计算机系统基础

Lab2 Bomb Lab

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目录

1 实验准备

1.1 获取Bomb

- 通过http://autolab.sur.moe:5550/22300240028获取Bomb:22300240028.out，它是二进制格式的代码，无法直接查看
- 将其与bomb.c放入一个文件夹中便于查看
- 在linux终端中执行./22300240028.out会看到以下文字，如果输入的答案不对，则Bomb会爆炸：

```
fwj@DESKTOP-H0129QB:/mnt/d/桌面/ics作业/Lab2/Lab2$ ./22300240028.out
Welcome to my fiendish little bomb. You have 6 phases with
which to blow yourself up. Have a nice day!
hello

BOOM!!!
The bomb has blown up.
fwj@DESKTOP-H0129QB:/mnt/d/桌面/ics作业/Lab2/Lab2$
```

1.2 实验目的

- 这个Bomb一共有6个phase和1个secret phase需要defuse
- 需要将答案字符串写在.txt文件中并在最后一行写上学号
- 因此，我们在终端vim ans.txt创建答案文件并写入，通过./22300240028.out ans.txt并观察文字提示来判断是否成功defuse Bomb

1.3 实验工具

- gdb
  具体方法可以参照gdb调试利器或者在终端中执行man gdb，gdb -help等命令查看

- objdump
  在终端中执行：objdump 22300240028.out > bomb.s 通过管道将反汇编文件保存到bomb.s中
  在终端中执行：objdump 22300240028.out > bomb.t 可以得到符号表，可能会有些帮助

2 实验过程

2.1 观察反汇编文件bomb.s以及c语言文件bomb.c

- 观察bomb.c文件，我们可以发现其main函数通过read_line函数读取输入，通过phase_i($1 \leq i \leq 6$)函数判断是否会使炸弹爆炸

- 观察bomb.s文件，我们可以发现read_line函数读入的值将会被存放在寄存器%rdi中，再调用相对应的函数。这是因为%rax通常作为存储函数返回值的寄存器，%rdi通常作为存储函数第一个入参的寄存器。phase_i函数使用%rdi寄存器作为输入。

```
299    400e32: e8 67 06 00 00        callq  40149e <read_line>
300    400e37: 48 89 c7              mov    %rax,%rdi
301    400e3a: e8 a1 00 00 00        callq  400ee0 <phase_1>
302    400e3f: e8 80 07 00 00        callq  4015c4 <phase_defused>
303    400e44: bf a8 23 40 00        mov    $0x4023a8,%edi
304    400e49: e8 c2 fc ff ff        callq  400b10 <puts@plt>
305    400e4e: e8 4b 06 00 00        callq  40149e <read_line>
306    400e53: 48 89 c7              mov    %rax,%rdi
307    400e56: e8 a1 00 00 00        callq  400efc <phase_2>
308    400e5b: e8 64 07 00 00        callq  4015c4 <phase_defused>
309    400e60: bf ed 22 40 00        mov    $0x4022ed,%edi
310    400e65: e8 a6 fc ff ff        callq  400b10 <puts@plt>
311    400e6a: e8 2f 06 00 00        callq  40149e <read_line>
312    400e6f: 48 89 c7              mov    %rax,%rdi
313    400e72: e8 cc 00 00 00        callq  400f43 <phase_3>
314    400e77: e8 48 07 00 00        callq  4015c4 <phase_defused>
```

- 我们可以在bomb.s汇编代码中通过Ctrl+F搜索phase_i来观察相应的函数

2.2 phase_1

```
346 00000000400ee0 <phase_1>:
347   400ee0: 48 83 ec 08           sub    $0x8,%rsp
348   400ee4: be 00 24 40 00        mov    $0x402400,%esi
349   400ee9: e8 4a 04 00 00        callq  401338 <strings_not_equal>
350   400eee: 85 c0                 test   %eax,%eax
351   400ef0: 74 05                 je     400ef7 <phase_1+0x17>
352   400ef2: e8 43 05 00 00        callq  40143a <explode_bomb>
353   400ef7: 48 83 c4 08           add    $0x8,%rsp
354   400efb: c3                    retq
355
```

- 第347行表示将栈顶指针−=8，为函数分配栈帧
- 第348行表示将寄存器%rsi的后32位，即寄存器%esi赋成立即数0x402400
- 第349行调用名为strings_not_equal的函数，猜想寄存器%esi应该存储了该函数的入参，该函数可能是判断字符串是否相等的函数
- 第350行用test指令检查寄存器%eax是负数，0，还是正数
- 第351行判断如果零标志ZF是1，即%eax是0则跳转到400ef7所在位置，发现刚好跳过了explode_bomb函数
- 一般来说，寄存器%rax会存储函数的返回值，由此我们可以猜想%eax存储了字符串比较函数的返回值，如果相等则返回0跳过爆炸，不相等则返回非0无法跳转
- 为了验证我们的猜想，我们需要查看strings_not_equal的函数
- 第705，706行表明了传入参数有%rdi和%rsi，其中%rsi的后32位存储了立即数0x402400。这两行将这两个参数存储到%rbx和%rbp这两个callee-free寄存器中。接着调用了string_length函数，猜测可能是求字符串长度的函数。

```
0000000000401338 <strings_not_equal>:
  401338: 41 54                push   %r12
  40133a: 55                   push   %rbp
  40133b: 53                   push   %rbx
  40133c: 48 89 fb             mov    %rdi,%rbx
  40133f: 48 89 f5             mov    %rsi,%rbp
  401342: e8 d4 ff ff ff       callq  40131b <string_length>
  401347: 41 89 c4             mov    %eax,%r12d
  40134a: 48 89 ef             mov    %rbp,%rdi
  40134d: e8 c9 ff ff ff       callq  40131b <string_length>
  401352: ba 01 00 00 00       mov    $0x1,%edx
  401357: 41 39 c4             cmp    %eax,%r12d
  40135a: 75 3f                jne    40139b <strings_not_equal+0x63>
  40135c: 0f b6 03             movzbl (%rbx),%eax
  40135f: 84 c0                test   %al,%al
  401361: 74 25                je     401388 <strings_not_equal+0x50>
  401363: 3a 45 00             cmp    0x0(%rbp),%al
  401366: 74 0a                je     401372 <strings_not_equal+0x3a>
  401368: eb 25                jmp    40138f <strings_not_equal+0x57>
  40136a: 3a 45 00             cmp    0x0(%rbp),%al
  40136d: 0f 1f 00             nopl   (%rax)
  401370: 75 24                jne    401396 <strings_not_equal+0x5e>
  401372: 48 83 c3 01          add    $0x1,%rbx
  401376: 48 83 c5 01          add    $0x1,%rbp
  40137a: 0f b6 03             movzbl (%rbx),%eax
  40137d: 84 c0                test   %al,%al
  40137f: 75 e9                jne    40136a <strings_not_equal+0x32>
  401381: ba 00 00 00 00       mov    $0x0,%edx
  401386: eb 13                jmp    40139b <strings_not_equal+0x63>
  401388: ba 00 00 00 00       mov    $0x0,%edx
  40138d: eb 0c                jmp    40139b <strings_not_equal+0x63>
  40138f: ba 01 00 00 00       mov    $0x1,%edx
  401394: eb 05                jmp    40139b <strings_not_equal+0x63>
  401396: ba 01 00 00 00       mov    $0x1,%edx
  40139b: 89 d0                mov    %edx,%eax
  40139d: 5b                   pop    %rbx
  40139e: 5d                   pop    %rbp
  40139f: 41 5c                pop    %r12
  4013a1: c3                   retq
```

```
688  000000000040131b <string_length>:
689    40131b: 80 3f 00             cmpb   $0x0,(%rdi)
690    40131e: 74 12                je     401332 <string_length+0x17>
691    401320: 48 89 fa             mov    %rdi,%rdx
692    401323: 48 83 c2 01          add    $0x1,%rdx
693    401327: 89 d0                mov    %edx,%eax
694    401329: 29 f8                sub    %edi,%eax
695    40132b: 80 3a 00             cmpb   $0x0,(%rdx)
696    40132e: 75 f3                jne    401323 <string_length+0x8>
697    401330: f3 c3                repz retq
698    401332: b8 00 00 00 00       mov    $0x0,%eax
699    401337: c3                   retq
700
```

