Dynamic Taint Analysis

Dynamic Taint Analysis for Automatic Detection, Analysis and Signature Generation of Exploits on Commodity Software

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Problem: Internet Worms

- Propagate by exploiting vulnerable software
- No human interaction needed to spread
- Able to rapidly infect vulnerable hosts
  - Slammer scanned 90% of Internet in 10 minutes
- Need **automatic** defense against new worms

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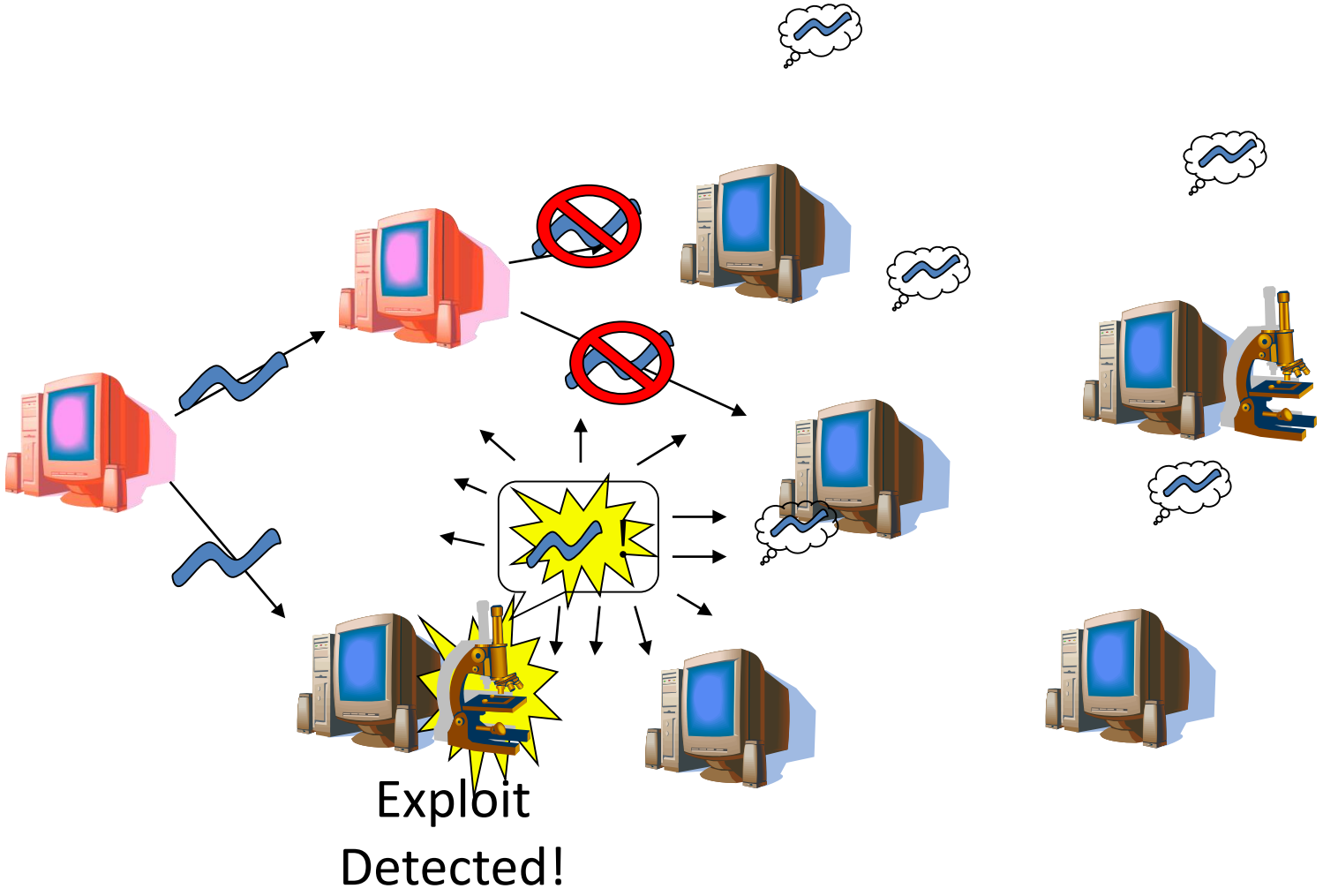
Automatic Worm Defense



