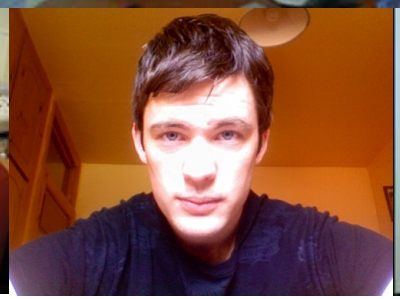
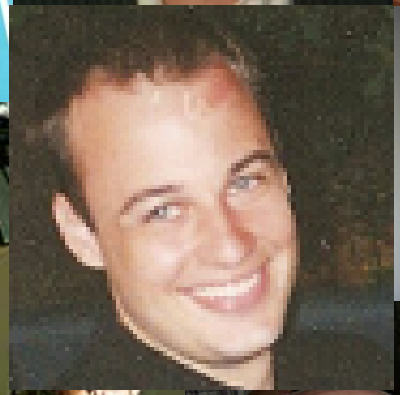
# The Stack is Back

Jon Oberheide

# The heap sucks



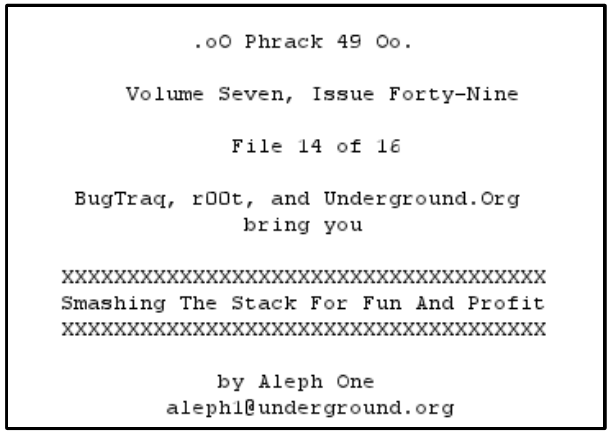
# Heap vs. stack

Excerpt from "*Objective quantitative scientific comparison of the heap and stack*" by Dr. Jono, PhD from the journal of Useless Computer Science:

- Heap:
  - Complicated
  - Requires skillz
  - Bad connotation: "heap of trash"
  - The 1%, elitist, pro-life, racist
- Stack:
  - Easy
  - Doesn't
  - Good connotation: "stack of bills"
  - Saves kittens from burning buildings

# Bringing the stack back

- What's left to exploit with the stack?


.oO Phrack 49 Oo.

Volume Seven, Issue Forty-Nine

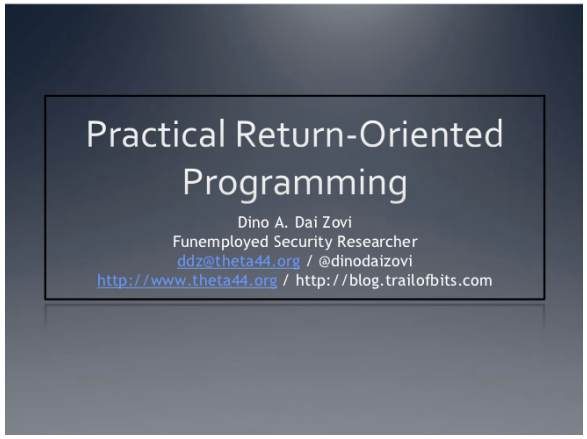
File 14 of 16

BugTraq, r00t, and Underground.Org
bring you

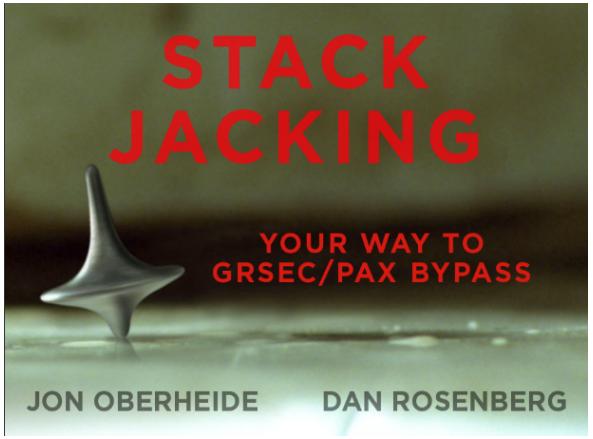
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Smashing The Stack For Fun And Profit
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

by Aleph One
aleph1@underground.org

**Smashing?**




**ROP'ing?**



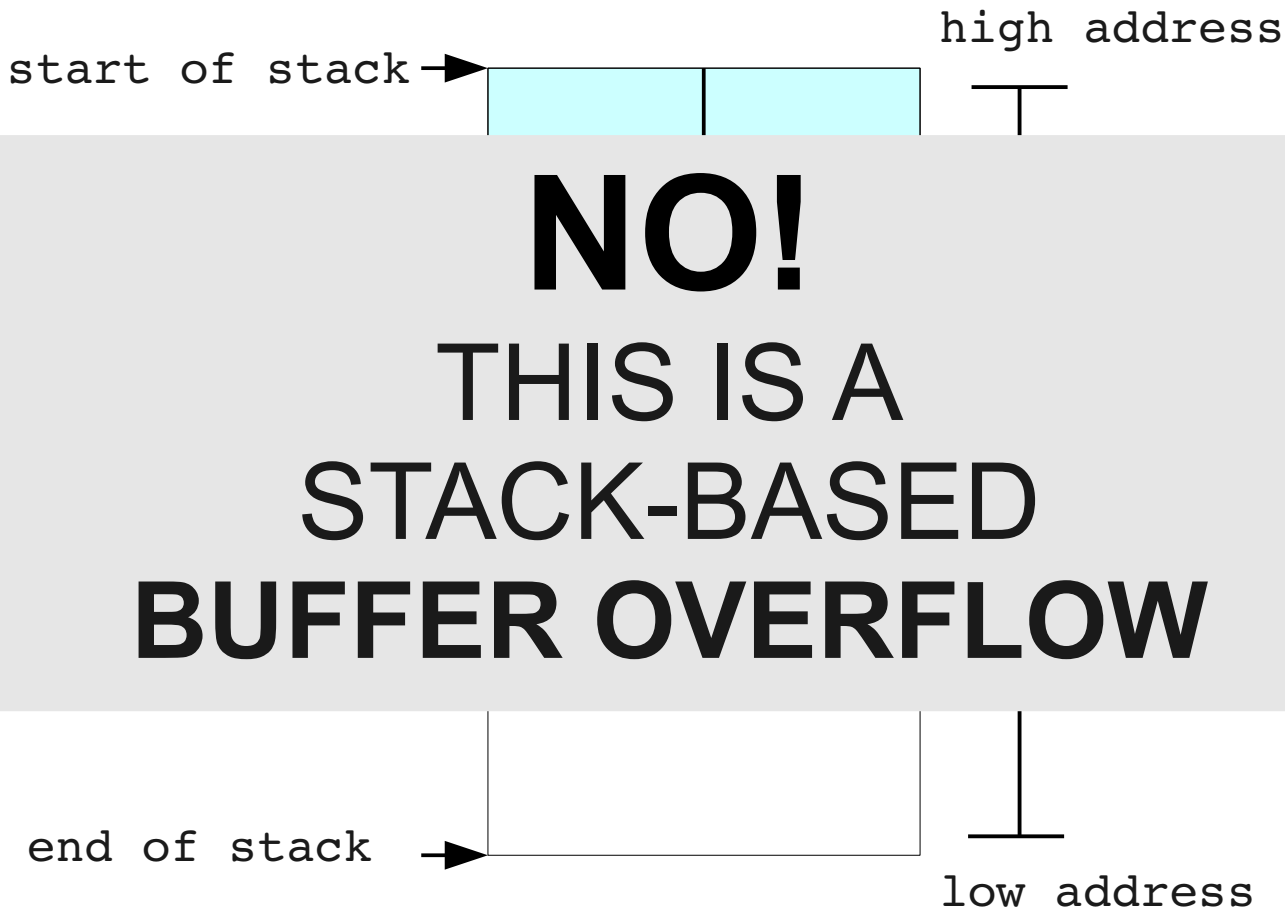

**Jacking?**

- Let's exploit ***stack overflows***!

