阿里云 | 云盾先知 安全情报

Hunting CVEs for fun and profit

Flanker

先知白帽大会
开放创新 · 先知先行

#whoami

- Flanker
  - Senior Security Researcher at KeenLab
  - Apple/Android/Chrome CVE hunter (“frequent creditor”)
  - Speaker at BlackHat USA/ASIA, DEFCON, RECON, CanSecWest, HITCON, QMSS
  - Pwn2Own 2016/ Mobile Pwn2Own 2016 winner
  - Recognized researcher of Android Security Reward Program

I've been working on…

- Kernel fuzzing/auditing
- Privilege Escalation in Userspace
- Sandbox escapes
- Browser fuzzing/exploitation
- Android/macOS/iOS

Agenda

- Browser fuzzing/exploitation
- Sandbox escapes
- Privilege escalation
- Kernel code execution

Lifetime of a complete exploit chain

- Remote vector is usually browser
- Escalate the sandbox via
  - Broker IPC calls
  - Userspace privileged components
  - Kernel
- Privilege Escalation

Chain in Mobile Pwn2Own 2016 Android Category

THE ENTRANCE – JAVASCRIPT ENGINES

V8 Javascript Engine

- Widely known and used
- Runtime optimization and JIT to machine code
  - Strongtalk
  - Crankshaft
  - Turbofan

Vulnerabilities in V8 showcase

- CVE-2016-1646
  - Property redefinition
- CVE-2016-5198
  - JIT optimization out-of-bound

Case study: CVE-2016-1646

- V8 Array.concat redefinition out-of-bounds in Pwn2Own 2016 by KeenLab

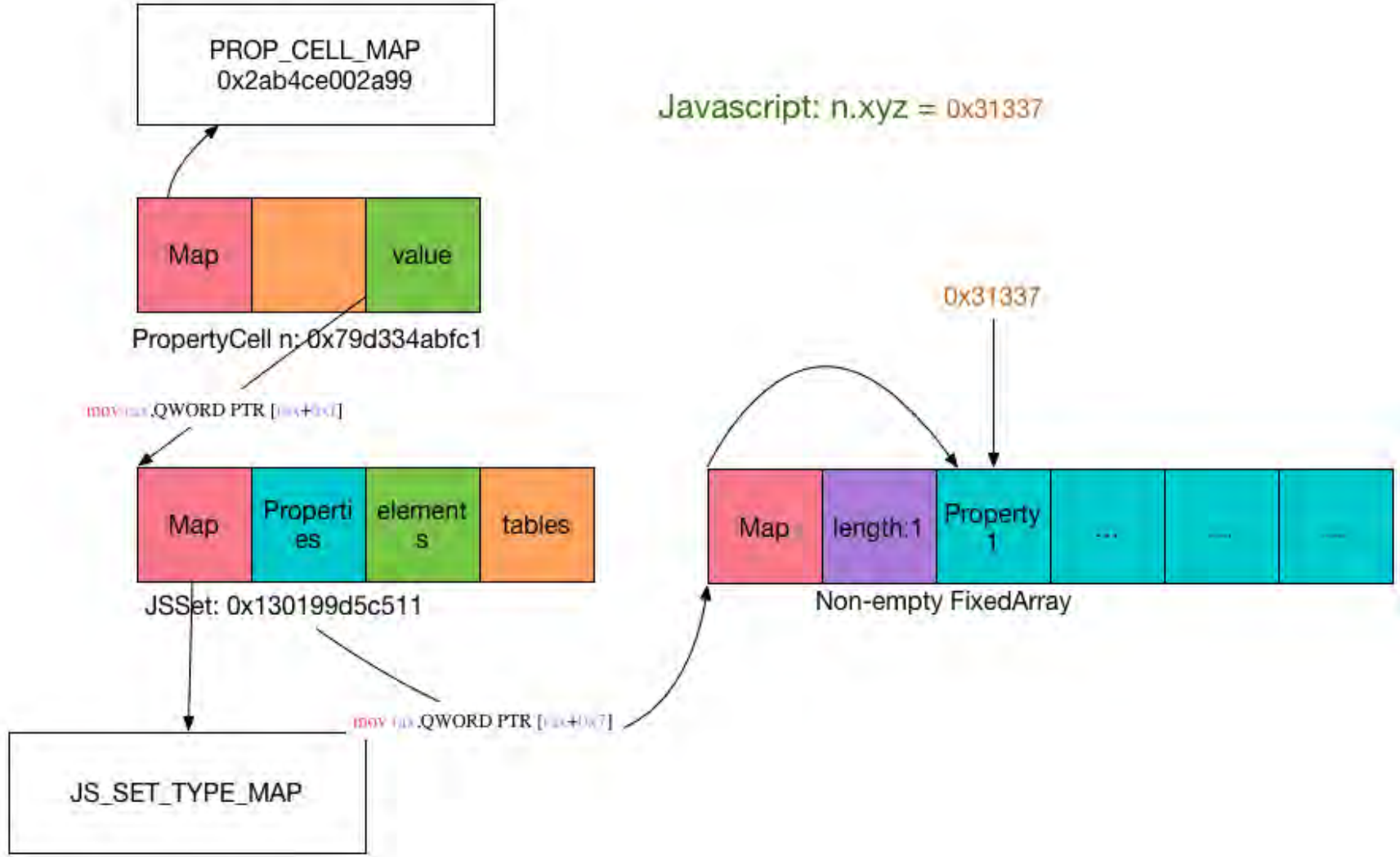
```
b = new Array(10);
b[0] = 0.1; <-- Note that b[1] is a hole!
b[2] = 2.1;
b[3] = 3.1;

Object.defineProperty(b.__proto__, 1, { <-- define b.__proto__[1] to gain the control in the middle of the loop
  get: function () {
    b.length = 1; <-- shorten the array
    gc(); <-- shrink the memory
    return 1;
  },
  set: function(new_value){
        /* some business logic goes here */
        value = new_value
    }
});
```