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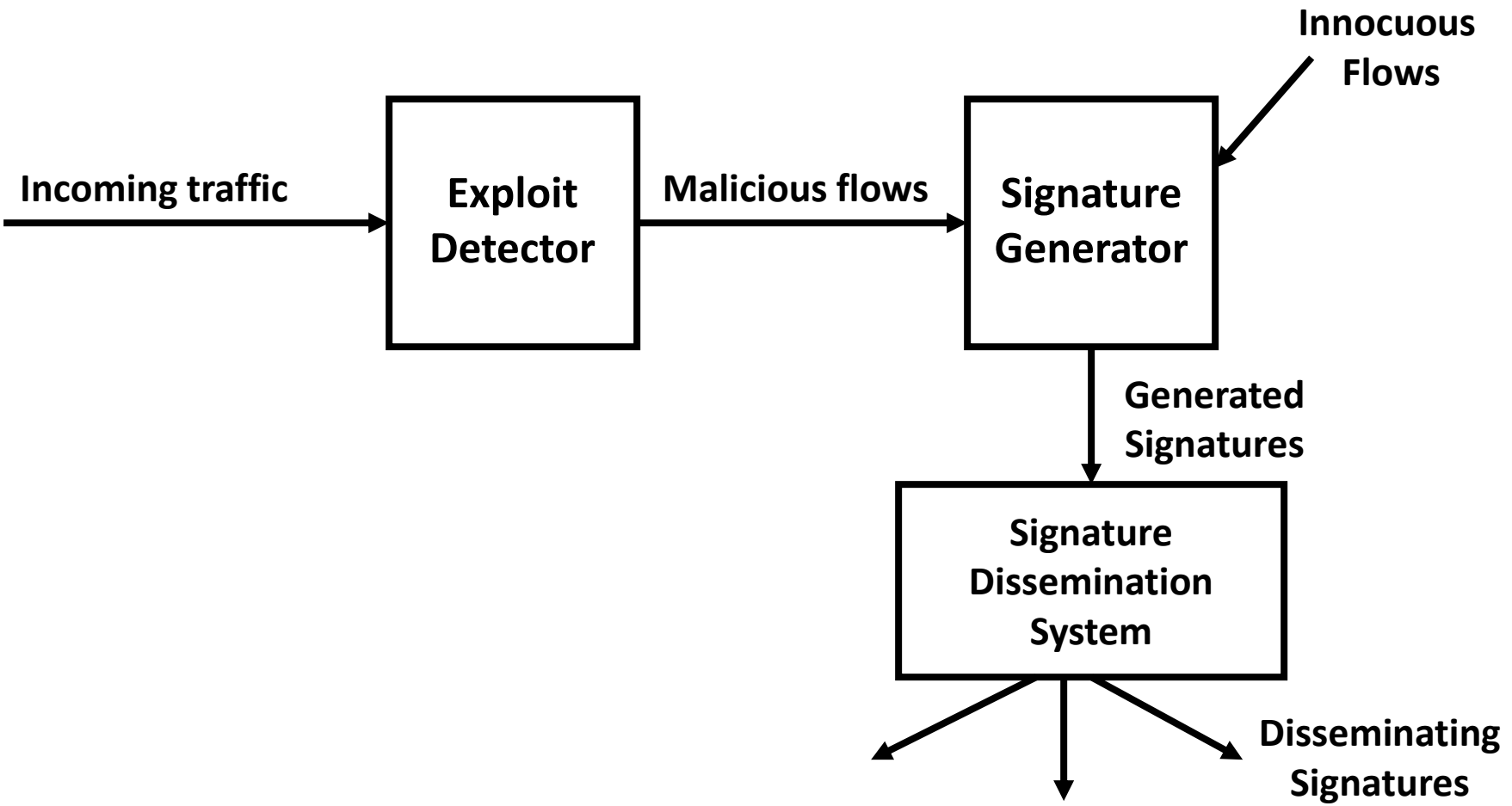
Architecture



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Common Traits of Software Exploits

- Most known exploits are *overwrite attacks*
- Attacker's data overwrites sensitive data
- Common overwrite vulnerabilities:
  - Buffer overflows
  - Format string
  - Double-free
- Common overwrite targets:
  - Return address
  - Function pointer

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Approach: Dynamic Taint Analysis

