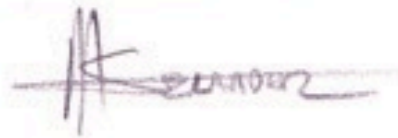




**Mining
Mach Services
within
OS X Sandbox**

Meder Kydyraliev, 2013



Agenda

- Sandboxing: what? why? how?
- OS X Sandbox aka Seatbelt
 - Quick overview
 - Enumerating attack surface
- Mach services
 - Quick overview
 - Fuzzing!

Disclaimer

IANAR

(I Am Not A Reverser)

Sandboxing: What?

- Sandbox - a mechanism for segregation and containment of a piece of code exposed to untrusted inputs
- MAC & RBAC
- Sandbox flavors:
 - LSM: SELinux, AppArmor, TOMOYO
 - TrustedBSD MAC: Seatbelt

Sandboxing: Why?

- Good software is hard
- Fixing bugs in software security researchers used to not care about is even harder (e.g. Adobe Reader)
- Indicator of “acceptance” by software vendors

Sandboxing: How?

- It all boils down to hooks:

```
int connect_nocancel(__unused proc_t p, struct connect_nocancel_args *uap,
                    __unused int32_t *retval) {
    ...
    #if CONFIG_MACF_SOCKET_SUBSET
        if ((error = mac_socket_check_connect(kauth_cred_get(), so, sa)) != 0) {
            if (want_free)
                FREE(sa, M_SONAME);
            goto out;
        }
    #endif /* MAC_SOCKET_SUBSET */
    ...
}
```

Sandboxing: How?