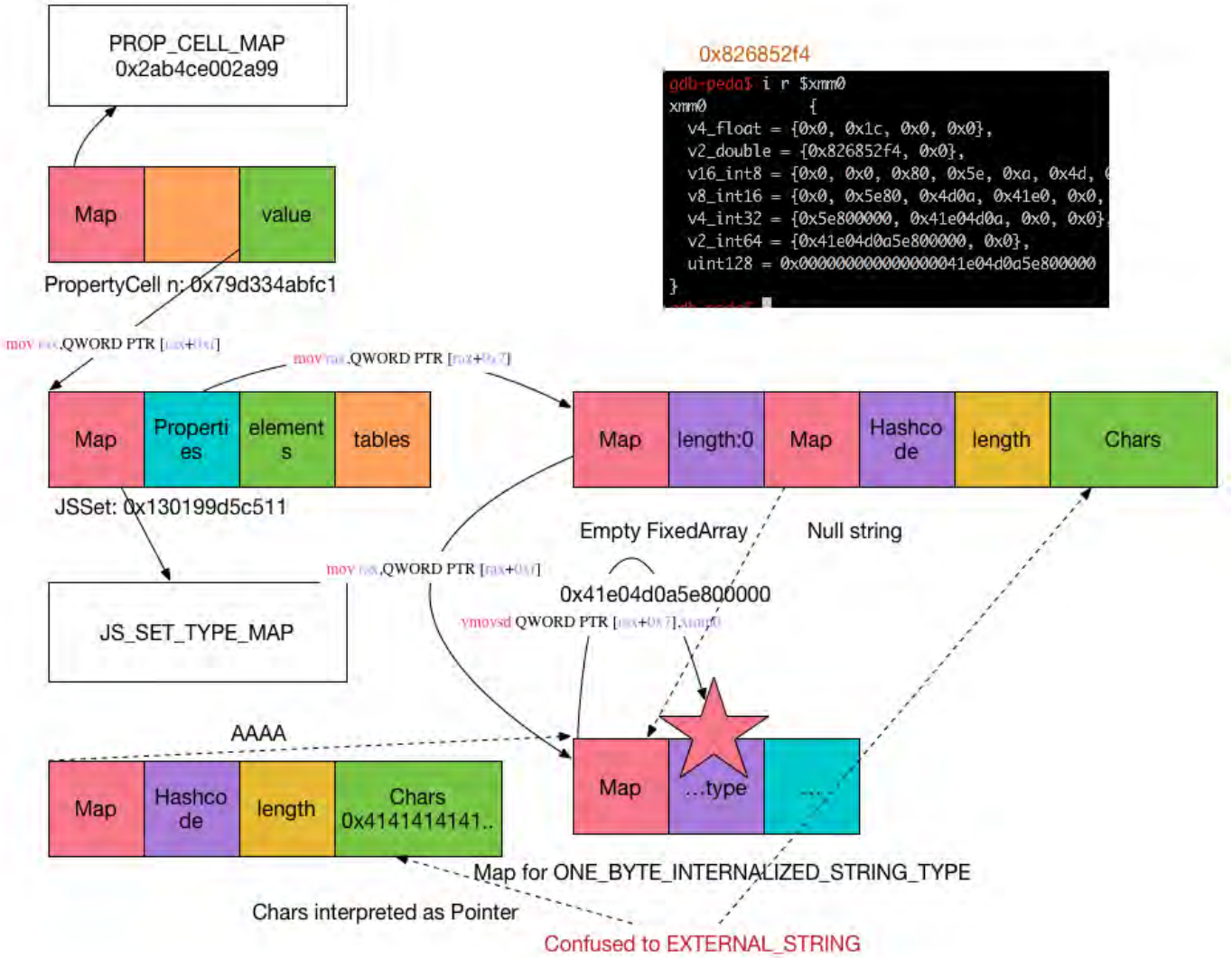
Case study: CVE-2016-1646

```
case FAST_HOLEY_DOUBLE_ELEMENTS:
case FAST_DOUBLE_ELEMENTS: {
  //.....
  for (int j = 0; j < fast_length; j++) {
    HandleScope loop_scope(isolate);
    if (!elements->is_the_hole(j)) {
      double double_value = elements->get_scalar(j);
      Handle<Object> element_value =
          isolate->factory()->NewNumber(double_value);
      visitor->visit(j, element_value);
    } else {
      Maybe<bool> maybe = JSReceiver::HasElement(array, j);
      if (!maybe.IsJust()) return false;
      if (maybe.FromJust()) {
        Handle<Object> element_value;
        ASSIGN_RETURN_ON_EXCEPTION_VALUE(
            isolate, element_value, Object::GetElement(isolate, array, j),
            false);
        visitor->visit(j, element_value);
      }
    }
  }
  break;
}
```

CVE-2016-5198 – oob in Deoptimization

- Eager Deoptimization
  - Usually seen in function argument checks
  - Bail out to interpreter mode immediately
- Lazy Deoptimization
  - Usually seen on global object access
  - Who changes the object is responsible for patching following users
    - What if itself is also JITed?


PROP_CELL_MAP
0x2ab4ce002a99
Javascript: n.xyz = 0x31337
Map
value
PropertyCell n: 0x79d334abfc1
0x31337
Map
Properti
es
element
s
tables
JSSet: 0x130199d5c511
Map
length:1
Property
1
Non-empty FixedArray
JS_SET_TYPE_MAP


PROP_CELL_MAP
0x2ab4ce002a99
Map
value
PropertyCell n: 0x79d334abfc1
0x826852f4
gdb-peda$ i r $xmm0
xmm0 {
v4_float = {0x0, 0x1c, 0x0, 0x0},
v2_double = {0x826852f4, 0x0},
v16_int8 = {0x0, 0x0, 0x80, 0x5e, 0xa, 0x4d,
v8_int16 = {0x0, 0x5e80, 0x4d0a, 0x41e0, 0x0,
v4_int32 = {0x5e800000, 0x41e04d0a, 0x0, 0x0}
v2_int64 = {0x41e04d0a5e800000, 0x0},
uint128 = 0x0000000000000000041e04d0a5e800000
}
mov rax,QWORD PTR [rax+0x1]
movrax,QWORD PTR [rax+0x7]
Map
Properti es
element s
tables
JSSet: 0x130199d5c511
Map
length:0
Map
Hashco de
length
Chars
Empty FixedArray
Null string
mov rax,QWORD PTR [rax+0x1]
0x41e04d0a5e800000
JS_SET_TYPE_MAP
vmovsd QWORD PTR [rax+0x7],xmm0
AAAA
Map
Hashco de
length
Chars 0x4141414141..
Map
…type
…
Map for ONE_BYTE_INTERNALIZED_STRING_TYPE
Chars interpreted as Pointer
Confused to EXTERNAL_STRING

Exploiting CVE-2016-5198

- OOB write chars field of null string to leak ArrayBuffer address
- Overwrite ArrayBuffer backing_store to leak Function code address
- Overwrite ArrayBuffer backing_store with Function code address
- Write shellcode to ArrayBuffer and exec!

How to fuzz Javascript engines?

