One Class to Rule Them All



USENIX WOOT '15

Or Peles & Roee Hay
IBM Security

We will see how this Android SDK class

```
public class OpenSSLX509Certificate
  extends X509Certificate {

  private ------- final long mContext;
  ...
}
```

MISSING MODIFIER BEFORE OUR DISCLOSURE! (NOW PATCHED)

Led to this…

REPLACEMENT OF APPS

SELINUX BYPASS

ACCESS TO APPS' DATA

KERNEL CODE EXEUCTION*

* On select devices

Introduction

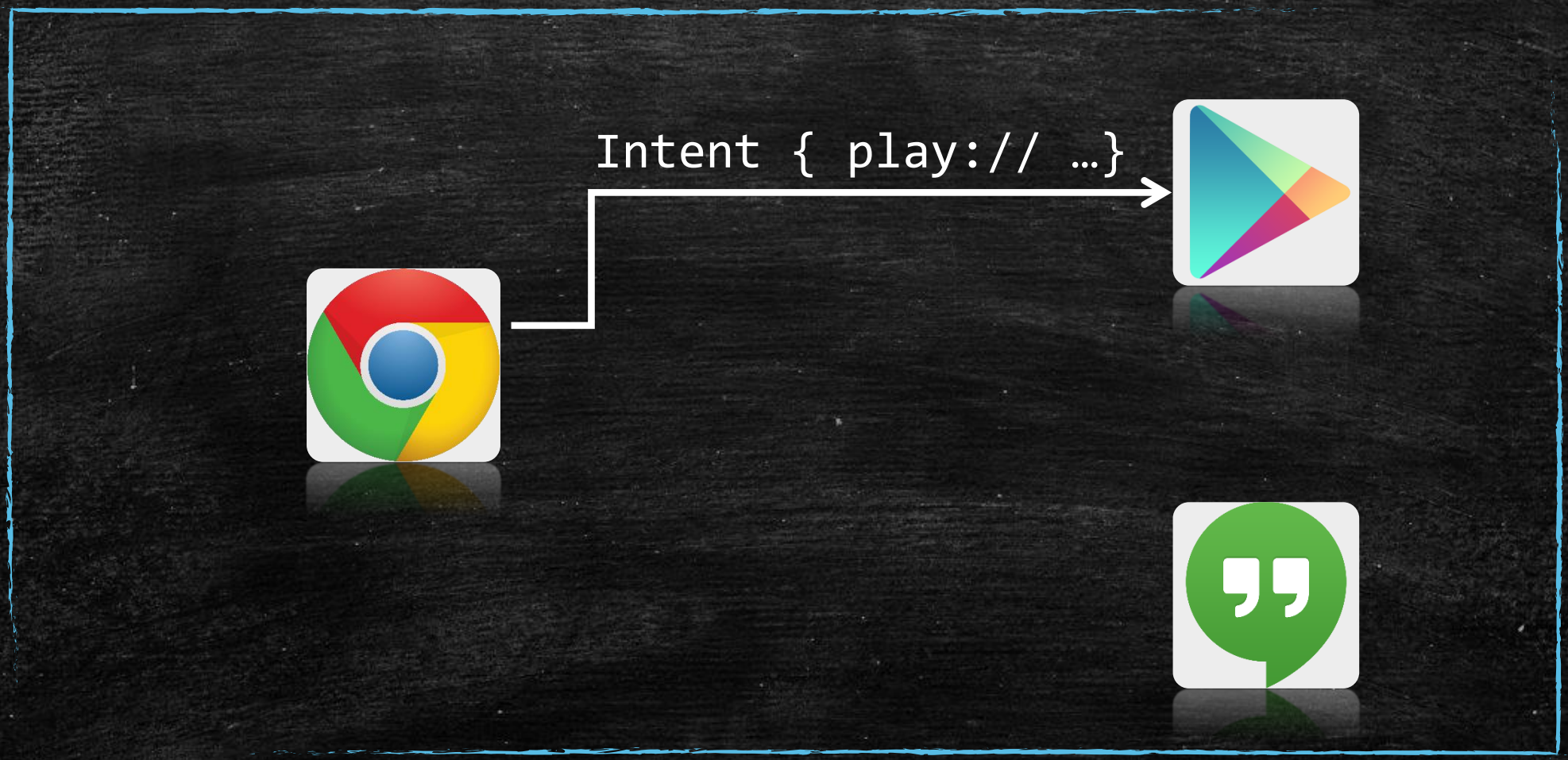
Android Inter-App Communication 101



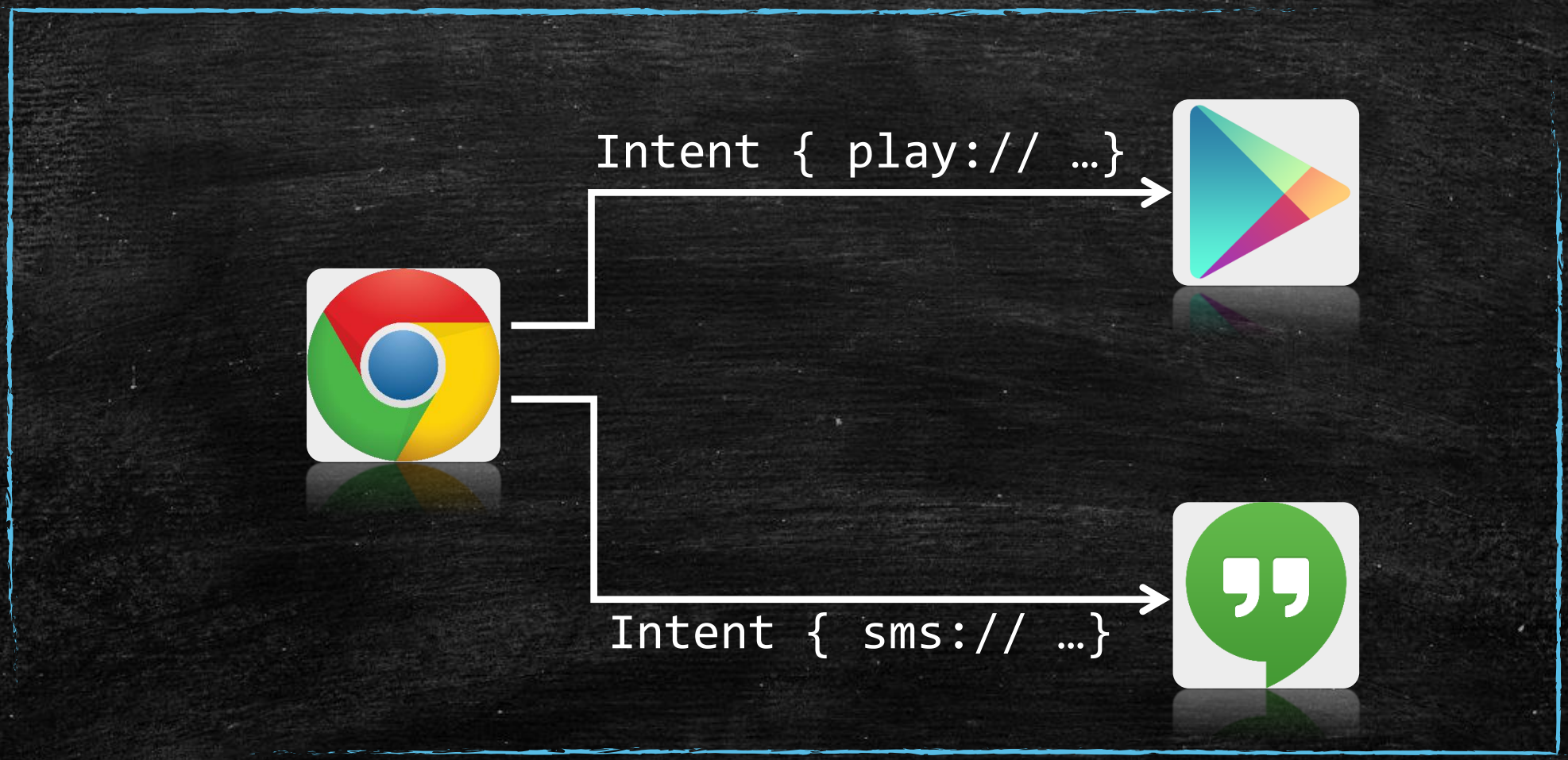




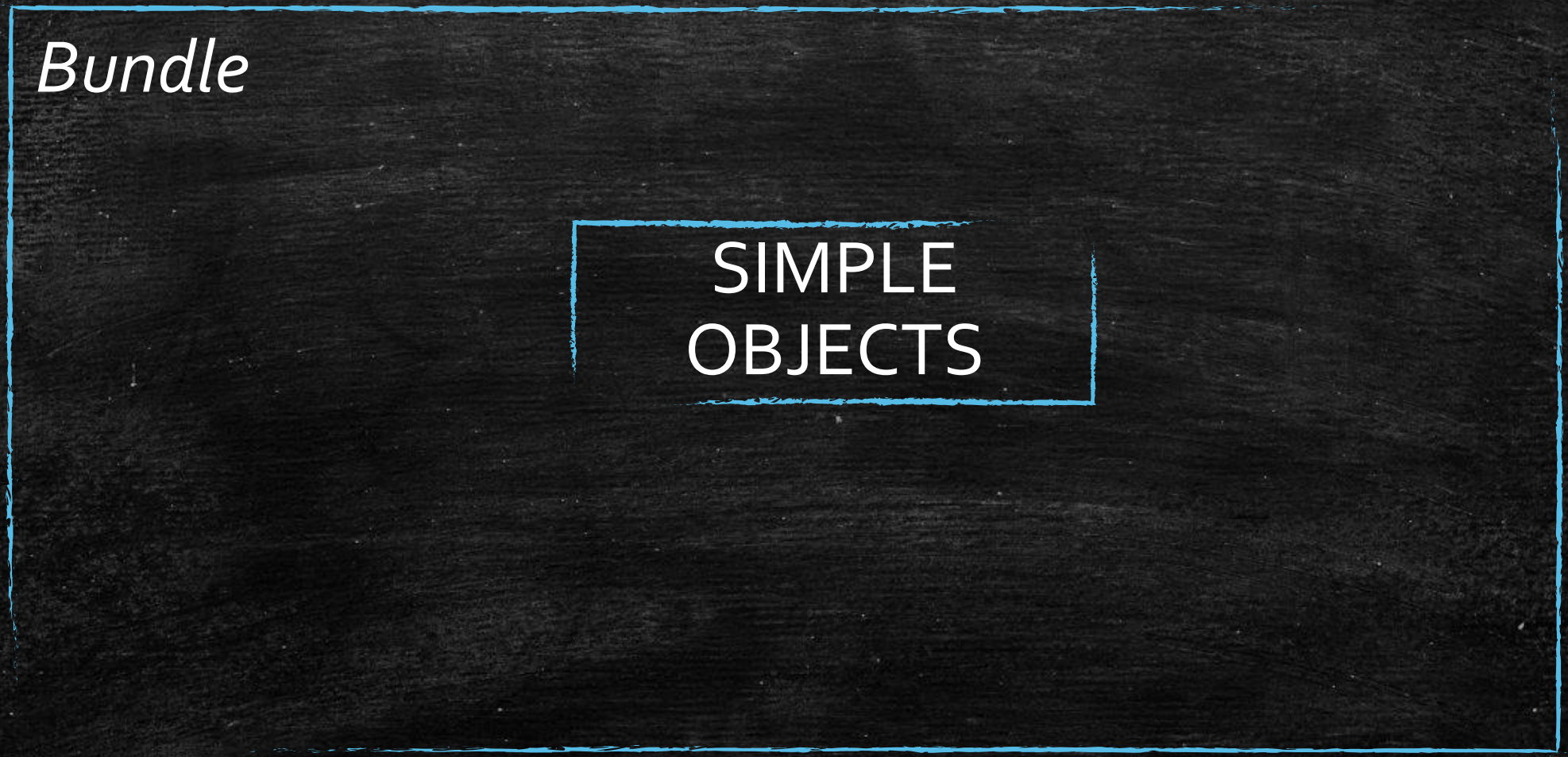
Android Inter-App Communication 101



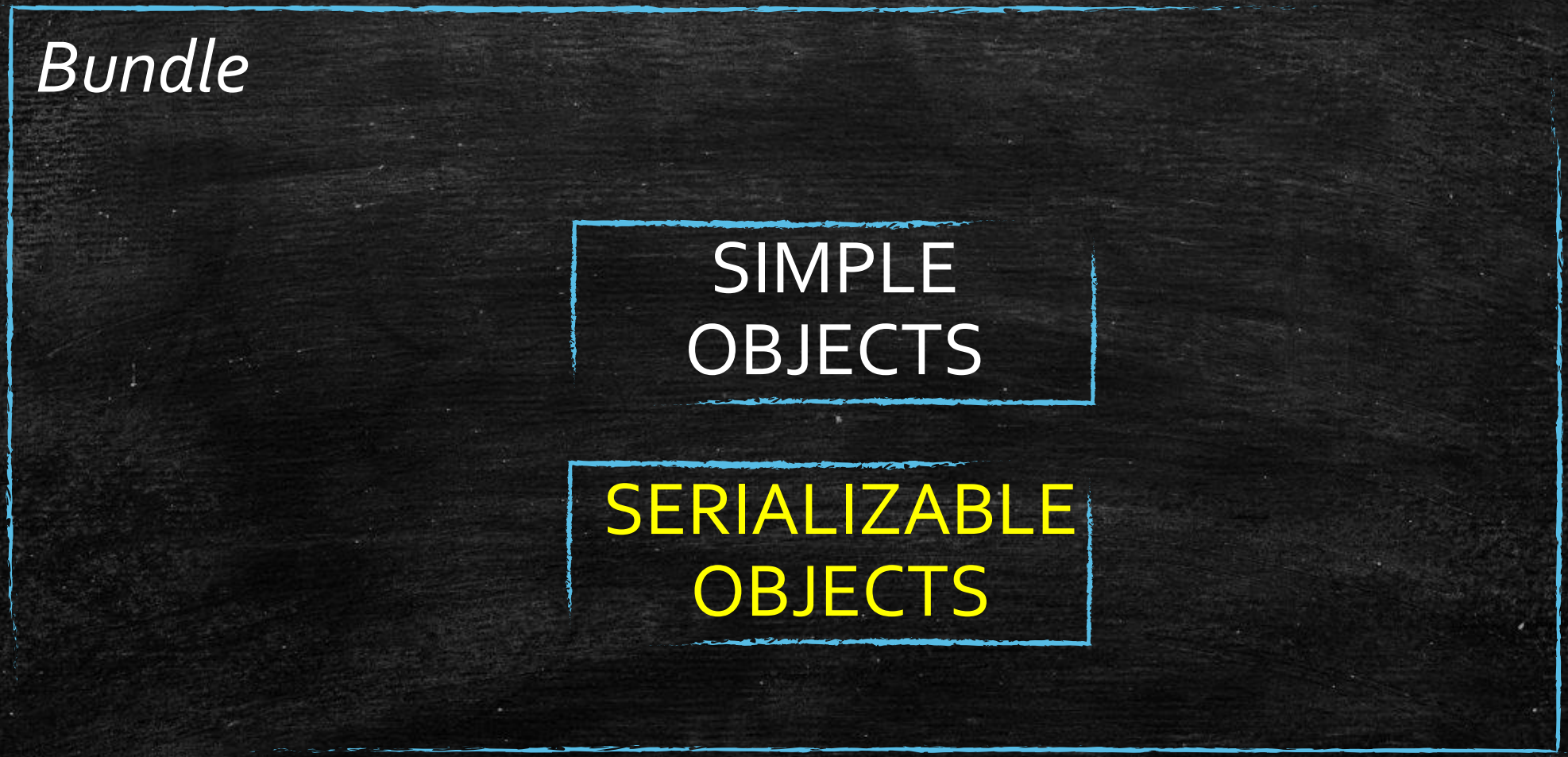
Android Inter-App Communication 101



An Intent can also contain



An Intent can also contain



Motivation