- 观察string_legnth函数，可知传入参数应该是字符串指针，该函数的大致作用是：将字符串指针一个一个往后指，同时更新字符串长度，如果指针指向了0x0，即字符串末尾的'\0'则返回。

- 回过头来继续观察strings_not_equal函数，我们可以理解：到710行为止，函数求出了输入字符串的长度，存放在%r12d中，答案字符串的长度，存放在%eax中。接下来将%edx赋值为1，判断两个字符串长度是否相等，如果不相等则跳转到735行，最后函数会返回1。接下来判断输入字符串中当前是否为空，为空则返回0，不为空则往后一个字符一个字符比较，一旦不相等就返回1。这基本验证了我们的猜想，所以本题的答案应该就是phase_1函数中%esi寄存器所存储的指针所指向的字符串。

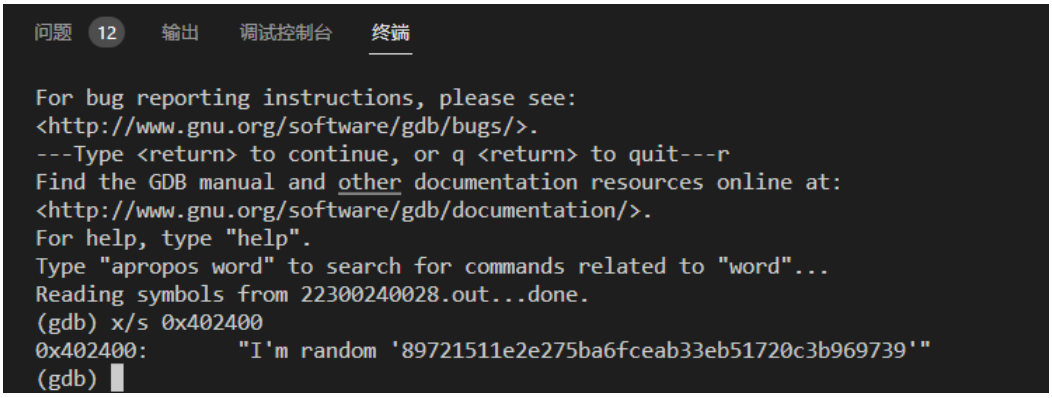
- 所以我们只需要gdb 22300240028.out 并x/s 0x402400查看答案字符串即可。

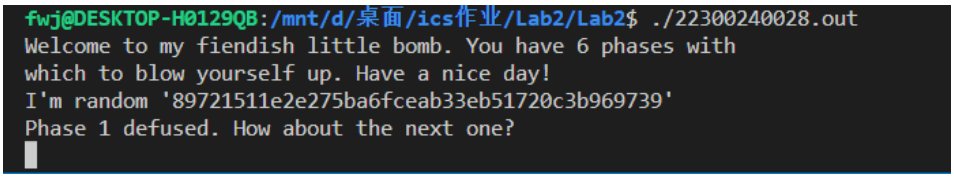
- phase_1 defuse成功!

2.3 phase_2

- 前四行压入寄存器，分配栈帧，保存%rsp的值到%rsi。接下来调用了函数read_six_numbers。

- 在read_six_numbers函数中，我们发现805到813行运用lea和mov为寄存器赋值，而814行将一个看起来像地址一样的值赋给了%esi，不妨用gdb查





看一下。可以猜想我们需要输入六个整数并以空格隔开。

- 再回过头来看phase_2函数。读入后首先判断栈顶指针指向的地址的值，即$M[R[\%rsp]]$是否为1。接下来不难发现是一个循环：以%rbx为计数器指针，每次加4，以%rbp为终点指针，0x18 / 0x4刚好等于6，意味着循环5次。在每次循环中%eax存储之前的%rbx寄存器指向的地址的值，并翻倍，与现在的寄存器%rbx寄存器指向的地址的值进行比较，如果不一样就会使得炸弹爆炸。