- Jsfunfuzz can be a good start
- Collect samples
  - Split, mutate and join
- New features, new vulnerabilities
  - Callbacks, protos, …
  - Intentionally generate them

Chain in Pwn2Own 2016 OSX category

BREAKING SANDBOX LIKE A BOSS

Sandbox

- In modern operating systems, a “Sandbox” is a mechanism to run code in a constrained environment.
- A Sandbox specifies which resources this code has access to
- Shift of approach/complementary approach:
  - **Let’s confine software, so even if it’s compromised it has restricted access to the system.**

Structure of the Safari Sandbox

- The UI Process is the parent and in charge of managing the other processes
- Web Process runs webkit/javascript engines

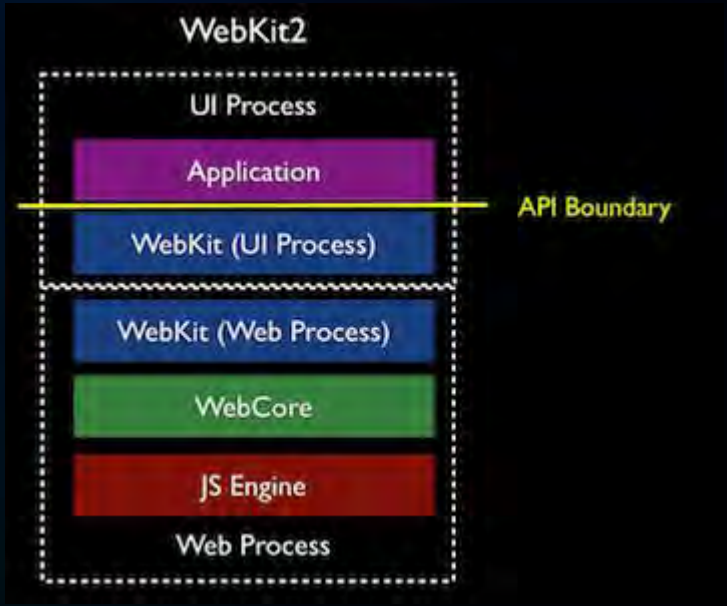
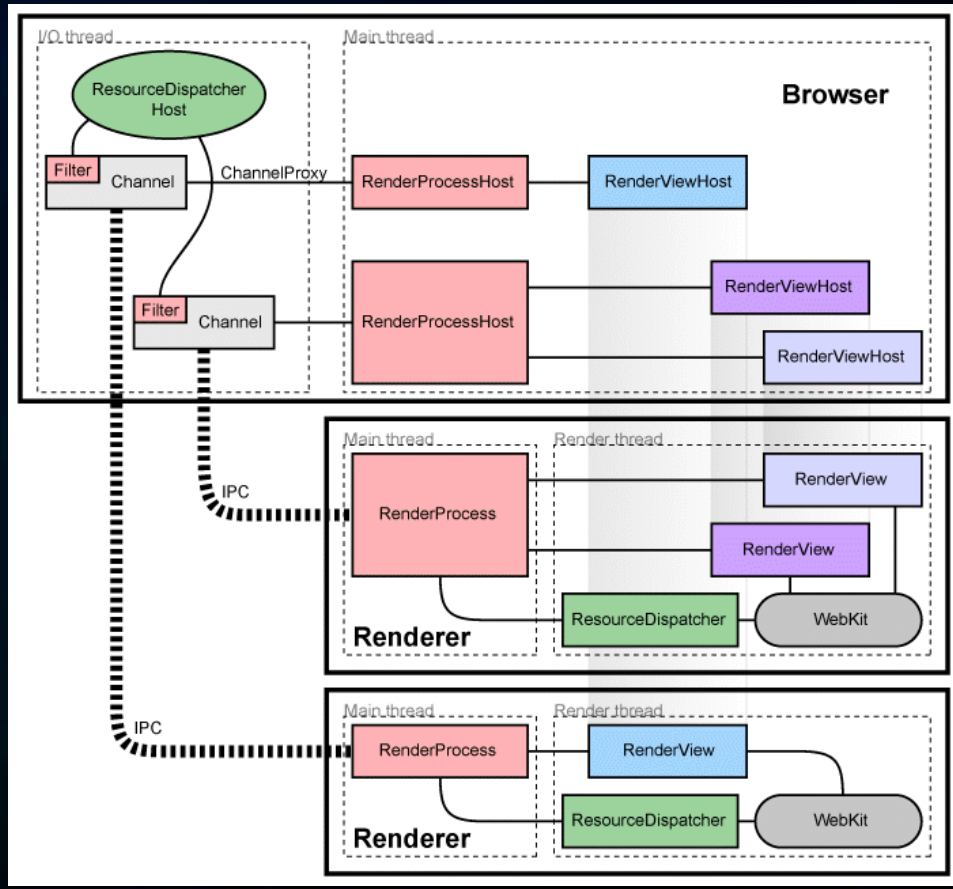


Image courtesy of:
https://trac.webkit.org/attachment/wiki/WebKit2/webkit2-stack.png

The anatomy of Chrome sandbox

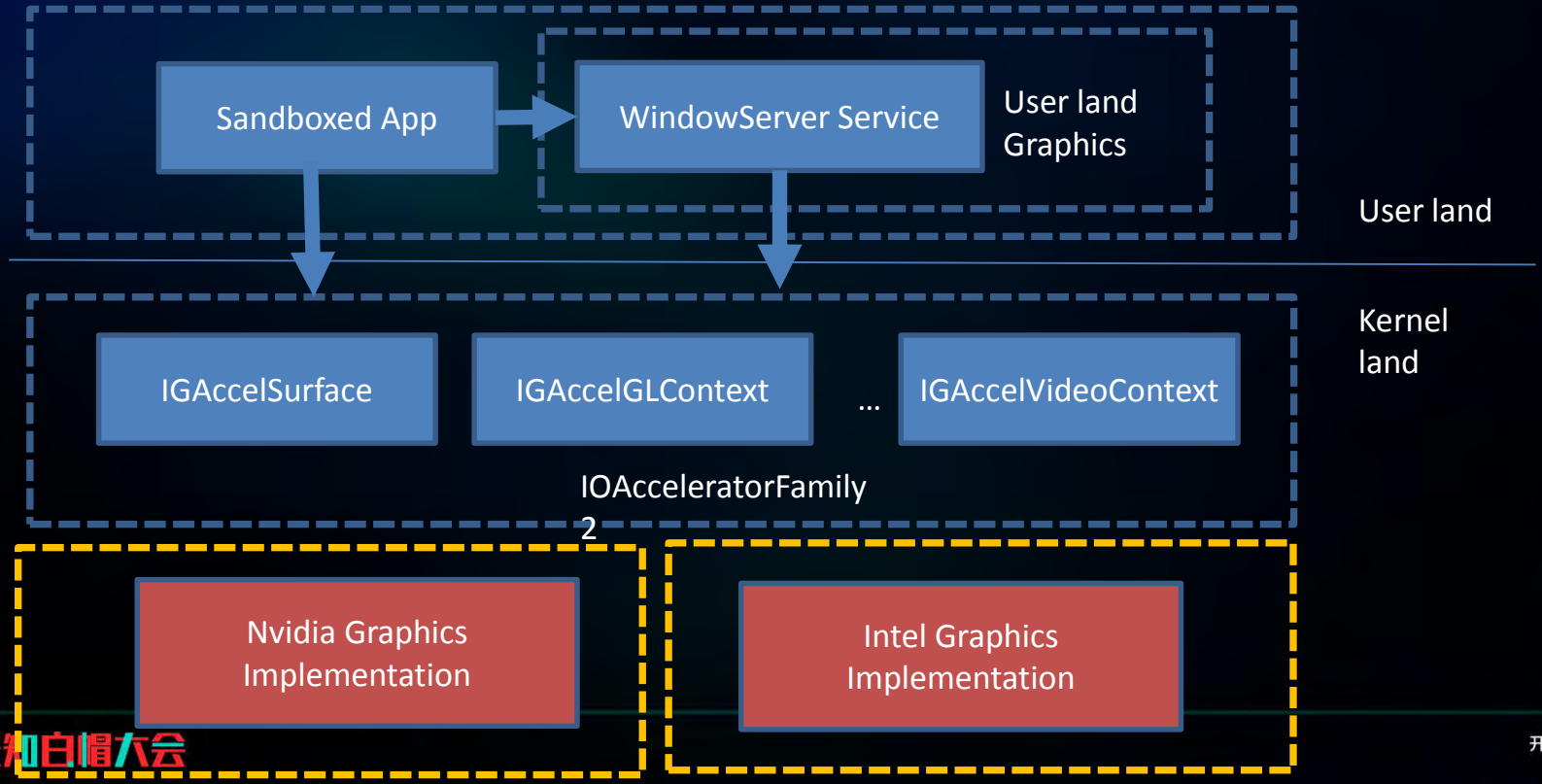
- All untrusted code runs in Target process
- Relay most operations to Broker
- Try best to
  - lock down the capabilities of renderer
- Even renderer is compromised
  - Access is still strictly prohibited
- GPU process have higher level access
  - Than normal sandbox process