Previous Work

CVE-2014-7911 (Jann Horn):

Non-Serializable Classes can be Deserialized on target.



Exploiting CVE-2014-7911

Step 1. Find an interesting target.

MALWARE

TARGET

The Target

system_server

Exploiting CVE-2014-7911

Step 2. Send target a 'serialized' object in a `Bundle`



The Serialized Object

```
final class BinderProxy implements IBinder {

        private long mOrgue;

        …

        private native final destroy();

        @Override
        protected void finalize() throws Throwable
        {
            try { destroy(); }
            finally { super.finalize(); }

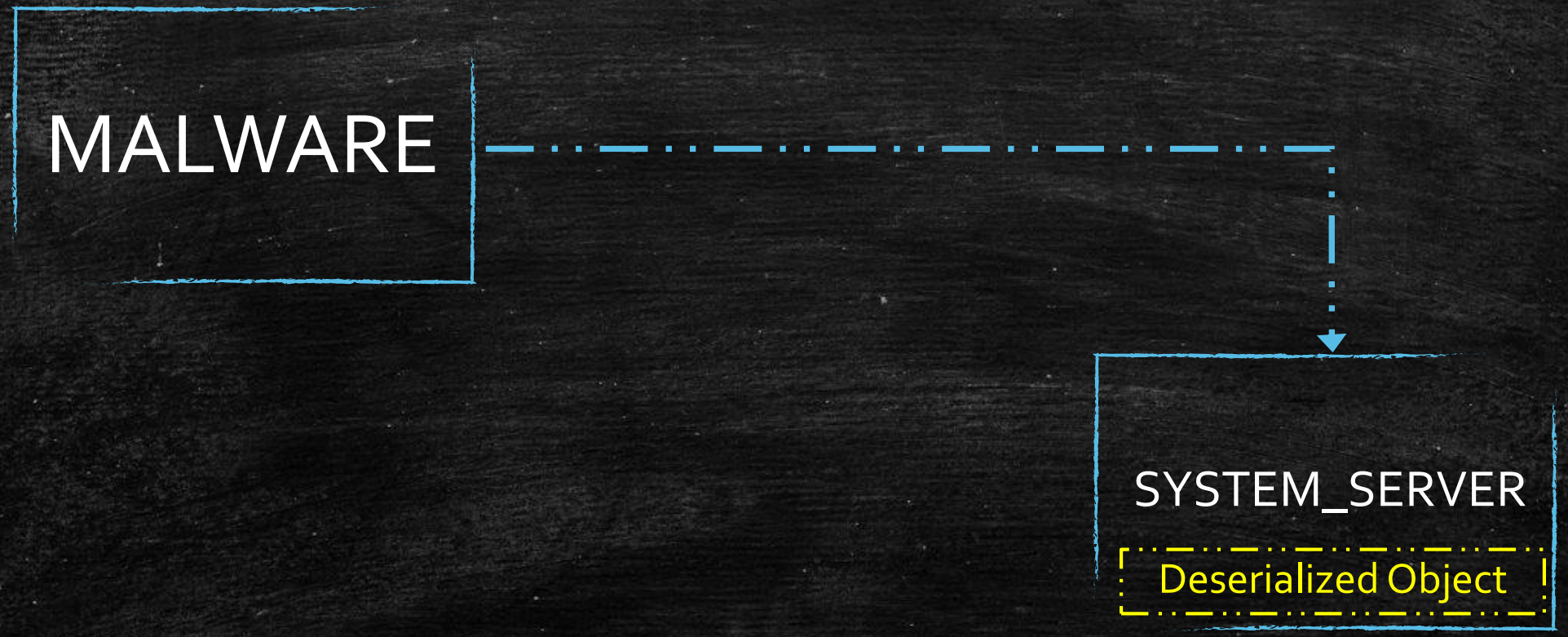
        }
```

← CONTROLALBLE NATIVE OBJECT

← USES THE OBJECT

Exploiting CVE-2014-7911

Step 3. Make it deserialize on the target.