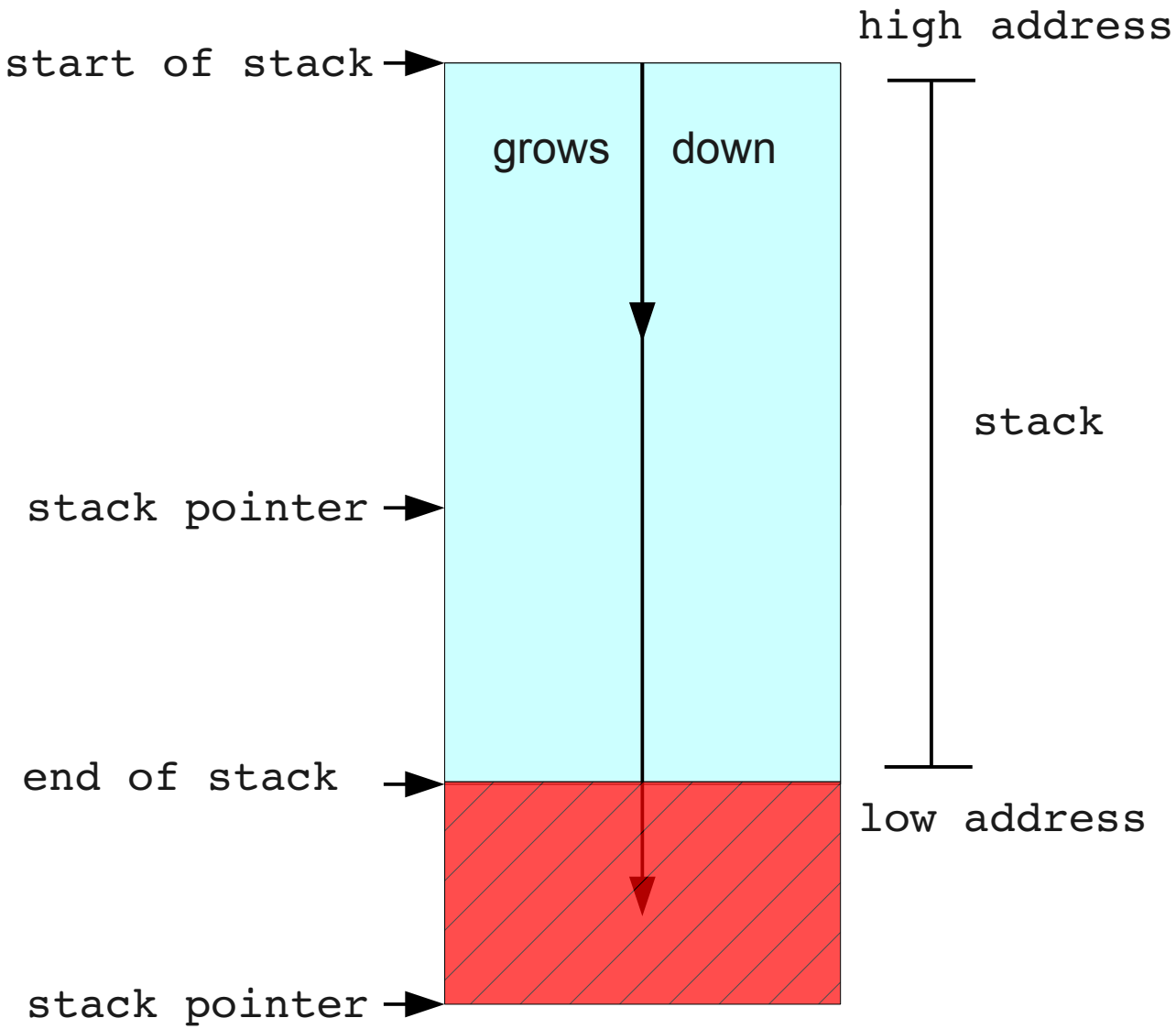
# The stack is back

- **A brief history of stack overflows**
- Stack overflows in the Linux kernel
- Exploiting exotic stack overflows
- Discovering and mitigating stack overflows

# Fake stack overflows



# Real stack overflows



# Stack overflows

- Stack overflows
  - Misuse of terminology
  - Jono's definition:

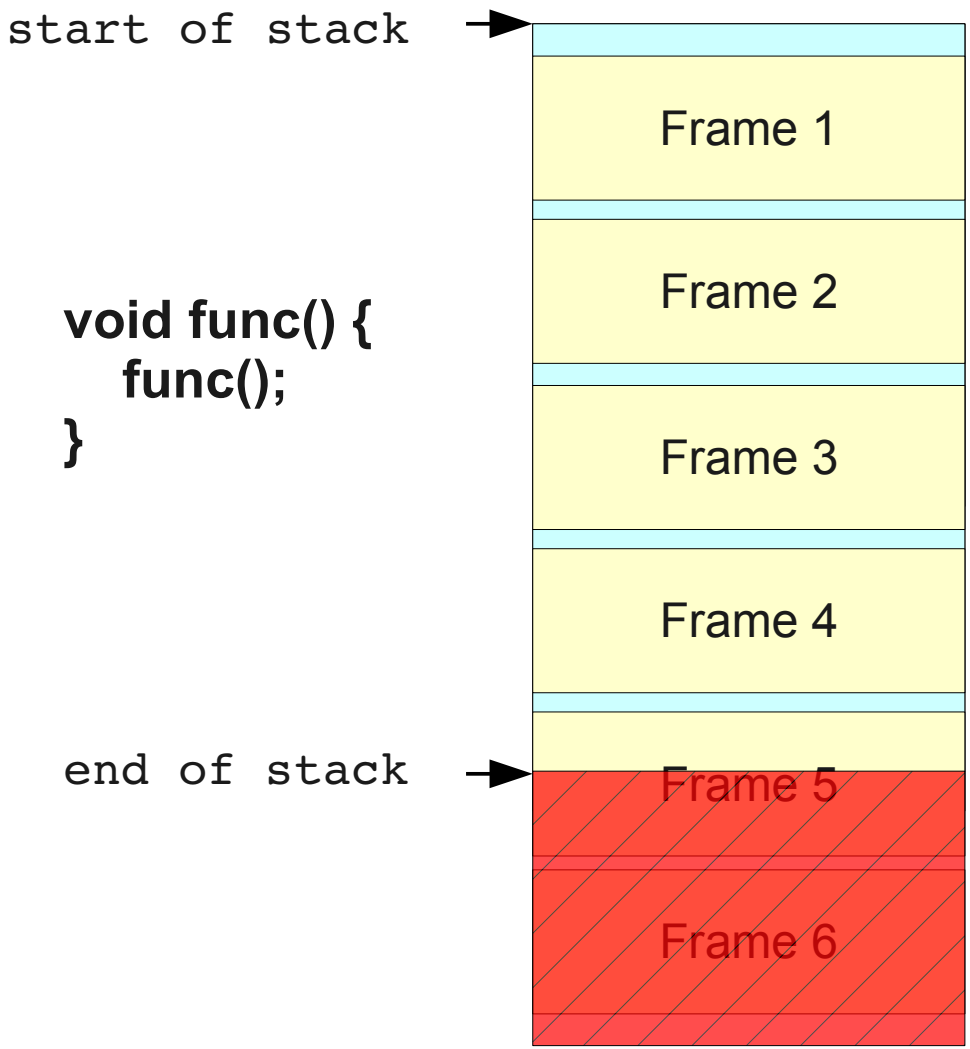
> Stack pointer decremented beyond the intended bounds of the stack's allocated VMA.