How to escape the sandbox?

- To beat your enemies, know them first
- Sandbox profiles

Apple graphics architecture



- On macOS, stored in */System/Library/Frameworks/WebKit.framework/Versions/A/Resources/com.apple.WebProcess.sb*
- On iOS, binary file embed in kernel:
  - Sandbox_toolkit：https://github.com/sektioneins/sandbox_toolkit
- What's in sandbox profile:
  - File opration
  - IPC
  - IOKit
  - Sharedmem
  - Etc.

```
(allow file-read*
       ;; Basic system paths
       (subpath "/Library/Dictionaries")
       (subpath "/Library/Fonts")
       (subpath "/Library/Frameworks")
       (subpath "/Library/Managed Preferences")
       (subpath "/Library/Speech/Synthesizers")
       (regex #"^/private/etc/(hosts|group|passwd)$")
```

```
;; Various services required by AppKit and other frameworks
(allow mach-lookup
       (global-name "com.apple.DiskArbitration.diskarbitrationd")
       (global-name "com.apple.FileCoordination")
       (global-name "com.apple.FontObjectsServer")
       (global-name "com.apple.FontServer")
       (global-name "com.apple.SystemConfiguration.configd")
       (global-name "com.apple.SystemConfiguration.PPPController")
       (global-name "com.apple.audio.VDCAssistant")
       (global-name "com.apple.audio.audiohald")
       (global-name "com.apple.audio.coreaudiod")
```

```
;; IOKit user clients
(allow iokit-open
       (iokit-user-client-class "AppleUpstreamUserClient")
       (iokit-user-client-class "IOHIDParamUserClient")
       (iokit-user-client-class "RootDomainUserClient")
       (iokit-user-client-class "IOAudioControlUserClient")
       (iokit-user-client-class "IOAudioEngineUserClient"))
```

Escaping the Safari sandbox

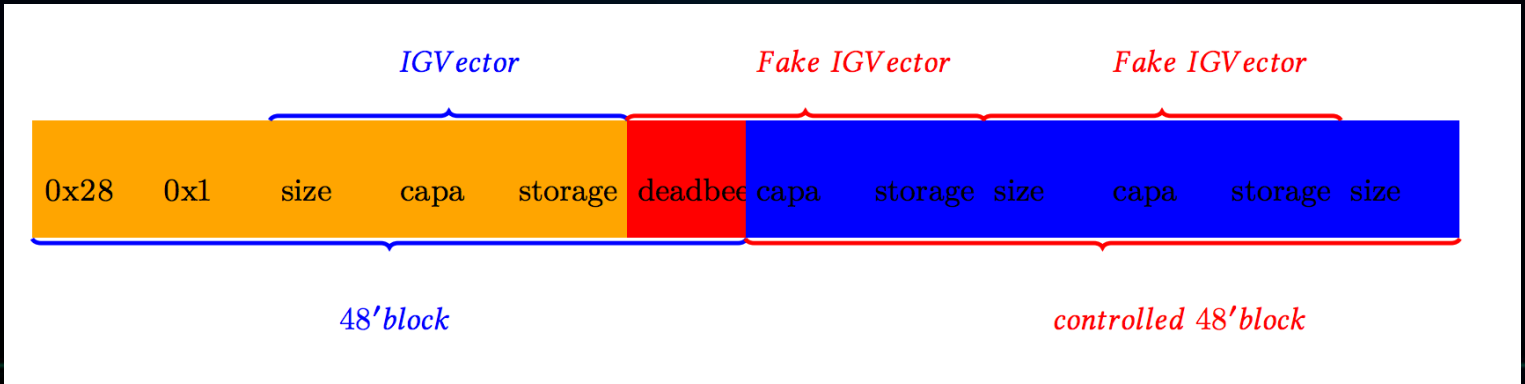
- Fuzzing Graphics IOKit calls
  - Actively generate
  - Passive injection
  - Coverage guidance – instrument the xnu kernel
- Fuzzing XPCs in privileged userspace daemons
  - Yes windowserver I’m talking about you

