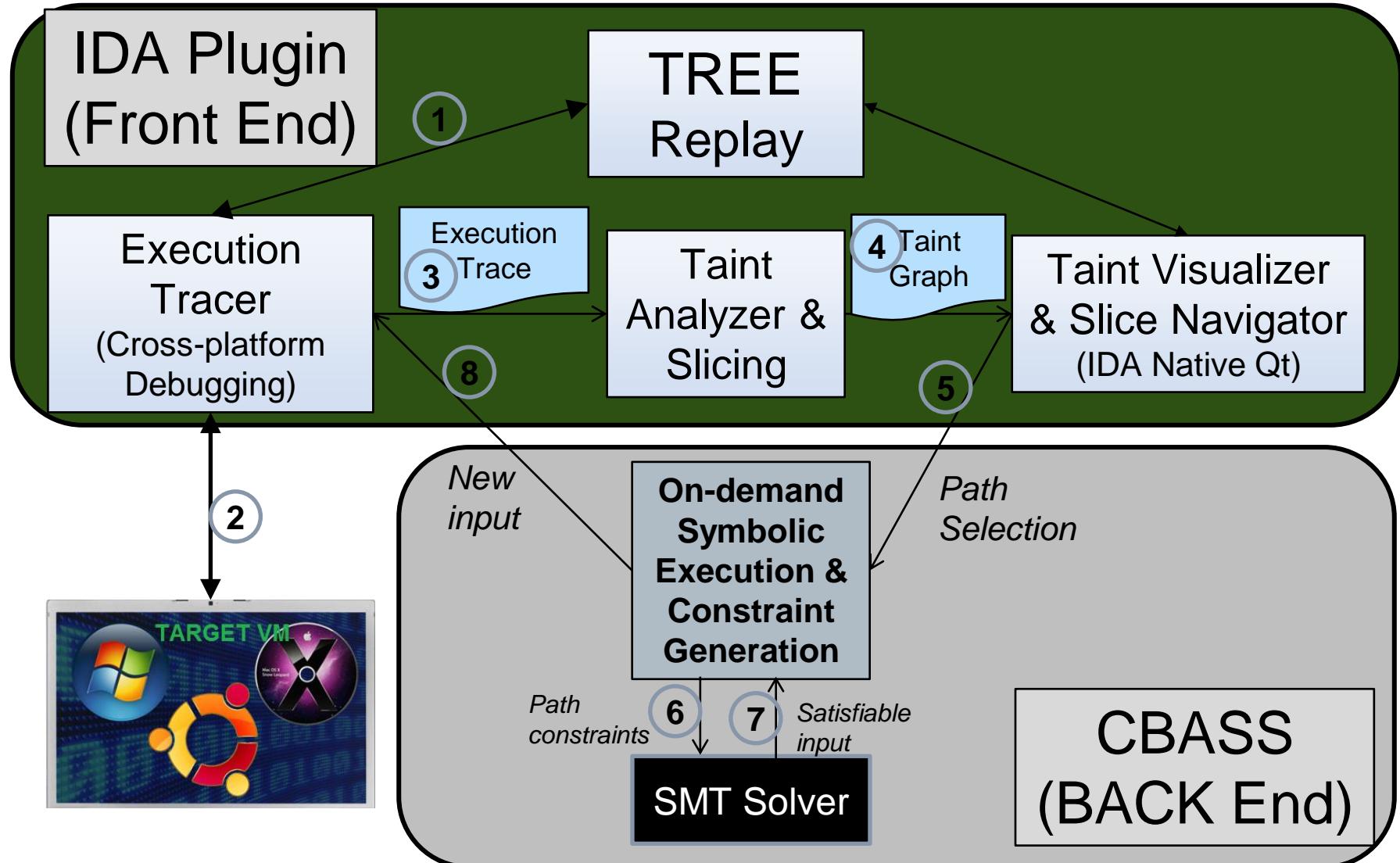


*TREE: Can
we negate
path
condition
at Y?*

CBASS:
This byte
must be 'b'



