Android – Static Analysis 2

REVERSE ENGINEERING

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Native Applications

Native Applications

- Apps developed with OS provider's language and frameworks.
  - Java, Kotlin, Ojective-C, Swift
- Typically, android applications are compiled to bytecode and packaged with resources
  - Reversing such app can be done to Java (JADX) or Smali (apktool)
- Can access all API's made available by OS vendor.
- But…
  - SDK's are platform-specific.
  - Each mobile OS comes with its own unique tools and GUI toolkit.
  - Developing a world wide app requires multiple implementations

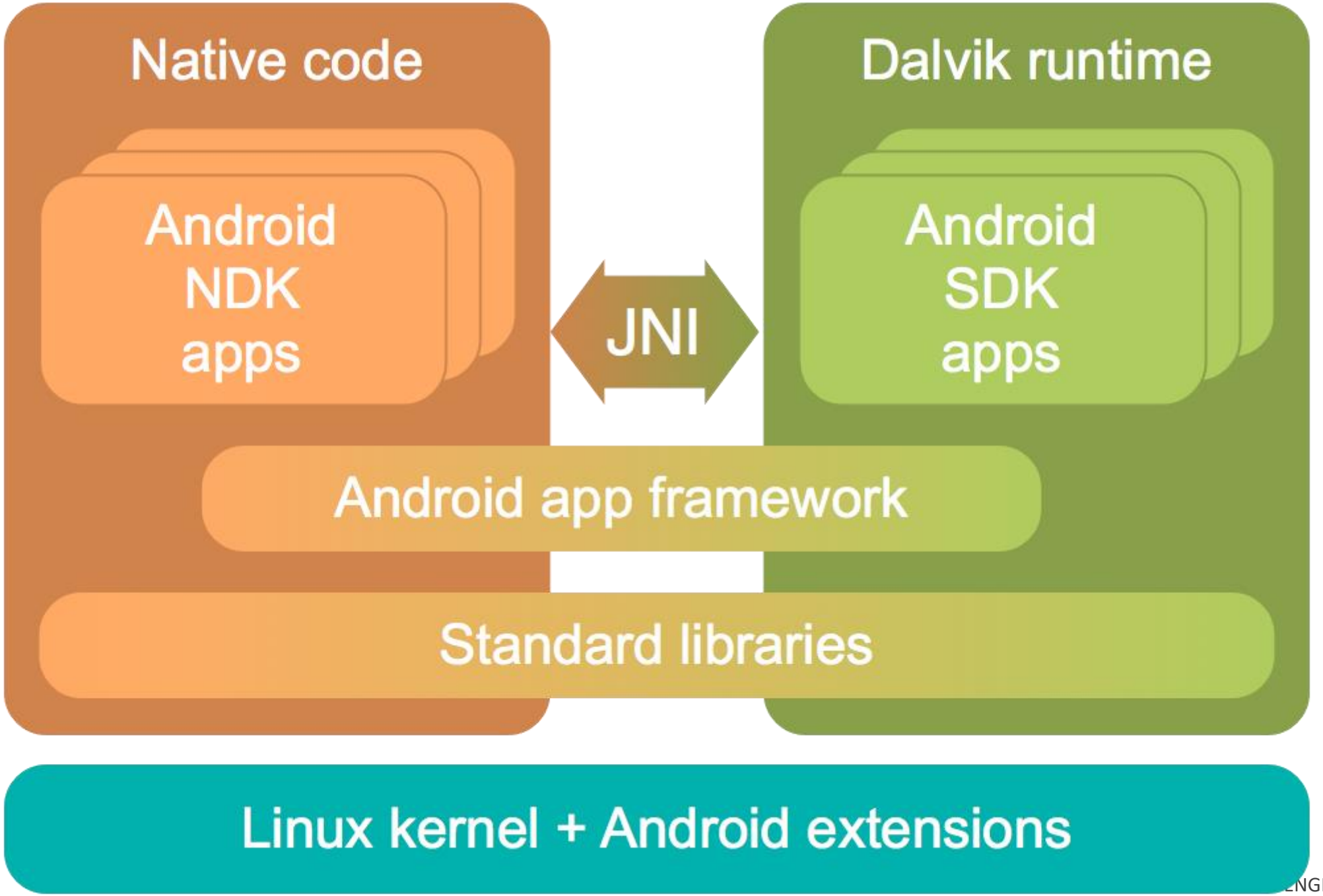
Java Native Interface

- Java applications can call functions from external libraries
  - Libraries can be implemented in Java, and packaged as classes
  - Libraries can also be implemented in any other language
    - Providing that an interfaces allows serialization and name resolution