Make it deserialize automatically

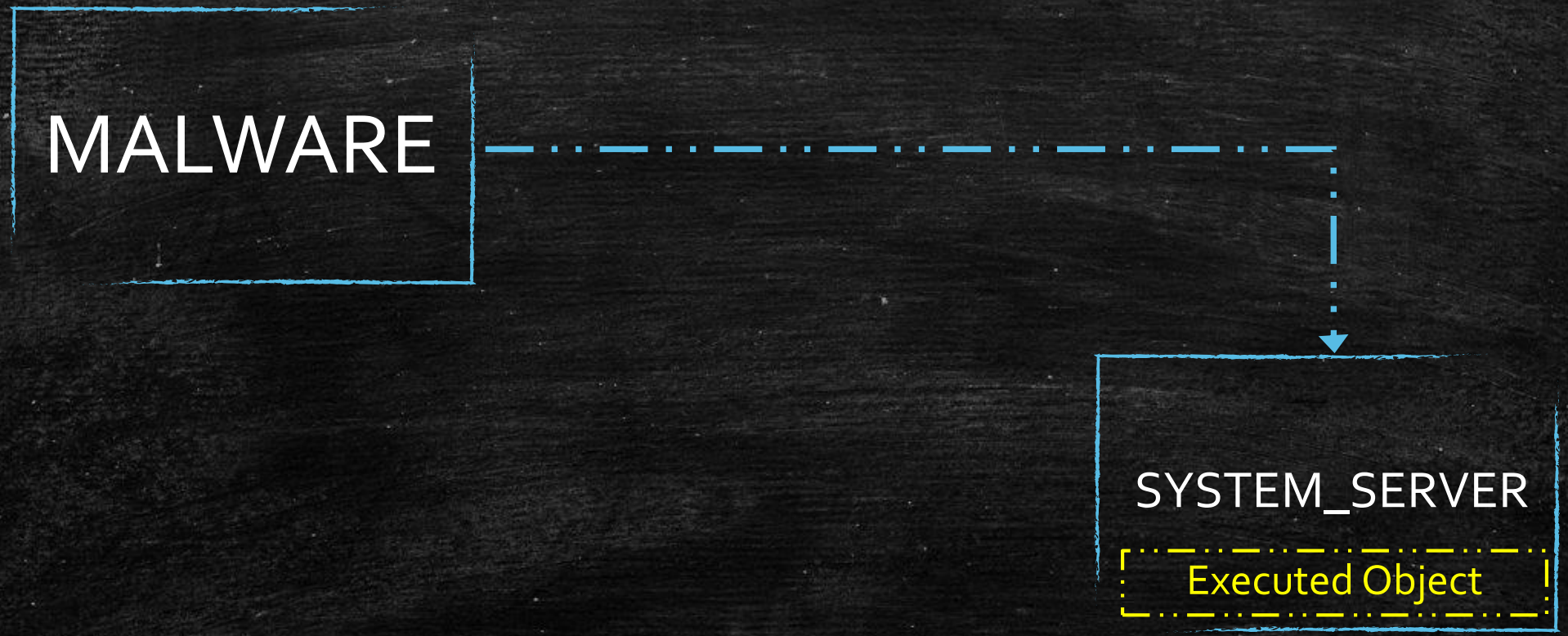
All Bundle members are deserialized with a single ‘touch’ on the incoming Bundle:

e.g.

```
public String getString(String key)
{
    unparcel(); ← DESERIALIZES ALL
    final Object o = mMap.get(key);
    try { return (String) o; }
    catch (ClassCastException e) {…}
}
```

Exploiting CVE-2014-7911

Step 4. Make one of its methods *execute* on target.



(4) Make it Execute some Sensitive Code

```
final class BinderProxy implements IBinder {

        private long mOrgue;

        …

        private native final destroy();

        @Override
        protected void finalize() throws Throwable
        {
            try { destroy(); }
            finally { super.finalize(); }

        }
```

← EXECUTED AUTOMATICALLY BY THE GC

Google's Fix for CVE-2014-7911

Do Not Deserialize Non-Serializable Classes

Our 1st Contribution: *The Android Vulnerability*

CVE-2015-3825

Our Research Question: A Potential Vulnerability

```
class Foo implements Serializable {

        private long mObject;

        …

        private native final destroy();

        @Override
        protected void finalize() throws Throwable
        {
            try { destroy(); }
            finally { super.finalize(); }

        }
```

CONTROLLABLE POINTER

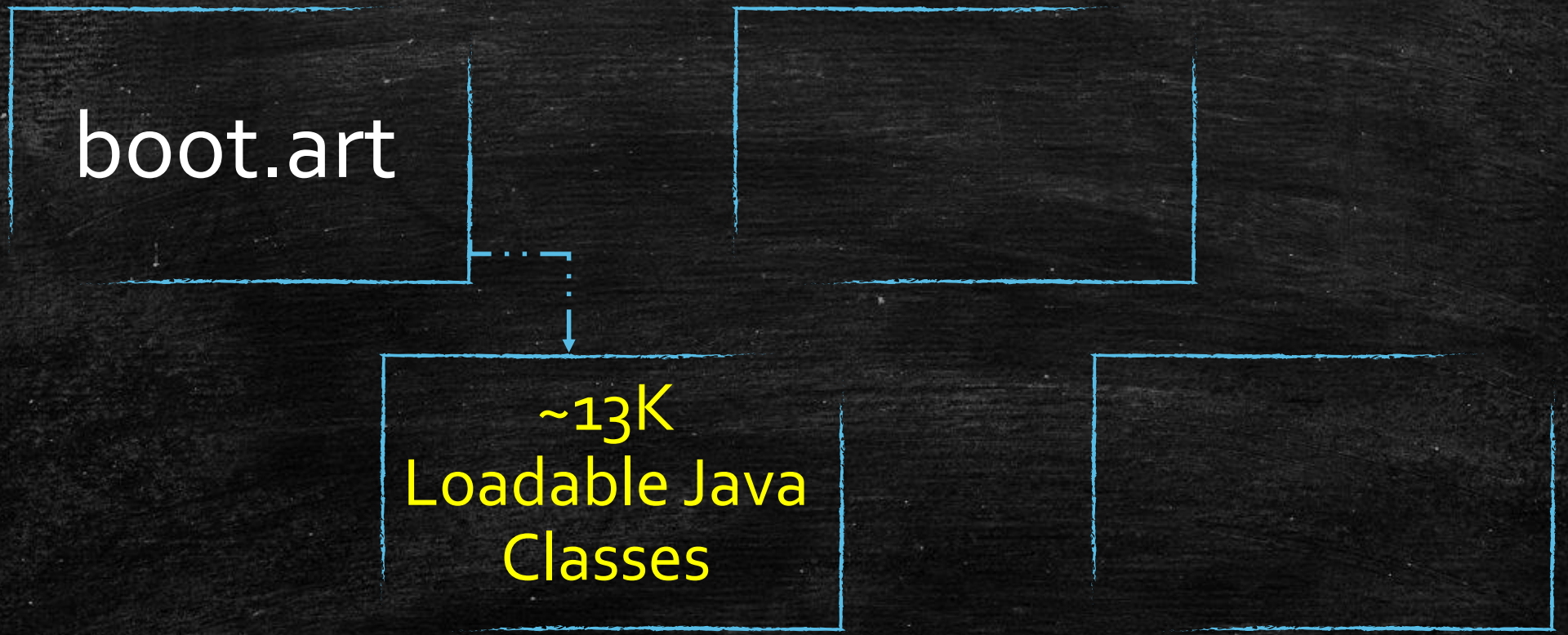
POINTER USED IN NATIVE CODE.