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    #endif /* MAC_SOCKET_SUBSET */
    ...
}
```

OS X Sandbox

- Based on TrustedBSD MAC Framework
- Prior work:
 - Iozzo, V. (2012). “A Sandbox odyssey”.
 - Blazakis, D. (2011). “The Apple Sandbox”.

TrustedBSD MAC

- A bunch of hooks are sprayed throughout the kernel
- Hooks loop over registered policy modules invoking corresponding functions (e.g. `mac_vnode_check_open`)
- Allows coexistence of multiple implementations
- Provides multiplex system call `mac_syscall()` for modules to expose functionality

Issues with TrustedBSD/MAC

- Relies on hooks to be present (missing vs. unimplemented)
- Argument parsing prior to hooks represents attack surface
- XNU extras:
 - Retrofitted for Mach (more hooks sprayed in user-land Mach services, e.g. mach-lookup)

mac_syscall()

<code>_syscall_set_profile</code>	applies profile to a process
<code>_syscall_set_profile_builtin</code>	applies default builtin profile to a process
<code>_syscall_check_sandbox</code>	checks specified action(e.g. mach-lookup) against policy
<code>_syscall_note</code>	associated “note” with current proc’s sandbox label
<code>_syscall_container</code>	???
<code>_syscall_suspend</code>	Suspends sandbox checks on supplied PID by setting boolean value on proc's label. PID must belong to the same user. Calling process must have <code>com.apple.private.security.sandbox-manager entitlement</code> and target process has to either have <code>com.apple.security.print entitlement</code> value set to 1 or <code>com.apple.security.temporary-exception.audio-unit-host</code> set to 1.
<code>_syscall_unsuspend</code>	Resume suspended sandbox checks.
<code>_syscall_passthrough_access</code>	???. Seems to take a descriptor, get corresponding vnode and call <code>vnode_authorize()</code> on parent's vnode.
<code>_syscall_vtrace</code>	

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mac_syscall()

<code>_syscall_extension_issue</code>	returns extension for a file operation or Mach lookup
<code>_syscall_extension_consume</code>	uses the above extension to augment current proc's policy by adding action authorized by the extension to the policy
<code>_syscall_extension_release</code>	disassociates "consumed" extension from the policy
<code>_syscall_extension_update_file</code>	???
<code>_syscall_extension_twiddle</code>	???

Seatbelt Extensions

Usage:

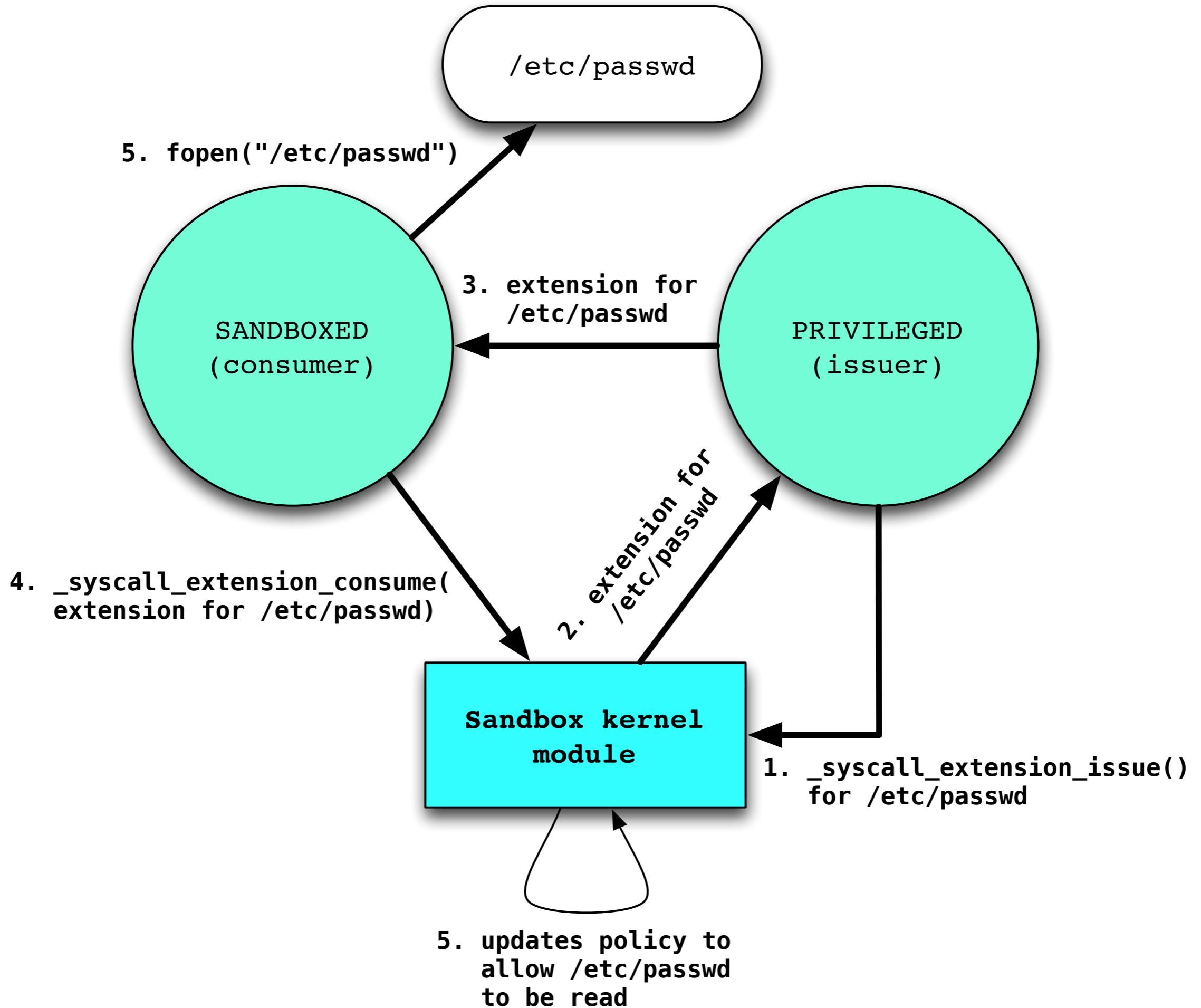
```
extension = _syscall_extension_issue("com.apple.app-sandbox.read", "/etc/passwd");  
_syscall_extension_consume(extension);  
FILE* f = fopen("/etc/passwd", "r");
```

Issuer Policy:

```
(allow file-issue-extension ....
```

Consumer Policy:

```
(allow file-read* (extension "com.apple.app-sandbox.read"))  
(allow mach-lookup (extension "com.apple.app-sandbox.mach"))
```



Seatbelt Extensions

- How to they work?

