Anti Return-Oriented Programming (ROP)

A Moving Target Defense

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Return oriented programming (ROP) attack

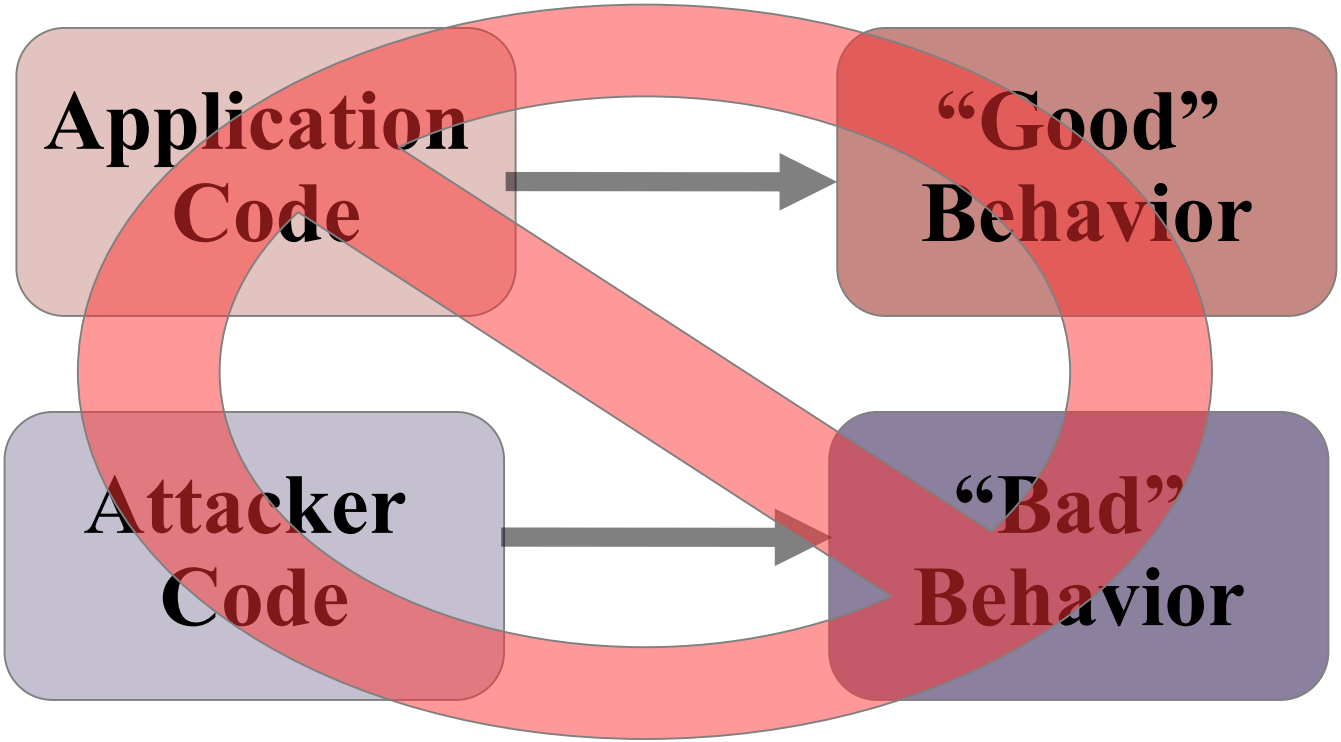
- Return-oriented programming (ROP) is a computer security exploit technique that allows an attacker to execute code in the presence of security defenses such as W⊕X memory and code signing.

- In this technique, an attacker gains control of the call stack or heap etc. to hijack program control flow and then executes carefully chosen machine instruction sequences typically ending with a ‘ret’ instruction (‘gadgets’) allowing an attacker to perform arbitrary operations.

* W⊕X - Each memory page is either Writable OR EXecutable

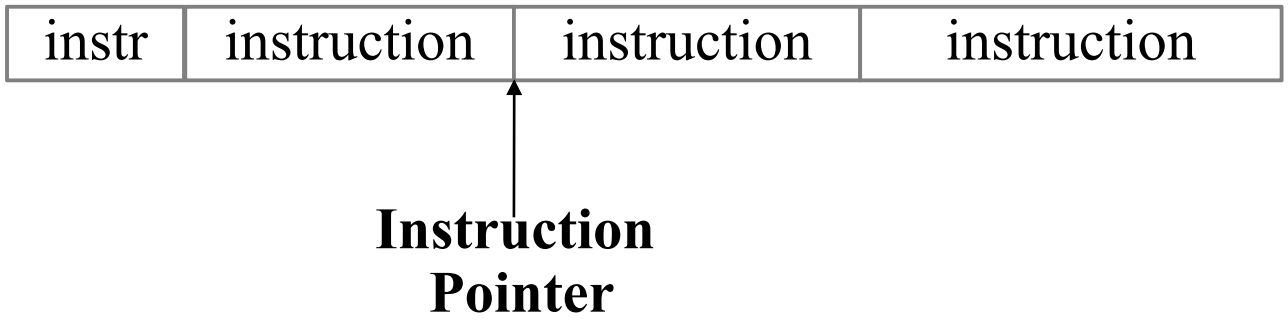
Return oriented programming (ROP) attack