EXECUTED AUTOMATICALLY BY THE GC

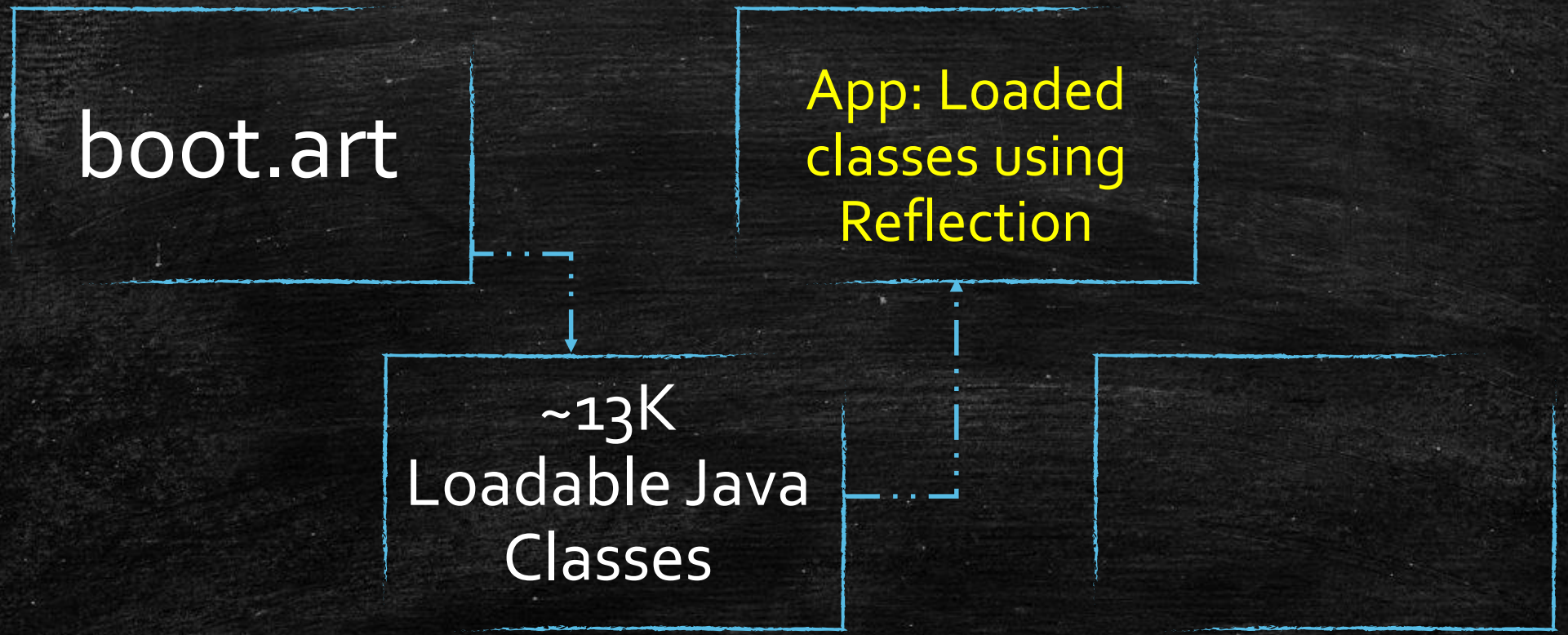
Experiment 1

boot.art

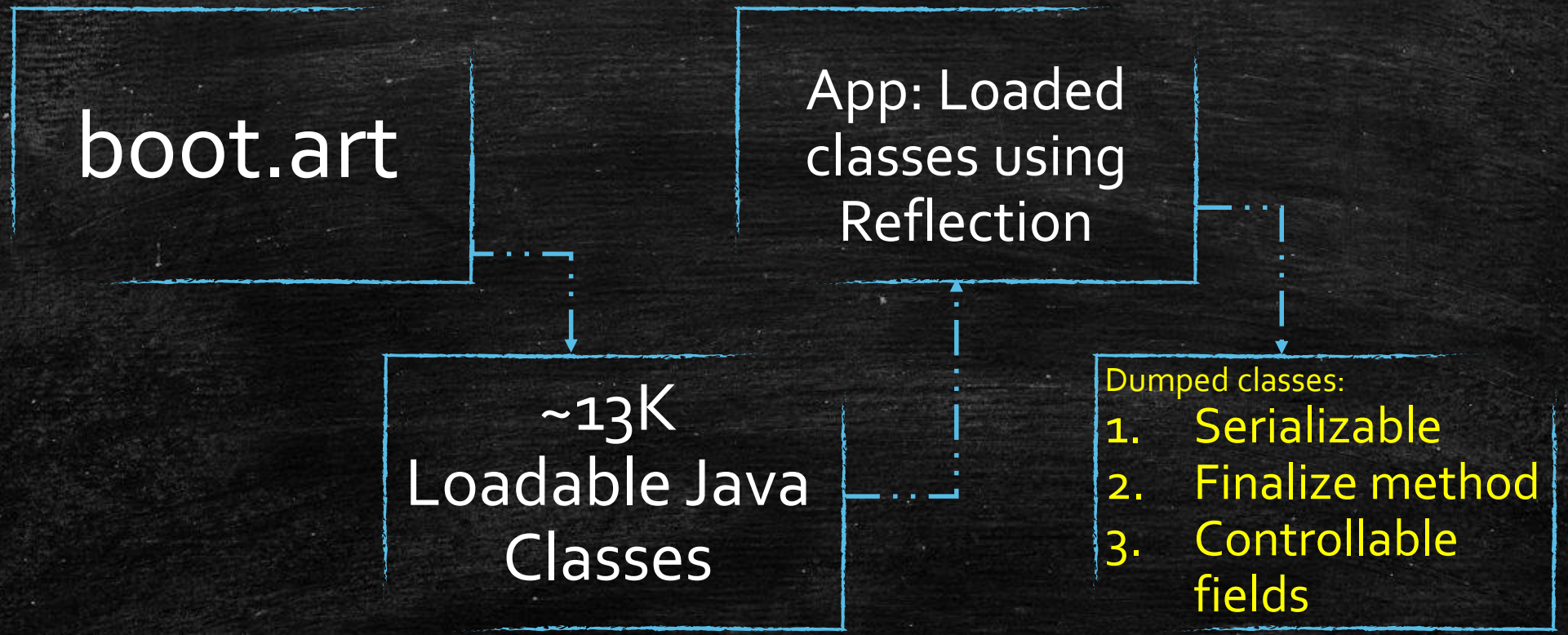
Experiment 1



Experiment 1



Experiment 1



The Result

OpenSSLX509Certificate

The Result

```
public class OpenSSLX509Certificate
extends X509Certificate {

  private final long mContext;

  @Override
  protected void finalize() throws Throwable {
  ...

    NativeCrypto.X509_free(mContext);
  ...

  }
}
```

The Result

```
public class OpenSSLX509Certificate
extends X509Certificate {

  private final long mContext;

  @Override
  protected void finalize() throws Throwable {
  ...

    NativeCrypto.X509_free(mContext);
  ...

  }
}
```

← (1) SERIALIZABLE

The Result

```
public class OpenSSLX509Certificate
extends X509Certificate {

  private final long mContext;

  @Override
  protected void finalize() throws Throwable {
  ...

    NativeCrypto.X509_free(mContext);
  ...

  }
}
```

← (1) SERIALIZABLE

← (2) CONTROLLABLE PTR

The Result

```
public class OpenSSLX509Certificate
extends X509Certificate {

  private final long mContext;

  @Override
  protected void finalize() throws Throwable {
  ...

    NativeCrypto.X509_free(mContext);
  ...

  }
}
```

← (1) SERIALIZABLE

← (2) CONTROLLABLE PTR

← (3) EXECUTED AUTOMATICALLY BY THE GC

Arbitrary Decrement

```
NativeCrypto.X509_free(mContext)
  └→ X509_free(x509);    // x509 = mContext
       └→ ASN1_item_free(x509, ...)
            └→ asn1_item_combine_free(&val, ...)     // val = *pval = mContext
                 if (asn1_do_lock(pval, -1,...) > 0)
                   return;
                          ↑
                // Decreases a reference counter (mContext+0x10)
                // MUST be POSITIVE INTEGER (MSB=0)
```

Arbitrary Decrement

```
ref = mContext+0x10
if (*ref > 0)
   *ref--
else
   free(…)
```

Proof-of-Concept Exploit

Arbitrary Code Execution in `system_server`

Exploit Outline



Exploit Outline



First Step of the Exploit

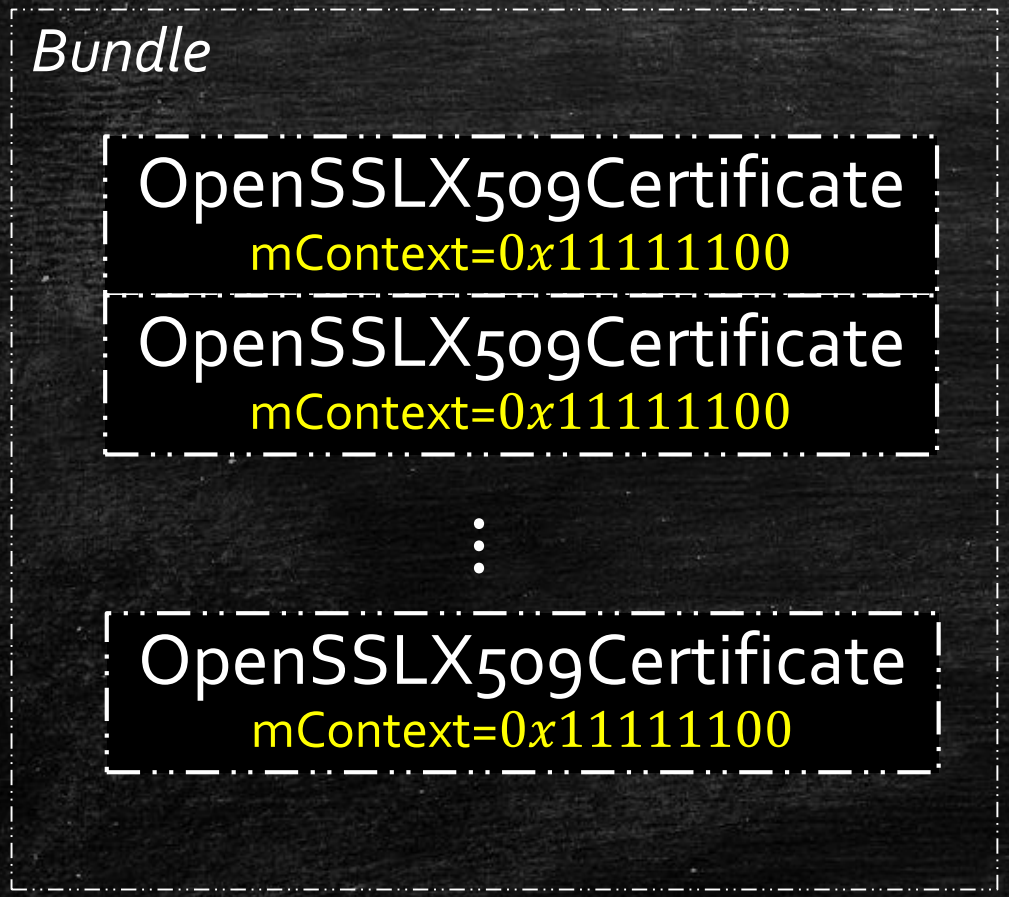
Own the Program Counter (PC)

Creating an Arbitrary Code Exec Exploit

ARSENAL

1. Arbitrary Decrement
2. Controlled Buffer

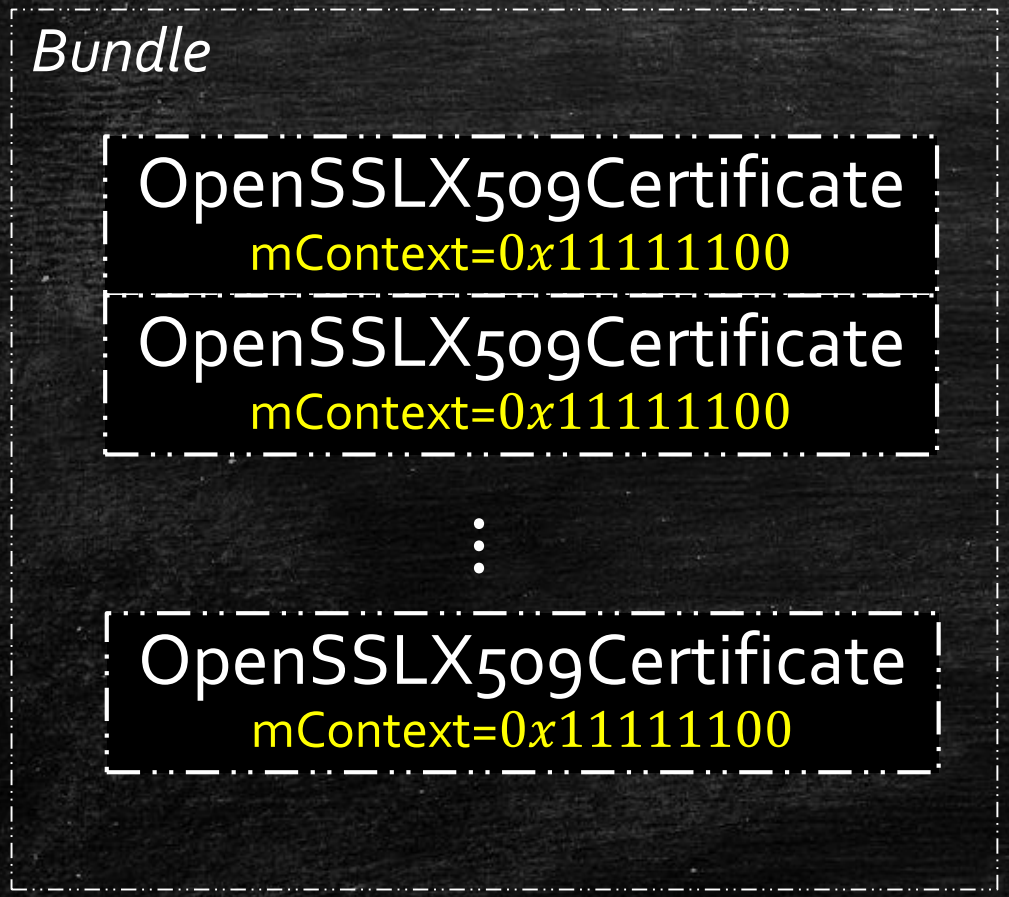
Constrained Arbitrary Memory Overwrite



Constrained Arbitrary Memory Overwrite



Constrained Arbitrary Memory Overwrite



$$*\,0x11111110 \mathrel{-}= n$$

If we knew the original value:
Arbitrary Overwrite

Why Constraint Overwrite?

