CSc 466/566

Computer Security

5 : Man-At-The-End — Attack Models

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Attack Targets

Who's our adversary?

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- What is the adversary's motivation for attacking your program?
- What information does he start out with as he attacks your program?

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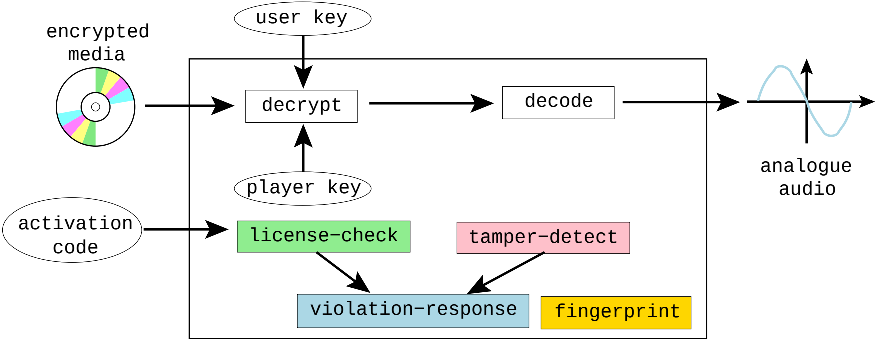
- What is his overall strategy for reaching his goals?
- What tools does he have to his disposal?
- What specific techniques does he use to attack the program?

Example Program



Example Program

```
typedef unsigned int uint;
typedef uint* waddr_t;
uint player_key = 0xbabeca75;
uint the_key;
uint* key = &the_key;
FILE* audio;
int activation_code = 42;
```

Example Program

```
void FIRST_FUN(){}
uint hash (waddr_t addr, waddr_t last) {
    uint h = *addr;
    for(;addr<=last;addr++) h^=*addr;
    return h;
}
void die(char* msg) {
    fprintf(stderr,”%s!\n”,msg);
    key = NULL;
}
```

Example Program

```
uint play(uint user_key,
          uint encrypted_media[],
          int media_len) {
   int code;
   printf("Please enter activation code: ");
   scanf("%i",&code);
   if (code!=activation_code) die("wrong code");

   *key = user_key ^ player_key;
```

Example Program

```
    int i;
    for(i=0;i<media_len;i++) {
        uint decrypted = *key ^ encrypted_media[i];
        asm volatile (
            "jmp L1                 \n\t"
            ".align 4               \n\t"
            ".long       0xb0b5b0b5\n\t"
            "L1:                    \n\t"
        );
        if (time(0) > 1221011472) die("expired");
        float decoded = (float)decrypted;
        fprintf(audio,"%f\n",decoded); fflush(audio);
    }
}
```

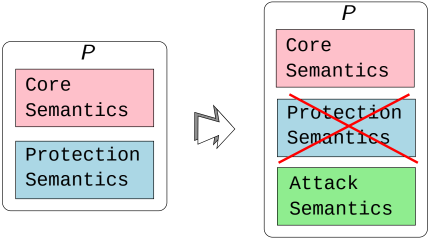
Example Program

```
void LAST_FUN(){}
uint player_main (uint argc, char *argv[]) {
    uint user_key = ···
    uint encrypted_media[100] = ···
    uint media_len = ···
    uint hashVal = hash((waddr_t)FIRST_FUN,
                        (waddr_t)LAST_FUN);
    if (hashVal != HASH) die("tampered");
    play(user_key, encrypted_media,media_len);
}
```

What's the Adversary's Motivation?

The adversary's wants to

- remove the protection semantics.



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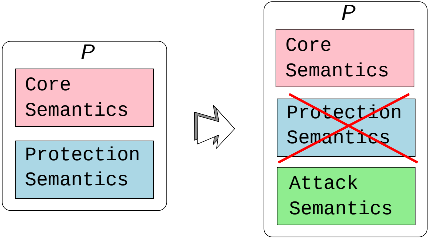
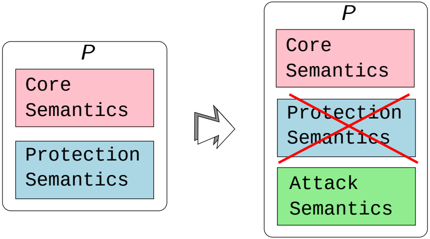
- add his own attack semantics (ability to save game-state, print,. . .)



