Auditing and Exploiting Apple IPC

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Jailbreak Security Summit May 2015

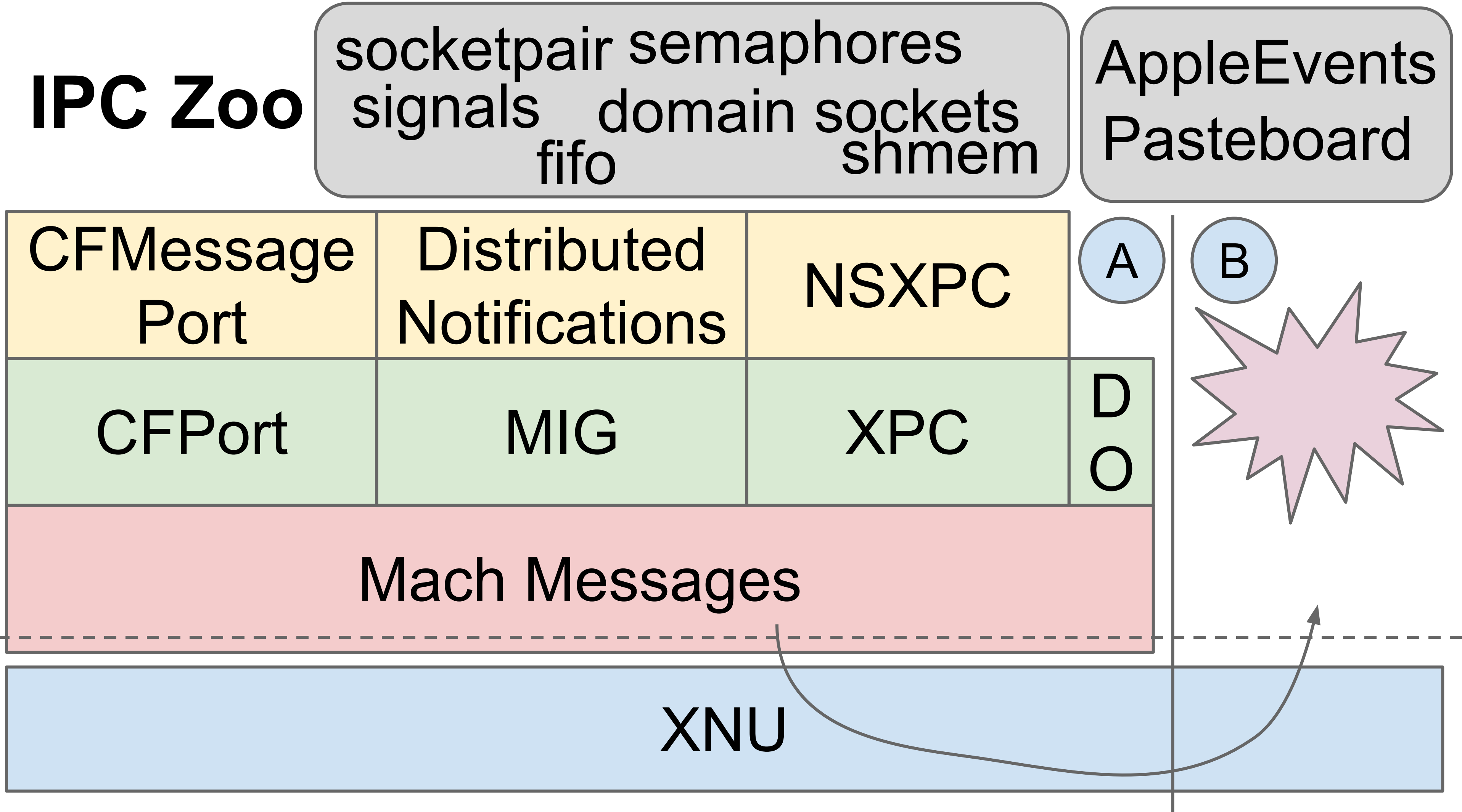
About me:

- Security Researcher with Project Zero
- Won pwn4fun last year with a JavaScriptCore bug and some kernel bugs
- That macbook air now runs ubuntu :)
- Over the last year reported ~60 OS X sandbox escapes/priv-escs (10 still unpatched)
- Some accidentally also present on iOS

This talk:

- Overview of (almost) all IPC mechanisms on iOS/OS X
- Quick look at Mach Message fundamentals
- Deep-dive into XPC services
- Exploiting XPC bugs
- fontd IPC and exploiting fontd bugs
- Mitigations and the future

IPC Zoo



socketpair semaphores

signals domain sockets

fifo shmem

AppleEvents

Pasteboard

CFMessage Port

Distributed Notifications

NSXPC

A

B

CFPort

MIG

XPC

D O

Mach Messages

XNU

Why care about IPC?

Sandboxing

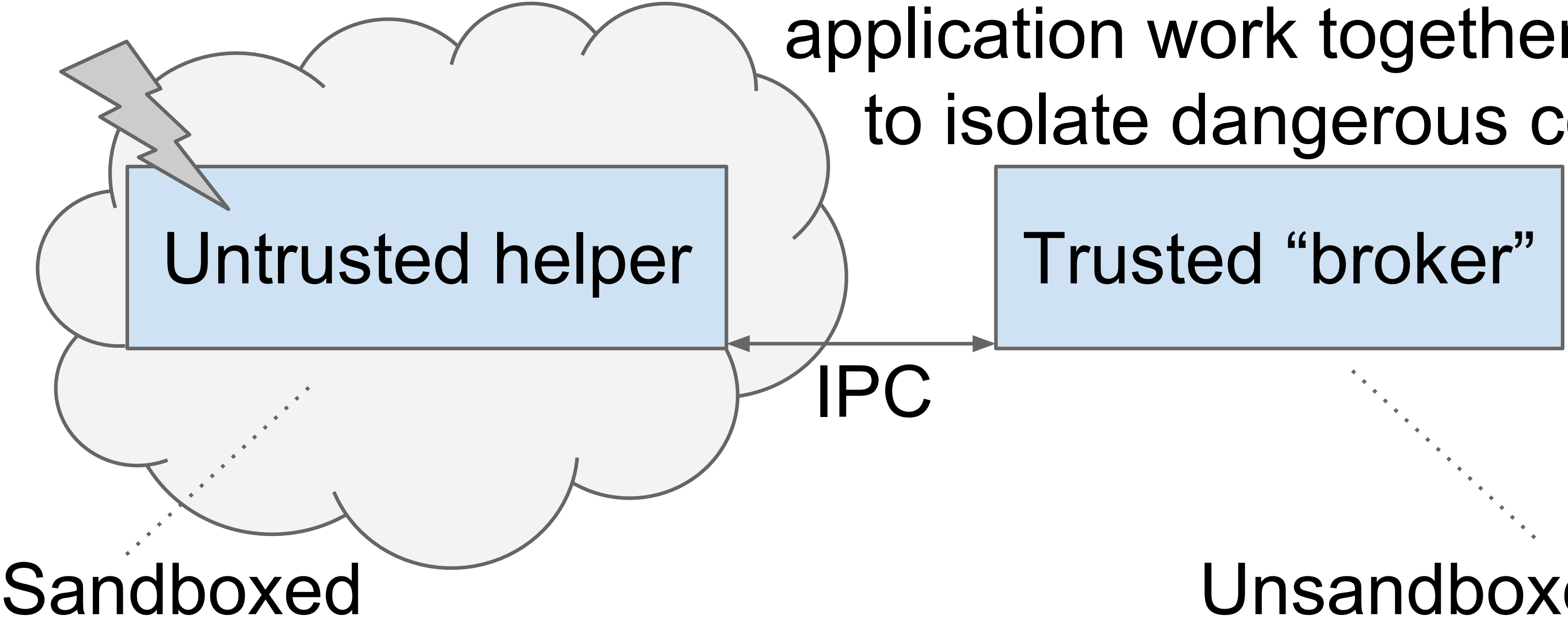
You *probably* get initial code execution in some kind of sandbox in userspace…

- renderer/plugin process
- quicklook-satellite
- ntpd
- appstore app

Plenty of stuff is still unsandboxed on OS X though
(...Adobe Reader...)

Sandbox escape models

Privilege separation: Two parts of the same application work together to isolate dangerous code



Untrusted helper

Trusted “broker”

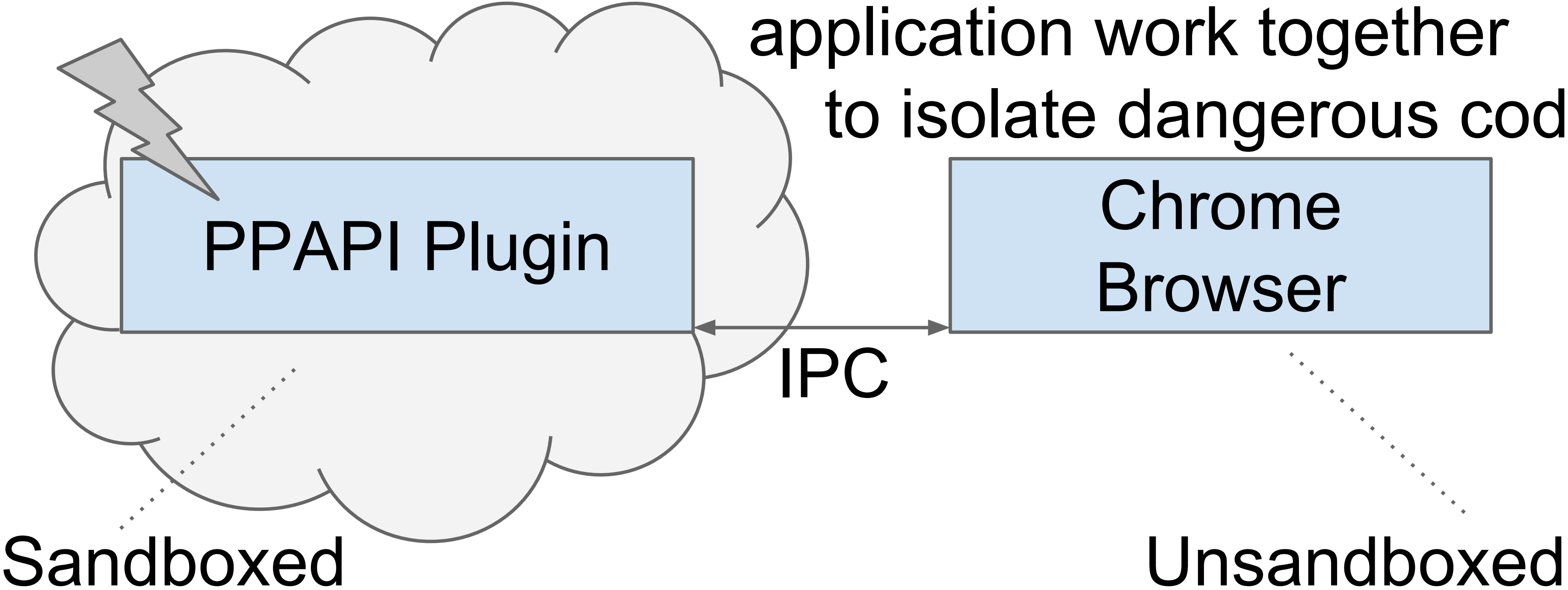
IPC

Sandboxed

Unsandboxed

Sandbox escape models

Privilege separation: Two parts of the same application work together to isolate dangerous code



