Instruction Set Filters and Other Exploit Defenses

Changing the architecture to make exploitation harder.

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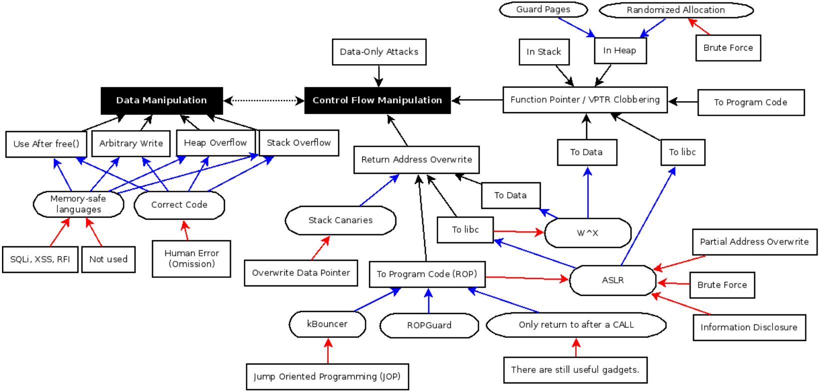
Background

Exploit Defenses

- All sufficiently complex software contains vulnerabilities.
- We want to run vulnerable software and stay safe.
- Defenses developed in response to specific attacks/techniques.
- Attacks developed in response to defenses.

Background

The not-so-periodic table of attack and defense



Background

A simpler defense categorization

- Attacker has to express their malicious computation somehow.
- Think of defenses as limiting the attacker's ability to express their malicious computation.
  1. Prevent attacker from "speaking" the language.
     - $W \oplus X$ (DEP)
     - Stack canaries
     - XFI
  2. Make the language unpredictable.
     - ASLR
     - Instruction set randomization
  3. Make the language smaller or less powerful.
     - RET always returns to an instruction after a CALL
     - Detect unusual call/jump sequences.
     - Enforce an order in which functions can be executed.
     - **Instruction Set Filters**

Background

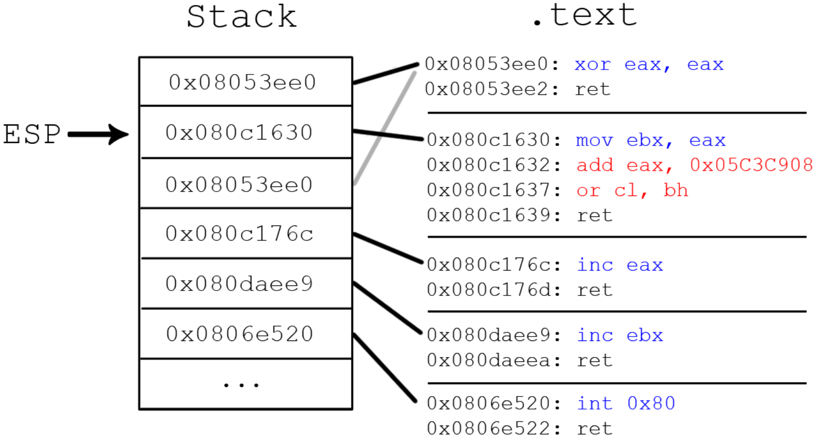
Return Oriented Programming

- Motivation
  - We can't inject our own code because of $W \oplus X$.
  - We can't return to `system()` because of ASLR.
- Let's re-use the application's code to perform our computation.
- Find useful code snippets (called *gadgets*) that end in RET.
- Stitch them together to perform our computation.

Background

Return Oriented Programming Example

- The stack contains our ROP program.
- The stack pointer (ESP) is the new program counter.



Stack

ESP →

0x08053ee0
0x080c1630
0x08053ee0
0x080c176c
0x080daee9
0x0806e520
...

.text

```
0x08053ee0: xor eax, eax
0x08053ee2: ret

0x080c1630: mov ebx, eax
0x080c1632: add eax, 0x05C3C908
0x080c1637: or cl, bh
0x080c1639: ret

0x080c176c: inc eax
0x080c176d: ret

0x080daee9: inc ebx
0x080daeea: ret

0x0806e520: int 0x80
0x0806e522: ret
```

- kBouncer
  - Vasilis Pappas, 2012
  - Winner of Microsoft BlueHat Prize ($200,000)
  - Use Last Branch Recording to keep history of code path.
  - When entering Win32 API call, look for ROP-like patterns.
- Smashing The Gadgets
  - Vasilis Pappas et al., 2012
  - Substitute equiv. instructions (randomizes unintended instrs).
  - Register re-assignment.
  - Randomize the order of instructions.
  - Program does the same thing, but gadgets break.

