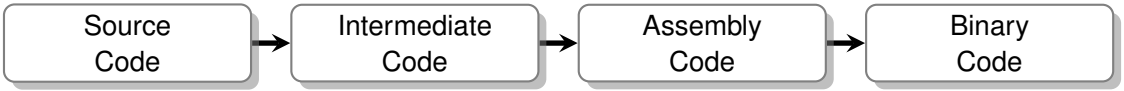
Lec 5: Control Flow Hijack

IS561: Binary Code Analysis and Secure Software Systems

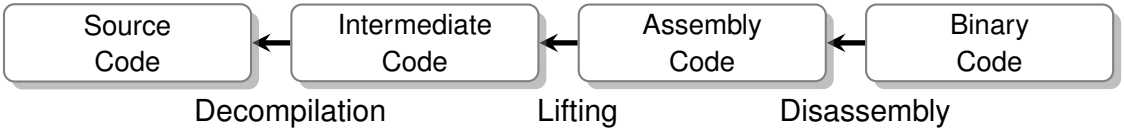
Sang Kil Cha

Disassembly Overview

Compilation Process



Reverse Engineering



Control Flow Hijack

Software Bug

Software bug is an ***error*** in a program.

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Q: What kind of bugs are important for security? If you only have time for fixing one bug out of hundred, which bug will you fix first?

Exploitable Bugs

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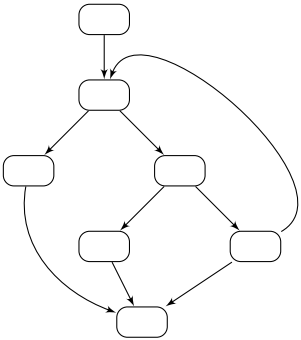
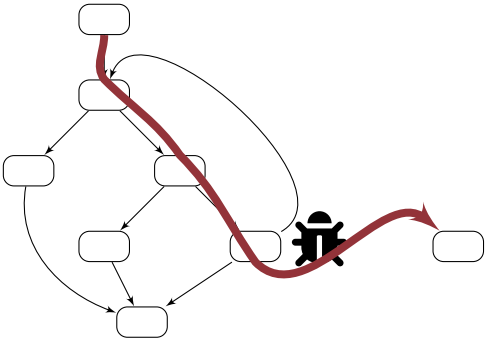
Exploitation is an act of taking advantage of a bug to cause ***unintended behavior*** of the target program.

Some vulnerabilities allow an attacker to run any ***arbitrary code*** on victim's machines without their consent.

Control Flow Hijack Exploit



Control Flow Hijack Exploit



Attacker's own code/logic

The Classic Exploitation

In 1988, the first computer worm (named Morris Worm) was born.

Robert Tappan Morris

- Creator of the worm.
- Cornell graduate.
- Tenured professor at MIT now.

Morris Worm

Exploited a ***buffer overflow*** vulnerability[1] in `fingerd`.

Simplified `fingerd` vulnerability.

```
int main(int argc, char* argv[])
{
  char line[512];
  /* omitted ... */
  gets(line); /* Buffer Overflow! */
  /* omitted ... */
}
```

[1] This simple vulnerability affected 10% of the internet computers in 1988.

Replicating Historic Exploitation

```
int main(int argc, char* argv[])
{
  char line[512];
  gets(line);
  printf(line);
  return 0;
}
```

Compile this program with:

```
$ gcc -m32
-mpreferred-stack-boundary=2 -O0
-fno-pic -no-pie -z execstack -o
morris morris.c
```