"good" codes may do "bad" behavior



Return oriented programming (ROP) attack

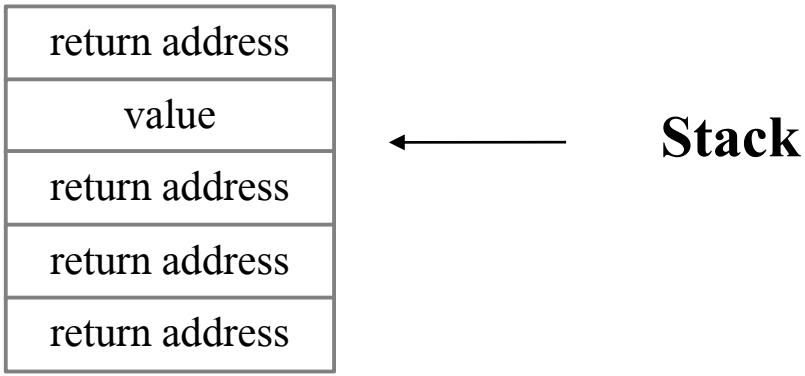
Ordinary programming



The value of Instuction Pointer defines the program control flow

Return oriented programming (ROP) attack

ROP programming



The content of the Stack defines the program control flow

Return oriented programming (ROP) attack

pulls an address into ebx and a value into eax.

```
pop %ebx
pop %eax
ret
```

```
mov %eax, (%ebx)
ret
```

The attacker control the stack's contents and so can make sure these instructions obtain the desired

writes the contents of eax into the memory address pointed to by ebx.

Chaining these together allows an attacker to edit the contents of any memory address the current running thread has permission to alter – this is called arbitrary write

Return oriented programming (ROP) attack

Areas of strength

- Turing-complete (there are ROP compilers)
- Circumvent Data Execution Prevention (NX)
- Circumvent code signing and trusted computing

Existing solutions

- Address Space Layout Randomization (ASLR)
  - ASLR is the state-of-the-art protection against ROP attacks.
  - Randomly choose base address of stack, heap and code segment
  - Randomly pad stack frames and dynamic memory allocation requests (malloc)
  - Randomize location of Global Offset Table
  - Not all files support ASLR
  - Using memory disclosure , the base address of the text section, stack, etc. can be discovered.
  - In 32 bit OS, the randomization range of the address space is small and attackers try to guess or infer the base.

Existing solutions

- Hardware
  - Shadow stack – size, legacy code
  - Branch recording units (LBR, BHRB) – size, pattern based , trigger

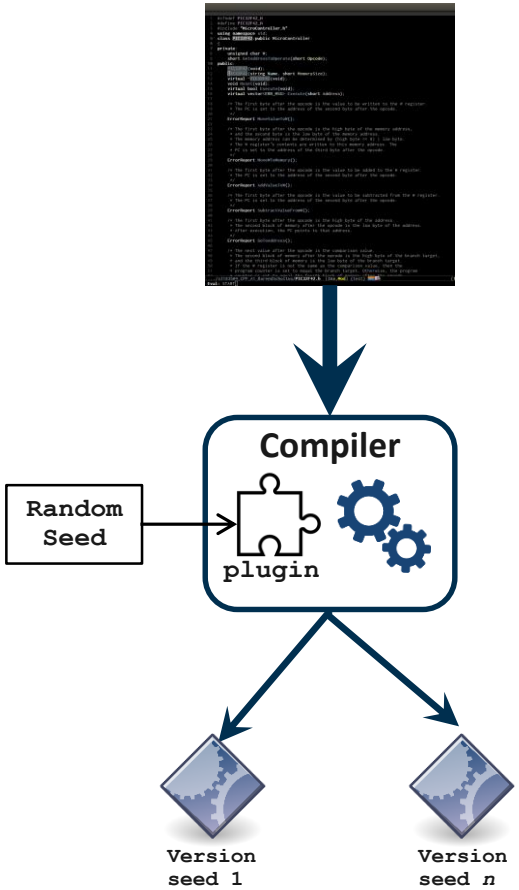
- Software tools
  - kBouncer, ROP guard, ROP pecker
  - Triggers - (e.g. calls to winAPI's, access violation when execution reaches a new page, ret miss-predictions)