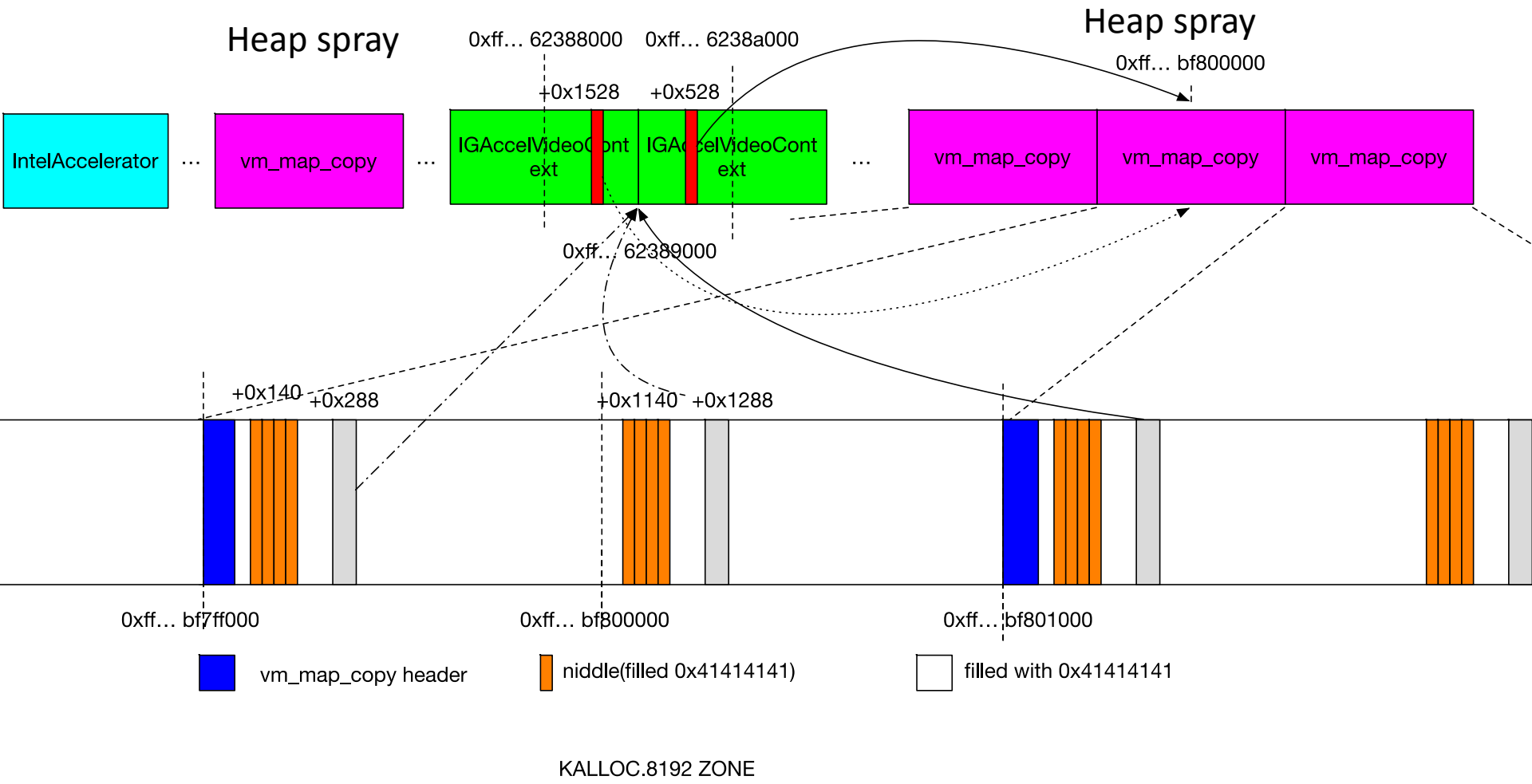
Python/Go wrappers for fuzzing

- Easy SMT solvers integration
- Feasible strategy evolution
- Import kitlib

CVE-2016-1815 – ‘Blit’zard - our P2O bug

- This bug lies in IOAcceleratorFamily
- A vector write goes out-of-bound under certain carefully prepared situations (8 IOkit calls) in a newly allocated kalloc.48 block
- Finally goes into IGVector::add lead to OOB write
- Arbitrary-write-but-content-limited




Heap spray
0xff… 62388000
0xff… 6238a000
Heap spray
0xff… bf800000
+0x1528
+0x528
IntelAccelerator
vm_map_copy
IGAccelVideoCont
ext
IGAccelVideoCont
ext
vm_map_copy
vm_map_copy
vm_map_copy
0xff… 62389000
+0x140
+0x288
+0x1140
+0x1288
0xff… bf7ff000
0xff… bf800000
0xff… bf801000
vm_map_copy header
niddle(filled 0x41414141)
filled with 0x41414141
KALLOC.8192 ZONE

Evolution of the Android Sandbox (old time)

Evolution of the Android Sandbox (current state)

Chromium Android Sandbox (1)

- On Android, Chromium leverages the isolatedProcess feature to implement its sandbox.

```
{% for i in range(num_sandboxed_services) %}
<service android:name="org.chromium.content.app.SandboxedProcessService{{ i }}"
    android:process=":sandboxed_process{{ i }}"
    android:permission="{{ manifest_package }}.permission.CHILD_SERVICE"
    android:isolatedProcess="true"
    android:exported="{{sandboxed_service_exported|default(false)}}"
    {% if (sandboxed_service_exported|default(false)) == 'true' %}
    tools:ignore="ExportedService"
    {% endif %}
    {{sandboxed_service_extra_flags|default('')}} />
{% endfor %}
```

Chromium Android Sandbox (2)

```
type isolated_app, domain;
app_domain(isolated_app)

# Access already open app data files received over Binder or local socket IPC.
allow isolated_app app_data_file:file { read write getattr lock };

allow isolated_app activity_service:service_manager find;
allow isolated_app display_service:service_manager find;

# only allow unprivileged socket ioctl commands
allow isolated_app self:{ rawip_socket tcp_socket udp_socket } unpriv_sock_ioctls;

#####
##### Neverallow
#####

# Isolated apps should not directly open app data files themselves.
neverallow isolated_app app_data_file:file open;

# b/17487348
# Isolated apps can only access two services,
# activity_service and display_service
neverallow isolated_app {
    service_manager_type
    -activity_service
    -display_service
}:service_manager find;

# Isolated apps shouldn't be able to access the driver directly.
neverallow isolated_app gpu_device:chr_file { rw_file_perms execute };
```

- Very restrictive Sandbox profile
- No data file access at all
- Only 2 IPC services
- Minimum interaction with sockets
- No graphic drivers access ☹
- ServiceManager also restricts implicit service export

Per interface constraint

- Isolated_app inherits from app_domain (app.te)
- Only interfaces without enforceNotIsolatedCaller can be invoked

```
void enforceNotIsolatedCaller(String caller) {
    if (UserHandle.isIsolated(Binder.getCallingUid())) {
        throw new SecurityException("Isolated process not allowed to call " + caller);
    }
}

void enforceShellRestriction(String restriction, int userHandle) {
    if (Binder.getCallingUid() == Process.SHELL_UID) {
        if (userHandle < 0
                || mUserManager.hasUserRestriction(restriction, userHandle)) {
            throw new SecurityException("Shell does not have permission to access user "
                    + userHandle);
        }
    }
}

@Override
public int getFrontActivityScreenCompatMode() {
    enforceNotIsolatedCaller("getFrontActivityScreenCompatMode");
    synchronized (this) {
        return mCompatModePackages.getFrontActivityScreenCompatModeLocked();
    }
}
```