What's the Adversary's Motivation?

The adversary's wants to

- remove the protection semantics.
- add his own attack semantics (ability to save game-state, print,. . .)
- ensure that the core semantics remains unchanged.



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- use the program after the expiration date
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- distribute the program to other users
    - remove fingerprint `0xb0b5b0b5`
- reverse engineer the algorithms in the player

What are the methods of attack?

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1. the *black box* phase
   - feed the program inputs,
   - record its outputs,
   - draw conclusions about its behavior.
2. the *dynamic analysis* phase
   - execute the program
   - record which parts get executed for different inputs.
3. the *static analysis* phase
   - examining the executable code directly
   - use disassembler, decompiler, . . .

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4. the *editing* phase
   - use understanding of the internals of the program
   - modify the executable
   - disable license checks

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4. the *editing* phase
   - use understanding of the internals of the program
   - modify the executable
   - disable license checks
5. the *automation* phase.
   - encapsulates his knowledge of the attack in an automated *script*
   - use in future attacks.

Cracking with gdb

Learning the executable (Linux)

1. Print dynamic symbols:

```
> objdump -T player2
```

2. Disassemble:

```
> objdump -d player2 | head
```

3. Start address:

```
> objdump -f player2 | grep start
```

4. Address and size of segments:

```
> objdump -x player2 | egrep 'rodata|text|Name'
```

Learning the executable (Mac OS X)

1. Print dynamic symbols:

```
> objdump -T player2
```

2. Disassemble:

```
> otool -t -v player2
```

3. Start address:

```
> otool -t -v player2 | head
```

4. Address and size of segments:

```
otool -l player2 | gawk '/__text/,/size/{print}'
otool -l player2 | gawk '/__cstring/,/size/{print}'
```

Learning the executable

1. Find strings in the program:

```
> strings player2
```

2. The strings and their offsets:

```
> strings -o player2
```

3. The bytes of the executable:

```
> od -a player2
```

Tracing the executable

1. `ltrace` traces library calls:

```
> ltrace -i -e printf player2
```

2. `strace` traces system calls:

```
> strace -i -e write player2
```

3. On Mac OS X:

```
   sudo dtruss player1
```

Debugging with gdb

1. To start gdb:

```
gdb -write -silent --args player2 0xca7ca115 100
```

2. Search for a string in an executable:

```
(gdb) find startaddress, +length, "string"
(gdb) find startaddress, stopaddress, "string"
```

Debugging with gdb

1. Breakpoints:

```
(gdb) break *0x......
(gdb) hbreak *0x......
```

   `hbreak` sets a hardware breakpoint which doesn't modify the executable itself.

2. Watchpoints:

```
(gdb) rwatch *0x......
(gdb) awatch *0x......
```

Debugging with gdb. . .

1. To disassemble instructions:

```
(gdb) disass startaddress endaddress
(gdb) x/3i address
(gdb) x/i $pc
```

2. To examine data (x=hex,s=string, d=decimal, b=byte,. . .):

```
(gdb) x/x address
(gdb) x/s address
(gdb) x/d address
(gdb) x/b address
```

3. Print register values:

```
(gdb) info registers
```

Debugging with gdb...

1. Examine the callstack:

```
(gdb) where
(gdb) bt          -- same as where
(gdb) up          -- previous frame
(gdb) down        -- next frame
```

2. Step one instruction at a time:

```
(gdb) display/i $pc
(gdb) stepi     -- step one instruction
(gdb) nexti     -- step over function calls
```

3. Modify a value in memory:

```
(gdb) set {unsigned char}address = value
(gdb) set {int}address = value
```

Patching executables with gdb

Cracking an executable proceedes in these steps:

1. find the right address in the executable,
2. find what the new instruction should be,
3. modify the instruction in memory,
4. save the changes to the executable file.

Start the program to allow patching:

```
> gdb -write -q player1
```

Make the patch and exit:

```
(gdb) set {unsigned char} 0x804856f = 0x7f
(gdb) quit
```

Let’s Attack!

Let's crack!

- Let's get a feel for the types of techniques attackers typically use.
- Our example cracking target will be the DRM player.
- Our chief cracking tool will be the gdb debugger.

