From “No Way” to 0-day: Weaponizing the Unweaponizable

“...you’re de0uing it wrong...”

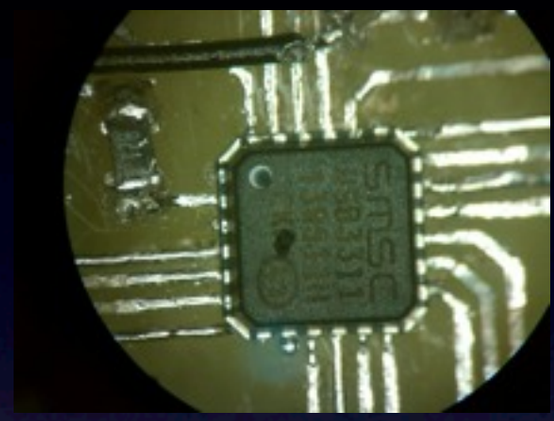
Joshua Wise

EMARHAVIL
HEAVY INDUSTRIES

Outline

- Intro
- Vulnerabilities: in general
  - What makes something easy to exploit?
- Vulnerabilities: a case study
  - Making something hard into something doable
- Briefly -- what went wrong?
  - How did this sort of thing happen?
- Q & A

Intro: Me



- Just some guy, you know?
- All-purpose embedded hacker
  - Got roped into Android at some point
- Recovering software guy
  - Now doing ASIC design
- Buzzword compliant
  - Working on IMB in ECE at CMU

unrevoked

Carnegie Mellon

Intro: You

- At least a little bit of kernel experience?
- Interested in security?
- Not a skript kiddie
  - No code for you to compile here
  - Enough description for a skilled programmer to repro this

image: me, 12 years old

Today's vulnerability

- While looking for ways to root Android phones, came across...
  - CVE-2010-1084
- "CVE request: kernel: bluetooth: potential bad memory access with sysfs files"
  - "...allows attackers to cause a denial of service (memory corruption)"
- First showed up in 2.6.18, fixed in 2.6.33
  - ...ouch!
  - Raise your hand if you haven't patched up to 2.6.33 yet

Mechanism of crash

- Classic vulnerability
  - for each Bluetooth socket, `sprintf()` onto the end of a string in a buffer
  - no check for end of buffer
- With a twist
  - gets the buffer from the frame allocator; scribbles into next frame (uncontrolled target)
  - contents not controlled
  - length only kind of controlled

Yesterday's vulnerability

- Refresher: easy vulnerability
- Simple stack smash:

```
void cs101_greeter() {              // prof said it has 2 be setuid root 4 term axx
    char buf[1024];
    printf("What is your name?\n");
    gets(buf);                      // my prof said not to use gets(3)
    printf("Hello, %s!\n", buf);// so i used gets(buf), thats ok rite?
}
```

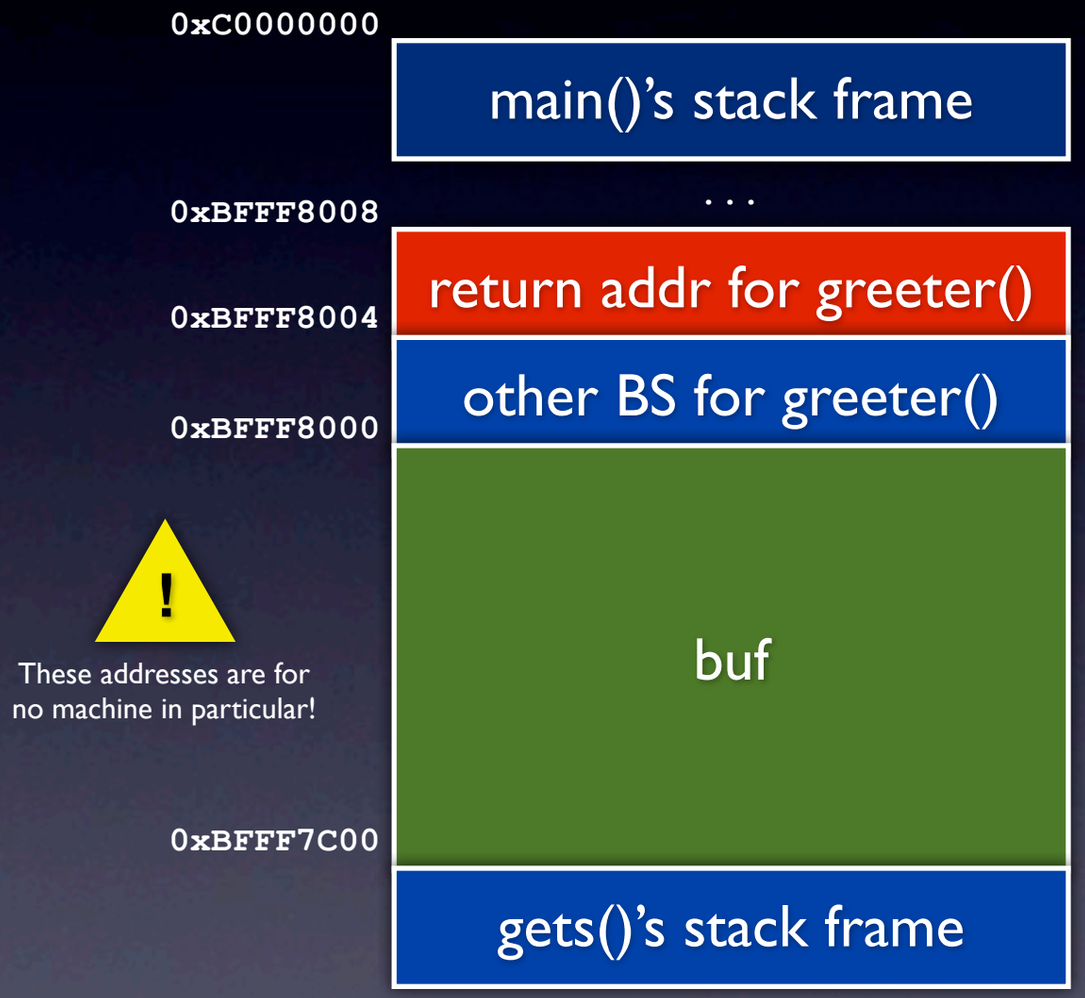
- Easily exploitable properties
  - Controlled target
  - Controlled length
  - Controlled contents (with a few limitations)

Watch that stack!