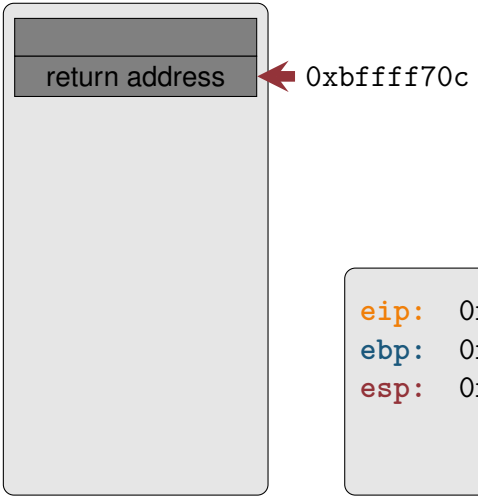
Compiler Warning: morris.c:(.text+0x2a): warning: the ‘gets’ function is dangerous and should not be used.

gets(char *s)

Reads a line from STDIN into the buffer pointed to by s until a terminating newline or EOF, which it replaces with a NULL byte (‘\0’).

★ Type “`man gets`” to see the manual. What does it say?

Analyzing the Vulnerability



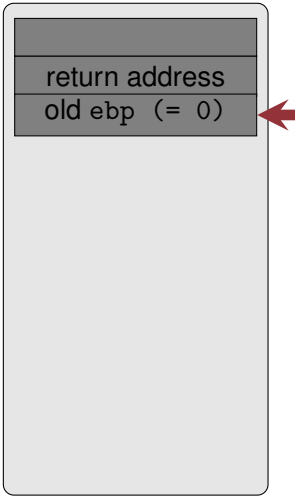
Virtual Memory

```
eip:  0x80483fb
ebp:  0x0
esp:  0xbffff70c
```

Execution Context

```
80483fb <main>:
80483fb: push ebp
80483fc: mov ebp,esp
80483fe: sub esp,0x200
8048404: lea eax,[ebp-0x200]
804840a: push eax
804840b: call 80482d0 ; gets
8048410: add esp,0x4
8048413: mov eax,0x0
8048418: leave
8048419: ret
```

Analyzing the Vulnerability



Virtual Memory

```
eip:  0x80483fc
ebp:  0x0
esp:  0xbffff708
```

Execution Context

```
80483fb <main>:
80483fb: push ebp
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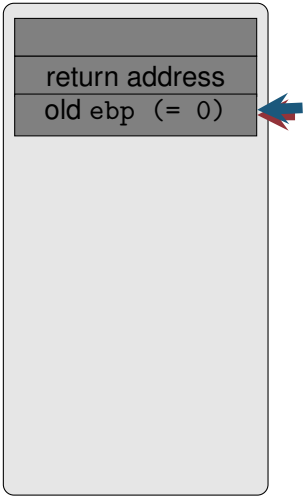

Virtual Memory

```
eip:  0x80483fe
ebp:  0xbffff708
esp:  0xbffff708
```

Execution Context

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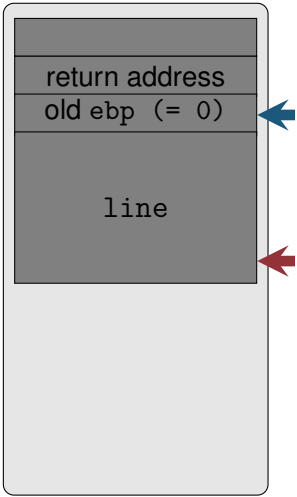

Virtual Memory

```
eip:  0x8048404
ebp:  0xbffff708
esp:  0xbffff508
```

Execution Context

```
80483fb <main>:
80483fb: push ebp
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80483fe: sub esp,0x200
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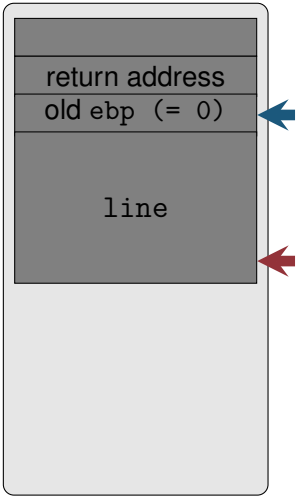

Virtual Memory

```
eip:  0x804840a
ebp:  0xbffff708
esp:  0xbffff508
eax:  0xbffff508
```