- 因此可以大致得出答案是1 2 4 8 16 32。

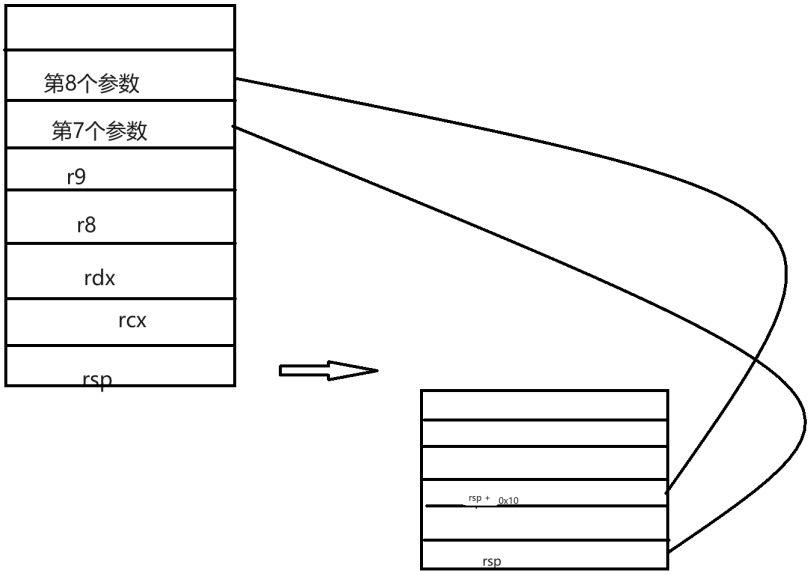
- 不过这么判断的前提是：read_six_numbers函数会将$M[R[\%rsp]], M[R[\%rsp]+0x4], \ldots, M[R[\%rsp]+0x14]$设置成输入的六个整数。因此我们还需要回过头来看一下这个函数一开始的寄存器赋值操作。

- %rdi和%rsi（原来的栈顶）作为前两个参数传入。read_six_numbers函数又将$M[R[\%rsi]], M[R[\%rsi]+0x4], \cdots, M[R[\%rsi]+0x14]$作为第3到8个传入参数，由于超出寄存器数量限制，最后两个参数被转移到内存上。如下图所示。同时我们可以看到这个函数的结尾处的跳出判定是大于5就可以，也就是说我们可以在答案结尾添加任意字符（和数字分开即可），例如：1 2 4 8 16 32*。

```
0000000000400efc <phase_2>:
  400efc: 55                    push   %rbp
  400efd: 53                    push   %rbx
  400efe: 48 83 ec 28           sub    $0x28,%rsp
  400f02: 48 89 e6              mov    %rsp,%rsi
  400f05: e8 52 05 00 00        callq  40145c <read_six_numbers>
  400f0a: 83 3c 24 01           cmpl   $0x1,(%rsp)
  400f0e: 74 20                 je     400f30 <phase_2+0x34>
  400f10: e8 25 05 00 00        callq  40143a <explode_bomb>
  400f15: eb 19                 jmp    400f30 <phase_2+0x34>
  400f17: 8b 43 fc              mov    -0x4(%rbx),%eax
  400f1a: 01 c0                 add    %eax,%eax
  400f1c: 39 03                 cmp    %eax,(%rbx)
  400f1e: 74 05                 je     400f25 <phase_2+0x29>
  400f20: e8 15 05 00 00        callq  40143a <explode_bomb>
  400f25: 48 83 c3 04           add    $0x4,%rbx
  400f29: 48 39 eb              cmp    %rbp,%rbx
  400f2c: 75 e9                 jne    400f17 <phase_2+0x1b>
  400f2e: eb 0c                 jmp    400f3c <phase_2+0x40>
  400f30: 48 8d 5c 24 04        lea    0x4(%rsp),%rbx
  400f35: 48 8d 6c 24 18        lea    0x18(%rsp),%rbp
  400f3a: eb db                 jmp    400f17 <phase_2+0x1b>
  400f3c: 48 83 c4 28           add    $0x28,%rsp
  400f40: 5b                    pop    %rbx
  400f41: 5d                    pop    %rbp
  400f42: c3                    retq
```

```
804 ∨ 000000000040145c <read_six_numbers>:
805     40145c: 48 83 ec 18           sub    $0x18,%rsp
806     401460: 48 89 f2              mov    %rsi,%rdx
807     401463: 48 8d 4e 04           lea    0x4(%rsi),%rcx
808     401467: 48 8d 46 14           lea    0x14(%rsi),%rax
809     40146b: 48 89 44 24 08        mov    %rax,0x8(%rsp)
810     401470: 48 8d 46 10           lea    0x10(%rsi),%rax
811     401474: 48 89 04 24           mov    %rax,(%rsp)
812     401478: 4c 8d 4e 0c           lea    0xc(%rsi),%r9
813     40147c: 4c 8d 46 08           lea    0x8(%rsi),%r8
814     401480: be c3 25 40 00        mov    $0x4025c3,%esi
815     401485: b8 00 00 00 00        mov    $0x0,%eax
816     40148a: e8 61 f7 ff ff        callq  400bf0 <__isoc99_sscanf@plt>
817     40148f: 83 f8 05              cmp    $0x5,%eax
818     401492: 7f 05                 jg     401499 <read_six_numbers+0x3d>
819     401494: e8 a1 ff ff ff        callq  40143a <explode_bomb>
820     401499: 48 83 c4 18           add    $0x18,%rsp
821     40149d: c3                    retq
```

```
0x4025c3:       "%d %d %d %d %d %d"
(gdb)
```



- phase_2 defuse成功!

```
fwj@DESKTOP-H0129QB:/mnt/d/桌面/ics作业/Lab2/Lab2$ ./22300240028.out
Welcome to my fiendish little bomb. You have 6 phases with
which to blow yourself up. Have a nice day!
I'm random '89721511e2e275ba6fceab33eb51720c3b969739'
Phase 1 defused. How about the next one?
1 2 4 8 16 32*
That's number 2.  Keep going!
```

2.4 phase_3

- 在第387行可以发现和phase_2函数中类似的读入，用gdb调试后可知需要输入两个整数，以空格隔开。同样可以在答案结尾添加任意字符（和数字分开即可）。

- 第393和394行表示如果$M[R[\%rsp]+8] > 7$就会爆炸。接下来是一个奇怪的间接跳转，跳转到$M[0x402470+8*R[\%rax]]$，注意这段地址储存在内存中。注意到之前将$M[R[\%rsp]+8]$赋值给了%eax，所以%rax是一个小于等于7的无符号型整数。所以跳转到的地址有：$M[0x402470], M[0x402478], \cdots, M[0x4024a8]$这8种情况。不妨用gdb查看一下。发现这分别与第397,414,399,401,403,405,407,409行相对应。

