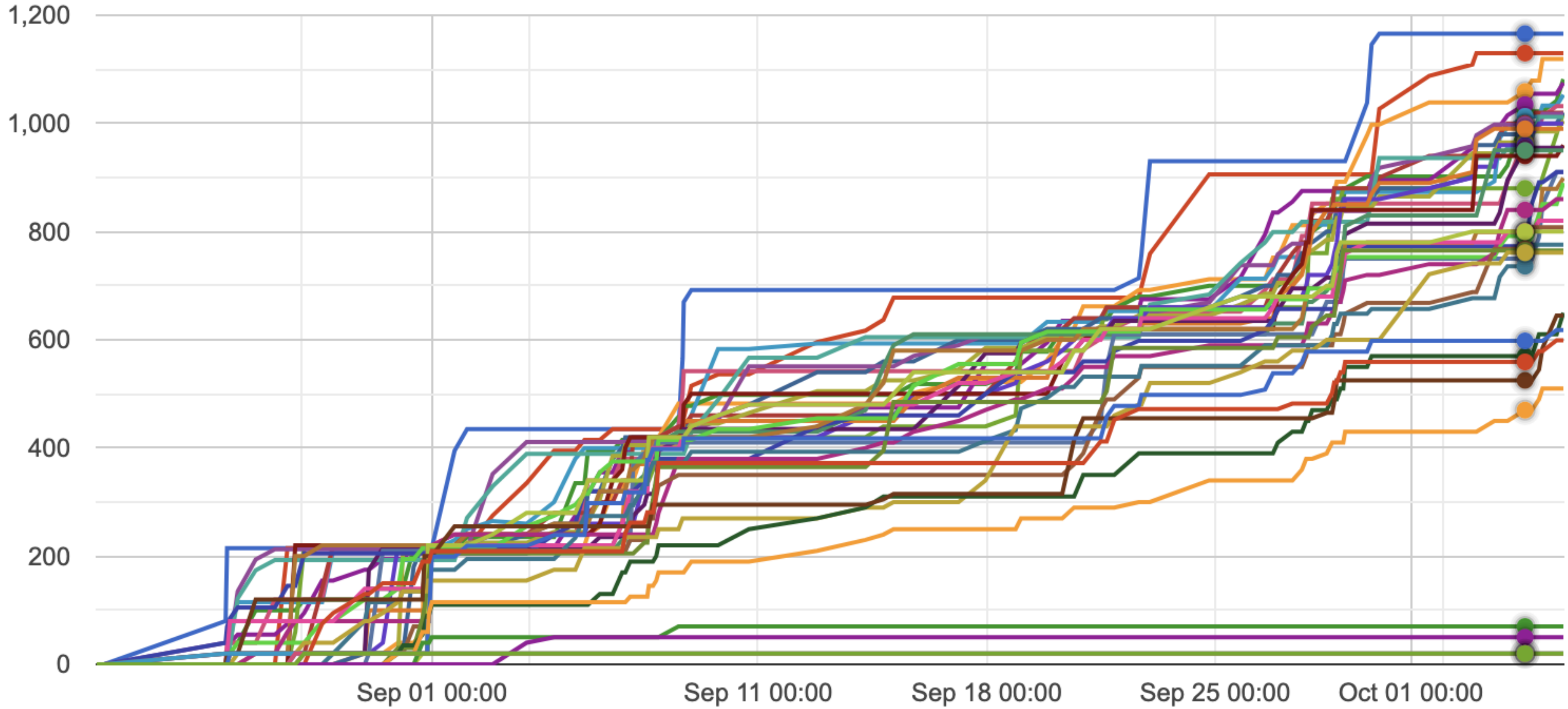
Lec07: Return-oriented Programming

Taesoo Kim

Scoreboard


1,200
1,000
800
600
400
200
0
Sep 01 00:00
Sep 11 00:00
Sep 18 00:00
Sep 25 00:00
Oct 01 00:00

Administrivia

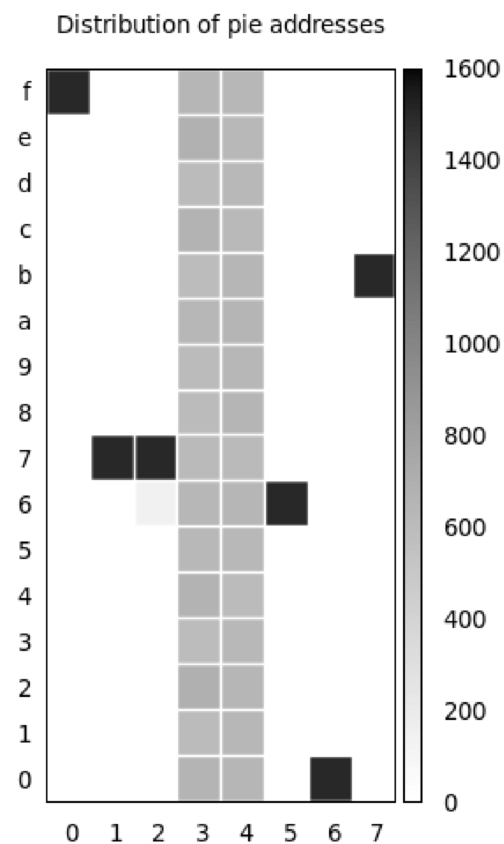
- Congrats! Just completed 50% of labs!
- Due: Lab06 is out and its due on Oct 19 (two weeks)!
- Lab10: NSA Codebreaker Challenge → Due: Dec 08
- In-class CTF (Dec 01): Please find your team mates (3-4 people)!