Userspace escapes in Android

- Broker IPCs
- Binder calls to privileged daemons
  - System server

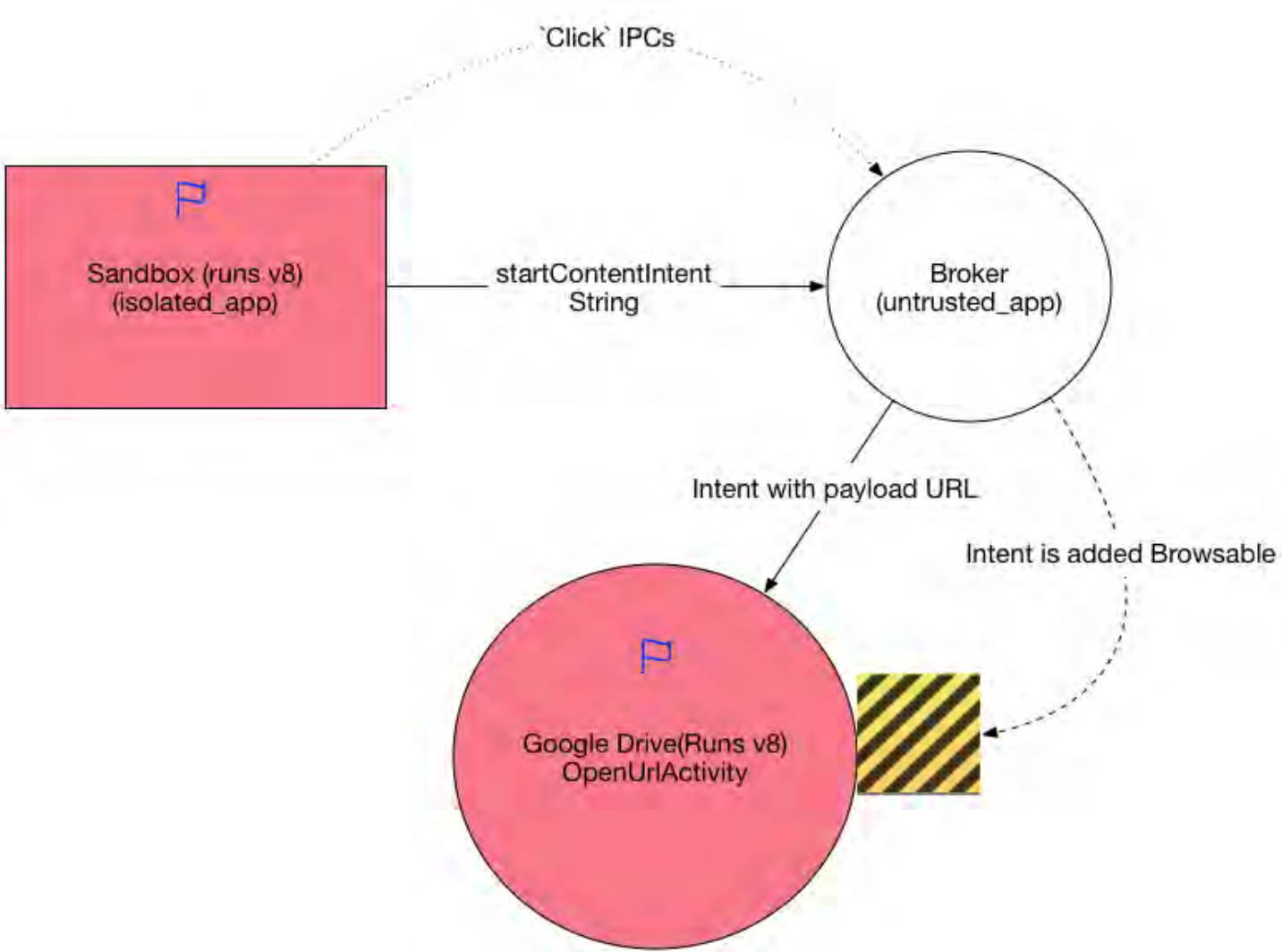
```
bool RenderWidgetHostViewAndroid::OnMessageReceived(
const IPC::Message& message) {
//...
bool handled = true;
IPC_BEGIN_MESSAGE_MAP(RenderWidgetHostViewAndroid, message)
IPC_MESSAGE_HANDLER(ViewHostMsg_StartContentIntent, OnStartContentIntent)
IPC_MESSAGE_HANDLER(ViewHostMsg_SmartClipDataExtracted,
OnSmartClipDataExtracted)
IPC_MESSAGE_HANDLER(ViewHostMsg_ShowUnhandledTapUIIfNeeded,
OnShowUnhandledTapUIIfNeeded)
IPC_MESSAGE_UNHANDLED(handled = false)
IPC_END_MESSAGE_MAP()
return handled;
}
```

```
public void onStartContentIntent(Context context, String intentUrl, boolean isMainFrame) {
   Intent intent;       // Perform generic parsing of the URI to turn it into an Intent.
 try {
  intent = Intent.parseUri(intentUrl, Intent.URI_INTENT_SCHEME);
String scheme = intent.getScheme();
intent.addFlags(Intent.FLAG_ACTIVITY_NEW_TASK);
 } catch (Exception ex) {
    Log.w(TAG, "Bad URI %s", intentUrl, ex);          return;
 }
    try {
context.startActivity(intent);
} catch (ActivityNotFoundException ex) {
}
 }
```

