

15-213 Recitation: Bomb Lab

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Agenda

■ Logistics

- Bomb Lab Overview
- Introduction to GDB
- Appendix
 - GDB and Assembly Tips
 - Activity walkthrough

What is Bomb Lab?

- An exercise in reading x86-64 assembly code.
- A chance to practice using GDB (a debugger).
- Why?
 - x86 assembly is low level machine code. Useful for understanding security exploits or tuning performance.
 - GDB can save you days of work in future labs *cough Malloc cough* and can be helpful long after you finish this class.

Downloading Your Bomb

- All the details you'll need are in the write-up, which you most definitely have to read carefully before starting this lab anyway.

Moving on.

Downloading Your Bomb

- Fine, here are some highlights of the write-up:
 - Bombs can only run on the shark machines. They fail if you run them locally or on another CMU server.
 - Each bomb is unique - if you download a second bomb, bad things can happen! Stick to only one bomb.
 - Bombs have six phases which get progressively harder.

Detonating Your Bomb

- Blowing up your bomb automatically notifies Autolab
 - **Dr. Evil** deducts 0.5 points each time the bomb explodes.
 - It's very easy to prevent explosions using break points in GDB. More information on that soon.
- Inputting the correct string moves you to the next phase.
- Don't tamper with the bomb. Skipping or jumping between phases detonates the bomb.
- You have to solve the phases in order they are given. Finishing a phase also notifies Autolab automatically.

Bomb Hints

- **Dr. Evil** may be evil, but he isn't cruel. You may assume that functions do what their name implies
 - i.e. phase_1() is most likely the first phase. printf() is just printf(). If there is an explode_bomb() function, it would probably help to set a breakpoint there!
- Use the man pages for library functions. Although you can examine the assembly for snprintf(), we assure you that it's easier to use the man pages (`$ man snprintf`) than to decipher assembly code for system calls.

GDB

- You can open gdb by typing into the shell:
- \$ gdb
- This is the notation we'll be using for the rest of the slides:
 - \$ cd // The command should be typed in the bash shell
 - (gdb) break // The command should be typed in GDB

Form Pairs

- One student needs a laptop
- SSH into a shark machine and type these commands:
- \$ wget <http://www.cs.cmu.edu/~213/activities/rec3.tar>
- \$ tar xvzf rec3.tar
- \$ cd rec3
- \$ make
- \$ gdb act1

Source code for Activity 1 (Abridged)

```
#include <stdio.h>

int main(int argc, char** argv) {
    int ret = printf("%s\n", argv[argc-1]);
    return ret;      // number of characters printed
}

// Follow along on the handout!
```

Source code for Activity 2 (Abridged)

```
#include <string.h>

int stc(char*, char*);      // Defined in a separate assembly file
int main(int argc, char** argv) {
    int ret = stc("15213", argv[argc-1]);
    argv[0] = '\0';        // Forces gcc to generate a callq instead of jmp
    return ret;
}

// Follow along on the handout!
```

Activity 3

- Activity 3 has a Bomb Lab feel to it. It will print out “good args!” if you type in the right numbers into the command line. Use GDB to find what numbers to use, and if you get stuck, look at the handout.
- \$ cat act3.c // display the source code of act3
- \$ gdb act3
- Q. Which register holds the return value from a function?
- (Hint: Use disassemble in main and look at what register is used right after the function call to compare)

Activity 4

Use what you have learned to get act4 to print “Finish.”

The source code is available in act4.c if you get stuck. Also, you can ask TAs for help understanding the assembly code.

What to do

- Don't understand what a big block of assembly does? **GDB**
- Need to figure out what's in a specific memory address? **GDB**
- Can't trace how 4 – 6 registers are changing over time? **GDB**
- Have no idea how to start the assignment? **Writeup**
- Need to know how to use certain GDB commands? **Writeup**
 - Also useful: <http://csapp.cs.cmu.edu/2e/docs/gdbnotes-x86-64.pdf>
- Don't know what an assembly instruction does? **Lecture slides**
- Confused about control flow or stack discipline? **Lecture slides**

Appendix

- GDB help
- Assembly help
- Text User Interface (TUI)
- Registers help
- Problem walkthroughs