```
58ffd694274b2b5575eff5e497fe4de1de815124;00000000;0000000000000001a;com.apple.app-sandbox.read;00000001;01000004;000000000000041ee;/private/etc/passwd
```

58ffd6942....5e497fe4de1de815124	SHA1 HMAC value.
0	0
0000000000000001a	Length of the extension type string that follows.
com.apple.app-sandbox.read	Extension type
1	1
1000004	File system ID (fsid_t) with type truncated.
000000000000041ee	inode number
/private/etc/passwd	file path

Seatbelt Extensions

- SHA1 HMAC key generated on startup by `Sandbox.kext`
- Constant time comparison

Users

- Used by Google Chrome.
- Used by Adobe Reader X(1).
- In some form or the other used by most OS X apps.

Challenges

- Complex interactions between components (server vs client apps)
- One-time sensitive resource access (e.g. config load on startup)
- Legacy apps: sandbox-aware vs. sandbox-unaware

Process Warm-up

- What?
 - exercise of code paths prior to sandbox being enabled
- Why?
 - communications channels are established
 - files are open/read/written

Enumerating Attack Surface

- BSD system calls
 - code that runs before MAC hook
 - hooks provided by MAC, but not implemented by Seatbelt
- Mach Services
 - in-kernel
 - user-land
- I/O Kit

BSD system calls

- There are a number of system call MAC hooks not implemented/allowed by Seatbelt, e.g.:
 - `socket()` - `AF_INET/AF_LOCAL` sockets of `SOCK_DGRAM/SOCK_STREAM` type are allowed
 - `setsockopt()`, `ioctl()`, `mmap()` - unimplemented by Seatbelt
 - `getfsstat()`, `readdir()` - unimplemented and provide the `fsid` and `inode` for extensions (if you already have the key)

...speaking of setsockopt()

- Turns out you can set `SO_EXECPATH(0x1085)` to a path of a preauthorized binary to bypass firewall prompts:

- `/usr/libexec/configd`

- `/usr/sbin/mDNSResponder`

- `/usr/sbin/racoon`

- `/usr/bin/nmblookup*` - doesn't exist hence prompt is displayed

- `/System/Library/PrivateFrameworks/Admin.framework/Versions/A/Resources/readconfig`



- Setting `0x1085` to any string without `'/'` results in `panic()` (NULL deref)

Mach Services



Remember warm-up?

- Exercising code paths leaves some interesting artifacts...Mach ports.
- Chrome renderer:
 - `policy: only fontd`
 - `reality (showipcint from kgmacros):`
 - `coreservicesd`
 - `cfprefsd`
 - `notifyd`
 - `distnoted`

Mach Services Intro

- Mach service is essentially a queue consumer
- Mach ports represent descriptors for queues
- Send == enqueue, receive == dequeue
- Sender/receiver can be either:
 - another process(e.g. `coreservicesd`)
 - kernel (e.g. `thread_set_state` ptrace replacement)
- See also Dai Zovi's "Hacking at Mach Speed"

Mach Ports

- Port just a descriptor of a port in task's (i.e. proc's) IPC namespace
- Lots of types end up being defined as `mach_port_t` (e.g. `clock_serv_t`)
- Mach ports can be obtained by:
 - calling Mach traps (e.g. `task_self_trap`, `task_for_pid`, `mach_port_allocate`)
 - via bootstrap/launchd...

Mach Lookup via launchd

```
mach_port_t bootstrap, svc_port;  
  
task_get_bootstrap_port(mach_task_self(), &bootstrap);  
  
bootstrap_look_up(bootstrap,  
                  "com.apple.FontObjectsServer",  
                  &svc_port);  
  