PPAPI Plugin

Chrome Browser

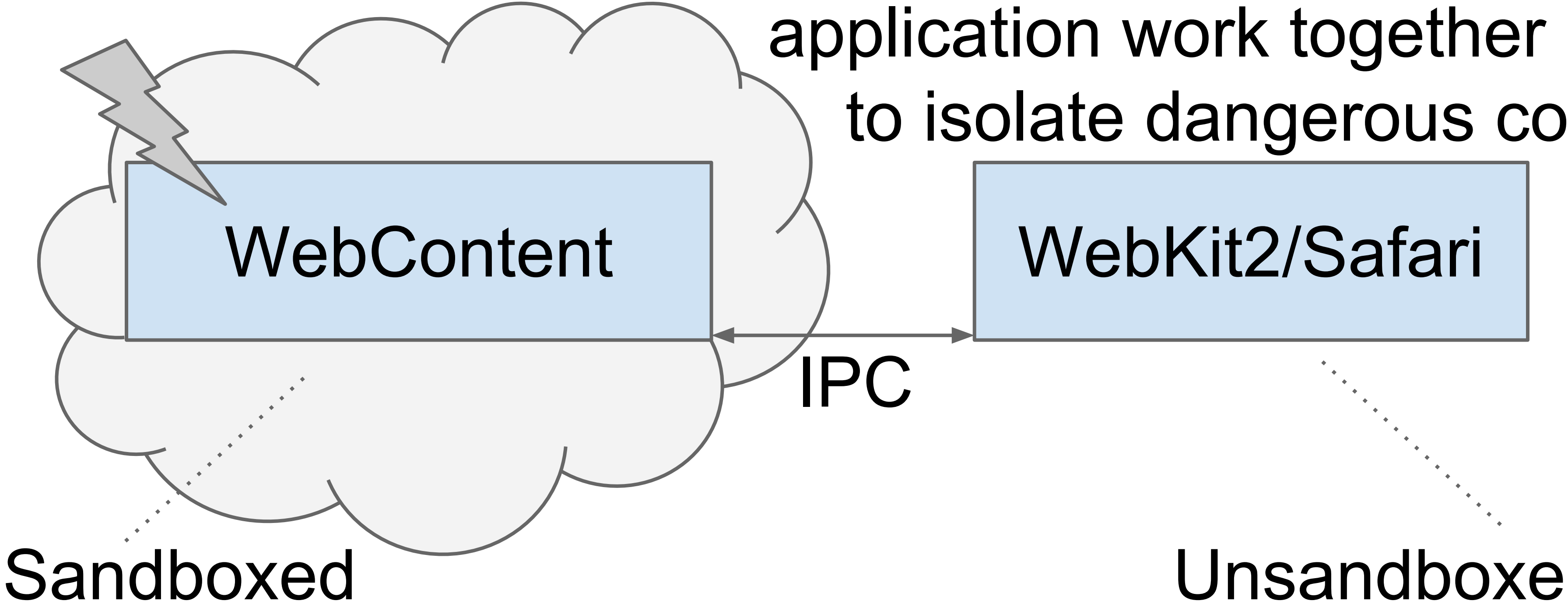
IPC

Sandboxed

Unsandboxed

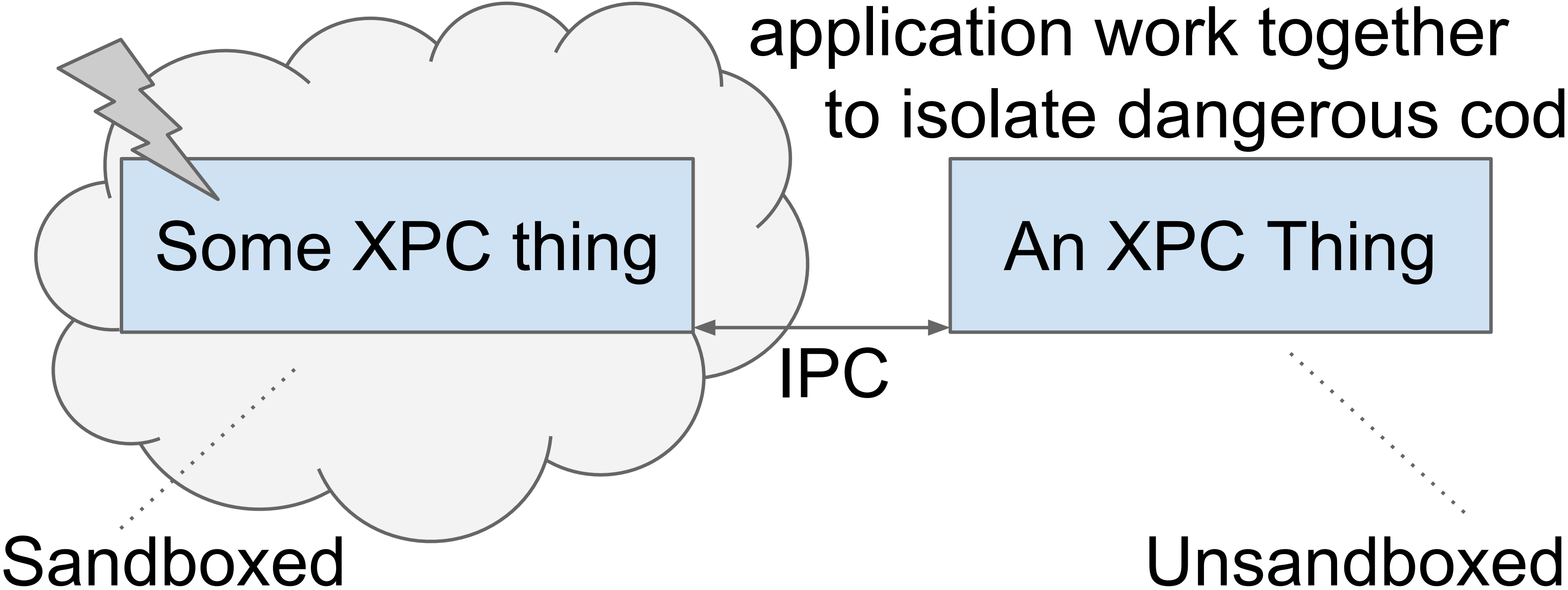
Sandbox escape models

Privilege separation: Two parts of the same application work together to isolate dangerous code



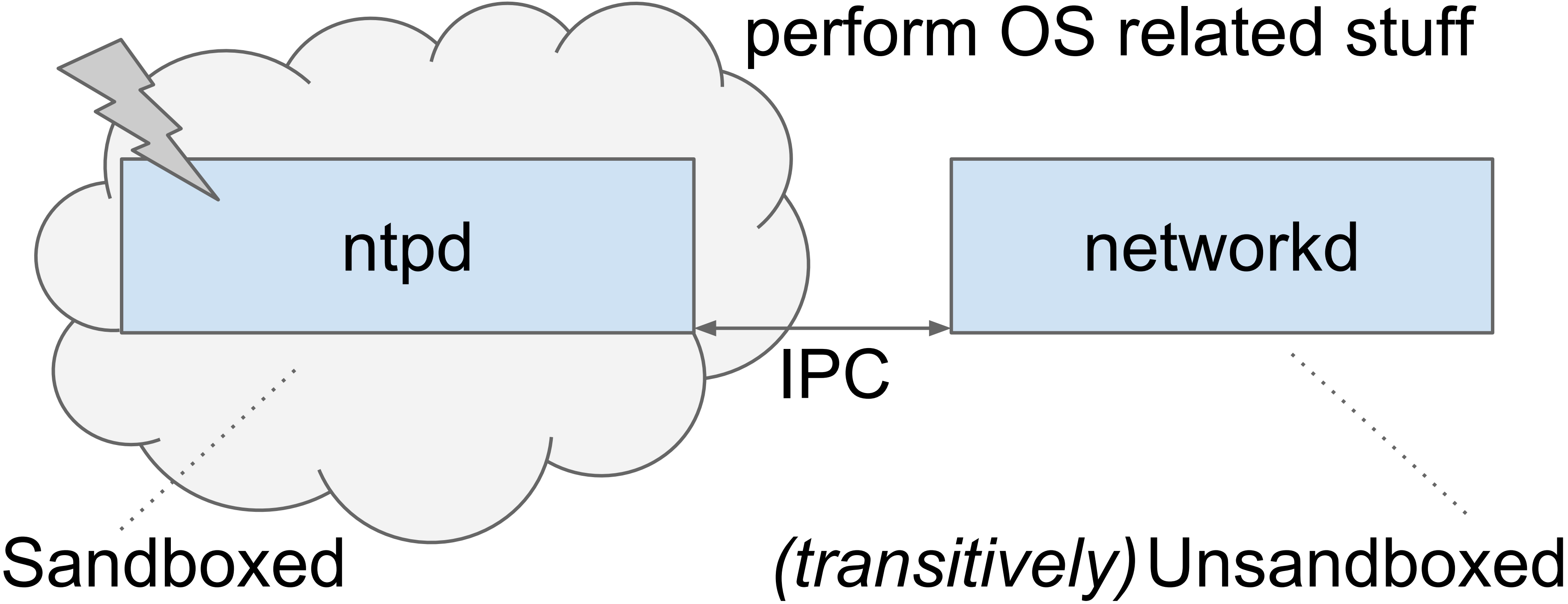
Sandbox escape models

Privilege separation: Two parts of the same application work together to isolate dangerous code



Sandbox escape models

System Services: OS provided IPC services which perform OS related stuff



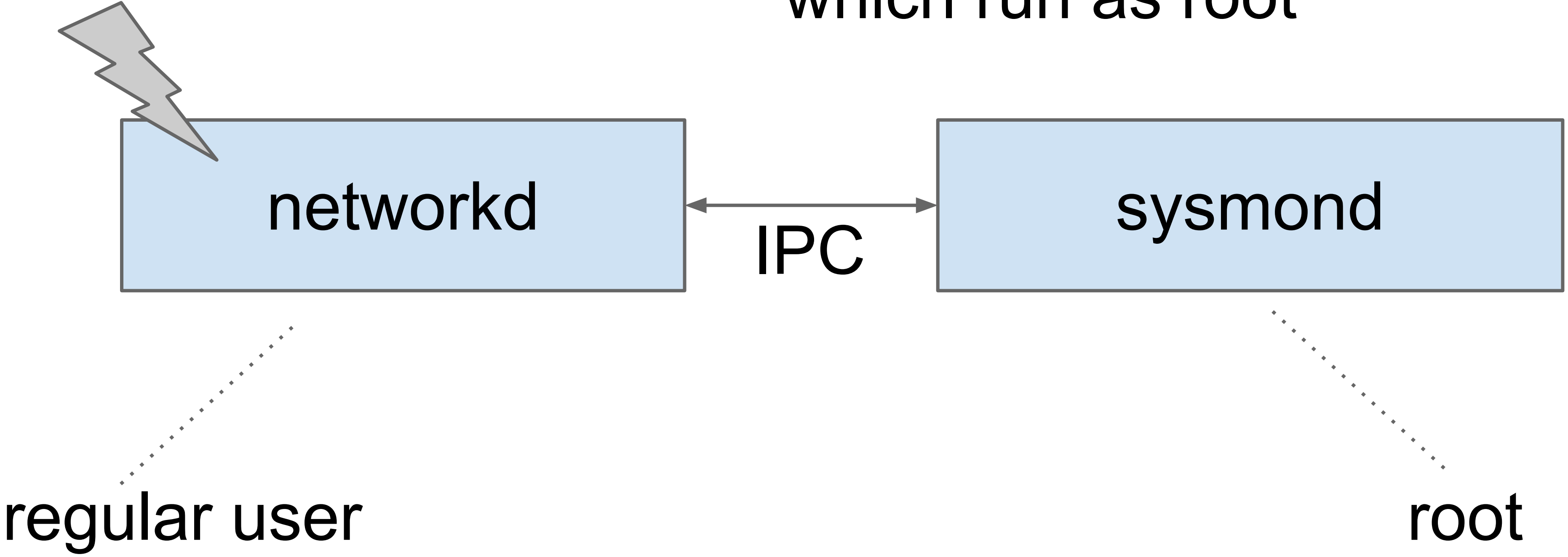
Privilege Escalation

OS X: root == kernel code execution

iOS: not that easy, but still, more attack surface

Privilege escalation model:

Root System Services: OS provided IPC services
which run as root

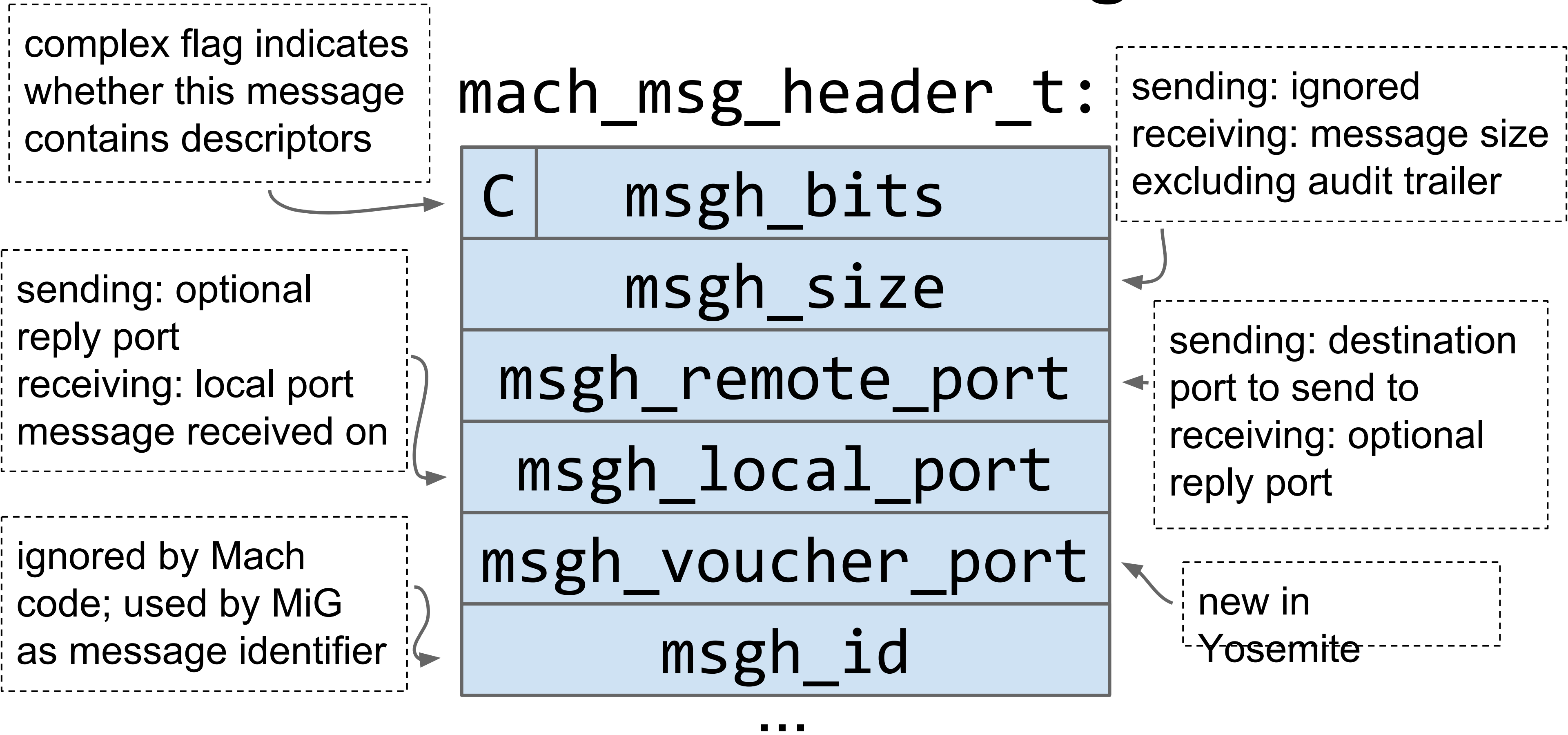


it takes two to IPC

low-level mach messages and bootstrapping

Building Mach Messages

Structure of a Mach Message:



mach_msg_header_t:

complex flag indicates whether this message contains descriptors

sending: ignored
receiving: message size excluding audit trailer

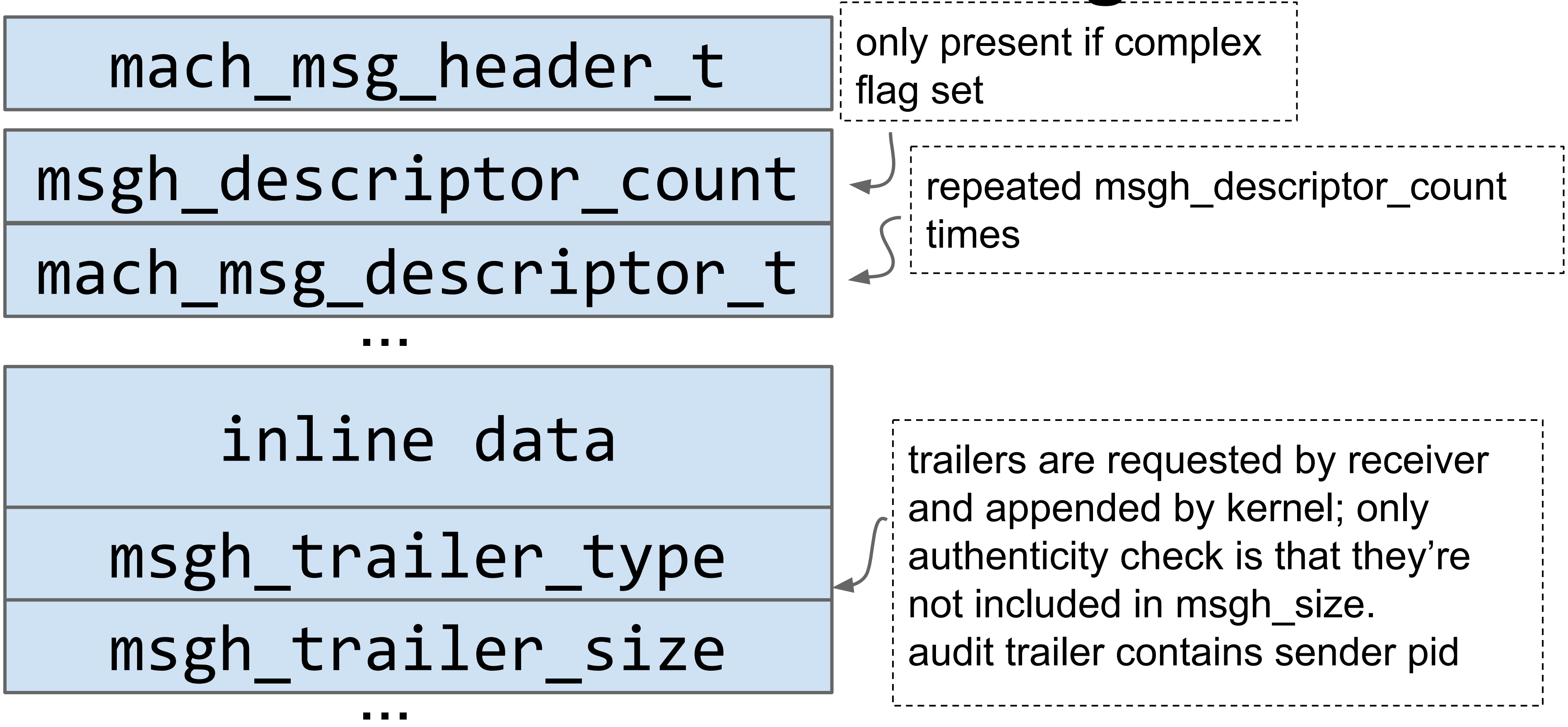
sending: optional reply port
receiving: local port message received on

sending: destination port to send to
receiving: optional reply port

ignored by Mach code; used by MiG as message identifier

new in Yosemite

Structure of a Mach Message:



mach_msg_header_t

only present if complex flag set

msgh_descriptor_count

mach_msg_descriptor_t

repeated msgh_descriptor_count times

...

inline data

msgh_trailer_type

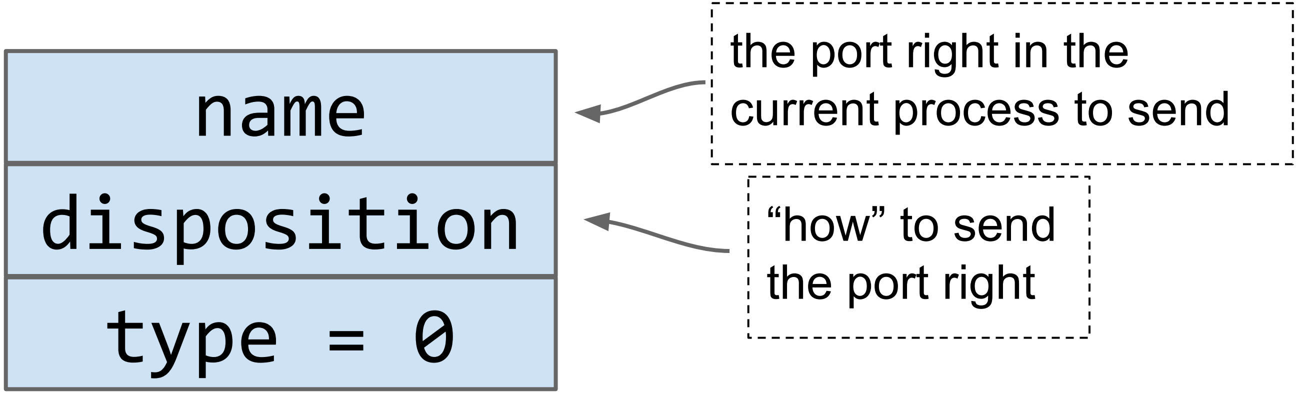
msgh_trailer_size

...

trailers are requested by receiver and appended by kernel; only authenticity check is that they're not included in msgh_size.
audit trailer contains sender pid

Port Descriptors

`mach_msg_port_descriptor_t:`



name

disposition

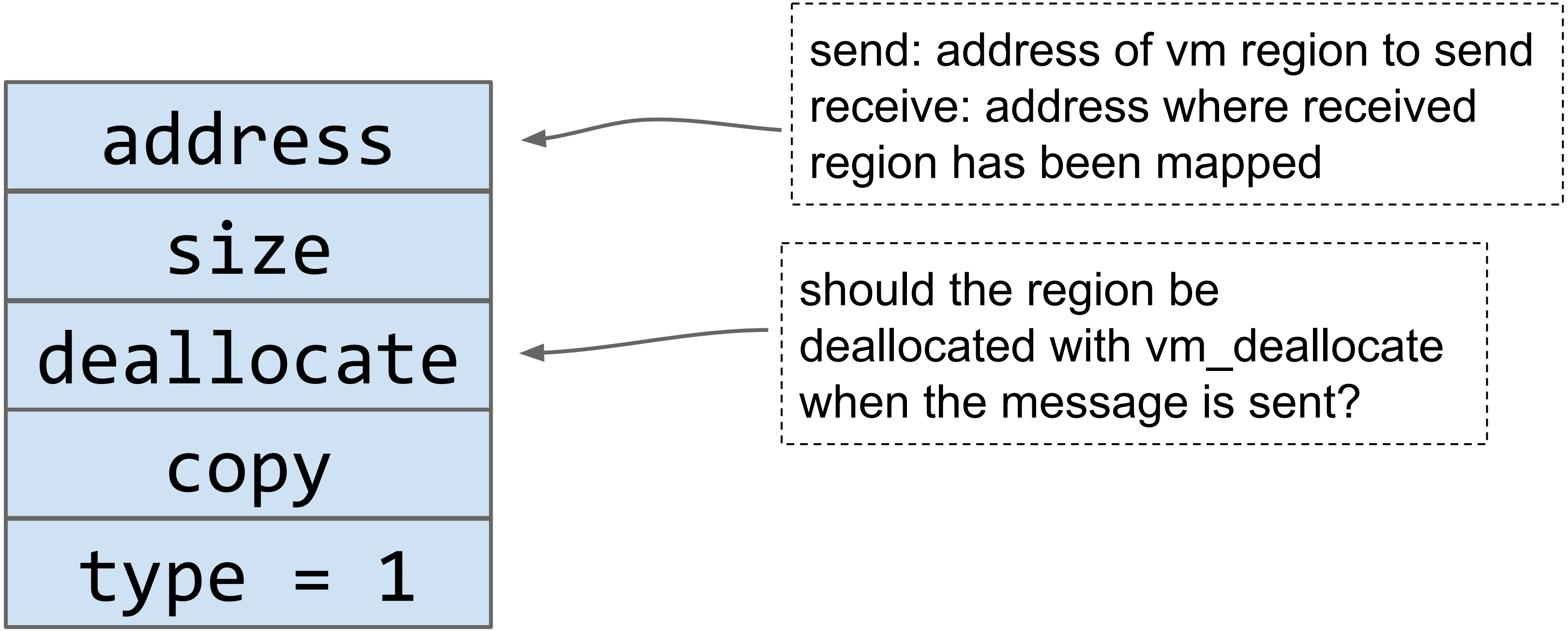
type = 0

the port right in the current process to send

“how” to send the port right

OOL Descriptors

`mach_msg_ool_descriptor64_t:`



address

size

deallocate

copy

type = 1

send: address of vm region to send
receive: address where received region has been mapped

should the region be deallocated with vm_deallocate when the message is sent?

launchd

launchd

- pid 1
- launchd manages system services
- All processes can talk to launchd
- provides the mechanisms to look up system services and connect to them
- system service == a send right to a mach port
    - launchd only cares about the initial connection, not the protocol

connecting to launchd services

```
mach_port_t connect_to_service(const char* service_name) {
  mach_port_t bs_port, service_port;
  kern_return_t err;

  task_get_bootstrap_port(mach_task_self(), &bs_port);
  err = bootstrap_look_up(bs_port, service_name, &service_port);
  if (err == KERN_SUCCESS) {
    return service_port;
  } else {
    return MACH_PORT_NULL;
  }
}
```

LaunchDaemons & LaunchAgents

- `/System/Library/Launch*` config files allow allow static registration of service names

```
<dict>
        <key>Label</key>
        <string>com.apple.nfsd</string>
        <key>ProgramArguments</key>
        <array>
                <string>/sbin/nfsd</string>
        </array>
</dict>
</plist>
```

bootstrap_checkin()

- Ask launchd for the mach port for the service name reserved in the Launch* plist:

```
bootstrap_check_in(bootstrap_port,
                   “service_name”,
                   &servicePort);
```

follow xrefs to find message handling code :)

bootstrap_register()

Deprecated (but still used) dynamic launchd service registration:

```
bootstrap_register(bootstrap_port,
                   “my_service”,
                   service_port);
```

follow xrefs to find message handling code :)

launchctl

- tool to manage launchd
- since launchd has been rewritten, so has launchctl, so most documentation out-of-date!
- but start with: `sudo launchctl print system`

building a list of root services

Use launchctl; here’s an incomplete list:

```
com.apple.ocspd
com.apple.launchd.peruser.0
com.apple.cfprefsd.daemon
com.apple.taskgated
com.apple.suhelperd
com.apple.revisiond
com.apple.diskmanagementd
com.apple.alf
com.apple.sysmond
com.apple.metadata.mds.index
com.apple.metadata.mds.xpc
com.apple.metadata.mds
com.apple.metadata.mds.xpcs
com.apple.cmio.VDCAssistant
com.apple.usbd
com.apple.airportd
com.apple.wifi.anqp
```

```
com.apple.wifi.anqp
com.apple.security.syspolicy
com.apple.FontWorker
com.apple.FontWorker.ATS
com.apple.installd
com.apple.FileCoordination
com.apple.ProgressReporting
com.apple.cvmsServ
com.apple.KernelExtensionServer
com.apple.tccd.system
com.apple.coreservices.launchservicesd
com.apple.system.opendirectoryd.libinfo
com.apple.system.opendirectoryd.membership
com.apple.system.opendirectoryd.api
com.apple.system.DirectoryService.libinfo_v1
com.apple.system.DirectoryService.membership_v1
com.apple.private.opendirectoryd.rpc
```

```
com.apple.securitydservice
com.apple.wdhelper
com.apple.DiskArbitration.diskarbitrationd
com.apple.systemstatsd
com.apple.networkd_privileged
com.apple.logind
com.apple.apsd
com.apple.network.IPConfiguration
com.apple.SystemConfiguration.configd
```

building a list of root services...

