Vulnerability Research of Android apps: from 0 to 0-day using fuzzing

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About me

- **Vulnerability Researcher**: IoT, ICS, embedded, mobile, etc.
- **System Developer**: tools for automatic analysis, observability systems, fuzzers, emulators, etc.

Agenda

Beginning
Telegram
Viber
WhatsApp
General summary

The further down the list, the more difficult it is…

Background

- Money

Background

- Money
- BugBounty

Background

- Money
- BugBounty
- Mobile Applications, OSs, HW

Background

- Money
- BugBounty
- Mobile Applications, OSs, HW
- Test Task

Beginning

Disclaimer

- No WEB vulnerabilities
- No Java vulnerabilities
- No vulnerabilities in protocols and specifications

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- No Java vulnerabilities
- No vulnerabilities in protocols and specifications

- Memory corruptions
- Binary vulnerabilities
- RCE and data-only exploits

Not about exploitation or a specific vulnerability/CVE, but the methodology

Without meme, sry 😢

APK Analysis

What’s interesting for me?

Android manifest file:

- Activities
- Services
- Broadcasts Receivers
- Content Providers
- Permissions

Resources:

- Libraries
- DSL parsers
- Protocol Buffers files
- Custom binary blobs

Java Decompilation:

- Deobfuscation
- Refactoring
- Analysis (control-flow, data-flow, etc.)

Shared/Native Libraries — my main target

Is source code exist?

- Telegram — YES
- Viber — NO
- WhatsApp — NO

Telegram

Why first?

- Source Code — ✅

Why first?

- Source Code — ✅
- BugBounty — ✅

Why first?

- Source Code — ✅
- BugBounty — ✅
- I’m a user of the app — ✅

Static Analysis

- Manifest file — ✅
- Resources — ❌

- Java
- C++

$\Longrightarrow$ Android Studio

Shared/Native libraries

Ordered by the “low-hanging fruit” principle:

1. Legacy code
2. Self-written components
3. …
5. Crypto implementation
6. …
9. Popular open-source frameworks
10. RFC, protocols and manifests

Plan

1. Translate the code architecture into a convenient format (mind map, graph, wiki, Zettelkasten, etc.)

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2. Identify the entry points and sinks
3. Building attack vectors
4. Isolating target components
5. Analysis (fuzzing in our case)

Attack Vectors & Components

- File parsers and decoders
  - FLAC
  - GIF
  - Opus
  - Lottie (modified)

- Connection
  - `tgnet`
  - `TLObject` — (de)serialization (legacy)
- VoIP
  - `tgcalls` (legacy)
  - WebRTC (modified)
- etc.

Fuzzing

Harness

Do you have the source code?

Harness

Do you have the source code?

YES ✅

Harness

Do you have the source code? YES ✅ $\Longrightarrow$ easy peasy lemon squeezy?..

NO

- Isolation is not always possible in complex components

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- Behavior emulation (sockets, files, server, protocol, Java code, etc.)

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- Isolation is not always possible in complex components
- Behavior emulation (sockets, files, server, protocol, Java code, etc.)
- Legacy code is a legacy code
- Build for Android or for a host x86_64 POSIX machine?

Example. `tgnet`

1. Replace Android code
2. ~~Modify~~Write CMake file
3. Develop server[1] (MTProto[2]) and emulate Java code & socket file
4. Develop a MitM PoC attack for triaging

[1] https://github.com/saruman9/tg_srv
[2] https://github.com/saruman9/010_editor_templates

Fuzzers

- AFL/AFL++
- libFuzzer / centipede / fuzztest
- honggfuzz
- LibAFL
- etc.

Catches

- DoS
- Leaks
- Cryptography weaknesses
- Vulnerabilities in open source components

Summary

- Not so interesting for the presentation, but important as a base
- Not good BugBounty program
- Good for a first research in this field
- Many other methods of analysis can be applied

Viber

Rakuten Viber

Sources

- Препарируем Viber. Мини-гид по анализу приложений для Android[1] © *Хакер*
- fuzzer + harness[2]

[1] https://xakep.ru/2023/05/16/analyzing-viber/
[2] https://github.com/saruman9/viber_linkparser_fuzzer/