1. We are limited to positive values.
2. Inefficiency.

Solution in the Paper

ONE CLASS TO RULE THEM ALL
0-DAY DESERIALIZATION VULNERABILITIES IN ANDROID

Or Peles, Roee Hay
IBM Security
{orpeles,roeeh}@il.ibm.com

Abstract

We present previously unknown high severity vulnerabilities in Android.

The first is in the Android Platform and Google Play Services. The Platform instance affects Android 4.3-5.1, M (Preview 1) or 55% of Android devices at the time of writing[1]. This vulnerability allows for arbitrary code execution in the context of many apps and services and results in elevation of privileges. In this paper we also demonstrate a Proof-of-Concept exploit against the *Google Nexus 5* device, that achieves code execution inside the highly privileged `system_server` process, and then either replaces an existing arbitrary application on the device with our own malware app or changes the device's *SELinux* policy. For some other devices, we are also able to gain kernel code execution by loading an arbitrary kernel module. We had responsibly disclosed the vulnerability to Android Security Team which tagged it as `CVE-2015-3825` (internally as `ANDROID-21437603/21583894`) and patched Android 4.4 / 5.x / M and Google Play Services.

For the sake of completeness we also made

I. Introduction

Android is the most popular mobile operating system with 78% of the worldwide smartphone sales to end users in Q1 2015 [1].

Android apps are executed in a sandboxed environment to protect both the system and the hosted applications from malware [2]. The Android sandbox relies on the Linux kernel's isolation facilities. While sandboxing is a central security feature, it comes at the expense of interoperability. In many common situations, apps require the ability to interact. For example, the browser app should be capable of launching the Google Play app if the user points toward the Google Play website. To recover interoperability, a key aspect of the Android architecture is Inter-App Communication (IAC) , which enables modular design and reuse of functionality across apps and app components. The Android IAC model is implemented as a message-passing system, where messages are encapsulated by `Intent` objects. Through `Intents`, an app (or app component) can utilize functionality exposed by another

Creating an Arbitrary Code Exec Exploit

ARSENAL

1. Arbitrary Decrement
2. Controlled Buffer
3. Arbitrary Overwrite*

* If we knew the original value

Creating an Arbitrary Code Exec Exploit

ARSENAL

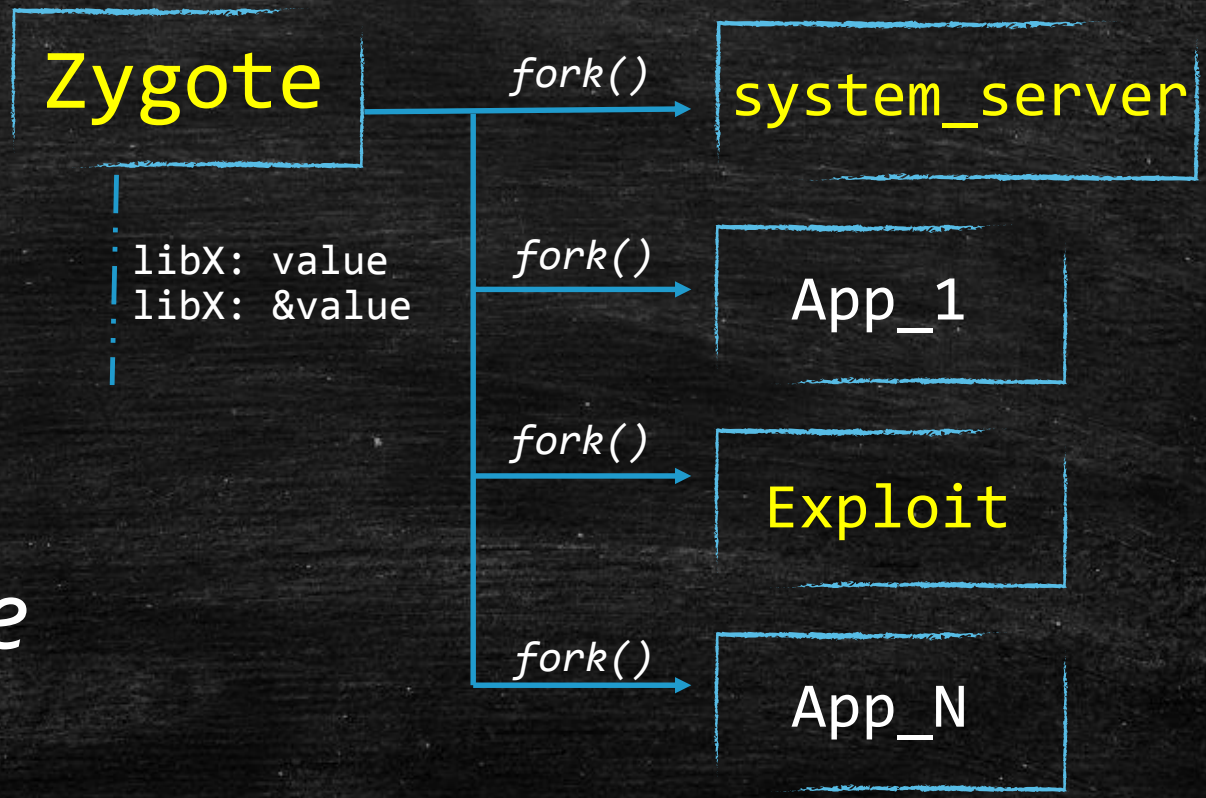
1. Arbitrary Decrement
2. Controlled Buffer
3. Arbitrary Overwrite*

DEFENSES

1. ASLR
2. RELRO
3. Non-Executable pages
4. SELinux

* If we knew the original value

Finding the Original Value: bye-bye ASLR



fork without *execve*
= no **ASLR**!

Creating an Arbitrary Code Exec Exploit

ARSENAL

1. Arbitrary Decrement
2. Controlled Buffer
3. Arbitrary Overwrite*

* If we knew the original value

DEFENSES

1. ~~ASLR~~
2. RELRO
3. Non-Executable pages
4. SELinux

Using the Arbitrary Overwrite

Goal

Overwrite some pointer

Problem

.got is read only (RELRO)

A Good Memory Overwrite Target

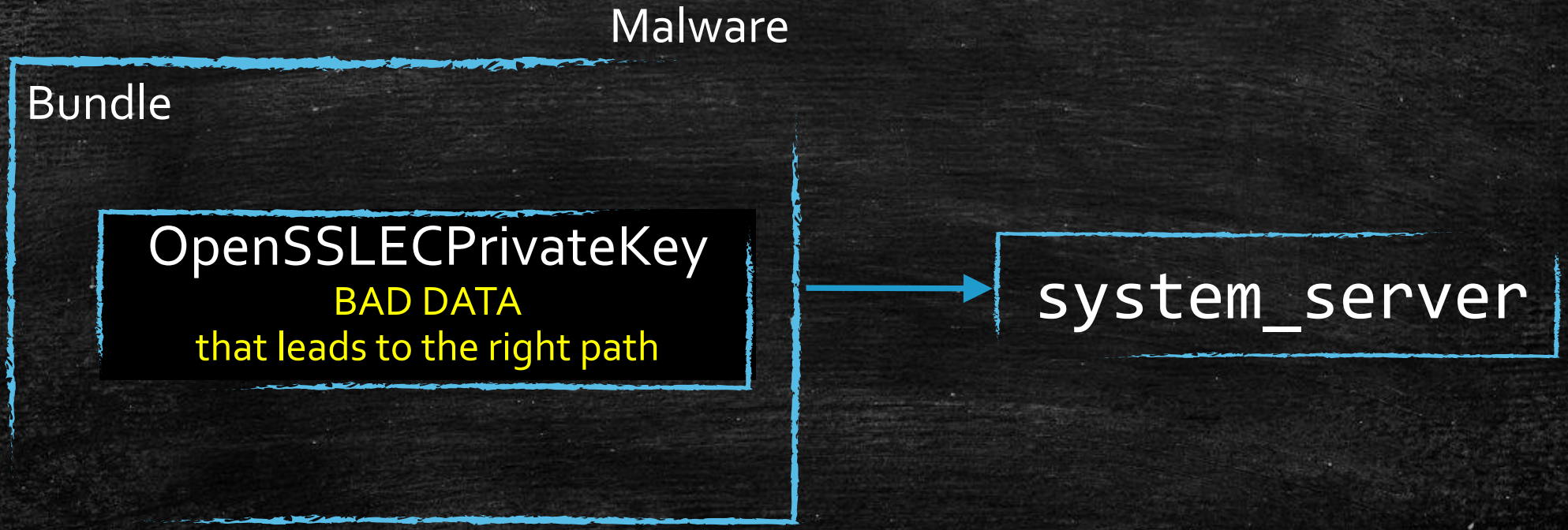
A function pointer under `.data`

`id_callback` in *libcrypto*

Called during *deserialization* of:

`OpenSSLECPrivateKey`

Triggering *id_callback* remotely



First step accomplished

We now own the Program Counter

Creating an Arbitrary Code Exec Exploit

ARSENAL

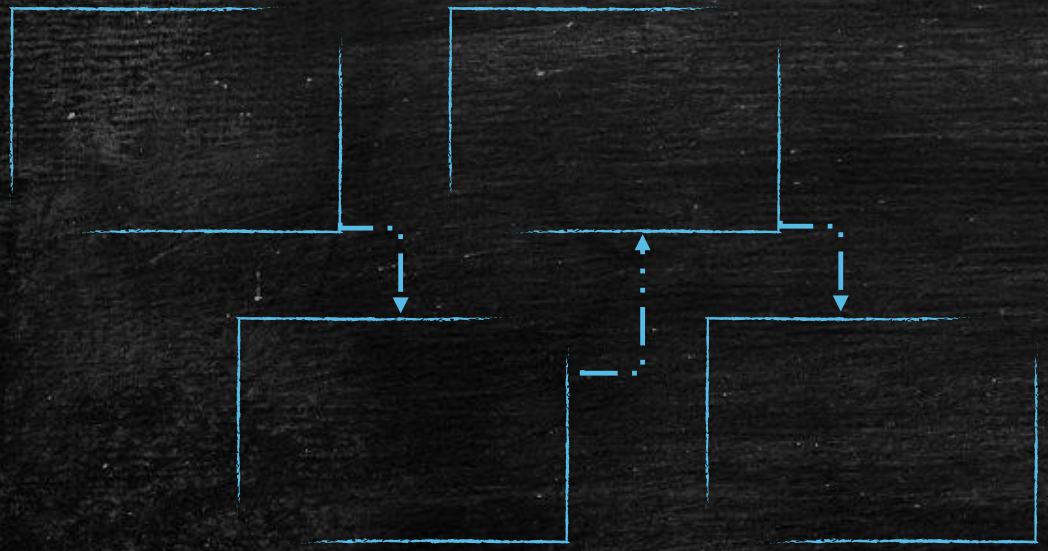
1. Arbitrary Decrement
2. Controlled Buffer
3. Arbitrary Overwrite*

* If we know the original value

DEFENSES

1. ~~ASLR~~
2. ~~RELRO~~
3. Non-Executable pages
4. SELinux

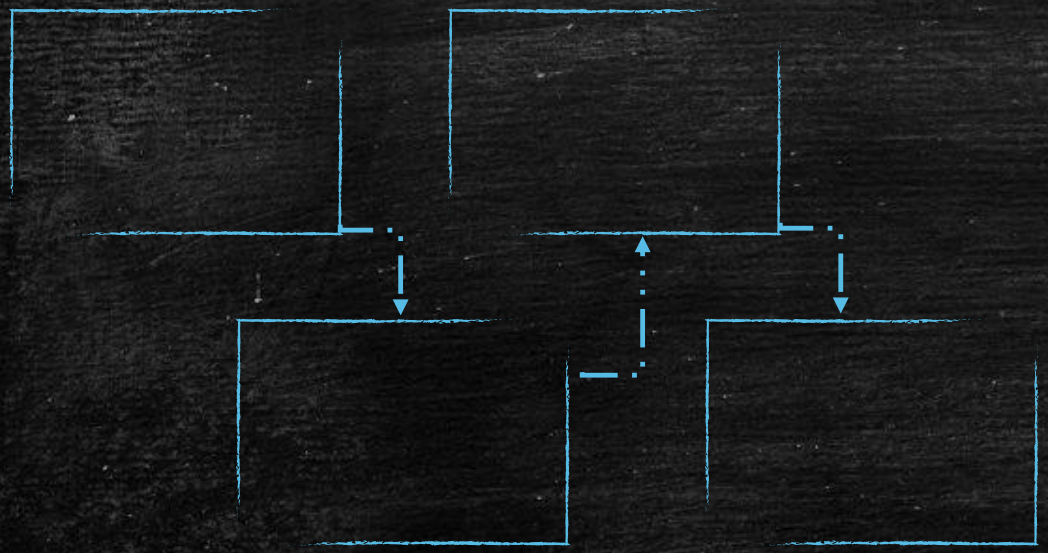
Next Steps of the PoC Exploit (simplified)



system_server

```
pc → r-x code
sp → rw- stack
     rw- ROP chain
     rw- shellcode
```

Problem 1: SP does not point at ROP chain

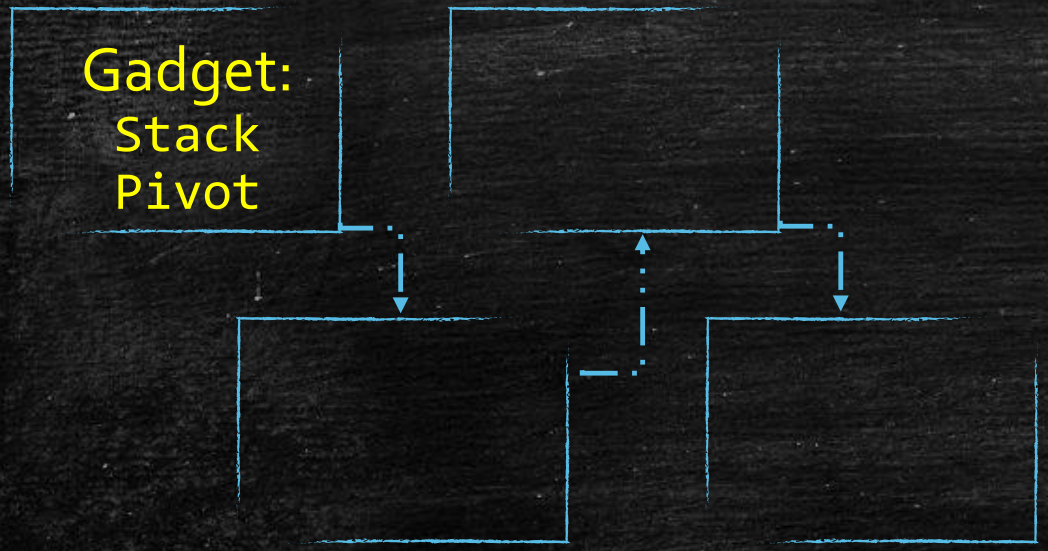


system_server

```
pc → r-x code
sp → rw- stack
     rw- ROP chain
     rw- shellcode
```

Solution: Stack Pivoting

Our buffer happens to be pointed by fp.
The Gadget: mov sp, fp; …, pop {…}

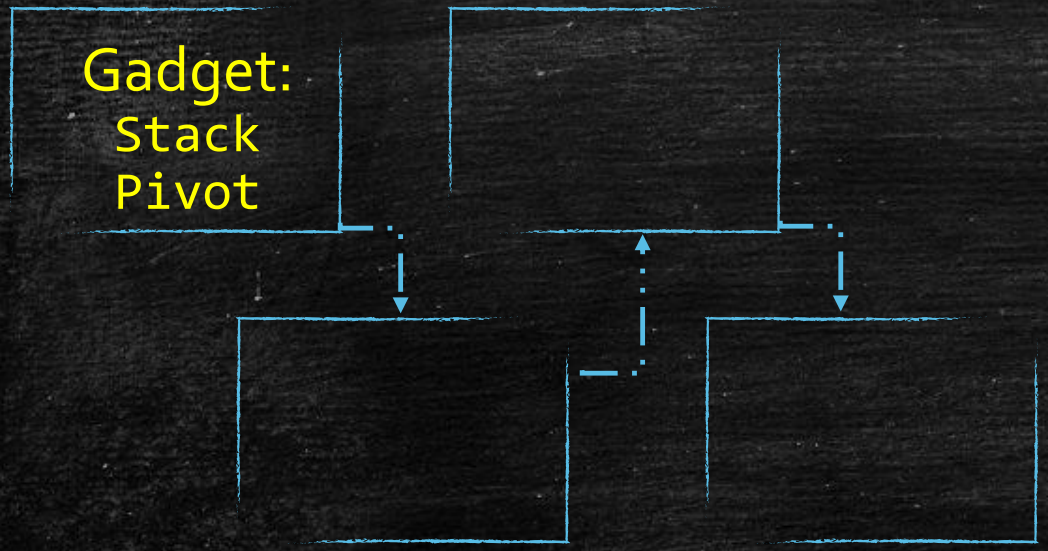


system_server

```
pc → r-x code/pivot
sp → rw- stack
fp → rw- ROP chain
     rw- shellcode
```

Solution: Stack Pivoting

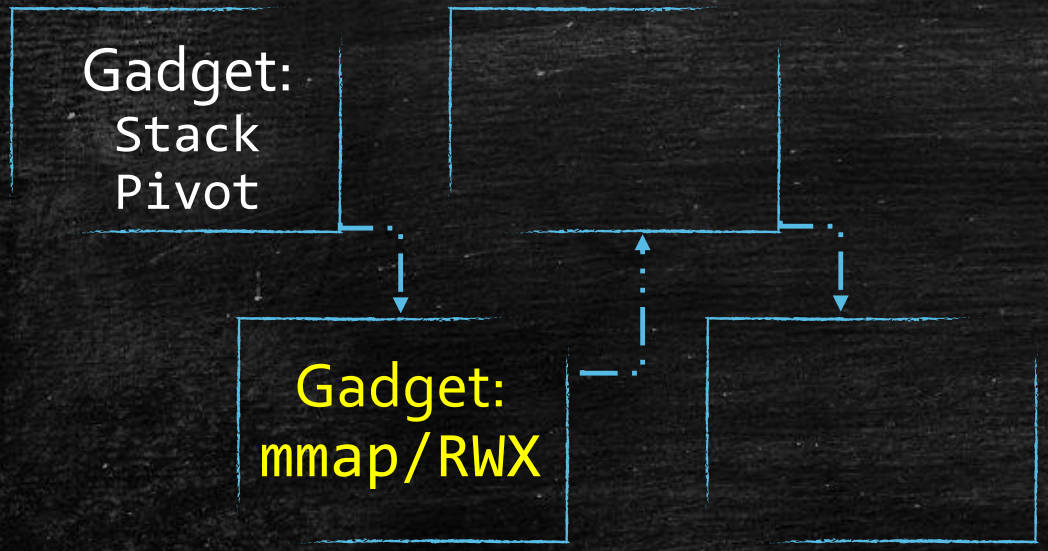
Our buffer happens to be pointed by fp.
The Gadget: mov sp, fp; …, pop {…}



system_server

```
pc → r-x code/pivot
     rw- stack
sp → rw- ROP chain
     rw- shellcode
```