- 然后将%eax赋值为一个常数，并跳转到第415行比较第二个参数和这个常数是否相等，不相等则爆炸。因此我们可以得出答案为：

第一个参数	第二个参数
0	207
1	311
2	707
3	256
4	389
5	206
6	682
7	327

```
0000000000400f43 <phase_3>:
  400f43: 48 83 ec 18           sub    $0x18,%rsp
  400f47: 48 8d 4c 24 0c        lea    0xc(%rsp),%rcx
  400f4c: 48 8d 54 24 08        lea    0x8(%rsp),%rdx
  400f51: be cf 25 40 00        mov    $0x4025cf,%esi
  400f56: b8 00 00 00 00        mov    $0x0,%eax
  400f5b: e8 90 fc ff ff        callq  400bf0 <__isoc99_sscanf@plt>
  400f60: 83 f8 01              cmp    $0x1,%eax
  400f63: 7f 05                 jg     400f6a <phase_3+0x27>
  400f65: e8 d0 04 00 00        callq  40143a <explode_bomb>
  400f6a: 83 7c 24 08 07        cmpl   $0x7,0x8(%rsp)
  400f6f: 77 3c                 ja     400fad <phase_3+0x6a>
  400f71: 8b 44 24 08           mov    0x8(%rsp),%eax
  400f75: ff 24 c5 70 24 40 00  jmpq   *0x402470(,%rax,8)
  400f7c: b8 cf 00 00 00        mov    $0xcf,%eax
  400f81: eb 3b                 jmp    400fbe <phase_3+0x7b>
  400f83: b8 c3 02 00 00        mov    $0x2c3,%eax
  400f88: eb 34                 jmp    400fbe <phase_3+0x7b>
  400f8a: b8 00 01 00 00        mov    $0x100,%eax
  400f8f: eb 2d                 jmp    400fbe <phase_3+0x7b>
  400f91: b8 85 01 00 00        mov    $0x185,%eax
  400f96: eb 26                 jmp    400fbe <phase_3+0x7b>
  400f98: b8 ce 00 00 00        mov    $0xce,%eax
  400f9d: eb 1f                 jmp    400fbe <phase_3+0x7b>
  400f9f: b8 aa 02 00 00        mov    $0x2aa,%eax
  400fa4: eb 18                 jmp    400fbe <phase_3+0x7b>
  400fa6: b8 47 01 00 00        mov    $0x147,%eax
  400fab: eb 11                 jmp    400fbe <phase_3+0x7b>
  400fad: e8 88 04 00 00        callq  40143a <explode_bomb>
  400fb2: b8 00 00 00 00        mov    $0x0,%eax
  400fb7: eb 05                 jmp    400fbe <phase_3+0x7b>
  400fb9: b8 37 01 00 00        mov    $0x137,%eax
  400fbe: 3b 44 24 0c           cmp    0xc(%rsp),%eax
  400fc2: 74 05                 je     400fc9 <phase_3+0x86>
  400fc4: e8 71 04 00 00        callq  40143a <explode_bomb>
  400fc9: 48 83 c4 18           add    $0x18,%rsp
  400fcd: c3                    retq
```

```
(gdb) x/s 0x4025cf
0x4025cf:       "%d %d"
(gdb)
```

```
(gdb) x/8g 0x402470
0x402470:       0x0000000000400f7c      0x0000000000400fb9
0x402480:       0x0000000000400f83      0x0000000000400f8a
0x402490:       0x0000000000400f91      0x0000000000400f98
0x4024a0:       0x0000000000400f9f      0x0000000000400fa6
(gdb)
```

- 我们取0 207*。phase_3 defuse成功!

```
fwj@DESKTOP-H0129QB:/mnt/d/桌面/ics作业/Lab2/Lab2$ ./22300240028.out
Welcome to my fiendish little bomb. You have 6 phases with
which to blow yourself up. Have a nice day!
I'm random '89721511e2e275ba6fceab33eb51720c3b969739'
Phase 1 defused. How about the next one?
1 2 4 8 16 32*
That's number 2.  Keep going!
0 207*
Halfway there!
```

2.5 phase_4

- 同phase_3，在第449行经gdb调试（x/s 0x4025cf）可知需要输入两个整数。但是根据判断条件（第452，453行），我们需要输入三个参数。

- 首先判断输入的第一个整数是否小于等于0xe，如果大于则爆炸，小于则把%edx赋成0xe、把%esi赋成0x0、把$M[R[\%rsp] + 8] \leq 0xe$赋给%edi，调用fun_4并传入参数。如果该函数返回值为0，并且第二个参数为0，则可以跳过爆炸。