- Types of overflows
  - Incremental overflows
  - Allocation overflows

# Incremental overflows

- Incremental overflows
  - Deep call chains
  - Recursion

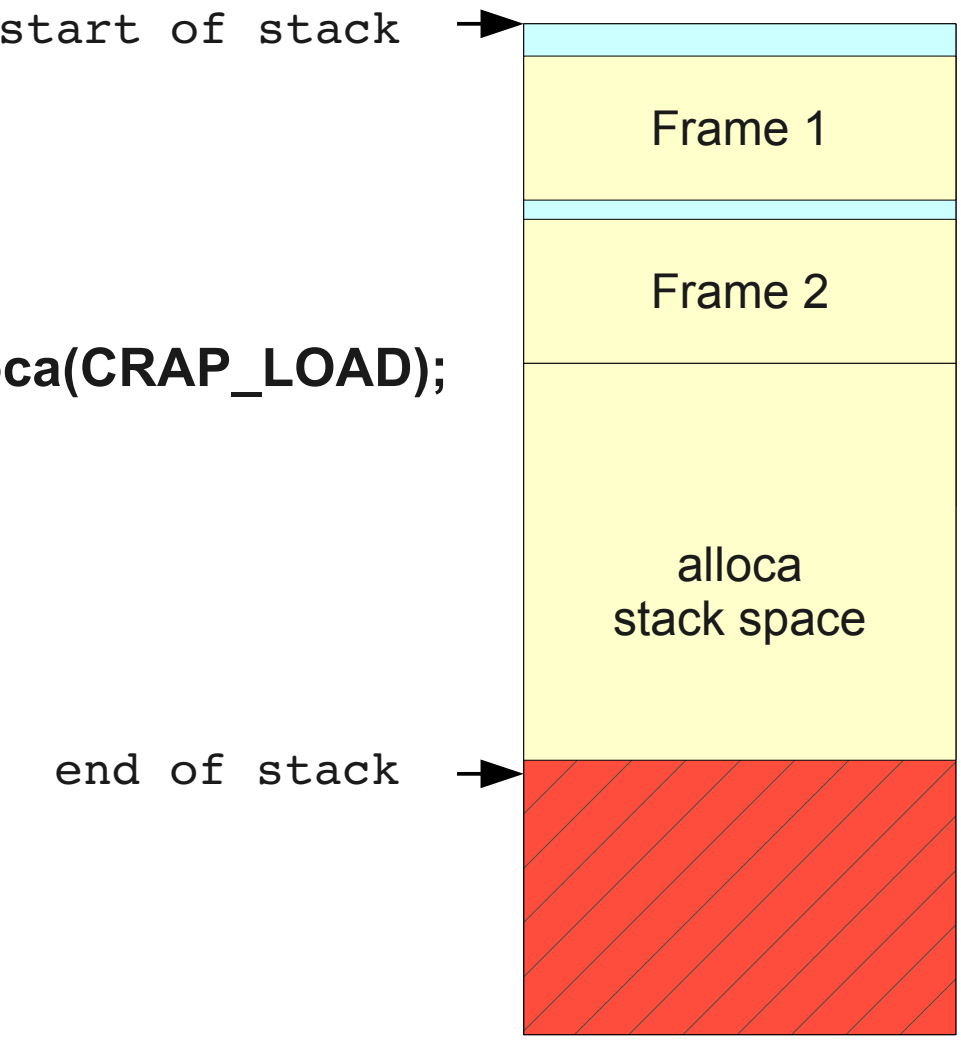
```
void func() {
   func();
}
```



# Allocation overflows

- Allocation overflows
  - Large local stack vars
  - Dynamic allocations: VLAs, alloca(3)

**alloca(CRAP_LOAD);**



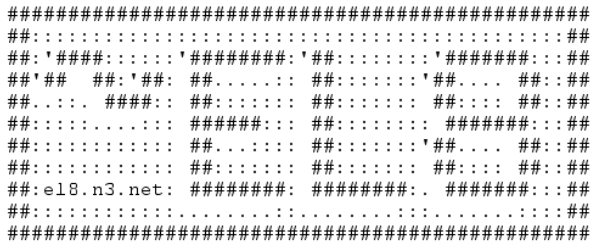
# Exploiting stack overflows

- Stack overflows in userspace
  - Not uncommon
  - Lots of controllable (and uncontrollable) recursion
  - Some use of C99 VLAs and alloca(3)
- ***Exploitable*** stack overflows
  - Exploitable = more than DoS
  - Quite rare!

# Trivia #1

What is one scenario where a userspace stack overflow might be exploitable?

Android Phone

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# Large MM vulns

## Large memory management vulnerabilities

### System, compiler, and application issues

**Gaël Delalleau**
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*Security consultant from*
Beijaflore NETWORK
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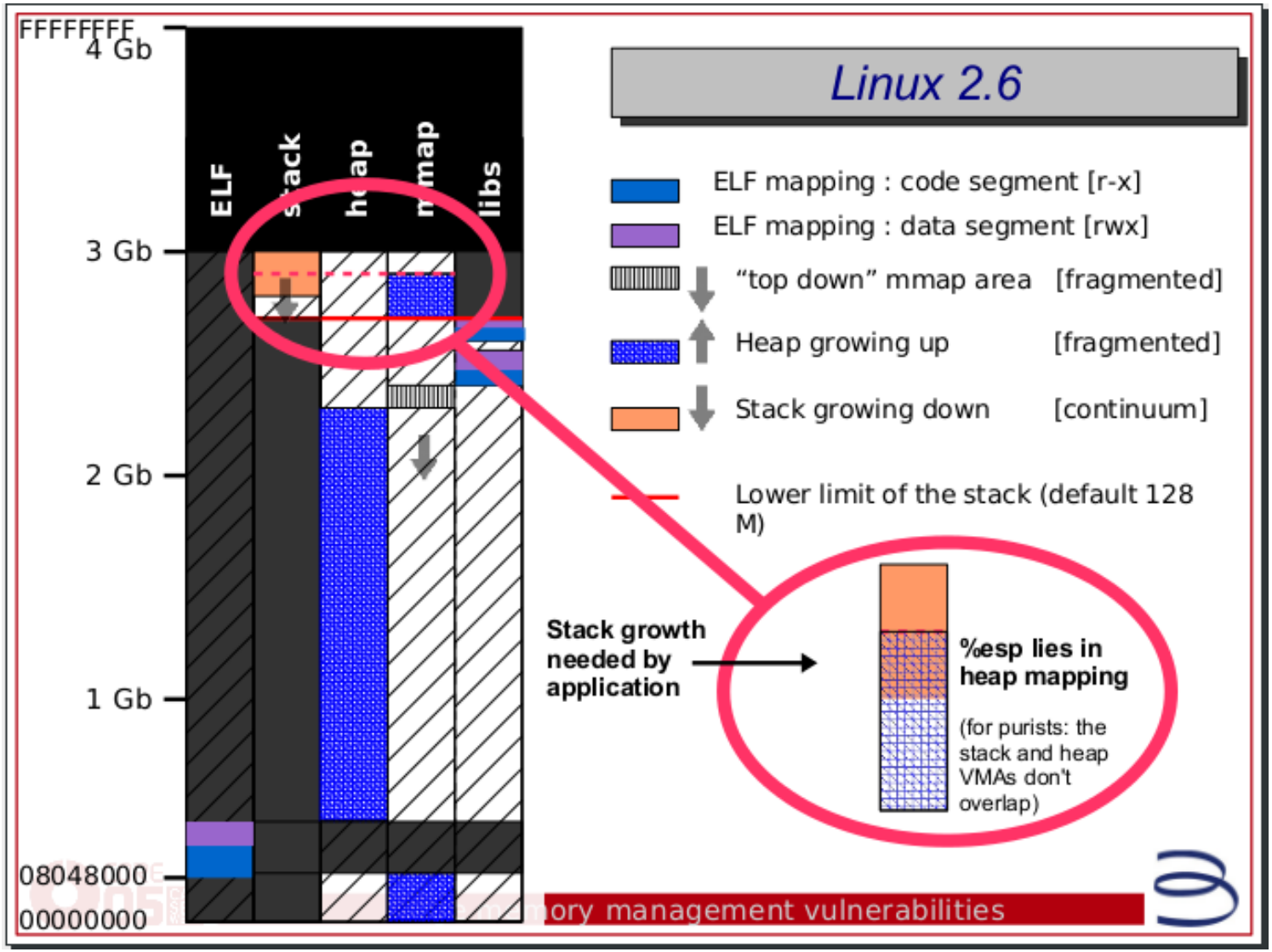
CancSecWest 2005
Vancouver – May 4-6

CORE 05 CANSECWEST

Large memory management vulnerabilities

# Stack overlap



# Real-world stack overflows

Not a lot of real-world examples...maybe one?

- Xorg large MM vuln by Rafal @ ITL
  - No guard page at end of stack on <= Linux 2.6.36
  - Allocate large pixmaps to exhaust address space
  - Force a shm allocation adjacent to the stack
  - Call recursive function to cause stack/shm overlap
  - Write to the shm and therefore the Xorg stack

# Embedded platforms

Limited memory → limited stack → stack overflows

# Remote kernel overflows?

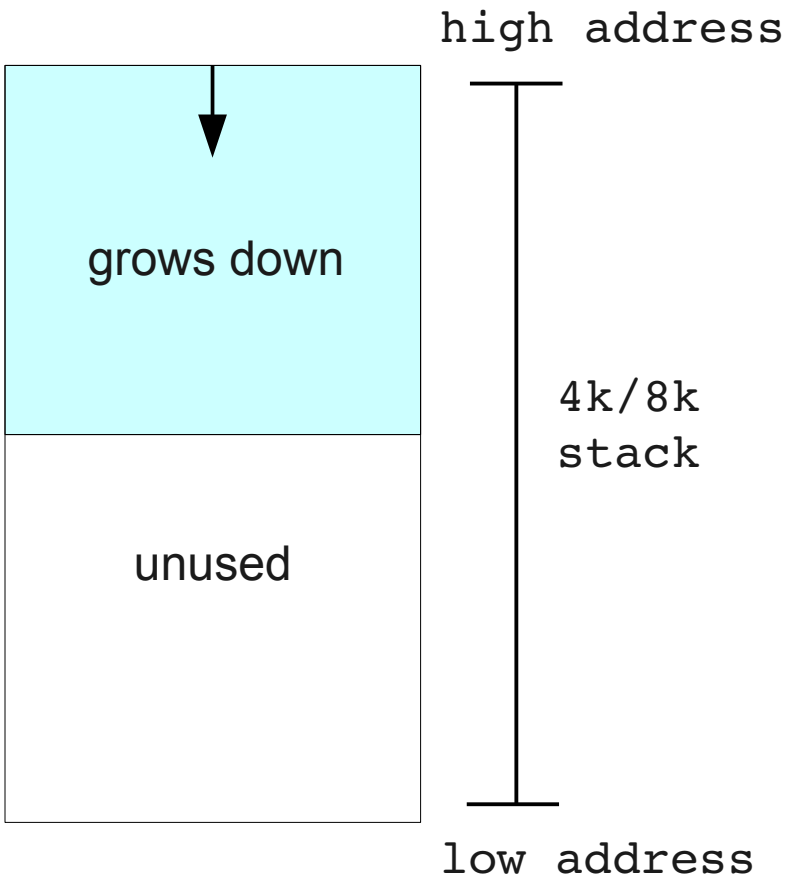
- BSD IPComp kernel stack overflow
  - Travis Normandy
  - Recursive decompression in IP stack
- Exploitable?
  - Ehhhh...