Execution Context

```
80483fb <main>:
80483fb: push ebp
80483fc: mov ebp,esp
80483fe: sub esp,0x200
8048404: lea eax,[ebp-0x200]
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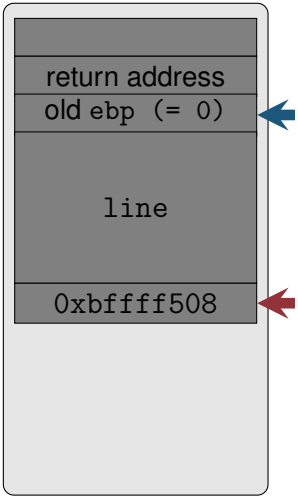

Virtual Memory

```
eip:  0x804840b
ebp:  0xbffff708
esp:  0xbffff504
eax:  0xbffff508
```

Execution Context

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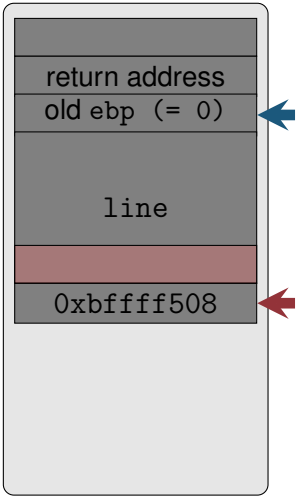

Virtual Memory

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eip:  0x804840b
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```

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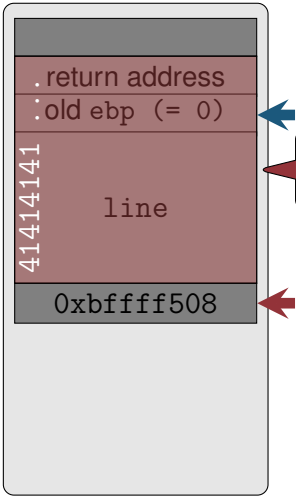

Assume user input is 520 consecutive ‘A’s

```
80483fb <main>:
80483fb: push ebp
80483fc: mov ebp,esp
80483fe: sub esp,0x200
8048404: lea eax,[ebp-0x200]
804840a: push eax
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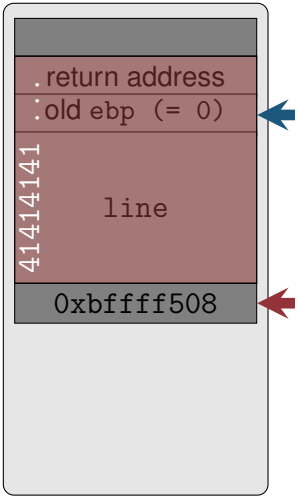
```

```
eip:  0x804840b
ebp:  0xbffff708
esp:  0xbffff504
eax:  0xbffff508
```

Virtual Memory

Execution Context

Analyzing the Vulnerability



Virtual Memory

```
eip:  0x8048410
ebp:  0xbffff708
esp:  0xbffff504
```

Execution Context

```
80483fb <main>:
80483fb: push ebp
80483fc: mov ebp,esp
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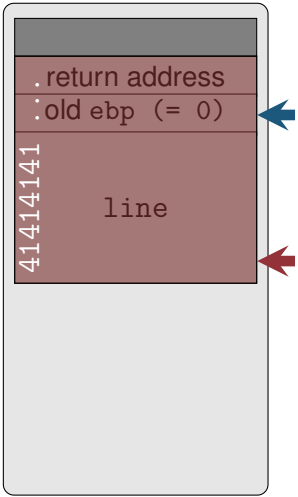