- Hard to tell if data is sensitive when it is *written*
  - Binary has no type information
- Easy to tell it is sensitive when it is *used*
- Approach: *Dynamic Taint Analysis*:
  - Keep track of *tainted* data from untrusted sources
  - Detect when tainted data is used in a sensitive way
    - *e.g.*, as return address or function pointer

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Design & Implementation: TaintCheck

- Use Valgrind to monitor execution
  - Instrument program binary at run-time
  - No source code required
- Track a taint value for each location:
  - Each byte of tainted memory
  - Each register

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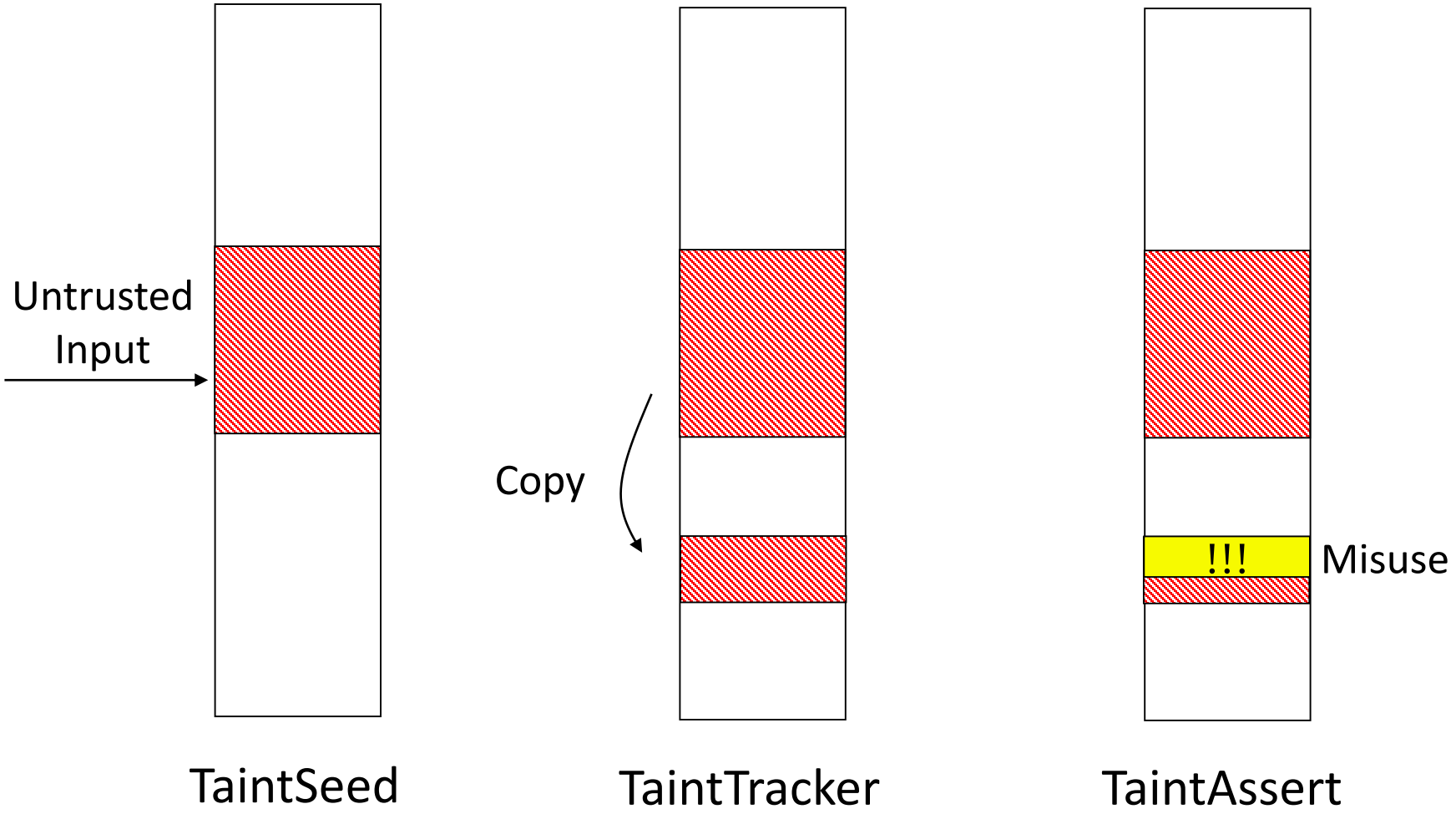
TaintCheck Components