Step 1: Learn about the executable

```
> file player
player: ELF 64-bit LSB executable, dynamically linked

> objdump -T player
DYNAMIC SYMBOL TABLE:
0xa4    scanf
0x90    fprintf
0x12    time

> objdump -x player | egrep 'rodata|text|Name'
Name          Size     VMA        LMA        File off
.text         0x4f8    0x4006a0   0x4006a0   0x6a0
.rodata       0x84     0x400ba8   0x400ba8   0xba8

> objdump -f player | grep start
start address 0x4006a0
```

Step 2: Breaking on library functions

- Treat the program as a black box
- Feed it inputs to see how it behaves.

```
> player 0xca7ca115 1 2 3 4
Please enter activation code: 42
expired!
Segmentation fault
```

- Find the assembly code equivalent of

  `if (time(0) >` *`some value`*`)`$\cdots$

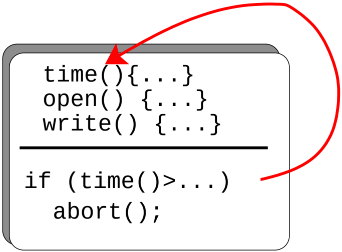
- Replace it with

  `if (time(0) <=` *`some value`*`)`$\cdots$

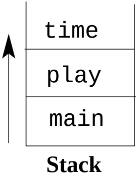
Example Program

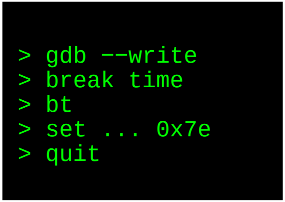
```
    int i;
    for(i=0;i<media_len;i++) {
        uint decrypted = *key ^ encrypted_media[i];
        if (time(0) > 1221011472) die("expired");
        float decoded = (float)decrypted;
        fprintf(audio,"%f\n",decoded); fflush(audio);
    }
}
```

Breaking on library functions



```
  time(){...}
  open() {...}
  write() {...}

if (time()>...)
  abort();
```





```
> gdb --write
> break time
> bt
> set ... 0x7e
> quit
```

Step 2: Breaking on library functions

At 0x4008bc is the offending conditional branch:

```
> gdb -write -silent --args player 0xca7ca115 \
                     1000 2000 3000 4000
(gdb) break time
Breakpoint 1 at 0x400680
(gdb) run
Please enter activation code: 42
Breakpoint 1, 0x400680 in time()
(gdb) where 2
#0  0x400680 in time
#1  0x4008b6 in ??
(gdb) up
#1  0x4008b6 in ??
(gdb) disassemble $pc-5 $pc+7
0x4008b1    callq  0x400680
0x4008b6    cmp    $0x48c72810,%rax
0x4008bc    jle    0x4008c8
```

X86 condition codes

CCCC	Name	Means
0000	O	overflow
0001	NO	Not overflow
0010	C/B/NAE	Carry, below, not above nor equal
0011	NC/AE/NB	Not carry, above or equal, not below
0100	E/Z	Equal, zero
0101	NE/NZ	Not equal, not zero
0110	BE/NA	Below or equal, not above
0111	A/NBE	Above, not below nor equal
1000	S	Sign (negative)
1001	NS	Not sign
1010	P/PE	Parity, parity even
1011	NP/PO	Not parity, parity odd
1100	L/NGE	Less, not greater nor equal
1101	GE/NL	Greater or equal, not less
1110	LE/NG	Less or equal, not greater
1111	G/NLE	Greater, not less nor equal

Step 2: Breaking on library functions

Patch the executable:

- replace the `jle` with a `jg` (x86 opcode 0x7f)

```
(gdb) set {unsigned char}0x4008bc = 0x7f
(gdb) disassemble 0x4008bc 0x4008be
0x4008bc    jg      0x4008c8
```

Step 3: Static pattern-matching

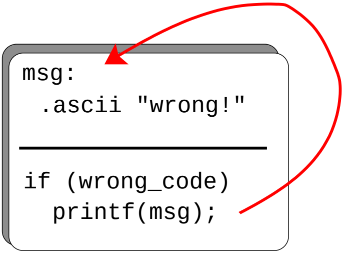
- search the executable for character strings.

```
> player 0xca7ca115 1000 2000 3000 4000
tampered!
Please enter activation code: 99
wrong code!
Segmentation fault
```