# The stack is back

- A brief history of stack overflows
- **Stack overflows in the Linux kernel**
- Exploiting exotic stack overflows
- Discovering and mitigating stack overflows

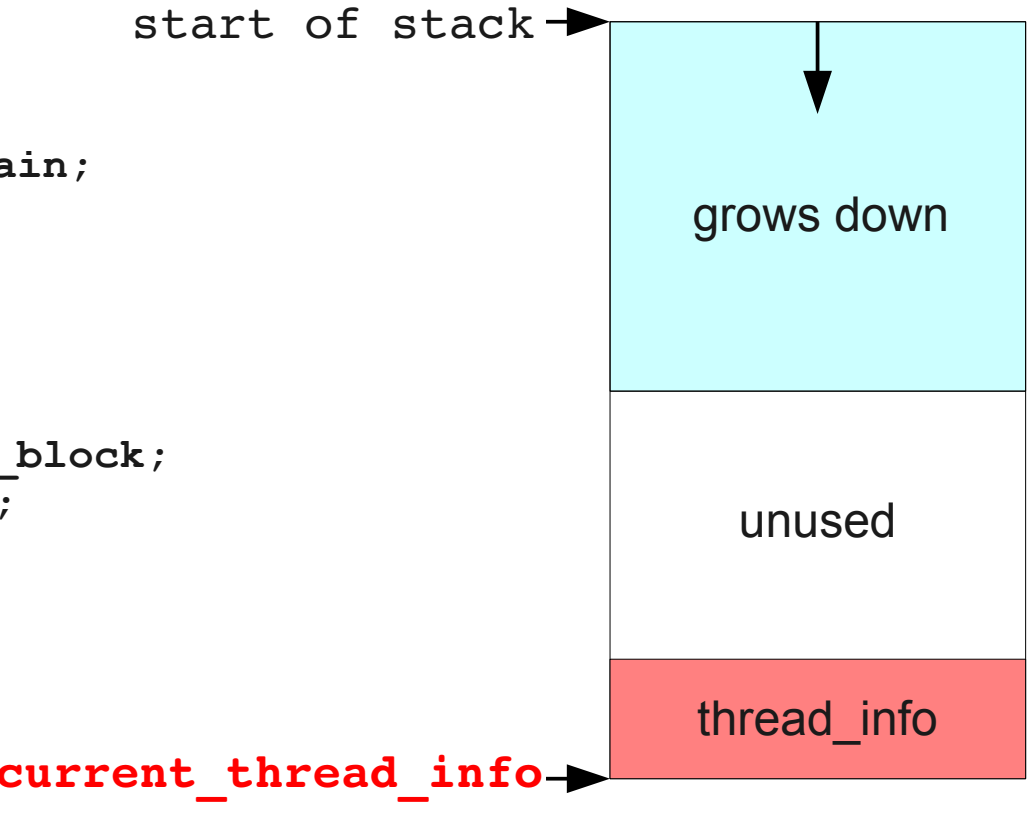
# Linux kernel stacks

- Each userspace thread is allocated a kernel stack
- Stores stack frames for kernel syscalls and other metadata
- Most commonly 8k, some distros use 4k
  - THREAD_SIZE = 2*PAGE_SIZE = 2*4086 = 8192



# Metadata on kernel stack

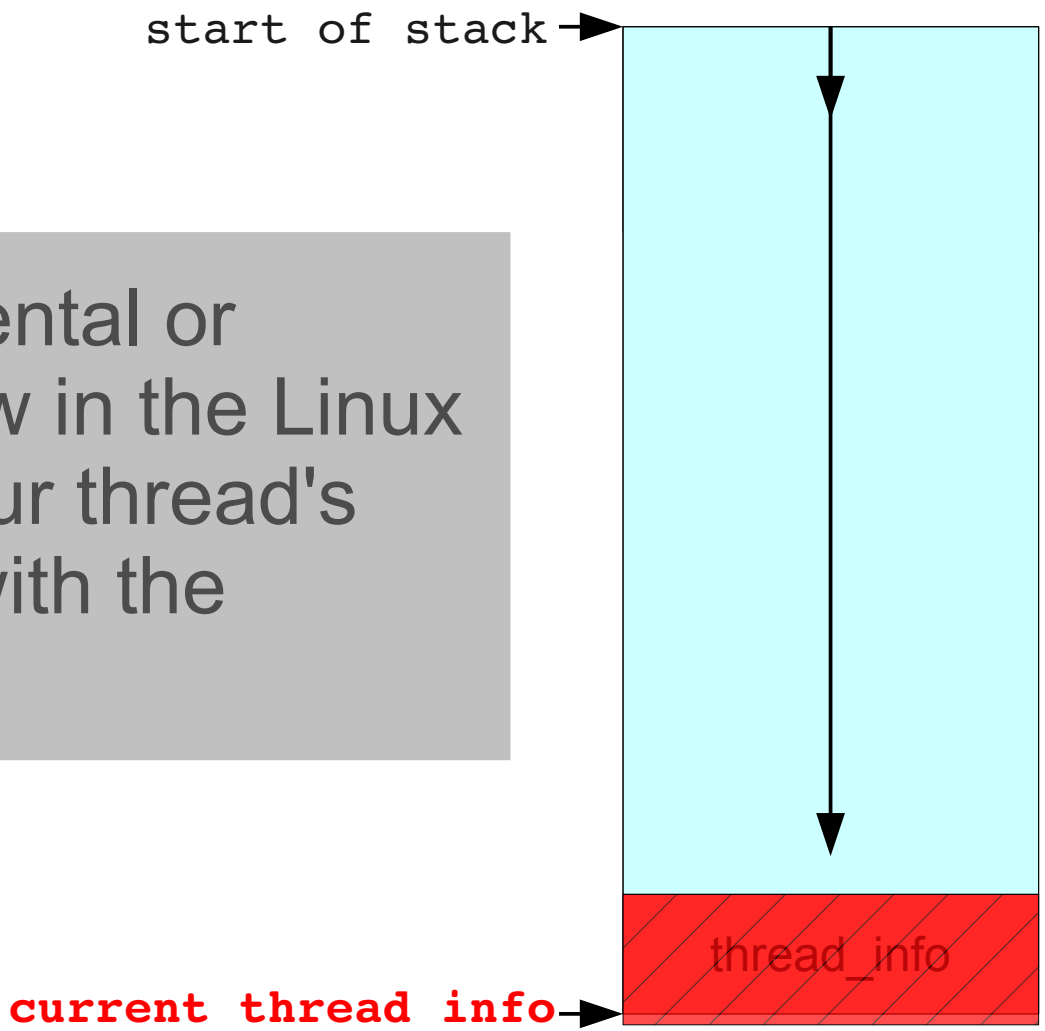
```
struct thread_info {
    struct task_struct *task;
    struct exec_domain *exec_domain;
    __u32 flags;
    __u32 status;
    __u32 cpu;
    int preempt_count;
    mm_segment_t addr_limit;
    struct restart_block restart_block;
    void __user *sysenter_return;
#ifdef CONFIG_X86_32
    unsigned long previous_esp;
    __u8 supervisor_stack;
#endif
    int uaccess_err;
};
```




thread_info struct is at the base of kstack!

# Exploiting stack overflows

If we control an incremental or allocation stack overflow in the Linux kernel, we can cause our thread's kernel stack to collide with the thread_info structure.



