컴퓨터 SW시스템 개론 Lab3 Report

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1. 개요

Lab 3에서는 gdb를 이용해 bomb 파일의 assembly code를 분석한다. 분석 결과를 이용해 폭탄을 해체하도록 올바른 입력을 넣는다.

2. 구조

먼저 bomb에 선언된 모든 함수를 보기 위해, info function를 입력했다.

```
All defined functions:

File bomb.c:
int main(int, char **);

Non-debugging symbols:
0x0000000000400ad0  _init
0x0000000000400b00  getenv@plt
0x0000000000400b10  strcasecmp@plt
0x0000000000400b20  __errno_location@plt
0x0000000000400b30  strcpy@plt
0x0000000000400b40  puts@plt
0x0000000000400b50  write@plt
0x0000000000400b60  printf@plt
0x0000000000400b70  alarm@plt
0x0000000000400b80  close@plt
0x0000000000400b90  read@plt
0x0000000000400ba0  __libc_start_main@plt
0x0000000000400bb0  fgets@plt
0x0000000000400bc0  signal@plt
0x0000000000400bd0  gethostbyname@plt
0x0000000000400be0  fprintf@plt
0x0000000000400bf0  __gmon_start__@plt
0x0000000000400c00  strtol@plt
0x0000000000400c10  memcpy@plt
0x0000000000400c20  fflush@plt
0x0000000000400c30  __isoc99_sscanf@plt
0x0000000000400c40  bcopy@plt
0x0000000000400c50  fopen@plt
```

```
0x0000000000400c60   gethostname@plt
0x0000000000400c70   sprintf@plt
0x0000000000400c80   exit@plt
0x0000000000400c90   connect@plt
0x0000000000400ca0   sleep@plt
0x0000000000400cb0   __ctype_b_loc@plt
0x0000000000400cc0   socket@plt
0x0000000000400cd0   _start
0x0000000000400d00   deregister_tm_clones
0x0000000000400d30   register_tm_clones
0x0000000000400d70   __do_global_dtors_aux
0x0000000000400d90   frame_dummy
0x0000000000400ef0   phase_1
0x0000000000400f0c   phase_2
0x0000000000400f5b   phase_3
0x00000000004010a5   func4
0x00000000004010dd   phase_4
0x000000000040112e   phase_5
0x000000000040119b   phase_6
0x000000000040128c   fun7
0x00000000004012ca   secret_phase
0x0000000000401320   sig_handler
0x0000000000401371   invalid_phase
0x0000000000401391   string_length
0x00000000004013ae   strings_not_equal
0x0000000000401417   initialize_bomb
0x00000000004014d0   initialize_bomb_solve
0x00000000004014d2   blank_line
0x000000000040150f   skip
0x0000000000401550   send_msg
0x0000000000401614   explode_bomb
0x000000000040164a   read_six_numbers
0x000000000040168c   read_line
0x00000000004017b2   phase_defused
0x0000000000401840   sigalrm_handler
0x0000000000401869   rio_readlineb
0x0000000000401980   submitr
0x000000000040213a   init_timeout
0x0000000000402161   init_driver
```

```
        0x00000000004022ff   driver_post
        0x0000000000402380   __libc_csu_init
        0x00000000004023f0   __libc_csu_fini
        0x00000000004023f4   _fini
```
볼드처리한 함수들은 Lab3에서 분석이 필요했다.

3. main

bomb이 전체 프로세스는 main에서 일어날 것이다. main 함수의 구조를 알기 위해 disas main을 실행했다.

```
Dump of assembler code for function main:
   0x0000000000400dbd <+0>:     push   %rbx
   0x0000000000400dbe <+1>:     cmp    $0x1,%edi
   0x0000000000400dc1 <+4>:     jne    0x400dd3 <main+22>
   0x0000000000400dc3 <+6>:     mov    0x2039be(%rip),%rax        #
0x604788 <stdin@@GLIBC_2.2.5>
   0x0000000000400dca <+13>:    mov    %rax,0x2039cf(%rip)        #
0x6047a0 <infile>
   0x0000000000400dd1 <+20>:    jmp    0x400e2c <main+111>
   0x0000000000400dd3 <+22>:    mov    %rsi,%rbx
   0x0000000000400dd6 <+25>:    cmp    $0x2,%edi
   0x0000000000400dd9 <+28>:    jne    0x400e10 <main+83>
   0x0000000000400ddb <+30>:    mov    0x8(%rsi),%rdi
   0x0000000000400ddf <+34>:    mov    $0x402914,%esi
   0x0000000000400de4 <+39>:    callq  0x400c50 <fopen@plt>
   0x0000000000400de9 <+44>:    mov    %rax,0x2039b0(%rip)        #
0x6047a0 <infile>
   0x0000000000400df0 <+51>:    test   %rax,%rax
   0x0000000000400df3 <+54>:    jne    0x400e2c <main+111>
   0x0000000000400df5 <+56>:    mov    0x8(%rbx),%rdx
   0x0000000000400df9 <+60>:    mov    (%rbx),%rsi
   0x0000000000400dfc <+63>:    mov    $0x402410,%edi
   0x0000000000400e01 <+68>:    callq  0x400b60 <printf@plt>
   0x0000000000400e06 <+73>:    mov    $0x8,%edi
   0x0000000000400e0b <+78>:    callq  0x400c80 <exit@plt>
   0x0000000000400e10 <+83>:    mov    (%rsi),%rsi
   0x0000000000400e13 <+86>:    mov    $0x40242d,%edi
   0x0000000000400e18 <+91>:    mov    $0x0,%eax
   0x0000000000400e1d <+96>:    callq  0x400b60 <printf@plt>
```

```
0x0000000000400e22 <+101>:    mov     $0x8,%edi
0x0000000000400e27 <+106>:    callq   0x400c80 <exit@plt>
0x0000000000400e2c <+111>:    callq   0x401417 <initialize_bomb>
0x0000000000400e31 <+116>:    mov     $0x402498,%edi
0x0000000000400e36 <+121>:    callq   0x400b40 <puts@plt>
0x0000000000400e3b <+126>:    mov     $0x4024d8,%edi
0x0000000000400e40 <+131>:    callq   0x400b40 <puts@plt>
0x0000000000400e45 <+136>:    callq   0x40168c <read_line>
0x0000000000400e4a <+141>:    mov     %rax,%rdi
0x0000000000400e4d <+144>:    callq   0x400ef0 <phase_1>
0x0000000000400e52 <+149>:    callq   0x4017b2 <phase_defused>
0x0000000000400e57 <+154>:    mov     $0x402508,%edi
0x0000000000400e5c <+159>:    callq   0x400b40 <puts@plt>
0x0000000000400e61 <+164>:    callq   0x40168c <read_line>
0x0000000000400e66 <+169>:    mov     %rax,%rdi
0x0000000000400e69 <+172>:    callq   0x400f0c <phase_2>
0x0000000000400e6e <+177>:    callq   0x4017b2 <phase_defused>
0x0000000000400e73 <+182>:    mov     $0x402447,%edi
0x0000000000400e78 <+187>:    callq   0x400b40 <puts@plt>
0x0000000000400e7d <+192>:    callq   0x40168c <read_line>
0x0000000000400e82 <+197>:    mov     %rax,%rdi
0x0000000000400e85 <+200>:    callq   0x400f5b <phase_3>
0x0000000000400e8a <+205>:    callq   0x4017b2 <phase_defused>
0x0000000000400e8f <+210>:    mov     $0x402465,%edi
0x0000000000400e94 <+215>:    callq   0x400b40 <puts@plt>
0x0000000000400e99 <+220>:    callq   0x40168c <read_line>
0x0000000000400e9e <+225>:    mov     %rax,%rdi
0x0000000000400ea1 <+228>:    callq   0x4010dd <phase_4>
0x0000000000400ea6 <+233>:    callq   0x4017b2 <phase_defused>
0x0000000000400eab <+238>:    mov     $0x402538,%edi
0x0000000000400eb0 <+243>:    callq   0x400b40 <puts@plt>
0x0000000000400eb5 <+248>:    callq   0x40168c <read_line>
0x0000000000400eba <+253>:    mov     %rax,%rdi
0x0000000000400ebd <+256>:    callq   0x40112e <phase_5>
0x0000000000400ec2 <+261>:    callq   0x4017b2 <phase_defused>
0x0000000000400ec7 <+266>:    mov     $0x402474,%edi
0x0000000000400ecc <+271>:    callq   0x400b40 <puts@plt>
0x0000000000400ed1 <+276>:    callq   0x40168c <read_line>
0x0000000000400ed6 <+281>:    mov     %rax,%rdi
```

```
    0x0000000000400ed9 <+284>:    callq   0x40119b <phase_6>
    0x0000000000400ede <+289>:    callq   0x4017b2 <phase_defused>
    0x0000000000400ee3 <+294>:    mov     $0x0,%eax
    0x0000000000400ee8 <+299>:    pop     %rbx
    0x0000000000400ee9 <+300>:    retq
End of assembler dump.
```