Existing solutions - limitations

- Kernel Level Approaches (32 bit processes on linux)
  - Low entropy: heap 13 bit, stack 24 bit
    - De-Randomization attack can defeat ASLR in minutes
  - Kernel support required
  - Pad wastes memory space.
  - Performance overhead
- User Level Approaches
  - Usually easily circumvented if approach is known
  - Limited , hard, ware resources
  - Runtime overhead, pattern based

Solution - Source

- Create many versions of the executable
  - At compilation time, we generate many versions of the executable.
  - These are distinct in binary form, but perform identical functionality
  - Libraries can be shuffled too (assuming we have source code)
  - Attackers have no knowledge regarding memory layout and content of their target
    - Attackers can't gather addresses of ROP widgets to create attack payload



Solution - Source

- How to generate distinct executables/libraries?
  - Shuffle functions order
  - Shuffle objects order
  - Insert empty sections between functions
  - NOPs? Illegal instructions? Dead code
  - Change code alignment

Solution - Source

```
$ SHAKEDOWN_SEED=123 shakedown-clang
mytest.c -o mytest-123

Shakedown: seed=123: Module mytest.c:
shuffling 5 functions... done

$ nm -n mytest-123

…

0000000000400530 t myfunc_a

0000000000400550 T main

0000000000400580 T myfunc_c

00000000004005b0 t myfunc_b

…
```

```
$ SHAKEDOWN_SEED=456 shakedown-clang
mytest.c -o mytest-456

Shakedown: seed=456: Module mytest.c:
shuffling 5 functions... done

$ nm -n mytest-456

…

0000000000400530 t myfunc_b

0000000000400550 T myfunc_c

0000000000400580 T main

00000000004005b0 t myfunc_a

…
```

Solution - binary

- Critical Observation
  - Attackers use absolute addresses during the attacks
- Nullify Attacker's Assumption
  - Makes the memory locations of program objects unpredictable
  - Forces attackers to guess memory location with low probability of success
- Low overhead
- Works on legacy code – backwards compatible – non intrusive
- Instruction level Permutation
- Can be done at load-time (requires OS loader support)
- Code and data segments are permuted with fine-grained randomization.

Solution – binary challenge

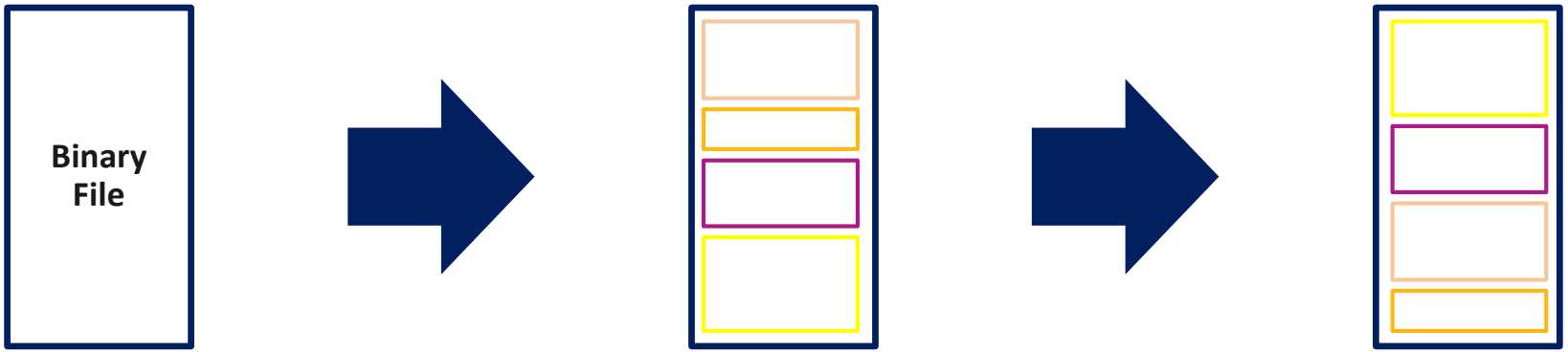
- What parts of an binary file needs rewriting?
- How do we find the correct locations of those parts and rewrite them?
- How those parts affect each other during run time?
- How to find cross-references between program objects

Solution - binary

Read and 'analyze' the binary

Divide it to distinct chunks

Generate random permutation



- *The shuffling has no overhead.*
- *No need for source code*
- *Support legacy code*

- *A different permutation is generated per-invocation*
- *Supports executable binaries and dlls*

Update references to/from the new code/data layout

Thanks