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

Matteo Di Pirro

BSc in Computer Science
Department of Mathematics

University of Padova

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Outline

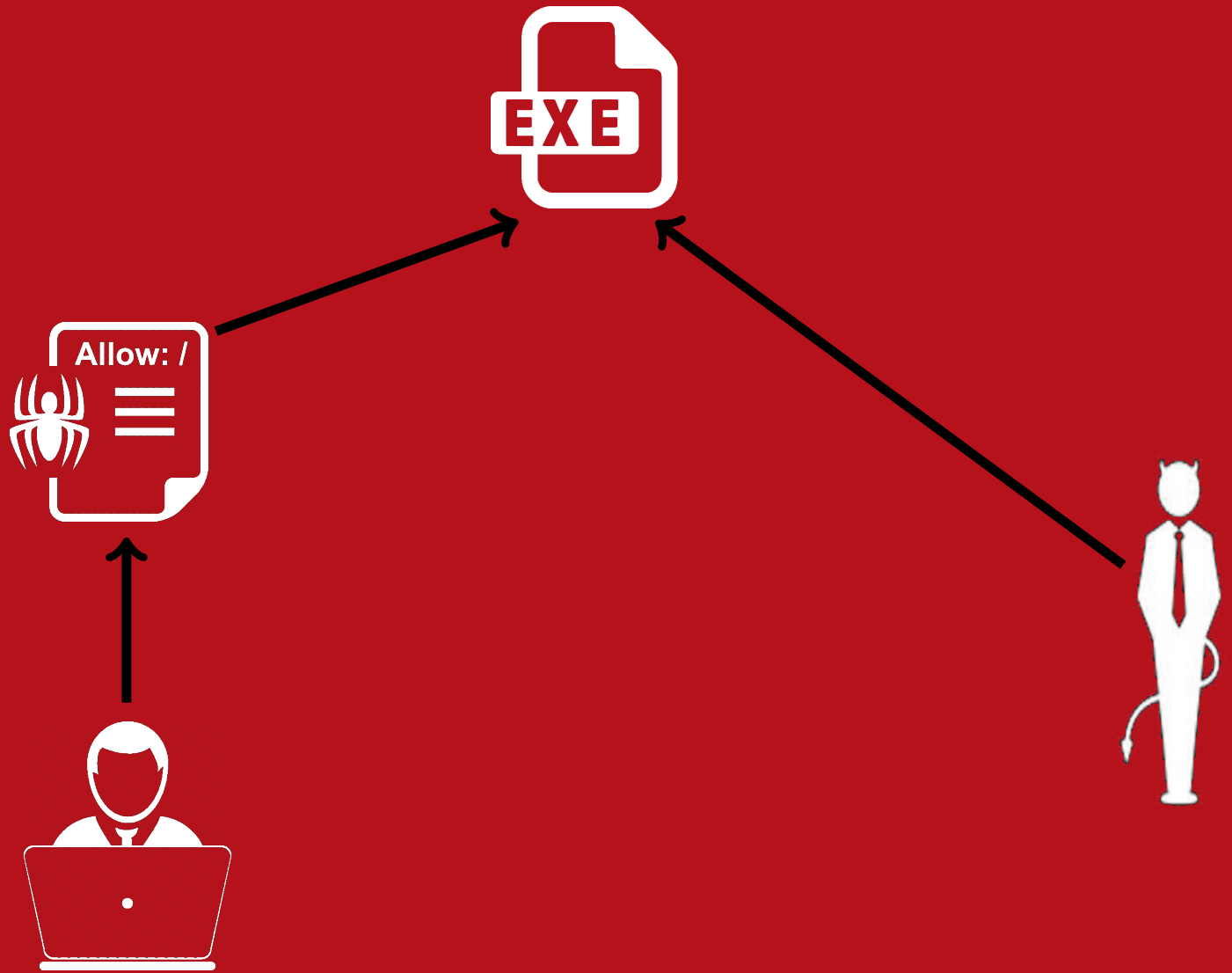
Introduction

Dynamic Taint Analysis

Forward Symbolic Execution

Conclusions

Of who or what do we trust?