main의 assembly code를 C-style의 pseudo code로 변화시켜, 코드의 흐름을 제시할 것이다. 코드 전체를 pseudo code로 변환하는 것은 많은 시간을 소요하기에, 필요한 부분만 추출해서 볼 것이다. 또한 자료형의 명시도 엄밀하지 않을 수 있다. 작동이해에는 지장이 없으므로 pseudo code는 strict하게 명시하지 않았다. assembly code에 직접적으로 명시되어 있지 않은 string들은 주소를 참조해 pseudo code에 삽입했다.

```
int main(int, char **)
{
  ... 중략 ...
  puts("Welcome to my fiendish little bomb. You have 6 phases with");
  puts("which to blow yourself up. Have a nice day!");
  line = read_line();
  phase_1(line);
  phase_defused();
  puts("Phase 1 defused. How about the next one?");
  line = read_line();
  phase_2(line);
  phase_defused();
  puts("That's number 2.  Keep going!");
  line = read_line();
  phase_3(line);
  phase_defused();
  puts("Halfway there!");
  line = read_line();
  phase_4(line);
  phase_defused();
  puts("So you got that one.  Try this one.");
  line = read_line();
  phase_5(line);
  phase_defused();
  puts("Good work!  On to the next...");
  line = read_line();
```

```
        phase_6(line);
        phase_defused();
        return 0;
}
```

전체적인 흐름을 요약하면 다음과 같다.

1. line을 읽는다(사용자의 입력을 받는다)
2. phase_{n}을 실행한다.
3. phase_{n}의 실행결과가 올바른 경우, phase_defused()를 실행한다.
4. phase_{n}의 실행결과가 올바르지 않은 경우, explode_bomb을 실행한다. (후술)
5. n을 1~6까지 반복한다.

read_line의 assembly code는 다음과 같다.

```
Dump of assembler code for function read_line:
   0x000000000040168c <+0>:     sub    $0x8,%rsp
   0x0000000000401690 <+4>:     mov    $0x0,%eax
   0x0000000000401695 <+9>:     callq  0x40150f <skip>
   0x000000000040169a <+14>:    test   %rax,%rax
   0x000000000040169d <+17>:    jne    0x40170d <read_line+129>
   0x000000000040169f <+19>:    mov    0x2030e2(%rip),%rax        #
0x604788 <stdin@@GLIBC_2.2.5>
   0x00000000004016a6 <+26>:    cmp    %rax,0x2030f3(%rip)        #
0x6047a0 <infile>
   0x00000000004016ad <+33>:    jne    0x4016c3 <read_line+55>
   0x00000000004016af <+35>:    mov    $0x402893,%edi
   0x00000000004016b4 <+40>:    callq  0x400b40 <puts@plt>
   0x00000000004016b9 <+45>:    mov    $0x8,%edi
   0x00000000004016be <+50>:    callq  0x400c80 <exit@plt>
   0x00000000004016c3 <+55>:    mov    $0x4028b1,%edi
   0x00000000004016c8 <+60>:    callq  0x400b00 <getenv@plt>
   0x00000000004016cd <+65>:    test   %rax,%rax
   0x00000000004016d0 <+68>:    je     0x4016dc <read_line+80>
   0x00000000004016d2 <+70>:    mov    $0x0,%edi
   0x00000000004016d7 <+75>:    callq  0x400c80 <exit@plt>
   0x00000000004016dc <+80>:    mov    0x2030a5(%rip),%rax        #
0x604788 <stdin@@GLIBC_2.2.5>
   0x00000000004016e3 <+87>:    mov    %rax,0x2030b6(%rip)        #
```

```
0x6047a0 <infile>
   0x00000000004016ea <+94>:    mov     $0x0,%eax
   0x00000000004016ef <+99>:    callq   0x40150f <skip>
   0x00000000004016f4 <+104>:   test    %rax,%rax
   0x00000000004016f7 <+107>:   jne     0x40170d <read_line+129>
   0x00000000004016f9 <+109>:   mov     $0x402893,%edi
   0x00000000004016fe <+114>:   callq   0x400b40 <puts@plt>
   0x0000000000401703 <+119>:   mov     $0x0,%edi
   0x0000000000401708 <+124>:   callq   0x400c80 <exit@plt>
   0x000000000040170d <+129>:   mov     0x203089(%rip),%edx        #
0x60479c <num_input_strings>
   0x0000000000401713 <+135>:   movslq %edx,%rax
   0x0000000000401716 <+138>:   lea     (%rax,%rax,4),%rsi
   0x000000000040171a <+142>:   shl     $0x4,%rsi
   0x000000000040171e <+146>:   add     $0x6047c0,%rsi
   0x0000000000401725 <+153>:   mov     %rsi,%rdi
   0x0000000000401728 <+156>:   mov     $0x0,%eax
   0x000000000040172d <+161>:   mov     $0xffffffffffffffff,%rcx
   0x0000000000401734 <+168>:   repnz scas %es:(%rdi),%al
   0x0000000000401736 <+170>:   not     %rcx
   0x0000000000401739 <+173>:   sub     $0x1,%rcx
   0x000000000040173d <+177>:   cmp     $0x4e,%ecx
   0x0000000000401740 <+180>:   jle     0x401788 <read_line+252>
   0x0000000000401742 <+182>:   mov     $0x4028bc,%edi
   0x0000000000401747 <+187>:   callq   0x400b40 <puts@plt>
   0x000000000040174c <+192>:   mov     0x20304a(%rip),%eax        #
0x60479c <num_input_strings>
   0x0000000000401752 <+198>:   lea     0x1(%rax),%edx
   0x0000000000401755 <+201>:   mov     %edx,0x203041(%rip)        #
0x60479c <num_input_strings>
   0x000000000040175b <+207>:   cltq
   0x000000000040175d <+209>:   imul    $0x50,%rax,%rax
   0x0000000000401761 <+213>:   movabs $0x636e7572742a2a2a,%rdi
   0x000000000040176b <+223>:   mov     %rdi,0x6047c0(%rax)
   0x0000000000401772 <+230>:   movabs $0x2a2a2a64657461,%rdi
   0x000000000040177c <+240>:   mov     %rdi,0x6047c8(%rax)
   0x0000000000401783 <+247>:   callq   0x401614 <explode_bomb>
   0x0000000000401788 <+252>:   sub     $0x1,%ecx
   0x000000000040178b <+255>:   movslq %ecx,%rcx
```

```
        0x000000000040178e <+258>:    movslq %edx,%rax
        0x0000000000401791 <+261>:    lea     (%rax,%rax,4),%rax
        0x0000000000401795 <+265>:    shl     $0x4,%rax
        0x0000000000401799 <+269>:    movb    $0x0,0x6047c0(%rcx,%rax,1)
        0x00000000004017a1 <+277>:    add     $0x1,%edx
        0x00000000004017a4 <+280>:    mov     %edx,0x202ff2(%rip)          #
    0x60479c <num_input_strings>
        0x00000000004017aa <+286>:    mov     %rsi,%rax
        0x00000000004017ad <+289>:    add     $0x8,%rsp
        0x00000000004017b1 <+293>:    retq
    End of assembler dump.
```

