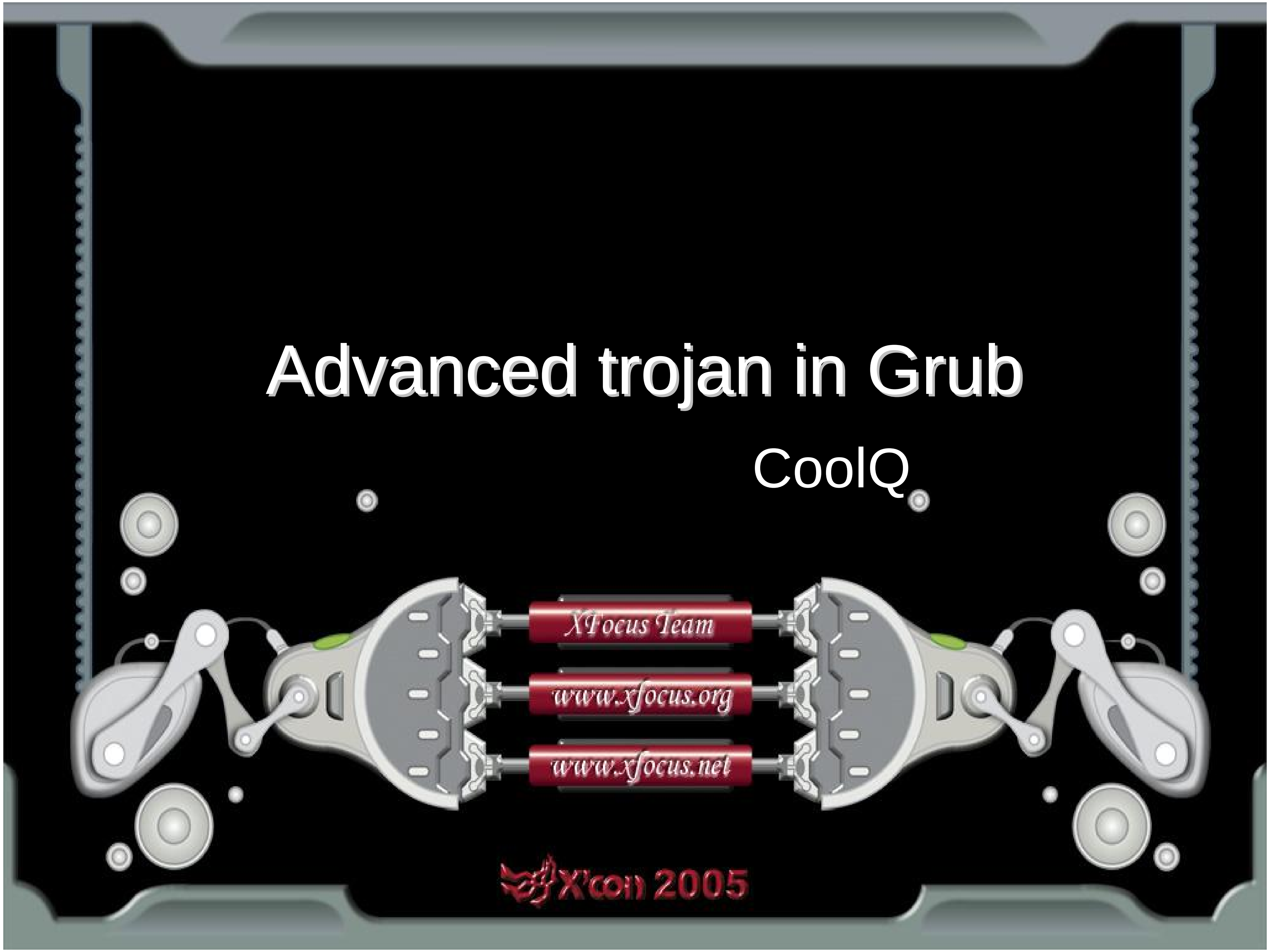
Advanced trojan in Grub

CoolQ



Contents

Overview

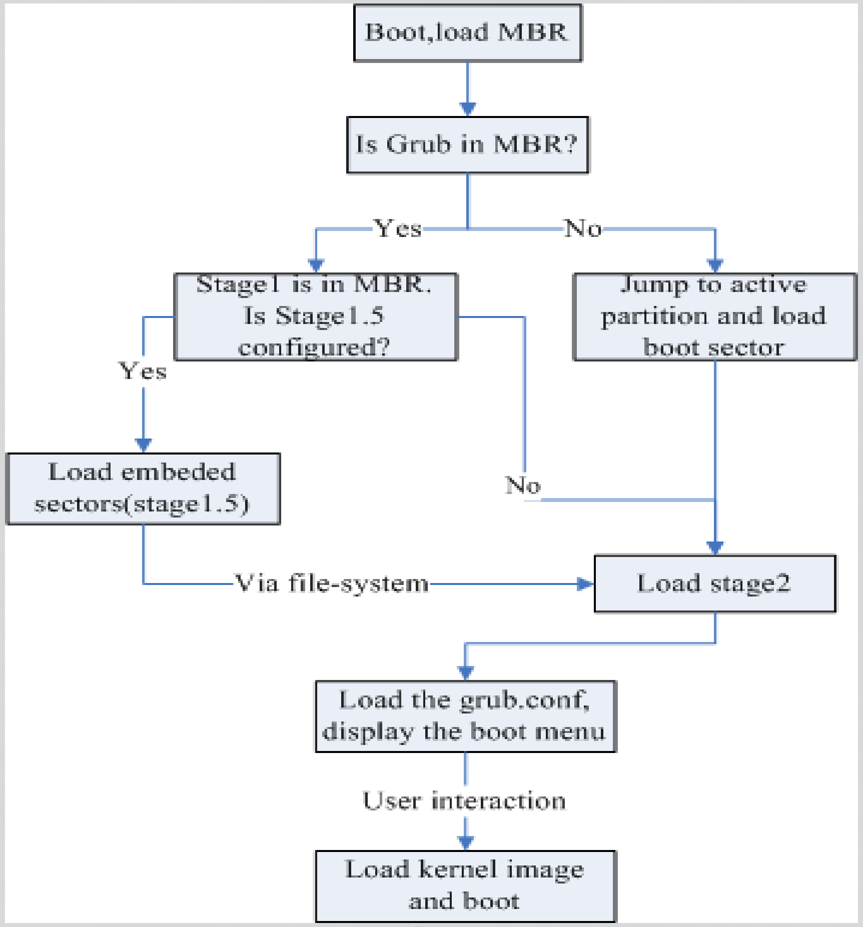
- In 1989, the 1st trojan horse appeared
  - Modify utmp,wtmp and lastlog, evade commands such as who, last, w
- LRK4/LRK5
  - Replace user-mode applications, such as ps, ls, netstat ……
- Knark/adore/adore-ng
  - LKM trojan, apply to Linux 2.2/2.4/2.6
- SuckIT
  - Via /dev/kmem
- Module injection
- Static kernel patching

What remains untouched?

Boot Loader！

- Grub
- Lilo
- …

Boot process


Boot,load MBR
Is Grub in MBR?
Yes
No
Stage1 is in MBR. Is Stage1.5 configured?
Jump to active partition and load boot sector
Yes
No
Load embeded sectors(stage1.5)
Via file-system
Load stage2
Load the grub.conf, display the boot menu
User interaction
Load kernel image and boot

stage1

- stage1.S
- 512 Bytes in size
- Located in MBR or boot sector of partition
- Its task is
  - Load specified sector(stage2_sector) to
    - 0200:0000 ß if stage1.5 is configured
    - 0800:0000 ß if stage1.5 is not configured

stage1.5 and stage2

File list

```
-rw-r--r--   1  root root        82            Feb  5     11:24       device.map
-rw-r--r--   1  root root     10848  Feb  5    11:24      e2fs_stage1_5