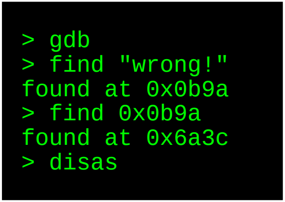
Example Program

```
uint play(uint user_key,
          uint encrypted_media[],
          int media_len) {
    int code;
    printf("Please enter activation code: ");
    scanf("%i",&code);
    if (code!=activation_code) die("wrong code");

    *key = user_key ^ player_key;
```

Static pattern-matching



```
msg:
  .ascii "wrong!"

if (wrong_code)
  printf(msg);
```



```
> gdb
> find "wrong!"
found at 0x0b9a
> find 0x0b9a
found at 0x6a3c
> disas
```

Step 3: Static pattern-matching

- the code that checks the activation code looks something like this:

```
addr1:    .ascii ”wrong code”
       ...
       cmp     read_value,activation_code
       je      somewhere
addr2: move    addr1, reg0
       call    printf
```

Step 3: Static pattern-matching

1. search the data segment to find address `addr1` where `"wrong code"` is allocated.
2. search through the text segment for an instruction that contains that address as a literal:

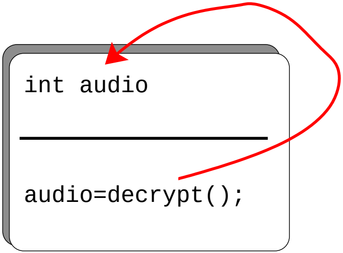
```
(gdb) find 0x400ba8,+0x84,”wrong code”
0x400be2
(gdb) find 0x4006a0,+0x4f8,0x400be2
0x400862
(gdb) disassemble 0x40085d 0x400867
0x40085d    cmp     %eax,%edx
0x40085f    je      0x40086b
0x400861    mov     $0x400be2,%edi
0x400866    callq   0x4007e0
```

Step 5: Recovering internal data

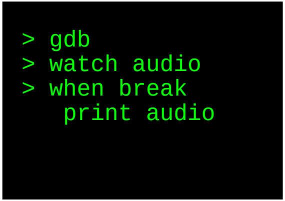
1. ask the debugger to print out decrypted media data!

```
(gdb) hbreak *0x4008a6
(gdb) commands
>x/x -0x8+$rbp
>continue
>end
(gdb) cont
Please enter activation code: 42
Breakpoint 2, 0x4008a6
0x7fffffffdc88: 0xbabec99d
Breakpoint 2, 0x4008a6
0x7fffffffdc88: 0xbabecda5
          ...
```

Recovering internal data



```
int audio

audio=decrypt();
```



```
> gdb
> watch audio
> when break
    print audio
```

Step 6: Tampering with the environment

1. To avoid triggering the timeout, wind back the system clock!
2. Change the library search path to force the program to pick up hacked libraries!
3. Hack the OS (we'll see this later).

Tampering with the environment

```
if (time()>...)
  abort();
```

```
> set time \
19551112,10:04pm

> player
```

Step 8: Differential attacks

1. Find two differently fingerprinted copies of the program
2. Diff them!

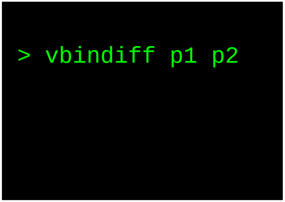
```
asm (
   "jmp L1              \n\t"
   ".align 4            \n\t"
   ".long     0xb0b5b0b5\n\t"
   "L1:                 \n\t"
);
```

```
asm (
   "jmp L1              \n\t"
   ".align 4            \n\t"
   ".long     0xada5ada5\n\t"
   "L1:                 \n\t"
);
```