Explore New Dots Demo



Task 1: Force the Program to Take “bad!” Path

//INPUT

```
ReadFile(hFile, sBigBuf, 16,  
&dwBytesRead, NULL);
```

//INPUT TRANSFORMATION

.....
//PATH CONDITION

```
if(sBigBuf[0]=='b') iCount++;  
if(sBigBuf[1]=='a') iCount++;  
if(sBigBuf[2]=='d') iCount++;  
if(sBigBuf[3]=='!') iCount++;  
if(iCount==4) // “bad!” path
```

//Vulnerable Function

```
StackOverflow(sBigBuf,dwBytesRead)  
else  
    printf("Good!");
```

Branch Conditions In Disassembly

```
movsx   edx, [ebp+Buffer]  
cmp    edx, 62h  
jnz    short loc_F3108F
```

```
mov    eax, [ebp+var_18]  
add    eax, 1  
mov    [ebp+var_18], eax
```

```
loc_F3108F:  
movsx   ecx, byte ptr [ebp+var_F]  
cmp    ecx, 61h  
jnz    short loc_F310A1
```

```
mov    edx, [ebp+var_18]  
add    edx, 1  
mov    [ebp+var_18], edx
```

```
loc_F310A1:  
movsx   eax, byte ptr [ebp+var_F+1]  
cmp    eax, 64h  
jnz    short loc_F310B3
```

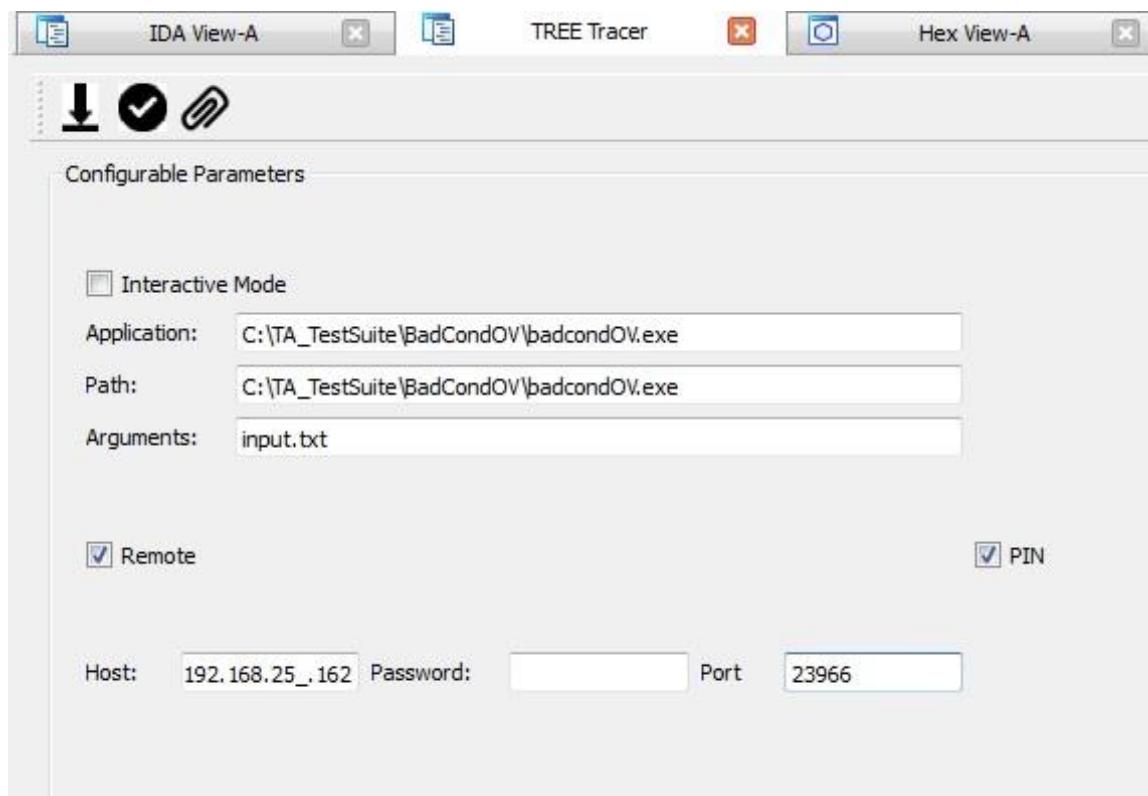
```
mov    ecx, [ebp+var_18]  
add    ecx, 1  
mov    [ebp+var_18], ecx
```

```
loc_F310B3:  
movsx   edx, byte ptr [ebp+var_F+2]  
cmp    edx, 21h  
jnz    short loc_F310C5
```