- What happens next?
  - "User" inputs something bad.
- Where does it go?

Watch that stack!

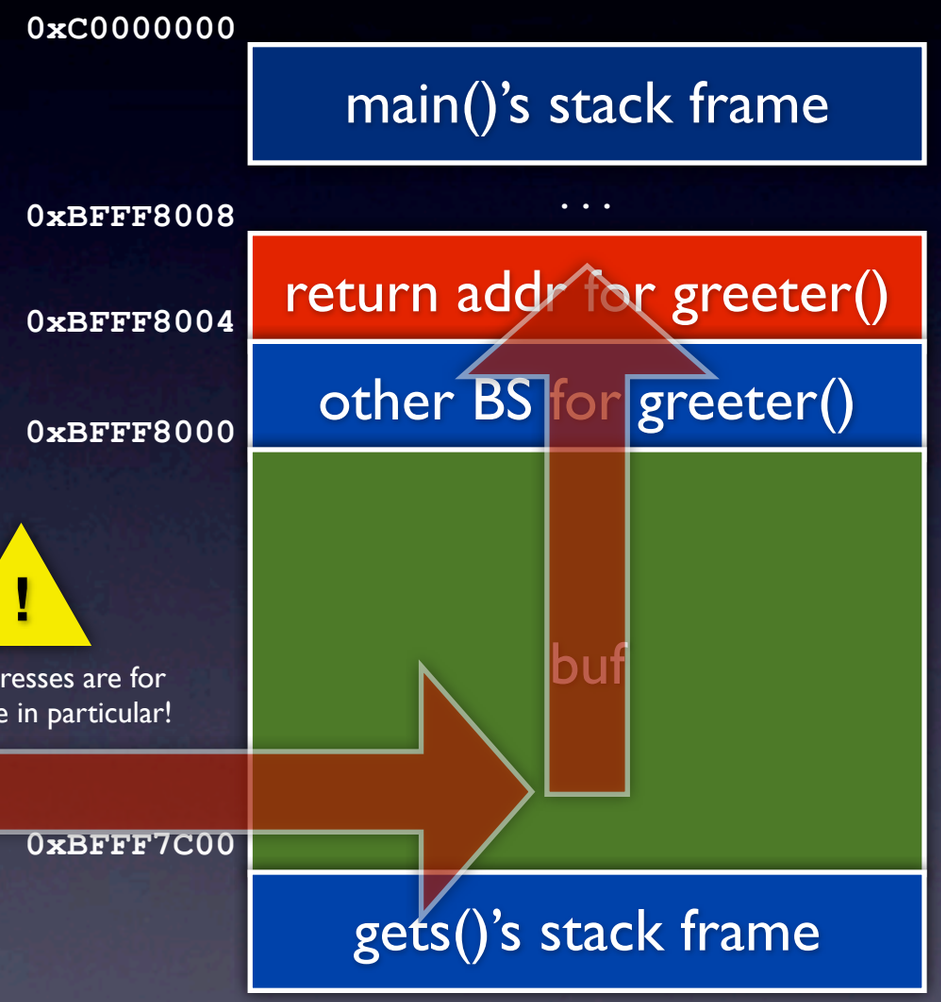
- What happens next?
  - "User" inputs something bad.
- Where does it go?



Watch that stack!

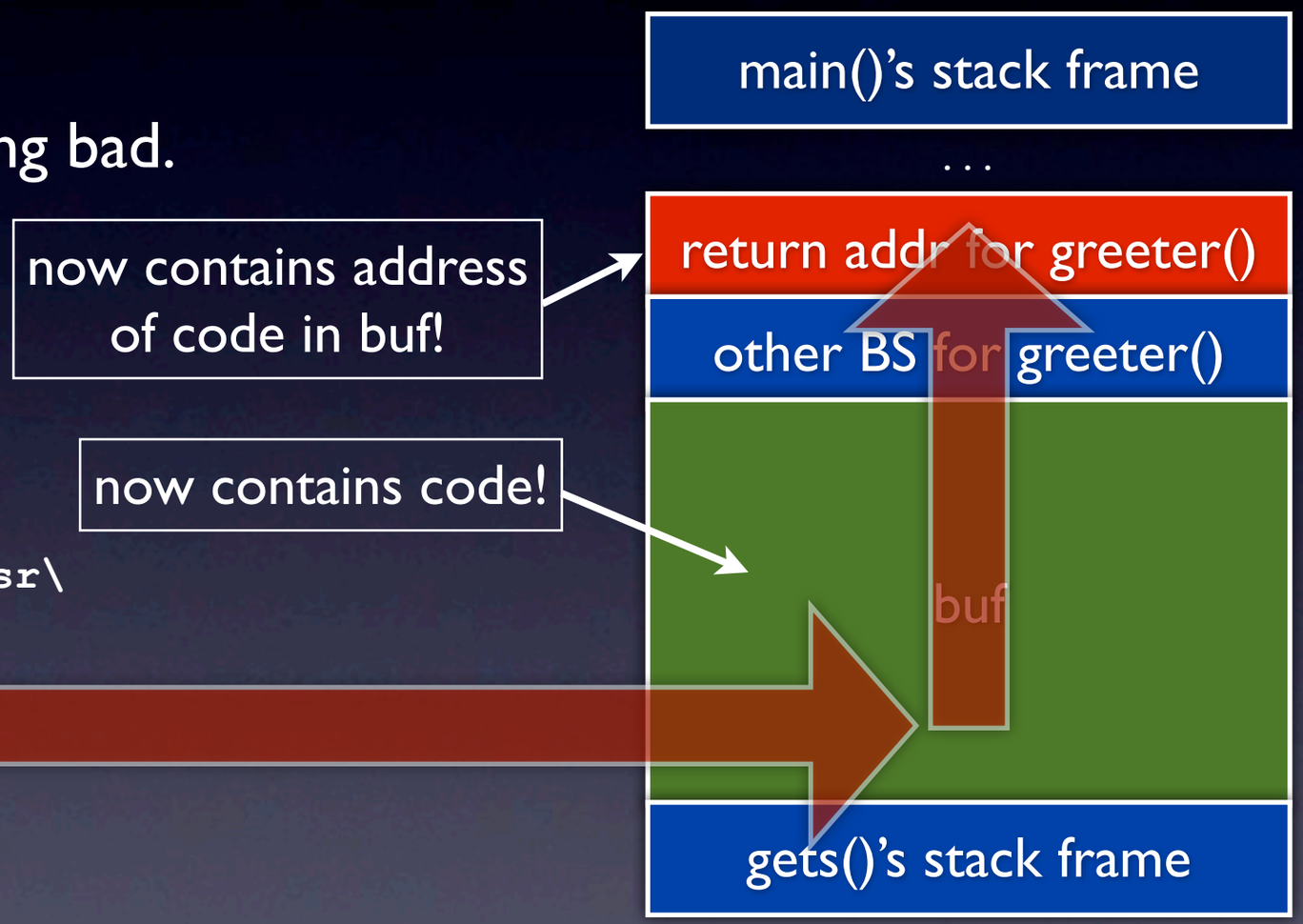
- What happens next?
  - "User" inputs something bad.
- Where does it go?

```
$ /afs/cs/course/15123-sfnoob/usr\
  /aashat/bin/greeter
What is your name?
AAAAAAAAAAAAA...ΔʃΔ∂œåµƒ...
Hello, AAAAAAAAA...
  [+] pwned
#
```