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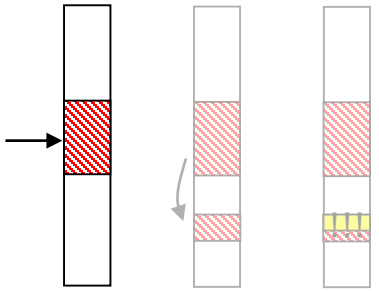
TaintSeed

- Monitors input via system calls
- Marks data from untrusted inputs as tainted
  - Network sockets (default)
  - Standard input
  - File input
    - (except files owned by root, such as system libraries)



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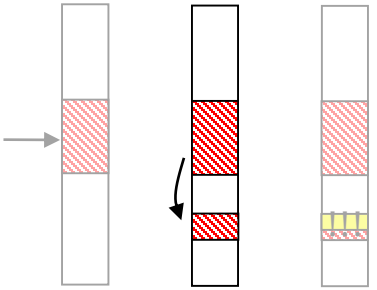
TaintTracker

- Propagates taint
- Data movement instructions:
  - *e.g.*, move, load, store, etc.
  - Destination tainted iff source is tainted
  - Taint data loaded via tainted index
    - *e.g.,* unicode = translation_table[tainted_ascii]
- Arithmetic instructions:
  - *e.g.,* add, xor, mult, etc.
  - Destination tainted iff *any* operand is tainted
- Untaint result of constant functions
    - xor eax, eax



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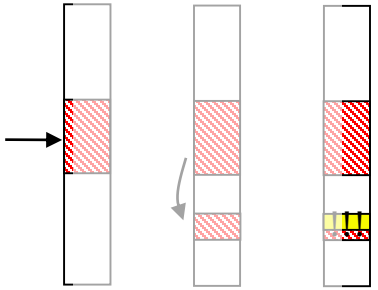
TaintAssert

- Detects when tainted data is misused
  - Destination address for control flow (default)
  - Format string (default)
  - Argument to particular system calls (e.g., `execve`)
- Invoke Exploit Analyzer when exploit detected



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Coverage: Attack Classes Detected

	Format String	Stack Overflow	Heap Overflow	Heap Corruption (Double Free)
Return Address	✓	✓	N/A	✓
Function Pointer	✓	✓	✓	✓
Fn Ptr Offset (GOT)	✓	✓	✓	✓
Jump Address	✓	✓	✓	✓

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Experimental Results: Detects Many Attacks

Vulnerable Program	Overwrite Method	Overwrite Target	Detected
ATPhttpd	Buffer overflow	Return address	✓
Synthetic	Buffer overflow	Function pointer	✓
Synthetic	Buffer overflow	Format string	✓
cfingerd	syslog format string	GOT entry	✓
wu-ftpd	vsnprintf format string	Return address	✓

Others including slapper, SQL Slammer

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Comparison to Previous Mechanisms

- Used Wilander testbed [NDSS03]
  - 20 exploit tests
  - Overwrite Targets: return address, base pointer, function pointer, longjmp buffer
  - Overwrite Techniques: overflow to target, overflow to pointer to target
  - Evaluate previous run-time detection mechanisms

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Comparison Results

Mechanisms	Attacks Prevented or Halted
StackGuard	15%
Stack Shield	30%
ProPolice	50%
Libsafe & Libverify	20%
TaintCheck	100%

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Other Applications

- Information leakage detection/analysis
- Malware analysis
- Fuzzing
- A base for symbolic execution/concolic testing
- …

Pointer Tainting

- mov eax, [ebx + 4]

  When ebx is tainted, shall eax be tainted?