Basic GDB tips

- Many commands have shortcuts. Dissasemble → disas. Disable → dis
 - Do not mix these up! Disable will disable all your breakpoints, which may cause you to blow up your bomb.
 - (gdb) print [any valid C expression]
 - This can be used to study any kind of local variable or memory location
 - Use casting to get the right type (e.g. print *(long *)ptr)
 - (gdb) x [some format specifier] [some memory address]
 - Examines memory. See the handout for more information. Same as print *(addr), but more convenient.
 - (gdb) set disassemble-next-line on
(gdb) show disassemble-next-line
 - Shows the next assembly instruction after each step instruction
 - (gdb) info registers
 - Shows the values of the registers
 - (gdb) info breakpoints
 - Shows all current breakpoints
 - (gdb) quit
 - Exits gdb

Quick Assembly Info

- \$rdi holds the first argument to a function call, \$rsi holds the second argument, and \$rax will hold the return value of the function call.
- Many functions start with “push %rbx” and end with “pop %rbx”. Long story short, this is because %rbx is “callee-saved”.
- The stack is often used to hold local variables
 - Addresses in the stack are usually in the 0x7fffffff... range
- Know how \$rax is related to \$eax and \$al.
- Most cryptic function calls you’ll see (e.g. `callq ... <_exit@plt>`) are calls to C library functions. If necessary, use the Unix man pages to figure out what the functions do.

Quick Assembly Info

- \$ objdump -d [name of executable] > [any file name]
 - Saves the assembly code of the executable into the file.
 - Feel free to annotate the assembly in your favorite text editor.

```
[dalud@angelshark:~/.../15213/s17/bomb16] $ objdump -d example > example.asm
```

```
0000000000400560 <function>:  
 400560: 48 83 ec 18          sub    $0x18,%rsp           // Setting things up  
 400564: 48 89 7c 24 08      mov    %rdi,0x8(%rsp)  
 400569: 48 83 7c 24 08 00   cmpq   $0x0,0x8(%rsp)      // Checks $rdi against 0  
 40056f: 74 0a                je     40057b <function+0x1b> // Jumps to the "if branch" if equal  
 400571: b8 00 00 00 00      mov    $0x0,%eax  
 400576: e8 0a 00 00 00      callq  400585 <quit>       // Calls "quit" (else branch)  
 40057b: b8 01 00 00 00      mov    $0x1,%eax           // Makes $rax = 1 (if branch)  
 400580: 48 83 c4 18          add    $0x18,%rsp           // Cleaning stuff up  
 400584: c3                  retq   // Looks like the return value is 1
```

Text User Interface (TUI) mode

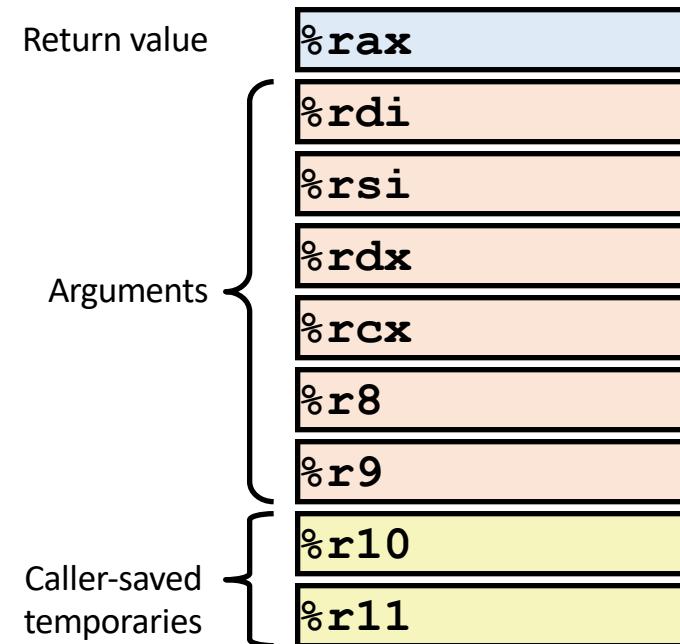
WARNING – do not use!

Although the TUI mode is very convenient, it has been known to accidentally set off student's bombs during Bomblab (but is fine for future labs like malloc).