- JNI: allows the definition of Java methods, whose implementation is present in native code
  - When a method is invoked, the objects are serialized, and the respective native symbol is loaded and the code executed.
  - There is a penalty due to serialization, but also a performance boost due to native code execution.
  - References:
    - JNI Functions (oracle.com)
    - Contents (oracle.com)

- Standard mechanism for Java (not specific for android)

JNI

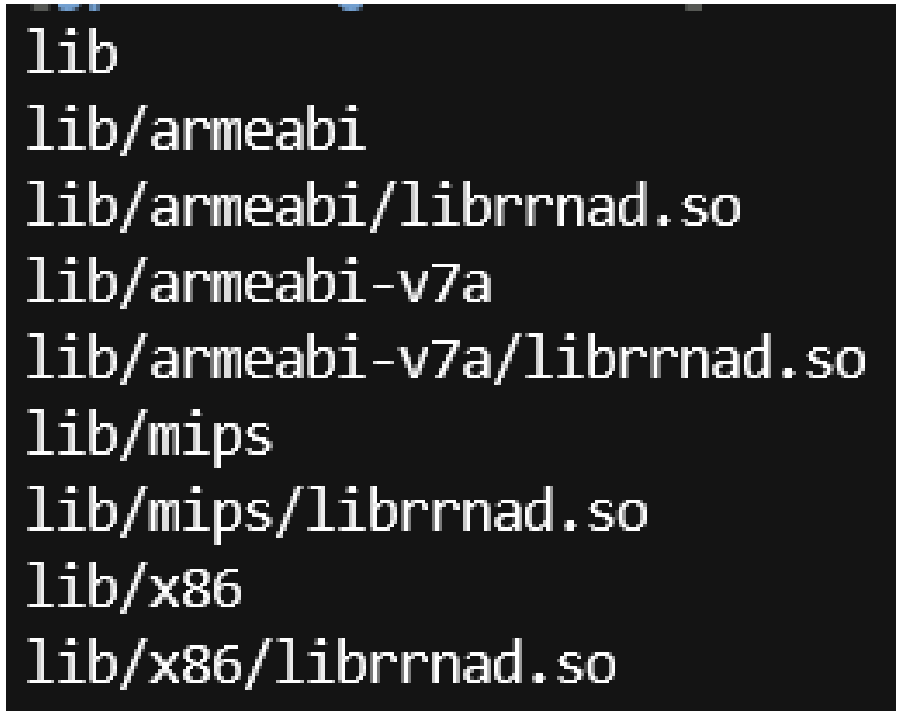

Native code
Android NDK apps
JNI
Dalvik runtime
Android SDK apps
Android app framework
Standard libraries
Linux kernel + Android extensions

Android Native Development Kit (NDK)

- Android provides a somewhat rich Development Kit allowing C/C++ applications to access Android resources
  - Similar to the standard SDK available to Java applications
- Developers may choose how to develop the code
  - Java: faster development and richer API
  - Native: faster execution, access to Linux subsystem, and more complex reverse engineering
    - Sometimes binary blobs are the only method to access a cryptographic method, DRM or hardware device
    - Sometimes the developer wishes to further obfuscate the code by compiling it to native code
- As libraries are native, an application must include multiple implementations
  - One for each architecture
  - A new device may not use applications that lack an implementation for that architecture
  - Implies using portable code that works in multiple architectures (arm, armv7, arm64, x86, x64, …)

Android binary libraries – Mediacode.apk

- Application contains DEX code and binary blobs
- One version for each architecture
  - armeabi: ARM 32bits no Floating Point
  - mips: MIPS
  - x86: intel X86 32bits
- Libraries export symbols to be used through JNI
  - nm -gD lib/x86/librrnad.so | grep JNI



Mediacode.apk

Android binary libraries – Mediacode.apk

- Before the binary libraries can be used, Java must load them
  - **`System.loadLibrary`**: argument is the library name (without lib, architecture or .so)
  - **`System.load`**: generic object load. Argument is the full path to the object
  - The JNI_OnLoad method is called automatically (in the lib)
    - Allows automatic setup of data structures and generic initialization
    - May be abused if malware is present

- If the library is not loaded, application will crash when external methods are requested

kxrkn.xiukxrkn.xiu.cmbutd.C0713lglx

```
80
81      /* renamed from: tt */
82      public static void m2055tt() {
83          f2132d = String.valueOf("tacd");
84          System.loadLibrary("rrnad");
85      }
```

JNI Arguments

- Native methods support arguments from Java code
  - Arguments are pointers to Java structures
  - Must be processed using specific methods, capable of handling the native Java types