- 可以看出该函数是一个递归函数，我们写出它对应的C语言代码来进行分析。为了直接求出答案，我们遍历所有可能的输入值。

```c
#include <stdio.h>
int cnt = 0;
int flag = 0;
//edi=input, edx = 14, esi = 0
```

```
000000000040100c <phase_4>:
  40100c: 48 83 ec 18           sub    $0x18,%rsp
  401010: 48 8d 4c 24 0c        lea    0xc(%rsp),%rcx
  401015: 48 8d 54 24 08        lea    0x8(%rsp),%rdx
  40101a: be cf 25 40 00        mov    $0x4025cf,%esi
  40101f: b8 00 00 00 00        mov    $0x0,%eax
  401024: e8 c7 fb ff ff        callq  400bf0 <__isoc99_sscanf@plt>
  401029: 83 f8 02              cmp    $0x2,%eax
  40102c: 75 07                 jne    401035 <phase_4+0x29>
  40102e: 83 7c 24 08 0e        cmpl   $0xe,0x8(%rsp)
  401033: 76 05                 jbe    40103a <phase_4+0x2e>
  401035: e8 00 04 00 00        callq  40143a <explode_bomb>
  40103a: ba 0e 00 00 00        mov    $0xe,%edx
  40103f: be 00 00 00 00        mov    $0x0,%esi
  401044: 8b 7c 24 08           mov    0x8(%rsp),%edi
  401048: e8 81 ff ff ff        callq  400fce <func4>
  40104d: 85 c0                 test   %eax,%eax
  40104f: 75 07                 jne    401058 <phase_4+0x4c>
  401051: 83 7c 24 0c 00        cmpl   $0x0,0xc(%rsp)
  401056: 74 05                 je     40105d <phase_4+0x51>
  401058: e8 dd 03 00 00        callq  40143a <explode_bomb>
  40105d: 48 83 c4 18           add    $0x18,%rsp
  401061: c3                    retq
```

```
(gdb) x/s 0x4025cf
0x4025cf:       "%d %d"
(gdb)
```

```
0000000000400fce <func4>:
  400fce: 48 83 ec 08          sub    $0x8,%rsp
  400fd2: 89 d0                mov    %edx,%eax
  400fd4: 29 f0                sub    %esi,%eax
  400fd6: 89 c1                mov    %eax,%ecx
  400fd8: c1 e9 1f             shr    $0x1f,%ecx
  400fdb: 01 c8                add    %ecx,%eax
  400fdd: d1 f8                sar    %eax
  400fdf: 8d 0c 30             lea    (%rax,%rsi,1),%ecx
  400fe2: 39 f9                cmp    %edi,%ecx
  400fe4: 7e 0c                jle    400ff2 <func4+0x24>
  400fe6: 8d 51 ff             lea    -0x1(%rcx),%edx
  400fe9: e8 e0 ff ff ff       callq  400fce <func4>
  400fee: 01 c0                add    %eax,%eax
  400ff0: eb 15                jmp    401007 <func4+0x39>
  400ff2: b8 00 00 00 00       mov    $0x0,%eax
  400ff7: 39 f9                cmp    %edi,%ecx
  400ff9: 7d 0c                jge    401007 <func4+0x39>
  400ffb: 8d 71 01             lea    0x1(%rcx),%esi
  400ffe: e8 cb ff ff ff       callq  400fce <func4>
  401003: 8d 44 00 01          lea    0x1(%rax,%rax,1),%eax
  401007: 48 83 c4 08          add    $0x8,%rsp
  40100b: c3                   retq
```

```
5  int fun_4(int esi, int edx, int edi)
6  {
7      cnt ++;
8      if(cnt >= 10000) {
9          flag = 1;
10         return 10086;
11     }
12     int eax = edx;
13     eax -= esi;
14     //eax = edx - esi;
15     int ecx = eax;
16     //ecx >>= 31;
17     for(int i = 1; i <=31; i ++) ecx /= 2;
18     eax += ecx;
19     eax >>= 1;
20     //eax = (eax + eax>>31)>>1;
21     ecx = eax + esi;
22     if(ecx > edi){
23         edx = ecx - 1;
24         return 2 * fun_4(esi, edx, edi);
25
26     }else{
27         eax = 0;
28         if(ecx >= edi){
29             return eax;
30         }else{
31             esi = ecx - 1;
32             return 2 * fun_4(esi, edx, edi) + 1;
33         }
34     }
35 }
```

```c
int main()
{
    for(int i = 0; i <= 14; i ++){
        cnt = 0;
        flag = 0;
        int res = fun_4(0, 14, i);
        if(!flag)
            printf("i=%d %d\n", i , res);
        else
            printf("i=%d No result\n", i);
    }
    return 0;
}
```

```
fwj@DESKTOP-H0129QB:/mnt/d/桌面/ics作业/Lab2/tryc/cs$ gcc main.c -o main
fwj@DESKTOP-H0129QB:/mnt/d/桌面/ics作业/Lab2/tryc/cs$ ./main
i=0 0
i=1 0
i=2 No result
i=3 0
i=4 2
i=5 No result
i=6 No result
i=7 0
i=8 No result
i=9 No result
i=10 1
i=11 3
i=12 7
i=13 No result
i=14 No result
fwj@DESKTOP-H0129QB:/mnt/d/桌面/ics作业/Lab2/tryc/cs$
```

- 这里的C程序假设了%eax = %rax，会导致有的输入进入死循环，不过这已经可以得出部分答案，足以跳过爆炸了。

第一个参数	第二个参数
0	0
1	0
3	0
7	0

- 我们取7 0。phase_4 defuse成功!

```
fwj@DESKTOP-H0129QB:/mnt/d/桌面/ics作业/Lab2/Lab2$ ./22300240028.out
Welcome to my fiendish little bomb. You have 6 phases with
which to blow yourself up. Have a nice day!
I'm random '89721511e2e275ba6fceab33eb51720c3b969739'
Phase 1 defused. How about the next one?
1 2 4 8 16 32*
That's number 2.  Keep going!
0 207*
Halfway there!
7 0
So you got that one.  Try this one.
```

2.6 phase_5

- 第477行调用string_length函数求出输入字符串的长度，必须是6，否则爆炸。然后将%rax从1到5循环：每次将$M[R[\%rbx] + R[\%rax]]$的后8位存在%rdx中并只取它后四位（&0xf）。把它作为索引找到$M[0x4024b0 + R[\%rdx]]$，取它的后8位存到$R[\%rsp] + R[\%rax] + 0x10$中。最后在结尾加上$'\backslash 0'$. 并和%esi寄存器所存储的指针所指向的字符串相比较，如果相等则跳过爆炸。