The course staff is not responsible if your bomb goes off due to the TUI, and will not remove the explosion from Autolab.

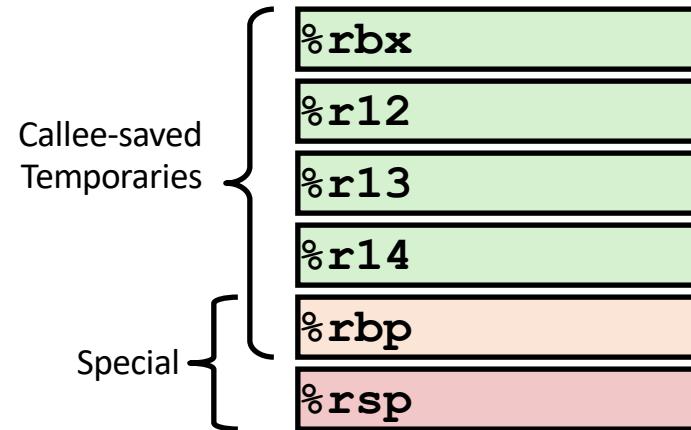
x86-64 Linux Register Usage #1

- **%rax**
 - Return value
 - Also caller-saved
 - Can be modified by procedure
- **%rdi, ..., %r9**
 - Arguments
 - Also caller-saved
 - Can be modified by procedure
- **%r10, %r11**
 - Caller-saved
 - Can be modified by procedure



x86-64 Linux Register Usage #2

- **%rbx, %r12, %r13, %r14**
 - Callee-saved
 - Callee must save & restore
- **%rbp**
 - Callee-saved
 - Callee must save & restore
 - May be used as a frame pointer
 - Can mix & match
- **%rsp**
 - Stack pointer, special form of callee save
 - Restored to original value upon exit from procedure



Activity Walkthroughs

Activity 1 trace

- (gdb) break main // tells GDB to pause right before entering main
- (gdb) run 15213 // starts execution with the argument “15213”
- You should see GDB print out:
- Breakpoint 1, main (argc=2, argv=[...]) at act1.c:5
- (gdb) continue // this continues execution until another break point or the end of execution
- (gdb) clear main // remove the breakpoint at function main
- (gdb) run 15213 // Q: What happens now?

Activity 1 trace

- (gdb) **disassemble main** // show the assembly instructions in main
- (gdb) **print (char*) [0x4...]** // hex code from <+14>
// prints a string
- Find the seemingly random \$0x... value in the assembly code
- Q: Does the printed value correspond to anything in the C code?
- (gdb) **break main**
- (gdb) **run 18213**
- (gdb) **print argv[1]** // Q: What does this print out?
- (gdb) **continue**
- (gdb) **quit** // exit GDB; agree to kill the running process

Activity 2 trace

- \$ gdb act2
 - (gdb) break main
 - (gdb) run
 - (gdb) print /x \$rsi // '/x' means print in hexadecimal
 - (gdb) print /x \$rdi
 - Q. RDI and RSI are registers that pass the first two arguments. Looking at their values, which is the first argument to main (the 'argc' argument)? Why?
-
- (gdb) disassemble main // note the call to stc at <+17>
 - (gdb) break stc // main calls the stc function, so we'll study that function too
 - (gdb) continue
 - Q. How could you view the arguments that have been passed to stc?
 - Try both of these: "print /x \$rdi", "x /s \$rdi"

Activity 2 trace

- (gdb) run 18213 // gdb will ask if you want to restart; choose yes
- (gdb) continue // Q. Which function is in execution now?
- (gdb) disassemble // note the “=>” on the left side
- (gdb) nexti // step through a single x86 instruction
- (gdb)
 - just press enter 3 to 4 times
 - GDB will repeat your previous instruction. Useful for single-stepping.
- (gdb) disassemble
- Q. Now where are the “=>” characters printed?
- (gdb) quit

Activity 3 trace

- \$ cat act3.c // display the source code of act3
- \$ gdb act3
- (gdb) disassemble compare
- Q. Where is the return value set in compare?