Static Analysis

- Manifest file — ✅
- Resources — ❌
- 1-day analysis + binary diffing — ✅

Shared/Native Libraries

Architecture — x86_64

- More tools
- Emulation at high speeds
- Partial analysis on a host machine

Native functions

- IDA Pro
- Binary Ninja
- rizin

Native functions

- ~~IDA Pro~~
- ~~Binary Ninja~~
- ~~rizin~~

```
$ readelf -W --demangle --symbols $(LIBRARY_SO) | \
tail -n +4 | \
sort -k 7 | \
# optional rg "FUNC.*Java_.*"
less
```

```
33: 0000000000001bb5    55 FUNC    GLOBAL DEFAULT   13 Java_com_viber_libnativehttp_HttpEngine_nativeCreateHttp
34: 0000000000001bec    15 FUNC    GLOBAL DEFAULT   13 Java_com_viber_libnativehttp_HttpEngine_nativeDelete
38: 0000000000001bfb   622 FUNC    GLOBAL DEFAULT   13 Java_com_viber_libnativehttp_HttpEngine_nativeTest
44: 00000000000018c3   109 FUNC    GLOBAL DEFAULT   13 Java_com_viber_libnativehttp_NativeDownloader_nativeOnConnected
39: 00000000000015e8   366 FUNC    GLOBAL DEFAULT   13 Java_com_viber_libnativehttp_NativeDownloader_nativeOnData
35: 0000000000001b0c    40 FUNC    GLOBAL DEFAULT   13 Java_com_viber_libnativehttp_NativeDownloader_nativeOnDisconnected
40: 0000000000001930   476 FUNC    GLOBAL DEFAULT   13 Java_com_viber_libnativehttp_NativeDownloader_nativeOnHead
```

```
$ rg "native.*nativeCreateHttp"
```

```
app/src/main/java/com/viber/libnativehttp/HttpEngine.java
9:    public static native long nativeCreateHttp();
```

Goals:

- Find open source components
- Find the target library
- Superficial analysis

Attack Vectors & Components

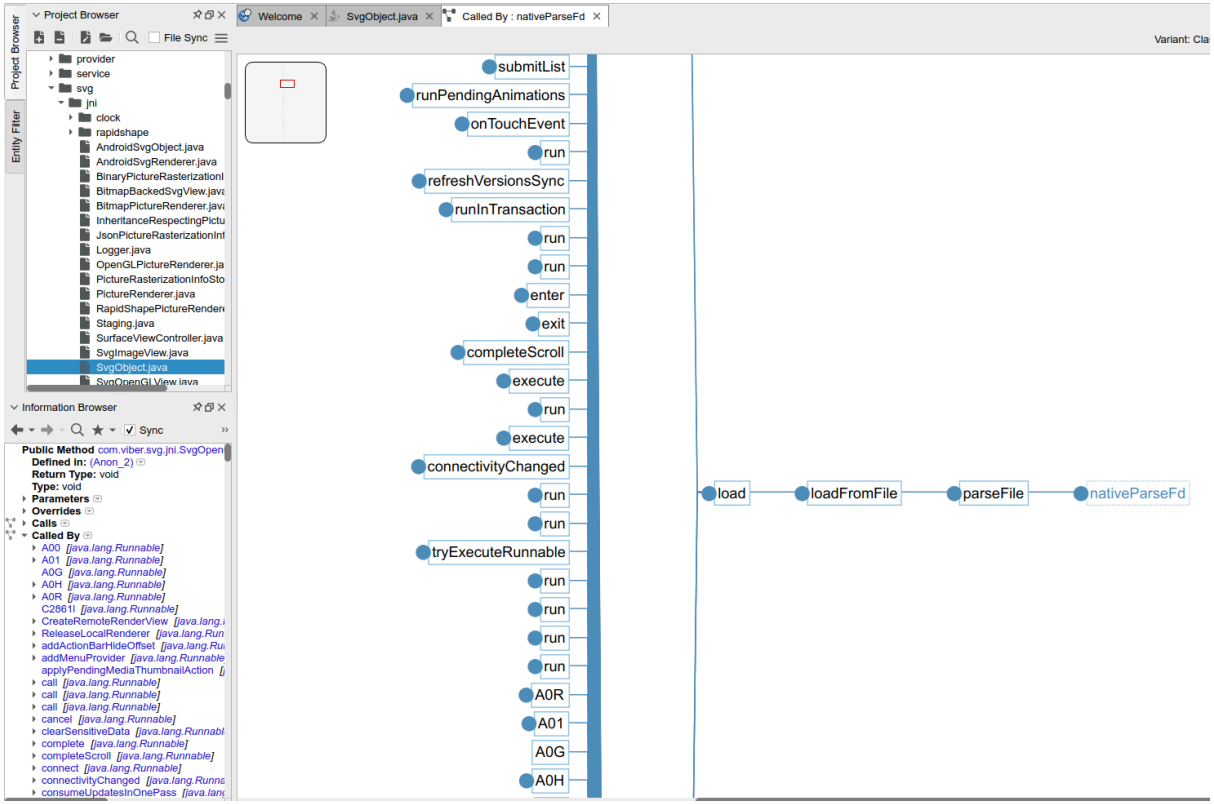
- Link parser
- SVG
- Viber RTC (WebRTC)
- VoIP engine

Accessibility (real sink?)