① TREE Pin Trace

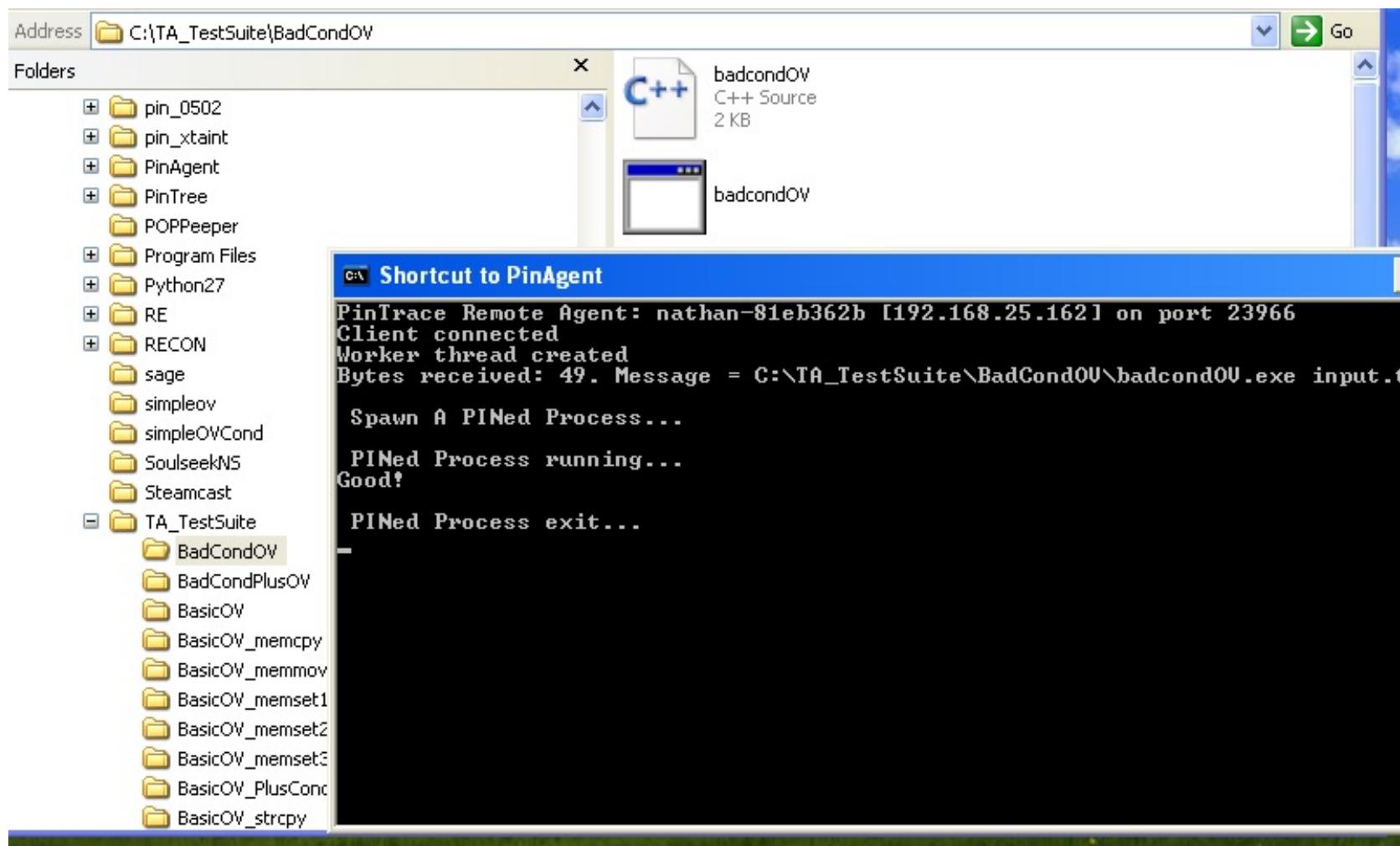
PIN: A popular Dynamic Binary Instrumentation (DBI) Framework