-rw-r--r--   1  root root      9744            Feb  5     11:24       fat_stage1_5
-rw-r--r--   1  root root      8864            Feb  5     11:24       ffs_stage1_5
-rw-------   1  root root       800            Jun  6     14:53       grub.conf
-rw-------   1  root root       800            Jun  6     14:53       menu.lst
-rw-r--r--   1  root root      9248            Feb  5     11:24       minix_stage1_5
-rw-r--r--   1  root root     12512  Feb  5    11:24      reiserfs_stage1_5
-rw-r--r--   1  root root     54044  Sep  5    20:01      splash.xpm.gz
-rw-r--r--   1  root root    108328  May 23    14:21      stage2
-rwxr-xr-x   1  root root       512            May 22     13:31       stage1
-rw-r--r--   1  root root      8512            Feb  5     11:24       vstafs_stage1_5
```

How to compile?

e2fs_stage1_5:

```
gcc -o e2fs_stage1_5.exec -nostdlib -Wl,-N -Wl,-Ttext -Wl,2000
    e2fs_stage1_5_exec-start.o e2fs_stage1_5_exec-asm.o
    e2fs_stage1_5_exec-common.o e2fs_stage1_5_exec-char_io.o
    e2fs_stage1_5_exec-disk_io.o e2fs_stage1_5_exec-stage1_5.o
    e2fs_stage1_5_exec-fsys_ext2fs.o e2fs_stage1_5_exec-bios.o
objcopy -O binary e2fs_stage1_5.exec e2fs_stage1_5
```

How to compile?(Cont.)