phase_defused의 assembly code는 다음과 같다.

```
    Dump of assembler code for function phase_defused:
        0x00000000004017b2 <+0>:     sub     $0x68,%rsp
        0x00000000004017b6 <+4>:     mov     $0x1,%edi
        0x00000000004017bb <+9>:     callq   0x401550 <send_msg>
        0x00000000004017c0 <+14>:    cmpl    $0x6,0x202fd5(%rip)          #
    0x60479c <num_input_strings>
        0x00000000004017c7 <+21>:    jne     0x401836 <phase_defused+132>
        0x00000000004017c9 <+23>:    lea     0x10(%rsp),%r8
        0x00000000004017ce <+28>:    lea     0x8(%rsp),%rcx
        0x00000000004017d3 <+33>:    lea     0xc(%rsp),%rdx
        0x00000000004017d8 <+38>:    mov     $0x4028d7,%esi
        0x00000000004017dd <+43>:    mov     $0x6048b0,%edi
        0x00000000004017e2 <+48>:    mov     $0x0,%eax
        0x00000000004017e7 <+53>:    callq   0x400c30 <__isoc99_sscanf@plt>
        0x00000000004017ec <+58>:    cmp     $0x3,%eax
        0x00000000004017ef <+61>:    jne     0x401822 <phase_defused+112>
        0x00000000004017f1 <+63>:    mov     $0x4028e0,%esi
        0x00000000004017f6 <+68>:    lea     0x10(%rsp),%rdi
        0x00000000004017fb <+73>:    callq   0x4013ae <strings_not_equal>
        0x0000000000401800 <+78>:    test    %eax,%eax
        0x0000000000401802 <+80>:    jne     0x401822 <phase_defused+112>
        0x0000000000401804 <+82>:    mov     $0x402738,%edi
        0x0000000000401809 <+87>:    callq   0x400b40 <puts@plt>
        0x000000000040180e <+92>:    mov     $0x402760,%edi
        0x0000000000401813 <+97>:    callq   0x400b40 <puts@plt>
    0x0000000000401818 <+102>:    mov     $0x0,%eax
    0x000000000040181d <+107>:    callq   0x4012ca <secret_phase>
    0x0000000000401822 <+112>:    mov     $0x402798,%edi
    0x0000000000401827 <+117>:    callq   0x400b40 <puts@plt>
    0x000000000040182c <+122>:    mov     $0x4027c8,%edi
    0x0000000000401831 <+127>:    callq   0x400b40 <puts@plt>
    0x0000000000401836 <+132>:    add     $0x68,%rsp
    0x000000000040183a <+136>:    retq
End of assembler dump.
```

secret_phase라는 함수가 호출되는 것을 보아 phase_defused에서 호출하는 phase가 있는 것으로 추정된다. 후에 secret_phase의 진입조건을 찾아볼 것이다.

4. phase_1

disas phase_1을 통해 phase_1의 assembly code를 추출하면 다음과 같다.

```
Dump of assembler code for function phase_1:
    0x0000000000400ef0 <+0>:      sub     $0x8,%rsp
    0x0000000000400ef4 <+4>:      mov     $0x402560,%esi
    0x0000000000400ef9 <+9>:      callq   0x4013ae <strings_not_equal>
    0x0000000000400efe <+14>:     test    %eax,%eax
    0x0000000000400f00 <+16>:     je      0x400f07 <phase_1+23>
    0x0000000000400f02 <+18>:     callq   0x401614 <explode_bomb>
    0x0000000000400f07 <+23>:     add     $0x8,%rsp
    0x0000000000400f0b <+27>:     retq
End of assembler dump.
```

<phase_1+4> 줄에서 rdi 말고 esi가 사용되는 것으로 보아, phase_1 함수는 argument를 한 개 받아 rdi에 저장함을 알 수 있다. esi에는 0x402560주소에 있는 string을 대입하고, strings_not_equal로 string이 edi와 esi가 같은지 검사한다. 같은 경우 <phase_1+23> 줄로 넘어가 리턴하는 것을 보아, 사용자의 입력과 $0x402560에 담긴 string이 같아야 폭탄이 터지지 않는다.

$0x402560에 담긴 string의 값은 다음과 같고, 이것이 phase_1의 답이다.

```
For NASA, space is still a high priority.
```

5. phase_2

disas phase_2를 통해 phase_2의 assembly code를 추출하면 다음과 같다.

```
Dump of assembler code for function phase_2:
   0x0000000000400f0c <+0>:     push   %rbp
   0x0000000000400f0d <+1>:     push   %rbx
   0x0000000000400f0e <+2>:     sub    $0x28,%rsp
   0x0000000000400f12 <+6>:     mov    %rsp,%rsi
   0x0000000000400f15 <+9>:     callq  0x40164a <read_six_numbers>
   0x0000000000400f1a <+14>:    cmpl   $0x0,(%rsp)
   0x0000000000400f1e <+18>:    jne    0x400f27 <phase_2+27>
   0x0000000000400f20 <+20>:    cmpl   $0x1,0x4(%rsp)
   0x0000000000400f25 <+25>:    je     0x400f48 <phase_2+60>
   0x0000000000400f27 <+27>:    callq  0x401614 <explode_bomb>
   0x0000000000400f2c <+32>:    jmp    0x400f48 <phase_2+60>
   0x0000000000400f2e <+34>:    mov    -0x8(%rbx),%eax
   0x0000000000400f31 <+37>:    add    -0x4(%rbx),%eax
   0x0000000000400f34 <+40>:    cmp    %eax,(%rbx)
   0x0000000000400f36 <+42>:    je     0x400f3d <phase_2+49>
   0x0000000000400f38 <+44>:    callq  0x401614 <explode_bomb>
   0x0000000000400f3d <+49>:    add    $0x4,%rbx
   0x0000000000400f41 <+53>:    cmp    %rbp,%rbx
   0x0000000000400f44 <+56>:    jne    0x400f2e <phase_2+34>
   0x0000000000400f46 <+58>:    jmp    0x400f54 <phase_2+72>
   0x0000000000400f48 <+60>:    lea    0x8(%rsp),%rbx
   0x0000000000400f4d <+65>:    lea    0x18(%rsp),%rbp
   0x0000000000400f52 <+70>:    jmp    0x400f2e <phase_2+34>
   0x0000000000400f54 <+72>:    add    $0x28,%rsp
   0x0000000000400f58 <+76>:    pop    %rbx
   0x0000000000400f59 <+77>:    pop    %rbp
   0x0000000000400f5a <+78>:    retq
End of assembler dump.
```

phase_2의 assembly code를 C-style의 pseudo code로 변화시키면 다음과 같다.

```
int phase_2(int arg)
{
int *next;
int result;
int array[6];
```

```
read_six_numbers(arg, array);
if (array[0] != 0 || array[1] != 1)
  explode_bomb();
next = array[2]
do
{
  result = *(array - 1) + *(array -2);
  if (result != *array)
    explode_bomb();
  next++;
} while(next != array + 5)
return;
```

array라는 6자리 배열이고, read_six_numbers로 값을 읽어 array에 값을 대입한다.