...  
mach_msg(...);
```

launchd

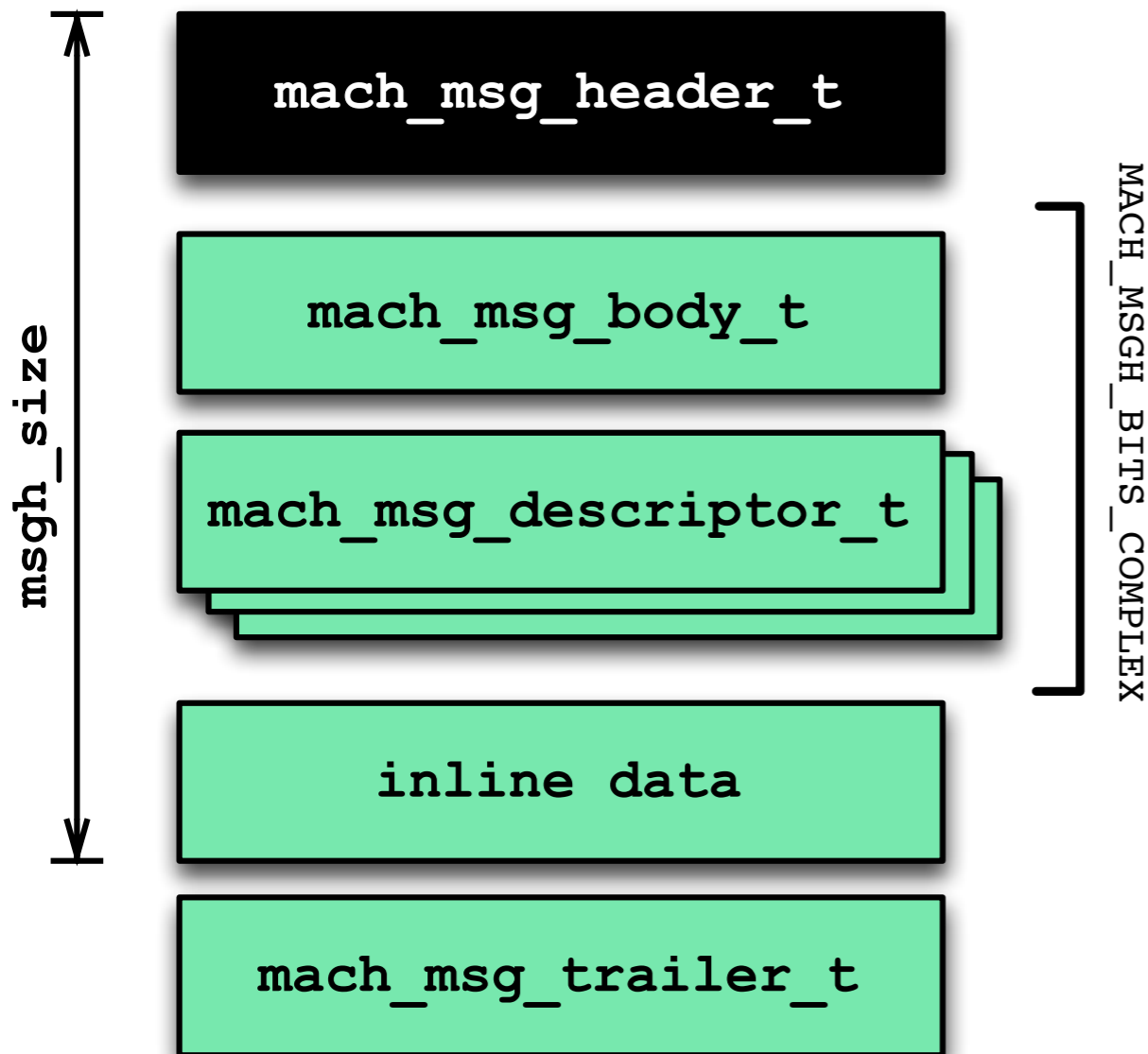
- And here's what happens in launchd:

```
job_mig_look_up2(job_t j, mach_port_t srp, name_t servicename, mach_port_t *serviceportp, pid_t
target_pid, uuid_t instance_id, uint64_t flags)
{
    ...
#endif