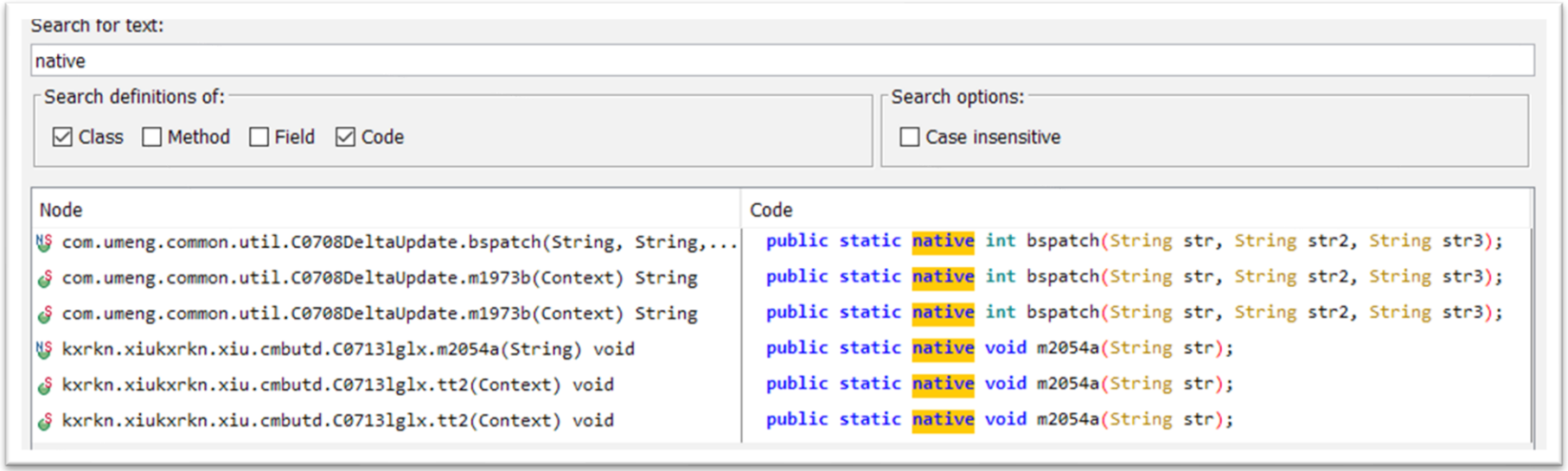
- Native methods can also call Java methods, and classes
  - Mainly achieved by the first argument of any JNI method: JNIEnv*

- JNIEnv* is a pointer to a structure with a large number of functions.
  - JNI Methods use it to invoke Java methods and handle Java types

Android binary libraries – Mediacode.apk

- In the java world native methods are declared:
  - With the keyword `native`
  - Without implementation

- Easy to spot if we have the java or smali code
  - Java: `public native String decryptString(String);`
  - Smali: `.method public native decryptString(Ljava/lang/String;)Ljava/lang/String`



JNI Dynamic Linking

- Dynamic linking is done “automagically” as long as the names of the methods in the library follow a fixed template
  - The library is loaded into the JVM and the methods are linked automatically
  - Implies that symbols are present in the library (not stripped)

- Assuming that our hello world app had a class named Worker, loading a method named doWork, the method in the function would be named:

```
Java_pt_ua_deti_hello_Worker_doWork()
```

magic | Package name | Class name | method

JNI Static Linking

- Linking must be done “manually”, by the binary code, before the methods are used
  - Allows methods to have any name (read obfuscation!)
  - A fixed method (`JNI_OnLoad`) is called after the lib is loaded
  - Library registers the mapping between java methods and native methods using `RegisterNatives`.
    - Must do this once for each method called.

```
jint RegisterNatives(JNIEnv *env, jclass clazz, const JNINativeMethod *methods, jint nMethods);

typedef struct {
    char *name;
    char *signature;
    void *fnPtr;
} JNINativeMethod;
```

JNI Static Linking

Java method name

```
typedef struct {
    char *name;
    char *signature;
    void *fnPtr;
} JNINativeMethod;
```

Address of native method

Signature using the following specifiers:

- Z: boolean
- B: byte
- C: char
- S: short
- I: int
- J: long
- F: float
- D: double
- L fully-qualified-class ; :fully-qualified-class
- [type: type[]
- (arg-types) ret-type: method type
- V: void

`String foo(Int, Boolean)` would result in:
`(IB)Ljava/lang/String`

JNI Types and Data Structures (oracle.com)

JNI Static Linking

- For static linking, reverse engineering of the library blob is the most viable alternative
  - Some symbols must always be available: **`JNI_Load`**
  - Remaining symbols usually are available, although they may have obfuscated names
- Process
  - Load the library in a tool: Ghidra, IDA, BinaryNinja, R2, etc…
  - Find the `JNI_Load method`
  - Determine when `RegisterNatives` is called
  - Determine the arguments passed to the function
    - Will allow determining the method mapping and the arguments of each function
    - Actually, the arguments may also help identifying the method

