CSci 4271W
Development of Secure Software Systems
Day 8: ROP and Fuzzing

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Outline

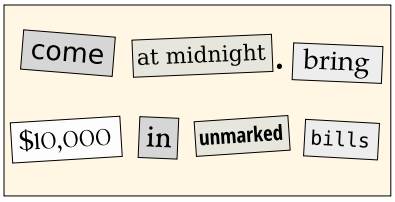
Return-oriented programming (ROP)

Announcements intermission

Testing and fuzzing

ROP shellcoding exercise

Pop culture analogy: ransom note trope



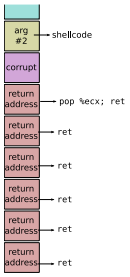
Basic new idea

- Treat the stack like a new instruction set
- "Opcodes" are pointers to existing code
- Generalizes return-to-libc with more programmability
- Academic introduction and source of name: Hovav Shacham, ACM CCS 2007

ret2pop (Nergal, Müller)

- Take advantage of shellcode pointer already present on stack
- Rewrite intervening stack to treat the shellcode pointer like a return address
  - A long sequence of chained returns, one pop

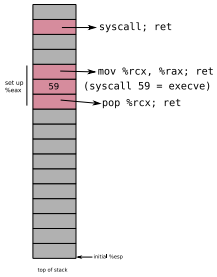
ret2pop (Nergal, Müller)



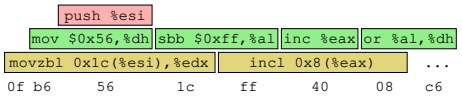
Gadgets

- Basic code unit in ROP
- Any existing instruction sequence that ends in a return
- Found by (possibly automated) search

Another partial example



Overlapping x86 instructions



- Variable length instructions can start at any byte
- Usually only one intended stream

Where gadgets come from

- Possibilities:
  - Entirely intended instructions
  - Entirely unaligned bytes
  - Fall through from unaligned to intended
- Standard x86 return is only one byte, 0xc3

Building instructions

- String together gadgets into manageable units of functionality
- Examples:
  - Loads and stores
  - Arithmetic
  - Unconditional jumps
- Must work around limitations of available gadgets

Hardest case: conditional branch

- Existing jCC instructions not useful
- But carry flag CF is
- Three steps:
  1. Do operation that sets CF
  2. Transfer CF to general-purpose register
  3. Add variable amount to `%esp`

Further advances in ROP

- Can also use other indirect jumps, overlapping not required
- Automation in gadget finding and compilers
- In practice: minimal ROP code to allow transfer to other shellcode

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Note to early readers

- This is the section of the slides most likely to change in the final version
- If class has already happened, make sure you have the latest slides for announcements

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Testing and security

- "Testing shows the presence, not the absence of bugs" – Dijkstra
- Easy versions of some bugs can be found by targeted tests:
  - Buffer overflows: long strings
  - Integer overflows: large numbers
  - Format string vulnerabilities: `%x`

Random or fuzz testing

- Random testing can also sometimes reveal bugs
- Original 'fuzz' (Miller): `program </dev/urandom`
- Even this was surprisingly effective

Mutational fuzzing

- Instead of totally random inputs, make small random changes to normal inputs
- Changes are called *mutations*
- Benign starting inputs are called *seeds*
- Good seeds help in exercising interesting/deep behavior

Grammar-based fuzzing

- Observation: it helps to know what correct inputs look like
- Grammar specifies legal patterns, run backwards with random choices to generate
- Generated inputs can again be basis for mutation
- Most commonly used for standard input formats
  - Network protocols, JavaScript, etc.

What if you don't have a grammar?

- Input format may be unknown, or buggy and limited
- Writing a grammar may be too much manual work
- Can the structure of interesting inputs be figured out automatically?

Coverage-driven fuzzing

- Instrument code to record what code is executed
- An input is interesting if it executes code that was not executed before
- Only interesting inputs are used as basis for future mutation

AFL

- Best known open-source tool, pioneered coverage-driven fuzzing
- American Fuzzy Lop, a breed of rabbits
- Stores coverage information in a compact hash table
- Compiler-based or binary-level instrumentation
- Has a number of other optimizations

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Setup

- Key motivation for ROP is to disable $W \oplus X$
- Can be done with a single syscall, similar to `execve` shellcode
- Your exercise: put together such shellcode from a limited gadget set
- Puzzle/planning aspect: order to avoid overwriting