#if HAVE_SANDBOX
    /* We don't do sandbox checking for XPC domains because, by definition, all
    * the services within your domain should be accessible to you.
    */
    if (!xpc_req && unlikely(sandbox_check(ldc->pid, "mach-lookup", per_pid_lookup ?
        SANDBOX_FILTER_LOCAL_NAME : SANDBOX_FILTER_GLOBAL_NAME, servicename) > 0)) {
        return BOOTSTRAP_NOT_PRIVILEGED;
    }
#endif
```

Anatomy of a Mach Message

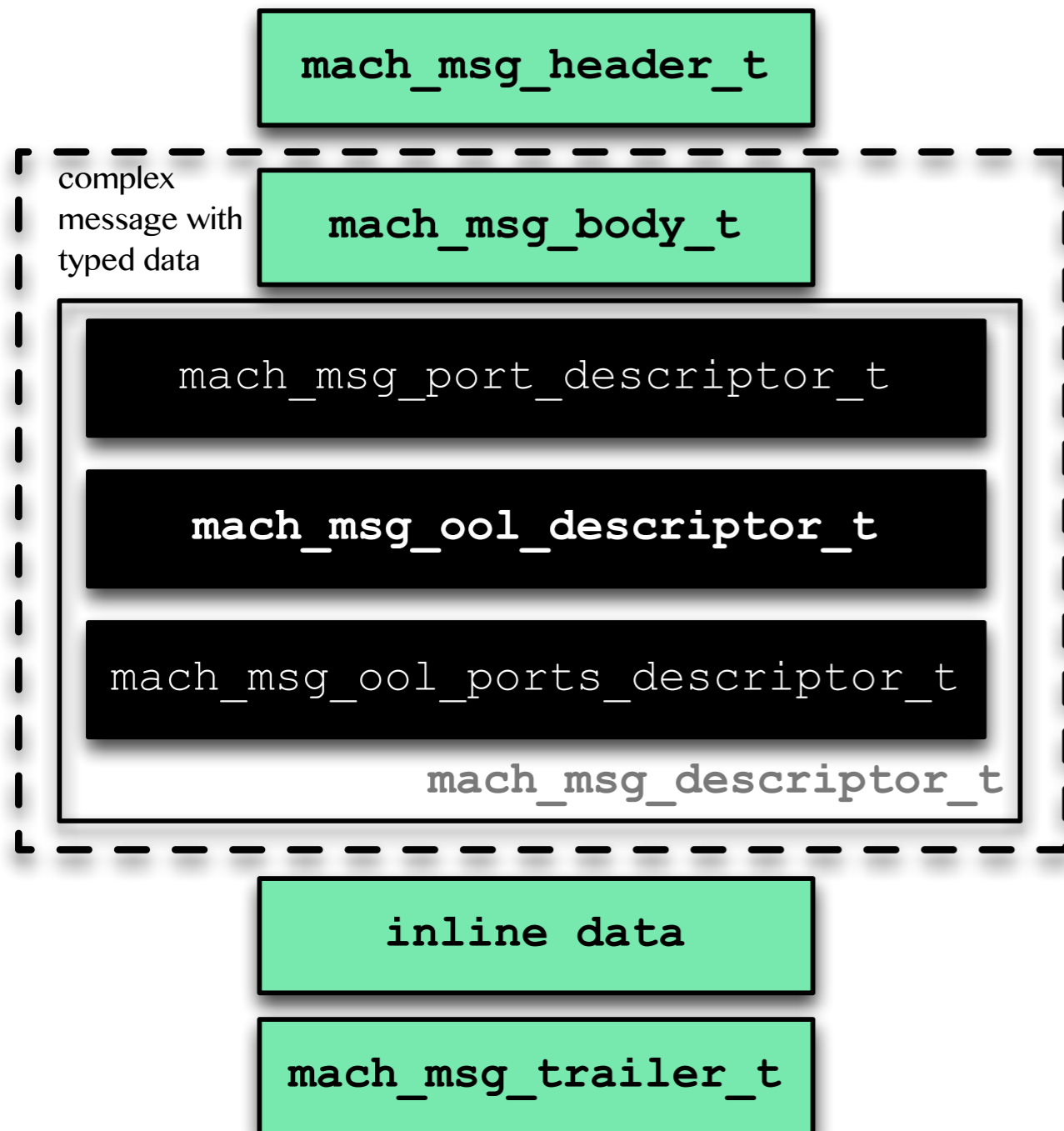
Mach Message - Header