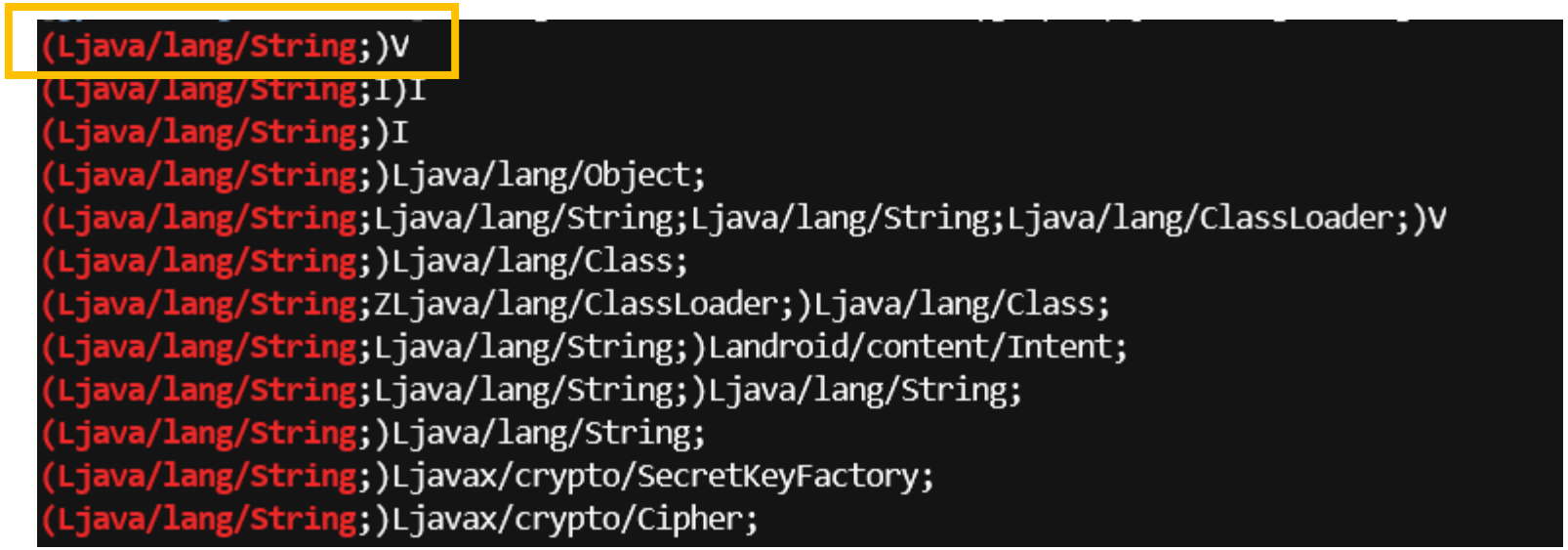
Exercises 1 and 2

Determine which method are actually loaded from the MediaCodec.apk shared libraries.

strings

- Do we have interfaces matching the functions we know to be native?
  - `int bspatch(String str, String str2, String str3)`
  - `void m2054a(String s)`

```
strings lib/x86/librrnad.so   |grep "(Ljava/lang/String"
```