Stage2

```
gcc -o pre_stage2.exec -nostdlib -Wl,-N -Wl,-Ttext -Wl,8200
    pre_stage2_exec-asm.o pre_stage2_exec-bios.o pre_stage2_exec-boot.o
    pre_stage2_exec-builtins.o pre_stage2_exec-common.o
    pre_stage2_exec-char_io.o pre_stage2_exec-cmdline.o
    pre_stage2_exec-disk_io.o pre_stage2_exec-gunzip.o
    pre_stage2_exec-fsys_ext2fs.o pre_stage2_exec-fsys_fat.o
    pre_stage2_exec-fsys_ffs.o pre_stage2_exec-fsys_minix.o
    pre_stage2_exec-fsys_reiserfs.o pre_stage2_exec-fsys_vstafs.o
    pre_stage2_exec-hercules.o pre_stage2_exec-serial.o
    pre_stage2_exec-smp-imps.o pre_stage2_exec-stage2.o pre_stage2_exec-md5.o
```

```
objcopy -O binary pre_stage2.exec pre_stage2
cat start pre_stage2 > stage2
```

File layout

- **e2fs_stage1_5**
  [start.S] [asm.S] [common.c] [char_io.c] [disk_io.c]
  [stage1_5.c] [fsys_ext2fs.c] [bios.c]
- **stage2**
  [start.S] [asm.S] [bios.c] [boot.c] [builtins.c] [common.c]
  [char_io.c] [cmdline.c][disk_io.c] [gunzip.c] [fsys_ext2fs.c]
  [fsys_fat.c] [fsys_ffs.c]
  [fsys_minix.c] [fsys_reiserfs.c] [fsys_vstafs.c] [hercules.c]
  [serial.c]
  [smp-imps.c] [stage2.c] [md5.c]

- **start.S is the sector that stage1 loads，512B in size**

Sector list of start.S

```
blocklist_default_start:
        .long 2                            /* this is the sector start parameter, in logical
                                           sectors from the start of the disk, sector 0 */
blocklist_default_len:                     /* this is the number of sectors to read */
#ifdef STAGE1_5
        .word 0                            /* the command "install" will fill this up */
#else
        .word (STAGE2_SIZE + 511) >> 9
#endif
blocklist_default_seg:
#ifdef STAGE1_5
        .word 0x220
#else
        .word 0x820                        /* this is the segment of the
                                           starting address to load the data into */
         #endif
         firstlist:                        /* this label has to
                                           be after the list data!!! */
```

An example

```
# hexdump -x -n 512 /boot/grub/stage2
   ...
00001d0  [ 0000    0000    0000    0000 ] [ 0000    0000    0000    0000 ]
00001e0  [ 62c7    0026    0064    1600 ] [ 62af    0026    0010    1400 ]
00001f0  [ 6287    0026    0020    1000 ] [ 61d0    0026    003f    0820 ]
```

We should interpret(backwards) it as: (8 bytes a time)

- load 0x3f sectors(start with No.0x2661d0) to 0x0820:0000
- load 0x20 sectors(start with No.0x266287) to 0x1000:0000
- load 0x10 sectors(start with No.0x2662af) to 0x1400:00
- load 0x64 sectors(start with No.0x2662c7) to 0x1600:0000

With the help of this list, stage1.5 can load **itself** without using file-system of OS

The connection between stage1.5 and stage2

- If stage1.5 is configured, stage1 loads the 1st sector of stage1.5(start.S). Start.S uses its sector list to load the rest part of stage1.5. Then, stage1.5 uses its mini file-system to load stage2
- If stage1.5 is not configured, stage1 loads the 1st sector of stage2(start.S). Start.S uses its sector list to load the rest part of stage2.
- So, If you rename /boot/grub/stage2 to stage2.bak, when stage1.5 is configured, boot fails; while when not, boot remains OK.