- (gdb) break compare
- Now run act3 with two numbers
- Q. Using nexti or stepi, how does the value in register %rbx change, leading to the cmp instruction?

Activity 3 trace

- (gdb) run 5208 10000
- About to run **push %rbx**
- \$rdi = 5208
- \$rsi = 10000
- \$rbx = [\$rbx from somewhere else]
- \$rax = [garbage value]
- Stack:
[some old stack items]
- (gdb) nexti

```
push    %rbx
mov     %rdi,%rbx
add    $0x5,%rbx
add    %rsi,%rbx
cmp    $0x3b6d,%rbx
sete   %al
movzbq %al,%rax
pop    %rbx
retq
```

Activity 3 trace

- About to run `mov %rdi, %rbx`
- `$rdi = 5208`
- `$rsi = 10000`
- `$rbx = [$rbx from somewhere else]`
- `$rax = [garbage value]`
- Stack:
[\$rbx from somewhere else]
[some old stack items]
- (gdb) nexti

```
push    %rbx
mov     %rdi,%rbx
add    $0x5,%rbx
add     %rsi,%rbx
cmp    $0x3b6d,%rbx
sete   %al
movzbq %al,%rax
pop    %rbx
retq
```

Activity 3 trace

- About to run `add $0x5, %rbx`
- `$rdi = 5208`
- `$rsi = 10000`
- `$rbx = 5208`
- `$rax = [garbage value]`
- Stack:
 - `[$rbx from somewhere else]`
 - `[some old stack items]`
- (gdb) nexti

```
push    %rbx
mov     %rdi,%rbx
add    $0x5,%rbx
add     %rsi,%rbx
cmp    $0x3b6d,%rbx
sete   %al
movzbq %al,%rax
pop    %rbx
retq
```

Activity 3 trace

- About to run `add %rsi, %rbx`
- `$rdi = 5208`
- `$rsi = 10000`
- `$rbx = 5213`
- `$rax = [garbage value]`
- Stack:
[\$rbx from somewhere else]
[some old stack items]
- (gdb) nexti

```
push    %rbx
mov     %rdi,%rbx
add    $0x5,%rbx
add    %rsi,%rbx
cmp    $0x3b6d,%rbx
sete   %al
movzbq %al,%rax
pop    %rbx
retq
```

Activity 3 trace

- About to run `cmp 0x3b6d, %rbx`
& other instructions
- `$rdi = 5208`
- `$rsi = 10000`
- `$rbx = 15213 (= 0x3b6d)`
- `$rax = [garbage value]`
- Stack:
 - [`$rbx` from somewhere else]
 - [some old stack items]
- (gdb) `nexti`
- (gdb) `nexti`
- (gdb) `nexti`

```
push    %rbx
mov     %rdi,%rbx
add    $0x5,%rbx
add    %rsi,%rbx
cmp    $0x3b6d,%rbx
sete   %al
movzbq %al,%rax
pop    %rbx
retq
```

Activity 3 trace

- About to run `pop %rbx`
- `$rdi = 5208`
- `$rsi = 10000`
- `$rbx = 15213 = 0x3b6d`
- `$rax = 1`
- Stack:
[\$rbx from somewhere else]
[some old stack items]
- (gdb) nexti

```
push    %rbx
mov     %rdi,%rbx
add    $0x5,%rbx
add     %rsi,%rbx
cmp    $0x3b6d,%rbx
sete   %al
movzbq %al,%rax
pop    %rbx
retq
```

Activity 3 trace

- About to run `retq`
- `$rdi = 5208`
- `$rsi = 10000`
- `$rbx = [$rbx from somewhere else]`
- `$rax = 1`
- Stack:
[some old stack items]

```
push    %rbx
mov     %rdi,%rbx
add    $0x5,%rbx
add    %rsi,%rbx
cmp    $0x3b6d,%rbx
sete   %al
movzbq %al,%rax
pop    %rbx
retq
```