Background

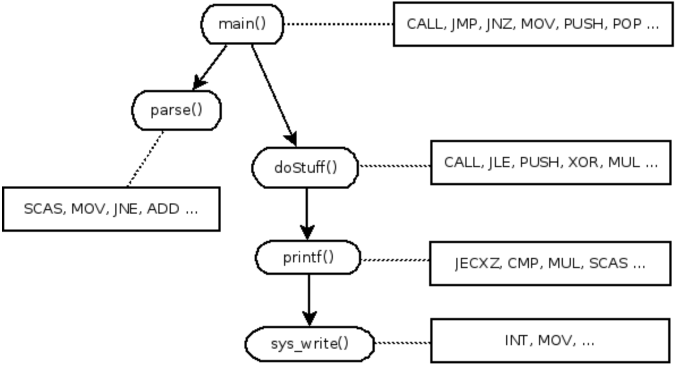
Attacker Model

- Need more rigorous way of evaluating defenses.
- Borrow from cryptography: Model it as a game.
- Chosen-PC Attack (CPCA)
  1. Attacker receives the process's memory and registers.
  2. Attacker sends a list L of N executable addresses.
  3. For each address L_i, start executing at L_i, then just before the next indirect call or jump, go to L_{i+1}.
- Adaptive Chosen-PC Attack (ACPCA)
  1. Attacker receives the process's memory and registers.
  2. Attacker selects an address A.
  3. Execution starts at A until the next indirect call or jump.
  4. Go back to step (1).
- These encompass all code reuse attacks.
- Even with ACPCA-security, *non-control data* attacks are possible.

Instruction Filters

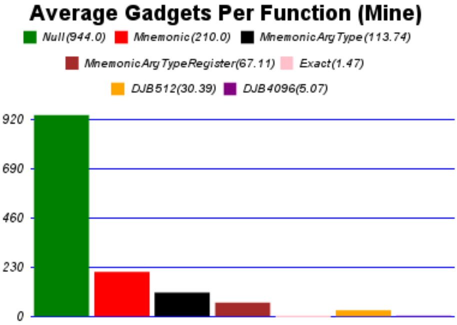
Overview

- Disable parts of the instruction set based on context.
- Protected shadow stack holding the current filters.
- If an exploit is triggered in parse(), INT won't be available.



Instruction Filters
Experimental Results (Apache httpd binary)

The average number of gadgets that would be allowed by a function's instruction filter.



[1]

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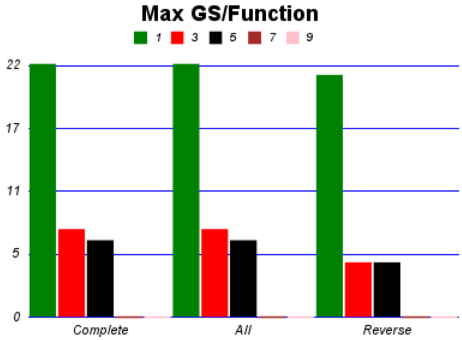
[1] Do not trust this data too much

Instruction Filters

Experimental Results 2 (Apache httpd binary)

Random sample of gadget sequences of different length.

- Complete: Make call graph complete (jump to any filter)
- All: Can traverse any edge of call graph
- Reverse: Can only traverse call edges backwards (returns).



2

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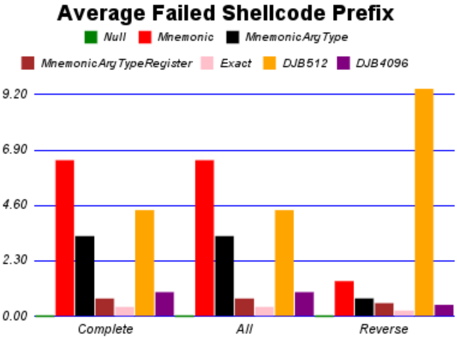
[2] Do not trust this data too much

Instruction Filters

Experimental Results 3 (Apache httpd binary)

If you could inject machine code, how much of a shellcode could you execute? Sample: 200 shellcodes from shell-storm.org.