Watch that stack!

- What happens next?
  - "User" inputs something bad.
- Where does it go?

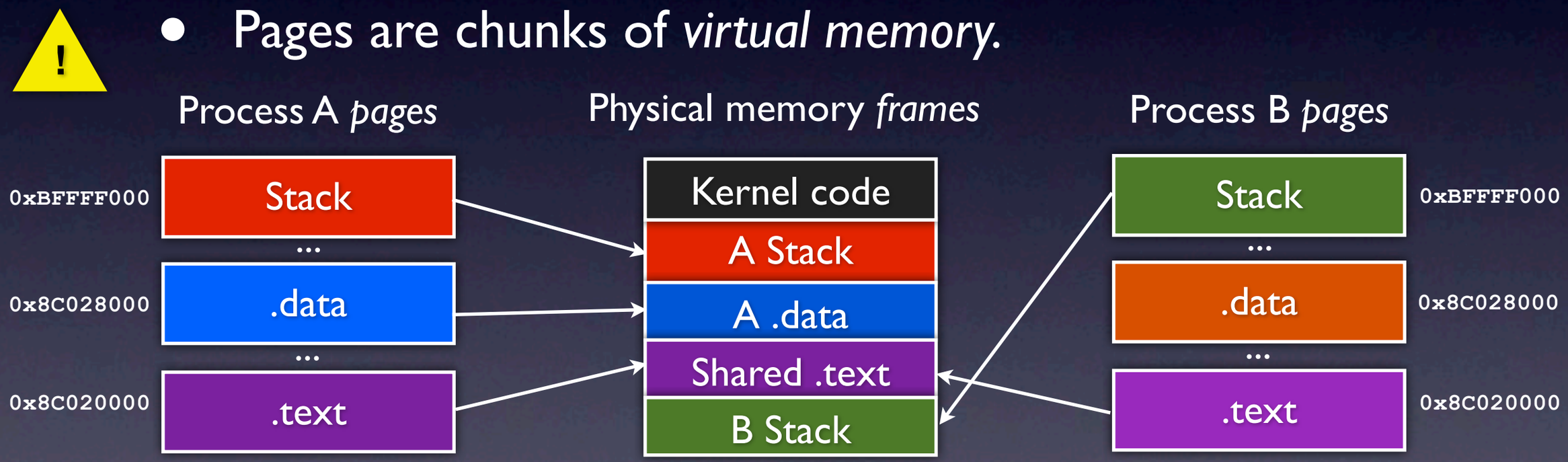
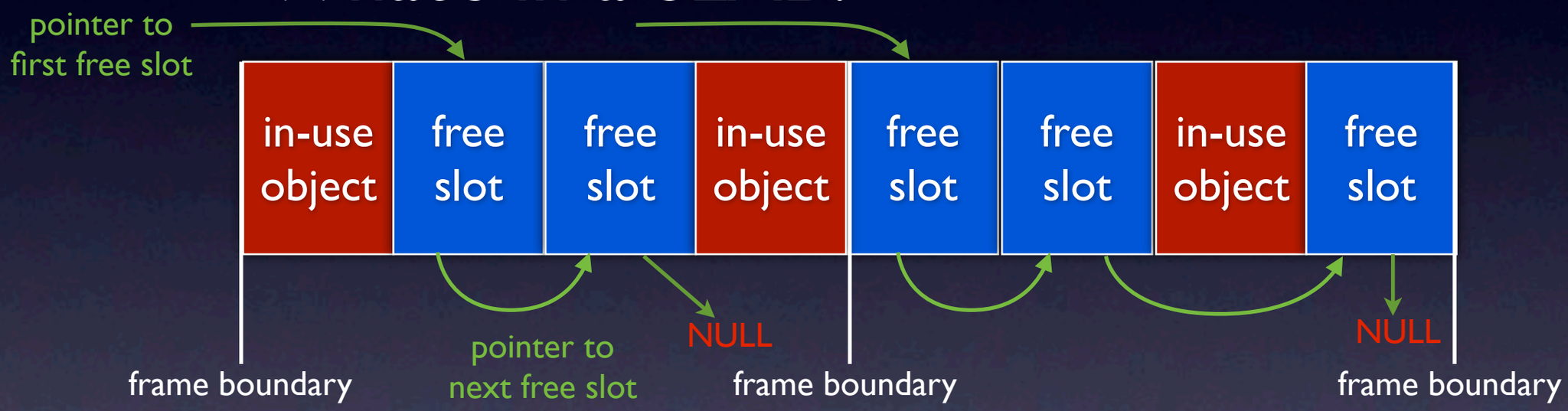
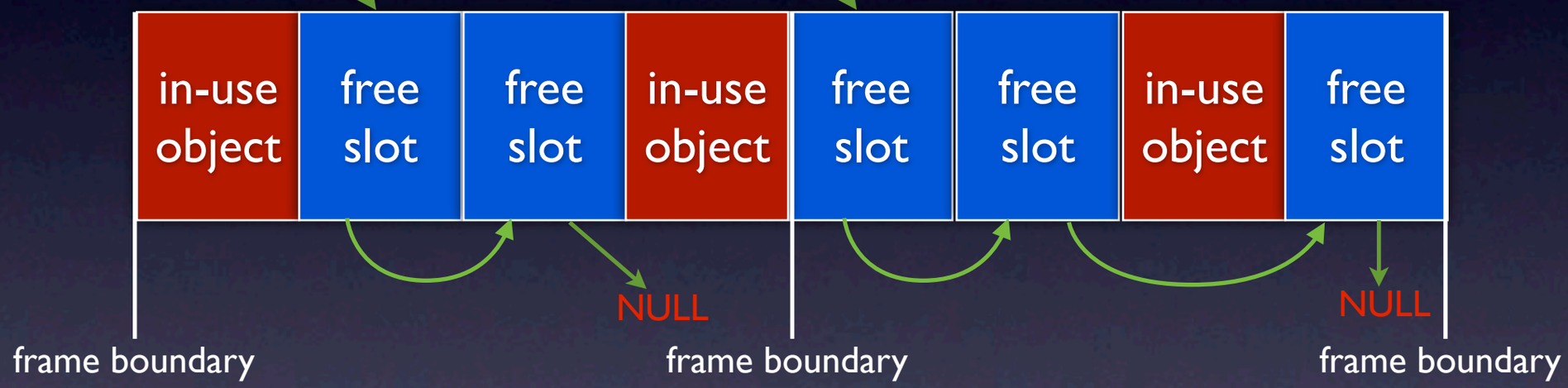
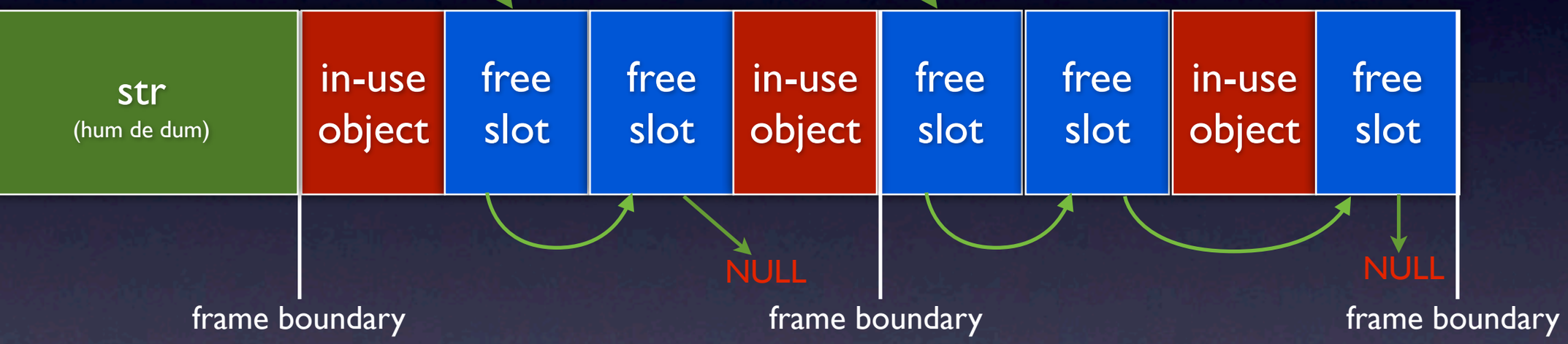



```
$ /afs/cs/course/15123-sfnoob/usr\
  /aashat/bin/greeter
What is your name?
AAAAAAAAAAAAA...ΔʃΔ∂œåµf...
Hello, AAAAAAAAA...