Activity 4 trace

- \$ gdb act4
- (gdb) disassemble main
- Note 3 functions called: strtoll, compute, fwrite
- If you look at the strtoll man page:
 - convert a string to a long integer
- Fwrite is probably a print function. Print values stored into \$rdi immediately before calling fwrite
 - Why are they put into \$rdi?
- Look at addresses at <+60> and <+94>, may be different when you do this
- (gdb) x /s 0x4942c0
 - “Please rerun with a positive number argument\n”
- (gdb) x /s 0x4942f0
 - “Argument was not a positive integer

```
(gdb) disassemble main
Dump of assembler code for function main:
0x0000000000400af0 <+0>:    sub   $0x8,%rsp
0x0000000000400af4 <+4>:    cmp   $0x1,%edi
0x0000000000400af7 <+7>:    je    0x400b1b <main+43>
0x0000000000400af9 <+9>:    mov   $0x8(%rsi),%rdi
0x0000000000400afd <+13>:   mov   $0xa,%edx
0x0000000000400b02 <+18>:   xor   %esi,%esi
0x0000000000400b04 <+20>:   callq $0x401e80 <strtoll>
0x0000000000400b09 <+25>:   test  %eax,%eax
0x0000000000400b0b <+27>:   js    0x400b3d <main+77>
0x0000000000400b0d <+29>:   mov   %eax,%edi
0x0000000000400b0f <+31>:   callq $0x400f20 <compute>
0x0000000000400b14 <+36>:   xor   %eax,%eax
0x0000000000400b16 <+38>:   add   $0x8,%rsp
0x0000000000400b1a <+42>:   retq 
0x0000000000400b1b <+43>:   mov   $0xbcc46(%rip),%rcx      # 0x6bd768 <stderr>
0x0000000000400b22 <+50>:   mov   $0xd,%edx
0x0000000000400b27 <+55>:   mov   $0x1,%esi
0x0000000000400b2c <+60>:   mov   $0x4942c0,%edi
0x0000000000400b31 <+65>:   callq $0x4025b0 <fwrite>
0x0000000000400b36 <+70>:   mov   $0x1,%eax
0x0000000000400b3b <+75>:   jmp   $0x400b16 <main+38>
0x0000000000400b3d <+77>:   mov   $0xbcc24(%rip),%rcx      # 0x6bd768 <stderr>
0x0000000000400b44 <+84>:   mov   $0x24,%edx
0x0000000000400b49 <+89>:   mov   $0x1,%esi
0x0000000000400b4e <+94>:   mov   $0x4942f0,%edi
0x0000000000400b53 <+99>:   callq $0x4025b0 <fwrite>
0x0000000000400b58 <+104>:  mov   $0x1,%eax
0x0000000000400b5d <+109>:  jmp   $0x400b16 <main+38>
End of assembler dump.
```

Activity 4 trace

- (gdb) disassemble compute
- We want it to print “Finish”. Note that the code jumps to <puts> at <+85>. Print the value stored into \$rdi immediately before <+80>
- (gdb) x /s 0x494290
 - “Finish”
- Want to get to either <+77> or <+80>
 - What happens if we get to <+75>?
- Because of <+75>, we know we have to jump to get to the puts jump at <+85>

```
(gdb) disassemble compute
Dump of assembler code for function compute:
0x0000000000400f20 <+0>:    lea    (%rdi,%rdi,2),%eax
0x0000000000400f23 <+3>:    mov    %eax,%edx
0x0000000000400f25 <+5>:    and    $0xf,%edx
0x0000000000400f28 <+8>:    nopl   0x0(%rax,%rax,1)
0x0000000000400f30 <+16>:   cmp    $0x4,%edx
0x0000000000400f33 <+19>:   ja    0x400f53 <compute+51>
0x0000000000400f35 <+21>:   jmpq   *0x494298(%rdx,8)
0x0000000000400f3c <+28>:   nopl   0x0(%rax)
0x0000000000400f40 <+32>:   and    $0x1,%eax
0x0000000000400f43 <+35>:   mov    %eax,%edx
0x0000000000400f45 <+37>:   jmp    0x400f30 <compute+16>
0x0000000000400f47 <+39>:   nopw   0x0(%rax,%rax,1)
0x0000000000400f50 <+48>:   sar    $0x2,%eax
0x0000000000400f53 <+51>:   mov    %eax,%edx
0x0000000000400f55 <+53>:   and    $0xf,%edx
0x0000000000400f58 <+56>:   test   %eax,%eax
0x0000000000400f5a <+58>:   jns    0x400f30 <compute+16>
0x0000000000400f5c <+60>:   repz   retq
0x0000000000400f5e <+62>:   xchg   %ax,%ax
0x0000000000400f60 <+64>:   add    %eax,%eax
0x0000000000400f62 <+66>:   jmp    0x400f53 <compute+51>
0x0000000000400f64 <+68>:   nopl   0x0(%rax)
0x0000000000400f68 <+72>:   sub    $0x1,%eax
0x0000000000400f6b <+75>:   jmp    0x400f53 <compute+51>
0x0000000000400f6d <+77>:   nopl   (%rax)
0x0000000000400f70 <+80>:   mov    $0x494290,%edi
0x0000000000400f75 <+85>:   jmpq   0x4027d0 <puts>

End of assembler dump.
```