<http://software.intel.com/en-us/articles/pin-a-dynamic-binary-instrumentation-tool>



② TREE Console: Trace Generation

PINAgent: Connects TREE with PIN tracer



③ TREE: Taint Analysis Configuration

Replayer Taint Analysis

Taint Propagation Policy

TAINT_DATA
 TAINT_BRANCH
 TAINT_COUNTER
 TAINT_ADDRESS

Instruction Set Architecture

x86
 x86_64
 ARM
 PPC
 MIPS

Misc

PIN
 Verbose

Image Load Table

Name	Address	Size
'badcon...	0x12f0000	0x5000
ntdll.dll	0x77e00000	0x180000
kernel32.dll	0x777c0000	0x110000
kernel32.dll	0x777c0000	0x110000
KernelBas...	0x75ff0000	0x47000
user32.dll	0x75e70000	0x100000

Taint Source Table

Input Address	Size	
0x38f7ac	16	62616421

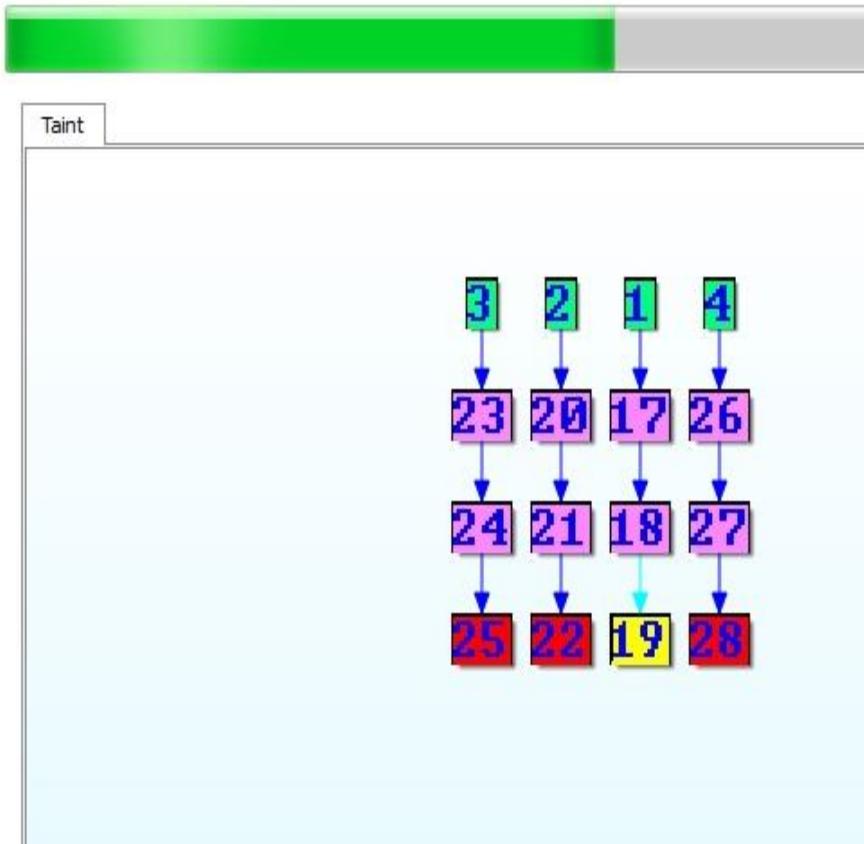
Taint Graph Output

Path Conditions:

```
[19]bc_0x3a[0x3a:0x0]<-jnz 0x9
[18]reg_eflags_0[0x39:0x0]
[0x3c:0x0]<-cmp $0x62, %edx
[17]reg_edx_0_0[0x38:0x0]
[0x41:0x0]<-movsxb -0x10(%ebp),
%edx
[1]in_0x12ff6c[0x0:0x0]
[0xa5b:0x0]<-0xffff:ReadFile
[22]bc_0x3d[0x3d:0x0]<-jnz 0x9
```