  [+] pwned
#
```

Why did that work so well?

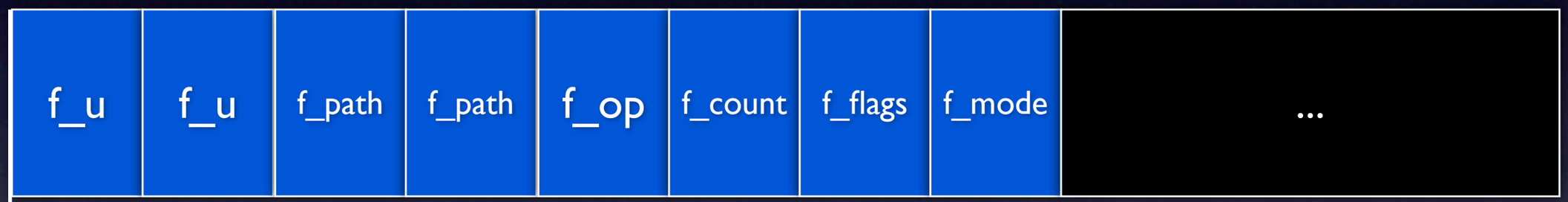
- Remember the three *controls*:
  - Attacker-controlled *target*
    - Always blast the ret addr - same memory each time
  - Attacker-controlled *length*
    - We never blast off the end of the stack into segfaultland
  - Attacker-controlled *contents*
    - Write anything we want but `0x00` and `'\n'`