Activity 4 trace

- There are 7 jumps. 3 to <+51>, 2 to <+16>, 1 to <puts>, and then:
 - jmpq *0x494298(%rdx,8)
 - Should jump to address *0x494298 + 8 * \$rdx
 - Note, may be different when you do this
- (gdb) x /x *0x494298
 - 0x400f70 <compute+80>
- The only way this get us to where we want to go is if \$rdx = 0.

```
(gdb) disassemble compute
Dump of assembler code for function compute:
0x0000000000400f20 <+0>:    lea    (%rdi,%rdi,2),%eax
0x0000000000400f23 <+3>:    mov    %eax,%edx
0x0000000000400f25 <+5>:    and    $0xf,%edx
0x0000000000400f28 <+8>:    nopl   0x0(%rax,%rax,1)
0x0000000000400f30 <+16>:   cmp    $0x4,%edx
0x0000000000400f33 <+19>:   ja    0x400f53 <compute+51>
0x0000000000400f35 <+21>:   jmpq   *0x494298(%rdx,8)
0x0000000000400f3c <+28>:   nopl   0x0(%rax)
0x0000000000400f40 <+32>:   and    $0x1,%eax
0x0000000000400f43 <+35>:   mov    %eax,%edx
0x0000000000400f45 <+37>:   jmp    0x400f30 <compute+16>
0x0000000000400f47 <+39>:   nopw   0x0(%rax,%rax,1)
0x0000000000400f50 <+48>:   sar    $0x2,%eax
0x0000000000400f53 <+51>:   mov    %eax,%edx
0x0000000000400f55 <+53>:   and    $0xf,%edx
0x0000000000400f58 <+56>:   test   %eax,%eax
0x0000000000400f5a <+58>:   jns    0x400f30 <compute+16>
0x0000000000400f5c <+60>:   repz   retq
0x0000000000400f5e <+62>:   xchg   %ax,%ax
0x0000000000400f60 <+64>:   add    %eax,%eax
0x0000000000400f62 <+66>:   jmp    0x400f53 <compute+51>
0x0000000000400f64 <+68>:   nopl   0x0(%rax)
0x0000000000400f68 <+72>:   sub    $0x1,%eax
0x0000000000400f6b <+75>:   jmp    0x400f53 <compute+51>
0x0000000000400f6d <+77>:   nopl   (%rax)
0x0000000000400f70 <+80>:   mov    $0x494290,%edi
0x0000000000400f75 <+85>:   jmpq   0x4027d0 <puts>

End of assembler dump.
```

