All You Ever Wanted to Know About Dynamic Taint Analysis & Forward Symbolic Execution (but might have been afraid to ask)

(Yes, we were trying to overflow the title length field on the submission server)

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A ***Few Things*** You Need to Know About Dynamic Taint Analysis & Forward Symbolic Execution (but might have been afraid to ask)

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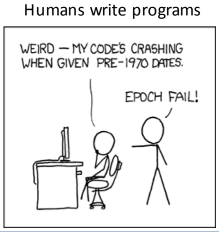
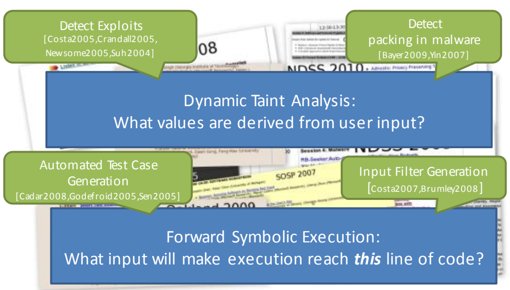
The Root of All Evil

Humans write programs



This Talk:
Computers Analyzing Programs Dynamically at Runtime

Two Essential Runtime Analyses



Detect Exploits [Costa2005,Crandall2005, Newsome2005,Suh2004]

Detect packing in malware [Bayer2009,Yin2007]

Dynamic Taint Analysis:
What values are derived from user input?

Automated Test Case Generation [Cadar2008,Godefroid2005,Sen2005]

Input Filter Generation [Costa2007,Brumley2008]

Forward Symbolic Execution:
What input will make execution reach ***this*** line of code?

Our Contributions

Computers Analyzing Programs Dynamically at Runtime

Dynamic Taint Analysis:
Is this value affected by user input?

Forward Symbolic Execution:
What input will make execution reach ***this*** line of code?

1: Turn English descriptions into an ***algorithm***
- Operational Semantics

2: Algorithm highlights caveats, issues, and unsolved problems that are deceptively hard

Our Contributions (cont'd)

3: Systematize recurring themes in a wealth of previous work

Dynamic Taint Analysis: What values are derived from user input?

1. How it works – example
2. Desired properties
3. Example issue. Paper has many more.

tainted untainted

```
x = get_input( )
y = x + 42
...
goto y
```

Input is tainted

Taint Introduction

$$\text{Input}\ \frac{t = \text{IsUntrusted}(src)}{\text{get\_input}(src) \downarrow t}$$

Δ

Var	Val
x	7

τ

Var	Tainted?
x	T

tainted untainted

```
x = get_input( )
y = x + 42
...
goto y
```

Data derived from user input is tainted

Taint Propagation

$$\text{BinOp}\ \frac{t_1 = \tau[x_1]\ ,\ t_2 = \tau[x_2]}{x_1 + x_2 \downarrow t_1 \vee t_2}$$

Δ

Var	Val
x	7
y	49

τ

Var	Tainted?
x	T
y	T

tainted untainted

```
x = get_input( )
y = x + 42
...
goto y
```

Policy Violation Detected

Taint Checking

$P_{goto}(t_a) = \neg\ t_a$

(Must be true to execute)

Δ

Var	Val
x	7
y	49

τ

Var	Tainted?
x	T
y	T


```
x = get_input( )
y = ...
...
goto y
```

Jumping to overwritten return address

Real Use: Exploit Detection

```
...
strcpy(buffer,argv[1]) ;
...
return ;
```


Memory Load

Variables

Δ

Var	Val
x	7

τ

Var	Tainted?
x	T

Memory

μ

Addr	Val
7	42

τ_μ

Addr	Tainted?
7	F

Problem: Memory Addresses

x = get_input( )
y = load(x)
...
goto y

All values derived from user input are tainted??