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Grub utils

```
# grub
  grub > find /grub/stage2                    ß If you have separate boot partition
  grub > find /boot/grub/stage2               ß If you don't have separate boot partition
  (hd0,0)                                     <= This is the outupt of 'find' command
  grub > root (hd0,0)                         ß Set root of boot partition
  grub > setup (hd0)                          ß If you want to install grub in MBR
  grub > setup (hd0,0)                        ß If you want to install grub in boot sector
  Checking if "/boot/grub/stage1" exists... yes
  Checking if "/boot/grub/stage2" exists... yes
  Checking if "/boot/grub/e2fs_stage1_t" exists... yes
  Running "embed /boot/grub/e2fs_stage1_5 (hd0)"... 22 sectors are
    embeded succeeded.           <= If you want to install grub in boot sector,  this step
    fails
  Running "install /boot/grub/stage1 d (hd0) (hd0)1+22 p
  (hd0,0)/boot/grub/stage2 /boot/grub/grub.conf"... succeeded
             Done
```

Possibility to load specified file

Grub uses its own mini file-system to read files of ext2/ext3

```
/* preconditions:     ext2fs_mount already executed, therefore supblk in buffer
 *                              known as SUPERBLOCK
 * returns:                     0 if error, nonzero iff we were able to find the file
 *                    successfully
 * postconditions:    on a nonzero return, buffer known as INODE contains the
 *                              inode of the file we were trying to look up
 * side effects:      messes up GROUP_DESC buffer area
 */
int ext2fs_dir (char *dirname) {
  int current_ino = EXT2_ROOT_INO;    /*start at the root */
  int updir_ino = current_ino;        /* the parent of the current directory */
  …
          }
```

kernel=/boot/vmlinuz-2.6.11 ro root=/dev/hda1

- grub_open ( ) à ext2fs_dir(“kernel=/boot/vmlinuz-2.6.11 ro root=/dev/hda1”)
- INODE à i_blocks[ ]
- ext2fs_dir internals
  - /boot/vmlinuz-2.6.11 ro root=/dev/hda1
    ^ inode = EXT2_ROOT_INO, put inode info of ‘/’ to INODE
  - /boot/vmlinuz-2.6.11 ro root=/dev/hda1
    ^ find ‘boot’ entry in ‘/’, put inode info of ‘/boot’ to INODE
  - /boot/vmlinuz-2.6.11 ro root=/dev/hda1
    ^ find ‘vmlinuz-2.6.11’ entry in ‘/boot’, put inode info of vmlinuz-2.6.11 to INODE
  - /boot/vmlinuz-2.6.11 ro root=/dev/hda1
    ^ Now the pointer is space, INODE contains regular file, function retuns 1(success), INODE contains inode info of vmlinuz-2.6.11

What if …

- /boot/vmlinuz-2.6.11 ro root=/dev/hda1
  ^ inode = EXT2_ROOT_INO
-   boot/vmlinuz-2.6.11 ro root=/dev/hda1
  ^ change'/' to 0x0, change EXT2_ROOT_INO to inode of file_fake
- boot/vmlinuz-2.6.11 ro root=/dev/hda1
  ^ read inode info of file_fake to INODE, the pointers points to 0x0, INODE contains regular file, return 1(success)
- Result: inode info of fake_file is fetched to INODE, grub considers file_fake as vmlinuz-2.6.11

Side effects?

- We have modified the parameter of ext2fs_dir, the latter part “ro root=/dev/hda1” is passed to kernel as boot parameters, do we need to change it back when returning from ext2fs_dir?

kernel=…

```
static int
kernel_func (char *arg, int flags)
{
  ...
  /* Copy the command-line to MB_CMDLINE.  */
  grub_memmove (mb_cmdline, arg, len + 1);
  kernel_type = load_image (arg, mb_cmdline, suggested_type, load_flags);
  ...
}
```

1) strcmp(mb_cmdline, arg) = = 0 && mb_cmdline != arg
2) In load_image function,mb_cmdline and arg are unrelated

So, no need to change 0x0 à ‘ / ’