Input Analysis

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1. **Is the final value affected by user input?**
   - **Dynamic Taint Analysis**!
   - Tracks information flow between sources and sinks

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1. **Is the final value affected by user input?**
   - **Dynamic Taint Analysis**!
   - Tracks information flow between sources and sinks
2. **What input will make execution reach this line of code?**
   - **Forward Symbolic Execution**
   - Allows us to reason about the behavior of a program on many different inputs

Dynamic Taint Analysis

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```
x := get_input(  )
z := 42
y := x + z
goto y
```

Dynamic Taint Analysis

Tainted

```
x := get_input()
z := 42
y := x + z
goto y
```

x is derived from a tainted source

Dynamic Taint Analysis

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```
x := get_input( )
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```

Untainted

z is a ”static” constant

Dynamic Taint Analysis


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Is y taited?

Dynamic Taint Analysis


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Is y taited?

It depends on the selected policy

What's a policy?

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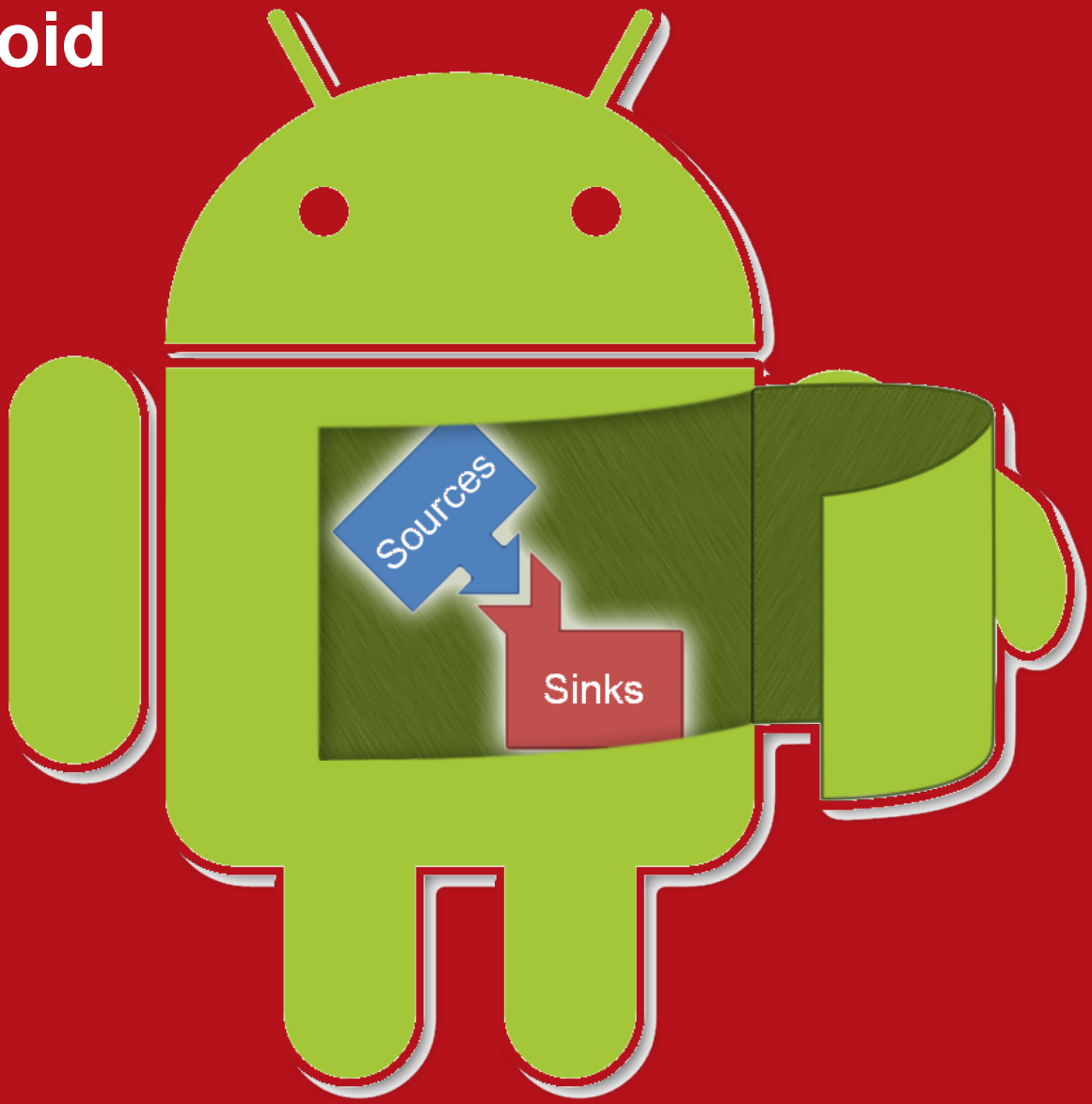
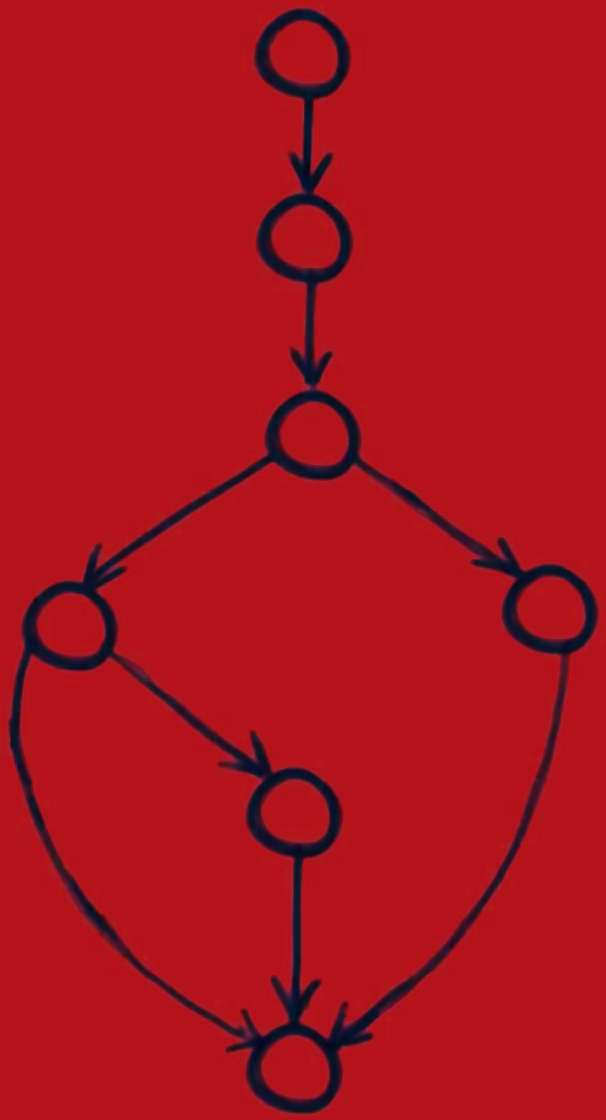
- A taint policy specifies three properties:
  - **Taint Introduction**
    - How is taint introduced into a system?