Static Analysis

- jadx[1] — decompilation IntelliJ IDEA — deobfuscation, refactoring
- SciTools Understand[2] — code-flow, data-flow analysis
- `strings`/`rizin`, `grep`/`ripgrep`

[1] https://github.com/skylot/jadx
[2] https://www.scitools.com/



Call graph of SVG native function in Understand

Dynamic Analysis

- Frida and public scripts
- `frida-trace`
- Smali patching
- Binary patching

Fuzzing

Greybox is more interesting

- libFuzzer / centipede / fuzztest

Greybox is more interesting

- ~~libFuzzer / centipede / fuzztest~~

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- honggfuzz

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Greybox is more interesting

- ~~libFuzzer / centipede / fuzztest~~
- ~~honggfuzz~~
- AFL++

Greybox is more interesting

- ~~libFuzzer / centipede / fuzztest~~
- ~~honggfuzz~~
- AFL++
- LibAFL
- etc.

Fuzzer	Instru-mentation	Emulator (x86_64)	Real device, aarch64
AFL++[1]	Frida	✅ AFL++ in	✅
AFL++[2]	Qemu	❌	✅
AFL++[3]	Qemu	✅	❌
AFL++	Unicorn + qiling	Unicorn	❌/✅?
honggfuzz/ AFL++	QBDI	QBDI	❌/✅?
LibAFL	Qemu	❌	✅

LibAFL	Qemu	✅	❌
LibAFL	Frida	✅ LibAFL in	✅

[1] **Android greybox fuzzing with AFL++ Frida mode** by Eric Le Guevel from Quarkslab
[2] **AFL++ on Android with QEMU support** by Itai Greenhut (@Gr33nh4t) from Aleph Research; **fpicker-aflpp-android** by marcinguy
[3] **MMS Exploit Part 2: Effective Fuzzing of the Qmage Codec** by Mateusz Jurczyk from Project Zero; **Sloth** by ant4g0nist

LibAFL + Frida

Why? Later we will review the remaining options

- I'm Rust developer
- I've already used LibAFL
- Frida is true cross platform software
- Rust is better for cross-compilation[1]

[1] not for Android, but not because Rust is bad

Harness

Reverse Engineering

Ghidra

- Ghidra fork[1]
- `ghidra_scripts`[2]
- Recaster plugin[3]
- “Ghidra. Dev” presentation[4]

[1] https://github.com/saruman9/ghidra
[2] https://github.com/saruman9/ghidra_scripts
[3] https://github.com/saruman9/recaster
[4] https://github.com/saruman9/ghidra_dev_pres

- Binary Ninja — `binja_snippets`[1]
- IDA Pro
- rizin

[1] https://github.com/saruman9/binja_snippets

C++

Ghidra

- `RecoverClassesFromRTTIScript.java`
- `ApplyClassFunctionSignatureUpdatesScript.java`
- `ApplyClassFunctionDefinitionUpdatesScript.java`
- C++ directory in Script Manager
- Ghidra-Cpp-Class-Analyzer[1] by astrelsky

[1] https://github.com/astrelsky/Ghidra-Cpp-Class-Analyzer

IDA Pro

- ida_medigate[1] by Metadorius — fork of fork of fork…
- Referee[2] by joeleong — a python port of James Koppel's Referee

[1] https://github.com/Metadorius/ida_medigate
[2] https://github.com/joeleong/ida-referee

Binary Ninja

- Use development release channel
- ClassyPP[1] by CySHell
- binja_itanium_cxx_abi[2] by whitequark