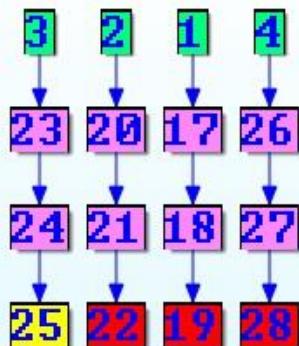
4

TREE: Branch Taint Graph



UUID	Type	Name
1	input	0x12ff6c
17	register	edx_0_0
18	register	eflags_0
19	branch	0x3a
2	input	0x12ff6d
20	register	ecx_0_0
21	register	eflags_0
22	branch	0x3d
23	register	eax_0_0
24	register	eflags_0
25	branch	0x40
26	register	edx_0_0
27	register	eflags_0
28	branch	0x43
3	input	0x12ff6e
4	input	0x12ff6f

⑤ Negate Tainted Path Condition to Exercise a New (“Bad”) Path



CBASS
(Cross-platform
Symbolic
Execution)

```
Connecting to CBASS server at 127.0.0.1:8888
Query on branch condition of: [19]bc_0x3a
[jnz 0x9]
```

```
Result: Offset=0,Value=98
```

'b'

```
Connecting to CBASS server at 127.0.0.1:8888
Query on branch condition of: [22]bc_0x3d
[jnz 0x9]
```

```
Result: Offset=1,Value=97
```

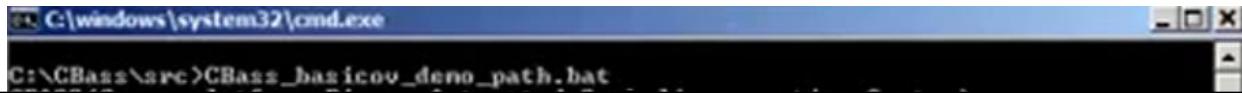
'a'

```
Connecting to CBASS server at 127.0.0.1:8888
Query on branch condition of: [25]bc_0x40
[jnz 0x9]
```

```
Result: Offset=2,Value=100
```

'd'

On-demand Symbolic Execution (What Happens Behind the Scene)



6

(set-logic QF_AUFBV)