Δ

Var	Val
x	7

μ

Addr	Val
7	42

τ_μ

Addr	Tainted?
7	F

Policy 1: Taint depends only on the memory cell

x = get_i...
y = load(...
...
goto y

Undertainting

Failing to identify tainted values
- e.g., missing exploits

Δ

Var	Val
x	7

μ

Addr	Val
7	42

Taint Propagation

$$\text{Load}\ \frac{v = \Delta[x]\ ,\ t = \tau_\mu[v]}{\text{load}(x) \downarrow t}$$

τ_μ

Addr	Tainted?
7	F

Policy 2: If either the address or the memory cell is tainted, then the value is tainted

x = get_i...
y = load(...
...
goto y

Overtainting

Unaffected values are tainted
- e.g., exploits on safe inputs

Memory

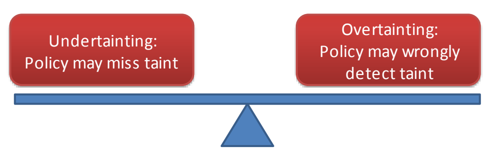
Address expression is tainted

printa
printb

Taint Propagation

$$\text{Load}\ \frac{v = \Delta[x]\ ,\ t = \tau_\mu[v],\ t_a = \tau[x]}{\text{load}(x) \downarrow t \lor t_a}$$

Research Challenge
State-of-the-Art is not perfect for all programs



Forward Symbolic Execution:
What input will make execution reach ***this*** line of code?

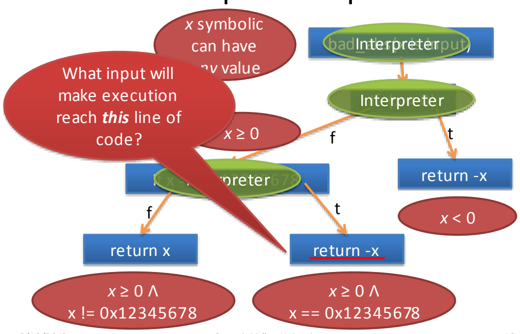
- How it works – example
- Inherent problems of symbolic execution
- Proposed solutions

The Challenge

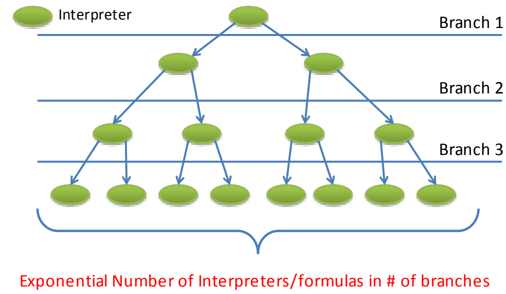

```
bad_abs(x is input)
  if (x < 0) then
      return -x
  if (x = 0x12345678) then
      return -x
  return x
```

Forward Symbolic Execution:
What input will make execution reach ***this*** line of code?

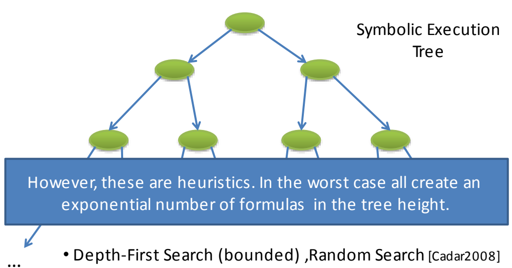
A Simple Example



One Problem:
Exponential Blowup Due to Branches



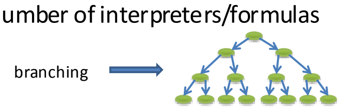
Path Selection Heuristics



- Depth-First Search (bounded) ,Random Search [Cadar2008]
- Concolic Testing [Sen2005,Godefroid2008]

Symbolic Execution is *not* Easy

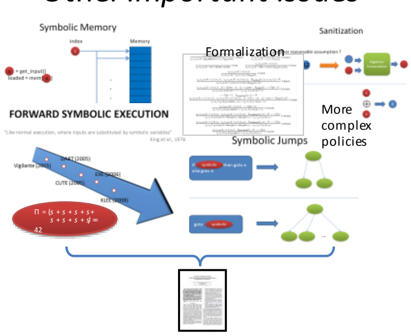
- Exponential number of interpreters/formulas



- Exponentially-sized formulas

- Solving a formula is NP-Complete!

Other *Important* Issues



Conclusion

- Dynamic taint analysis and forward symbolic execution used extensively in literature
  - Formal algorithm and what is done for each possible step of execution often not emphasized
- We provided a formal definition and summarized
  - Critical issues
  - State-of-the-art solutions
  - Common tradeoffs

Thank You!
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Questions?