From yesterday comes tomorrow

- Today's exploit, at its core:
  - (for those of you following along at home, in **`l2cap_sysfs_show`**)
  - ```
    str = get_zeroed_page(GFP_KERNEL);
    ...
    for each l2cap_sk_list as sk:
        str += sprintf(str, "%s %s %d %d 0x%4.4x 0x%4.4x %d %d %d\n"
                       batostr(&bt_sk(sk)->src),...);
    ```
- What year is it? I seem to have forgotten
    ```

sprintf() out of control

- Issue is obvious, and crash is inevitable -- but what of our three controls?
- *Controlled target*
  - How is buf allocated?
    - sysfs buffer comes from *frame allocator*
  - What comes after?
    - *Some other poor noob's frame!*

(aside: frames and pages)

- Frames are *physical memory* backings of pages.
  - Don't confuse with 'stack frames'!
- Pages are chunks of *virtual memory.*



- Linux kernel has *both* mapped into A.S.!
  - Needed for frame allocations (__GFP_KERNEL) -- more later

sprintf() out of control

- Issue is obvious, and crash is inevitable -- but what of our three controls?
- *Controlled length*
  - Writes take place through a sprintf() to a strange place
  - We can't stop it before it smashes something else

sprintf() out of control

- Issue is obvious, and crash is inevitable -- but what of our three controls?
- *Controlled contents*
  - No data comes directly from us
  - All data comes formatted

sprintf() out of control

- Issue is obvious, and crash is inevitable -- but what of our three controls?
- ***Zero for three!***
- Now would be a good time to start controlling our environment.

Target practice

- How can we control the *target*?
- Let's use an old-fashioned heap spray.
  - ...but what?
  - First idea: kstack!
    - It worked so well in CS101, right?

"With Emarhavil, your target is our target."

Jenga

- Let's *assume*:
  - kernel stack is the frame after the sysfs page
  - we know which pid the kstack belongs to
- Given that, what happens?
  - What does a kstack even look like?

Jenga

- Like other stacks, a kstack has stack frames
- Unlike other stacks, a kstack has a TCB attached to it!

Jenga

- What happens when we write?

```
sprintf(str, "ownedownedownedowned"
             "ownedownedownedowned"
             ...);
```

Jenga

- What happens when we write?


```
sprintf(str, "ownedownedownedowned"
             "ownedownedownedowned"
             ...);
```

Jenga

- What happens when we write?
  - TCB is clobbered!
  - Could be OK; this time not.

Getting physical

- What *else* goes in physical frames?
- Linux kernel has interesting mechanism called *SLAB allocator*
  - Creates uniform "caches" of specific objects
    - conveniently, frame-sized!
  - Localizes similar objects in memory
  - Avoids expensive variable-size allocation
  - Originally designed by the Sun guys

SLABs of memory

- What's in a SLAB?



- Where's the list of SLABs available?
  - SLAB metadata stored in... a SLAB!

SLABs of memory

- What's in a SLAB?



- No per-SLAB header
  - Convenient...

SLABs of memory

- What's in a SLAB?



- No per-SLAB header
  - Convenient...

Who eats SLABs?

- Pretty much every kernel subsystem
  - ```
    joshua@escape:~/linux$ find . | \
                           xargs grep kmem_cache_alloc | \
                           wc -l
    305
    ```
  - ```
    joshua@nyus:/proc$ cat slabinfo | wc -l
    183
    ```
- Something in there has to be an easy target
- How about... file descriptors?
  - Stored in `struct file`, in SLABs

Filed away for reference

- What does a `struct file` look like?
  - ```
    struct file {
        union {...} f_u; /* morally, two pointers */
        struct path f_path; /* morally, two pointers */
        struct file_operations *f_op;
        unsigned int f_count, f_flags, f_mode;
        ...
    }
    struct file_operations {
        struct module *owner;
        loff_t (*llseek)(...);
        ssize_t (*read)(...);
        ssize_t (*write)(...);
        ssize_t (*aio_read)(...);
    ```
    ```

Filed away for reference

- What does a `struct file` look like?
  - (best case!)



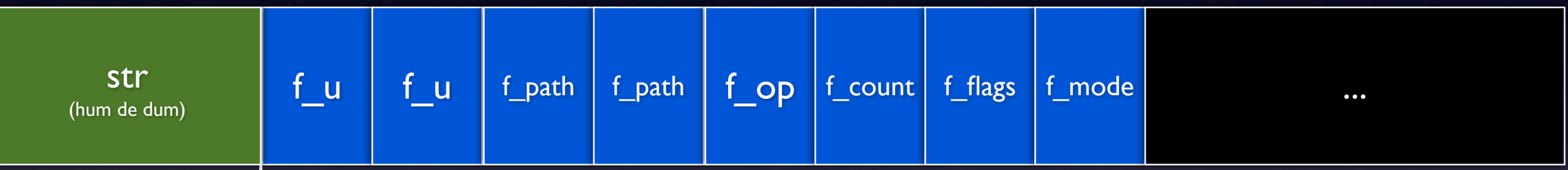
frame boundary

remember, this is at the start of a SLAB!

each block is one pointer size

Filed away for reference

- What does a `struct file` look like?
  - (really really best case!)



frame boundary

get_zeroed_page comes from same pool as SLABs (more later)

remember, this is at the start of a SLAB!