Activity 4 trace

- Working backwards from <+21> with \$rdx = 0
- cmp \$0x4, %edx
 - ja will jump to <+51> if 4 > \$edx. Let's try \$edx = 0
- Want \$edx = 0. Thus from <+3> want \$eax = 0
- lea (%rdi,%rdi,2),%eax
 - Does \$eax = \$rdi + 2 * \$rdi = 3 * \$rdi
 - We want \$edx = \$eax = 0, so \$rdi = 0
- Since the input \$rdi = 0, let's run with 0.
- (gdb) run 0
 - What happens?

```
(gdb) disassemble compute
Dump of assembler code for function compute:
0x0000000000400f20 <+0>:    lea    (%rdi,%rdi,2),%eax
0x0000000000400f23 <+3>:    mov    %eax,%edx
0x0000000000400f25 <+5>:    and    $0xf,%edx
0x0000000000400f28 <+8>:    nopl   0x0(%rax,%rax,1)
0x0000000000400f30 <+16>:   cmp    $0x4,%edx
0x0000000000400f33 <+19>:   ja    0x400f53 <compute+51>
0x0000000000400f35 <+21>:   jmpq   *0x494298(%rdx,8)
0x0000000000400f3c <+28>:   nopl   0x0(%rax)
0x0000000000400f40 <+32>:   and    $0x1,%eax
0x0000000000400f43 <+35>:   mov    %eax,%edx
0x0000000000400f45 <+37>:   jmp    0x400f30 <compute+16>
0x0000000000400f47 <+39>:   nopw   0x0(%rax,%rax,1)
0x0000000000400f50 <+48>:   sar    $0x2,%eax
0x0000000000400f53 <+51>:   mov    %eax,%edx
0x0000000000400f55 <+53>:   and    $0xf,%edx
0x0000000000400f58 <+56>:   test   %eax,%eax
0x0000000000400f5a <+58>:   jns    0x400f30 <compute+16>
0x0000000000400f5c <+60>:   repz   retq
0x0000000000400f5e <+62>:   xchg   %ax,%ax
0x0000000000400f60 <+64>:   add    %eax,%eax
0x0000000000400f62 <+66>:   jmp    0x400f53 <compute+51>
0x0000000000400f64 <+68>:   nopl   0x0(%rax)
0x0000000000400f68 <+72>:   sub    $0x1,%eax
0x0000000000400f6b <+75>:   jmp    0x400f53 <compute+51>
0x0000000000400f6d <+77>:   nopl   (%rax)
0x0000000000400f70 <+80>:   mov    $0x494290,%edi
0x0000000000400f75 <+85>:   jmpq   0x4027d0 <puts>

End of assembler dump.
```

Activity 4 trace

- Compare the code to the assembly. Does it do what you expected?
- What do the jump statements to <+16> and <+51> correspond to?
- Working backwards like this could be helpful in bomb lab.

```
(gdb) disassemble compute
Dump of assembler code for function compute:
0x0000000000400f20 <+0>:    lea    (%rdi,%rdi,2),%eax
0x0000000000400f23 <+3>:    mov    %eax,%edx
0x0000000000400f25 <+5>:    and    $0xf,%edx
0x0000000000400f28 <+8>:    nopl   0x0(%rax,%rax,1)
0x0000000000400f30 <+16>:   cmp    $0x4,%edx
0x0000000000400f33 <+19>:   ja    0x400f53 <compute+51>
0x0000000000400f35 <+21>:   jmpq   *0x494298(%rdx,8)
0x0000000000400f3c <+28>:   nopl   0x0(%rax)
0x0000000000400f40 <+32>:   and    $0x1,%eax
0x0000000000400f43 <+35>:   mov    %eax,%edx
0x0000000000400f45 <+37>:   jmp    0x400f30 <compute+16>
0x0000000000400f47 <+39>:   nopw   0x0(%rax,%rax,1)
0x0000000000400f50 <+48>:   sar    $0x2,%eax
0x0000000000400f53 <+51>:   mov    %eax,%edx
0x0000000000400f55 <+53>:   and    $0xf,%edx
0x0000000000400f58 <+56>:   test   %eax,%eax
0x0000000000400f5a <+58>:   jns    0x400f30 <compute+16>
0x0000000000400f5c <+60>:   repz   retq
0x0000000000400f5e <+62>:   xchg   %ax,%ax
0x0000000000400f60 <+64>:   add    %eax,%eax
0x0000000000400f62 <+66>:   jmp    0x400f53 <compute+51>
0x0000000000400f64 <+68>:   nopl   0x0(%rax)
0x0000000000400f68 <+72>:   sub    $0x1,%eax
0x0000000000400f6b <+75>:   jmp    0x400f53 <compute+51>
0x0000000000400f6d <+77>:   nopl   (%rax)
0x0000000000400f70 <+80>:   mov    $0x494290,%edi
0x0000000000400f75 <+85>:   jmpq   0x4027d0 <puts>
End of assembler dump.
```