# Targeting thread_info

- What would the overflow collide with?
  - uaccess_err
    - No security impact, but safe to clobber
  - **restart_block**
    - A function pointer, BINGO!
  - **addr_limit**
    - Define u/k boundary, BONGO!
  - preempt_count .. task_struct
    - Pretty sensitive members, avoid clobbering

```
struct restart_block {
    long (*fn)(struct restart_block *);
    union {} /* safe to clobber */
};
```

```
access_ok()/__range_not_ok():

Test whether a block of memory
is a valid user space address.

addr + size > addr_limit.seg
```

# Controlling the clobber

- Can we control the clobbering value?
  - Incremental overflow: tip of the stack, unlikely
  - Allocation overflow: VLA values, maybe
- Good news, don't need *much* control!
- Two categories:
  - Value represents a kernel space address
    - Value > TASK_SIZE
  - Value represents a user space address
    - Value < TASK_SIZE

# Clobber → Code Exec

- If value < TASK_SIZE
  - Clobber restart_block fptr with userspace value
  - mmap privesc payload at that address in userspace
  - Trigger fptr via syscall(SYS_restart_syscall);
- If value > TASK_SIZE
  - Clobber addr_limit with a high kernel space value
  - You can now pass copy_from_user()/access_ok() checks up to that kernel address
  - So we can read(2) from a fd and write into kmem

# Vanilla exploitation

We consider these “vanilla” stack overflows.

- thread_info clobbering technique
  - Will work in the common case for Linux kernel stack overflows
- Example vuln @ CSAW CTF
  - Controlled recursion with userspace value at tip of the stack

http://jon.oberheide.org/blog/2011/11/27/csaw-ctf-2011-kernel-exploitation-challenge/

# Architecture specifics

- x86_64
  - Pretty clean, dedicated interrupt stacks
- x86_32
  - Interrupt stack shared with process stack
  - Less predictability, but more opportunity to trigger a stack overflow
- ARM, alpha, others
  - restart_block is on end of thread_info :-)

# The stack is back

- A brief history of stack overflows
- Stack overflows in the Linux kernel
- **Exploiting exotic stack overflows**
- Discovering and mitigating stack overflows

# Real world vulnerability

Let's look at a real-world Linux kernel stack overflow vulnerability.

- Two great bugs from Nelson
  - CVE-2010-3848
  - CVE-2010-3850
  - And a bonus bug that will come into play later
- Econet packet family
  - Stack overflow in econet_sendmsg()

# Vulnerable code

```
int econet_sendmsg(struct kiocb *iocb, struct socket
*sock, struct msghdr *msg, size_t len)
{
...
    struct iovec iov[msg->msg_iovlen+1];
```

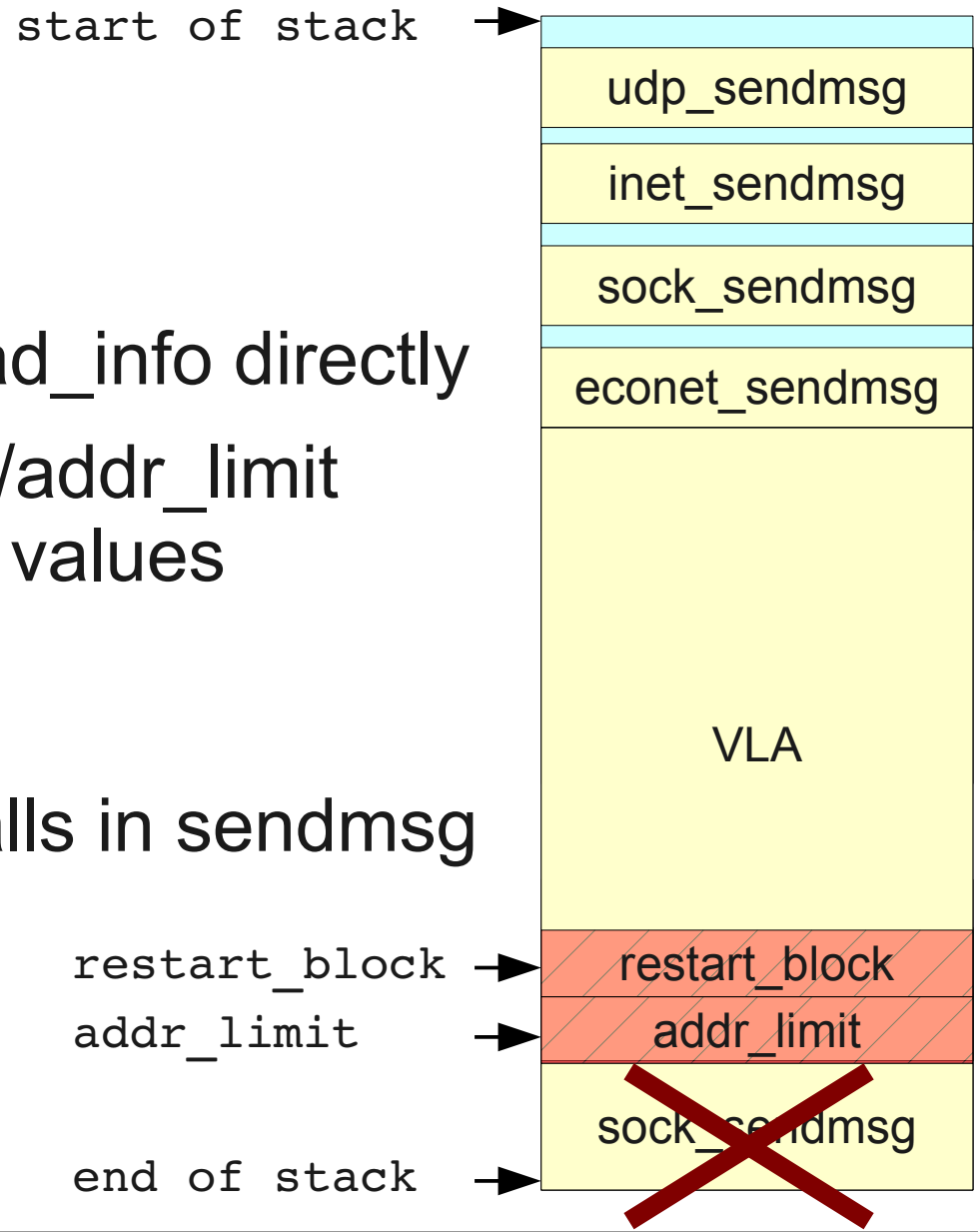
Oh snap! A VLA on the stack with an attacker controlled length!

```
        for (i = 0; i < msg->msg_iovlen; i++) {
        ...
            iov[i+1].iov_base = base;
            iov[i+1].iov_len = iov_len;
        ...
        }
```

Hey, we (mostly) control the contents too! Game over, eh?

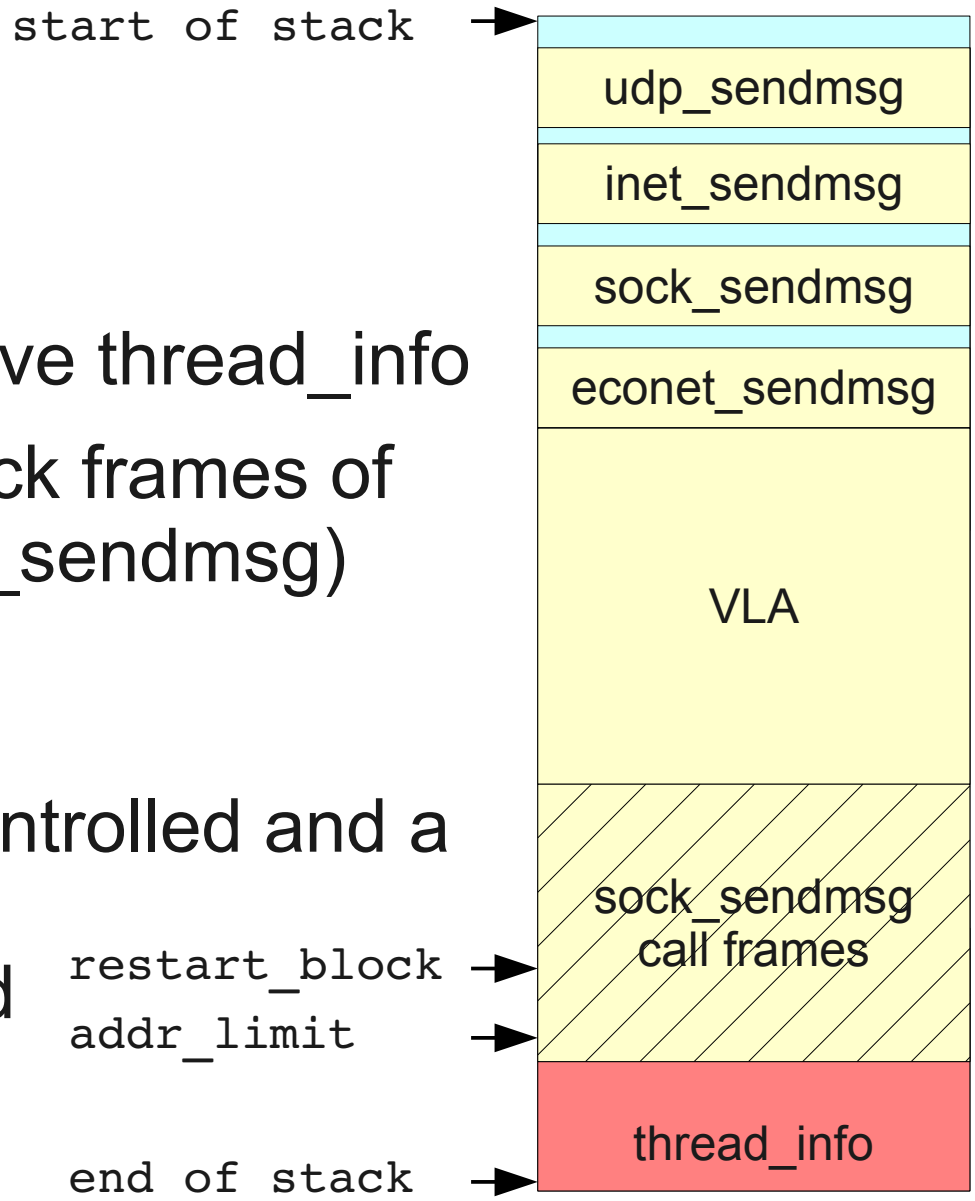
# Attempt #1

- Attempt #1
  - Expand VLA to hit thread_info directly
  - Overwrite restart_block/addr_limit with attacker controlled values
- Thwarted!
  - Subsequent function calls in sendmsg will clobber sensitive thread_info members