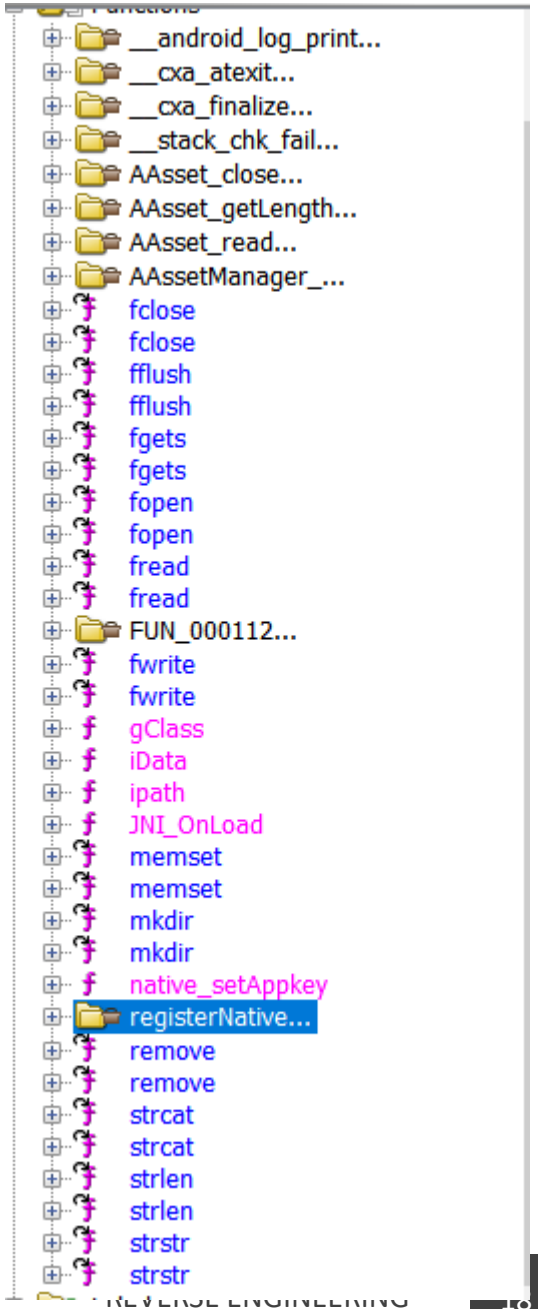


nm

- Do we have dynamic linking?
- Let's look for methods following the known pattern
- `nm -gD lib/x86/librrnad.so |grep Java_`
  - None…
- Conclusion
  - We have artifacts pointing to Java types
  - We do not have indication of Dynamic Linking

Ghidra

- Open Ghidra
- Create a new project
- Load a library
  - I loaded all and selected ARMEABI
- Several interesting functions discovered
  - **`JNI_Load`**
  - `registerNatives, registerNativeMethods`
  - `FUN_00011230, FUN_000270, FUN_11290, FUN_112b4`
  - `native_setAppKey`
- Coherent with Static Linking
- Explore the functions, exports, Classes, etc… lots of info