Differential attacks

```
user:
  .ascii "BOB"
```

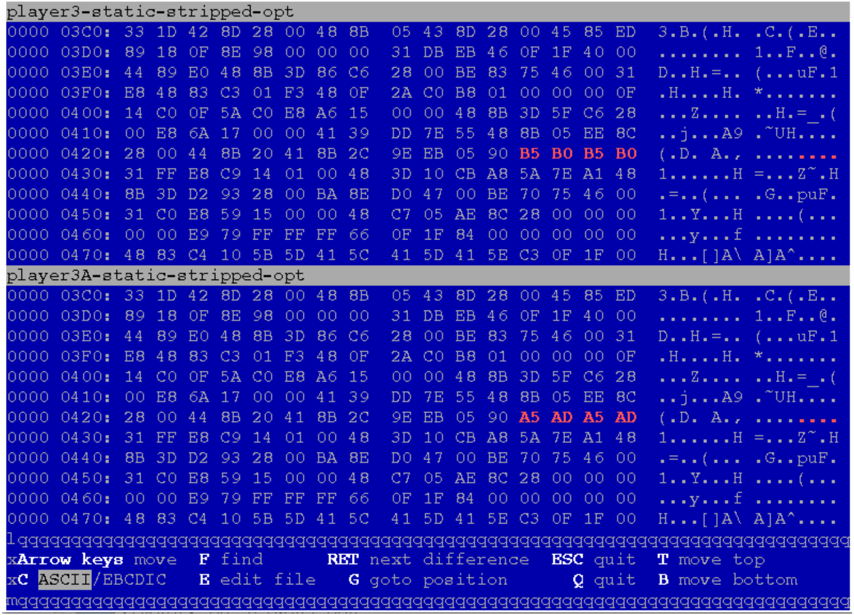
```
user:
  .ascii "CAL"
```



```
> vbindiff p1 p2
```

"I AM BOB!"

"I AM CAL!"



```
player3-static-stripped-opt
0000 03C0: 33 1D 42 8D 28 00 48 8B  05 43 8D 28 00 45 85 ED  3.B.(.H. .C.(.E..
0000 03D0: 89 18 0F 8E 98 00 00 00  31 DB EB 46 0F 1F 40 00  ........ 1..F..@.
0000 03E0: 44 89 E0 48 8B 3D 86 C6  28 00 BE 83 75 46 00 31  D..H.=.. (...uF.1
0000 03F0: E8 48 83 C3 01 F3 48 0F  2A C0 B8 01 00 00 00 0F  .H....H. *.......
0000 0400: 14 C0 0F 5A C0 E8 A6 15  00 00 48 8B 3D 5F C6 28  ...Z.... ..H.=_.(
0000 0410: 00 E8 6A 17 00 00 41 39  DD 7E 55 48 8B 05 EE 8C  ..j...A9 .~UH....
0000 0420: 28 00 44 8B 20 41 8B 2C  9E EB 05 90 B5 B0 B5 B0  (.D. A., ........
0000 0430: 31 FF E8 C9 14 01 00 48  3D 10 CB A8 5A 7E A1 48  1......H =...Z~.H
0000 0440: 8B 3D D2 93 28 00 BA 8E  D0 47 00 BE 70 75 46 00  .=..(... .G..puF.
0000 0450: 31 C0 E8 59 15 00 00 48  C7 05 AE 8C 28 00 00 00  1..Y...H ....(...
0000 0460: 00 00 E9 79 FF FF FF 66  0F 1F 84 00 00 00 00 00  ...y...f ........
0000 0470: 48 83 C4 10 5B 5D 41 5C  41 5D 41 5E C3 0F 1F 00  H...[]A\ A]A^....
player3A-static-stripped-opt
0000 03C0: 33 1D 42 8D 28 00 48 8B  05 43 8D 28 00 45 85 ED  3.B.(.H. .C.(.E..
0000 03D0: 89 18 0F 8E 98 00 00 00  31 DB EB 46 0F 1F 40 00  ........ 1..F..@.
0000 03E0: 44 89 E0 48 8B 3D 86 C6  28 00 BE 83 75 46 00 31  D..H.=.. (...uF.1
0000 03F0: E8 48 83 C3 01 F3 48 0F  2A C0 B8 01 00 00 00 0F  .H....H. *.......
0000 0400: 14 C0 0F 5A C0 E8 A6 15  00 00 48 8B 3D 5F C6 28  ...Z.... ..H.=_.(
0000 0410: 00 E8 6A 17 00 00 41 39  DD 7E 55 48 8B 05 EE 8C  ..j...A9 .~UH....
0000 0420: 28 00 44 8B 20 41 8B 2C  9E EB 05 90 A5 AD A5 AD  (.D. A., ........
0000 0430: 31 FF E8 C9 14 01 00 48  3D 10 CB A8 5A 7E A1 48  1......H =...Z~.H
0000 0440: 8B 3D D2 93 28 00 BA 8E  D0 47 00 BE 70 75 46 00  .=..(... .G..puF.
0000 0450: 31 C0 E8 59 15 00 00 48  C7 05 AE 8C 28 00 00 00  1..Y...H ....(...
0000 0460: 00 00 E9 79 FF FF FF 66  0F 1F 84 00 00 00 00 00  ...y...f ........
0000 0470: 48 83 C4 10 5B 5D 41 5C  41 5D 41 5E C3 0F 1F 00  H...[]A\ A]A^....
lqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqq
xArrow keys move   F find       RET next difference  ESC quit  T move top
xC ASCII/EBCDIC    E edit file   G goto position       Q quit  B move bottom
mqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqqq
```