Virtual Memory

```
eip:  0x8048413
ebp:  0xbffff708
esp:  0xbffff508
```

Execution Context

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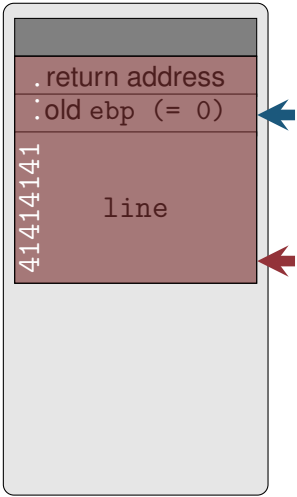

Virtual Memory

```
eip:  0x8048418
ebp:  0xbffff708
esp:  0xbffff508
eax:  0x0
```

Execution Context

```
80483fb <main>:
80483fb: push ebp
80483fc: mov ebp,esp
80483fe: sub esp,0x200
8048404: lea eax,[ebp-0x200]
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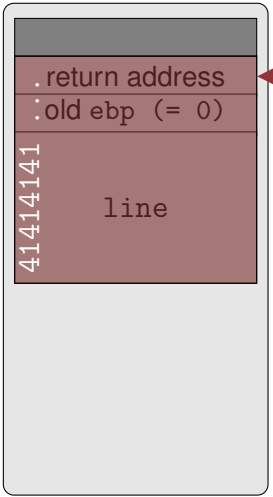

Virtual Memory

```
eip:  0x8048419
ebp:  0x41414141
esp:  0xbffff708
eax:  0x0
```

Execution Context

```
80483fb <main>:
80483fb: push ebp
80483fc: mov ebp,esp
80483fe: sub esp,0x200
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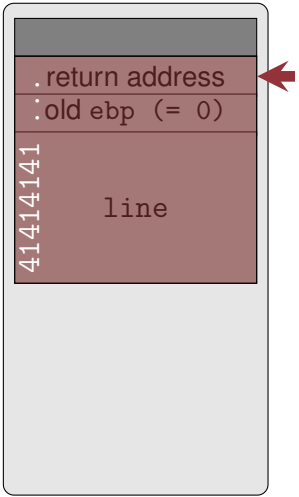
Analyzing the Vulnerability



Virtual Memory

```
eip:  0x41414141
ebp:  0x0
esp:  0xbffff708
eax:  0x0
```

Execution Context

```
80483fb <main>:
80483fb: push ebp
80483fc: mov ebp,esp
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```

```
41414141:  ???
```

So Far ...

- We hijacked the control flow of the program, i.e., we can jump to anywhere!
- But, where do we jump to?

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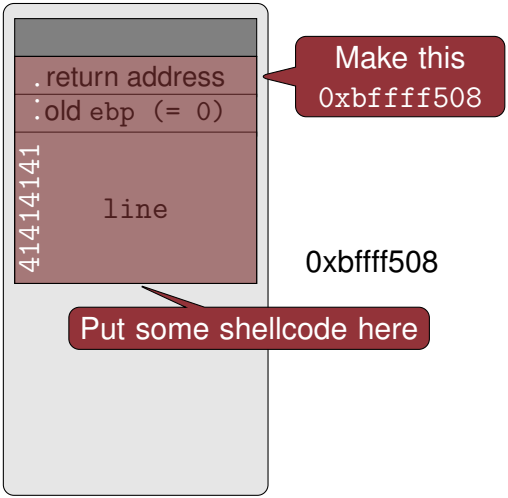
Injecting code to run

Return-to-Stack Exploit



Virtual Memory

Recall Shellcode Requirement

Shellcode should run regardless of the address it is loaded. In other words, it should be ***position independent***.

What to Run?

- Shellcode can run any arbitrary logic
  - Download `/etc/passwd`.
  - Install malicious software (malware).
  - etc.
- But executing `/bin/sh` is mostly enough.
  - This is the most powerful attack: we can run arbitrary commands.
  - You can achieve this with relatively ***small amount of code***.
  - This is the reason why we call it as ***shellcode***.

Simplistic Shellcode: Infinite Loop Shellcode

Writing a shellcode for spawning `/bin/sh` is your homework. Let's use a simpler shellcode here.