Discussion: moving-target

- What's `check-aslr.sh` and `pie.c`?
- How many times should we try to exploit?

Lack of entropy is a fundamental limitation (e.g., 32-bit x86).

Discussion: moving-target



→ How many bits of entropy?

Discussion: fmtstr-*?

- fmtstr-read/write/digging are relatviely easy

But, How to Prevent fmtstr-*?

But, How to Prevent fmtstr-*?

1. Relaxing POSIX compliance (e.g., Windows)
    - Discarding `%n` - Q1. Why?
    - Limiting width (e.g., `%.512x` in XP, `%.622496x` in 2000) - Q2. Why?
2. **Dynamic**: enabling `FORTIFY` in gcc (e.g., Ubuntu)
3. **Static**: code annotation (e.g., Linux)

FORTIFY (-D_FORTIFY_SOURCE=2)

- Ensuring that all positional arguments are used
  - e.g., `%2$d` is not ok without `%1$d` - Q3. Why?
- Ensuring that fmtstr is in the read-only region (when `%n`)
  - e.g., `%n` should not be in a writable region - Q4. Why?

```
$ ./fortify-yes %2$d
*** invalid %N$ use detected ***

$ ./fortify-yes %n
*** %n in writable segment detected ***
```

Discussion: mini-sudo (CVE-2012-0809)

- What is `-D9` for?

Discussion: mini-sudo (CVE-2012-0809)

```c
void sudo_debug(int level, const char *fmt, ...) {
  va_list ap;
  char *fmt2;

  if (level > debug_level) return;

  /* Backet fmt with program name and a newline to make it
     a single write */
  easprintf(&fmt2, "%s: %s\n", getprogname(), fmt);
  va_start(ap, fmt);
  vfprintf(stderr, fmt2, ap);
  va_end(ap);
  efree(fmt2);
}
```

CVE-2013-1848: Linux ext3

```c
void ext3_msg(struct super_block *sb, const char *prefix,
        const char *fmt, ...)
{
  struct va_format vaf;
  va_list args;

  va_start(args, fmt);

  vaf.fmt = fmt;
  vaf.va = &args;

  printk("%sEXT3-fs (%s): %pV\n", prefix, sb->s_id, &vaf);

  va_end(args);
}
```

CVE-2013-1848: Linux ext3

- Intended/correct usages:

```
void ext3_msg(struct super_block *sb, const char *prefix,
        const char *fmt, ...);

ext3_msg(sb, KERN_ERR, "Invalid uid value %d", option);
```

CVE-2013-1848: Linux ext3

- What’s wrong? and why so fascinating?

```
// @get_sb_block()
ext3_msg(sb, "error: invalid sb specification: %s",
ata);

// @ext3_blkdev_get()
ext3_msg(sb, "error: failed to open journal device %s:
d",
        __bdevname(dev, b), PTR_ERR(bdev));
```

CVE-2013-1848: Linux ext3

- Annotating fmtstr for automatic checking at compilation time

```
extern __printf(3, 4)
void ext3_msg(struct super_block *sb, const char *prefix,
        const char *fmt, ...);

// Compilation ERROR!
ext3_msg(sb, "error: invalid sb specification: %s",
ata);
ext3_msg(sb, "error: failed to open journal device %s:
d",
         __bdevname(dev, b), PTR_ERR(bdev));
```

→ The compiler checks if the arguments are correctly matched w/ fmt specifiers

Summary of Lab05

- **Fundamental limitations** of DEP/ASLR (e.g., lack of entropy, info leaks)
  - brainfxxk: leaking code pointer
  - logic error: incorrectly using fd
  - profile: uninitialized use + leaking code pointers
- Powerful **format string vulnerability**
  - fmtstr-heap: data pointers not in the input buffer
  - mini-sudo: overwriting local variables

Take-outs from DEP/ASLR?

- Are DEP/ASLR bullet-proof defenses? No!
- Do you think DEP/ASLR make attackers' life more difficult? Yes!