[1] https://github.com/CySHell/ClassyPP
[2] https://github.com/whitequark/binja_itanium_cxx_abi

```
liblinkparser.bndb
Types  Search types
0018     int64_t statusCode;
0020     int64_t contentLength;
0028     struct jni_string redirectedUrl;
0040     void* field_40;
0048     int128_t field_48;
0058 };

     struct __packed LinkParser::AndroidHttp
     {
0000     struct LinkParser_vtbl* vtbl;
0008     jobject http;
0010     JNIEnv* env;
0018 };

     struct __packed LinkParser::PushParserDownloader
     {
0000     struct LinkParser::PushParserDownloader_vtbl* vtbl;
0008     struct inner_LinkParser::PushParserDownloader* inner;
0010 };

     struct __packed LinkParser::PushParserDownloader_vtbl
     {
0000     void* LinkParser::PushParserDownloader::dtr;
0008     void* LinkParser::~PushParserDownloader;
0010     void* field_10;
0018     void* field_18;
0020     void* field_20;
0028     void (* w_init_inner_push_parser_downloader)(struct LinkParser::PushParserDow
0030     void* field_30;
0038 };

Cross References
Filter (0)
```

```
ELF ▾  Linear ▾  High Level IL ▾

00011db0  jobject nativeGeneratePreview(JNIEnv* env, jstring url, jobject http)

00011dbd  void* fsbase
00011dbd  int64_t rax = *(fsbase + 0x28)
00011dcb  jobject r15 = nullptr
00011ddd  if (url != 0 && http != 0)
00011df1      struct jni_string jni_url
00011df1      jni_getUtf8Bytes(dst: &jni_url, env: env, jstr: url)
00011e01      struct LinkParser::AndroidHttp link_parser_http
00011e01      LinkParser::AndroidHttp(android_http: &link_parser_http, env: env, http: http)
00011e15      struct jni_string preview_jni_str
00011e15      sub_18e00(preview_jni_str: &preview_jni_str, jni_url: &jni_url, http: &link_parser_http)
00011e1d      struct jni_string dst_jni_str
00011e1d      dst_jni_str.small_len.o = 0
00011e21      dst_jni_str.buf = 0
00011e2f      if ((preview_jni_str.small_len & 1) == 0)
00011e36          dst_jni_str.buf = preview_jni_str.buf
00011e40          dst_jni_str.small_len.o = preview_jni_str.small_len.o
00011e46      else
00011e46          uint64_t rbx_2 = preview_jni_str.len
00011e4f          if (rbx_2 u>= 0xfffffffffffffff0)
00011f1d              w_throw()
00011f1d              noreturn
00011e55          void* r15_1 = preview_jni_str.buf
00011e5e          char* r12_1
00011e5e          if (rbx_2 u>= 0x17)
00011e76              uint64_t r13_2 = (rbx_2 + 0x10) & 0xfffffffffffffff0
00011e7d              char* rax_3 = operator new(r13_2)
00011e82              r12_1 = rax_3
00011e85              dst_jni_str.buf = rax_3
00011e8e              dst_jni_str.small_len.q = r13_2 | 1
00011e92              dst_jni_str.len = rbx_2
00011e63          else
```

BTW try Binary Ninja[1]

[1] A very old comparison of IDA and Binary Ninja — **Binary Ninja 1.1.1184-dev vs IDA Pro 7.0.171130 (RU)**

Signatures

- Ghidra: Function ID[1]
- IDA Pro: lumen[2] — Lumina private server
- Binary Ninja: Signature Libraries[3]

[1] **FunctionID** help topic
[2] **https://github.com/naim94a/lumen**
[3] **https://binary.ninja/2020/03/11/signature-libraries.html**

Diffing

- Version Tracking[1] in Ghidra
- Program Differences[2] in Ghidra
- BinDiff[3]
- Diaphora[4]

[1] **Version Tracking** help topic
[2] **Program Differences** help topic
[3] **https://www.zynamics.com/bindiff.html**
[4] **https://github.com/joxeankoret/diaphora**

Difficulties & Resolving

- ? Java + C++
- ? Threads
- ? Other shared libraries as dependencies
- ? Initialization in `JNI_OnLoad`