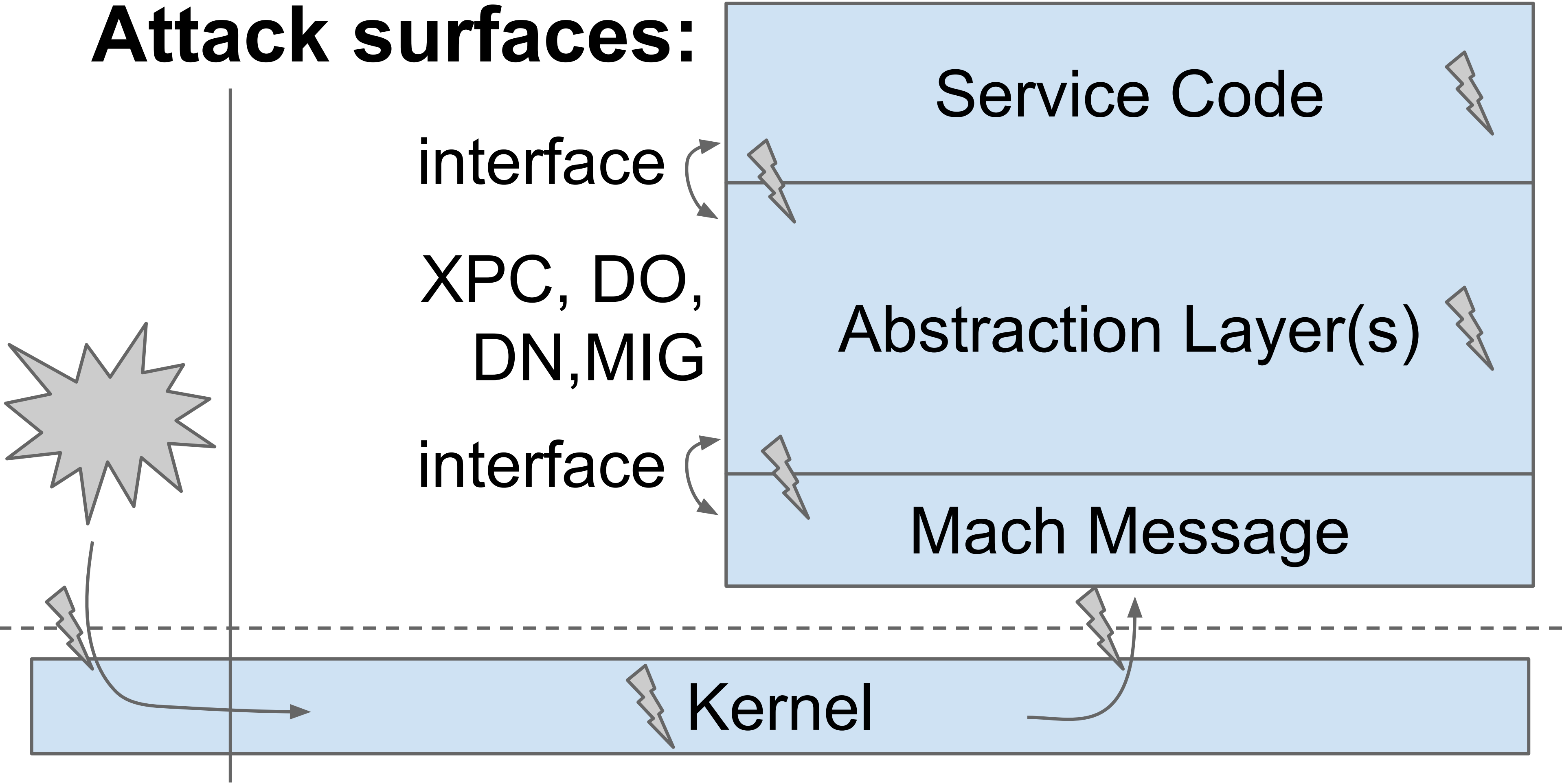
```
com.apple.SystemConfiguration.NetworkInformation
com.apple.SystemConfiguration.PPPController-priv
com.apple.network.EAPOLController
com.apple.SystemConfiguration.SCNetworkReachability
com.apple.SystemConfiguration.DNSConfiguration
com.apple.SystemConfiguration.PPPController
com.apple.networking.captivenetworksupport
com.apple.SleepServices
com.apple.warmd.server
com.apple.sandboxd
com.apple.coresymbolicationd
com.apple.FSEvents
com.apple.distributed_notifications@1v3
com.apple.distributed_notifications@0v3
com.apple.familycontrols
com.apple.familycontrols.authorizer
com.apple.system.notification_center
com.apple.system.logger
com.apple.PowerManagement.control
com.apple.iohideventsystem
```

```
com.apple.AOSNotification.aps-production
com.apple.AOSNotification
com.apple.AOSNotification.aps-development
com.apple.AOSNotification.aps-demo
com.apple.CoreServices.coreservicesd
com.apple.SecurityServer
```

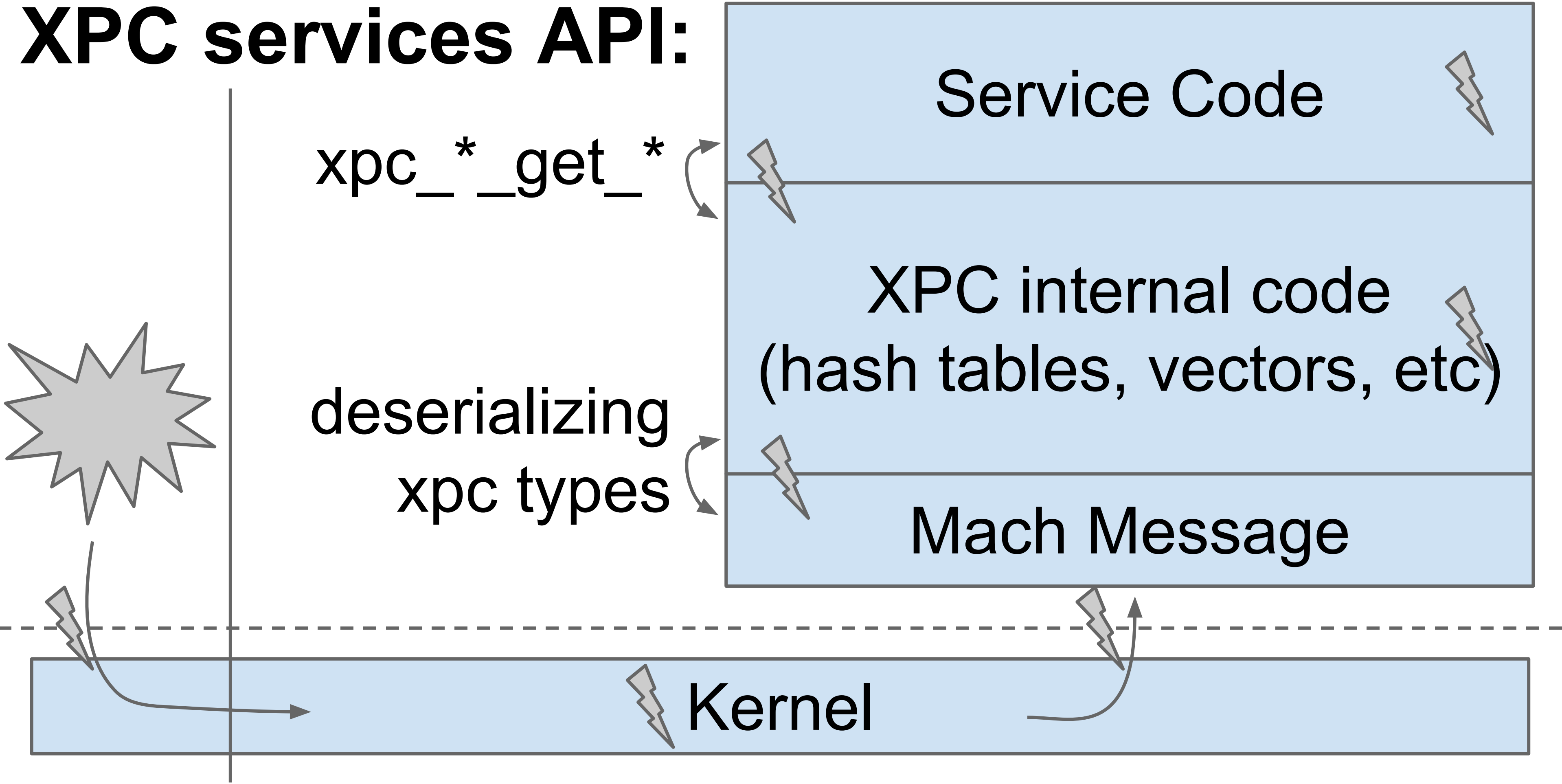
Building useful services

IPC services

Attack surfaces:



XPC services API:



Service Code

xpc_*_get_*

XPC internal code (hash tables, vectors, etc)

deserializing xpc types

Mach Message

Kernel

XPC Internals

XPC Services Overview

- **not** built on MiG
- schema-less message passing abstraction
- messages are strongly-typed dictionaries
- data-types:
    - `xpc_dictionary_t`
    - `xpc_array_t`
    - `xpc_string_t`
    - `xpc_(u)int64_t`
    - `xpc_uuid_t`
    - `xpc_data_t`
    - `xpc_date_t`
    - `xpc_bool_t`

    `...`

Example XPC Message:

```
msg = { “type”          = 6,
        “connection_id” = 1,
        “state”         = { “power_slot”: 0 },
        “parameters”    = { “duration” = 0,
                            “start” = 0,
                            “connection entry list” = [
                              { “hostname”: “example.com” }
                            ],
                          }
}
```

The wire format isn’t quite as nice as this...

XPC Wire Format: Simple Dictionary

Write test program to send XPC messages

```
(lldb) break set --name _xpc_serializer_get_dispatch_mach_msg
(lldb) continue
(lldb) finish
(lldb) x/22xw $rax+0x40 ;this is the mach message
```

```
dict {“key”: “value”}

0x00000013 0x00000040 0x00000000 0x00000000 ; mach_msg_header_t
0x00000000 0x10000000 0x58504321 0x00000004 ; fixed_header XPC! 0x4
0x0000f000 0x00000018 0x00000001 0x0079656b ; dict_type  byte_len n_entries “key\x00”
0x00009000 0x00000006 0x756c6176 0x00000065 ; string_type byte_len ”value\x00”
0x00000000 0x00000000 0x00000000 0x00000000
0x00000000 0x00000000
```

XPC Wire Format: Bigger Dictionary

```
dict {“key”: “value”, “auint64”: 0x41414141...}
0x00000013 0x00000054 0x00000000 0x00000000
0x00000000 0x10000000 0x58504321 0x00000004
0x0000f000 0x0000002c 0x00000002 0x6e697561 ; n_entries “auint64\x00”
0x00343674 0x00004000 0x41414141 0x41414141 ; uint64_type uint64_value
0x0079656b 0x00009000 0x00000006 0x756c6176
0x00000065 0x00000000 0x00000000 0x00000000
0x00000000 0x00000000
```

XPC Wire Format: Dictionary with Data

```
dict {“key”: “value”,
      “auint64”: 0x41414141…
      “data”: \x41\x42\x43\x44 }  //short data is inline
0x00000013 0x00000068 0x00000000 0x00000000
0x00000000 0x10000000 0x58504321 0x00000004
0x0000f000 0x00000040 0x00000003 0x6e697561 ; n_entries
0x00343674 0x00004000 0x41414141 0x41414141
0x0079656b 0x00009000 0x00000006 0x756c6176
0x00000065 0x61746164 0x00000000 0x00008000 ; “data\x00” data_type
0x00000004 0x44434241                       ; data_byte_len data_payload
```