# Attempt #2

- Attempt #2
  - Expand VLA to just above thread_info
  - Overwrite using the stack frames of subsequent calls (sock_sendmsg)
- Semi-thwarted!
  - Overwrite value is uncontrolled and a kernel space value so restart_block is no good
  - What about addr_limit?



# Attempt #2 continued

- We can hit addr_limit with a value that represents a high kernel space value
  - Overwrite of addr_limit occurs in sock_sendmsg call

```
oldfs = get_fs();
set_fs(KERNEL_DS);
err = sock_sendmsg(udpsock, &udpmsg, size);
set_fs(oldfs);
```

- You can't be serious...
  - addr_limit is being saved/restored before/after the sock_sendmsg call, nullifying our overwrite

# Attempt #2 continued

- We could try other subsequent function calls besides sock_sendmsg
  - Cause error condition, return from econet_sendmsg early with a terminating mutex_unlock call. Eg:

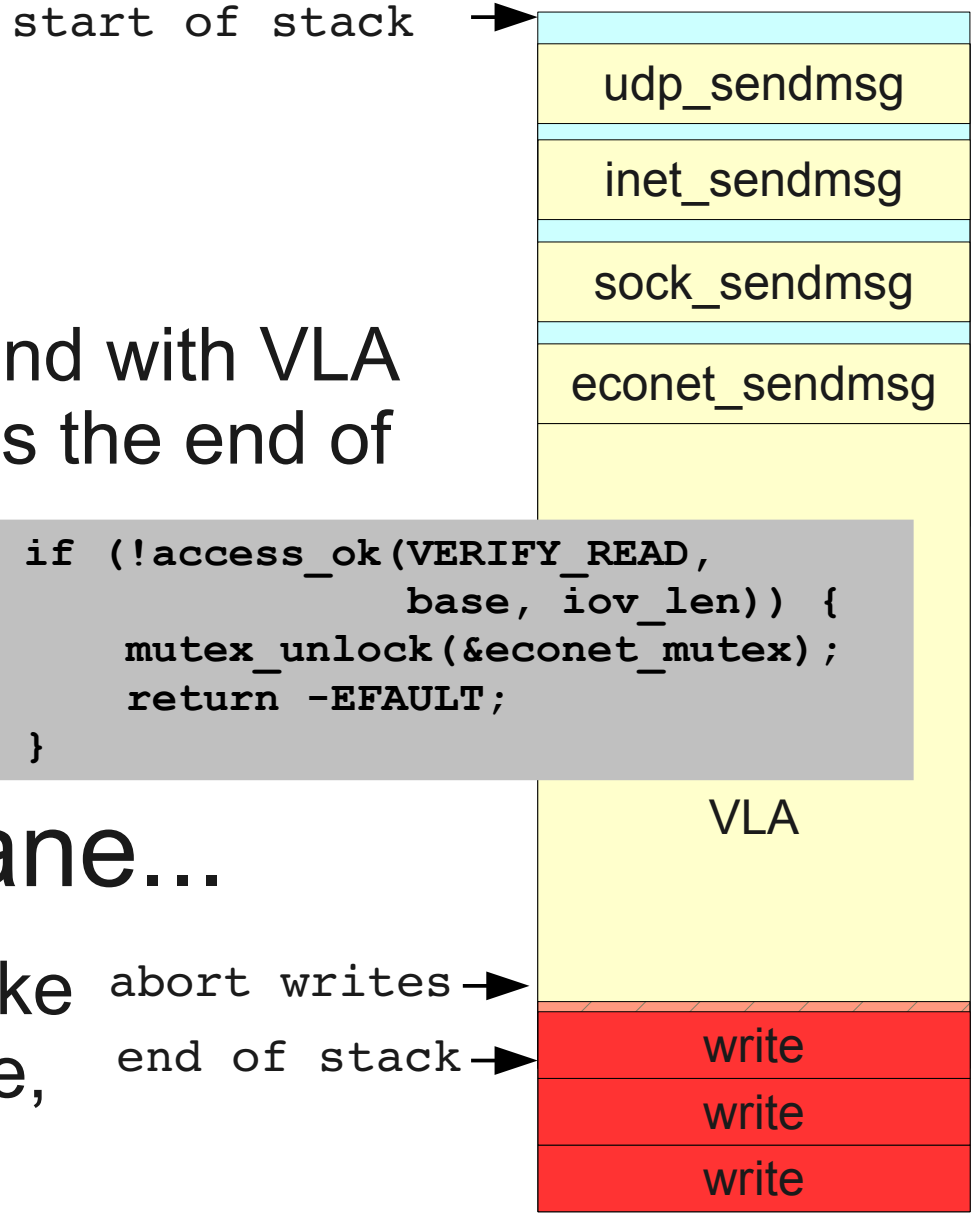
```
if (len + 15 > dev->mtu) {
    mutex_unlock(&econet_mutex);
    return -EMSGSIZE;
}
```

- Write offsets of the stack frame don't align
  - Pattern: chunks of two 8-byte writes w/kernel value
  - Hit restart_block with kernel value (useless) or hit both addr_limit (good) and preempt_count (crash)

# Attempt #3

- Attempt #3
  - Blow past thread_info and with VLA and “write-back” towards the end of the kernel stack
  - Overwrite task_struct w controlled address
- Ok, this is just insane...
  - Yes, you can make a fake task_struct in userspace, but not in this century

```
if (!access_ok(VERIFY_READ,
                base, iov_len)) {
    mutex_unlock(&econet_mutex);
    return -EFAULT;
}
```



# Need a different approach

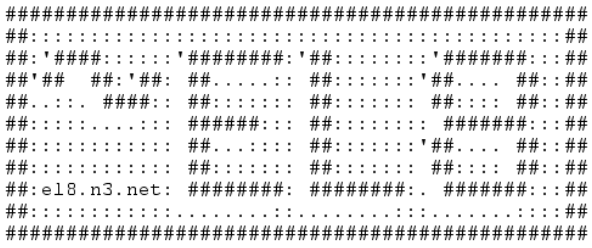
It's clear the thread_info technique is not going to work here due to extenuating circumstances

- If thread_info is out, what can we do?
- Nothing useful *on* the stack, but...
- Need some audience help here...

# Trivia #2

Any ideas of what to do if the thread_info technique isn't going to work?