  - **Taint Propagation**
    - How does taint propagate into a system?
  - **Taint Checking**
    - Is the current operation secure?
- **Undertainting** vs **Overtainting**

Can we go further?
TaintDroid



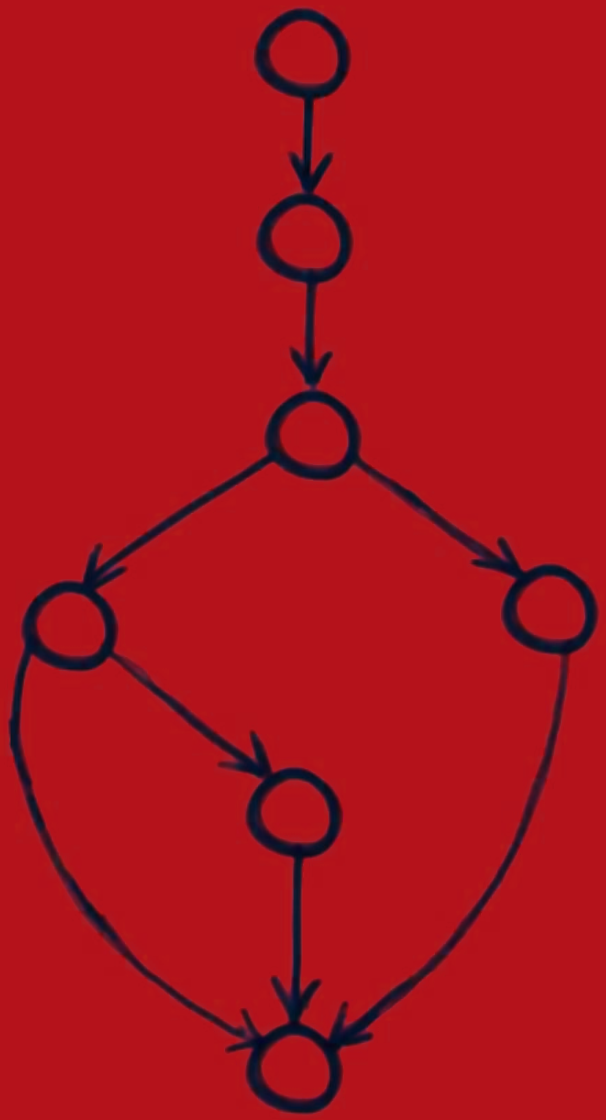
Malware detection and Pointer Tainting

Limitations



- **Sanitization problem**

Limitations



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  `b := a` $\oplus$ `a`

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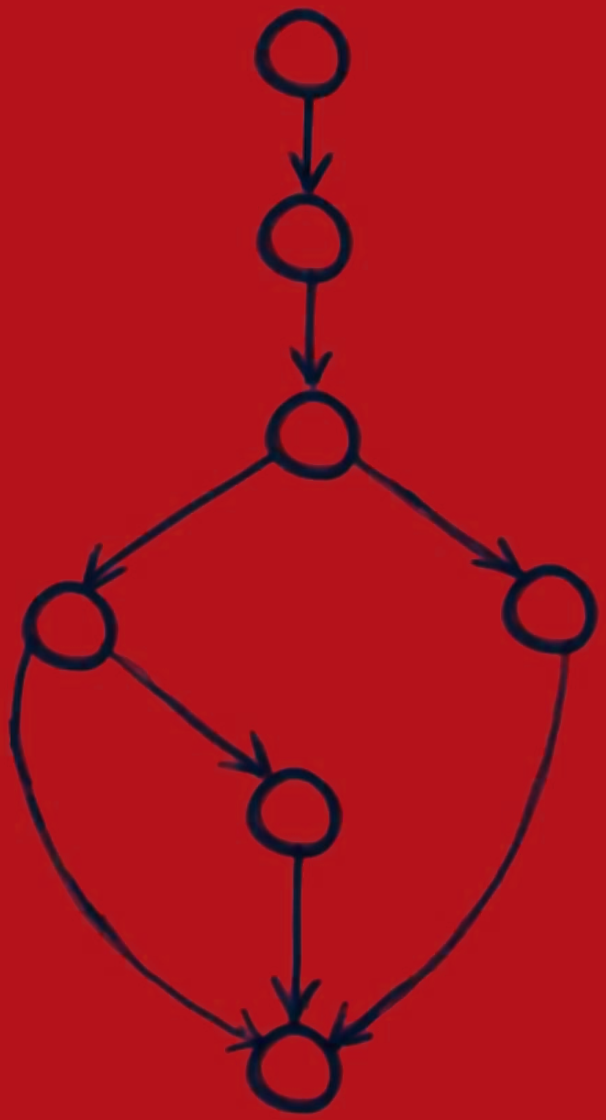

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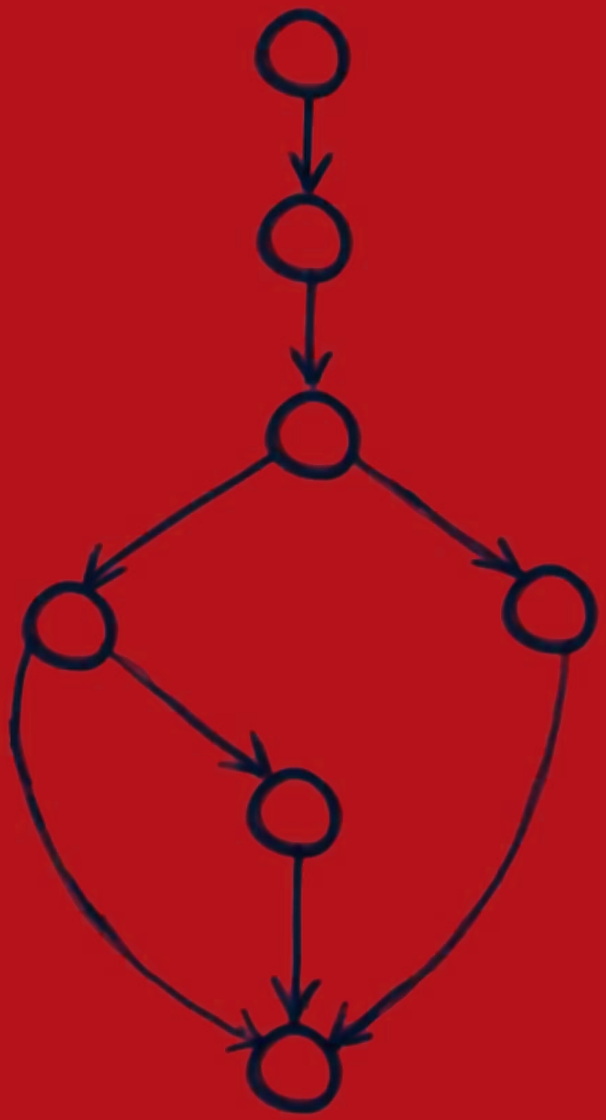
  $b := a \oplus a$

- Pure dynamic taint analysis considers **data flows**...

  ...but it ignores **control-flows**