XPC Wire Format: Dictionary with port

```
dict {“key”: xpc_connection(NULL)}

0x80000013 0x00000044 0x00000000 0x00000000 ; MACH_MSGH_BITS_COMPLEX
0x00000000 0x10000000 0x00000001 0x00001003 ; msgh_id descriptor_count
0x00000000 0x00110000 0x58504321 0x00000004 ; port_desc_type port_move_send
0x0000f000 0x0000000c 0x00000001 0x00434241
0x00013000                                  ; xpc_connection_type
```

XPC Deserialization Code

```
_xpc_TYPE_deserialize(xpc_serializer_t*);
```

```
xpc_serializer_t + 0x48
  = pointer to data
xpc_serializer_t + 0x50
  = remaining data length
```

Deserializers seem reasonably robust, impose sensible limits etc

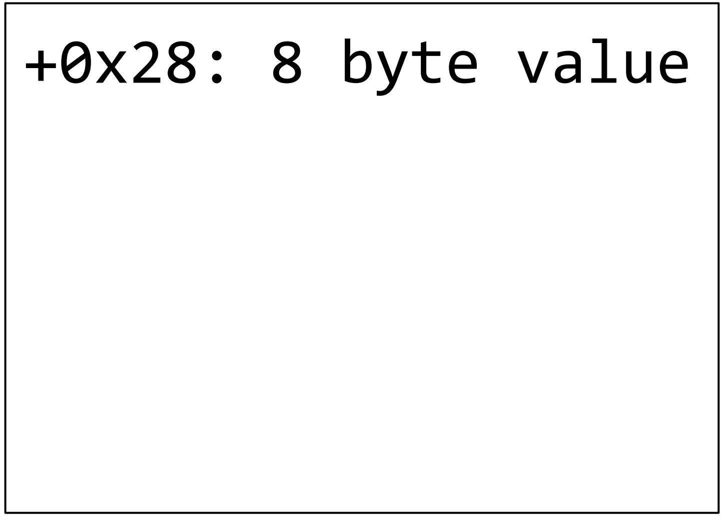
XPC Object Creation:

```
_xpc_object_create(OBJC_CLASS* type,
                   uint32_t extra);
```

extra bytes to allocate
for object fields

XPC Object Internals:

```
xpc_{(u)int64_t, double, date}
```



```
+0x28: 8 byte value
```

Simple objects,
1 8-byte data field

XPC Object Internals:

`xpc_string_t`

```
+0x28: string length
+0x30: pointer to strdup’ed chars
```

XPC Object Internals:

`xpc_uuid_t`

```
+0x28: first 8 UUID bytes
+0x30: second 8 UUID bytes
```

XPC Object Internals:

`xpc_data_t`

```
+0x28: dispatch_once count
+0x30: *dispatch_object_t
+0x38: offset
+0x40: dispatch data size
+0x48: mapped_already flag
```

XPC Object Internals:

`xpc_array_t`

```
+0x2c: array length
+0x30: calloc’ed xpc_object_t buffer
```

XPC Object Internals:

```
xpc_dictionary_t
```

```
+0x60: ll hash_buckets[6]
```

XPC Object Internals:

xpc dictionary linked-list entries:

```
struct ll {
    struct ll* forward;
    struct ll* backward;
    xpc_object_t* object;
    uint64_t flags;
    char key[0]; // allocated inline
}
```

Knowing the internals of this structure is super-helpful for exploitation

XPC Services API: safe version

```
xpc_{dictionary, array}_get_{TYPE}()
```

Checks that the entry is of the expected type; returns a NULL value if not

XPC Services API: unsafe version

`xpc_{dictionary, array}_get_value()`

returns an `xpc_object_t`,
which is really:

```
typedef void * xpc_object_t;
```

Remember, xpc is schema-less,
an attacker can send any xpc type

Type Confusion in XPC:

The use of void* means the compiler won’t warn about bad uses of xpc_object_t

But is that interesting?

Avoiding Type Confusion in XPC:

Either:

- ~~XPC API entrypoints must check types~~

Before Yosemite, <u>no</u> entrypoints checked types

- ~~API consumers must check types~~

some did, some didn’t ;)

Implications of XPC type confusion

If API consumer code doesn’t check types, we can force a controlled, incorrect, xpc_* type to be passed to an xpc_ API.

Implications depend on:

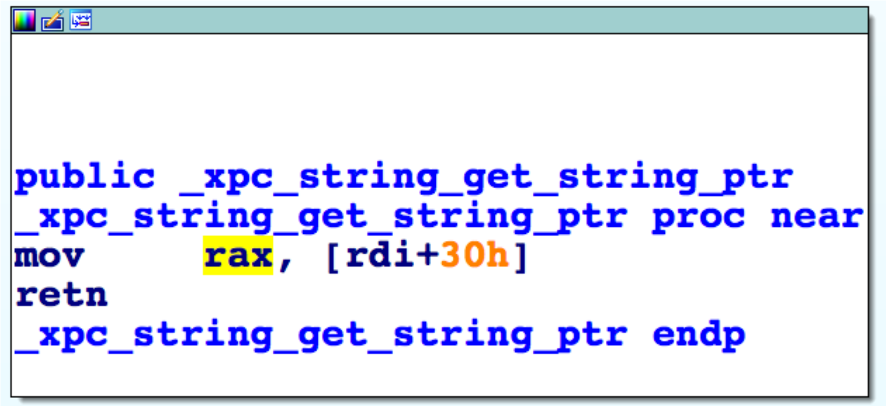
- What fields overlap with what
- How are those fields are used

XPC type confusion example

str can be of any type

attacker-controlled dictionary

```
xpc_object_t str = xpc_dictionary_get_value(msg, “foo”);
printf(“%s\n”, xpc_string_get_string_ptr(str));
```



```
public _xpc_string_get_string_ptr
_xpc_string_get_string_ptr proc near
mov     rax, [rdi+30h]
retn
_xpc_string_get_string_ptr endp
```

simply treats the value at +0x30 as a c-string pointer!

Cool, can we do more?

XPC object overlap

offset	**uint64**	**string**	**array**	**uuid**	**data**
+0x28	value	length	length	value[0:8]	dispatch_count
+0x30	---	char*	xpc_object_t*	value[8:16]	dispatch_object_t*

This has been strdup-ed, so no NULL bytes means tougher to use

Can confuse a pointer with 8 completely controlled bytes :)

What is a dispatch_object_t?

- Objective-C object
- Objective-C method called on it
- nemo already covered this!

Example vulnerable code:

attacker passes an XPC_UUID

```
xpc_object_t obj = xpc_dictionary_get_value(msg, “data”);
const void* data = xpc_data_get_bytes_ptr(obj);
```

Will treat second 8 bytes as an Objective-C object pointer :)

There is actually one more hurdle: the byte at +48 has to be 0, but the XPC UUID is smaller than that...

Dictionary deserialization

The heap object following the UUID will be the UUID’s dictionary LL entry:

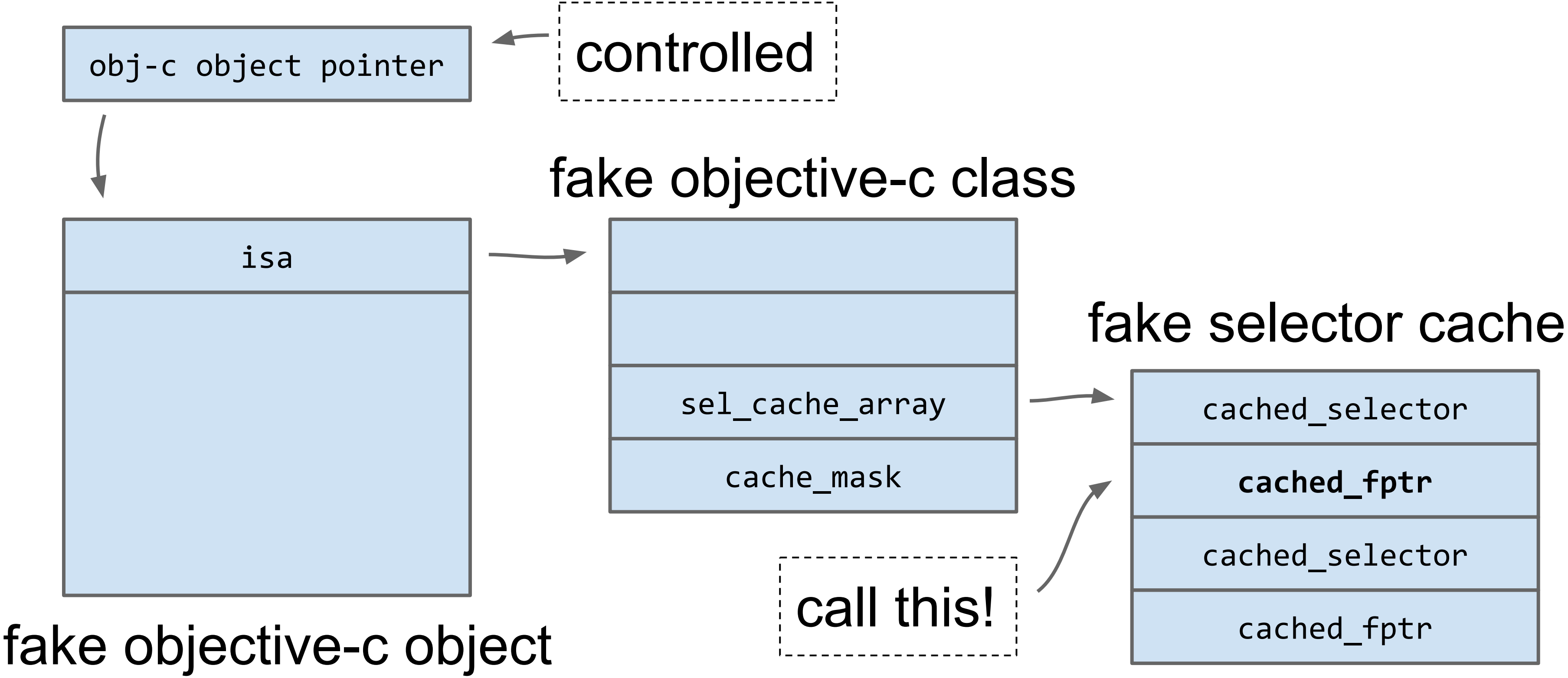
```
struct ll {
    struct ll* forward;
    struct ll* backward;
    xpc_object_t* object;
    uint64_t flags;
    char key[0];
}
```

The least-significant byte of that entry’s `backward` pointer will be the `already_mapped` flag

easy :) ensure that the most recently deserialized LL entry in this hash bucket was > 512 bytes which will make the allocation 256-byte aligned

XPC type confusion exploitation techniques

Exploiting Objective-C bugs



What/Where

- Need known data at a known location
- Lame heap spray!
- Depressingly effective :(
- nemo has told you about fancier techniques :)

Heap spraying with XPC

```
// fill a page (hs) with the data you want
size_t heap_spray_pages = 0x40000; // 1GB
size_t heap_spray_bytes = heap_spray_pages * 0x1000;
char* heap_spray_copies = malloc(heap_spray_bytes);
for (int i = 0; i < heap_spray_pages; i++){
  memcpy(heap_spray_copies+(i*0x1000), hs, 0x1000);
}

xpc_dictionary_set_data(msg, "heap_spray", heap_spray_copies,
heap_spray_bytes);
// find your data at 0x120200000 in the target :)
```

Are there really services with that very specific pattern?

Yes, lots!

networkd XPC type confusion bug

https://code.google.com/p/google-security-research/issues/detail?id=130

breaks you out of ntpd and safari sandboxes

sysmond XPC type confusion bug

https://code.google.com/p/google-security-research/issues/detail?id=121

user -> root priv-esc

Finding all the bugs

- This bug class can be pretty easily described and found using Abstract Interpretation
- Wrote a hacky AI framework for x64 (~600 lines of python)
- Ran it over all executables
- Found many more bugs :) Apple since patched xpc_data entrypoints

Apple patches

- Minimal

fontd

to MiG or not to MiG...