Difficulties & Resolving

❓ Java + C++

💡 Find “pure” functions

❓ Threads

❓ Other shared libraries as dependencies

❓ Initialization in `JNI_OnLoad`

Difficulties & Resolving

✅ Java + C++

❓ Threads

❓ Other shared libraries as dependencies

❓ Initialization in `JNI_OnLoad`

Difficulties & Resolving

✅ Java + C++

❓ Threads

💡 Find a target function in a call graph without threads

❓ Other shared libraries as dependencies

❓ Initialization in `JNI_OnLoad`

Difficulties & Resolving

✅ Java + C++

✅ Threads

❓ Other shared libraries as dependencies

❓ Initialization in `JNI_OnLoad`

Difficulties & Resolving

✅ Java + C++

✅ Threads

❓ Other shared libraries as dependencies

💡 To do patching of shared libraries

💡 Load dependencies inside harness code

❓ Initialization in `JNI_OnLoad`

Difficulties & Resolving

✅ Java + C++

✅ Threads

✅ Other shared libraries as dependencies

❓ Initialization in `JNI_OnLoad`

Difficulties & Resolving

✅ Java + C++

✅ Threads

✅ Other shared libraries as dependencies

❓ Initialization in `JNI_OnLoad`

💡 Write stubs, call initialization functions

Difficulties & Resolving

- ✅ Java + C++
- ✅ Threads
- ✅ Other shared libraries as dependencies
- ✅ Initialization in `JNI_OnLoad`

Example of a harness for the target function

```
const ptrdiff_t ADDR_JNI_ONLOAD = 0x0000000000011640;
const ptrdiff_t ADDR_PARSE_LINK = 0x000000000002F870;
const ptrdiff_t ADDR_COPY_JNI_STRING_FROM_STR = 0x0000000000011160;
[...]
Functions *load_functions()
{
  LIBC_SHARED = dlopen("/data/local/tmp/libc++_shared.so", RTLD_NOW | RTLD_GLOBAL);
  LIBICU_BINDER = dlopen("/data/local/tmp/libicuBinder.so", RTLD_NOW | RTLD_GLOBAL);
  LIBLINKPARSER = dlopen("/data/local/tmp/liblinkparser.so", RTLD_NOW | RTLD_GLOBAL);
  if (LIBLINKPARSER != NULL && LIBC_SHARED != NULL && LIBICU_BINDER != NULL)
  {
    int (*JNI_OnLoad)(void *, void *) = dlsym(LIBLINKPARSER, "JNI_OnLoad");
    void (*binder_init)() = dlsym(LIBICU_BINDER, "_ZN22IcuSqliteAndroidBinder4initEv");

    if (JNI_OnLoad != NULL && binder_init != NULL /* && binder_getInstance != NULL */)
    {
[...]
```

Catches

- DoS
- Leaks
- Deadlocks

Sources (once again)

- Препарируем Viber. Мини-гид по анализу приложений для Android[1] © *Хакер*
- fuzzer + harness[2]

[1] https://xakep.ru/2023/05/16/analyzing-viber/
[2] https://github.com/saruman9/viber_linkparser_fuzzer/

Summary

- More details in the article 👆
- The research has been interrupted, so go ahead!
- The basic things for graybox fuzzing were considered, further — more

WhatsApp

Static Analysis

- Manifest file — ✅
- Resources — ✅, see the next slide
- 1-day analysis + binary diffing — ✅

Shared/Native Libraries

Superpack

Android app compression, which combines compiler analysis with data compression.

See *Superpack: Pushing the limits of compression in Facebook's mobile apps*[1] by Sapan Bhatia from Facebook.

[1] https://engineering.fb.com/2021/09/13/core-data/superpack/

Solutions:

- Reverse engineering and developing
- Reverse engineering and developing a wrapper (calling functions from a shared library in an emulator)
- Decompression in an emulator/Docker

Solutions:

- Reverse engineering and developing
- Reverse engineering and developing a wrapper (calling functions from a shared library in an emulator)
- ✅ Decompression in an emulator/Docker

Attack Vectors & Components

- Java part
- Many open-source components
- `libwhatsapp.so`
  - Statically linked
  - More and more Rust

After a long CFG/DFG analysis…

- MP4 checking (incoming messages), converting (outgoing messages)
- GIF checking
- WEBP parsing (stickers)
- `libmagi` (MIME type identification)
- VoIP (PJSIP project[1])

[1] https://github.com/pjsip/pjproject

Fuzzing

AFL++ + Frida

- Not as hard to build for Android as I expected[1]
- Perfect for those who prefer C++
- Not as flexible as LibAFL, but rich in functionality

[1] https://github.com/saruman9/AFLplusplus/tree/android

LibAFL + Frida

Android NDK + Frida + Rust = Building is the real pain!