Android Phone

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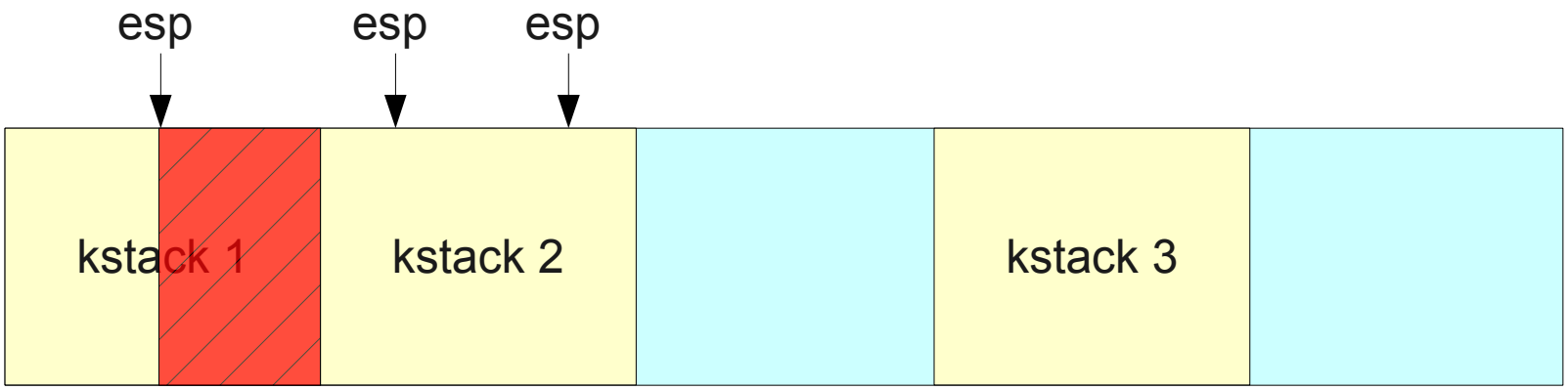
# Beyond our stack

- A thread's kstack doesn't exist in a vacuum
- Each kstack allocated from the buddy allocator




- Screw *intra-stack* exploitation, let's talk *inter-stack* exploitation

# Attacking adjacent kstacks

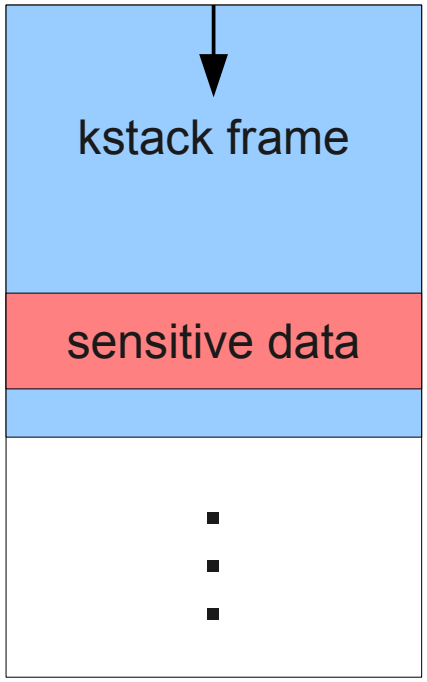
In an allocation-based overflow, we can blow past the end of our stack and into an adjacent stack!

- Two big questions:
  - How do we get two thread kernel stacks allocated adjacently?
  - How do we sanely modify another thread's stack to gain code exec?

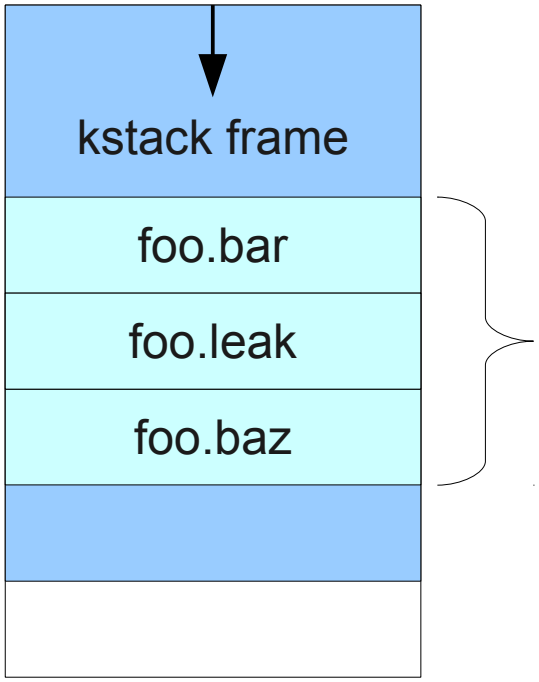
We sort of did this with stackjacking self-discovery!

We sort of did this with stackjacking Obergrope!

# Kernel stack disclosures




1) process makes syscall and leaves sensitive data on kstack




2) kstack is reused on subsequent syscall and struct overlaps with sensitive data

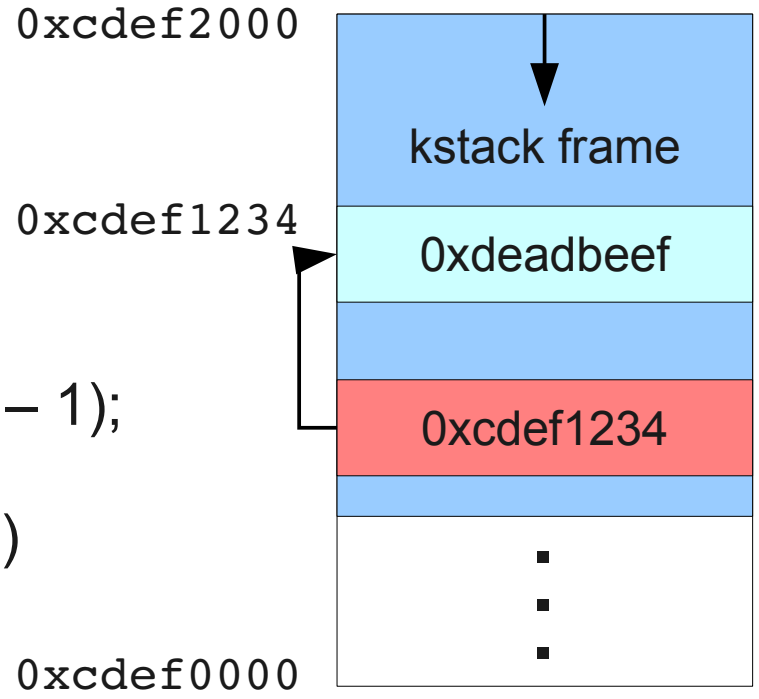
```
struct foo {
  uint32_t bar;
  uint32_t leak;
  uint32_t baz;
};

syscall() {
  struct foo;
  foo.bar = 1;
  foo.baz = 2;
  copy_to_user(foo);
}
```

3) foo struct is copied to userspace, leaking 4 bytes of kstack through uninitialized foo.leak member

# Kernel stack self-discovery

- If we can leak an pointer to the kstack off the kstack, we can calculate the base address of the kstack




kstack_base = addr & ~(THREAD_SIZE – 1);

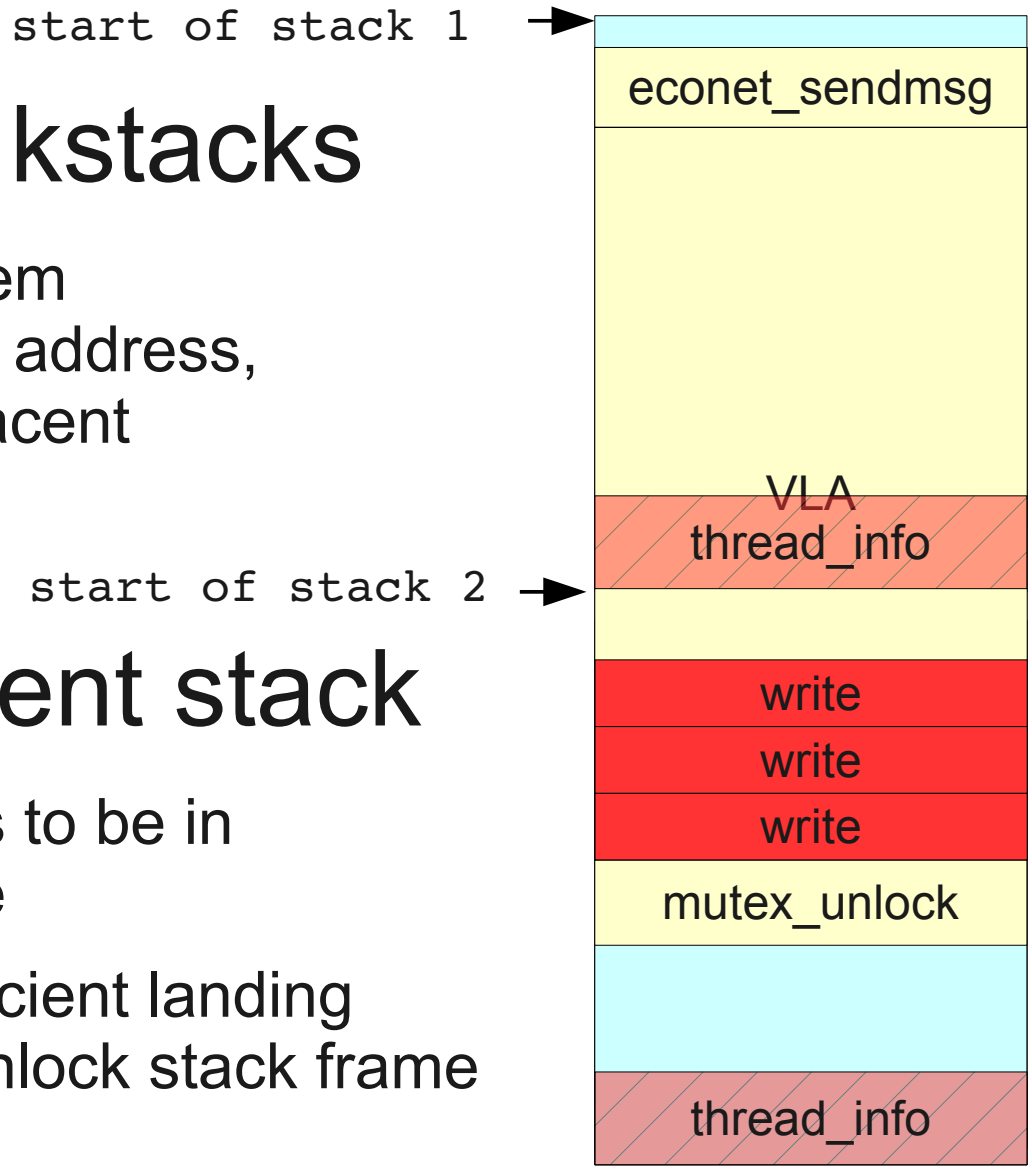
kstack_base = 0xcdef1234 & ~(8192 – 1)