Fontd

The fontd process actually hosts two services:

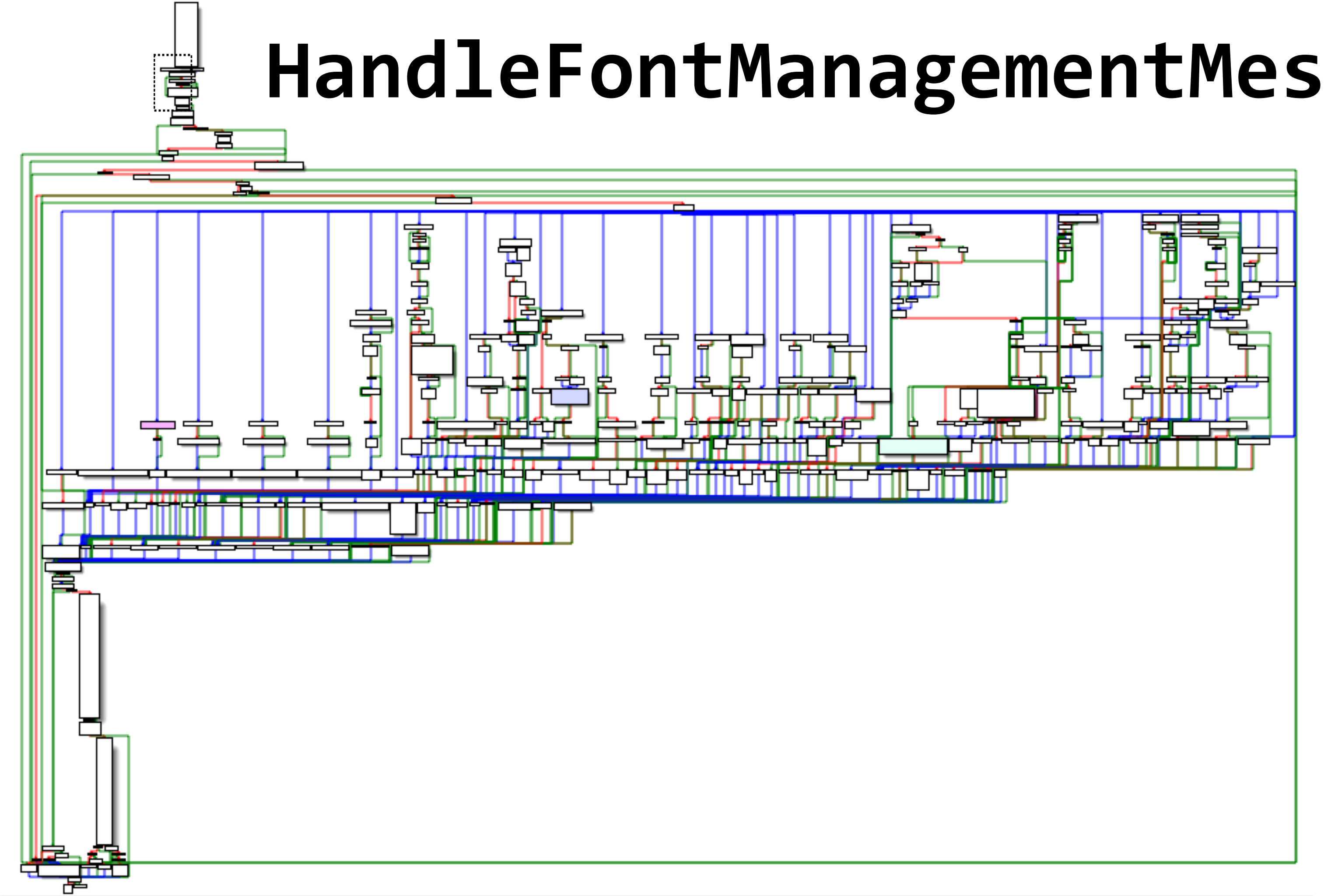
```
com.apple.FontObjectsServer
com.apple.FontServer
```

reachable from a lot of interesting sandboxes

com.apple.FontObjectsServer

- Doesn’t use MiG
- Hand-rolled mach message parsing atop CFMachPort
- Crazy legacy code paths (supports sender and receiver having different endian-ness?!)
- Implemented in `libATSServer.dylib`

HandleFontManagementMessage:



unspaghettifying: IDAPython

```
import idaapi
jmp_table_addr = 0x85964     # where’s the jump table?
jmp_table_cases = 47         # how big is it?
jmp_table_labels = 0x96120   # where are the labels?
label_len = 0x30             # how big are they?
for i in range(jmp_table_cases):
  case_addr = ((jmp_table_addr + Dword(jmp_table_addr + (i*4))) & 0xffffffff)
  label_str = GetString(jmp_table_labels + (i*label_len))
  comment = GetCommentEx(case_addr, 0)
  if comment is None:
    comment = ""
  else:
    comment += '\n'
  comment += label_str + " case:" + str(i)
  MakeComm(case_addr, comment)
```

FontObjectsServer method names:

```
kFORendezvousMessage
kFODBSynchMessage
kFOSynthesizeTablesMessage
kFOActivateFontsMessage
kFODeactivateFontsMessage
kFOActivateFontsFromMemoryMessage
kFODeactivateFontsInContainerMessage
kFOGetContainerMappingMessage
kFOGetAnnexDataMessage
kFOGetFileTokenFlatFSRefMessage
kFOResolveFileTokenMessage
kFOComputeFontSpecsMessage
kFOMarkFontAsBadMessage
kFOEnableFontProtectionMessage
kFOScanFontDirectoriesMessage
kFOUserDirInfoMessage
kFOShutdownServerMessage
kFOPingServerMessage
kFOAddToFontNamesCacheMessage
kFOFindUnicodeEncodingMessage
kFOGetFCacheDataMessage
kFOMapSharedMemoryMessage
kFOFindFontIDFromNameMessage
kFOGetKnownDirsInfoMessage
kFORegisterQueryPortMessage
kFOUnregisterQueryPortMessage
kFOSynthesizeFontFamilyResourcesMessage
kFOGetPSFontEncodingMessage
kFOEnableFontMessage
kFODBDumpForFileTokenMessage
```

FontObjectsServer method names:

```
kFOActivateFontsWithInfoMessage
kOFAStreamMessage
kOFAStrikeMessage
kOFAGeneralMessage
kOFACacheSynchMessage
kOFACacheProcessUsageMessage
kOFACacheFindMessage
kFOEnableFinderNotificationsMessage
kFOEnableUINotificationsMessage
kFOGetPersistentDataMessage
kFOSavePersistentDataMessage
kFOGetFontProtectionMessage
kFOGetFontTraitsMessage
kFOSetFontFlagsMessage
kXTURLActionMessage
```

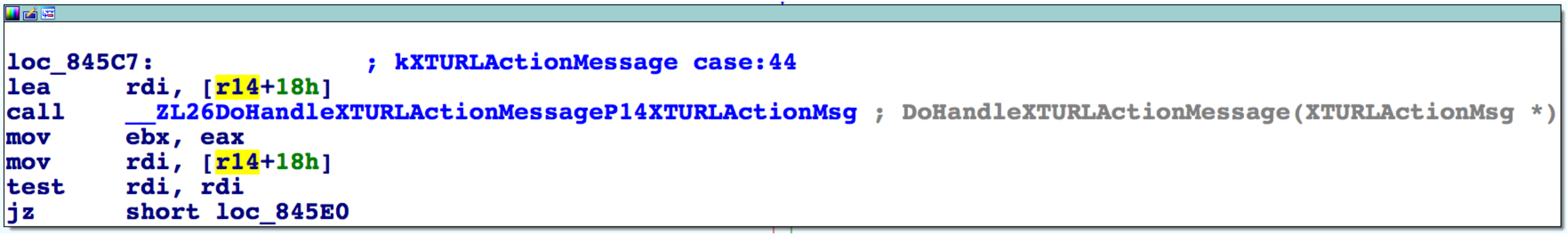
```
kXTGenDBCompleteMessage
kXTURLActionClientMessage
```

More IDAPython: make a switch tab

```
# based on https://github.com/aaronportnoy/toolbag/blob/master/user/bin/switchViewer.py

import idautils

import idaapi

import idc

class SwitchTab(idaapi.simplecustviewer_t):

  def __init__(self, table_addr, targets):

    self.table_addr = table_addr

    self.targets = targets

    self.Create()

    self.Show()

  def Create(self):

    idaapi.simplecustviewer_t.Create(self, "0x%x switch destinations" % self.table_addr)

    comment = idaapi.COLSTR("; Double-click to follow", idaapi.SCOLOR_BINPREF)

    self.AddLine(comment);

    for t in self.targets:

      line = idaapi.COLSTR("0x%x:" % t, idaapi.SCOLOR_REG)

      self.AddLine(line)

    return True
```

```
def OnDblClick(self, shift):
    line = self.GetCurrentLine()
    if "0x" not in line:
      return False
    target = int(line[2:line.find(':')], 16)
    idc.Jump(target)
    return True

jmp_addr = ScreenEA()
switch_info = idaapi.get_switch_info_ex(jmp_addr)
if switch_info == None:
  print "that isn't a jump-table jump"
else:
  # number of cases
  num_cases = switch_info.get_jtable_size()
  print '0x%08x: switch (%d cases)' % (jmp_addr, num_cases)
  for t in idautils.CodeRefsFrom(jmp_addr, 1):
    print "0x%x" % t
  SwitchTab(jmp_addr, idautils.CodeRefsFrom(jmp_addr, 1))
```

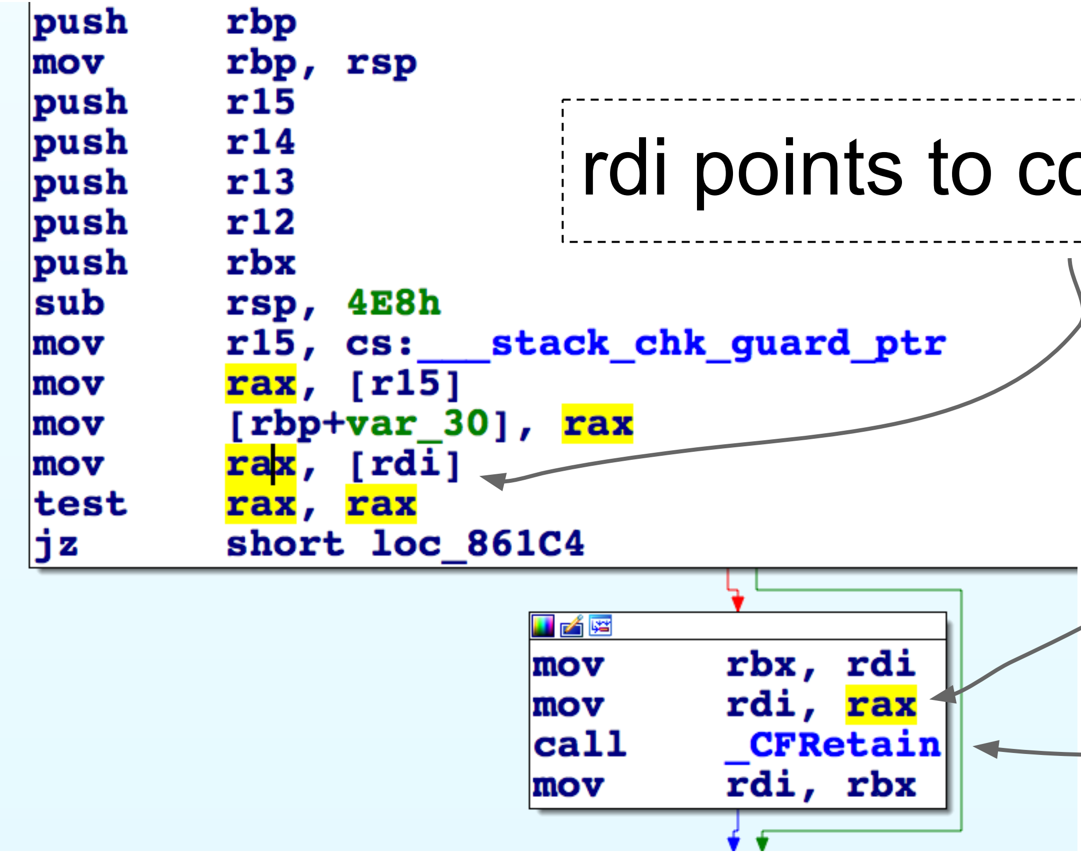
a first FontObjectsServer bug:



```
loc_845C7:                  ; kXTURLActionMessage case:44
lea     rdi, [r14+18h]
call    __ZL26DoHandleXTURLActionMessageP14XTURLActionMsg ; DoHandleXTURLActionMessage(XTURLActionMsg *)
mov     ebx, eax
mov     rdi, [r14+18h]
test    rdi, rdi
jz      short loc_845E0
```

r14 points to the received mach message, so rdi will point to controlled data...

a first FontObjectsServer bug:



```
push    rbp
mov     rbp, rsp
push    r15
push    r14
push    r13
push    r12
push    rbx
sub     rsp, 4E8h
mov     r15, cs:___stack_chk_guard_ptr
mov     rax, [r15]
mov     [rbp+var_30], rax
mov     rax, [rdi]
test    rax, rax
jz      short loc_861C4
```

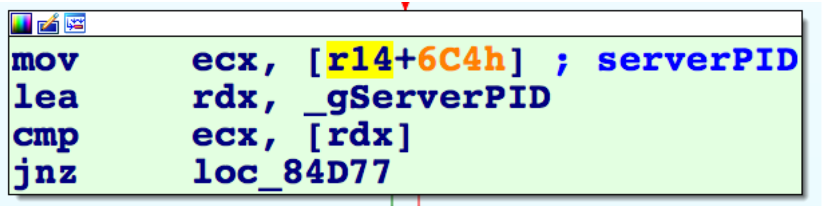
```
mov     rbx, rdi
mov     rdi, rax
call    _CFRetain
mov     rdi, rbx
```

rdi points to controlled data

so we control rax here...

this will msgSend CFRetain to rax?!

message format weirdness:



```
mov     ecx, [r14+6C4h] ; serverPID
lea     rdx, _gServerPID
cmp     ecx, [rdx]
jnz     loc_84D77
```

Dumb generational fuzzer unlikely to make it past this...