따라서 입력값으로 6개의 정수를 넣어줘야 한다.

array[0] != 0 || array[1] != 1이 참일 때 explode_bomb이 호출되므로, array[0]는 0, array[1]은 1이어야 한다.

do-while 문의 내용은 현재 array pointer에 들어있는 값이 전 pointer와 전전 pointer에 들어있는 값들의 합과 같은지 검사한다. 이것을 array의 3번째 원소부터 6번째 원소까지 계속한다. 따라서 do-while문은 array에 담긴 값들이 피보나치 수열의 관계를 만족하고 있는지 검사한다고 판단할 수 있다.

따라서 phase_2의 답은 다음과 같다.

```
0 1 1 2 3 5
```

6. phase_3

disas phase_3를 통해 phase_3의 assembly code를 얻으면 다음과 같다.

```
Dump of assembler code for function phase_3:
   0x0000000000400f5b <+0>:     sub    $0x18,%rsp
   0x0000000000400f5f <+4>:     lea    0x8(%rsp),%r8
   0x0000000000400f64 <+9>:     lea    0x7(%rsp),%rcx
   0x0000000000400f69 <+14>:    lea    0xc(%rsp),%rdx
   0x0000000000400f6e <+19>:    mov    $0x4025b6,%esi
```

```
0x0000000000400f73 <+24>:    mov    $0x0,%eax
0x0000000000400f78 <+29>:    callq  0x400c30 <__isoc99_sscanf@plt>
0x0000000000400f7d <+34>:    cmp    $0x2,%eax
0x0000000000400f80 <+37>:    jg     0x400f87 <phase_3+44>
0x0000000000400f82 <+39>:    callq  0x401614 <explode_bomb>
0x0000000000400f87 <+44>:    cmpl   $0x7,0xc(%rsp)
0x0000000000400f8c <+49>:    ja     0x40108b <phase_3+304>
0x0000000000400f92 <+55>:    mov    0xc(%rsp),%eax
0x0000000000400f96 <+59>:    jmpq   *0x4025c0(,%rax,8)
0x0000000000400f9d <+66>:    mov    $0x76,%eax
0x0000000000400fa2 <+71>:    cmpl   $0x279,0x8(%rsp)
0x0000000000400faa <+79>:    je     0x401095 <phase_3+314>
0x0000000000400fb0 <+85>:    callq  0x401614 <explode_bomb>
0x0000000000400fb5 <+90>:    mov    $0x76,%eax
0x0000000000400fba <+95>:    jmpq   0x401095 <phase_3+314>
0x0000000000400fbf <+100>:   mov    $0x77,%eax
0x0000000000400fc4 <+105>:   cmpl   $0x12b,0x8(%rsp)
0x0000000000400fcc <+113>:   je     0x401095 <phase_3+314>
0x0000000000400fd2 <+119>:   callq  0x401614 <explode_bomb>
0x0000000000400fd7 <+124>:   mov    $0x77,%eax
0x0000000000400fdc <+129>:   jmpq   0x401095 <phase_3+314>
0x0000000000400fe1 <+134>:   mov    $0x68,%eax
0x0000000000400fe6 <+139>:   cmpl   $0x61,0x8(%rsp)
0x0000000000400feb <+144>:   je     0x401095 <phase_3+314>
0x0000000000400ff1 <+150>:   callq  0x401614 <explode_bomb>
0x0000000000400ff6 <+155>:   mov    $0x68,%eax
0x0000000000400ffb <+160>:   jmpq   0x401095 <phase_3+314>
0x0000000000401000 <+165>:   mov    $0x77,%eax
0x0000000000401005 <+170>:   cmpl   $0x1e3,0x8(%rsp)
0x000000000040100d <+178>:   je     0x401095 <phase_3+314>
0x0000000000401013 <+184>:   callq  0x401614 <explode_bomb>
0x0000000000401018 <+189>:   mov    $0x77,%eax
0x000000000040101d <+194>:   jmp    0x401095 <phase_3+314>
0x000000000040101f <+196>:   mov    $0x63,%eax
0x0000000000401024 <+201>:   cmpl   $0x2b7,0x8(%rsp)
0x000000000040102c <+209>:   je     0x401095 <phase_3+314>
0x000000000040102e <+211>:   callq  0x401614 <explode_bomb>
0x0000000000401033 <+216>:   mov    $0x63,%eax
0x0000000000401038 <+221>:   jmp    0x401095 <phase_3+314>
```

```
        0x000000000040103a <+223>:    mov     $0x78,%eax
        0x000000000040103f <+228>:    cmpl    $0x2aa,0x8(%rsp)
        0x0000000000401047 <+236>:    je      0x401095 <phase_3+314>
        0x0000000000401049 <+238>:    callq   0x401614 <explode_bomb>
        0x000000000040104e <+243>:    mov     $0x78,%eax
        0x0000000000401053 <+248>:    jmp     0x401095 <phase_3+314>
        0x0000000000401055 <+250>:    mov     $0x7a,%eax
        0x000000000040105a <+255>:    cmpl    $0x1b0,0x8(%rsp)
        0x0000000000401062 <+263>:    je      0x401095 <phase_3+314>
        0x0000000000401064 <+265>:    callq   0x401614 <explode_bomb>
        0x0000000000401069 <+270>:    mov     $0x7a,%eax
        0x000000000040106e <+275>:    jmp     0x401095 <phase_3+314>
        0x0000000000401070 <+277>:    mov     $0x79,%eax
        0x0000000000401075 <+282>:    cmpl    $0x133,0x8(%rsp)
        0x000000000040107d <+290>:    je      0x401095 <phase_3+314>
        0x000000000040107f <+292>:    callq   0x401614 <explode_bomb>
        0x0000000000401084 <+297>:    mov     $0x79,%eax
        0x0000000000401089 <+302>:    jmp     0x401095 <phase_3+314>
        0x000000000040108b <+304>:    callq   0x401614 <explode_bomb>
        0x0000000000401090 <+309>:    mov     $0x61,%eax
        0x0000000000401095 <+314>:    cmp     0x7(%rsp),%al
        0x0000000000401099 <+318>:    je      0x4010a0 <phase_3+325>
        0x000000000040109b <+320>:    callq   0x401614 <explode_bomb>
        0x00000000004010a0 <+325>:    add     $0x18,%rsp
        0x00000000004010a4 <+329>:    retq
End of assembler dump.
```

phase_3의 assembly code를 C-style의 pseudo code로 변화시키면 다음과 같다.

```
      int phase_3(int arg)
      {
        int result;
        char key;
        int value;
        int mod;

        if ( (int)__isoc99_sscanf(arg, "%d %c %d", &mod, &key, &value) <= 2 )
          explode_bomb();
        switch ( mod )
        {
```

```
case 0:
  result = 118;
  if ( value != 633 )
    explode_bomb();
  return result;
case 1:
  result = 119;
  if ( value != 299 )
    explode_bomb();
  return result;
case 2:
  result = 104;
  if ( value != 97 )
    explode_bomb();
  return result;
case 3:
  result = 119;
  if ( value != 483 )
    explode_bomb();
  return result;
case 4:
  result = 99;
  if ( value != 695 )
    explode_bomb();
  return result;
case 5:
  result = 120;
  if ( value != 682 )
    explode_bomb();
  return result;
case 6:
  result = 122;
  if ( value != 432 )
    explode_bomb();
  return result;
case 7:
  result = 121;
  if ( value != 307 )
    explode_bomb();
```

```
                return result;
            default:
                explode_bomb();
        }
        if ( result != key )
            explode_bomb();
        return result;
}
```

isco_99_scanf의 인자로 mod, key, value가 들어온다. 입력값이 2개 이하이면 explode_bomb이 실행되므로, mod, key, value의 값이 다 들어와야 한다.

switch-case문은 다음과 같은 구조를 가진다.

```
해당하는 case에 대해서:
매칭되는 result 값 할당
case에 매핑된 value와 input value가 다르면 explode_bomb 실행
```

switch-case문을 벗어나면 result와 key를 비교하여 두 값이 같지 않으면 explode_bomb이 실행된다.