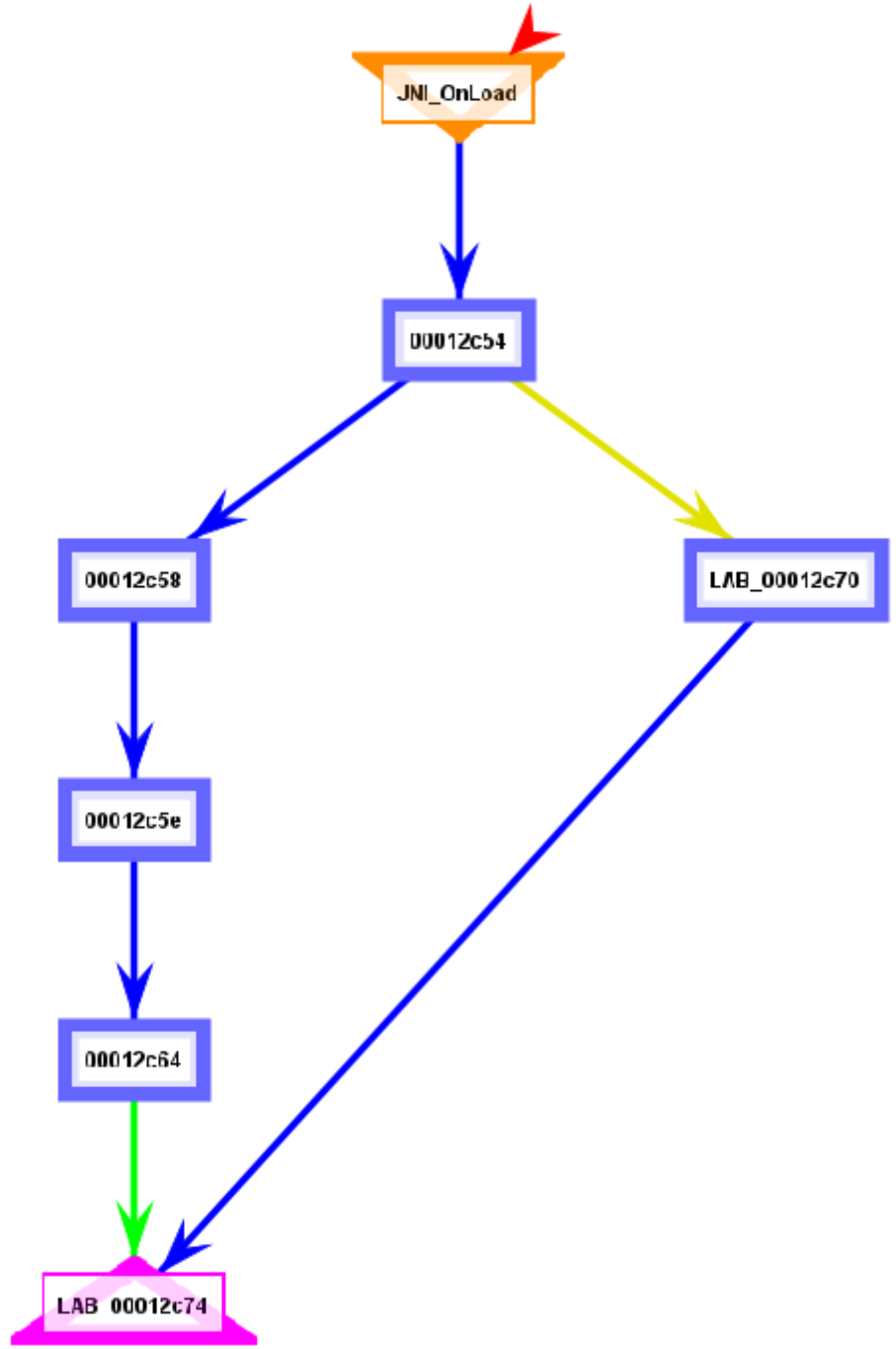
ghidra

- Graph -> Block Flow from JNI_OnLoad
- Decompile JNI_OnLoad

```
undefined8 JNI_OnLoad(int *param_1,undefined4 param_2,undefined4 param_3)

{
  int iVar1;
  uint uVar2;
  _JNIEnv *local_c;
  undefined4 uStack8;

  local_c = (_JNIEnv *)0x0;
  uStack8 = param_3;
  iVar1 = (**(code **)(*param_1 + 0x18))(param_1,&local_c,0x10004);
  if (iVar1 == 0) {
    iData(local_c);
    iVar1 = registerNatives(local_c);
    uVar2 = -(uint)(iVar1 == 0) | 0x10004;
  }
  else {
    uVar2 = 0xffffffff;
  }
  return CONCAT44(param_1,uVar2);
}
```



JNI_OnLoad

```
2  undefined8 JNI_OnLoad(int *param_1,undefined4 param_2,undefined4 param_3)
3
4  {
5    int iVar1;
6    uint uVar2;
7    _JNIEnv *local_c;
8    undefined4 uStack8;
9
10   local_c = (_JNIEnv *)0x0;
11   uStack8 = param_3;
12   iVar1 = (**(code **)(*param_1 + 0x18))(param_1,&local_c,0x10004);
13   if (iVar1 == 0) {
14     iData(local_c);
15     iVar1 = registerNatives(local_c);
16     uVar2 = -(uint)(iVar1 == 0) | 0x10004;
17   }
18   else {
19     uVar2 = 0xffffffff;
20   }
21   return CONCAT44(param_1,uVar2);
22 }
23
```

Call registerNatives

JNI_OnLoad: ghidra with a JNI GDT and retyping

- Loading the `jni_all.gdt`, and retyping the variables, allows resolution of symbols, such as the `FindClass`.

```
undefined8 JNI_OnLoad(JNIEnv *param_1,undefined4 param_2,undefined4 param_3)

{
  jclass p_Var1;
  int iVar2;
  uint uVar3;
  JNIEnv *local_c;
  undefined4 uStack8;

  local_c = (JNIEnv *)0x0;
  uStack8 = param_3;
  p_Var1 = (*(*param_1)->FindClass)(param_1,(char *)&local_c);
  if (p_Var1 == (jclass)0x0) {
    iData((_JNIEnv *)local_c);
    iVar2 = registerNatives((_JNIEnv *)local_c);
    uVar3 = -(uint)(iVar2 == 0) | 0x10004;
  }
  else {
    uVar3 = 0xffffffff;
  }
  return CONCAT44(param_1,uVar3);
}

```

registerNatives

```
2  /* registerNatives(_JNIEnv*) */
3
4  void registerNatives(JNIEnv *param_1)
5
6  {
7    undefined *local_14;
8    char *local_10;
9    code *local_c;
10
11   local_14 = &DAT_0001503b;
12   local_10 = "(Ljava/lang/String;)V";
13   local_c = native_setAppkey + 1;
14   registerNativeMethods(param_1,nativeClassForJni,(JNINativeMethod *)&local_14,1);
15   return;
16 }
17
```

Name of Java method name

Prototype int foo(String)

Native Function

Call registerNativesMethods
Is this the actual register method?

registerNativeMethods

```
4  jclass registerNativeMethods(JNIEnv *param_1,char *param_2,JNINativeMethod *param_3,int param_4)
5
6  {
7    jclass clazz;
8    uint uVar1;
9    jthrowable p_Var2;
10
11   clazz = (*(*param_1)->FindClass)(param_1,param_2);
12   if (clazz != (jclass)0x0) {
13     uVar1 = (*(*param_1)->RegisterNatives)(param_1,clazz,(JNINativeMethod *)param_3,param_4);
14     p_Var2 = (*(*param_1)->ExceptionOccurred)(param_1);
15     if (p_Var2 == (jthrowable)0x0) {
16       clazz = (jclass)(~uVar1 >> 0x1f);
17     }
18     else {
19       (*(*param_1)->ExceptionClear)(param_1);
20       clazz = (jclass)0x1;
21     }
22   }
23   return clazz;
24 }
25
```

Actual registration made through JNIEnv method

Web and Hybrid applications

Why not Native apps?