CVE-2016-5197
Arbitrary intent start in broker

IPC sandbox escapes

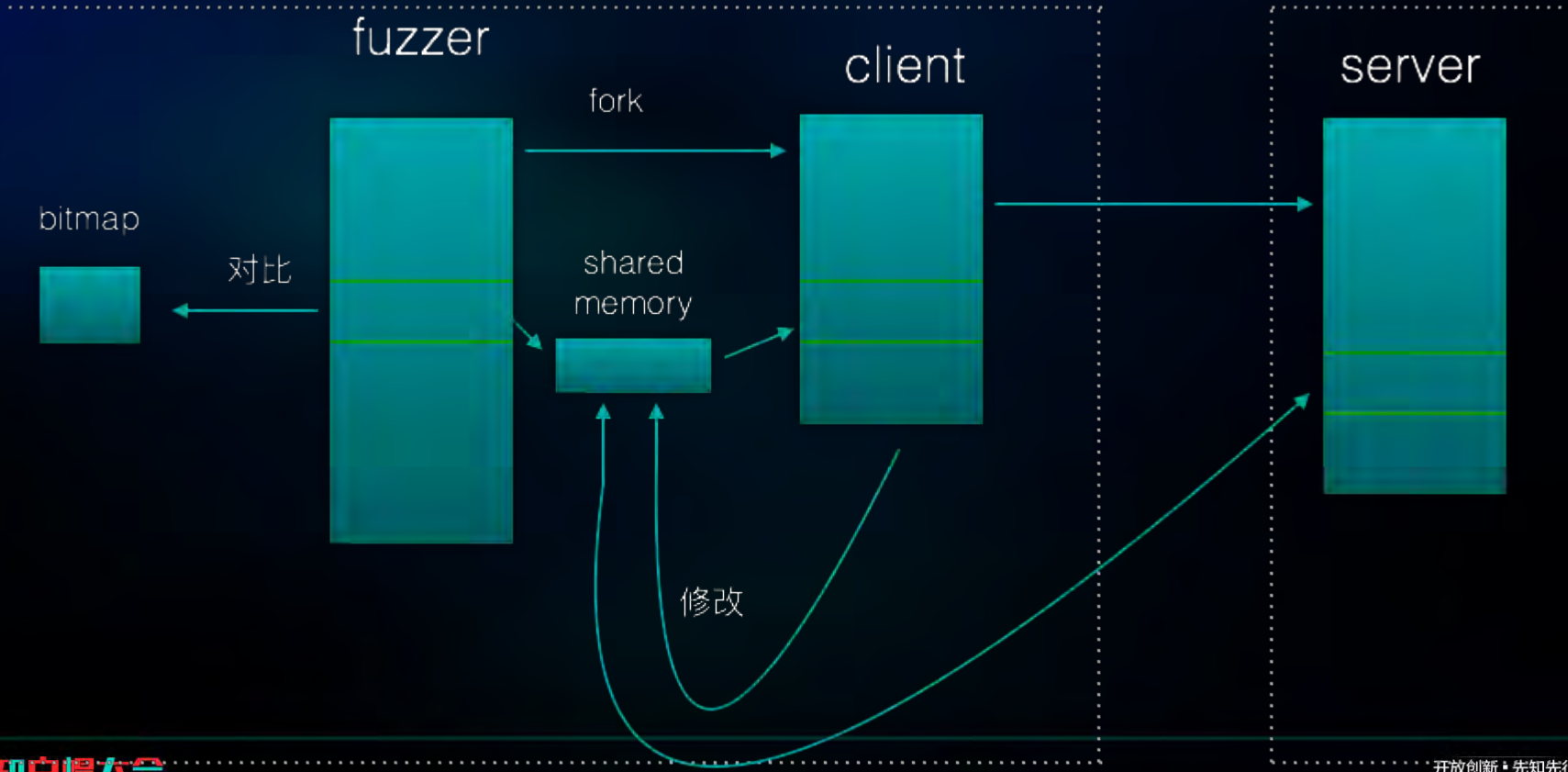
- See that holy Google Drive
- Have full access to Google account
- Trusted by Google Play
  - To “install” app
- Blindly opens any intent-controlled URL
- Pwn it to jump from isolated to untrusted
  - Plus App installation ability!


`Click` IPCs
Sandbox (runs v8)
(isolated_app)
startContentIntent
String
Broker
(untrusted_app)
Intent with payload URL
Intent is added Browsable
Google Drive(Runs v8)
OpenUrlActivity

Privilege escalations

GO DEEPER

Fuzzing daemons with AFL+ASAN



Coverage guided kernel fuzzing

- GCC6 fully supports instrumentation in each basic block
- Coverage exported via /sys/kernel/debug/kcov
- Only samples increasing coverage survives
- KASAN instrumentation
- Go integration

Some bugs can be reached from sandbox

- CVE-2015-1805
- Race-condition in pipe_read
  - Waste for qiku though

Majority kernel bugs are not

- Example: CVE-2015-6637 for Qiku phones rooting
  - Driver protected by SELinux policy
  - Userspace escalation come to rescue
    - CVE-2016-3832
- Credit also goes to James & nforest

CVE-2015-6637 in /dev/misc-sd

```
if(msdc_ctl->total_size <= 0) return -EINVAL;
host_ctl = mtk_msdc_host[msdc_ctl->host_num]; <== Bug here
BUG_ON(!host_ctl); BUG_ON(!host_ctl->mmc);

if (host->ops->enable && !stop && host->claim_cnt == 1)
host->ops->enable(host); <== Code execution
```

Who can access misc-sd?

- Em_srv is a system executable, holds em_svr context

```
# ps -Z | grep "em_svr"
u:r:em_svr:s0 system 619 1 /system/bin/em_svr
```

- Listens on @EngineerModeServer socket
- Execute command

```
# cat qiku_av.txt | grep "ALLOW " | grep ">misc_sd_device" | grep "ioctl"
[AV] 4378: ALLOW factory-->misc_sd_device (chr_file) [ioctl read open]
[AV] 7554: ALLOW em_svr-->misc_sd_device (chr_file) [ioctl read open]
[AV] 10552: ALLOW unconfineddomain-->misc_sd_device (file) [append create write ... [AV] 10556: ALLOW
recovery-->misc_sd_device (chr_file) [append create execute ... [AV] 10559: ALLOW unconfineddomain--
>misc_sd_device (chr_file) [append create ... [AV] 10562: ALLOW vold-->misc_sd_device (chr_file)
[ioctl read open]
[AV] 12202: ALLOW mmc_ffu-->misc_sd_device (chr_file) [ioctl read open]
```

How can it access misc-sd?

- SELinux forbids em_srv from running /data executable directly
- But /system/bin/toolbox keeps ioctl gadget for our interest ☺

```
# cat qiku_av.txt | grep "ALLOW " | grep "em_svr-->" | grep "execute"
[AV] 4418: ALLOW em_svr-->system_file (file) [execute_no_trans]
[AV] 5393: ALLOW em_svr-->shell_exec (file) [execute read execute_no_trans open] [AV]
6076: ALLOW em_svr-->thermal_manager_exec (file) [execute getattr read ... [AV] 7135:
ALLOW em_svr-->em_svr_exec (file) [execute getattr read entrypoint open]
```

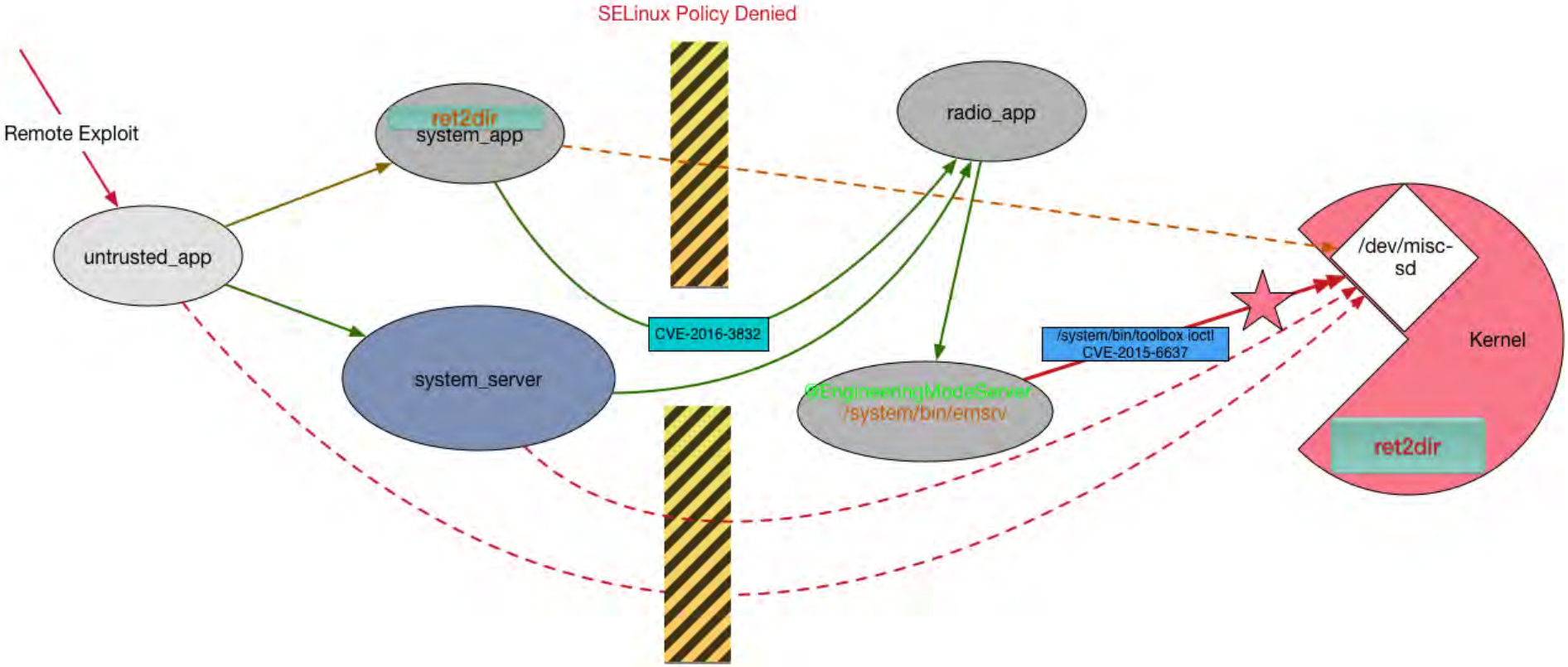
Who can access em_srv?