따라서 mod, key, value은 다음과 같은 규칙을 따라야 한다.

```
mod: 0 ~ 7 사이 정수 중 아무 값
key: 선택한 mod에 대응되는 result 값
value: 선택한 mod에 대응되는 value 값
```

mod로 5를 선택하면, result는 120 (ascii로 변환시 x), value는 682가 되어야 한다.

따라서 phase_3의 답안은 다음과 같다.

```
5 x 682
```

7. phase_4

disas phase_4를 통해 phase_4의 assembly code를 얻으면 다음과 같다.

```
Dump of assembler code for function phase_4:
   0x00000000004010dd <+0>:     sub    $0x18,%rsp
   0x00000000004010e1 <+4>:     lea    0xc(%rsp),%rcx
   0x00000000004010e6 <+9>:     lea    0x8(%rsp),%rdx
   0x00000000004010eb <+14>:    mov    $0x40288d,%esi
   0x00000000004010f0 <+19>:     mov     $0x0,%eax
   0x00000000004010f5 <+24>:     callq   0x400c30 <__isoc99_sscanf@plt>
   0x00000000004010fa <+29>:     cmp     $0x2,%eax
   0x00000000004010fd <+32>:     jne     0x40110b <phase_4+46>
   0x00000000004010ff <+34>:     mov     0xc(%rsp),%eax
   0x0000000000401103 <+38>:     sub     $0x2,%eax
   0x0000000000401106 <+41>:     cmp     $0x2,%eax
   0x0000000000401109 <+44>:     jbe     0x401110 <phase_4+51>
   0x000000000040110b <+46>:     callq   0x401614 <explode_bomb>
   0x0000000000401110 <+51>:     mov     0xc(%rsp),%esi
   0x0000000000401114 <+55>:     mov     $0x7,%edi
   0x0000000000401119 <+60>:     callq   0x4010a5 <func4>
   0x000000000040111e <+65>:     cmp     0x8(%rsp),%eax
   0x0000000000401122 <+69>:     je      0x401129 <phase_4+76>
   0x0000000000401124 <+71>:     callq   0x401614 <explode_bomb>
   0x0000000000401129 <+76>:     add     $0x18,%rsp
   0x000000000040112d <+80>:     retq
End of assembler dump.
```

phase_4의 assembly code를 C-style의 pseudo code로 변화시키면 다음과 같다.

```
int phase_4(int arg)
{
  int result;
  int key;
  int bias;

  if ( __isoc99_sscanf(a1, "%d %d", &key, &bias) != 2 || bias - 2 > 2 )
    explode_bomb();
  result = func4(7, bias);
  if ( result != key )
    explode_bomb();
  return result;
}
```

input으로 key와 bias를 받는다. (__isoc99_sscanf(a1, "%d %d", &key, &bias) != 2 조건에 따라 key와 bias 모두 받고, bias - 2 > 2 조건에 따라 bias가 4 이하인 값이어야 폭탄이 터지지 않는다.

그 다음 func4를 호출하여, fucn4의 반환값이 key와 같아야 폭탄이 터지지 않는다.

disas func4를 통해 func_4의 assembly code를 얻으면 다음과 같다.

```
Dump of assembler code for function func4:
   0x00000000004010a5 <+0>:     push   %r12
   0x00000000004010a7 <+2>:     push   %rbp
   0x00000000004010a8 <+3>:     push   %rbx
   0x00000000004010a9 <+4>:     mov    %edi,%ebx
   0x00000000004010ab <+6>:     test   %edi,%edi
   0x00000000004010ad <+8>:     jle    0x4010d3 <func4+46>
   0x00000000004010af <+10>:    mov    %esi,%ebp
   0x00000000004010b1 <+12>:    mov    %esi,%eax
   0x00000000004010b3 <+14>:    cmp    $0x1,%edi
   0x00000000004010b6 <+17>:    je     0x4010d8 <func4+51>
   0x00000000004010b8 <+19>:    lea    -0x1(%rdi),%edi
   0x00000000004010bb <+22>:    callq  0x4010a5 <func4>
   0x00000000004010c0 <+27>:    lea    (%rax,%rbp,1),%r12d
   0x00000000004010c4 <+31>:    lea    -0x2(%rbx),%edi
   0x00000000004010c7 <+34>:    mov    %ebp,%esi
   0x00000000004010c9 <+36>:    callq  0x4010a5 <func4>
   0x00000000004010ce <+41>:    add    %r12d,%eax
   0x00000000004010d1 <+44>:    jmp    0x4010d8 <func4+51>
   0x00000000004010d3 <+46>:    mov    $0x0,%eax
   0x00000000004010d8 <+51>:    pop    %rbx
   0x00000000004010d9 <+52>:    pop    %rbp
   0x00000000004010da <+53>:    pop    %r12
   0x00000000004010dc <+55>:    retq
End of assembler dump.
```

func_4의 assembly code를 C-style의 pseudo code로 변화시키면 다음과 같다.

```
int func4(int count, int value)
{
  int result;
  int left_term;

  if ( count <= 0 )
    return 0;
  result = value;
  if ( count != 1 )
  {
    left_term = func4((count - 1), value) + value;
    return left_term + func4((count - 2), value);
    }
    return result;
}
```

재귀함수의 형태를 가짐을 알 수 있다. bias 값이 4 이하이면 되므로, bias를 3으로 지정하고 func4(7, 3)을 계산하면 **99**를 얻을 수 있다.

key에 99가 들어가야 explode_bomb이 실행되지 않고 phase_4를 통과할 수 있다. 따라서 phase_4의 답은 다음과 같다.

```
99 3
```