```
x := get_input(src)
if x == 1 then goto 3 else goto 4
y := 1
z := 42
```

Limitations



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- What about different security policies for different I/O channels?

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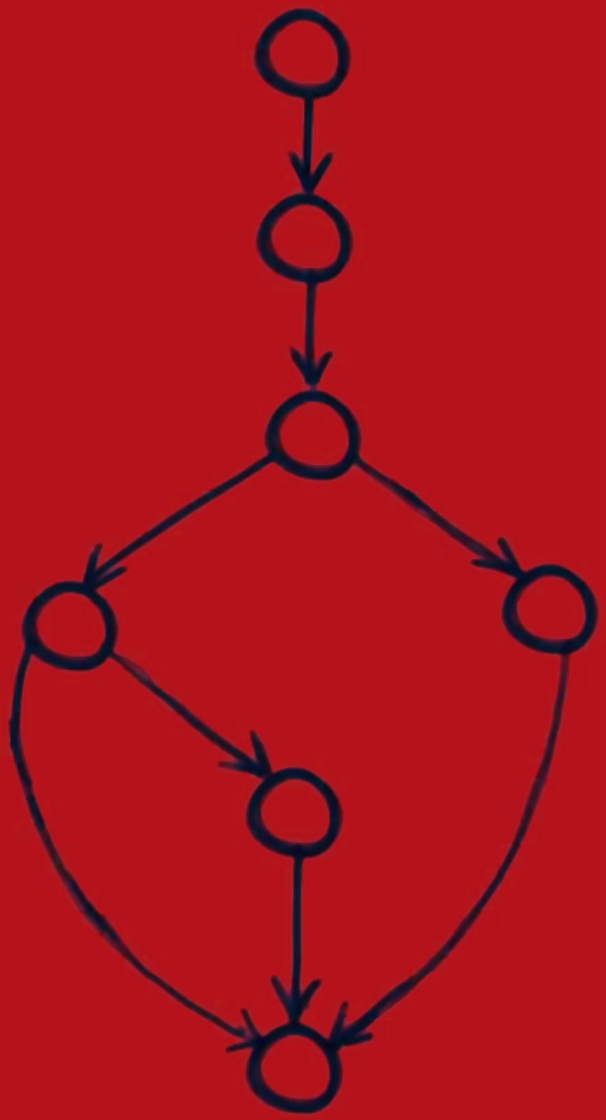

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  $$\texttt{b := a} \oplus \texttt{a}$$

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```

- What about different security policies for different I/O channels?
  $\rightarrow$ **Static analysis**

Forward Symbolic Execution

- We can reason about the behavior of a program using the logic...
- ... and it is **conceptually** a very simple process