**kstack_base = 0xcdef0000**

We call this ***kstack self-discovery***

# Writing the adjacent kstack

- Getting adjacent kstacks
  - Spawn children, have them self-discover their kstack address, spin until we get two adjacent allocations
- Writing the adjacent stack
  - Process #2 kstack needs to be in a stable predictable state
  - Process #1 needs a sufficient landing zone to absorb mutex_unlock stack frame

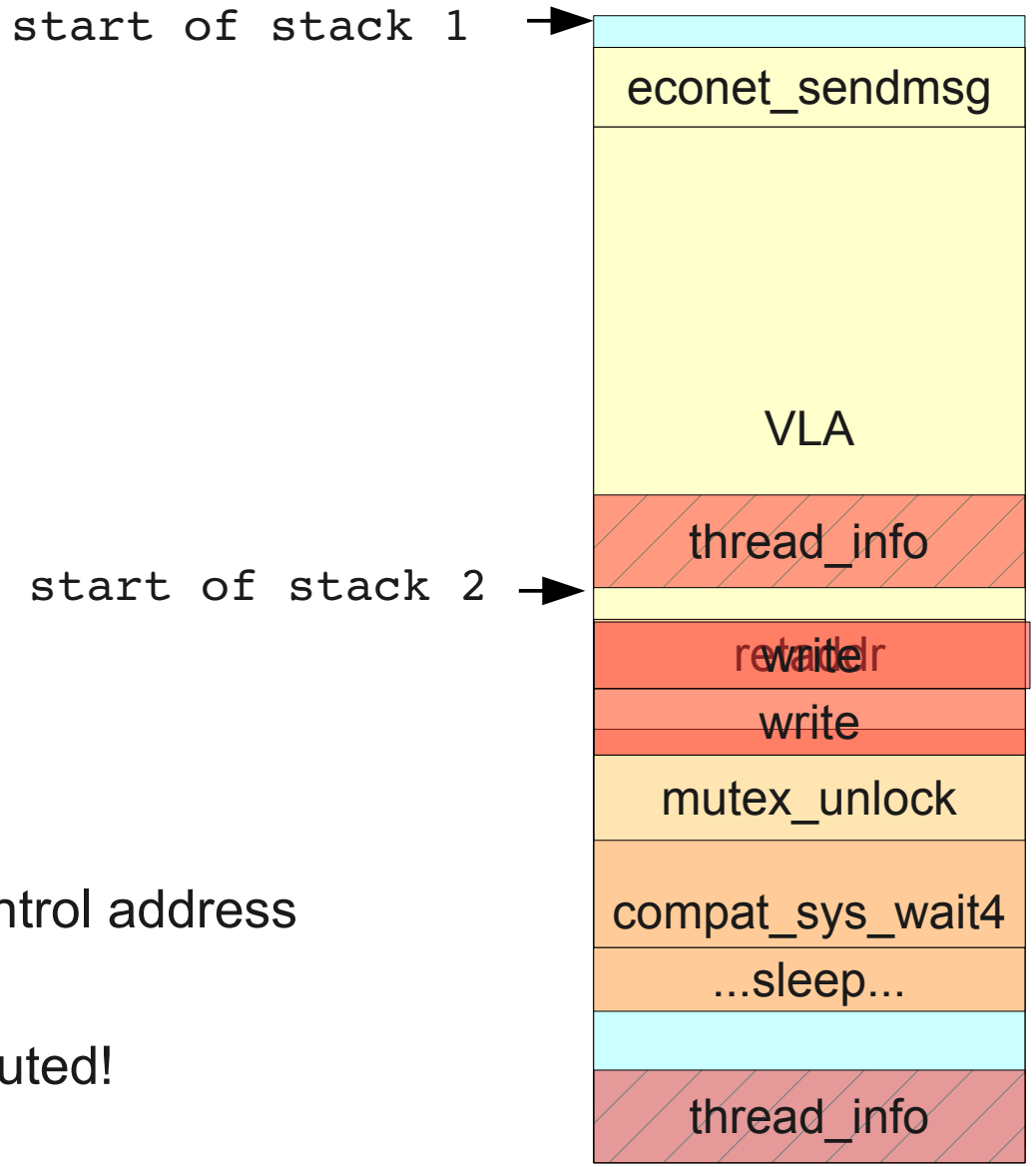


# Sleepy syscalls are back

- Process #2 will enter a “sleepy syscall”
  - Arbitrary sleeping to avoid dangerous race conditions with the overflow write
  - While asleep, process #1 will overwrite a return address on process #2's kstack
- compat_sys_wait4 looks good
  - Hey, same function we used for stackjacking!
  - Large unused local stack vars to absorb the mutex_unlock stack frame

# Final exploit flow

- Achieve adjacent kstacks
- Process #2 goes to sleep
- Stack overflow in process #1
- Overwrite return address on process #2 kernel stack
- Process #2 wakes up
- Process #2 returns to attacker control address
- Privilege escalation payload executed!



# Demo

DEMO TIME?

http://jon.oberheide.org/files/half-nelson.c

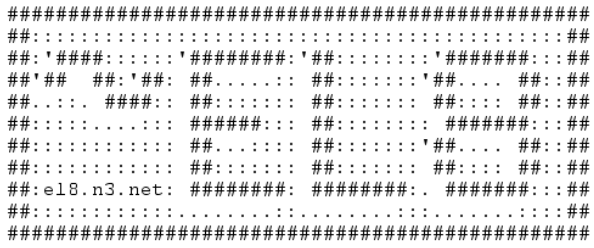
# The stack is back

- A brief history of stack overflows
- Stack overflows in the Linux kernel
- Exploiting exotic stack overflows
- **Discovering and mitigating stack overflows**

# Trivia #3

What is one way to discover potential stack overflow vulnerabilities?

Android Phone

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# jono discovery method

Ghetto kstack overflow discovery mechanism:

Advanced l33t static analysis:

```
egrep -R "^[[:space:]]*(struct |char |
(u)?int(8_t|16_t|32_t|64_t)? |void )
[^=]+\[[a-z]+.*[\+\*]?.*\];" * |
grep -v sizeof
```

Projected to win grugq's #grep2pwn 2012.

# pipacs discovery method

## The proper way to do it: gcc plugin

Artist's depiction of “theowl”

> 13:27 < pipacs> jono btw, i'm sorry to burst your infiltrate bubble but the next stackleak plugin will fix the alloca problems...
>
> 13:28 < pipacs> (and if you want to find all those bugs, the same plugin can tell you exactly where they occur ;)

pax_check_alloca verifies kstack sanity after alloca calls.

Inserted at compile time by stackleak_check_alloca into any functions that use __builtin_alloca.

See tools/gcc/stackleak_plugin.c in latest PaX patch

# Exploiting hardened kernels

- On grsec/PaX kernels, thread_info is no longer stored at the base of the kernel stack
  - Mitigated the Rosengrope stackjacking method
  - So, the standard thread_info overwrite is ineffective

Can we use the adjacent process exploitation technique against hardened kernels?

- Yes...
  - But RANDKSTACK makes it hard and new STACKLEAK plugin makes it near infeasible

# Mitigating exploitation

- Move thread_info off the stack!
  - Thwarts vanilla thread_info exploitation technique
  - Patches years ago to LKML, rejected by mainline
- Thwarting the adjacent process technique is a bit harder
  - Something like PaX's RANDKSTACK would make things harder

# Wrap-up

- GIVE UP HEAPSTERS!
  - Win8 fixed everything, the heap is over
- Stack overflows *are* exploitable
  - At least in the Linux kernel
  - How about your favorite OS? Windows/BSD/etc?
- Don't shun “unexploitable” vuln classes
  - Other situations? Userspace via browser/js?

# Greetz

- #busticati
- $1$kk1q85Xp$Id.gAcJOg7uelf36VQwJQ/
- ;PpPppPpPpPPPpP

# Q&A

# QUESTIONS?

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