8. phase_5

disas phase_5를 통해 phase_5의 assembly code를 추출하면 다음과 같다.

```
Dump of assembler code for function phase_5:
   0x000000000040112e <+0>:     sub    $0x18,%rsp
   0x0000000000401132 <+4>:     lea    0x8(%rsp),%rcx
   0x0000000000401137 <+9>:     lea    0xc(%rsp),%rdx
   0x000000000040113c <+14>:    mov    $0x40288d,%esi
   0x0000000000401141 <+19>:    mov    $0x0,%eax
   0x0000000000401146 <+24>:    callq  0x400c30 <__isoc99_sscanf@plt>
   0x000000000040114b <+29>:    cmp    $0x1,%eax
   0x000000000040114e <+32>:    jg     0x401155 <phase_5+39>
   0x0000000000401150 <+34>:    callq  0x401614 <explode_bomb>
   0x0000000000401155 <+39>:    mov    0xc(%rsp),%eax
   0x0000000000401159 <+43>:    and    $0xf,%eax
   0x000000000040115c <+46>:    mov    %eax,0xc(%rsp)
   0x0000000000401160 <+50>:    cmp    $0xf,%eax
   0x0000000000401163 <+53>:    je     0x401191 <phase_5+99>
   0x0000000000401165 <+55>:    mov    $0x0,%ecx
   0x000000000040116a <+60>:    mov    $0x0,%edx
   0x000000000040116f <+65>:    add    $0x1,%edx
   0x0000000000401172 <+68>:    cltq
   0x0000000000401174 <+70>:    mov    0x402600(,%rax,4),%eax
   0x000000000040117b <+77>:    add    %eax,%ecx
   0x000000000040117d <+79>:    cmp    $0xf,%eax
   0x0000000000401180 <+82>:    jne    0x40116f <phase_5+65>
   0x0000000000401182 <+84>:    mov    %eax,0xc(%rsp)
   0x0000000000401186 <+88>:    cmp    $0xf,%edx
```

```
        0x0000000000401189 <+91>:     jne     0x401191 <phase_5+99>
        0x000000000040118b <+93>:     cmp     0x8(%rsp),%ecx
        0x000000000040118f <+97>:     je      0x401196 <phase_5+104>
        0x0000000000401191 <+99>:     callq   0x401614 <explode_bomb>
        0x0000000000401196 <+104>:    add     $0x18,%rsp
        0x000000000040119a <+108>:    retq
      End of assembler dump.
```

phase_5의 assembly code를 C-style의 pseudo code로 변화시키면 다음과 같다.

```
      int phase_5(int arg)
      {
        int result;
        int sum;
        int count;
        int input_sum;
        int index;

        if ( __isoc99_sscanf(arg, "%d %d", &index, &input_sum) <= 1 )
          explode_bomb();
        LODWORD(result) = index & 0xF;
        index = result;
        if (result == 15 )
          explode_bomb();
        sum = 0;
        count = 0;
        do
        {
          count++;
          index = array_3160[index];
          sum += index;
        }
        while ( index != 15 );
        if ( count != 15 || sum != input_sum )
          explode_bomb();
        return result;
}
```

array_3160(0x402600)의 값은 다음과 같다.

```
0xA, 0x2, 0xE, 0x7, 0x8, 0xC, 0xF, 0xB, 0x0, 0x4, 0x1, 0xD, 0x3, 0x9, 0x6, 0x5
```

phase5는 index와 input_sum을 입력받는다. (__isoc99_sscanf의 반환값이 1 이하이면

explode_bomb()이 실행되므로, index와 input_sum 모두 입력해야한다.

index에 0xF를 마스킹해주어 index가 15이하의 값만 가지도록 만들어준다.

index의 초기값이 15이면 explode_bomb이 실행되므로, index의 초기값은 15가 아니다.

array_3160을 총 16번 읽는데, index는 각 array_3160 값으로 설정되고, array_3160은 0~15의 값을 저장하므로 index에 array_3160의 index가 다시 들어감을 알 수 있다.

그리고 sum에 index들의 합을 저장한다.

do-while문 종료 후 count가 15, input_sum이 sum과 같으면 phase_5를 통과할 수 있다.

count가 15가 될 때 do-while문이 종료되는 index를 찾아보면 그 값은 5이고, index가 5일 때 sum은 115이므로 input_sum은 115이어야한다.

따라서 phase_5의 답은 다음과 같다.

```
5 115
```

9. phase_6

disas phase_6를 통해 phase_6의 assembly code를 얻으면 다음과 같다.

```
Dump of assembler code for function phase_6:
   0x000000000040119b <+0>:     push   %r13
   0x000000000040119d <+2>:     push   %r12
   0x000000000040119f <+4>:     push   %rbp
   0x00000000004011a0 <+5>:     push   %rbx
   0x00000000004011a1 <+6>:     sub    $0x58,%rsp
   0x00000000004011a5 <+10>:    lea    0x30(%rsp),%rsi
   0x00000000004011aa <+15>:    callq  0x40164a <read_six_numbers>
   0x00000000004011af <+20>:    lea    0x30(%rsp),%r13
   0x00000000004011b4 <+25>:    mov    $0x0,%r12d
   0x00000000004011ba <+31>:    mov    %r13,%rbp
   0x00000000004011bd <+34>:    mov    0x0(%r13),%eax
   0x00000000004011c1 <+38>:    sub    $0x1,%eax
   0x00000000004011c4 <+41>:    cmp    $0x5,%eax
   0x00000000004011c7 <+44>:    jbe    0x4011ce <phase_6+51>
   0x00000000004011c9 <+46>:    callq  0x401614 <explode_bomb>
   0x00000000004011ce <+51>:    add    $0x1,%r12d
   0x00000000004011d2 <+55>:    cmp    $0x6,%r12d
   0x00000000004011d6 <+59>:    jne    0x4011df <phase_6+68>
```

```
0x00000000004011d8 <+61>:    mov    $0x0,%esi
0x00000000004011dd <+66>:    jmp    0x401221 <phase_6+134>
0x00000000004011df <+68>:    mov    %r12d,%ebx
0x00000000004011e2 <+71>:    movslq %ebx,%rax
0x00000000004011e5 <+74>:    mov    0x30(%rsp,%rax,4),%eax
0x00000000004011e9 <+78>:    cmp    %eax,0x0(%rbp)
0x00000000004011ec <+81>:    jne    0x4011f3 <phase_6+88>
0x00000000004011ee <+83>:    callq  0x401614 <explode_bomb>
0x00000000004011f3 <+88>:    add    $0x1,%ebx
0x00000000004011f6 <+91>:    cmp    $0x5,%ebx
0x00000000004011f9 <+94>:    jle    0x4011e2 <phase_6+71>
0x00000000004011fb <+96>:    add    $0x4,%r13
0x00000000004011ff <+100>:   jmp    0x4011ba <phase_6+31>
0x0000000000401201 <+102>:   mov    0x8(%rdx),%rdx
0x0000000000401205 <+106>:   add    $0x1,%eax
0x0000000000401208 <+109>:   cmp    %ecx,%eax
0x000000000040120a <+111>:   jne    0x401201 <phase_6+102>
0x000000000040120c <+113>:   jmp    0x401213 <phase_6+120>
0x000000000040120e <+115>:   mov    $0x6042f0,%edx
0x0000000000401213 <+120>:   mov    %rdx,(%rsp,%rsi,2)
0x0000000000401217 <+124>:   add    $0x4,%rsi
0x000000000040121b <+128>:   cmp    $0x18,%rsi
0x000000000040121f <+132>:   je     0x401236 <phase_6+155>
0x0000000000401221 <+134>:   mov    0x30(%rsp,%rsi,1),%ecx
0x0000000000401225 <+138>:   cmp    $0x1,%ecx
0x0000000000401228 <+141>:   jle    0x40120e <phase_6+115>
0x000000000040122a <+143>:   mov    $0x1,%eax
0x000000000040122f <+148>:   mov    $0x6042f0,%edx
0x0000000000401234 <+153>:   jmp    0x401201 <phase_6+102>
0x0000000000401236 <+155>:   mov    (%rsp),%rbx
0x000000000040123a <+159>:   lea    0x8(%rsp),%rax
0x000000000040123f <+164>:   lea    0x30(%rsp),%rsi
0x0000000000401244 <+169>:   mov    %rbx,%rcx
0x0000000000401247 <+172>:   mov    (%rax),%rdx
0x000000000040124a <+175>:   mov    %rdx,0x8(%rcx)
0x000000000040124e <+179>:   add    $0x8,%rax
0x0000000000401252 <+183>:   cmp    %rsi,%rax
0x0000000000401255 <+186>:   je     0x40125c <phase_6+193>
0x0000000000401257 <+188>:   mov    %rdx,%rcx
```

```
            0x000000000040125a <+191>:    jmp      0x401247 <phase_6+172>
            0x000000000040125c <+193>:    movq     $0x0,0x8(%rdx)
            0x0000000000401264 <+201>:    mov      $0x5,%ebp
            0x0000000000401269 <+206>:    mov      0x8(%rbx),%rax
            0x000000000040126d <+210>:    mov      (%rax),%eax
            0x000000000040126f <+212>:    cmp      %eax,(%rbx)
            0x0000000000401271 <+214>:    jge      0x401278 <phase_6+221>
            0x0000000000401273 <+216>:    callq    0x401614 <explode_bomb>
            0x0000000000401278 <+221>:    mov      0x8(%rbx),%rbx
            0x000000000040127c <+225>:    sub      $0x1,%ebp
            0x000000000040127f <+228>:    jne      0x401269 <phase_6+206>
            0x0000000000401281 <+230>:    add      $0x58,%rsp
            0x0000000000401285 <+234>:    pop      %rbx
            0x0000000000401286 <+235>:    pop      %rbp
            0x0000000000401287 <+236>:    pop      %r12
            0x0000000000401289 <+238>:    pop      %r13
            0x000000000040128b <+240>:    retq
End of assembler dump.
```