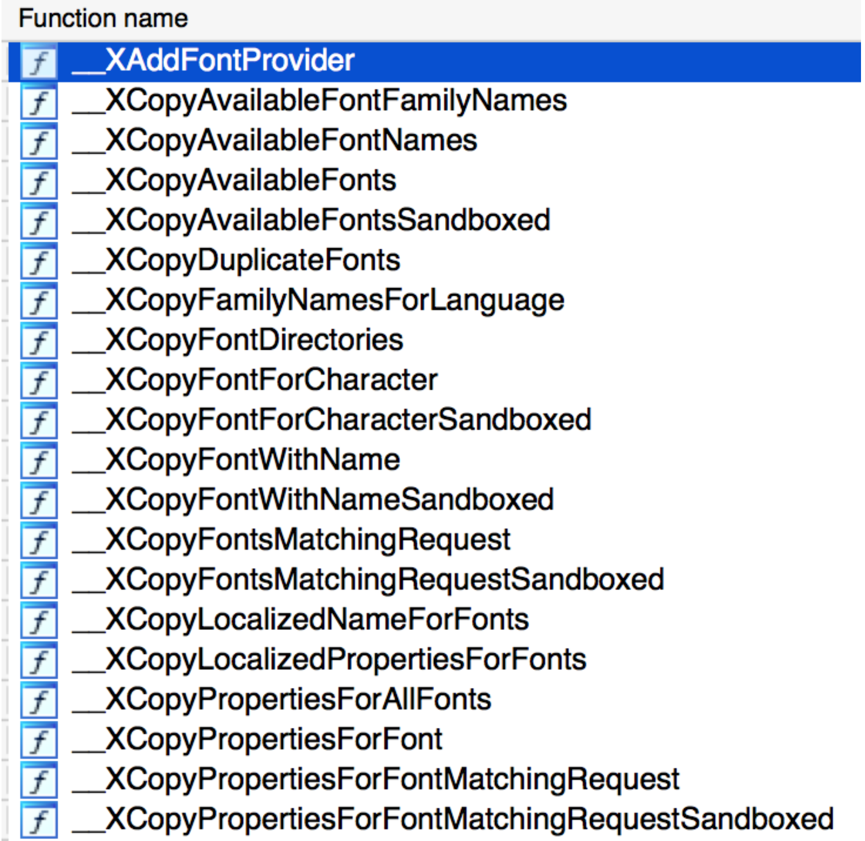
But manual analysis gets past this trivially...

com.apple.FontServer

- The other service hosted by fontd
- MiG-based
- Implemented in `libFontRegistryServer.dylib`
- Custom CF object serialization format :)
- Also allow by a bunch of interesting sandboxes:
    - Chrome renderer
    - Safari

Finding MiG entrypoints without .defs

If there are some symbols, MiG functions nearly always use a common prefix:



Function name
__XAddFontProvider
__XCopyAvailableFontFamilyNames
__XCopyAvailableFontNames
__XCopyAvailableFonts
__XCopyAvailableFontsSandboxed
__XCopyDuplicateFonts
__XCopyFamilyNamesForLanguage
__XCopyFontDirectories
__XCopyFontForCharacter
__XCopyFontForCharacterSandboxed
__XCopyFontWithName
__XCopyFontWithNameSandboxed
__XCopyFontsMatchingRequest
__XCopyFontsMatchingRequestSandboxed
__XCopyLocalizedNameForFonts
__XCopyLocalizedPropertiesForFonts
__XCopyPropertiesForAllFonts
__XCopyPropertiesForFont
__XCopyPropertiesForFontMatchingRequest
__XCopyPropertiesForFontMatchingRequestSandboxed

with no symbols at all:

Look for this structure in the __DATA:__const:

```
/* Description of this subsystem, for use in direct RPC */
const struct _notify_ipc_subsystem {
        mig_server_routine_t    server; /* Server routine */
        mach_msg_id_t   start;  /* Min routine number */
        mach_msg_id_t   end;    /* Max routine number + 1 */
        unsigned int    maxsize;        /* Max msg size */
        vm_address_t    reserved;       /* Reserved */
        struct routine_descriptor       /*Array of routine descriptors */
                routine[38];
} _notify_ipc_subsystem = {
        notify_ipc_server_routine,
        78945668,
        78945706,
        (mach_msg_size_t)sizeof(union __ReplyUnion___notify_ipc_subsystem),
        (vm_address_t)0,
        {
          { (mig_impl_routine_t) 0,
          (mig_stub_routine_t) _X_notify_server_post, 12, 0, (routine_arg_descriptor_t)0,
(mach_msg_size_t)sizeof(__Reply___notify_server_post_t)}, // ...
```

Reversing MiG function prototypes

- If `__MigTypeCheck` is defined (which is hopefully is!) then MiG will generate “type-checking” code
    - Null-termination check for strings
    - Number of OOL descriptors
- Will then unpack arguments + return value pointers and pass to service code

Serialization

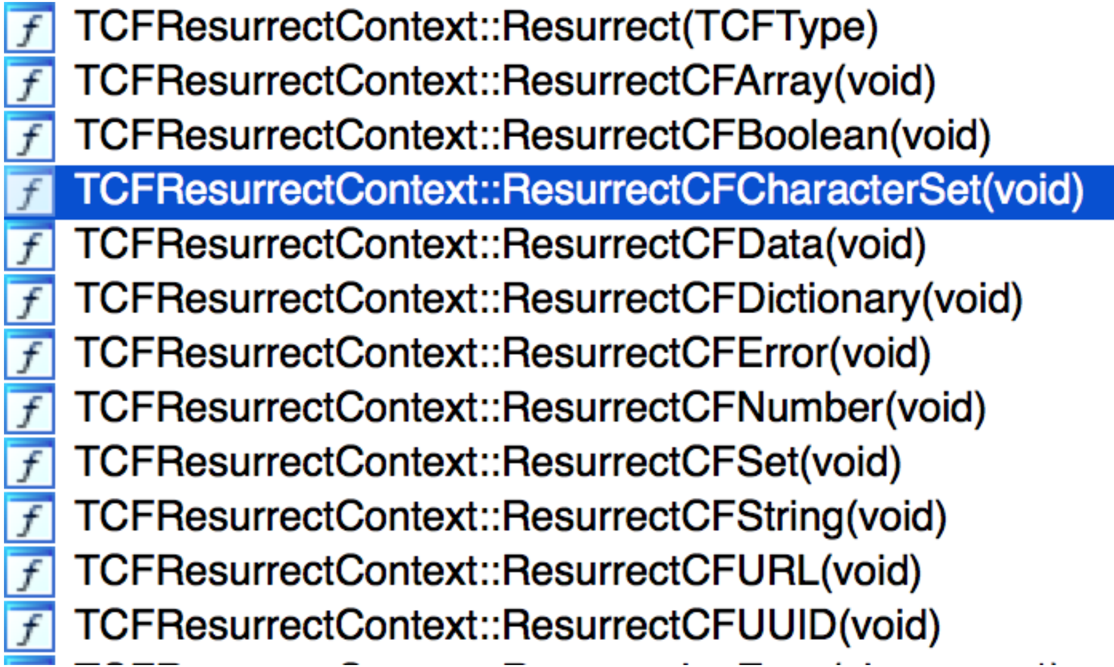
- Probably the most fundamental property of any IPC system
- There are an almost uncountable number of object serialization implementations in OS X/iOS, and new ones are being added all the time

FontServer object serialization

- Most FontServer RPCs take serialized CF objects
- CF already has some object serialization (eg plist)
- but hey, why not write a custom one for fontd? :)

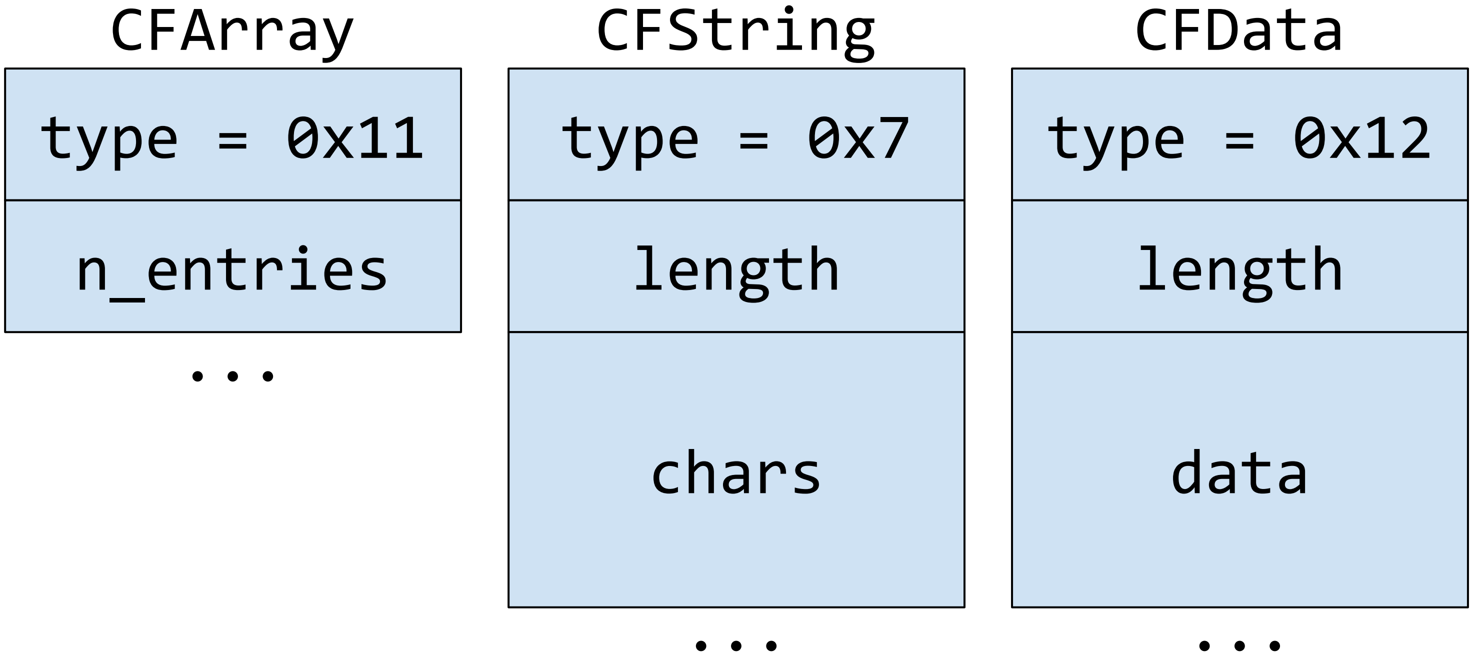
TCFResurrectContext

Implements the deserialization



TCFResurrectContext::Resurrect(TCFType)
TCFResurrectContext::ResurrectCFArray(void)
TCFResurrectContext::ResurrectCFBoolean(void)
TCFResurrectContext::ResurrectCFCharacterSet(void)
TCFResurrectContext::ResurrectCFData(void)
TCFResurrectContext::ResurrectCFDictionary(void)
TCFResurrectContext::ResurrectCFError(void)
TCFResurrectContext::ResurrectCFNumber(void)
TCFResurrectContext::ResurrectCFSet(void)
TCFResurrectContext::ResurrectCFString(void)
TCFResurrectContext::ResurrectCFURL(void)
TCFResurrectContext::ResurrectCFUUID(void)

TCFResurrectContext format:



CFArray

type = 0x11

n_entries

...

CFString

type = 0x7

length

chars

...

CFData

type = 0x12

length

data

...

They’re almost all very simple...