- Radio uid
- But how?

```
1.# cat qiku_av.txt | grep "ALLOW " | grep ">em_svr" | grep "connect"
[AV] 2244: ALLOW radio-->em_svr (unix_stream_socket) [connectto]
[AV] 8567: ALLOW em_svr-->em_svr (unix_stream_socket) [append bind
connect ... [AV] 8571: ALLOW em_svr-->em_svr (unix_dgram_socket)
[append bind connect ...
```

Do you have radio contact?

- Get system_server context
  - Transient to radio
- Or:
  - bindBackupAgent provides a way for us to get arbitrary context/uid from system_app context
  - How to get system_app uid?
    - Too easy on MTK phones..


SELinux Policy Denied
Remote Exploit
untrusted_app
ret2dir
system_app
radio_app
system_server
CVE-2016-3832
@EngineeringModeServer
/system/bin/emsrv
/system/bin/toolbox ioctl
CVE-2015-6637
/dev/misc-
sd
Kernel
ret2dir

Conclusion

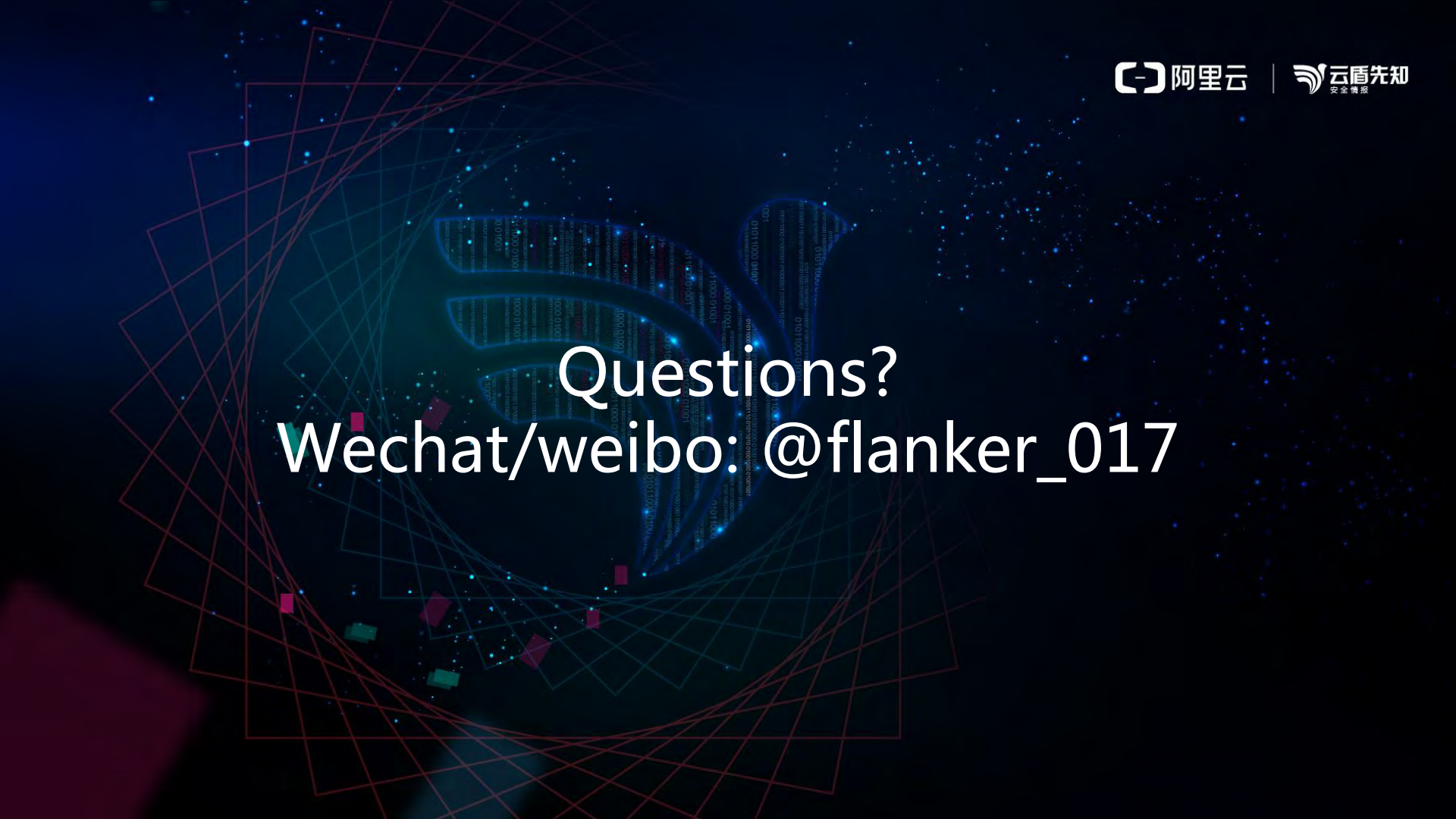
- Fuzzing is proved useful against complex system with coverage guidance
  - Domain knowledge lead to better result
- Mitigations make whole exploit chain longer and longer
  - Multiple vulnerabilities required than before, e.s.p on Google products

Fun!Profit?Profit!

- $$$
- $$$$$
- $$$$$$$

Credits

- All colleagues at KeenLab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