[3]

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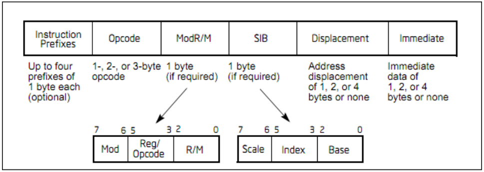
[3] Do not trust this data too much

Implementation
Classifying Instructions



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

- We filter on the opcode number, because it's easy and fast.
- Instructions are mapped to integer between 0x000 and 0x3FF
- Opcodes are either 1 byte, 2 bytes, or 3 bytes:
  1. Opcode = 0x??, Number = 0x0??
  2. Opcode = 0x0F??, Number = 0x1??
  3. Opcode = 0x0F38??, Number = 0x2??
  4. Opcode = 0x0F3A??, Number = 0x3??

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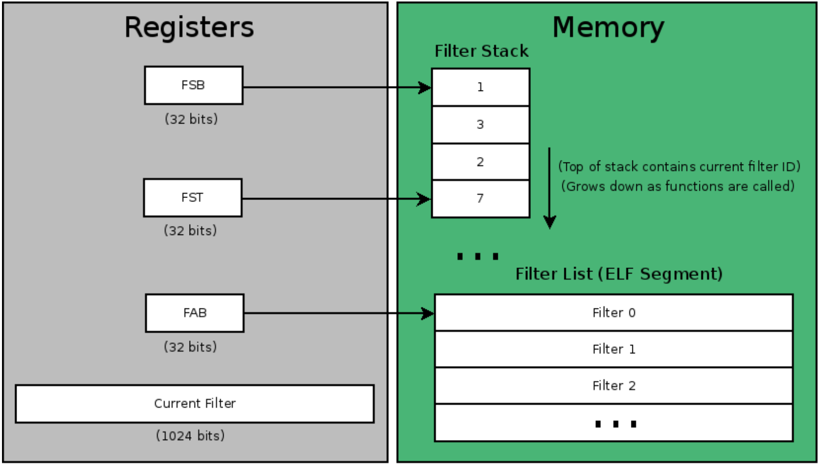
[4] Taken from Intel Software Developer's Manual Volume 2C

Implementation

Registers and Memory



Implementation

New Behaviour

- Added Instructions
  - FLOW *n*: Push *n* onto the filter stack.
  - UNFLOW *n*: Pop *n* from the filter stack.
  - FCHECK *n*: Assert current filter ID is *n*.
  - Privileged instructions for setup and context switching.
- Memory between FST and FSB can only be modified by FLOW or UNFLOW.
- Using PEBIL to add filters to ELF binaries.
  - http://www.sdsc.edu/PMaC/projects/pebil.html

Implementation

Problems

- My implementation doesn't really work.
- This is my fault, not because the idea is bad.
- Problem is with the static instrumentation.
    - Lots of crazy code that needs manual filter exceptions.
    - PEBIL changes the code in weird ways.
- So I just disable the filter for everything that doesn't work, which eliminates many of the security properties.
- The right place to do this is in the compiler.
- But I can show you it stopping an attack...

Demo

Analysis

Attacker's Perspective

- Breaks existing exploits with high probability.
- What about exploits designed with knowledge of the defense?
- Attacker can:
  - Execute code allowed by the current filter.
  - Execute UNFLOW n, which pops the current filter off the stack and enables the previous one (unless the stack is empty).
  - Execute FLOW n, which switches to a different filter. These are always at the start of procedures.
- If the attacker wants to perform some computation, they have to search for a sequence of filters that will let it execute, then find a way to switch into those filters *while* performing the computation (all while reusing the application's code).

Analysis

Work in progress

- Haven't analysed with respect to CPCA or ACPCA
  - Implementation is not complete.
  - Analysis is hard
    - Depends on program state.
    - Attacker's goal needs to be defined.
    - Need tools to perform analysis.

Conclusion

Future

- We need rigorous evaluation of defenses.
- We can have defenses that apply to all exploit techniques.

Questions?