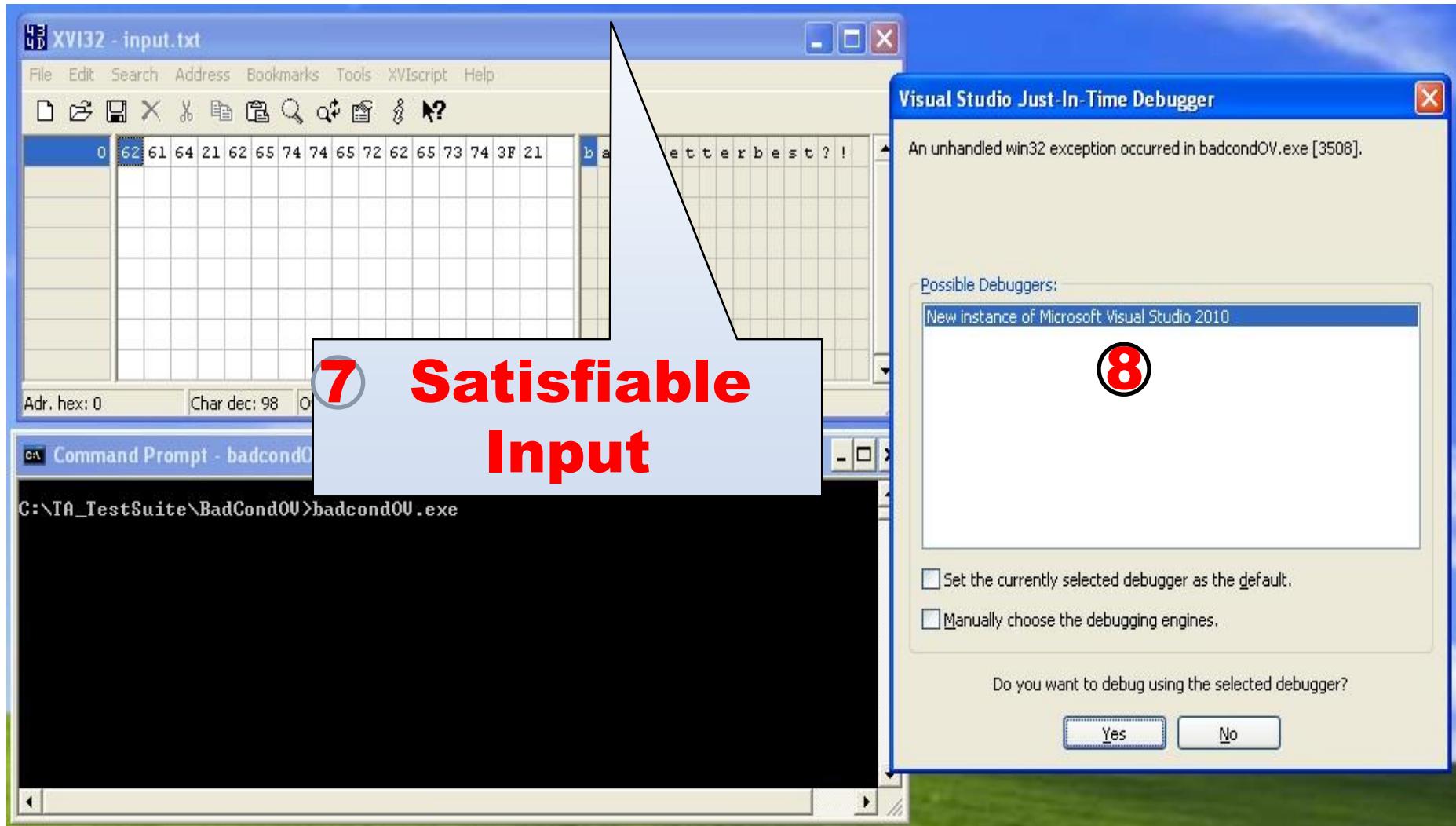
```
(declare-fun _IN_0x12ff6c_0x0_SEQ0 () (_ BitVec 8))
(declare-fun EXPR_0 () (_ BitVec 32))
(assert (= EXPR_0 (bvsqrt (_ sign_extend 24) (bvxor _IN_0x12ff6c_0x0_SEQ0 (_ bv128 8)) (_ bv4294967168 32))))  
  
(assert (= (ite (not (= (ite (not (= (bvand (_ extract 63 0) (bvsqrt (_ sign_extend 32) (bvand (_ extract 31 0) EXPR_0) (_ bv4294967295 32))) (_ bv98 64))) (_ bv4294967295 64)) (_ bv0 64))) (_ bv1 32) (_ bv0 32)) (_ bv0 32))) (_ bv1 8) (_ bv0 8)))  
  
(check-sat)
(get-value (_IN_0x12ff6c_0x0_SEQ0))
```

```
RD t5, EMPTY , DWORD edx]
58:4810272  cmp edx, 98
[48102700: and EDWORD edx, DWORD 2147483648, DWORD t0], 48102701: and EDWORD 98, DWORD 2147483648, DWORD t1], 48102702: sub EDWORD edx, DWORD 98, QWORD t2], 48102703: and QWORD t2, QWORD 2147483648, DWORD t3], 48102704: bsh EDWORD t3, DWORD -31, BYTE SF], 48102705: xor EDWORD t0, DWORD t1, DWORD t4], 48102706: xor EDWORD t0, DWORD t3, DWORD t5], 48102707: and EDWORD t4, DWORD t5, DWORD t6], 48102708: bsh EDWORD t6, DWORD -31, BYTE OF], 48102709: and QWORD t2, QWORD 4294967296, QWORD t7], 4810270A: bsh QWORD t7, QWORD -32, BYTE CF], 4810270B: and QWORD t2, QWORD 4294967295, DWORD t8], 4810270C: biss EDWORD t8, EMPTY , BYTE ZF]]  
59:481027a jnz loc_48108E
[48102700: biss BYTE ZF, EMPTY , BYT
Y , DWORD 41985421]
Invoke Z3 solver z3.exe /smt2 /m path_conditions.smt2
sat
(<_IN_0x12ff6c_0x0_SEQ0 #x62>)
```