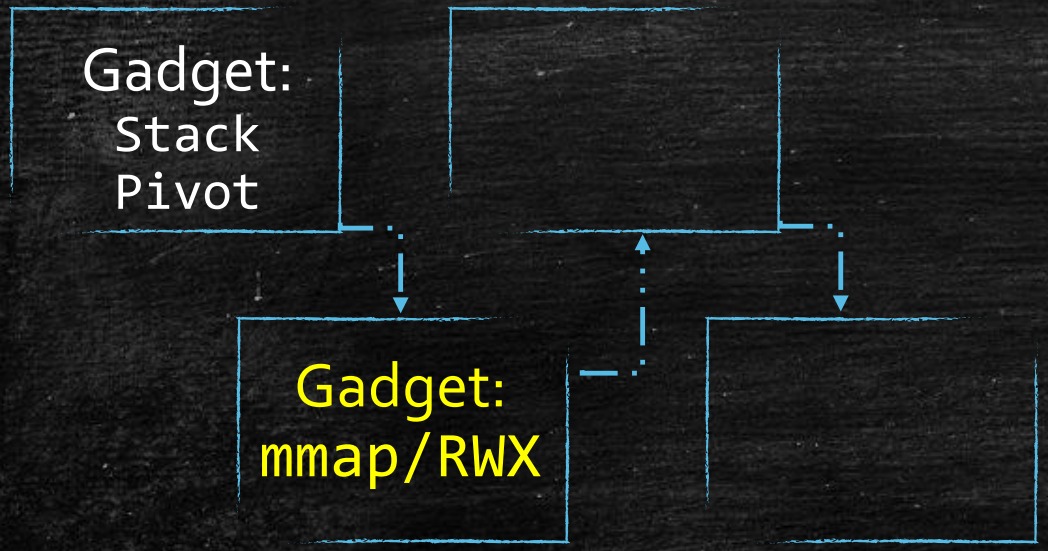
Allocating RWX Memory



system_server

```
pc → r-x code/mmap
     rw- stack
sp → rw- ROP chain
     rw- shellcode
```

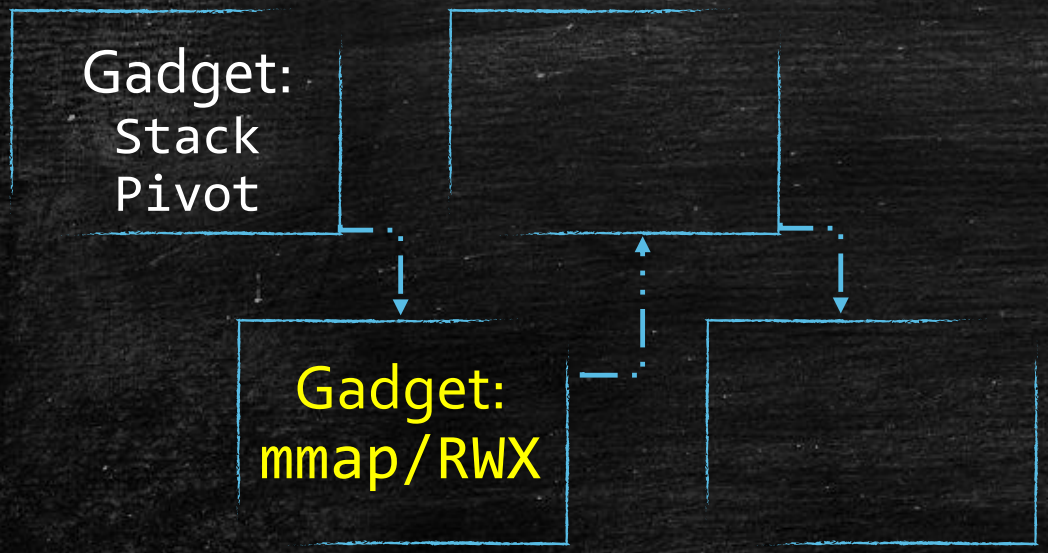
Problem 2: SELinux should prohibit mmap/RWX



system_server

```
pc → r-x code/mmap
     rw- stack
sp → rw- ROP chain
     rw- shellcode
```

Solution: Weak SELinux Policy for system_server



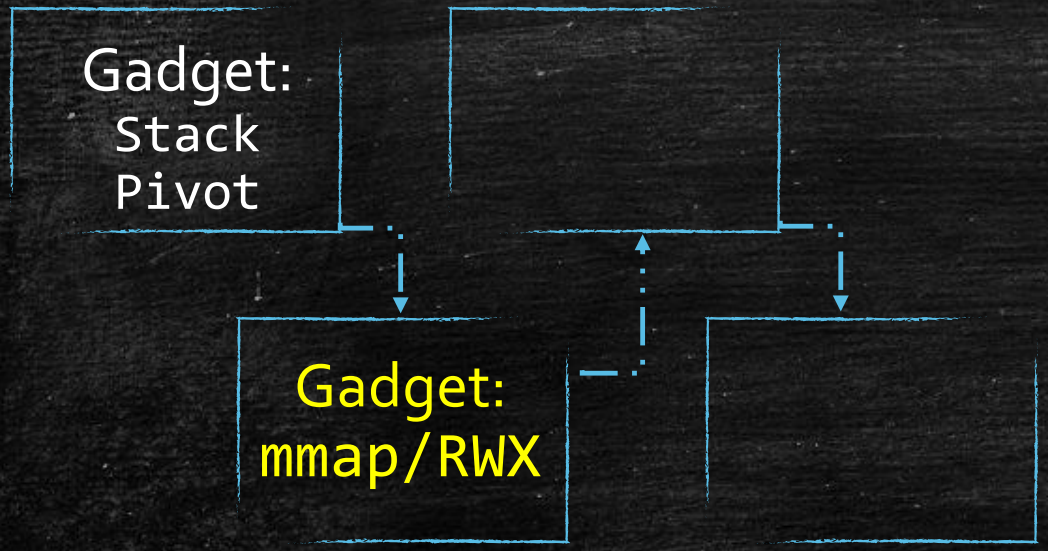
system_server

```
pc → r-x code/mmap
     rw- stack
sp → rw- ROP chain
     rw- shellcode
```

Solution: Weak SELinux Policy for system_server



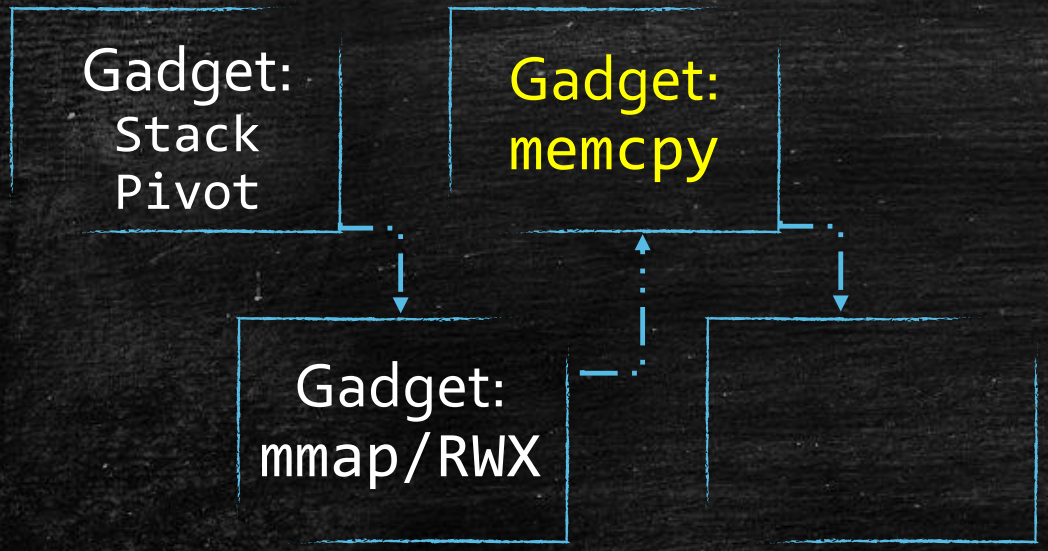
Allocating RWX Memory



system_server

```
pc → r-x code/mmap
     rw- stack
sp → rw- ROP chain
     rw- shellcode
     rwx -
```

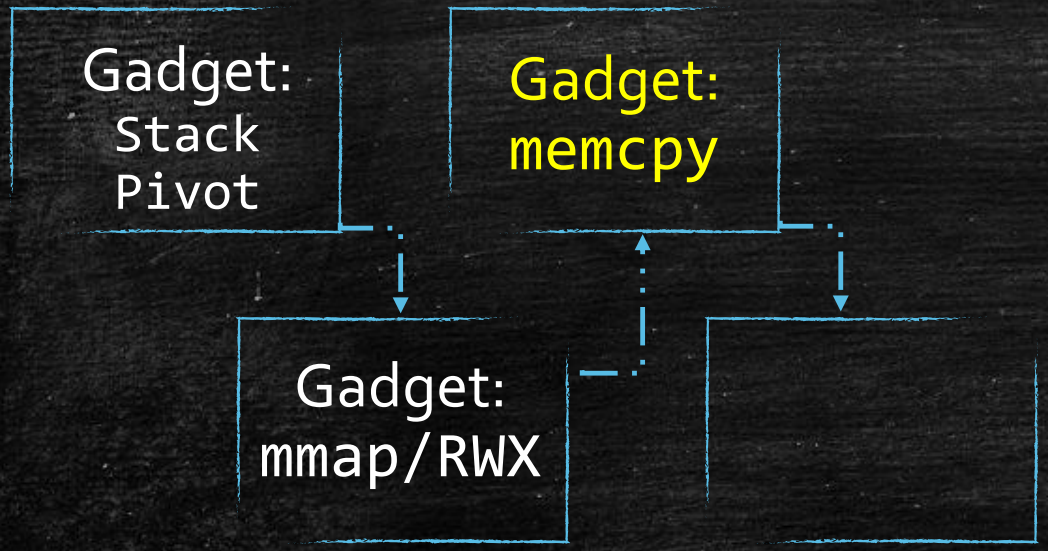
Copying our Shellcode



system_server

```
pc → r-x code/memcpy
     rw- stack
sp → rw- ROP chain
     rw- shellcode
     rwx -
```