- Native Apps are not that good (or not always that good)
  - Have low Code Reusability
  - Require more development and maintenance
  - Requires designers and developers' experts on multiple architectures
  - Have low upgrade flexibility
- Once was the traditional way of developing applications
  - Currently being surpassed by web and hybrid applications
- From a RE perspective, the toolset and languages are very different
  - More complex to analyze
  - Better commonly available obfuscators

Web apps

- Use standard web technologies (HTML, CSS, Javascript)
- Especially since HTML5 allowed:
  - Advanced UI components
  - Access to media types and sources
  - Access to geolocation
  - Access to local storage
- Look like a standard application (present an Icon)
- Completely different stack
  - Standalone Mobile Web Browser

Hybrid apps

- Combine both worlds: Native and Web
  - a thin Java application with a Web application
- Most commonly:
  - Web for the interface
  - Java for the application backend
  - Custom Interface connecting both levels
- Installable from the store and indistinguishable from native apps
  - As devices are more powerful, these are becoming very common

Typical frameworks

RE Perspective

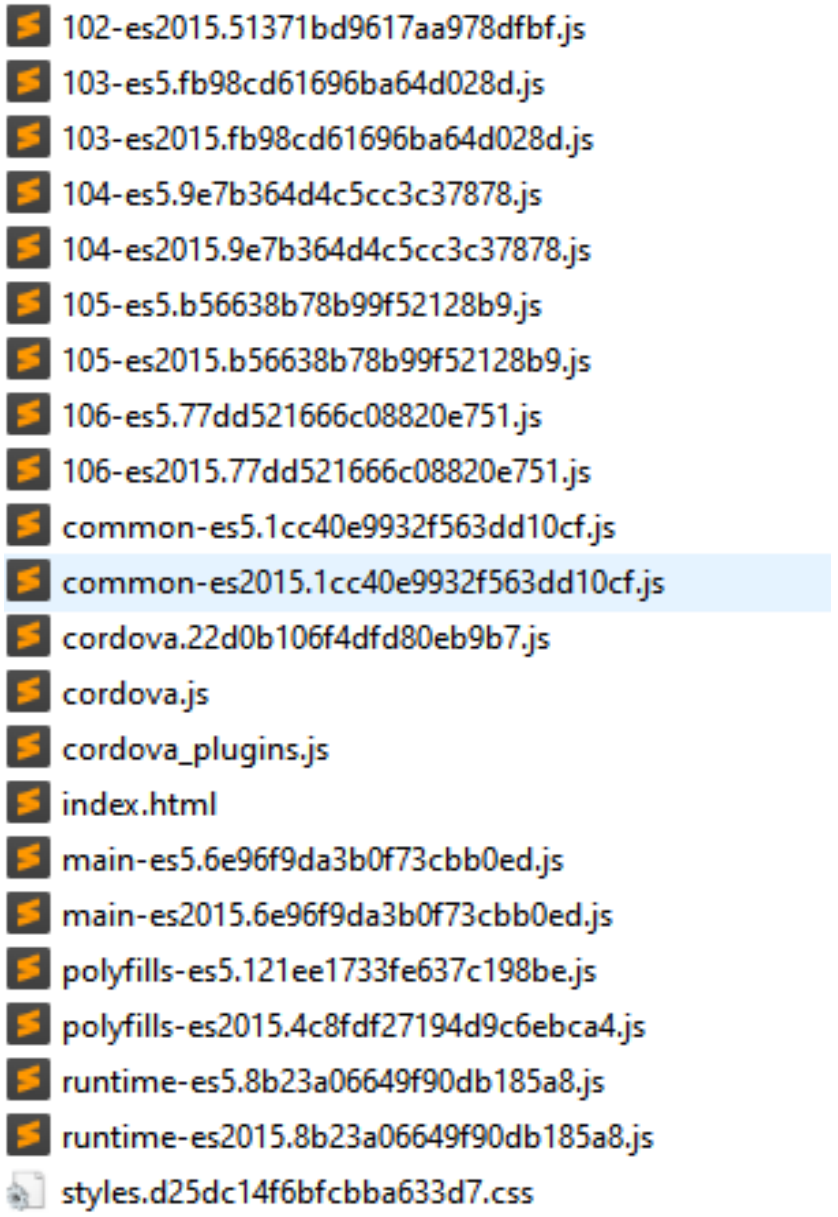
- Most frameworks use JS, but sometimes with custom VMs
- Packaging consists of adding the application JS code, HTML, styles and remaining resources
  - May use a bundle, including all resources
  - May leave resources bare in the APK
  - May use binary libs with obfuscated code, but frequently they are just plugins for native functions
- Code is frequently obfuscated
  - An inheritance of the JS obfuscators available
- Code may be compiled to an intermediate representation
  - Decompilers are not that robust as the ones for Java
- RE support is lacking…