Step 9: Decompilation

```
L080482A0(A8, Ac, A10) {
    ebx = A8;
    esp = "Please enter activation code: ";
    eax = L080499C0();
    V4 = ebp - 16;
    *esp = 0x80a0831;
    eax = L080499F0();
    eax = *(ebp - 16);
    if(eax != *L080BE2CC) {
        V8 = "wrong code";
        V4 = 0x80a082c;
        *esp = *L080BE704;
        eax = L08049990();
        *L080BE2C8 = 0;
    }
```

Example Program

```c
uint play(uint user_key,
          uint encrypted_media[],
          int media_len) {
   int code;
   printf("Please enter activation code: ");
   scanf("%i",&code);
   if (code!=activation_code) die("wrong code");

   *key = user_key ^ player_key;
```

```
    eax = *L080BE2C8;
    edi = 0;
    ebx = ebx ^ *L080BE2C4;
    *eax = ebx;
    eax = A10;
    if(eax <= 0) {} else {
        while(1) {
            esi = *(Ac + edi * 4);
L08048368:  *esp = 0;
            if(L08056DD0() > 1521011472) {
                V8 = "expired";
                V4 = 0x80a082c;
                *esp = *L080BE704;
                L08049990();
                *L080BE2C8 = 0;
            }
```

Example Program

```
typedef unsigned int uint;
typedef uint* waddr_t;
uint player_key = 0xbabeca75;
uint the_key;
uint* key = &the_key;
FILE* audio;
int activation_code = 42;

void FIRST_FUN(){}
uint hash (waddr_t addr, waddr_t last) {
    uint h = *addr;
    for(;addr<=last;addr++) h^=*addr;
    return h;
}
void die(char* msg) {
    fprintf(stderr,"%s!\n",msg);
    key = NULL;
}
```

```
            ebx = ebx ^ esi;
            (save)0;
            edi = edi + 1;
            (save)ebx;
            esp = esp + 8;
            V8 = *esp;
            V4 = "%f\n"; *esp = *L080C02C8;
            eax = L08049990();
            eax = *L080C02C8;
            *esp = eax;
            eax = L08049A20();
            if(edi == A10) {goto L080483a7;}
            eax = *L080BE2C8; ebx = *eax;
        }
        ch = 176; ch = 176;
        goto L08048368;
    }
L080483a7:
}
```

```
L080483AF(A8, Ac) {
    ...
    ecx = 0x8048260;
    edx = 0x8048230;
    eax = *L08048230;
    if(0x8048260 >= 0x8048230) {
        do {
            eax = eax ^ *edx;
            edx = edx + 4;
        } while(ecx >= edx);
    }
    if(eax != 318563869) {
        V8 = "tampered";
        V4 = 0x80a082c;
        *esp = *L080BE704;
        L08049990();
        *L080BE2C8 = 0;
    }
    V8 = A8 - 2;
    V4 = ebp + -412;
    *esp = *(ebp + -416);
    return(L080482A0());
}
```

Example Program

```c
typedef unsigned int uint;
typedef uint* waddr_t;
uint player_key = 0xbabeca75;
uint the_key;
uint* key = &the_key;
FILE* audio;
int activation_code = 42;

void FIRST_FUN(){}
uint hash (waddr_t addr, waddr_t last) {
   uint h = *addr;
   for(;addr<=last;addr++) h^=*addr;
   return h;
}
void die(char* msg) {
   fprintf(stderr,"%s!\n",msg);
   key = NULL;
}
```

Discussion

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- Modify the executable.
- Tamper with the execution environment.

In-Class Exercise

- Alice writes a program that she only wants Bob to execute 5 times.
- At the end of each run, the program writes a file `.AliceSecretCount` with the number of runs so far.
- At the beginning of each run, the program reads the file `.AliceSecretCount` and, if the number of runs so far is ≥ 5, it exits with an error message `BAD BOB!`.
- Draw a detailed attack tree with all attacks available to Bob!