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Hacking techniques

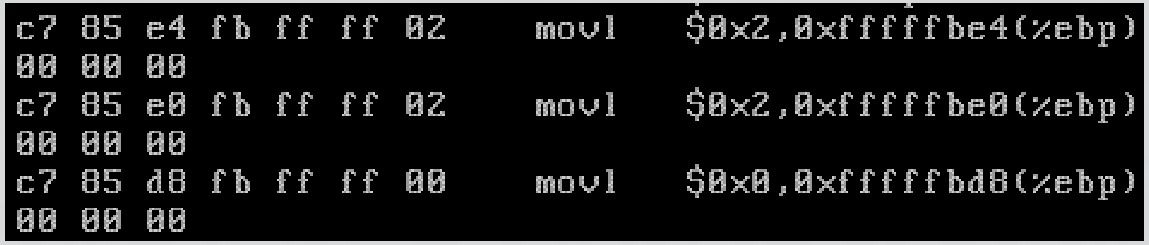
- how to load file_fake
- how to locate ext2fs_dir
- how to hack grub
- how to make things sneaky

how to load file_fake

1) JMP at the begninning of ext2fs_dir
2) Change the 1st char of ext2fs_dir's parameter to 0x0
3) current_ino = EXT2_ROOT_INO
   =>
   current_ino = INODE_OF_FILE_FAKE
   (In certain case)
4) JMP back

How to implement current_ino = INODE_OF_FILE_FAKE

```
int ext2fs_dir (char *dirname) {
  int current_ino = EXT2_ROOT_INO;            /*start at the root */
  int updir_ino = current_ino;        /* the parent of the current directory */
 ..
```



```
c7 85 e4 fb ff ff 02    movl   $0x2,0xffffbe4(%ebp)
00 00 00
c7 85 e0 fb ff ff 02    movl   $0x2,0xffffbe0(%ebp)
00 00 00
c7 85 d8 fb ff ff 00    movl   $0x0,0xffffbd8(%ebp)
00 00 00
```

Optimized result might be

"movl $2, %reg"

"movl %reg, 0xffffXXXX($esp)"

"movl %reg, 0xffffYYYY($esp)"

Other cases? Low in possibility

xor %eax, %eax; inc %eax; inc %eax

xor %eax, %eax; movb $0x2, %al

Our method

ext2fs_dir

```
push %ebp  ß jmp embed
mov %esp, %ebp
Push %edi
push %esi
sub $0x42c, %esp
mov $2, 0xfffffbe4(%esp)
mov $2, 0xfffffbe0(%esp)
back:
```

embed

```
Save registers
Compare strings
If match,  goto 1
else goto 2
1: restore registers
jmp change_inode
2: restore registers
jmp not_change_inode
```

**not_
change_inode**

```
push %ebp
mov %esp, %ebp
mush %edi
push %esi
sub $0x42c, %esp
mov $2, 0xfffffbe4(%esp)
mov $2, 0xfffffbe0(%esp)
jmp back
```

change_inode

```
push %ebp
mov %esp, %ebp
mush %edi
push %esi
sub $0x42c, %esp
mov $?, 0xfffffbe4(%esp)
mov $?, 0xfffffbe0(%esp)
jmp back
```

INODE_OF_
FAKE_FILE

How to locate ext2fs_dir()

- Because ext2fs_dir is generated by objcopy, all ELF infos are stripped, NO SYMBOL TABLE! So we have to use other hacks to locate this function.

1st try

```
#define long2(n) ffz(~(n))
   static __inline__ unsigned long
   ffz (unsigned long word)
   {
       __asm__ ("bsfl %1, %0"
               :"=r" (word)
               :"r" (~word));
       return word;
   }
group_desc = group_id >> log2 (EXT2_DESC_PER_BLOCK (SUPERBLOCK));
```

ffz is declared as __inline__, so the find result is hard to predict, MAYBE inline, MAYBE not, so we give it up！

2nd try

- **SUPERBLOCK->s_inodes_per_group**

```
group_id = (current_ino - 1) / (SUPERBLOCK->s_inodes_per_group);
   #define RAW_ADDR(x) (x)
   #define FSYS_BUF RAW_ADDR(0x68000)
   #define SUPERBLOCK ((struct ext2_super_block *)(FSYS_BUF))
   struct ext2_super_block{
       ...
       __u32 s_inodes_per_group      /* # Inodes per group */
       ...
```

SUPERBLOCK->s_inodes_per_group is at 0x68028, search backward for t beginning of function

- Question
  - How to locate RET? Search backword for 0xc3?
  - How to locate the beginning of ext2fs_dir? Function align(4/8/16 bytes, junk codes vary)
- Conclusion: practical but not reliable