phase_6의 assembly code를 C-style의 pseudo code로 변화시키면 다음과 같다.

```
int phase_6(int arg)
{
    int *array_ptr;
    int count;
    int i;
    int index;
    node* *node_ptr;
    int node_count
    int node_index
    node* head;
    node* node_link;
    node* j;
    node* temp;
    int node_index2;
    int result;
    node *node_array;
    int array[6];

    read_six_numbers(arg, array);
```

```
array_ptr = array;
count = 0;
while ( 1 )
{
  if (*array_ptr - 1 > 5 )
    explode_bomb();
  count++;
  if ( count == 6 )
    break;
  index = count;
  do
  {
    if ( *array_ptr == array[index] )
      explode_bomb();
    index++;
  }
  while ( index <= 5 );
  array_ptr++;
}
for ( i = 0; i != 6; i++ )
{
  node_index = array[i];
  if ( node_index <= 1 )
    node_ptr = &node1;
  else
  {
    node_count = 1;
    node_ptr = &node1;
    do
    {
      node_ptr = (_QWORD *)node_ptr[1];
      node_count++;
    }
    while ( node_count != node_index );
  }
  * (&node_array + i) = node_ptr;
}
head = node_array;
node_link = &(node_array[1]);
```

```
          for ( j = node_array; ; j = temp )
          {
             temp = node_link;
             j->next = node_link;
             node_link = node_link + 1;
             if ( node_link == (end_of_node_array) )
                break;
          }
          temp->next = 0;
          node_index2 = 5;
          do
          {
             result = (head->next)->value;
             if ( head->value < result )
                explode_bomb();
             head = head->next;
             node_index2--;
          }
          while (node_index2 != 0);
          return result;
}
```

node1은 linked list의 node의 구조를 가지고 있다. 위의 pseudo code는 node의 구조가 다음과 같은 구조라고 가정하고 구성하였다.

```
struct node
{
   int value;         // <+0>
   node* next;        // <+8>
}
```

node는 총 node1, node2, node3, node4, node5, node6가 있다. 각각 value는 다음과 같다.

```
node1.value = 0x0CA
node2.value = 0x3C0
node3.value = 0x05B
node4.value = 0x209
node5.value = 0x132
```

```
node6.value = 0x1E7
```

pseudo code를 해석하면 다음과 같다.

1. array에 6자리 정수를 담는다.
2. array에 있는 정수 중 모든 정수가 서로 다르다면 explode_bomb을 실행시키지 않고, 그렇지 않다면 실행한다.
3. node_array[i]에 각각 node_{array[i]}의 주소를 넣어준다.
4. node_array의 순서에 따라 node들의 next들을 다음 node로 연결해준다. (곧, linked list를 구성한다.)
5. linked list를 처음부터 끝까지 순서대로 탐색하는데, 다음 노드의 value가 현재 노드의 value보다 크면 explode_bomb을 실행시킨다.
6. 5번에서 explode_bomb이 실행되지 않았다면 phase_6이 해결된다.

node의 value가 내림차순이 되도록 node의 index를 지정해주면 phase_6를 풀 수 있다. 따라서 답은 다음과 같다.

```
2 4 6 5 1 3
```

10. secret_phase

먼저, secret_phase를 실행하기 위한 진입 조건을 알아야한다.

phase_defused의 pseudo code를 구성하면 다음과 같다.

```
int phase_defused()
{
  int result;
  char b;
  char a;
  char key[88];

  result = send_msg(1);
  if ( num_input_strings == 6 )
  {
    if ( __isoc99_sscanf(&6048B0, "%d %d %s", &a, &b, key) == 3
      && ! strings_not_equal(key, "DrEvil") )
    {
      puts("Curses, you've found the secret phase!");
      puts("But finding it and solving it are quite different...");
      secret_phase();
```

```
            }
            puts("Congratulations! You've defused the bomb!");
            return puts("Your instructor has been notified and will verify your
        solution.");
          }
          return result;
}
```

num_input_strings가 6일 때, &6048B0을 “%d %d %s” format으로 파싱했을 때 a, b, key 세개의 변수를 얻을 수 있어야하고, key 값이 “DrEvil”이면 secret_phase로 진입할 수 있다.

num_input_strings는 read_line 실행시 계속 1씩 증가하므로, phase_6 종료 후 secret_phase가 실행된다.

&unk_6048B0에 저장된 값을 알기 위해 gdb로 값을 찍어보면, phase 4의 답이 들어있음을 알 수 있다. 따라서 phase_4에서 답으로 99 3 대신 99 3 DrEvil을 입력하면 phase_6 종료후 secret_phase를 실행할 수 있다.

disas secret_phase로 assembly code를 얻으면 다음과 같다.

```
Dump of assembler code for function secret_phase:
   0x00000000004012ca <+0>:     push   %rbx
   0x00000000004012cb <+1>:     callq  0x40168c <read_line>
   0x00000000004012d0 <+6>:     mov    $0xa,%edx
   0x00000000004012d5 <+11>:    mov    $0x0,%esi
   0x00000000004012da <+16>:    mov    %rax,%rdi
   0x00000000004012dd <+19>:    callq  0x400c00 <strtol@plt>
   0x00000000004012e2 <+24>:    mov    %rax,%rbx
   0x00000000004012e5 <+27>:    lea    -0x1(%rax),%eax
   0x00000000004012e8 <+30>:    cmp    $0x3e8,%eax
   0x00000000004012ed <+35>:    jbe    0x4012f4 <secret_phase+42>
   0x00000000004012ef <+37>:    callq  0x401614 <explode_bomb>
   0x00000000004012f4 <+42>:    mov    %ebx,%esi
   0x00000000004012f6 <+44>:    mov    $0x604110,%edi
   0x00000000004012fb <+49>:    callq  0x40128c <fun7>
   0x0000000000401300 <+54>:    cmp    $0x7,%eax
   0x0000000000401303 <+57>:    je     0x40130a <secret_phase+64>
   0x0000000000401305 <+59>:    callq  0x401614 <explode_bomb>
   0x000000000040130a <+64>:    mov    $0x402590,%edi
   0x000000000040130f <+69>:    callq  0x400b40 <puts@plt>
```

```
            0x0000000000401314 <+74>:     callq   0x4017b2 <phase_defused>
            0x0000000000401319 <+79>:     pop      %rbx
            0x000000000040131a <+80>:     retq
End of assembler dump.
```

secret_phase의 pseudo code는 다음과 같다.

```
         int secret_phase()
         {
           const char *line; // rdi
           int key; // ebx

           line = read_line();
           key = strtol(line, 0, 10);
           if ( key - 1 > 0x3E8 )
             explode_bomb(line, 0LL);
           if (fun7(&n1, key) != 7 )
             explode_bomb();
           puts("Wow! You've defused the secret stage!");
           return phase_defused();
}
```

key값이 1001이하이고, fun7(&n1, key) 값이 7이어야 secret_phase를 해결할 수 있다.