Filed away for reference

- What does a `struct file` look like?
  - Parts that the kernel can survive for a little while without darkened

frame boundary

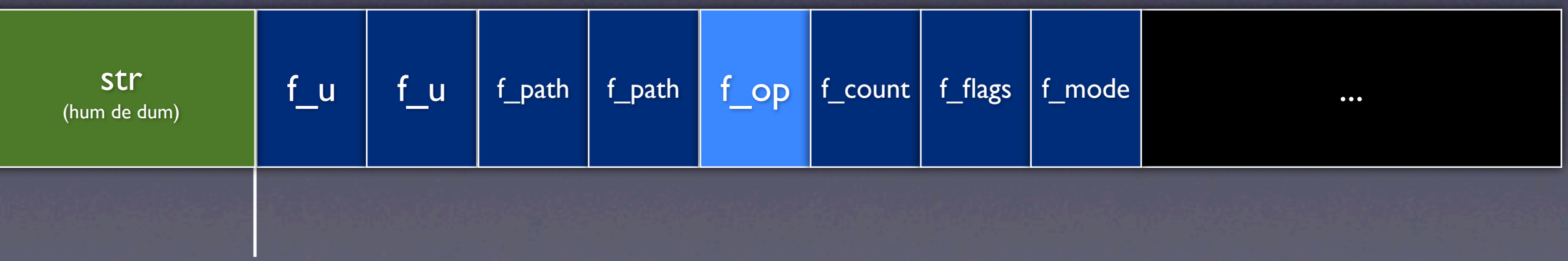
get_zeroed_page comes from same pool as SLABs (more later)

remember, this is at the start of a SLAB!

Great news!

Great news!

- In essence -- `struct file` can be paved over at will
  - ... just as long as we get a reasonable value into `f_op`.



One for three

- Remember the three controls:
  - Attacker-controlled *length*
  - Attacker-controlled *contents*
  - Attacker-controlled *target*
- Length is *no longer an issue*
  - We can go over by a little ways without causing an immediate crash

Back to the content

- It is *difficult* to write arbitrary content...
  - ...but *easy* to predict content.
  - `str += sprintf(str, "%s %s %d %d 0x%4.4x 0x%4.4x %d %d %d\n" batostr(&bt_sk(sk)->src),...);`
- Usually looks like:
  - `"00:00:00:00:00:00 00:00:00:00:00:00 2 0 0x0000 0x0000 672 0 1"` repeated a bunch
    - well, as many times as we want...
- What does this mean for us?

Back to the content

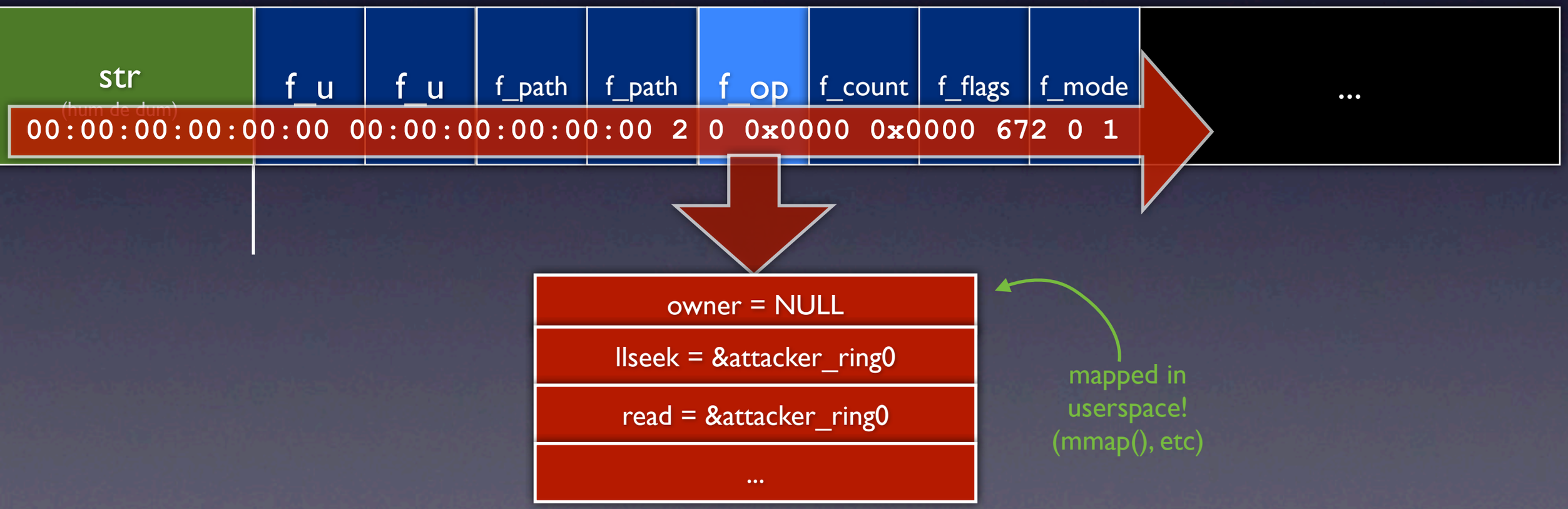
- Data that looks like this *must* end up in the file structure.
  - `"00:00:00:00:00:00 00:00:00:00:00:00 2 0 0x0000 0x0000 672 0 1"`
  - Substring *must* end up in `f_op`!
- What, exactly, *can* go in `f_op`?
  - more importantly, can *this* go in `f_op`?

Addressability

- `f_op` is just a pointer into kernel's A.S.!
  - Remember: kernel's A.S. is superset of user's A.S.
  - `f_op` can be pointer to *user* memory
- Game plan
  - Map all substrings
  - ASCII representations should be valid pointers to `f_op` target.
    - `"00:0" -> 0x30303A30`
    - `"0:00" -> 0x303A3030`
    - `"0 0:" -> 0x3020303A`
    - …