3rd try

- At last, we noticed fsys_table

```
struct fsys_entry fsys_table[NUM_FSYS + 1] =
  {
    ...
  # ifdef FSYS_FAT
    {"fat", fat_mount, fat_read, fat_dir, 0, 0},
  # endif
  # ifdef FSYS_EXT2FS
    {"ext2fs", ext2fs_mount, ext2fs_read, ext2fs_dir, 0, 0},
  # endif
  # ifdef FSYS_MINIX
    {"minix", minix_mount, minix_read, minix_dir, 0, 0},
  # endif


  }
```

fsys_table is called like this:

```
[illegible] ((*(fsys_table[fsys_type].mount_func)) () != 1)
```

Our method

- Search stage2 for string "ext2fs", get its offset, then convert it to memory address(stage2 starts from 0800:0000) addr_1.
- Search stage2 for addr_1, get its offset, then get next 5 integers (A, B, C, D, E), A<B ? B<C ? C<addr_1 ? D==0 ? E==0? If any one is "No", goto 1 and continue search
- Then C is memory address of ext2fs_dir, convert it to file offset. OK, that's it

How to hack grub

- With the help of above, things are much easizer. But at the beginning of ext2fs_dir, where should we jump to?
  - The tail of stage2? It will change the size of stage2 (more…)
  - fat_mount(It's right after ext2fs_dir)?
    - **NO !**

```
root_func()->open_device()->attemp_mount()
   for (fsys_type = 0; fsys_type < NUM_FSYS
        && (*(fsys_table[fsys_type].mount_func)) () != 1; fsys_type++);
```

Fat is ahead of ext2fs, so fat_mount will run before ext2fs_mount.

  - At last, we choose minix_dir

how to make things sneaky

- Drawback of the above method: the checksum of stage2 changes
- Countermeasure: let stage1 loads stage2_fake
- Notice:
  - Refill the sector list of stage2_fake
  - If stage1.5 is not configured, let stage1 load stage2_fake directly()，修改stage1直接调用stage2_fake(stage2_sector should be the sector number of stage2_fake), this may change MBR

how to make things sneaky(Cont.)

- If stage1.5 is configured,
  - Modify stage1 to bypass stage1.5, load stage2 directly (modify stage2_sector,stage2_address,stage2_segment)
    - Drawbacks: MBR and boot messages change
  - Use the same techniques to modify the file-system of stage1.5, refill the sector list of stage1.5
- You can hide stage2_fake and file_fake as well
- Wanna anti-FSCK? No problem…

Usage

- Combined with static kernel patching
  1)cp kernel.orig kernel.fake
  2)Static kernel patch with kernel.fake
  3)cp stage2 stage2.fake
  4)hack_grub stage2.fake kernel.orig inode_of_kernel.fake
  5)Hide kernel.fake **and** stage2.fake (Optional)

Usage(Cont.)

- Combined with module injection
  1) cp initrd.img.orig initrd.img.fake
  2) Do module injection with initrd.img.fake, e.g. ext3.[k]o
  3) cp stage2 stage2.fake
  4) hack_grub stage2.fake initrd.img inode_of_initrd.img.fake
  5) Hide initrd.img.fake and stage2.fake (Optional)
- Use fake grub.conf
- More…

Detection

1) Keep an eye on MBR and the following 63 sectors, also primary boot sectors.
2) If not 1), then
   a) If stage1.5 is configured, compare sectors from 3(absolute address, MBR is sector No. 1) with /boot/grub/e2fs_stage1_5
   b) if stage1.5 is not configured, see if stage2_sector points to real /boot/grub/stage2 file
3) check the file consistency of e2fs_stage1_5 and stage2
4) If not 3), things are more difficult(Hey, are you a qualified sysadmin?)
   a) If you're suspicious about kernel, dump the kernel and make a byte-to-byte with kernel on disk.
   b) If you're suspicious about module, that's a hard challenge, maybe you can dump it and disassemble it?

What about Lilo?

- Lilo doesn’t have built-in file-system, so, no need to patch mini built-in file-system like Grub.
- Lilo relies on /boot/bootsect.b and /boot/map.b
- Lazy way: lilo –C fake_config
- More details? Depends on yourself…

Thanks to …

- madsys & grip2 for help me solve some hard-to-crack things
- airsupply and other guys for stage2 samples
- zhtq for some comments about paper-writing

References

- Design and Implementation of the Second Extended Filesystem
- Static Kernel Patching
- Infecting Loadable Kernel Modules
- module injection in 2.6 kernel
- Ways to hide files in ext2/3 filesystem
- Ways to find 2.6 kernel rootkits

Questions & Answers