Works: Rust 1.67, NDK 22, clang30

Doesn’t work:

- Rust 1.67, NDK 25, clang*
- Rust 1.70, NDK 21, clang*
- Rust 1.70, NDK 22, clang*
- Rust 1.70, NDK 25, clang*

1. Moving Android toolchains from libgcc to libclang_rt[1]
2. Updating the Android NDK in Rust 1.68[2]
3. Fixing build error for NDK 23 and above[3]
4. Patches for Frida (only for NDK below 23)[4]
5. Workaround for aarch64 `__clear_cache` issue[5]
6. A dirty hack for `frida-rust`[6]

[1] https://github.com/android/ndk/wiki/Changelog-r23#changes
[2] https://blog.rust-lang.org/2023/01/09/android-ndk-update-r25.html
[3] https://github.com/rust-lang/rust/pull/85806#issuecomment-1096266946
[4] https://github.com/AFLplusplus/LibAFL/issues/1359#issuecomment-1693328137
[5] https://github.com/AFLplusplus/LibAFL/issues/1359#issuecomment-1695346506
[6] https://github.com/frida/frida-rust/pull/112

LibAFL problems

- DrCov coverage doesn’t work as expected[1,2]
- Asan doesn’t work for Android x86_64[3]
- miniBSOD doesn’t work for Android x86_64[4]

[1] https://github.com/AFLplusplus/LibAFL/pull/1579
[2] https://github.com/AFLplusplus/LibAFL/pull/1581
[3] https://github.com/AFLplusplus/LibAFL/pull/1578
[4] https://github.com/AFLplusplus/LibAFL/pull/1577

- Additional changes[1]:
  - Option to continue fuzzing
  - Catching of timeout objectives
  - Option to disable coverage
  - The option of minimizing a corpus

[1] https://github.com/saruman9/LibAFL/branches/all

Frida

- I had a lot of problems because I didn’t understand how Stalker works. Especially when analyzing complex objects (JIT is terrible)
- Be sure to read the documentation[1] for Stalker (and Gum interface) before using it

[1] https://frida.re/docs/stalker/

Frida

- I had a lot of problems because I didn’t understand how Stalker works. Especially when analyzing complex objects (JIT is terrible)
- Be sure to read the documentation[1] for Stalker (and Gum interface) before using it
- LibAFL + Frida = Multithreading doesn’t work
- The sanitizer based on Frida doesn’t work correctly on some arch/platforms

[1] https://frida.re/docs/stalker/

Java VM

Harness = Java + Native Libraries

But how?

Java VM

Harness = Java + Native Libraries

But how?

Create Java VM from C/C++/Rust code of a harness/ fuzzer!

Sources:

- Creating a Java VM from Android Native Code[1] by Caleb Fenton
- Calling JNI Functions with Java Object Arguments from the Command Line[2] by Caleb Fenton
- Loading Android ART virtual machine from native executables[3] by Eugene Gershnik

[1] https://calebfenton.github.io/2017/04/05/creating_java_vm_from_android_native_code/
[2] https://calebfenton.github.io/2017/04/14/calling_jni_functions_with_java_object_arguments_from_the_command_line/
[3] https://gershnik.github.io/2021/03/26/load-art-from-native.html

Where hell begins?

Creating a Java VM is a non-trivial task!

Where hell begins?

Compliance with all legacy designs in Android is hard!

I did a separate research on the ASOP source code

Where hell begins?

Running Java VM under a fuzzer and Frida is a pain!

I spent many hours debugging

Where hell begins?

A real device and an emulator are two different things!

I have used 3 real devices and countless versions of an emulator

Where hell begins?

It still doesn't work stably…

But it works![1,2]

[1] **https://github.com/saruman9/jnienv**

[2] BTW Valgrind for Android: **https://github.com/saruman9/valgrind**

Smali patching

Does anyone know a tool that is comfortable to use for Smali patching?

Smali patching

- Smali the Parseltongue Language[1] by Benoît Forgette from Quarkslab
- Ghidra
- Binary Ninja
- Smalise extension for VSCode[2] by LoyieKing

[1] https://blog.quarkslab.com/smali-the-parseltongue-language.html
[2] https://github.com/LoyieKing/Smalise

Catches

DoS. Sender side

- Gallery
  - TIFF, SVG
  - OGG, WAV, MP3
- Live
  - Opus (audio recorder)
  - Video stream from a camera
- Sending
  - MP4

DoS. Receiver side

- Media hijacking
- Android Java exceptions, native iOS crashes

Summary

- Only DoS… yet
- VoIP is still waiting for me

General summary

- The journey is 1 year long

General summary

- The journey is 1 year long
- From zero to ~~hero~~ some bugs with only fuzzing

General summary

- The journey is 1 year long
- From zero to ~~hero~~ some bugs with only fuzzing
- This is the vulnerability research for now, next time — exploitation development

Thank you!