- Often used for table lookup, e.g.,
  - Convert from ascii to Unicode
  - Convert a date from one format to another

- It may cause taint explosion

Over tainting & Under tainting

- xor eax, eax
- sub eax, eax

- Taint granularity is important (bit, byte, word, etc.)
  - Coarser granularity may cause over tainting

Examples of bit-level tainting rules

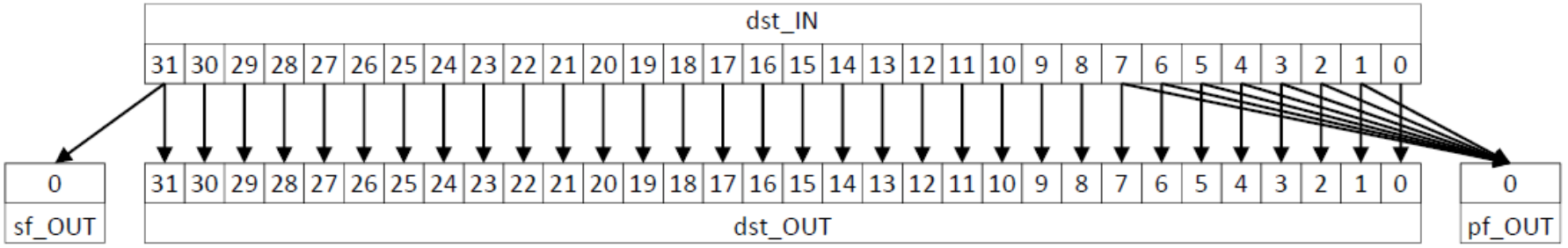

Figure 2: Information flows of *dst* in the `or` instruction

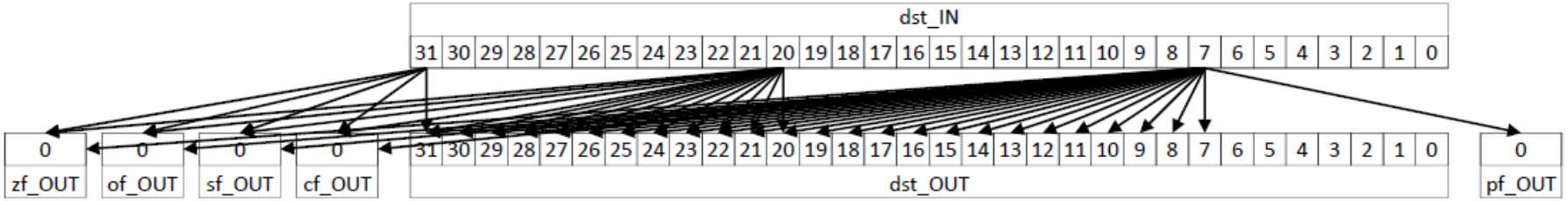

Figure 3: Information flow of bits 7, 20 and 31 of `dst` in `sbb`

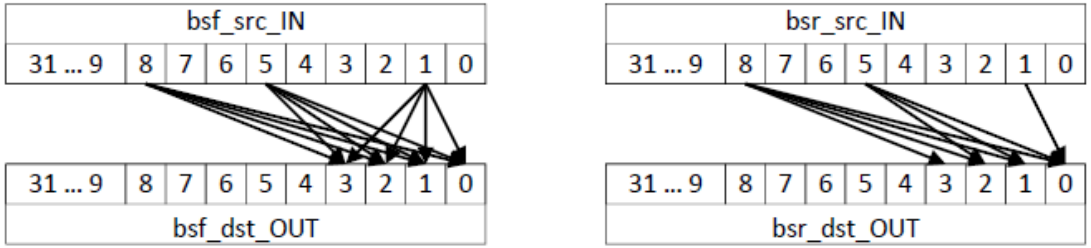

Figure 4: Comparison between *bsf* and *bsr*

Rules for x86 Instructions

						Previously Published Taint Trackers								
Instruction	**Inputs**	**Outputs**	**# Cases**	**Runtime**	**Flow Type**	**DroidScope[16]**	**Cat1**	**libdft[9]**	**Minemu[10]**	**Cat2**	**TEMU[15]**	**Cat3**	**Memcheck[32]**	**SPITA**
adc *dst, src*	dst,src,cf	dsr,src,zf,of,sf,af,cf,pf	4550	1m19s	U	A	A	I	A	A	S	S	U	S
add *dst, src*	dst,src	dst,src,zf,of,sf,af,cf,pf	4480	1m13s	U	A	A	I	A	A	A	A	S	S
and *dst, src*	dst,src	dst,src,zf,sf,pf	4288	1m05s	I	A	I	I	A	I	I	S	S	S
dec *dst*	dst	dst,zf,of,sf,af,pf	1184	20s	U	A	A	I	A	A	A	A	U	S
div *rm32*	edx,eax,rm32	edx,eax,rm32	9216	95m48s	D	A	A	I	N	A	A	A	A	D
idiv *rm32*	edx,eax,rm32	edx,eax,rm32	9216	307m04	A	A	A	I	N	A	A	A	A	A
imul1 *rm32*	eax,rm32	edx,eax,rm32,of,cf	6272	289m51s	U	A	A	I	N	A	A	A	U	U