- 用gdb调试得到0x4024b0和0x40245e处的字符串。

- 我们需要在第一个字符串里找第二个字符串的字母。也就是说，我们输入的6个字符的后四位十进制值必须是9 15 14 5 6 7。

- 编写C语言程序可以快速得到我们要找的答案。

```c
#include <stdio.h>
int main()
```

```
0000000000401062 <phase_5>:
  401062: 53                    push   %rbx
  401063: 48 83 ec 20           sub    $0x20,%rsp
  401067: 48 89 fb              mov    %rdi,%rbx
  40106a: 64 48 8b 04 25 28 00  mov    %fs:0x28,%rax
  401071: 00 00
  401073: 48 89 44 24 18        mov    %rax,0x18(%rsp)
  401078: 31 c0                 xor    %eax,%eax
  40107a: e8 9c 02 00 00        callq  40131b <string_length>
  40107f: 83 f8 06              cmp    $0x6,%eax
  401082: 74 4e                 je     4010d2 <phase_5+0x70>
  401084: e8 b1 03 00 00        callq  40143a <explode_bomb>
  401089: eb 47                 jmp    4010d2 <phase_5+0x70>
  40108b: 0f b6 0c 03           movzbl (%rbx,%rax,1),%ecx
  40108f: 88 0c 24              mov    %cl,(%rsp)
  401092: 48 8b 14 24           mov    (%rsp),%rdx
  401096: 83 e2 0f              and    $0xf,%edx
  401099: 0f b6 92 b0 24 40 00  movzbl 0x4024b0(%rdx),%edx
  4010a0: 88 54 04 10           mov    %dl,0x10(%rsp,%rax,1)
  4010a4: 48 83 c0 01           add    $0x1,%rax
  4010a8: 48 83 f8 06           cmp    $0x6,%rax
  4010ac: 75 dd                 jne    40108b <phase_5+0x29>
  4010ae: c6 44 24 16 00        movb   $0x0,0x16(%rsp)
  4010b3: be 5e 24 40 00        mov    $0x40245e,%esi
  4010b8: 48 8d 7c 24 10        lea    0x10(%rsp),%rdi
  4010bd: e8 76 02 00 00        callq  401338 <strings_not_equal>
  4010c2: 85 c0                 test   %eax,%eax
  4010c4: 74 13                 je     4010d9 <phase_5+0x77>
  4010c6: e8 6f 03 00 00        callq  40143a <explode_bomb>
  4010cb: 0f 1f 44 00 00        nopl   0x0(%rax,%rax,1)
  4010d0: eb 07                 jmp    4010d9 <phase_5+0x77>
  4010d2: b8 00 00 00 00        mov    $0x0,%eax
  4010d7: eb b2                 jmp    40108b <phase_5+0x29>
  4010d9: 48 8b 44 24 18        mov    0x18(%rsp),%rax
  4010de: 64 48 33 04 25 28 00  xor    %fs:0x28,%rax
  4010e5: 00 00
  4010e7: 74 05                 je     4010ee <phase_5+0x8c>
  4010e9: e8 42 fa ff ff        callq  400b30 <__stack_chk_fail@plt>
  4010ee: 48 83 c4 20           add    $0x20,%rsp
  4010f2: 5b                    pop    %rbx
  4010f3: c3                    retq
```

```
(gdb) x/s 0x4024b0
0x4024b0 <array.3449>:  "maduiersnfotvbylSo you think you can stop the bomb with ctrl-c, do you?"
0x40245e:       "flyers"
(gdb)
```

```
3  {
4      for(int i = 0; i <= 255; i ++)
5      {
6          if(i % 16 == 5)
7              printf("5: %c\n", i);
8          else if(i % 16 == 6)
9              printf("6: %c\n", i);
10         else if(i % 16 == 7)
11             printf("7: %c\n", i);
12         else if(i % 16 == 9)
13             printf("9: %c\n", i);
14         else if(i % 16 == 14)
15             printf("e: %c\n", i);
16         else if(i % 16 == 15)
17             printf("f: %c\n", i);
18     }
19     return 0;
20 }
```

```
fwj@DESKTOP-H0129QB:/mnt/d/桌面/ics作业/Lab2/tryc/cs$ gcc ascii.c -o ascii
fwj@DESKTOP-H0129QB:/mnt/d/桌面/ics作业/Lab2/tryc/cs$ ./ascii
5: 6: 7: 9: e: f: 5: 6: 7: 9: e: f: 5: % 6: & 7: ' 9: ) e: . f: / 5: 5 6: 6 7: 7 9: 9 e: > f: ? 5: E 6: F 7: G 9: I e: N f: O 5: U 6: V 7:
W 9: Y e: ^ f: _ 5: e 6: f 7: g 9: i e: n f: o 5: u 6: v 7: w 9: y e: ~ f: 5: ◆6: ◆7: ◆9: ◆e: ◆f: ◆5: ◆6: ◆7: ◆9: ◆e: ◆f: ◆5: ◆6: ◆7: ◆9: ◆e:
 ◆f: ◆5: ◆6: ◆7: ◆9: ◆e: ◆f: ◆5: ◆6: ◆7: ◆9: ◆e: ◆f: ◆5: ◆6: ◆7: ◆9: ◆e: ◆f: ◆5: ◆6: ◆7: ◆9: ◆e: ◆f: ◆
fwj@DESKTOP-H0129QB:/mnt/d/桌面/ics作业/Lab2/tryc/cs$
```

- 不妨取)/ > %FG。phase_5 defuse成功!

```
So you got that one.  Try this one.
)/>%FG
Good work!  On to the next...
```