```
typedef struct
{
    mach_msg_bits_t  msgh_bits;
    mach_msg_size_t  msgh_size;
    mach_port_t      msgh_remote_port;
    mach_port_t      msgh_local_port;
    mach_msg_size_t  msgh_reserved;
    mach_msg_id_t    msgh_id;
} mach_msg_header_t;
```

- **msgh_bits** - determines how **msgh_remote_port** and **msgh_local_port** are handled and specifies if message is complex (**MACH_MSGH_BITS_COMPLEX**)
- **msgh_local_port** - reply port
- **msgh_id** - used by services to demux calls.

Mach Message - Body

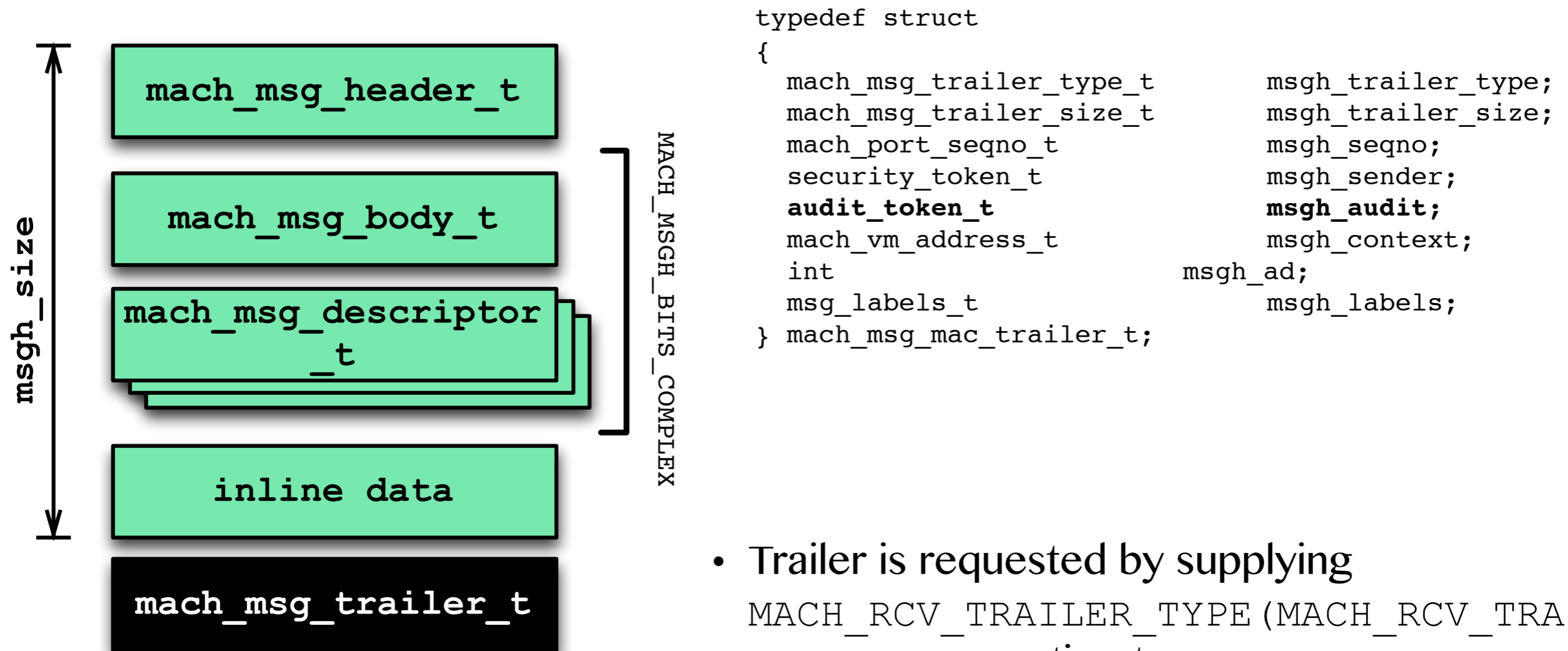


```
typedef struct
{
    mach_msg_size_t msgh_descriptor_count;
} mach_msg_body_t
```

```
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**, **size** - pointer to out-of-line(OOL) memory and it's size
- **copy** - option instructing kernel on how to treat the memory (MACH_MSG_VIRTUAL_COPY or MACH_MSG_PHYSICAL_COPY)

Mach Message - Body



- Trailer is requested by supplying `MACH_RCV_TRAILER_TYPE(MACH_RCV_TRAILER_SENDER)` option to `mach_msg()`.
- `audit_token_to_au32()` extracts {r,e}uid/gid and pid from `audit_token_t`

Sending/Receiving

`mach_msg()` / `mach_msg_overwrite()` are used to both send and receive messages:

```
mach_msg_return_t mach_msg
                  (mach_msg_header_t      msg,
                   mach_msg_option_t      option,
                   mach_msg_size_t        send_size,
                   mach_msg_size_t        receive_limit,
                   mach_port_t            receive_name,
                   mach_msg_timeout_t     timeout,
                   mach_port_t            notify);
```