imul2 *dst, rm32*	dst,rm32	dst,rm32,of,cf	4224	52m37s	U	A	A	I	N	A	A	A	U	U
imul3 *dst, rm32, imm32*	rm32,imm32	dst,rm32,imm32,of,cf	6272	53m56s	U	A	A	I	N	A	A	A	U	U
inc *dst*	dst	dst,zf,of,sf,af,pf	1184	19s	U	A	A	I	A	A	A	A	U	S
mul *rm32*	eax,rm32	edx,eax,rm32,of,cf	6272	16m02s	U	A	A	I	N	A	A	A	U	U
not *dst*	dst	dst	1024	15s	I	A	I	I	A	I	I	I	I	I
or *dst, src*	dst,src	dst,src,zf,sf,pf	4288	1m05s	I	A	I	I	A	I	I	S	S	S
rcl *dst, imm8*	dst,imm8,cf	dst,imm8,of,cf	1722	42s	A	A	A	N	A	A	A	A	A	S
rcr *dst, imm8*	dst,imm8,cf	dst,imm8,of,cf	1722	42s	A	A	A	N	A	A	A	A	A	S
rol *dst, imm8*	dst,imm8	dst,imm8,of,cf	1680	41s	A	A	A	N	A	A	A	A	S	S
ror *dst, imm8*	dst,imm8	dst,imm8,of,cf	1680	41s	A	A	A	N	A	A	A	A	S	S
sal *dst, imm8*	dst,imm8	dst,imm8,zf,of,sf,af,cf,pf	1840	35s	U	A	A	N	A	A	S	S	S	S
sar *dst, imm8*	dst,imm8	dst,imm8,zf,of,sf,af,cf,pf	1840	34s	D	A	A	N	A	A	S	S	S	S
sbb *dst, src*	dst,src,cf	dst,src,zf,of,sf,af,cf,pf	4550	1m21s	U	A	A	I*	A*	A	A	A*	A	S
shr *dst, imm8*	dst,imm8	dst,imm8,zf,of,sf,af,cf,pf	1840	35s	D	A	A	N	A	A	S	S	S	S
sub *dst, src*	dst,src	dst,src,zf,of,sf,af,cf,pf	4480	1m17s	U	A	A	I*	A*	A*	A*	A*	S	S
xor *dst, src*	dst,src	dsr,src,zf,sf,pf	4288	1m05s	I	A	I	I*	A*	A*	A*	A*	I	I
bsf *dst, src*	src	dst,src,zf	2080	31s	A	N	A	I	N	A	A	A	A	S
bsr *dst, src*	src	dst,src,zf	2080	31s	S	N	A	I	N	A	A	A	A	S
cmpxchg *rm32, r32*	eax,rm32,r32	eax,rm32,r32,zf,of,sf,af,cf,pf	9792	2m39s	S	N	E	E	N	E	E	E	E	S
TOTAL			102064	13h52m48s										