```
x := 2 * get_input(src)
if x - 5 == 14 then goto 3 else goto 4
// line 3:  catastrophic failure
// line 4:  normal behavior
```

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- We can reason about the behavior of a program using the logic...
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x := 2 * get_input(src)
if x - 5 == 14 then goto 3 else goto 4
// line 3:  catastrophic failure
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```
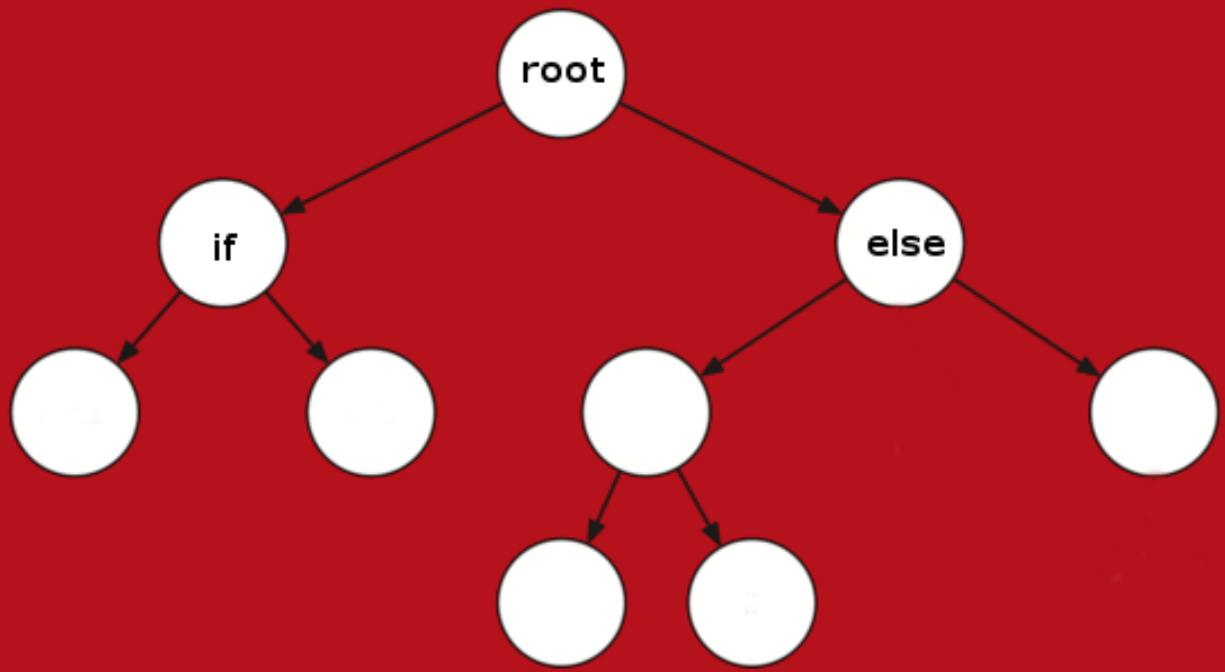

- `get_input(src)` now returns a **symbol** instead of a concrete value
- But now expressions **cannot** be fully evaluated to a concrete value

Path Selection and Performance

- For each conditional jump we must decide what path to follow first
  - But some path may never terminate
- Exponential blowup due to branches



Path Selection and Performance

- For each conditional jump we must decide what path to follow first
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$$\texttt{while } (3^n + 4^n == 5^n) \texttt{ \{n++; ...\}}$$

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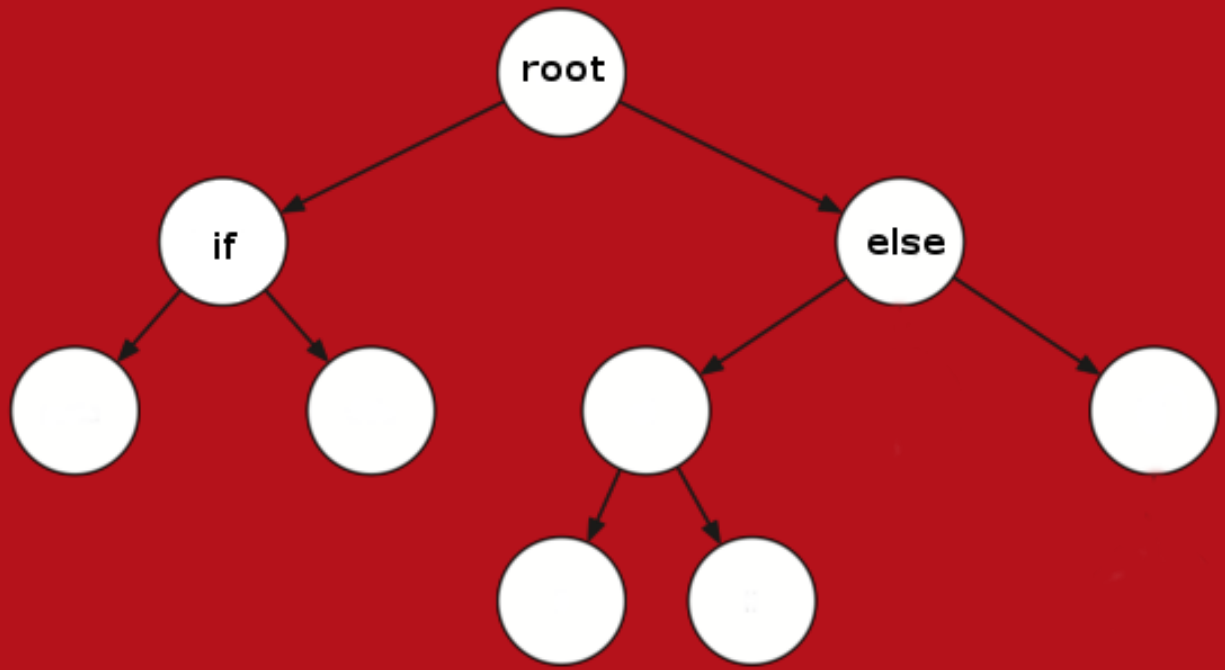