→ Although we can't place shellcode into stack/heap, we can **still** hijack the control flow of a program in many interesting ways

Modern Exploit against DEP/ASLR

1. Leak code pointers
    - i.e., decoding the memory layout of a library or program
2. Construct Return-Oriented Programming (**ROP**!)
    - i.e., arbitrary code execution

→ Need 1+ more bugs that allow leaks and control-flow hijack!

Today’s Tutorial

- In-class tutorial:
  - Ret-to-libc
  - Code pointer leakage / gadget finding
  - First ROP in x86!

Reminder: crackme0x00 (again!)

```c
void start() {
  printf("IOLI Crackme Level 0x00\n");
  printf("Password:");

  char buf[32];
  memset(buf, 0, sizeof(buf));
  read(0, buf, 256);

  if (!strcmp(buf, "250382"))
    printf("Password OK :)\n");
  else
    printf("Invalid Password!\n");
}
```

Reminder: crackme0x00

```
$ checksec ./target
 [*] '/home/lab/tut-rop/target'
  Arch:     i386-32-little
  RELRO:    Partial RELRO      <- (later)
  Stack:    No canary found    <- Hey!
  NX:       NX enabled         <- No shellcode in data sections
  PIE:      No PIE (0x8048000) <- The code section is not randomized
```

Reminder: crackme0x00

```c
int main(int argc, char *argv[]) {
  setvbuf(stdout, NULL, _IONBF, 0);
  setvbuf(stdin, NULL, _IONBF, 0);

  void *self = dlopen(NULL, RTLD_NOW);
  printf("stack    : %p\n", &argc);
  printf("system(): %p\n", dlsym(self, "system"));
  printf("printf(): %p\n", dlsym(self, "printf"));

  start();

  return 0;
}
```

→ Assumed you first leaked these code pointers! (In fact, not needed)!

Ret-to-libc: printf

```
printf("Password OK:)");

[buf  ]
[.....]
[ra   ] => printf
[dummy]
[arg1 ] => "Password OK :)"
```

Ret-to-libc: system

```
system("/bin/sh");

[buf   ]
[.....]
[ra    ] => system
[dummy]
[arg1  ] => "/bin/sh"
```

Chaining Two Function Calls


```
printf("Password OK:)");
system("/bin/sh");
```

Chaining Two Function Calls

```
 printf("Password OK:)");
 system("/bin/sh");

> ret (after stack smashing)

          [buf      ]
          [.....    ]
   esp -> [ra       ] => (1) printf
          [dummy    ]
          [arg1     ] => (1) "Password OK :)"
          [         ]
```

Chaining Two Function Calls

```
 printf("Password OK:)");
 system("/bin/sh");

> push ebp (in printf())

          [buf       ]
          [.....     ]
          [          ]
  esp ->  [dummy     ]
          [arg1      ] => (1) "Password OK :)"
          [          ]
```

Chaining Two Function Calls

```
 printf("Password OK:)");
 system("/bin/sh");

> ret (in printf())

        [buf       ]
        [.....     ]
        [          ]
esp ->  [dummy     ]
        [arg1      ] => (1) "Password OK :)"
        [          ]
```

→ It takes `dummy` as an instruction pointer! so let's chain it.

Chaining Two Function Calls

```
 printf("Password OK:)");
 system("/bin/sh");

> ret (in printf())

         [buf       ]
         [.....     ]
         [          ]
  esp -> [ret       ] -> (2) system
         [arg1      ] => (1) "Password OK :)"
         [          ]
```

→ Where to put system()'s argument?

Chaining Two Function Calls

```
 printf("Password OK:)");
 system("/bin/sh");

> ret (in printf())

        [buf       ]
        [.....     ]
        [          ]
  esp -> [ret       ] -> (2) system
        [old-arg1 ] => (1) "Password OK :)"
        [arg1      ] -> (2) "bin/sh"
```

Chaining Two Function Calls

```
printf("Password OK:)");
system("/bin/sh");
```

```
[buf       ]
[.....     ]
[(1)ret    ] => (1) printf
[(2)ret    ] -> (2) system
[(1)arg1   ] => (1) "Password OK :)"
[(2)arg1   ] -> (2) "bin/sh"
```

Chaining Two Function Calls

```
printf("Password OK:)");
system("/bin/sh");
```

```
[buf       ]
[.....     ]
[(1)ret    ] => (1) printf
[(2)ret    ] -> (2) system
[(1)arg1   ] => (1) "Password OK :)"
[(2)arg1   ] -> (2) "bin/sh"
```

→ What happens when `system()` returns?