- option - `MACH_SEND_MSG`, `MACH_RCV_MSG`

Fuzzing Mach Services

<https://github.com/meder/mach-fuzz>

...but before that

- Mach services generally considered less sexy:
 - local privesc
 - require extra knowledge
- Some Mach services are a b!@#% to fuzz...

coreservicesd

- Runs as root
- Will segfault within seconds of fuzzing
 - Out-of-memory reads
 - Huge allocations
- ...which brings down lots of other stuff (must restart)
- Instead of fuzzing explored APIs exposed over Mach...

coreservicesd

- Has checks sprinkled to check if app is sandboxed
- Checks are missing/wrong in:
 - `__XSetContentTypeHandler`
 - `__XSetSchemeHandler`
 - `_XRegisterItemInfo`

coreservicesd

- `__XSetContentTypeHandler` - associates arbitrary registered bundle ID with arbitrary MIME type. Attack: associate `public.plain-text` with `com.apple.JarLauncher`
- `__XSetSchemeHandler` - associated URL schemes with arbitrary registered bundle ID. Attack: change default browser, mail agent, PDF reader.
- `_XRegisterItemInfo` - registers items (e.g. applications) with `launchd`. Used by `mdworker` to automatically register any valid `.app` directories on your HDD (e.g. if you unzipped something with `.app` and `Info.plist`) with `launchd`. Newly registered bundle ID can be used in above calls. NOTE: calls `processIsInAppSandbox()`, which returns `false` for Chrome.

...back to fuzzing

- Usual steps involved:
 - pick target
 - collect samples
 - fuzz

Collecting Samples

- Can't download off the internet :(
- Random generation ineffective
 - `msgh_id` - correct ID range is crucial for reaching target code:

```
mov    eax,0xffffc180;
add    eax,DWORD PTR [rdi+0x14] ; msgh_id
cmp    eax,0x21             ; 0x3e80
jbe    process_message
xor    eax,eax
jmp    return
```

- `msgh_size` - size is often checked right after `msgh_id` for expected size.

Collecting Samples

- mach_dump.py on target process
- trigger code paths (e.g. drag and drop, install stuff, visit web pages)
- uses gdb + python
 - OS X gdb 6.3.50-20050815
 - Compile + sign latest gdb for Python support(symbols are borked)
 - use both!

mach_dump.py

- Parses Mach message and saves it on disk (including OOL memory)
- Implements GDB breakpoint
- Must be set right after server-side `mach_msg()` call and given register name with mach message
- To find the right spot:

```
break mach_msg
commands
    bt
    c
end
```

Sample stacktrace

```
#0 0x00007fff8389dc0d in mach_msg ()
#1 0x00007fff8c030835 in serverMainHandler ()
#2 0x00007fff8c623e40 in __CFMachPortPerform ()
#3 0x00007fff8c623d09 in
    __CFRUNLOOP_IS_CALLING_OUT_TO_A_SOURCE1_PERFORM_FUNCTION__ ()
#4 0x00007fff8c623a49 in __CFRunLoopDoSource1 ()
#5 0x00007fff8c656c02 in __CFRunLoopRun ()
#6 0x00007fff8c6560e2 in CFRunLoopRunSpecific ()
#7 0x00007fff8c664dd1 in CFRunLoopRun ()
#8 0x00007fff8c02fff7 in main_handler ()
#9 0x00007fff8cf807e1 in start ()
```

Fuzzing

- Basic fuzzer
- Parses messages saved with `mach_dump.py`
- Allocates ports where needed
- Can cycle through a range of `msg_ids`

Results (fontd)

- Incorrectly bounded `rol` loop on stack with attacker controlled count
- Arbitrary `vm_deallocate()` on a pointer
- Over reading in `memcpy/memmove`
- Huge allocations

Recommendations

- Know the descriptors and ports accessible from sandboxed process
 - Close unused mach ports
- OR
- Broker out mach calls (tricky!)

References

- Iozzo, V. (2012). “A Sandbox odyssey”: <http://prezi.com/lxljhzem6js/a-sandbox-odyssey-infiltrate-2012/>
- Dai Zovi. (2011). “Hacking at Mach2”: <http://blog.trailofbits.com/2011/01/11/hacking-at-mach-2/>
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