Path Selection and Performance

- For each conditional jump we must decide what path to follow first
  - But some path may never terminate

    `while (`$3^n + 4^n == 5^n$`) {n++; ...}`
- Exponential blowup due to branches
- Solutions
  - **Path Selection Heuristics**
    - Concolic Testing
    - Depth-First or Random Search
  - More and faster **hardware**
  - Identify **redundancies** between formulas
  - Identify **independent subformulas**

A small comparison

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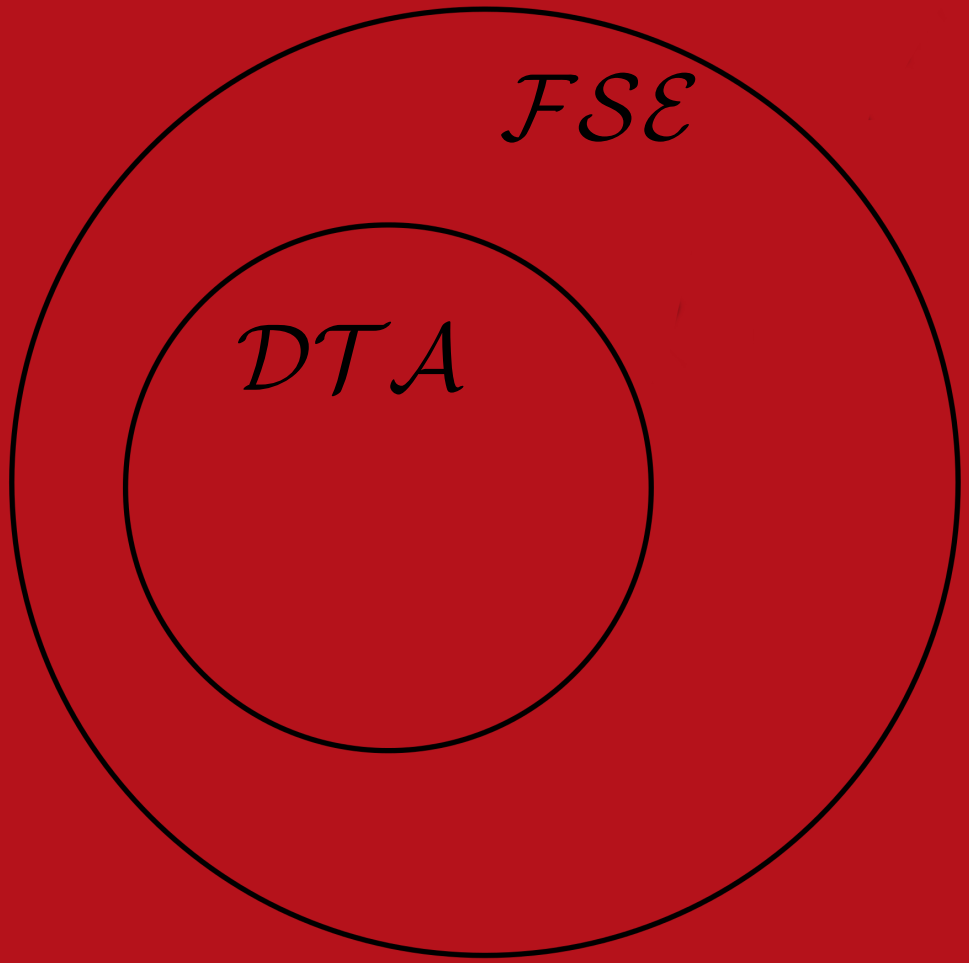
Dynamic Taint Analysis

Forward Symbolic Execution

A small comparison



Dynamic taint analysis analyzes only ***feasible*** paths

Conclusions

- ✓ Conceptually simple methods of analysis
- ✓ There are a lot of possible use cases
  - Malware detection and analysis
  - Automatic testing
  - Automatic programs understanding

- ✗ Usable with some care
- ✗ The effectiveness depends on the application

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Thank you for allowing me to taint your time!

Questions?

DIPARTIMENTO
MATEMATICA

SimpIL Grammar

program	::=	*stmt**