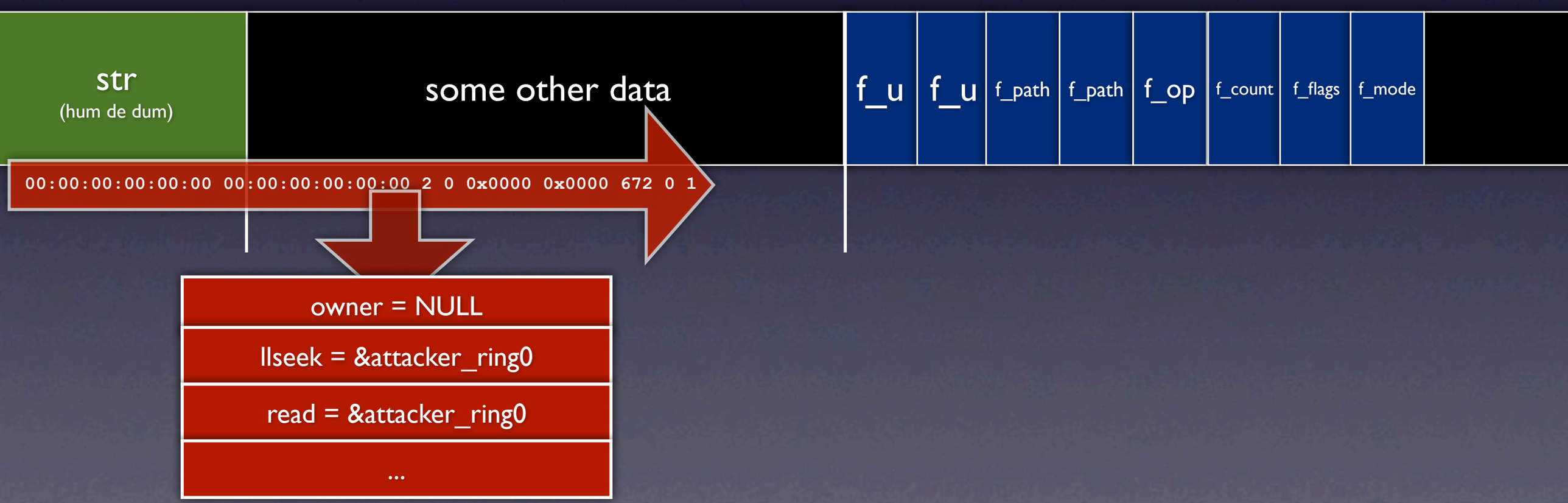
Now what?

- We're done, right?



Now what?

- Not so fast.
  - Real life, more likely:



Two for three

- Remember the three controls:
  - Attacker-controlled *length*
  - Attacker-controlled *contents*
  - Attacker-controlled *target*
- Contents not controlled... but predicted.
  - We now have *length* and *contents* handled.

Let's be buddies

- How do we *control* the relative placement of frames?
  - (i.e., the *target*)
- Physical frames allocated on Linux using "buddy allocator"
  - *Really* old best-fit allocator -- Markowitz, 1963
  - Works *really* well with fragmentation-reducing strategies like SLAB
  - `linux/mm/page_alloc.c`
    - *Run in god-damn fear.*

Let's be buddies

- Buddy allocator has important features
  - Injects *determinism* and *predictability* into otherwise unordered frame allocation
  - Localizes size-one frames when able
- Implementation details beyond scope of this talk
  - You gotta pick one, and I think SLAB is cooler

Localizer approach

- Plan:
  - Fill up memory
    - Cause frames that would result in discontinuities to be paged to disk
  - Free memory to generate contiguous chunks
  - Allocate chunks of memory for struct files
  - Allocate buffer page
    - Opening sysfs file does this. This is critical!
  - Allocate more chunks of memory for `struct files`
  - Fire!

Localizer approach

Initial configuration

free	free	free	in use	free	in use	free	free
free	free	in use	free	free	free	free	free
free	in use	free	free	free	in use	free	free
free	free	in use	free	free	in use	free	free

Localizer approach

Allocate all memory for us

ours	ours	ours	ours	ours	ours	ours	ours
ours	ours	ours	ours	ours	ours	ours	ours
ours	ours	ours	ours	ours	ours	ours	ours
ours	ours	ours	ours	ours	ours	ours	ours

Localizer approach

Free and allocate to get contiguous phys chunks

ours	ours	ours	ours	ours	ours	ours	ours
ours	ours	ours	ours	ours	ours	ours	ours
ours	ours	ours	ours	ours	ours	ours	ours
ours	ours	ours	ours	ours	ours	ours	ours

Localizer approach

Release contiguous phys frames

ours	ours	ours	ours	ours	ours	ours	ours
ours	ours	ours	ours	ours	ours	ours	ours
free	free	free	free	ours	ours	ours	ours
ours	ours	ours	ours	ours	ours	ours	ours