disas fun7을 통해 fun7의 assembly code를 얻으면 다음과 같다.

```
         Dump of assembler code for function fun7:
            0x000000000040128c <+0>:      sub      $0x8,%rsp
            0x0000000000401290 <+4>:      test     %rdi,%rdi
            0x0000000000401293 <+7>:      je       0x4012c0 <fun7+52>
            0x0000000000401295 <+9>:      mov      (%rdi),%edx
            0x0000000000401297 <+11>:     cmp      %esi,%edx
            0x0000000000401299 <+13>:     jle      0x4012a8 <fun7+28>
            0x000000000040129b <+15>:     mov      0x8(%rdi),%rdi
            0x000000000040129f <+19>:     callq    0x40128c <fun7>
            0x00000000004012a4 <+24>:     add      %eax,%eax
            0x00000000004012a6 <+26>:     jmp      0x4012c5 <fun7+57>
            0x00000000004012a8 <+28>:     mov      $0x0,%eax
            0x00000000004012ad <+33>:     cmp      %esi,%edx
            0x00000000004012af <+35>:     je       0x4012c5 <fun7+57>
            0x00000000004012b1 <+37>:     mov      0x10(%rdi),%rdi
            0x00000000004012b5 <+41>:     callq    0x40128c <fun7>
            0x00000000004012ba <+46>:    lea     0x1(%rax,%rax,1),%eax
            0x00000000004012be <+50>:    jmp      0x4012c5 <fun7+57>
            0x00000000004012c0 <+52>:    mov      $0xffffffff,%eax
            0x00000000004012c5 <+57>:    add      $0x8,%rsp
            0x00000000004012c9 <+61>:    retq
End of assembler dump.
```

fun7의 pseudo code는 다음과 같다.

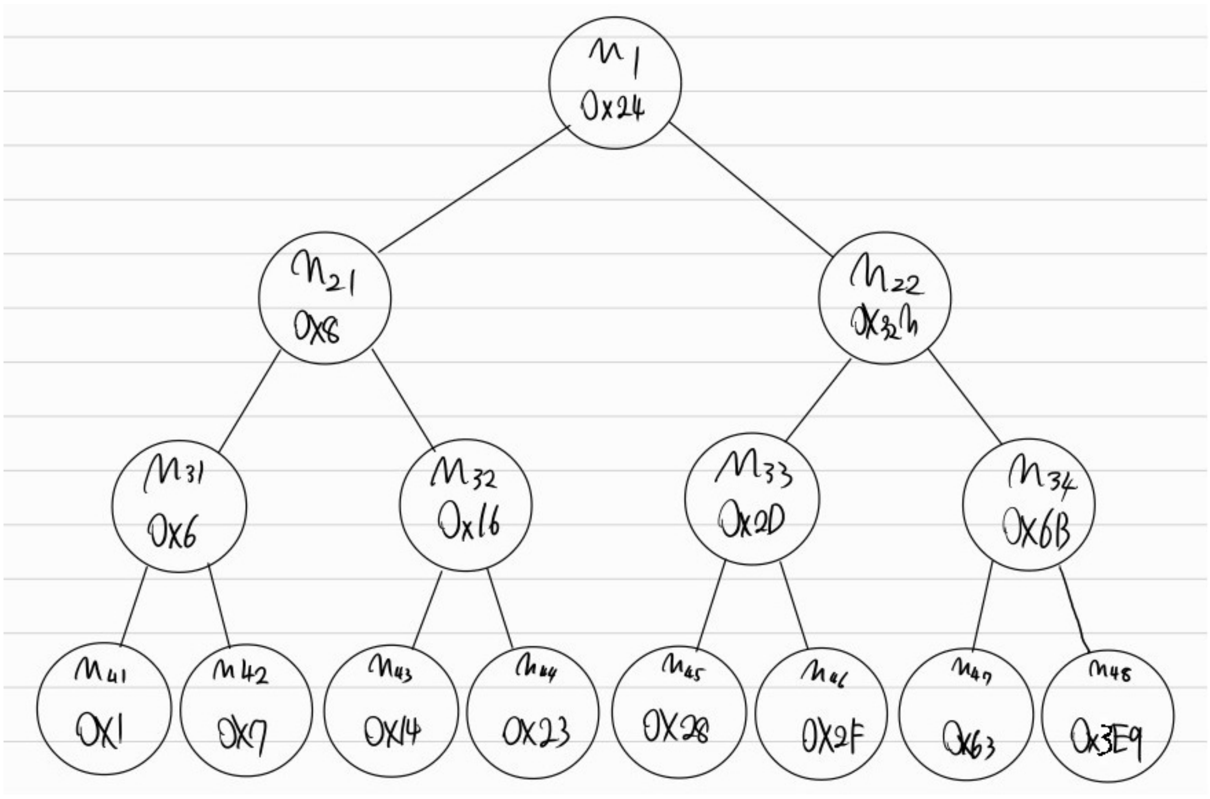
```
         int fun7(tree_node* a1, int key)
         {
           int result; // rax

           if ( a1 == NULL)
             return 0xFFFFFFFFLL;
           if (a1->value > key )
             return 2 * fun7( a1->left, key);
           result = 0;
           if (a1->value != key )
             return 2 * fun7(a1->right, key) + 1;
           return result;
}
```

tree_node는 다음과 같은 구조이다.

```
struct tree_node
{
  int value;             // <+0>
  tree_node* left;       // <+8>
  tree_node* right       // <+16>
}
```

n1의 데이터를 읽어보면, tree_node들의 연결이 binary tree 구조를 가짐을 알 수 있다.

n1을 따라서 데이터를 파싱해 tree를 구축하면 다음과 같다.



fun7(&n1, key) 값이 7이 되려면, 재귀함수의 반환값은 다음과 같은 구조를 가져야한다.

```
7 = 2 ( 2 (2 (0) + 1) + 1) + 1
```

따라서, n1 -> n22 -> n34 -> n48의 순서대로 fun7가 호출되어야한다. 그렇게 호출되기 위해선 key 값은 다음 조건을 만족해야한다.

```
key > 0x24
key > 0x32
key > 0x6B
key = 3E9h
```

이 모든 조건을 만족하는 key는 1001이다. 따라서 secret phase의 답은 다음과 같다.

```
1001
```

11. 결과

최종 답안은 다음과 같다.

```
Phase 1: For NASA, space is still a high priority.
Phase 2: 0 1 1 2 3 5
Phase 3: 5 x 682
Phase 4: 99 3 DrEvil
Phase 5: 5 115
Phase 6: 2 4 6 5 1 3
Secret Phase: 1001
```

실제로 폭탄이 잘 해체되었고, 다음과 같은 메시지를 얻었다.

```
Congratulations! You've defused the bomb!
Your instructor has been notified and will verify your solution.
```