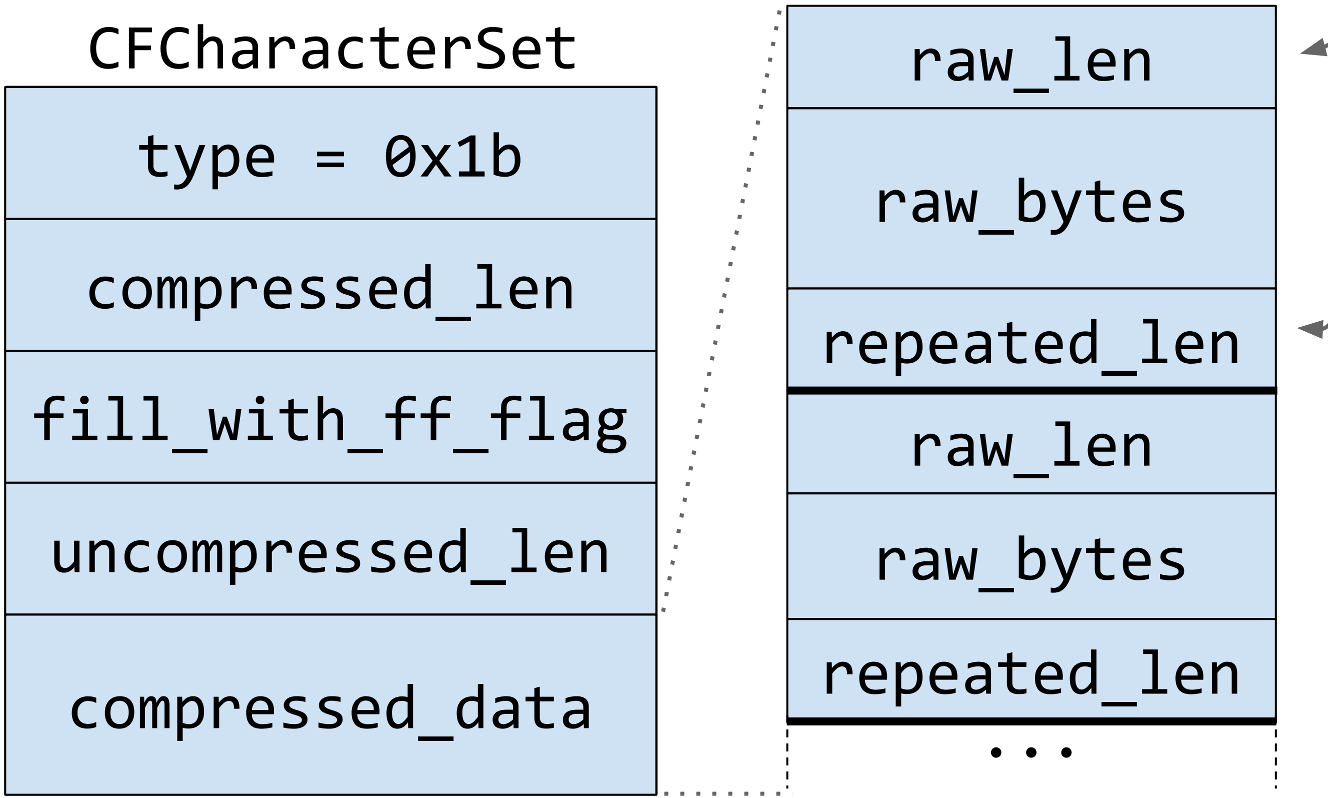
CFCharacterSet

“*A CFCharacterSet object represents a set of Unicode compliant characters.*”

https://developer.apple.com/library/mac/documentation/CoreFoundation/Reference/CFCharacterSetRef/index.html

Basically a bitmap, this should also be uninteresting...

CFCharacterSet serialization



CFCharacterSet

type = 0x1b

compressed_len

fill_with_ff_flag

uncompressed_len

compressed_data

raw_len

raw_bytes

repeated_len

raw_len

raw_bytes

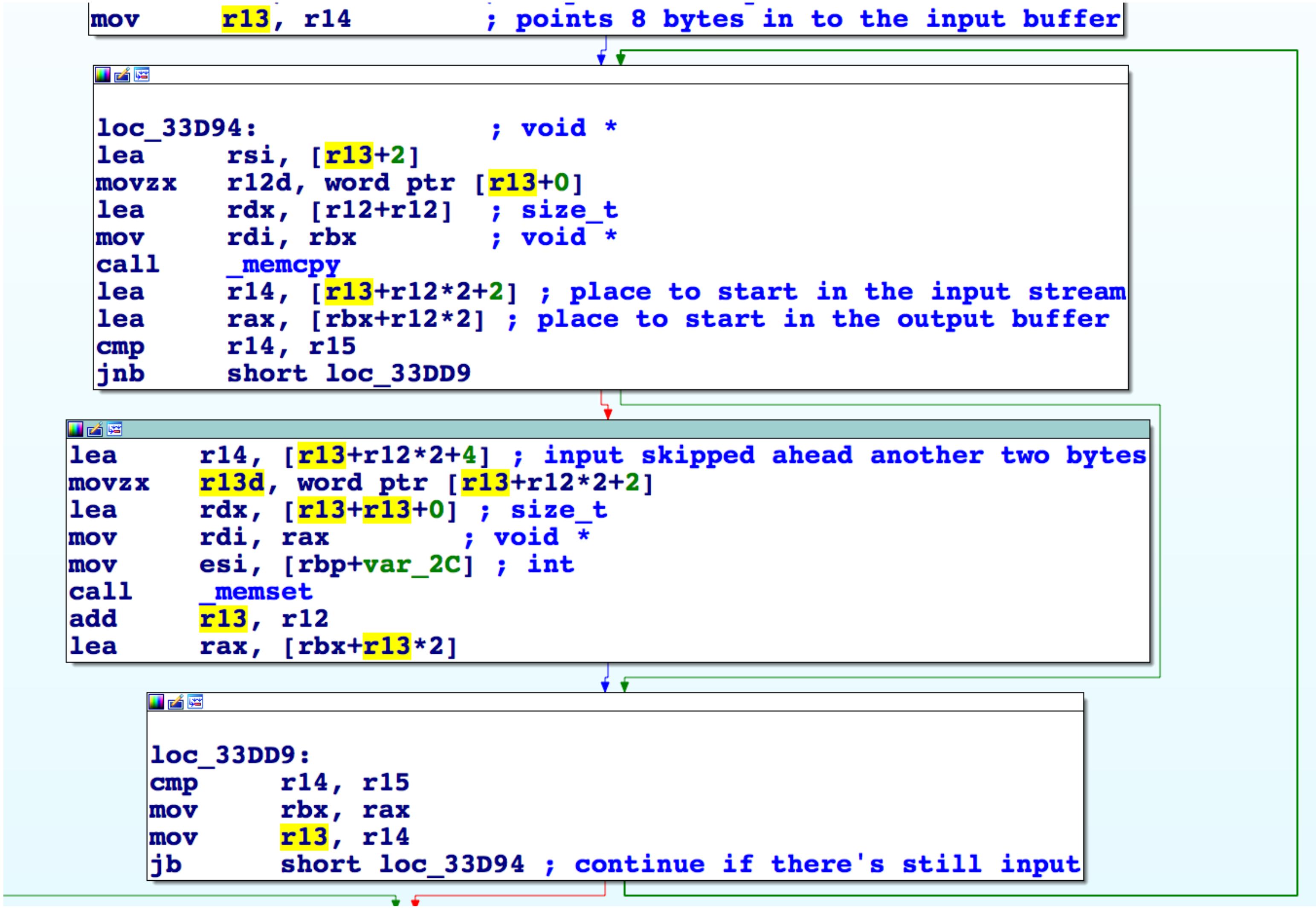
repeated_len

...

2-byte length of raw data in 2-byte units

fill with twice this number of either 0xff or 0x00 bytes

No bounds checking in decompression :(



```
mov     r13, r14          ; points 8 bytes in to the input buffer
```

```
loc_33D94:                ; void *
lea     rsi, [r13+2]
movzx   r12d, word ptr [r13+0]
lea     rdx, [r12+r12]    ; size_t
mov     rdi, rbx          ; void *
call    _memcpy
lea     r14, [r13+r12*2+2] ; place to start in the input stream
lea     rax, [rbx+r12*2] ; place to start in the output buffer
cmp     r14, r15
jnb     short loc_33DD9
```

```
lea     r14, [r13+r12*2+4] ; input skipped ahead another two bytes
movzx   r13d, word ptr [r13+r12*2+2]
lea     rdx, [r13+r13+0] ; size_t
mov     rdi, rax        ; void *
mov     esi, [rbp+var_2C] ; int
call    _memset
add     r13, r12
lea     rax, [rbx+r13*2]
```

```
loc_33DD9:
cmp     r14, r15
mov     rbx, rax
mov     r13, r14
jb      short loc_33D94 ; continue if there's still input
```

More IPC Mechanisms

and how to find them

Distributed Objects

- very old Cocoa RPC technology
- allows “transparent” RPC by exposing local Objective-C objects via proxy objects in other processes
- calling a method on the proxy forwards the method call to the real object
- it’s actually still used!

vending an object via DO:

```
#import <objc/Object.h>
#import <Foundation/Foundation.h>

@interface VendMe : NSObject
- (oneway void) foo: (int) value;
@end

@implementation VendMe
- (oneway void) foo: (int) value;
{
  NSLog(@"%d", value);
}
@end
```

```
int main (int argc, const char * argv[]) {
  VendMe* toVend = [[VendMe alloc] init];

  NSConnection *conn;
  conn = [NSConnection defaultConnection];

  [conn setRootObject:toVend];
  [conn registerName:@"service_name"];

  [[NSRunLoop currentRunLoop] run];
  return 0;
}
```

vend this object

under this service name

connecting to a Distributed Object:

```
#import <Cocoa/Cocoa.h>

int main(int argc, char** argv){
  id theProxy = [[NSConnection
      rootProxyForConnectionWithRegisteredName:@"service_name"
      host:nil] retain];
  [theProxy foo:123];
  return 0;
}
```

create a proxy object by connecting to the named service

call the foo method on the remote object passing 123 as the argument

DO Protocols

- restrict vended object methods
- can use to enumerate exposed attack surface

define a protocol

```
@protocol MyProtocol
- (oneway void) foo: (int) value;
@end
```

```
@interface VendMe: NSObject <MyProtocol>
...
@end
```

implement it

use it remotely

```
[proxy setProtocolForProxy:@protocol(MyProtocol)];
```

Custom DO serialization

Scope for memory corruption :)

```
NSCoding -initWithCoder:
```

NSXPCConnection

- A “modern” equivalent to Distributed Objects:

```
NSXPCConnection *conn = [[NSXPCConnection alloc]
  initWithServiceName:@"service_name"];

conn.remoteObjectInterface =
 [NSXPCInterface interfaceWithProtocol:@protocol(MyProtocol)];

[conn resume];

[[conn remoteObjectProxy] foo:123];
```

connect to this service

protocol same as DO

call remote method

Vending NSXPCConnection Objects

```
NSXPCListener *listener = [NSXPCListener serviceListener];
id delegate = [MyDelegate new];
listener.delegate = delegate;
[listener resume];
```

register a delegate

that delegate’s `shouldAcceptNewConnection` method:

```
- (BOOL)listener:(NSXPCListener *)listener
 shouldAcceptNewConnection:(NSXPCConnection *)conn {
 conn.exportedInterface =
 [NSXPCInterface interfaceWithProtocol:@protocol(MyProtocol)];
 connection.exportedObject = [VendMe new];
 [connection resume];
 return YES;
}
```

The exported object

DistributedNotifications

- Broadcast named messages to all subscribers
- Can attach optional CFDictionary with the usual CF data types
- You don’t know who actually sent the notification, don’t trust them!
    - (especially if you’re running as root...)
- Pretty widely used

Sending a Distributed Notification:

```
CFMutableDictionaryRef dictionary =
    CFDictionaryCreateMutable(NULL,
                              0,
                              &kCFTypeDictionaryKeyCallBacks,
                              &kCFTypeDictionaryValueCallBacks);

CFDictionaryAddValue(dictionary, @"a_key", @"a_value");

CFNotificationCenterPostNotificationWithOptions(
    CFNotificationCenterGetDistributedCenter(),
    CFSTR("my.notification.name"),
    NULL,
    dictionary,
    kCFNotificationDeliverImmediately | kCFNotificationPostToAllSessions);
```

CFDictionary will be copied to all subscribers

Post this notification name with that dictionary

Receiving a Distributed Notification:

```
CFNotificationCenterAddObserver(CFNotificationCenterGetDistributedCenter(),
                                NULL,
                                MyNotificationCallback,
                                CFSTR("my.notification.name"),
                                NULL,
                                CFNotificationSuspensionBehaviorDeliverImmediately);
```

register this callback function

for this notification name

```
void MyNotificationCallback(CFNotificationCenterRef center,
                            void *observer,
                            CFStringRef name,
                            const void *object,
                            CFDictionaryRef userInfo);
```

attacker controlled CFDictionary passed to callback

Defense-in-depth

stronger sandboxing on OS X

Mach message “firewall”

- Want more granular sandboxing than launchd provides
- See `launchd_interception_server.cc` in chromium
- But, broken in Yosemite:
  - launchd rewrite
  - no more bootstrap namespaces
- Everything is now XPC based

Final notes

- Improve userspace 64-bit ASLR!
  - heap spraying shouldn’t be this effective
- Provide a mechanism for more granular sandboxing of Mach services
- Ubuntu runs really nicely on Apple hardware!

More Info:

https://www.mikeash.com/pyblog/friday-qa-2009-01-16.html

http://nshipster.com/inter-process-communication/

http://adcdownload.apple.com//wwdc_2012/wwdc_2012_session_pdfs/session_241__cocoa_interprocess_communication_with_xpc.pdf

“Mac OS X and iOS Internals - To The Apple's Core” - J. Levin

“Mac OS X Internals: A Systems Approach” - A. Singh

https://code.google.com/p/google-security-research/issues/