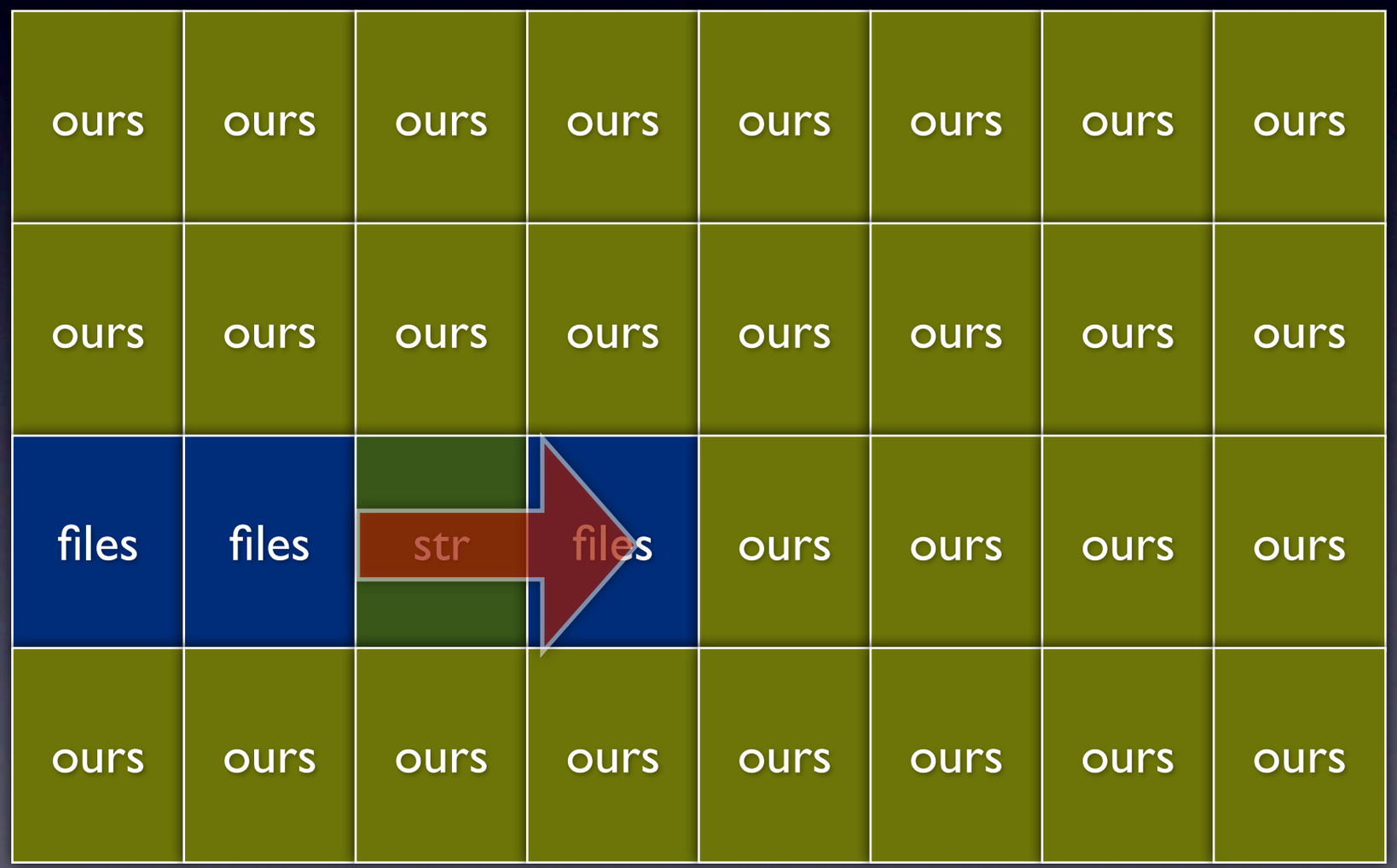
Localizer approach

Set up files, buffer, files

ours	ours	ours	ours	ours	ours	ours	ours
ours	ours	ours	ours	ours	ours	ours	ours
files	files	str	files	ours	ours	ours	ours
ours	ours	ours	ours	ours	ours	ours	ours

Localizer approach

Pwn

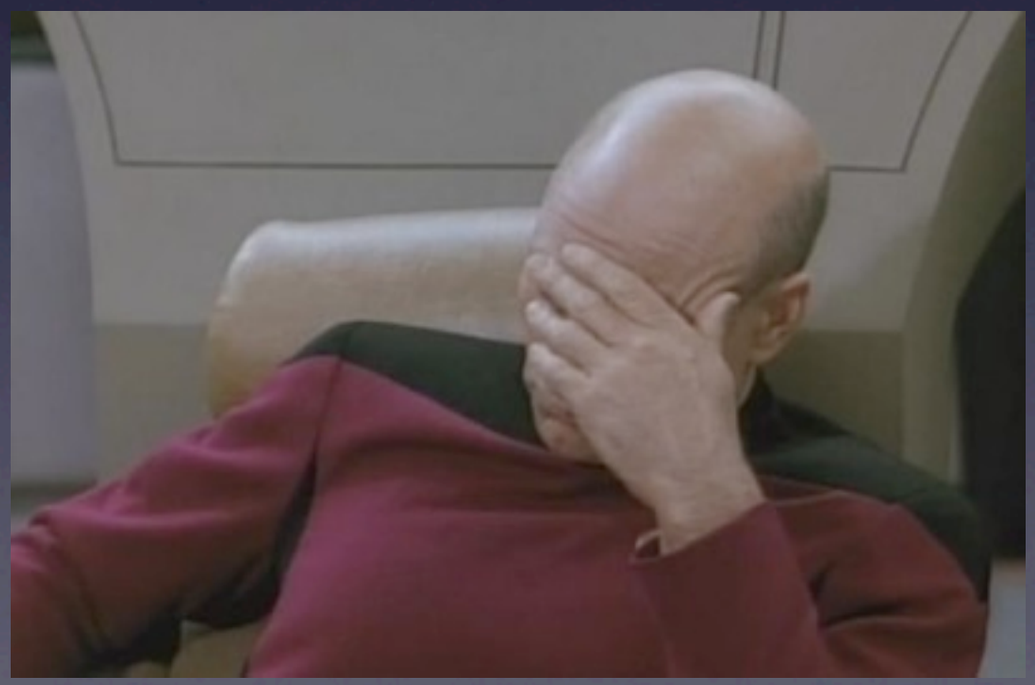


Three for three!

- Remember the three controls:
  - Attacker-controlled *length*
  - Attacker-controlled *contents*
  - Attacker-controlled *target*
- Target *became* controlled by *deterministic memory permutation.*
- Result: *system owned.*

So close, guys

```
/*
 * The code works fine with PAGE_SIZE return but it's likely to
 * indicate truncated result or overflow in normal use cases.
 */
if (count >= (ssize_t)PAGE_SIZE) {
        print_symbol("fill_read_buffer: %s returned bad count\n",
                (unsigned long)ops->show);
        /* Try to struggle along */
        count = PAGE_SIZE - 1;
}
```



Demo

Conclusions

- Difficult-to-exploit bugs can be made *easier* by thinking about *controlling your environment*
  - Attacker-controlled *length*
  - Attacker-controlled *contents*
  - Attacker-controlled *target*
- *Just because it's not easy, that doesn't mean that it's impossible!*

Conclusions

- Difficult-to-exploit bugs can be made *easier* by thinking about *controlling your environment*
  - Attacker-controlled *length*
  - Attacker-controlled *contents*
  - Attacker-controlled *target*
- *Just because it's not easy, that doesn't mean that it's impossible!*
- Side conclusion:
  - Phone vendors: we will win. We have physical access; root on these phones will be ours. Please stop your crusade to keep me from using my own phone.

Questions?