IONIC

- Runs on the Apache Cordova infrastructure
  - Framework implemented in Java
  - Application presented through a Web View
- Actual application is a webpage in the assets/www directory
  - Cordova Plugins in www/plugins
    - Implemented in JS, communicating with main framework through interface
- Framework is event driver with actions activated on interactions

IONIC

- Every file contains a single line
  - Minified code
  - Pushing logic, or a handler
- Index.html as the entry point
- Workflow:
  - Beautify code and extract information
  - Launching Cordova on local PC
  - Inspection through browser
  - Dynamic Analysis



App ionfits.apk

IONIC

```
(window.webpackJsonp = window.webpackJsonp || []).push([
    [3], {
        a4YZ: function(t, e, n) {
            "use strict";
            n.r(e), n.d(e, "createSwipeBackGesture", (function() {
                return a
            }));
            var r = n("AzGJ"),
                a = function(t, e, n, a, i) {
                    var o = t.ownerDocument.defaultView;
                    return Object(r.createGesture)({
                        el: t,
                        gestureName: "goback-swipe",
                        gesturePriority: 40,
                        threshold: 10,
                        canStart: function(t) {
                            return t.startX <= 50 && e()
                        },
                        onStart: n,
                        onMove: function(t) {
                            a(t.deltaX / o.innerWidth)
                        },
                        onEnd: function(t) {
                            var e = o.innerWidth,
                                n = t.deltaX / e,
                                r = t.velocityX,
                                a = r >= 0 && (r > .2 || t.deltaX > e / 2),
                                c = (a ? 1 - n : n) * e,
                                u = 0;
                            if (c > 5) {
                                var s = c / Math.abs(r);
                                u = Math.min(s, 540)
                            }
                            i(a, n <= 0 ? .01 : n, u)
                        }
                    })
                }
        }
    }
]);
```

App ionfits.apk

Flutter

- "Recent" UI from Google based on the Dart Language
  - Compiled under the scope of the Dart VM (https://github.com/dart-lang/sdk)
  - Designed as a dual purpose framework: Web and Mobile
  - With Native and Web components
    - In mobile devices, Flutter is compiled to a native object (libapp.so)
  - As good reference, check: https://mrale.ph/dartvm/
- Two deployment flavors
  - AOT: Ahead of Time – the most frequent – as a bytecode for the Dart VM
  - JIT: Just in Time – for debug builds, interpreted from Source Code
- Project structure:
  - Small java shim to load the actual code
  - Framework in libfutter.so
  - Application in another .so libapp.so (yes, an ELF!)
    - Actually it contains a snapshot of the VM to be loaded

From a RE perspective

- Flutter compiles Dart to native assembly in a single bundle
  - Internal formats are not publicly known in detail
- By default there is no obfuscation or encryption
  - However the formats are not known
- Flutter applications are difficult to reverse engineer
  - Good for intellectual property
- Some tools start to scratch the surface (mostly extract information from libapp.so), extracting information
  - https://github.com/mildsunrise/darter
  - https://github.com/rscloura/Doldrums

Flutter: Flutter-Weather

- Simple application showing weather info
  - https://github.com/1hanzla100/flutter-weather
- Follows typical structure
  - 2 .so: Framework and App for multiple archs
- Current tools extract classes from VM snapshot, but there is little similarity with original code

```
lib
lib/arm64-v8a
lib/arm64-v8a/libapp.so
lib/arm64-v8a/libflutter.so
lib/armeabi-v7a
lib/armeabi-v7a/libapp.so
lib/armeabi-v7a/libflutter.so
lib/x86_64
lib/x86_64/libapp.so
lib/x86_64/libflutter.so
```

```
lib/x86_64/libapp.so: ELF 64-bit LSB pie executable, x86-64, version 1 (SYSV),
 dynamically linked, BuildID[md5/uuid]=409a650592e15d744a33d6a1bdbaa652, strip
ped
```