2.7 phase_6

- 第520行看到read_six_numbers函数可知调用者的栈上按顺序存储了输入的六个数。接下来到542行为止是循环中套了循环，需要保证：每个数字小于等于6且互不相同。其C语言代码如下：

```
0000000004010f4 <phase_6>:
  4010f4: 41 56                push   %r14
  4010f6: 41 55                push   %r13
  4010f8: 41 54                push   %r12
  4010fa: 55                   push   %rbp
  4010fb: 53                   push   %rbx
  4010fc: 48 83 ec 50          sub    $0x50,%rsp
  401100: 49 89 e5             mov    %rsp,%r13
  401103: 48 89 e6             mov    %rsp,%rsi
  401106: e8 51 03 00 00       callq  40145c <read_six_numbers>
  40110b: 49 89 e6             mov    %rsp,%r14
  40110e: 41 bc 00 00 00 00    mov    $0x0,%r12d
  401114: 4c 89 ed             mov    %r13,%rbp
  401117: 41 8b 45 00          mov    0x0(%r13),%eax
  40111b: 83 e8 01             sub    $0x1,%eax
  40111e: 83 f8 05             cmp    $0x5,%eax
  401121: 76 05                jbe    401128 <phase_6+0x34>
  401123: e8 12 03 00 00       callq  40143a <explode_bomb>
  401128: 41 83 c4 01          add    $0x1,%r12d
  40112c: 41 83 fc 06          cmp    $0x6,%r12d
  401130: 74 21                je     401153 <phase_6+0x5f>
  401132: 44 89 e3             mov    %r12d,%ebx
  401135: 48 63 c3             movslq %ebx,%rax
  401138: 8b 04 84             mov    (%rsp,%rax,4),%eax
  40113b: 39 45 00             cmp    %eax,0x0(%rbp)
  40113e: 75 05                jne    401145 <phase_6+0x51>
  401140: e8 f5 02 00 00       callq  40143a <explode_bomb>
  401145: 83 c3 01             add    $0x1,%ebx
  401148: 83 fb 05             cmp    $0x5,%ebx
  40114b: 7e e8                jle    401135 <phase_6+0x41>
  40114d: 49 83 c5 04          add    $0x4,%r13
  401151: eb c1                jmp    401114 <phase_6+0x20>
  401153: 48 8d 74 24 18       lea    0x18(%rsp),%rsi
  401158: 4c 89 f0             mov    %r14,%rax
  40115b: b9 07 00 00 00       mov    $0x7,%ecx
  401160: 89 ca                mov    %ecx,%edx
  401162: 2b 10                sub    (%rax),%edx
  401164: 89 10                mov    %edx,(%rax)
  401166: 48 83 c0 04          add    $0x4,%rax
  40116a: 48 39 f0             cmp    %rsi,%rax
  40116d: 75 f1                jne    401160 <phase_6+0x6c>
  40116f: be 00 00 00 00       mov    $0x0,%esi
  401174: eb 21                jmp    401197 <phase_6+0xa3>
  401176: 48 8b 52 08          mov    0x8(%rdx),%rdx
  40117a: 83 c0 01             add    $0x1,%eax
  40117d: 39 c8                cmp    %ecx,%eax
  40117f: 75 f5                jne    401176 <phase_6+0x82>
  401181: eb 05                jmp    401188 <phase_6+0x94>
  401183: ba d0 32 60 00       mov    $0x6032d0,%edx
  401188: 48 89 54 74 20       mov    %rdx,0x20(%rsp,%rsi,2)
  40118d: 48 83 c6 04          add    $0x4,%rsi
  401191: 48 83 fe 18          cmp    $0x18,%rsi
  401195: 74 14                je     4011ab <phase_6+0xb7>
  401197: 8b 0c 34             mov    (%rsp,%rsi,1),%ecx
  40119a: 83 f9 01             cmp    $0x1,%ecx
  40119d: 7e e4                jle    401183 <phase_6+0x8f>
  40119f: b8 01 00 00 00       mov    $0x1,%eax
  4011a4: ba d0 32 60 00       mov    $0x6032d0,%edx
  4011a9: eb cb                jmp    401176 <phase_6+0x82>
  4011ab: 48 8b 5c 24 20       mov    0x20(%rsp),%rbx
  4011b0: 48 8d 44 24 28       lea    0x28(%rsp),%rax
  4011b5: 48 8d 74 24 50       lea    0x50(%rsp),%rsi
  4011ba: 48 89 d9             mov    %rbx,%rcx
  4011bd: 48 8b 10             mov    (%rax),%rdx
  4011c0: 48 89 51 08          mov    %rdx,0x8(%rcx)
  4011c4: 48 83 c0 08          add    $0x8,%rax
  4011c8: 48 39 f0             cmp    %rsi,%rax
  4011cb: 74 05                je     4011d2 <phase_6+0xde>
  4011cd: 48 89 d1             mov    %rdx,%rcx
  4011d0: eb eb                jmp    4011bd <phase_6+0xc9>
  4011d2: 48 c7 42 08 00 00 00 movq   $0x0,0x8(%rdx)
  4011d9: 00
  4011da: bd 05 00 00 00       mov    $0x5,%ebp
  4011df: 48 8b 43 08          mov    0x8(%rbx),%rax
  4011e3: 8b 00                mov    (%rax),%eax
  4011e5: 39 03                cmp    %eax,(%rbx)
  4011e7: 7d 05                jge    4011ee <phase_6+0xfa>
  4011e9: e8 4c 02 00 00       callq  40143a <explode_bomb>
  4011ee: 48 8b 5b 08          mov    0x8(%rbx),%rbx
  4011f2: 83 ed 01             sub    $0x1,%ebp
  4011f5: 75 e8                jne    4011df <phase_6+0xeb>
  4011f7: 48 83 c4 50          add    $0x50,%rsp
  4011fb: 5b                   pop    %rbx
  4011fc: 5d                   pop    %rbp
  4011fd: 41 5c                pop    %r12
  4011ff: 41 5d                pop    %r13
  401201: 41 5e                pop    %r14
  401203: c3                   retq
```

```
1  r14 = 0;
2  r13 = 0;
3  r12d = 0;
4  while(1){
5      rbp = r13;
6      if(num[r13] - 1 > 5)
7          goto bomb;
8      r12d++;
9      if(r12d == 6)
10         break;
11     for(ebx = r12d; ebx <= 5; ebx++){
12         if(num[ebx] == num[rbp])
13             goto bomb;
14     }
15     r13++;
16 }
```

- 接下来到551行是一个循环：将六个整数分别赋值成为用7减去它们自身。
- 接下来到569行是一个链表操作，通过我们输入的6个数字为索引对链表进行重排。即$M[R[\%rsp]+0x20] = node[M[R[\%rsp]]], M[R[\%rsp]+0x28] = node[M[R[\%rsp]+0x4]], \cdots, M[R[\%rsp]+0x48] = node[M[R[\%rsp]+0x14]]$。

```
(gdb) x/24wx 0x6032d0
0x6032d0 <node1>:       0x0000014c      0x00000001      0x006032e0      0x00000000
0x6032e0 <node2>:       0x000000a8      0x00000002      0x006032f0      0x00000000
0x6032f0 <node3>:       0x0000039c      0x00000003      0x00603300      0x00000000
0x603300 <node4>:       0x000002b3      0x00000004      0x00603310      0x00000000
0x603310 <node5>:       0x000001dd      0x00000005      0x00603320      0x00000000
0x603320 <node6>:       0x000001bb      0x00000006      0x00000000      0x00000000
(gdb)
```

- 接下来到580行按照栈内链表节点位置顺序重排单链表。即原来链表的$1 \to 2 \to \cdots \to 6$顺序被修改为$M[R[\%rsp]] \to M[R[\%rsp]+0x4] \to \cdots \to M[R[\%rsp]+0x14]$

- 最后的循环是用来判断新链表是否是非严格单调递减的。由于：$node3 > node4 > node5 > node6 > node1 > node2$，所以栈中的六个数应该是3 4 5 6 1 2。由于输入的数被7减过，所以答案应该是：4 3 2 1 6 5。

- phase_6 defuse成功!

```
fwj@DESKTOP-H0129QB:/mnt/d/桌面/ics作业/Lab2/Lab2$ ./22300240028.out
Welcome to my fiendish little bomb. You have 6 phases with
which to blow yourself up. Have a nice day!
I'm random '89721511e2e275ba6fceab33eb51720c3b969739'
Good work!  On to the next...
4 3 2 1 6 5
Congratulations! You've defused the bomb!
```

2.8 secret_phase

- 我们发现bomb.s中还有secret_phase函数，但是之前没有遇到。Ctrl+F查询发现phase_defused函数调用了它。用gdb查看一些地址的字符串时发现了隐藏关卡的突破口：当我们在某个关卡中要输入三个参数，并且最后一个参数是"HiEvil"时就能开启隐藏关卡。检查了一下前面的发现phase_4需要我们输入三个参数，但是只有前两个参数在当时是有用的。

```
(gdb) x/s 0x402619
0x402619:       "%d %d %s"
(gdb) x/s 0x603870
0x603870 <input_strings+240>:    ""
(gdb) x/s 0x402622
0x402622:       "HiEvil"
(gdb) x/s 0x402558
0x402558:       "Congratulations! You've defused the bomb!"
(gdb) x/s 0x402520
0x402520:       "But finding it and solving it are quite different..."
(gdb) x/s 0x4024f8
0x4024f8:       "Curses, you've found the secret phase!"
(gdb)
```