```
.intel_syntax noprefix
loop:
        jmp loop
```

Final Exploitation

- Put our shellcode (2 bytes) at the beginning of the buffer.
- Fill the rest of the buffer (510 bytes) with any character (e.g., ‘A’s).
- Overwrite the old `ebp` on the stack with any character.
- Overwrite the return address to point to the shellcode (`0xbffff508`)[2].

[2]The buffer address should differ from machine to machine. Thus, it is necessary to obtain the right address from a debugger (e.g., GDB).

Caveat

We assume that we know the exact address of the buffer.

But, this is not always possible!

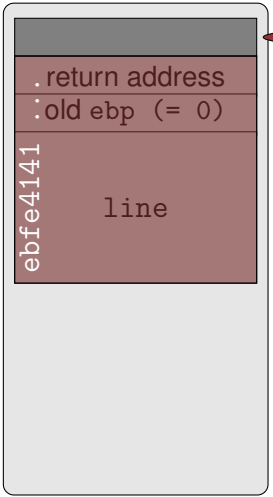
Using GDB

- GDB reference: `http://www.yolinux.com/TUTORIALS/GDB-Commands.html`.
- It is recommended to always turn on the Intel syntax by modifying "`$HOME/.gdbinit`" file.

Exploit w/ or w/o GDB

- The buffer address identified through GDB is not the same as it without GDB.
- Thus, our exploit doesn't work outside GDB!

Why Different?



This space is allocated for storing
environment variables

0xbffff508?

- GDB puts extra environment variables.
- Different machines have different environment variables.

Making Exploit Robust: NOP Sled

NOP sled (a.k.a. NOP slide) is used to make the exploit robust against different buffer addresses.

- One-byte NO-OP (NOP) instruction is equivalent to `xchg eax, eax`.
- 0x90 represents the NOP instruction.

Making Exploit Robust: Environment Variable

This is only for local (non-remote) exploitation.

- We can use an environment variable to store a large payload with a large NOP sled.
- This is useful when the input buffer size is limited.

Off-by-One Error

Subtle Error

```c
#include <stdio.h>
#include <string.h>
#define BUFSIZE  (512)
void printer(char* str)
{
  char buf[BUFSIZE];
  strcpy(buf, str);
  printf("%s\n", buf);
}
int main(int argc, char* argv[])
{
  if ( argc < 2 || strlen(argv[1]) > BUFSIZE ) return -1;
  printer(argv[1]);
  return 0;
}
```

Subtle Error

```
#include <stdio.h>
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#define BUFSIZE  (512)
void printer(char* str)
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int main(int argc, char* argv[])
{
  if ( argc < 2 || strlen(argv[1]) > BUFSIZE ) return -1;
  printer(argv[1]);
  return 0;
}
```
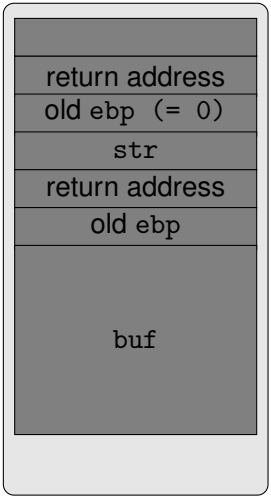

We can just overwrite 1 byte NULL beyond the size of the buffer (`buf`).

Off-by-one Bugs Can be Exploitable



Virtual Memory

`leave` = `mov esp, ebp; pop ebp`

Recommended Reading

Smashing the Stack for Fun and Profit, Phrack 1996, by Alphe One

- `http://phrack.org/issues/49/14.html`

Summary

- Only some bugs are exploitable.
- Some exploits allow an attacker to hijack the control flow of the program and to run any arbitrary code.
- Return-to-stack exploit puts a shellcode on the stack and jumps to it by overwriting the return address.
- We can make return-to-stack exploits robust by using NOP sleds.
- Off-by-one errors can sometimes be exploitable.

Question?

Exercise

- Write your own off-by-one error exploit for the example program.