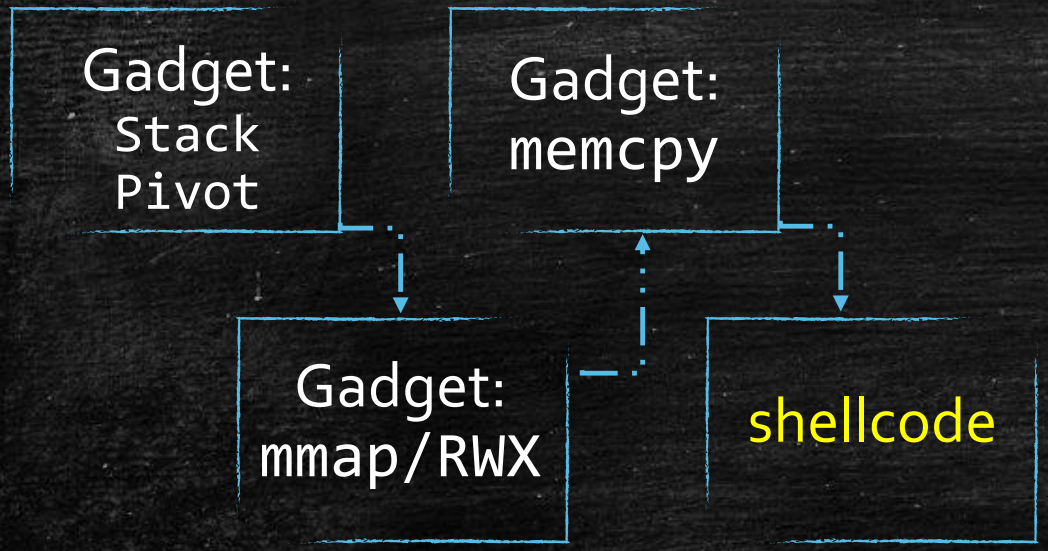
Copying our Shellcode



system_server

```
pc → r-x code/memcpy
     rw- stack
sp → rw- ROP chain
     rw- shellcode
     rwx shellcode
```

Executing our Shellcode



system_server

```
      r-x code
      rw- stack
sp →  rw- ROP chain
      rw- shellcode
pc →  rwx shellcode
```

Creating an Arbitrary Code Exec Exploit

ARSENAL

1. Arbitrary Decrement
2. Controlled Buffer
3. Arbitrary Overwrite*

DEFENSES

1. ~~ASLR~~
2. ~~RELRO~~
3. ~~Non-Executable pages~~
4. ~~SELinux~~

* If we know the original value

Shellcode

Runs as system, still subject to the SELinux, but can:

- REPLACEMENT OF APPS
- SELINUX BYPASS
- ACCESS TO APPS' DATA
- KERNEL CODE EXEUCTION*

* On select devices

Demo


One Class to Rule Them All
Exploiting CVE-2015-3825 for Replacing an Existing App on the Device
USENIX WOOT '15
Or Peles & Roee Hay
IBM Security

Google's Patch for CVE-2015-3825

```
public class OpenSSLX509Certificate
  extends X509Certificate {

  private ________ final long mContext;
  …

}
```


MISSING MODIFIER BEFORE OUR DISCLOSURE! (NOW PATCHED)

Google's Patch for CVE-2015-3825

```
public class OpenSSLX509Certificate
  extends X509Certificate {

  private transient final long mContext;
  ...
}
```

MISSING MODIFIER BEFORE OUR DISCLOSURE! (NOW PATCHED)

Our 2nd Contribution: Vulnerabilities in SDKs

CVE-2015-2000/1/2/3/4/20

Finding Similar Vulnerabilities in SDKs

Goal. Find vulnerable *Serializable* classes in 3rd -party SDKs.

Why. Fixing the Android Platform Vulnerability is not enough.

Experiment 2

Analyzed over 32K of popular Android apps using `dexlib2`.

Main Results

CVE-2015-2000	Jumio SDK	Code Exec.
CVE-2015-2001	MetaIO SDK	Code Exec.
CVE-2015-2002	Esri ArcGis SDK	Code Exec.
CVE-2015-2003	PJSIP PJSUA2 SDK	Code Exec.
CVE-2015-2004	GraceNote SDK	Code Exec.
CVE-2015-2020	MyScript SDK	Code Exec.

Root Cause (for most of the SDKs)

SWIG, a C/C++ to Java interoperability tool, can generate vulnerable classes.

```
public class Foo implements Bar {
  private long swigCPtr;
  protected boolean swigCMemOwn;
  ...
  protected void finalize() {
     delete();
  }
  public synchronized void delete() {
    …
    exampleJNI.delete_Foo(swigCPtr);
    …
  }
  ...
}
```

POSSIBLY SERIALIZABLE

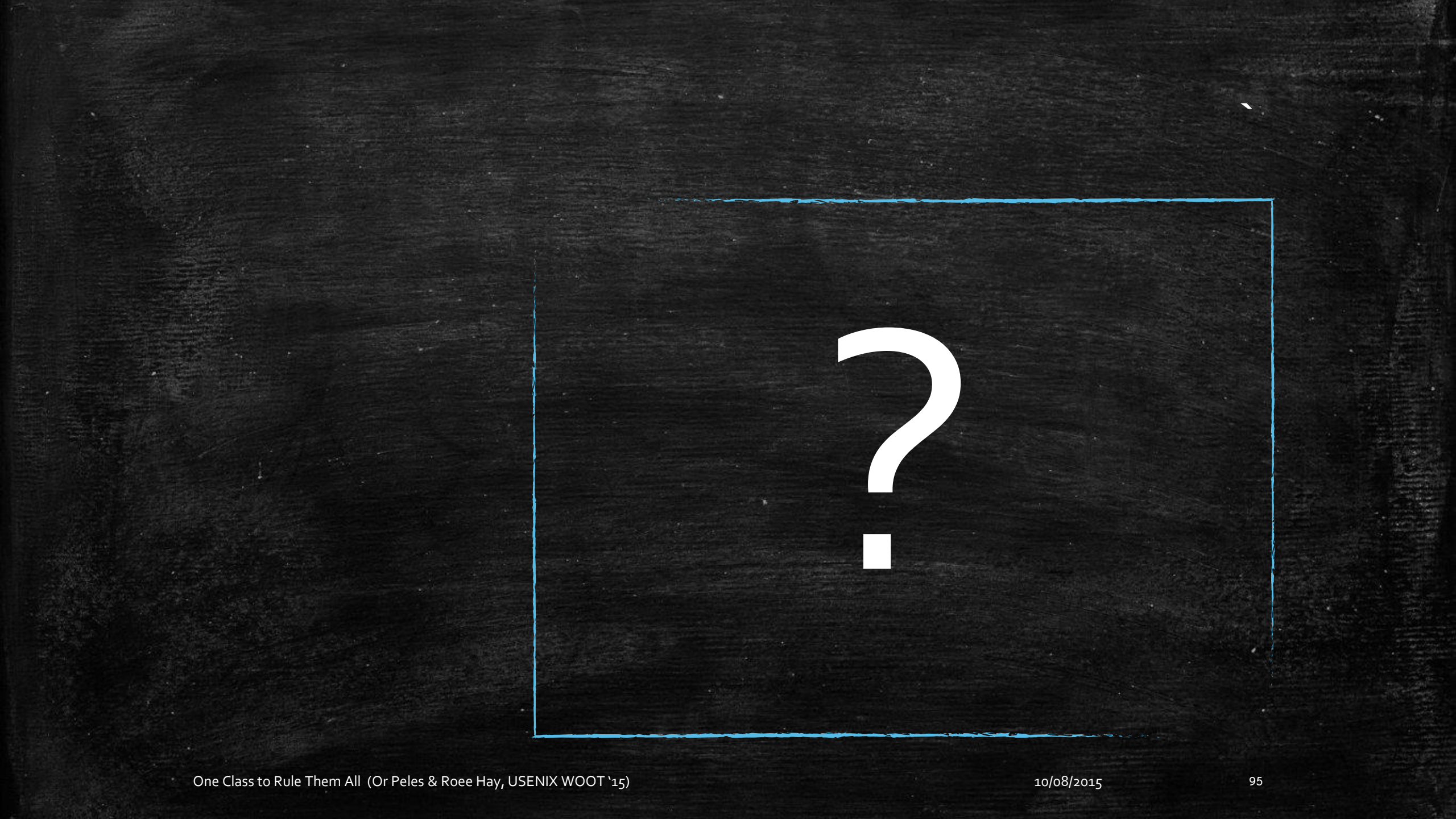
CONTROLLABLE POINTER

POINTER USED IN NATIVE CODE

Wrap-up

Summary

- Found a high severity vulnerability in Android (Exp. 1).
- Wrote a reliable PoC exploit against it
- Found similar vulnerabilities in 6 third-party SDKs (Exp. 2)
- Patches are available for all of the vulnerabilities and also for SWIG.



Statement of Good Security Practices: IT system security involves protecting systems and information through prevention, detection and response to improper access from within and outside your enterprise. Improper access can result in information being altered, destroyed, misappropriated or misused or can result in damage to or misuse of your systems, including for use in attacks on others. No IT system or product should be considered completely secure and no single product, service or security measure can be completely effective in preventing improper use or access. IBM systems, products and services are designed to be part of a lawful, comprehensive security approach, which will necessarily involve additional operational procedures, and may require other systems, products or services to be most effective. IBM DOES NOT WARRANT THAT ANY SYSTEMS, PRODUCTS OR SERVICES ARE IMMUNE FROM, OR WILL MAKE YOUR ENTERPRISE IMMUNE FROM, THE MALICIOUS OR ILLEGAL CONDUCT OF ANY PARTY.

THANK YOU

www.ibm.com/security





IBM **Security**

Intelligence. Integration. Expertise.

© Copyright IBM Corporation 2015. All rights reserved. The information contained in these materials is provided for informational purposes only, and is provided AS IS without warranty of any kind, express or implied. IBM shall not be responsible for any damages arising out of the use of, or otherwise related to, these materials. Nothing contained in these materials is intended to, nor shall have the effect of, creating any warranties or representations from IBM or its suppliers or licensors, or altering the terms and conditions of the applicable license agreement governing the use of IBM software. References in these materials to IBM products, programs, or services do not imply that they will be available in all countries in which IBM operates. Product release dates and / or capabilities referenced in these materials may change at any time at IBM's sole discretion based on market opportunities or other factors, and are not intended to be a commitment to future product or feature availability in any way. IBM, the IBM logo, and other IBM products and services are trademarks of the International Business Machines Corporation, in the United States, other countries or both. Other company, product, or service names may be trademarks or service marks of others.