Chaining Two Function Calls

```
 printf("Password OK:)");
 system("/bin/sh");

> push ebp (in system())

        [buf       ]
        [.....     ]
        [(1)ret    ] => (1) printf
        [(2)ret    ] -> (2) system
 esp -> [(1)arg1   ] => (1) "Password OK :)"
        [(2)arg1   ] -> (2) "bin/sh"
```

Chaining Two Function Calls

```
printf("Password OK:)");
system("/bin/sh");

> ret (in system())

          [buf        ]
          [.....      ]
          [(1)ret     ] => (1) printf
          [(2)ret     ] -> (2) system
   esp -> [(1)arg1    ] => (1) "Password OK :)"
          [(2)arg1    ] -> (2) "bin/sh"
```

→ Segmentation fault at the address of “Password OK :)”!

Chaining Two Function Calls

```
 printf("Password OK:)");
 system("/bin/sh");

> ret (in system())

          [buf      ]
          [.....    ]
          [(1)ret   ] => (1) printf
          [(2)ret   ] -> (2) system
   esp -> [(1)arg1  ] => (1) "Password OK :)"
          [(2)arg1  ] -> (2) "bin/sh"
```

→ How would you chain more than two calls?

Chaining N Function Calls

```
printf("Password OK:)");
system("/bin/sh");

> ret (in printf())

         [buf       ]
         [.....     ]
         [ret       ] => (1) printf
esp ->   [dummy     ]
         [arg1      ] => (1) "Password OK :)"
         [          ]
```

→ Trick: Clean up the stack first instead of calling system(), making it repeatable!

Chaining N Function Calls

```
 printf("Password OK:)");
 system("/bin/sh");

> ret (in printf())

          [buf       ]
          [.....     ]
          [ret       ] => (1) printf
          [dummy     ]
  ^       [arg1      ] => (1) "Password OK :)"  ^
  +-------------------------------------------+ (first call)
  esp ->  [ret       ] => (2) system
          [dummy     ]
          [arg1      ] => (2) "/bin/sh"
```

→ How to make the stack as if it's first call?

Chaining N Function Calls

```
 printf("Password OK:)");
 system("/bin/sh");

> ret (in printf())

          [buf       ]
          [.....     ]
          [ret       ] => (1) printf
    esp -> [gadget    ] ------------------------------> pop/ret!
          [arg1      ] => (1) "Password OK :)"  ^
        ---------------
          [ret       ] => (2) system
          [dummy     ]
          [arg1      ] => (2) "/bin/sh"
```

→ A code snippet that contains pop/ret (e.g., `pop ebp; ret`)

Chaining N Function Calls

```
printf("Password OK:)");
system("/bin/sh");

> pop ebp (in a pop/ret gadget)

        [buf      ]
        [.....    ]
        [ret      ] => (1) printf
        [gadget   ] ------------------------------> pop/ret!
esp ->  [arg1     ] => (1) "Password OK :)"   ^
      ---------------
        [ret      ] => (2) system
        [dummy    ]
        [arg1     ] => (2) "/bin/sh"
```

→ `pop` will consume one more slot in the stack.

Chaining N Function Calls

```
     printf("Password OK:)");
     system("/bin/sh");

  > ret (in a pop/ret gadget)

          [buf      ]
          [.....    ]
          [ret      ] => (1) printf
          [gadget   ] ------------------------------> pop/ret!
          [arg1     ] => (1) "Password OK :)"  ^
        ---------------
   esp -> [ret      ] => (2) system
          [dummy    ]
          [arg1     ] => (2) "/bin/sh"
```

→ system() will be invoked as if it's a first call

Chaining N Function Calls

```
printf("Password OK:)");
system("/bin/sh");
exit(0);
```

```
      [buf        ]
      [.....      ]
      [ret        ] => (1) printf
      [gadget     ] ------------------------------> pop/ret!
      [arg1       ] => (1) "Password OK :)"  ^
    ---------------
      [ret        ] => (2) system
      [gadget     ] ------------------------------> pop/ret!
      [arg1       ] => (2) "/bin/sh"
    ---------------
      [ret        ] => (3) exit
      [gadget     ] ------------------------------> pop/ret!
      [arg1       ] => (3) 0
```

Calling Functions with 1+ Arguments?

```
open("/proc/flag", O_RDONLY)
...

        [buf         ]
        [.....       ]
        [ret         ] => (1) open
        [gadget      ] ------------------------------> pop/pop/ret!
        [arg1        ] => (1) "/proc/flag"
        [arg2        ] => (1) O_RDONLY
     ---------------
        [ret         ]
        [gadget      ]
        [arg1        ]
        ...
```

→ `pop/pop/ret` will clean up two slots instead!

Today's Tutorial: Chaining Three Calls

```
open("/proc/flag", O_RDONLY)
read(3, tmp, 1024)
write(1, tmp, 1024)
```

In-class Tutorial

- Step1: Ret-to-libc
- Step2: Understanding module base
- Step3: First ROP

```
$ ssh lab06@54.88.195.85
Password: <password>

$ cd tut07-rop
$ cat README
```

References

- ROP
- The advanced return-into-lib(c) exploits