stmt s	::=	*var* := *exp* | store(*exp*, *exp*) | goto *exp* | assert *exp* | if *exp* then goto *exp* else goto *exp*
exp e	::=	load(*exp*) | *exp* $\Diamond_b$ *exp* | $\Diamond_u$ *exp* | *var* | get_input(*src*) | *v*
$\Diamond_b$	::=	typical binary operators
$\Diamond_u$	::=	typical unary operators
value v	::=	32-bit unsigned integer

SimplL Operational Semantic

- **Each** statement rule of the operational semantic is like:

$$\frac{\text{computation}}{<\text{current state}>, \text{stmt} \rightarrow <\text{end state}>, \text{stmt}}$$

- The `state` is composed of:
  - Program statements ($\sum$)
  - Current memory state (μ)
  - Current values for variables (Δ)
  - Program counter (***pc***)
  - Current statement (***i***)

Memory Address Problems
Forward Symbolic Execution

- What are we supposed to do if a referenced address is derived from user input?
  - `LOAD`, `STORE` $\rightarrow$ **Symbolic Memory Address**
  - `GOTO` $\rightarrow$ **Symbolic Jumps**
- Solutions
  - Concolic testing
  - SMT (**S**atisfiability **M**odulo **T**heories) solvers
    - $\mathcal{NP}$**-Complete** problem!
  - Static and alias analysis