- 尝试了一下，开启了隐藏关卡。

- 发现在secret_phase中也有read_line，说明我们要在最后再输入一个参数。这个参数和一个地址0x6030f0作为两个参数传入fun_7函数，我们需要使得这个函数的返回值为2。

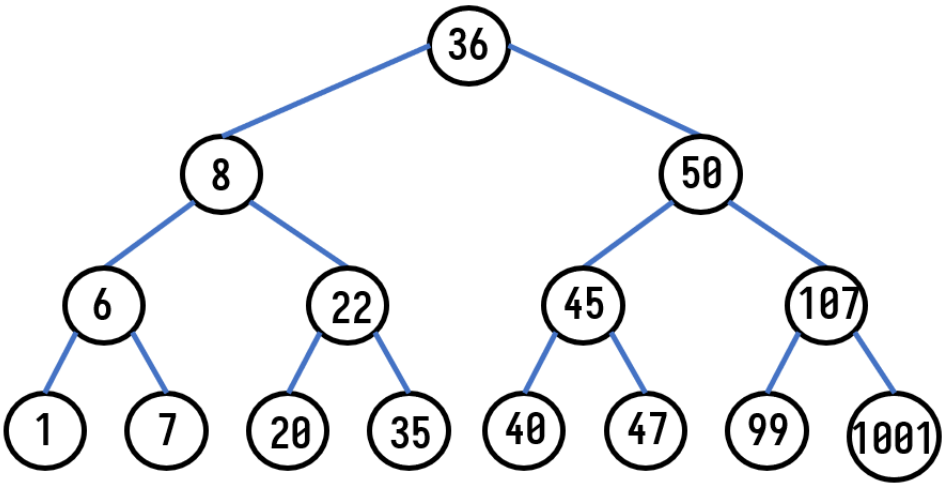
```
which to blow yourself up. Have a nice day!
I'm random '89721511e2e275ba6fceab33eb51720c3b969739'
Phase 1 defused. How about the next one?
1 2 4 8 16 32*
That's number 2.  Keep going!
0 207*
Halfway there!
7 0 HiEvil
So you got that one.  Try this one.
)/>%FG
Good work!  On to the next...
4 3 2 1 6 5
Curses, you've found the secret phase!
But finding it and solving it are quite different...
```

- 查看这个地址，发现是一个树型结构。

```
0x6030f0 <n1>:  0x00000024      0x00000000      0x00603110      0x00000000
0x603100 <n1+16>:       0x00603130      0x00000000      0x00000000      0x00000000
0x603110 <n21>: 0x00000008      0x00000000      0x00603190      0x00000000
0x603120 <n21+16>:      0x00603150      0x00000000      0x00000000      0x00000000
0x603130 <n22>: 0x00000032      0x00000000      0x00603170      0x00000000
0x603140 <n22+16>:      0x006031b0      0x00000000      0x00000000      0x00000000
0x603150 <n32>: 0x00000016      0x00000000      0x00603270      0x00000000
0x603160 <n32+16>:      0x00603230      0x00000000      0x00000000      0x00000000
0x603170 <n33>: 0x0000002d      0x00000000      0x006031d0      0x00000000
0x603180 <n33+16>:      0x00603290      0x00000000      0x00000000      0x00000000
0x603190 <n31>: 0x00000006      0x00000000      0x006031f0      0x00000000
0x6031a0 <n31+16>:      0x00603250      0x00000000      0x00000000      0x00000000
0x6031b0 <n34>: 0x0000006b      0x00000000      0x00603210      0x00000000
0x6031c0 <n34+16>:      0x006032b0      0x00000000      0x00000000      0x00000000
0x6031d0 <n45>: 0x00000028      0x00000000      0x00000000      0x00000000
0x6031e0 <n45+16>:      0x00000000      0x00000000      0x00000000      0x00000000
0x6031f0 <n41>: 0x00000001      0x00000000      0x00000000      0x00000000
0x603200 <n41+16>:      0x00000000      0x00000000      0x00000000      0x00000000
0x603210 <n47>: 0x00000063      0x00000000      0x00000000      0x00000000
0x603220 <n47+16>:      0x00000000      0x00000000      0x00000000      0x00000000
0x603230 <n44>: 0x00000023      0x00000000      0x00000000      0x00000000
0x603240 <n44+16>:      0x00000000      0x00000000      0x00000000      0x00000000
0x603250 <n42>: 0x00000007      0x00000000      0x00000000      0x00000000
0x603260 <n42+16>:      0x00000000      0x00000000      0x00000000      0x00000000
0x603270 <n43>: 0x00000014      0x00000000      0x00000000      0x00000000
0x603280 <n43+16>:      0x00000000      0x00000000      0x00000000      0x00000000
0x603290 <n46>: 0x0000002f      0x00000000      0x00000000      0x00000000
0x6032a0 <n46+16>:      0x00000000      0x00000000      0x00000000      0x00000000
0x6032b0 <n48>: 0x000003e9      0x00000000      0x00000000      0x00000000
0x6032c0 <n48+16>:      0x00000000      0x00000000      0x00000000      0x00000000
```

- 画出示意图。
- 查看fun_7函数，发现是一个递归函数，写出其C语言代码。

```c
int fun7(Tree* rdi, int esi) {
    if (!rdi)
        return -1;
    if (rdi->val == esi)
        return 0;
    else if (rdi->val < esi)
        return 2 * fun7(rdi -> right, esi) + 1;
```




```
8       else
9           return 2 * fun7(rdi -> left, esi);
10  }
```

- 要使得其返回2，需要先从左子树返回1。要想返回1，需要先从右子树返回0。所以我们从36开始，esi一定小于36；进入左子树，esi一定大于8；进入右子树esi一定等于22。故答案为22。
- secret_phase defuse成功!

2.9 答案ans.txt

I'm random '89721511e2e275ba6fceab33eb51720c3b969739'
1 2 4 8 16 32*
0 207*
7 0 HiEvil
)/ > %FG
4 3 2 1 6 5
20
22300240028