7

Satisfiable Input (0x62, 'b')

⑧ TREE: Re-execute with “Satisfiable” Input

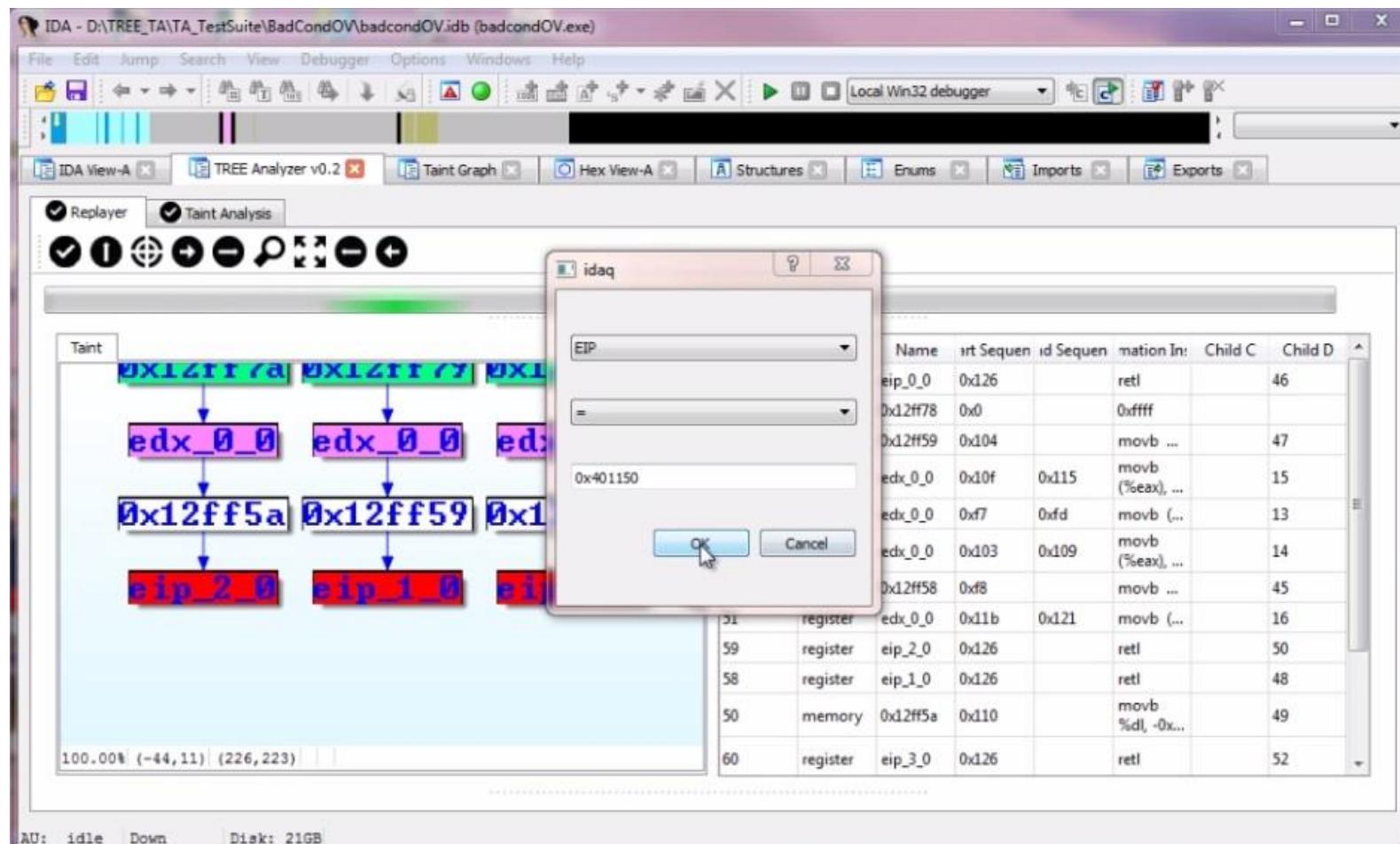


Task 2: Own the Execution

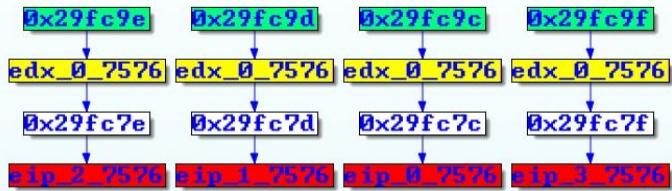
Assume Payload at 0x401150

```
.text:00401144 ;-----  
.text:00401145  
.text:00401150 align 10h  
push    ebp  
.text:00401151 mov     ebp, esp  
push    1010h  
.text:00401153 push    offset aYouHaveBeenHac ; "*** Yo  
.text:0040115D push    offset aCbassCrossPlat ; "CBASS<  
.text:00401162 push    0  
.text:00401164 call    ds:MessageBoxA  
.text:0040116A push    0FFFFFFFh  
.text:0040116C call    ds:exit  
.text:00401172 ;-----
```

TREE Constraint Dialogue



Task 2: Own the Execution: From Crash to Exploit



Symbolize Input and perform concrete-symbolic execution

Symbolic eip =
(= expr_0 (concat (bvand (bvor
_IN_0x12ff6c_0xd_SEQ0 (_ bv0 8)) (_ bv255 8))
(bvand (bvor _IN_0x12ff6c_0xc_SEQ0 (_ bv0 8))
(_ bv255 8))))
Query:
get-value (_IN_0x12ff6c_0xd_SEQ0
_IN_0x12ff6c_0xc_SEQ0
_IN_0x12ff6c_0xe_SEQ0
_IN_0x12ff6c_0xf_SEQ0)

Sat:
(_IN_0x12ff6c_0xd_SEQ0 #x11
_IN_0x12ff6c_0xc_SEQ0 #x50
_IN_0x12ff6c_0xe_SEQ0 #x40
_IN_0x12ff6c_0xf_SEQ0 #x00

SMT
Solver

TREE/CBASS Demo

**Using CBASS/TREE to Explore
Bad Paths and Refine Exploits**

Real World Case Studies

Target Vulnerability	Vulnerability Name	Target Application Mode	Target OS
CVE-2005-4560	Windows WMF	User Mode	Windows
CVE-2207-0038	ANI Vulnerability	User Mode	Windows
OSVDB-2939	AudioCoder Vulnerability	User Mode	Windows
CVE-2011-1985	Win32k Kernel Null Pointer Dereference	Kernel Mode	Windows
CVE-2004-0557	Sound eXchange (SoX) WAV Multiple Buffer Overflow	User Mode	Linux
Compression/Decompression	Zip on Android	User Mode	Real Device Trace Generation

Conclusions

- **Dynamic taint analysis and symbolic analysis**
 - Their success in vulnerability discovery
 - Challenges in exploitation analysis
- **Our analysis platform**
 - CBASS (Cross-platform Symbolic-execution System)
 - Supporting automated analysis
 - TREE (Taint-enabled Reverse Engineering Environment)
 - Supporting interactive analysis

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Questions?

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