How to verify tainting rules

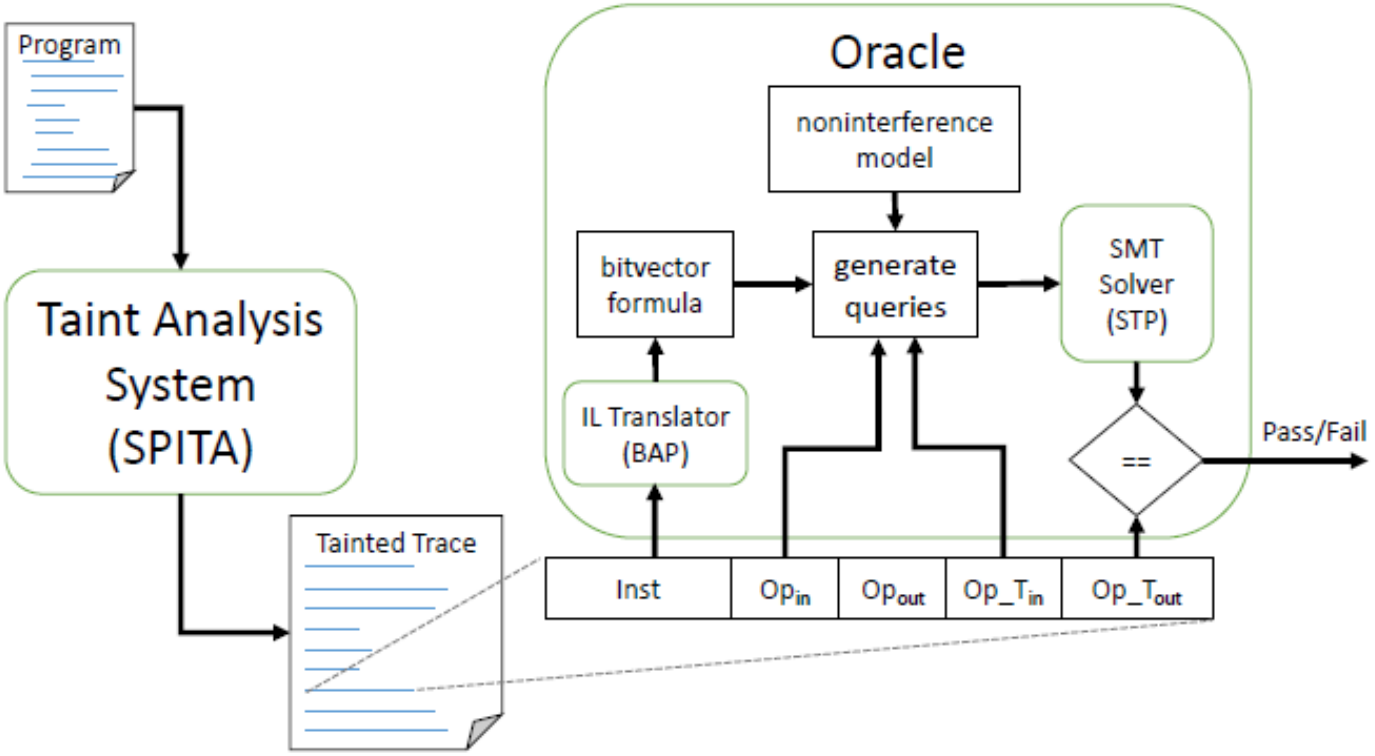

Figure 8: Per-Trace Verification Overview

```
 1. // Query for bit [31] of R_EBX:u32
 2. R_EBX_C:u32 = 0x46018902:u32
 3. R_EBX_T:u32 = 0x56718e20:u32
 4. //Concretization of flags
 5. goal:bool = false
 6. R_EBX:u32 = (R_EBX_O1:u32 & R_EBX_T:u32)
              | (R_EBX_C:u32 & ~R_EBX_T:u32)
 7. R_EBX:u32 = 0:u32 // sets R_EBX to 0
 8. //BAP IR for calculating the flags for xor ebx, ebx
 9. goal1:u32 = R_EBX:u32 & 0x80000000:u32
10. R_EBX:u32 = (R_EBX_O2:u32 & R_EBX_T:u32)
              | (R_EBX_C:u32 & ~R_EBX_T:u32)
11. //Same BAP IR for emulating xor
12. goal2:u32 = R_EBX:u32 & 0x80000000:u32
13. goal:bool = goal1:u32 <> goal2:u32
```

Figure 9: Query to determine whether bit 31 of EBX should be tainted

Table IV: **Comparing SPITA with TEMU on tainted shell commands.** "n / m" indicates that "n" bytes are tainted, and "m" tainted EIPs are observed.

Command	SPITA	TEMU
`dir`	207 / 0	639 / 0
`cd`	146 / 0	616 / 0
`cipher c:`	929 / 0	3617 / 0
`echo hello`	660 / 0	3808 / 0
`find "jone" a.txt`	967 / 0	5684 / 0
`findstr /s /i jone ./*`	945 / 0	1333 / 0
`ls`	350 / 3	34923 / 0
`cd`	306 / 3	301 / 0
`cat ./readme`	545 / 31	26619 / 0
`echo hello`	744 / 9	704 / 0
`ln -s a.txt nbench`	1122 / 35	24707 / 0
`mkdir test`	551 / 9	23766 / 0